

U.S. Coast Guard Oceanographic Report  
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Woods Hole Oceanographic Institution

CG 373-22

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PHOTOGRAPHIC INVESTIGATION OF SEDIMENT  
TEXTURE, BOTTOM CURRENT ACTIVITY, AND  
BENTHONIC ORGANISMS IN THE  
WILMINGTON SUBMARINE CANYON

U.S.C.G.C. ROCKAWAY-SMITHSONIAN INSTITUTION  
CRUISE (R0S<sub>2</sub>)

December 1967



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# REPORT No. 22 <sup>CG 373-22</sup>

## PHOTOGRAPHIC INVESTIGATION OF SEDIMENT TEXTURE, BOTTOM CURRENT ACTIVITY, AND BENTHONIC ORGANISMS IN THE WILMINGTON SUBMARINE CANYON

U.S.C.G.C. ROCKAWAY-SMITHSONIAN INSTITUTION  
CRUISE (RoS<sub>2</sub>)

December 1967

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WASHINGTON, D.C.



FEBRUARY 1968



*Frontispiece:* USCGC ROCKAWAY (WAGO-377), a 311 ft oceanographic research vessel that conducts major oceanographic studies on a world-wide basis. Home port: Governors Island, New York

# Abstract

This report describes the investigation of the sea floor in the vicinity of Wilmington submarine canyon (38°00'N to 38°35'N Lat.; 72°35'W to 73°40'W Long.) by means of underwater photography. The techniques of both equipment operation and of interpretation are detailed. More than 1200 photographs were obtained from a net of 54 stations on the continental shelf, slope and upper continental rise in the region encompassing the Wilmington submarine canyon. These photographs, linked to precise navigation, enable assessment of the areal distribution of several sedimentary attributes, notably the texture of bottom sediments, the patterns of recent current activity (neocurrents) and movement of materials, and the role of benthic organisms in modifying bottom sediments.

Studies of bottom texture indicate that the head of this canyon is presently acting as a sediment trap. Admixtures of sand, silt and even coarse gravel are characteristic of the headward part of the canyon, whereas silt (near the canyon) and silty clay are dominant on the lower slope and upper rise. However, patches of gravel, sand and silt are associated with rock-ledges on the lower part of the Nyckel Ridge, a topographic elevation forming the southern margin of Wilmington Canyon.

The inferred patterns of recent bottom current movement suggest westward supply of coarse shelf sediment to the canyon head, some southerly, down-axis transport in the shallower portions of the canyon, and weaker southwesterly moving contour currents on the outer part of the upper rise. Significant transport of coarse sediment in a general northerly direction has also been observed in the vicinity of the Nyckel Ridge, near the base of the continental slope.

Organisms living on or near the sea floor profoundly affect bottom sediment, thus the distribution of the more important groups of such animals has been plotted.

Although underwater photography has proved valuable in elucidating the nature of the bottom in this canyon, some caution must be exercised in extending these conclusions to the geologically recent past. Cores indicate that the thin, fine-grained sediment veneer presently being reworked by benthic organisms actually masks the effects of recently active sedimentation in the canyon area. The combined pattern of current activity and sediment distribution as observed in the bottom photographs suggests that the Wilmington submarine canyon has played an important role in funnelling sediments from the shelf area to the deep-sea in the recent past.



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# I. INTRODUCTION

Submarine canyons are large, steep-sided, generally sinuous depressions incised into the continental slope and rise and often heading on the shelf. They occur on the margins of most continental regions and their mode of origin has long been a source of debate and controversy among geologists and others concerned with the morphology of the sea floor (Lawson, 1893; Pruvot, 1894; Daly, 1936; Johnson, 1938; Kuenen, 1950; Shepard, 1963; and others). More recently it has been suggested that submarine canyons are responsible for funnelling sediment from shallow shelf regions, down the continental slope and onto the deep ocean floor of the rise and abyssal plain beyond (Shepard, 1965a). Submarine canyons best studied to date are of the type that head on relatively narrow shelves in tectonically active areas (Shepard and Dill, 1966). Canyons located off wide shelves in structurally stable areas have received less attention.

A program of investigation undertaken by staff of the Division of Sedimentology, U.S. National Museum, Smithsonian Institution, with active cooperation and support of the U.S. Coast Guard Oceanographic Unit, has as long-term objective, the detailing of the geometry and sedimentary processes associated with canyons in general. One of the major purposes of this study is the formulation of a sedimentary model for modern canyons located on shelves off low coastal regions which are apparently tectonically stable. Four submarine canyons (from North to South: Wilmington, Baltimore, Washington and Norfolk) located on the Atlantic seaboard of the United States southeast of Delaware and Chesapeake Bays are of particular interest in this respect (see inset, Fig. 1). All four of these canyons, mapped in consider-

able detail by Veatch and Smith (1939), are deeply incised as much as 12 nautical miles into the outer edge of the wide continental shelf. The canyons form two distinct paired systems (Wilmington-Baltimore and Washington-Norfolk), each consisting of a long and a closely associated shorter canyon, as noted by Pratt (1967). The selection of these specific canyons for study was, in part, determined by logistics, i.e., their proximity to major ports which facilitates repetitive runs over the same area and ease of monitoring with different marine geological and oceanographic techniques.

The cruise described in the following account was made by the USCGC ROCKAWAY (WAGO 377) during the period 4 to 10 December, 1967 and is referred to as cruise RoS<sub>2</sub>. The purpose of this cruise was to obtain photographic records of the ocean floor in the vicinity of Wilmington submarine canyon, the most northerly of the 4 features. Free-fall cores of the bottom sediment were also collected at several of the photographic stations. This, the second of a series of 5 cruises in this area, was preceded by a morphological-subbottom investigation (RoS<sub>1</sub>, Kelling and Stanley, in preparation) and followed by bottom sampling (RoS<sub>3</sub>) and underwater television (RoS<sub>4</sub>) programs (data presently under examination at the Division of Sedimentology, Smithsonian Institution and Department of Geology, University of Wales at Swansea). This report presents photographic data obtained during RoS<sub>2</sub> and a summary of results.<sup>1</sup>

<sup>1</sup>A published presentation made by the authors at the Ocean Sciences and Engineering of the Atlantic Shelf Symposium, Marine Technology Society, Philadelphia (Stanley and Kelling, 1968b) is an interpretative summary of the data presented in this Report.

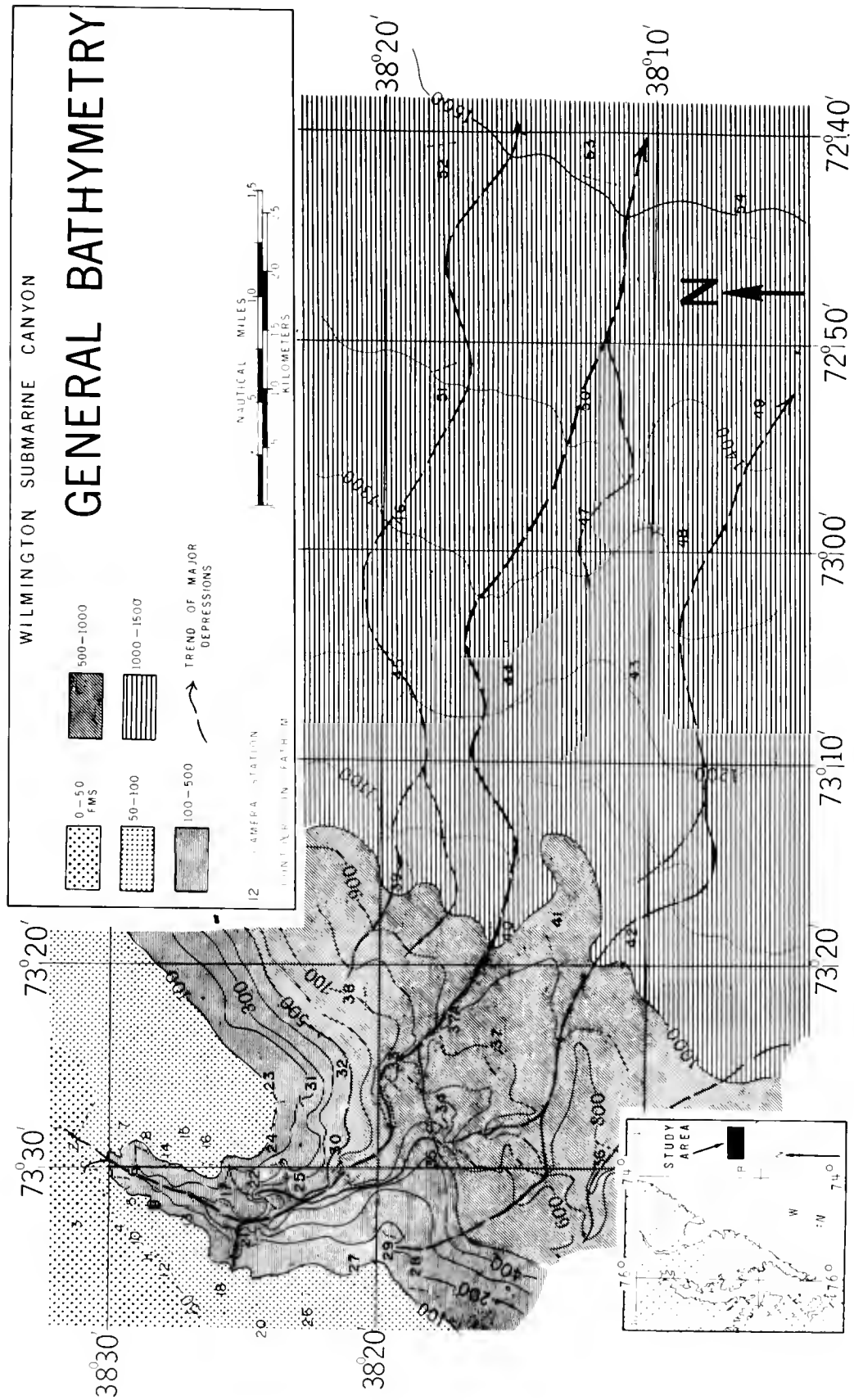


Figure 1. General bathymetry of the Wilmington Canyon area. Chart is based on soundings collected during RoS<sub>1</sub> (November 1967 and RoS<sub>2</sub> (December 1967). The canyon head is incised well into the shelf at approximately 38° 30' N Lat., 73° 30' W Long. Major linear depressions on the slope and rise are indicated by heavy dashed lines. Topographic high west and south of canyon axis is the Nyckel Ridge. On inset map: N, Norfolk Canyon; W, Washington Canyon; B, Baltimore Canyon.

## II. AREA OF STUDY

Wilmington Canyon originates near the edge of the continental shelf approximately 95 nautical miles east-southeast of the mouth of Delaware Bay. The canyon head may be traced northeastward (landward) to a minimum depth of 45 fathoms, at which point it is incised into the shelf for a distance of about 10 miles (Fig. 1). From this point the canyon trends south-southwest for nearly 7 miles to an axial depth of 380 fms and then makes a sharp turn to a general southeasterly course. This course is maintained to an axial depth of about 1000 fms, near the base of the continental slope, and is interrupted only by an abrupt turn to the east for almost 3 miles at 700 to 780 fms. The canyon trends almost due east across the upper part of the continental rise where it gradually diminishes in relief. Beyond the 1300 fms isobath the canyon, which would better be described as a submarine valley because of its low relief, extends toward the east-southeast to a depth of about 1800 fms. The gradient of the canyon axis become steeper and the relief increases in the lower rise (1800-2500 fms). The canyon trend is almost due south between 1800 and 2000 fms, then becomes generally southeast.

The gradient of the canyon axis is maintained at between 1 in 20 and 1 in 25 throughout most of the headward portion and on the upper continental slope. However steeper gradients are encountered locally, in the vicinity of the acute changes in the trend of the canyon axis described above. Beyond an axial depth of 800 fms the gradient decreases first to 1 in 50 then, at about 1350 fms, to about 1 in 90.

Followed from its head towards the regional shelf-break the canyon gradually increases in dimensions, attaining both its maximum width (6 miles) and its greatest relief (approximately 500 fms) at the regional shelf edge. In this headward portion, the canyon is generally steep-sided with lateral slopes of  $10^\circ$  to  $20^\circ$  which frequently expose bedrock. The transverse profile of the canyon tends to be acute and V-shaped in the shallower part of the head

but becomes less acute or even flat-based beyond about 400 fms. The walls of the canyon in this headward region are extensively modified by many depressions and secondary ridges, including several cirque-like tributary canyons as much as a mile wide (Fig. 1).

Descending the continental slope the canyon diminishes both in width and depth. Near the 1000 fms isobath the canyon is a sharply incised feature 0.6 n.miles wide and with a relief of some 45 fms. At an axial depth of 1350 fms the width of the canyon has diminished to 0.3 n.miles and the V-shaped depression is barely 30 fms deep. At greater depths the Wilmington submarine valley is an inconspicuous, rather broadly terraced depression which includes one or more narrow, gully-like features, usually less than 0.2 n.m. across and 10 to 20 fms deep.

An important morphological high (here termed the Nyckel Ridge, after Veatch and Smith, 1939) runs parallel to Wilmington Canyon from the shelf, down the continental slope and across the rise to the 1400 fms isobath. It is described in detail elsewhere (Stanley and Kelling, 1968a, 1968b). Other subsidiary canyons and ridges, most of them originating on the middle or lower regions of the slope, occur both to north and south of the main Wilmington Canyon.

In contrast to the numerous secondary depressions which mark the course of this feature in its headward region and across the continental slope, only one tributary canyon can be linked to the Wilmington submarine canyon as it crosses the upper continental rise. This tributary originates on the north side of the Nyckel Ridge near the 1200 fms isobath and eventually merges into the Wilmington submarine valley system at about 1500 fms (Fig. 1).

A further feature of morphological interest in this area is the marked contrast in bottom relief between the upper and lower portions of the continental slope. Except in the immediate vicinity of the major canyons, the shelf-break

and upper part of the slope are relatively smooth, with only minor undulations in both slope-parallel and slope-normal directions. However, below the 500 fms isobath the bottom morphology becomes appreciably rougher, the slope being modified by many ridges and hollows with a slope-normal relief often exceeding 150 fms. This rugged topography extends on to the uppermost part of the continental rise but beyond the 1200 fms isobath the relief is less conspicuous. Here a few large, isolated ridges are separated by wide, relatively smooth depressions (Fig. 1).

The ship's track for cruise RoS<sub>2</sub> (Fig. 2) follows a broadly rectilinear pattern compris-

ing legs which are alternately parallel and perpendicular to the course of the canyon axis. Such a track (total of 502 n.miles) not only provides extremely useful bathymetric data from PESR records but also facilitates the creation of a net of bottom camera stations which encompasses not only the canyon itself but also the adjacent areas of the shelf, slope and rise (Fig. 3, Table 1). Slope corrections were applied to soundings after the method of Shalowitz (1930). Soundings from Coast and Geodetic Survey Charts H5350, H6200 and H5713 were utilized to amplify the bathymetric data in a few areas of the shelf and upper slope.

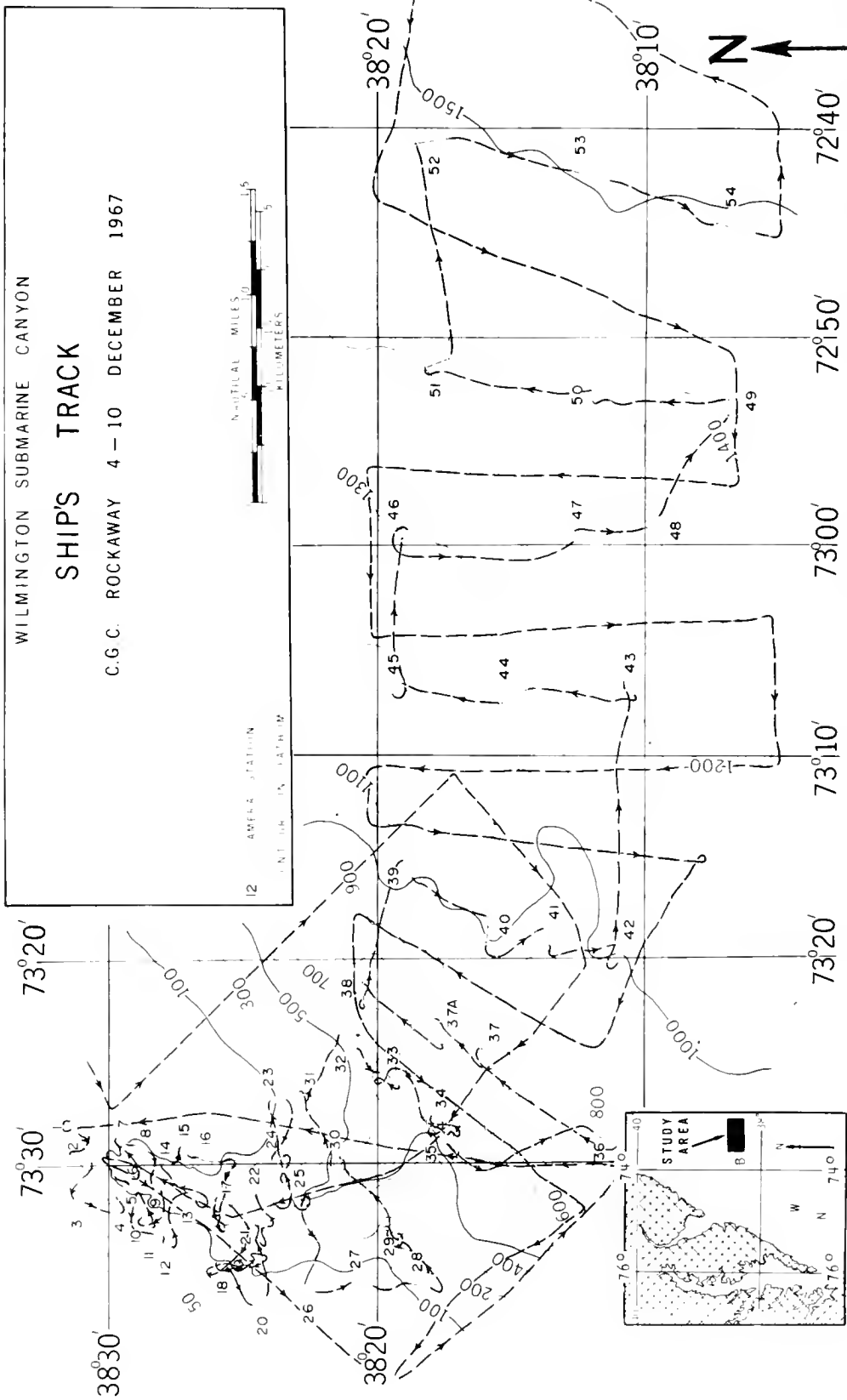


Figure 2. Track of the USCGC ROCKAWAY (WAGO 377) during cruise RoS., 4-10 December, 1967. Track position based on LORAN-C navigation.

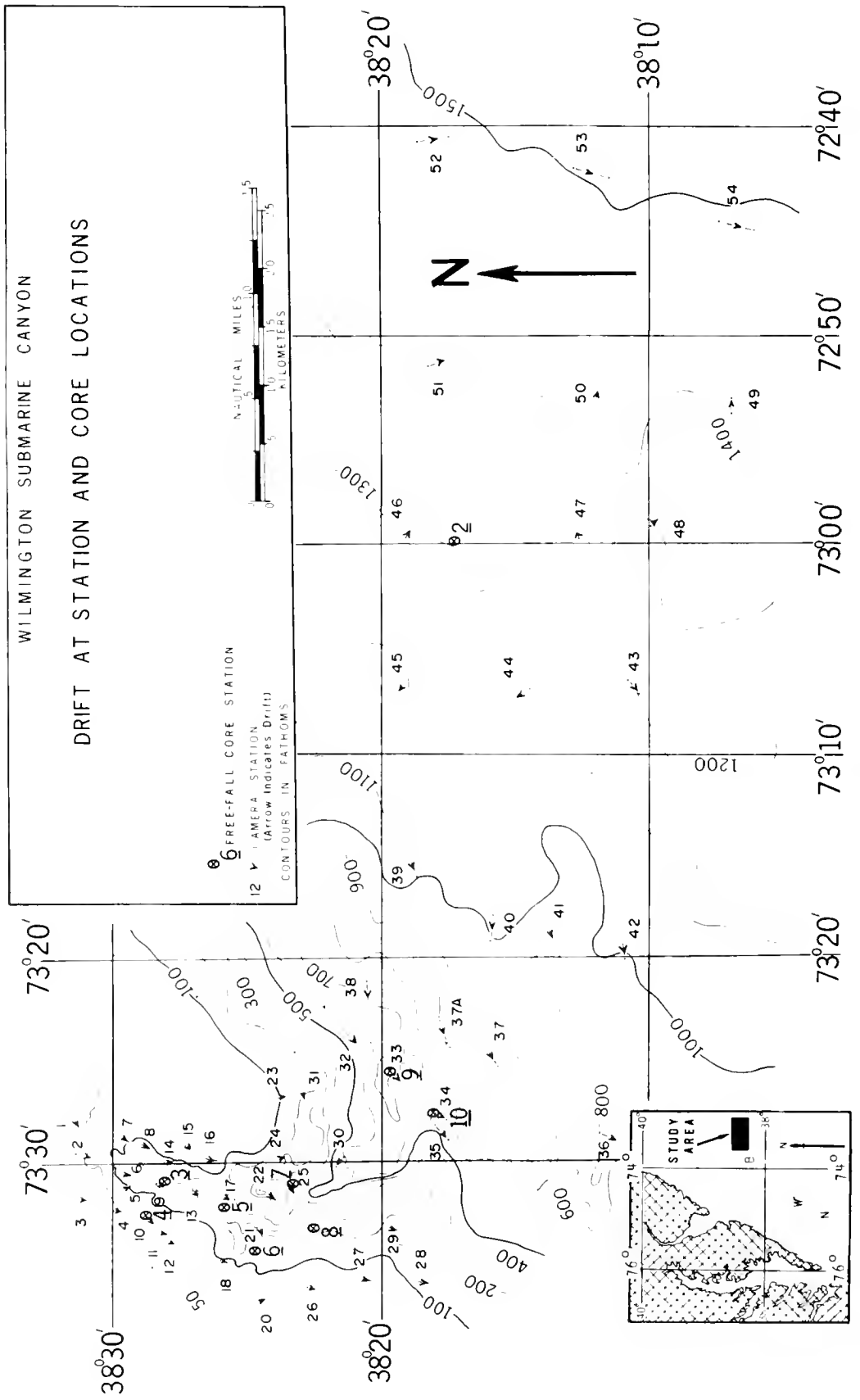


Figure 3. Direction and distance of drift on photographic stations and location of free-fall cores. Data obtained during RoS, 4-10 December, 1967.

### III. PROCEDURES

The camera rig used on this cruise was on loan from the U.S. Naval Oceanographic Office, Washington, D.C. and the operation of the camera was supervised by personnel from that office, Messrs. Robert K. Oser and Martin G. Fagot. The photographic system consists of an E.G.&G. Model 204 Underwater Camera used in conjunction with a Model 214 Stroboscopic Light source. These are mounted in a steel frame which also carried an E.G.&G. Pinger System (Fig. 4). An E.G.&G. Model 260 Current Compass was suspended on a nylon cord below the frame. The camera system was lowered and raised off the stern-mounted A-frame with 3/16" wire using a steam winch.

The operation of such a photographic system has been described in detail by Edgerton (1967) and Hersey (1967). It is sufficient to note here that the camera is a 35 mm self-cycling, automatic unit, synchronized with the light-source to permit one exposure every 18–23 seconds. At shallow stations the camera and light source were activated on deck and many frames, therefore, consist of shots of the water column taken during lowering and raising of the rig. At deeper stations, a timing device was used to activate the camera and light source after a preset interval corresponding to the estimated time required to lower the rig to the bottom.

The camera and light source were mounted in a vertical position (Fig. 4) in order to obtain more accurate observations of the orientation of bottom features with respect to the compass. This resulted in some consequent loss of bottom relief as compared with oblique mounting. Black and white TriX-Pan film was used for most stations but one 100 ft roll of color film (Ektachrome ER, Type B) was used at Stations 40–43 inclusive (See Table II).

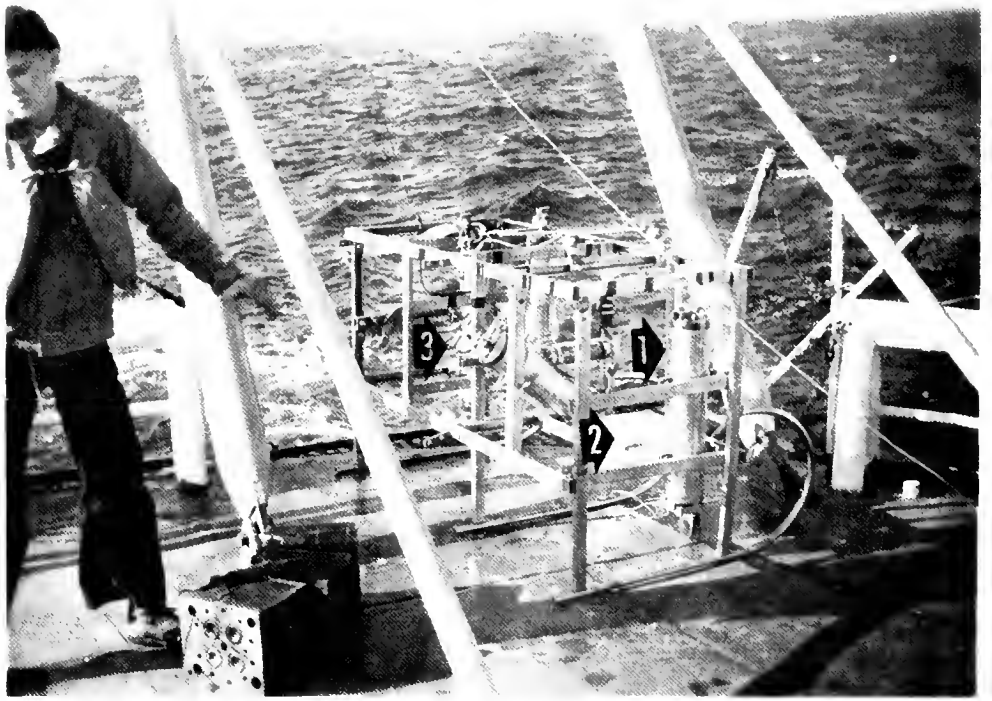
The use of a pinger allows the course of the rig to be followed on the PESR record during lowering and raising and also while the camera is actually photographing the sea-bed (Fig. 5). The use of a supplementary oscilloscope

also enabled more precise control of the camera's position at between 0.5–2 fathoms above the bottom. Subsequent evaluation of the photographs indicated that in order to ascertain details of the bottom texture, structures and organisms the optimum height for the camera is between 0.5 and 1 fms above the seabed.

In addition to its function as an orientation-datum, the suspended compass furnishes a useful means of estimating the size of objects on the bottom. This is achieved by determining the diameter of the shadow of the compass or the vane by a comparison with the measured diameter of the compass itself (3 inches) or the length of the vane (10 inches) knowing the spatial relationship of the compass with respect to the light source and the camera lens (Fig. 6).

Throughout the cruise navigational fixes accurate to within  $\pm 0.25$  miles were obtained by LORAN C. Fixes were taken at 6-minute intervals while changing stations and further fixes were obtained during the lowering and raising operations. The total time spent at a single camera station comprises components due to lowering and raising the camera-rig in addition to the time actually spent in photographing the sea-bed (usually 10 to 15 minutes on the bottom). The total period of time may amount to more than an hour for deep stations and during this interval the ship (and the trailing gear) will drift for a distance and in a direction which is dependent on conditions of sea, wind, etc. On this cruise the total drift on station varied between 0.2 and 2.1 nautical miles (see Table I). The distance and direction of drift during the period when the camera was close to the bottom are indicated in Fig. 3

Prints from each of the ten 100 ft reels of film used on this cruise were enlarged to a size of 3½" x 2" on continuous strip which was threaded on to a pair of rollers for examination. Each photographic frame is accompanied by a data-chamber which includes the film roll-number (numbered from 1 to 10), the consecu-



*Figure 4. (a):* Photograph of sled-mounted camera rig used on cruise RoS<sub>2</sub>.

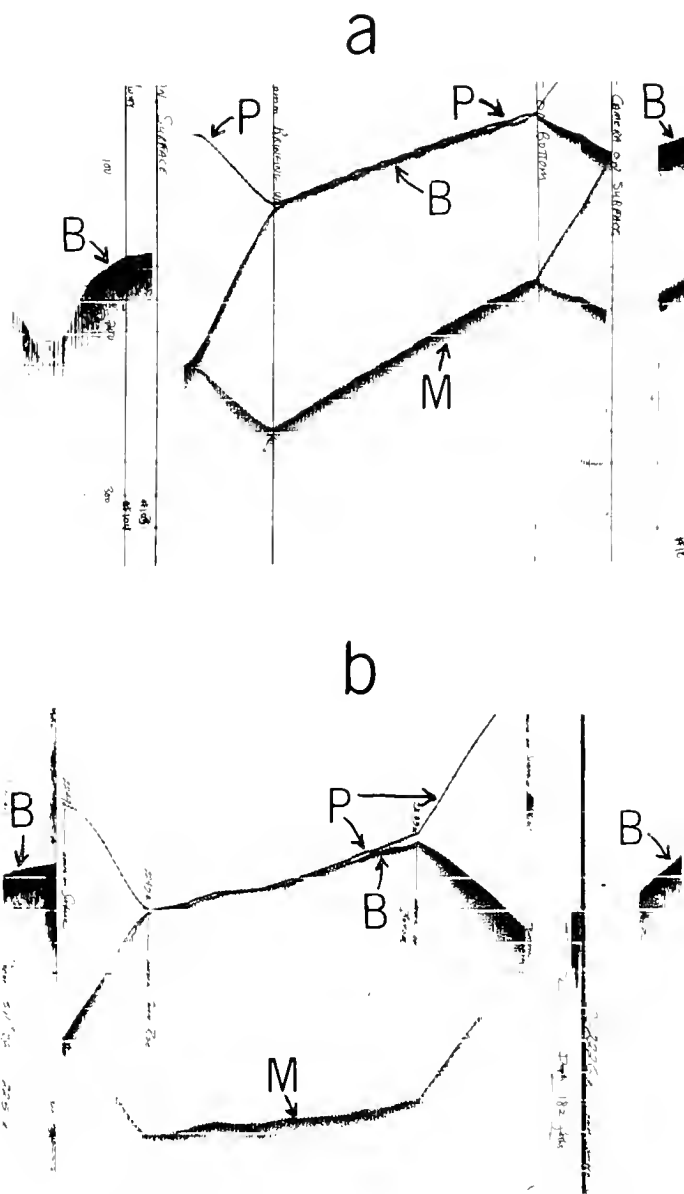
- 1—Camera;
- 2—Pinger transducer;
- 3—Stroboscopic light-source.



*(b):* Photograph of camera-rig being lowered over the stern of the USCGC ROCKAWAY (WAGO 377) December 7, 1967.

- 1—Camera;
- 2—Battery packs for light and camera.





**Figure 5.** Typical "pinger-traces" of camera-rig during descent, bottom photography near the sea-bed, and ascent as indicated on PESR record.

(a) Camera Station 23, near shelf-break, north of canyon head.

(b) Camera Station 28, near shelf-break on open slope, southwest of canyon.

P—trace given by pinger attached to camera-rig;

B—true bottom (sediment-water interface);

M—multiple of bottom and pinger-trace.

tive frame-number and a clock. This allows the position of each frame to be accurately located with respect to the known position of the ship at a given instant of time. Moreover, each

frame may be linked to timed events on the PESR record, allowing more precise location as to depth of individual frames and groups of frames within each station.

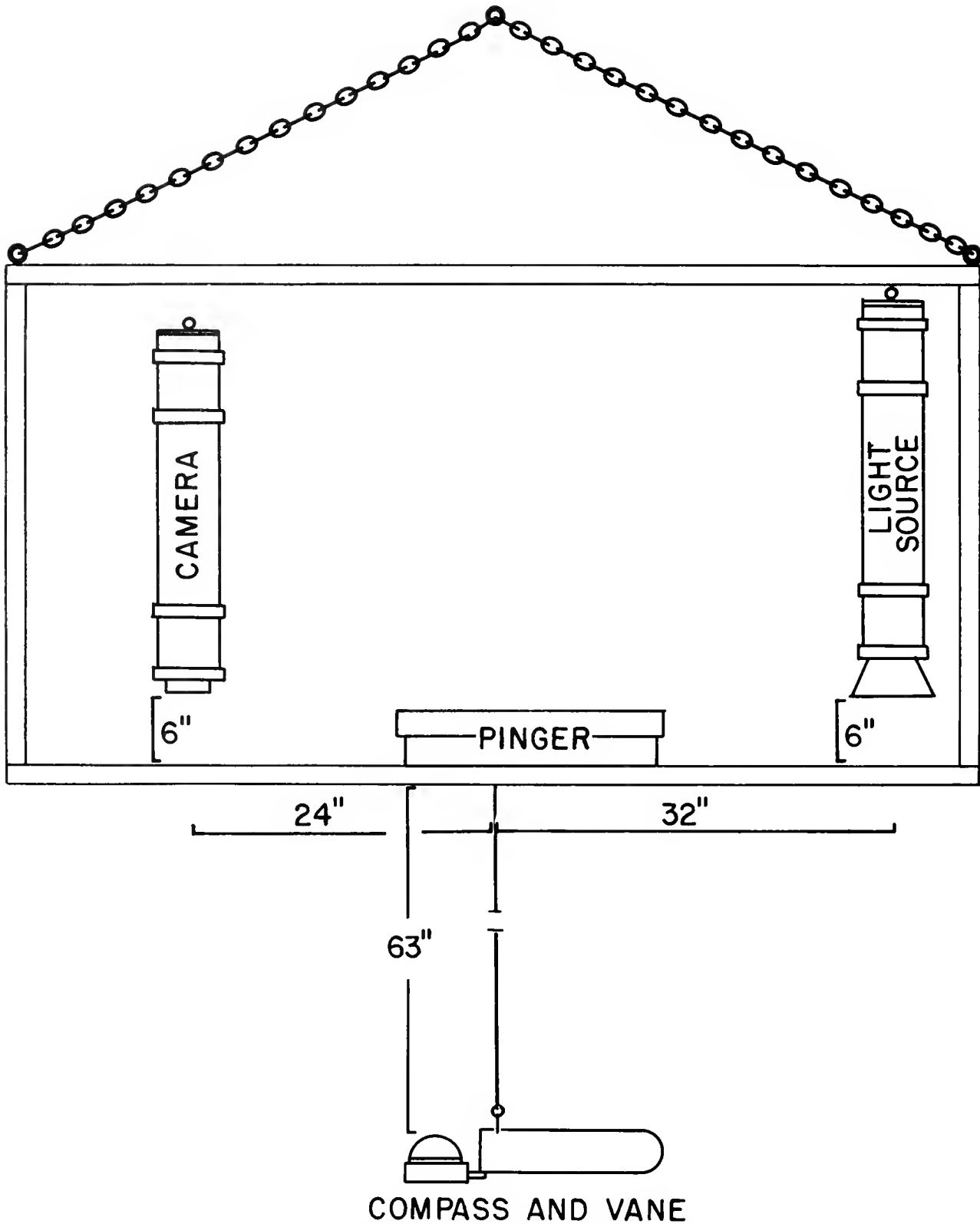


Figure 6. Diagram illustrating the relative dimensions of the main components of the camera-rig used on cruise RoS.

Each print was carefully examined by means of an illuminated table magnifier and the results of this examination recorded on a standardized form. In addition to statistics concerned with the operation of the camera, the station number and location, this form details the sedimentary and organic features observed within the photographs.<sup>1</sup> These include the inferred texture of the bottom sediment; the nature, orientation and dimension of ripple-marks and other features indicating current movement, including oriented organic structures; the occurrence and relative abundance of shell, and the presence of living organisms and their traces.

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<sup>1</sup>Copies of the completed forms used in this study have been lodged with the National Oceanographic Data Center, Washington, D.C. The original negatives and prints are housed in the collection, Division of Sedimentology, U.S. National Museum, Washington, D.C. 20560.

The dimensions of objects and structures in the photographs can generally be determined by comparison with the compass shadow as described earlier or by relation to other objects of known approximate diameter in the photograph, such as sand-dollars, etc. The texture of the sediment forming the bottom may be indicated directly (as in the case of gravel or coarse sand) or it may be inferred from associated features, such as ripple marks. For example, the firmness of the bottom and the proportion of mud (clay and silt) in the sediment is indicated by the character of the mark made on the bottom or the nature of the cloud of sediment raised by the compass or vane striking the sea-bed. The size and character of sedimentary structures and of organic tracks, burrows and mounds provide further evidence of the nature of bottom sediment type.

### PLATE 1

Fig. A.—Station 1, outer shelf, north of canyon head, 46–50 fms.

Figs. B–D.—Station 3, outer shelf, northwest of canyon head, 35–37 fms.

Figs. E–F.—Station 6, canyon head, northwest wall, 115–120 fms.

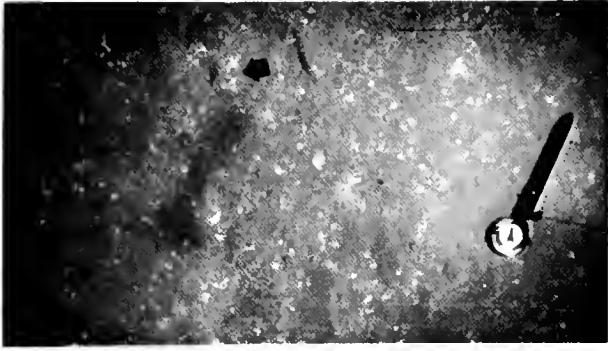
A, Coarse shelly sand; faint, slightly sinuous symmetrical ripple marks with crest orientation of  $015^{\circ}$ – $195^{\circ}$ ; abundant disarticulated pelecypod shells; 2 canceroid crabs (arrows) and 1 fish (*Urophycis*) resting on bottom.

B, Shelly, silty sand; straight short-crested asymmetric ripple marks (old); current toward WSW; large articulated pelecypod shells, partially buried. Concave-up attitude of the shells suggest weak bottom current activity.

C&D, Bottom similar to B; ripple crests are sharper, with suggestion of current interference pattern. Note turbid state of water in D.

E, Sandy, somewhat shelly, silt; poor ripple mark development; ripple crest orientation  $145^{\circ}$ – $325^{\circ}$ ; disarticulated, partially buried pelecypod; small fish near compass vane.

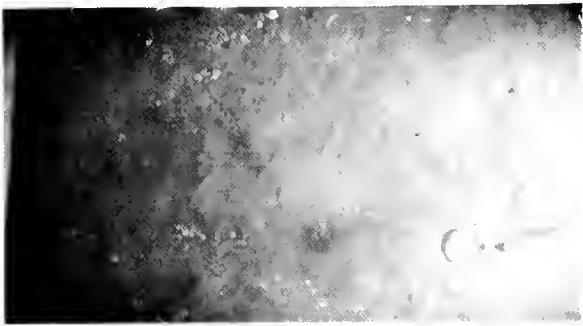
F, Bottom similar to E. Compass striking bottom reveals muddy nature of bottom.



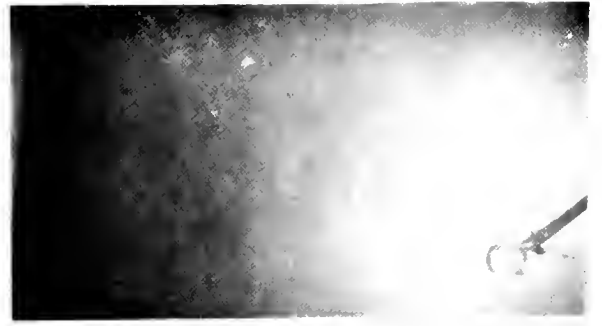
A



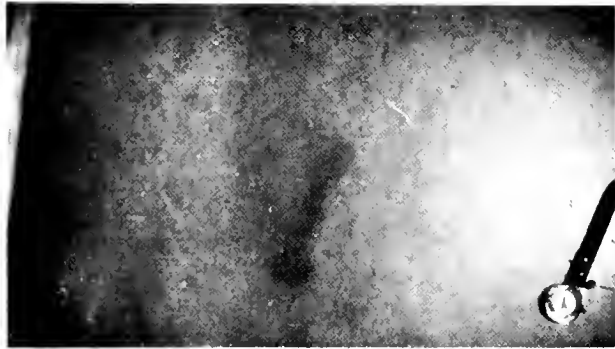
B



C



D



E



F

PLATE 2

Figs. A-B.—Station 6, canyon head, northwest wall, 115–120 fms.

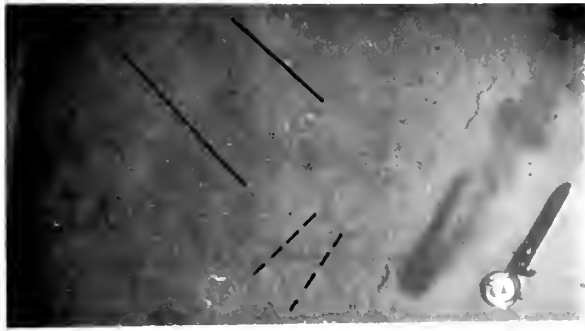
Figs. C-F.—Station 7, outer shelf, east of canyon head, 58–82 fms.

A, Sandy, somewhat shelly, silt; interference ripple marks with a dominant crest orientation (solid line) of  $120^{\circ}$ – $300^{\circ}$  and small ripple crest orientation (dotted line) of  $030^{\circ}$ – $210^{\circ}$ ; cloud trailing compass reveals muddy nature of bottom; hagfish (*Myxine glutinosa*) resting on bottom.

B, Bottom similar to A; fish (*Urophycis*) resting on bottom (arrow).

C, Shelly, silty sand; straight asymmetric, anastomosing ripple marks indicating current movement towards west. Shell in ripple troughs.

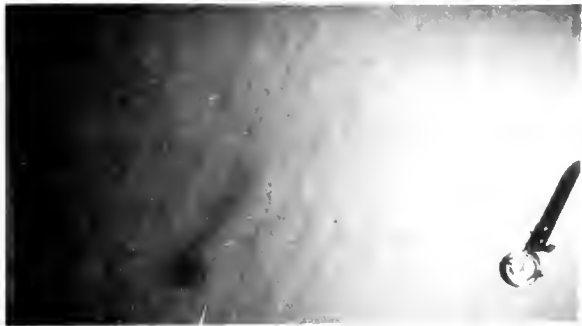
D–F, Bottom similar to C; ripple marks more linguoid in form. Note fish (in E and F) and canceroid crab (arrow, in F).



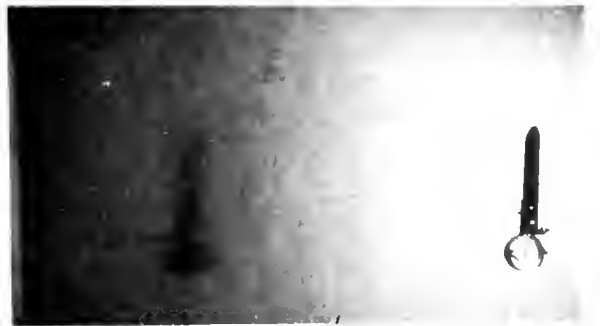
A



B



C



D



E



F

PLATE 3

**Figs. A-F.**—Station 8, canyon head, east wall, 110–128 fms.

**A,** Sandy silt; interference ripple marks with dominant crest orientation of  $155^{\circ}$ – $335^{\circ}$  (old ripples); partially buried shell.

**B,** Bottom similar to A; flat fish (arrow 1) and depression (arrow 2), possibly formed by fish. The steep margin of depression indicates cohesiveness of the bottom sediment.

**C,** Bottom similar to above; skate and two other fish; canceroid crab in center of photo.

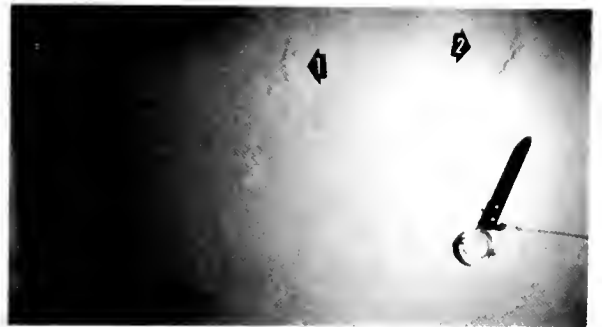
**D,** Close-up of bottom showing cell-like, interference ripple pattern, also possible “fish-nest” depression (arrow) and small tracks made by crabs.

**E&F,** Bottom similar to the above, with cloud of mud trailing compass. Note canceroid crab and partially obscured flat fish (arrow) in E, and fish in F.

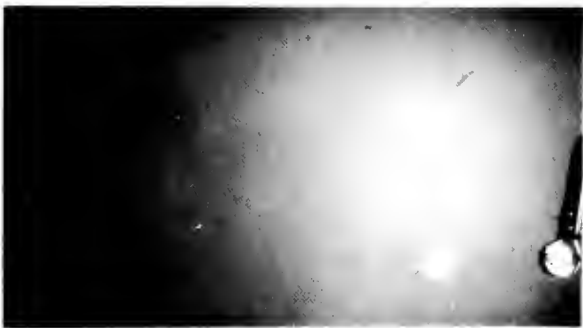




A



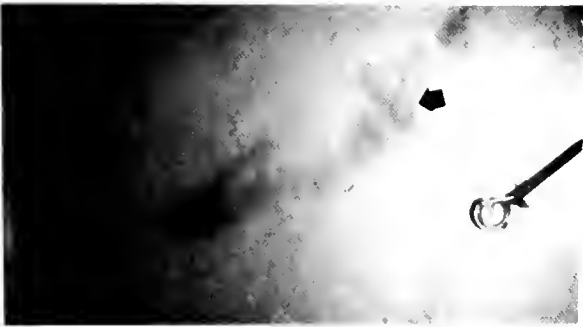
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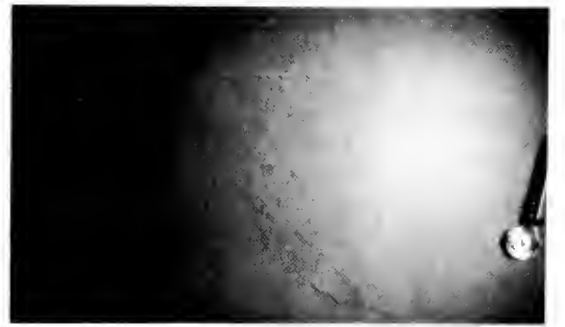
C



D



E



F

PLATE 4

Figs. A-D.—Station 9, canyon head near axis, 195–208 fms.

Figs. E-F.—Station 10, outer shelf, west of canyon head, 57–59 fms.

A&B, Silty bottom with poorly defined (old) ripple marks. Burrows in lower left corner of A and upper part of B; possible crustacean tracks on left margin of B.

C&D, Bottom similar to above. Tubes of polychaete worms (arrows), and hagfish (*Myxine*) (in D).

E&F, Coarse shelly sand; straight asymmetric ripple marks with rounded crests indicating current toward the west. Concentration of shell in ripple troughs and partially buried larger shells in F; Concave-up attitude of shells suggest only weak bottom current activity.



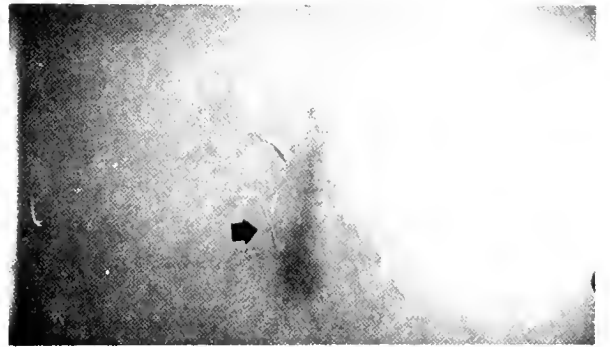
A



B



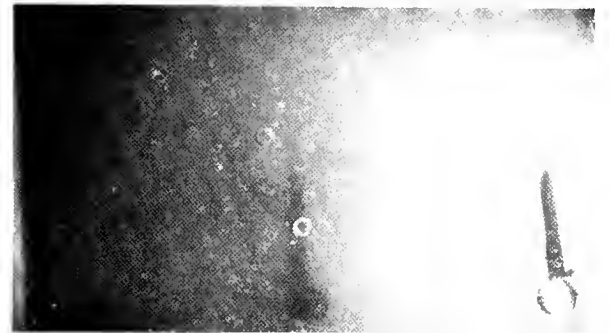
C



D



E



F

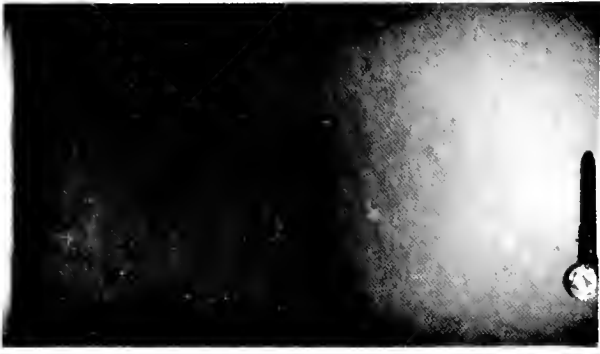
PLATE 5

Figs. A-B.—Station 11, outer shelf, west of canyon head, 54-56 fms.

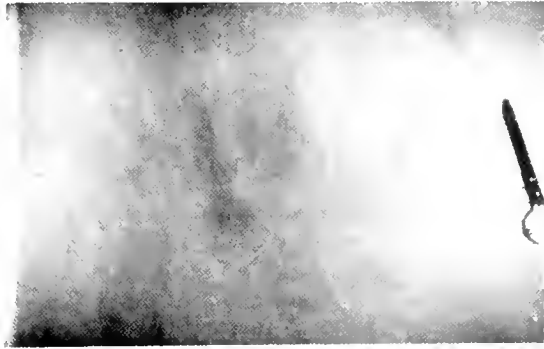
Fig. C.—Station 12, outer shelf, west of canyon head, 52-55 fms.

A&B, Shelly silty sand, with straight asymmetric ripples indicating current toward WNW; canceroid crab (arrow in A) and starfish, common asteroid.

C, Sandy silt, with straight symmetrical ripple marks (crest orientation: 070°-250°); some current interference indicated. Mud or silt partially covering ripples produces a mottled effect.



A



B

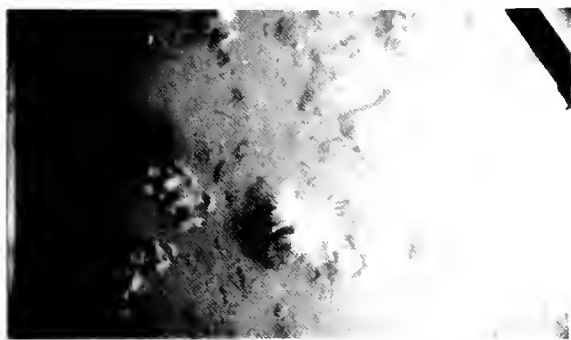


C

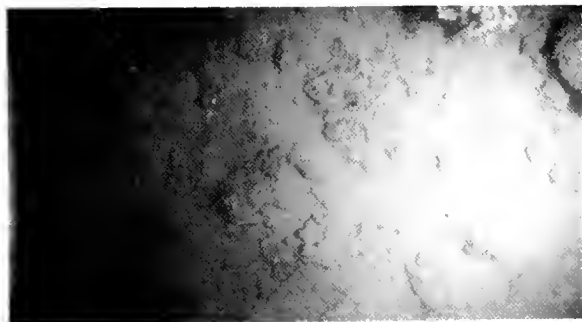
PLATE 6

Figs. A-F.—Station 13, canyon head near axis, 258–278 fms.

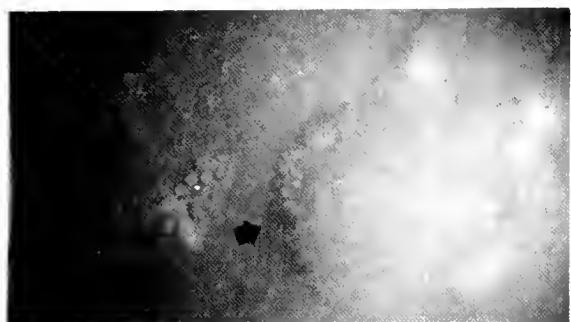
A-F, Poorly sorted, gravelly silty mud; large subangular cobbles covered by coelenterates (sea-anemones?) and a veneer of mud. Particularly large boulder (>60 cms. diameter) is designated by arrow in C. Cloudy appearance of all photographs suggest presence of substantial amounts of suspended sediment.



A



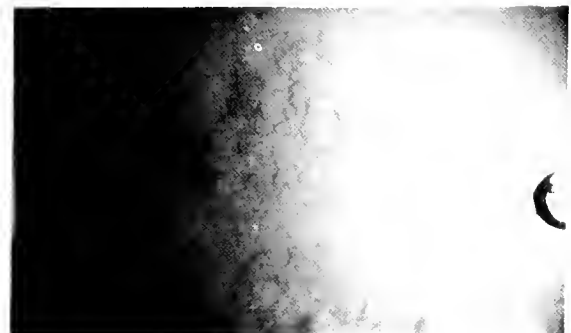
B



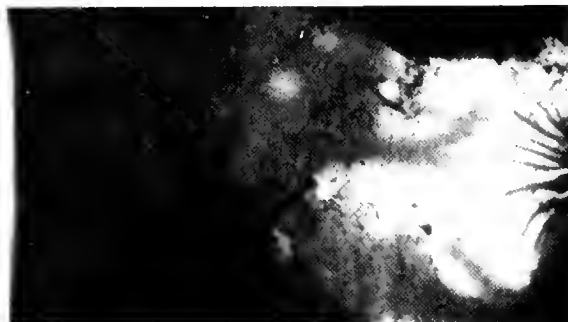
C



D



E



F

PLATE 7

Figs. A-F.—Station 14, canyon head, east wall, 100 fms.

A-C, Shelly, gravelly, sandy silt; slight northeast-southwest lineation of pelecypod shells (mostly concave up and partially buried). Arrows in A, B, and C show lobsters (*Homarus americanus*) adjacent to cobbles; fish resting on bottom, in C.

D-F, Bottom similar to above; hint of ripple interference in D and E; two fish in E; unidentified organism or object in F (arrow).





A



B



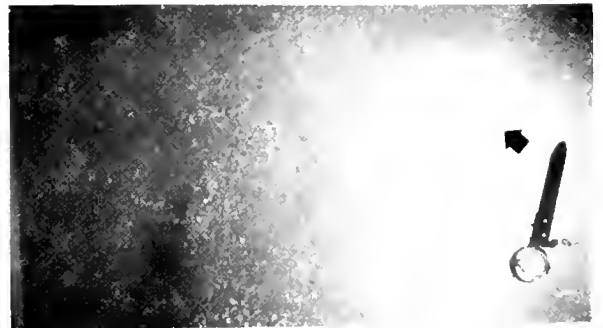
C



D



E



F

PLATE 8

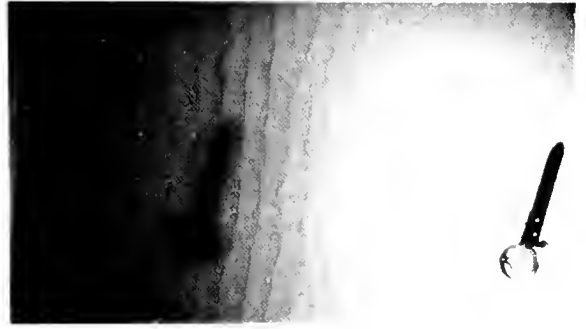
Figs. A-F.—Station 15, outer shelf, east of canyon head, 65 fms.

A-D. Shelly, gravelly sand; straight, anastomosing asymmetric ripple marks indicate current toward WNW. Shell hash concentrated in troughs; several large, partially buried pelecypod valves, in A.

E-F, Bottom similar to above; ripple marks more linguoid in form but similar orientation; fish (*Urophycis*) near bottom, in E.



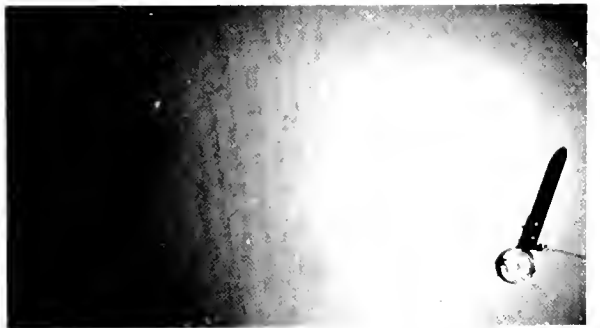
A



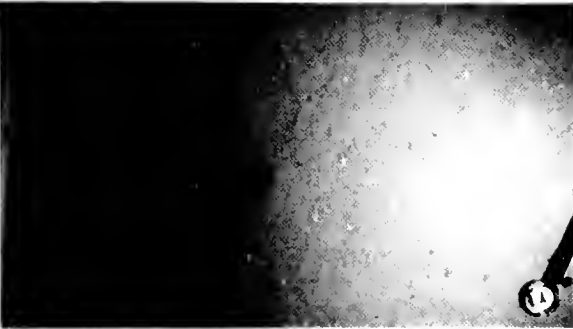
B



C



D



E



F

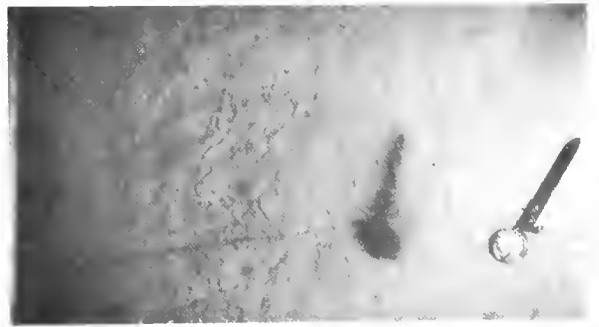
PLATE 9

Figs. A-F.—Station 16, outer shelf, east of canyon head, 125–135 fms.

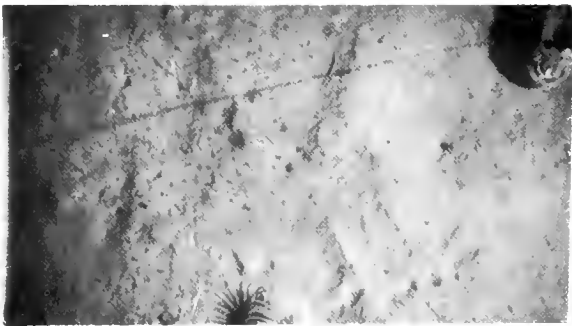
A-F, Muddy silty bottom (cloud trailing compass in A indicates silty nature of sediment; indication of straight asymmetric ripples with some interference, predominant current trend toward the WNW). Tube-dwelling polychaete worms (*Hyalinoecia*) in all photographs (note particularly long tube in A, and tendency towards parallel orientation in A and B); coelenterate in C, crab (*Cancer*-sp.) in D, flat fish (arrow) in E, and probable "fish nest" depressions in F.



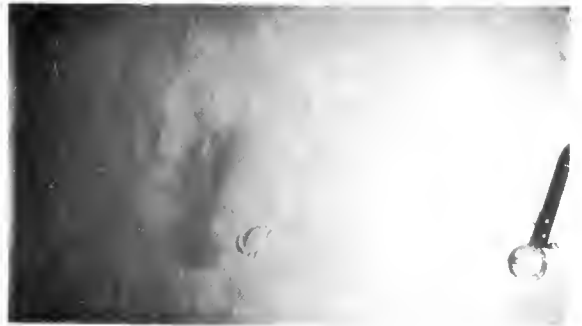
A



B



C



D



E



F

PLATE 10

Fig. A.—Station 17, canyon head, near axis, 350 fms.

Figs. B-C.—Station 18, outer shelf, west of canyon head, 70-75 fms.

Figs. D-F.—Station 22, canyon head, near axis, 395-405 fms.

A, Muddy silt bottom with occasional small pebbles (arrows 1, 2); suggestion of low amplitude ripple marks; crest orientation of  $005^{\circ}$ - $185^{\circ}$ , burrow, right of compass vane.

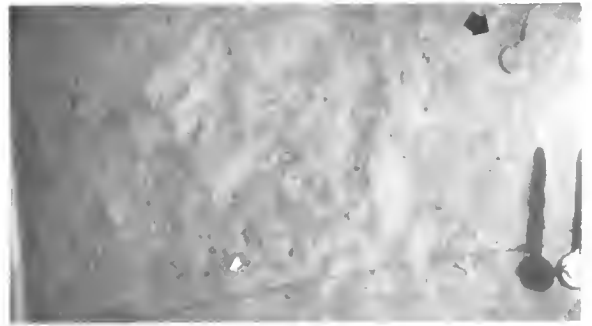
B&C, Sandy silt, slightly shelly; patchy distribution of silt veneer produces mottled effect. Depression (arrows) in upper right corner of B, caused by impact of compass; reveals cohesive nature of sediment. Interference ripple marks (crest orientations:  $020^{\circ}$ - $200^{\circ}$  and  $165^{\circ}$ - $345^{\circ}$ ; dominant current towards west), lumps in lower left corner of B may be small pebbles or faecal casts; pelecypod shells partially buried and concave up; fish near bottom in C.

D, Silty mud, granular nature of bottom probably due to faecal pellets. Two asteroid depressions ("lebensspuren") formed by unknown organism.

E&F, Silty mud (compass cloud reveals muddy nature). Note scour lineations (arrow indicates probable current direction toward south) in E. Abundant small tubes of polychaete worms (*Hyalinoecia*) trending generally parallel to scour lineations. Note also steep-sided depression of uncertain origin in E.



A



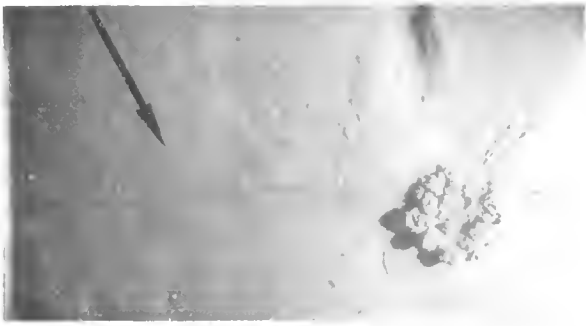
B



C



D



E



F

PLATE 11

Figs. A-F.—Station 23, outer shelf, east of canyon, 120–130 fms.

A-F, Shelly silty sand and sandy silt; vague, round crested, low amplitude interference ripple forms suggesting dominant movement toward the west. Patchy distribution of fine shell hash. Subcircular depressions (arrows 1 in C and F) formed by flat fish. Urophycid fish in B, C, E, and F. Plant-like forms (arrows 2 in C and F) may be sea-anemones.

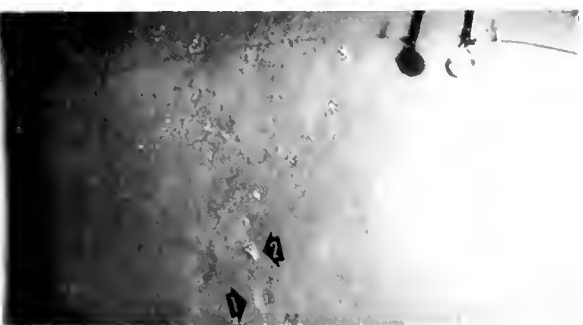




A



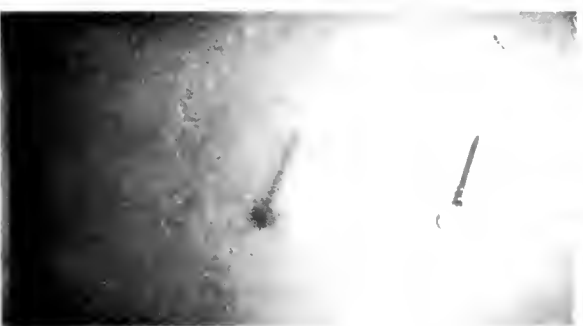
B



C



D



E



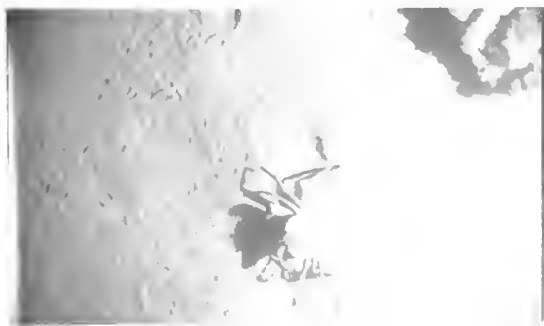
F

PLATE 12

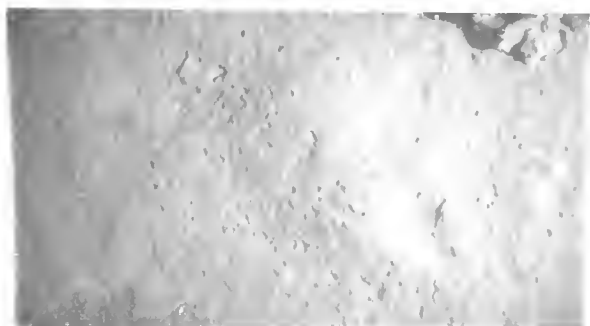
Figs. A-F.—Station 24, canyon head, east wall, 250–280 fms.

A–D, Silty mud (cloud produced by compass indicates mud content); small linear depressions, particularly noticeable in B, produced by crabs. Crab in A is *Geryon quinquedens* Smith. Another unidentified crab in D (arrow). Subcircular depressions probably formed by benthic fish. Linear depressions of unknown origin in B. Worm tubes (arrows) projecting from bottom in C.

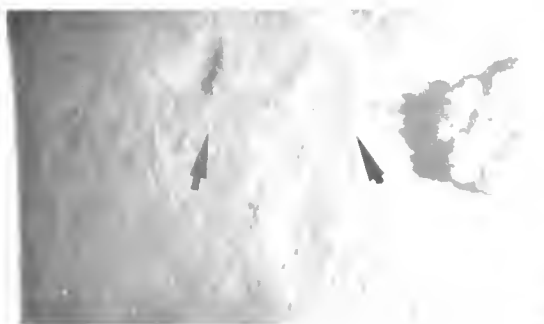
E&F, Bottom similar to above. Bottom-living flat fish (arrow in E) produce sub-circular depressions in fine sediment.



A



B



C



D



E



F

PLATE 13

Figs. A-B.—Station 25, canyon head, near axis, 480 fms.

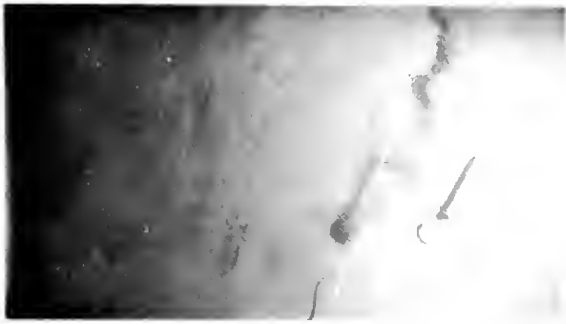
Fig. C.—Station 26, outer shelf, west of canyon head, 62 fms.

Figs. D-F.—Station 27, outer shelf, west of canyon head, 71 fms.

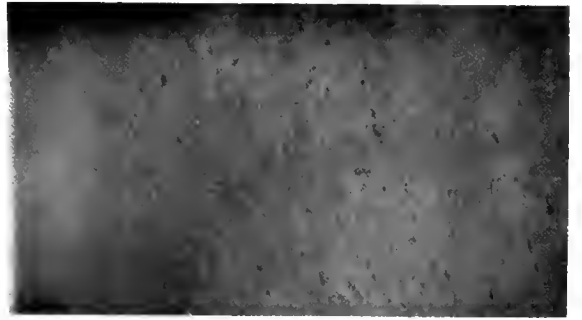
A&B, Silt (cloud trailing compass indicates muddy nature of bottom); granular nature of bottom (E) may be due to faecal pellets or reworked sediment clasts. Tracks (probably in part crustacean) and fish (in A).

C, Shelly silty bottom; two fish above bottom.

D-F, Shelly silty sand and sandy silt; low amplitude buried ripples (best seen in D) indicate current toward WNW. Shells, concave-up and partially buried, are concentrated in clusters. Coelenterate (arrow) upon shell in F.



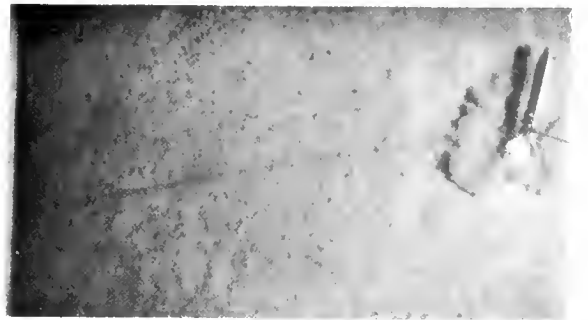
A



B



C



D



E



F

PLATE 14

Figs. A-F.—Station 28, upper slope, west of canyon, 140–160 fms.

A-F, Silty mud bottom (note cloud trailing compass in A and F). Abundant small burrows, some of which may be due to worm tubes. Tubes of polychaete worms (*Hyalinoecia tubicola*), most lying on bottom and some projecting obliquely (see D center), common throughout station; note alignment of tubes in B and C. Bottom-living flatfish of the type seen in D may be responsible for wavy tracks (“fin tracks”, arrow 1 in A and E) and subcircular depressions (“fish-nest”, arrow 2 in F). A canceroid crab occurs in the upper left corner of E (arrow 3).



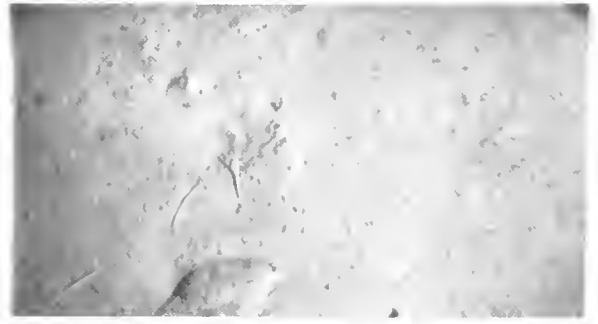
A



B



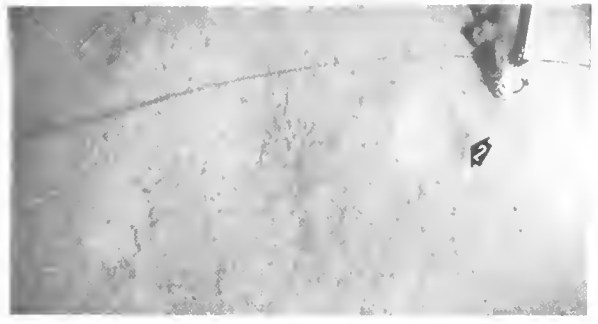
C



D



E



F

PLATE 15

Figs. A-F.—Station 29, upper slope, west of canyon, on small ridge, 150–180 fms.

A–C, Sandy silt bottom with some shell; poorly preserved interference ripple marks in upper margin of A; burrows in B; subcircular “fish-nest” structures in A and B probably produced by benthic fish; unidentified fish above bottom in B and C. Canceroid crab and floating medusoid coelenterate (arrow) in C.

D&E, Shelly sandy silt bottom with patches of subrounded granules, pebbles and cobbles (See D, north of compass vane). Poorly preserved, low amplitude ripple marks in D. Abundant *Hyalinoecia* tubes in E. Canceroid crab in D. Small eel in E (arrow).

F, Bottom similar to above. Note abundance of polychaete tubes having a statistical bimodal orientation.

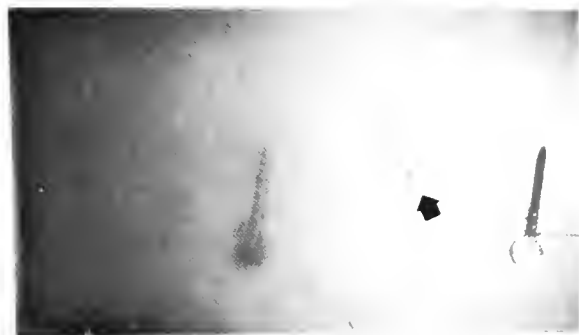




A



B



C



D



E



F

PLATE 16

Figs. A-F.—Station 30, near canyon axis, on slope, 598–610 fms.

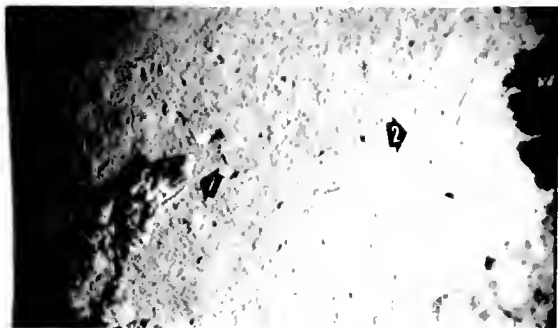
A–C, Mud, largely clay bottom, as shown by clouds, some of which are caused by flat fish (arrow 1 in B and C). These fish probably also produce paired curved tracks (arrow 2 in A, B, and C). Burrows are also common. Granules visible in B may represent faecal pellets.

D, Bottom, similar to above; obscured by suspended sediment. Note four eels.

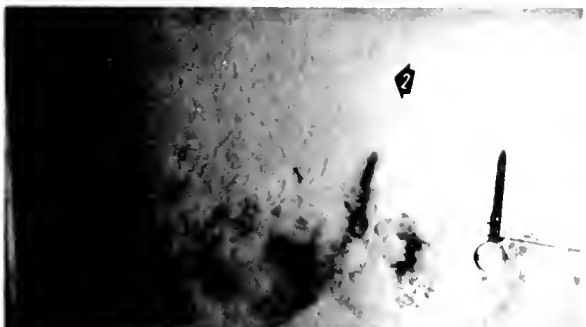
E&F, Bottom similar to above; close-up view reveals granular texture (faecal pellets?), depressions (fish?), paired tracks (arrow in F), and abundant burrows.



A



B



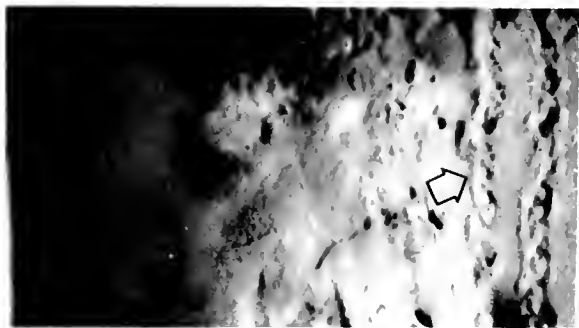
C



D



E



F

PLATE 17

Figs. A-F.—Station 31, upper slope, east of canyon, 200-235 fms.

A-C, Mud, largely clay, bottom; local shell concentrations (A and C). Burrows and semi-circular depressions common; sea-anemones are present; crab (*Geryon sp.*) in C. Note small polychaete worm tubes in A and B, and rat-tail (Macrourid) fish in A.

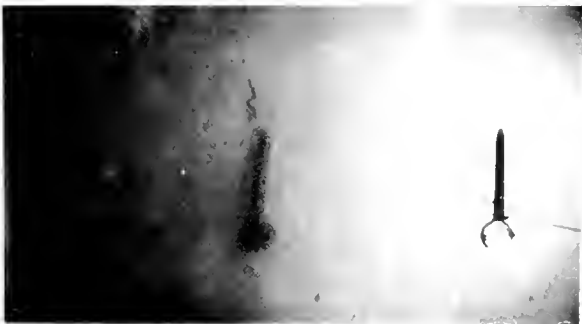
D-F, Bottom similar to the above; close-up view reveals abundance of tracks and trails ("lebensspuren") some produced by fish and crustaceans.



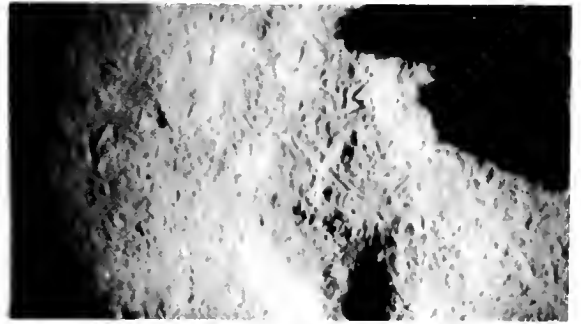
A



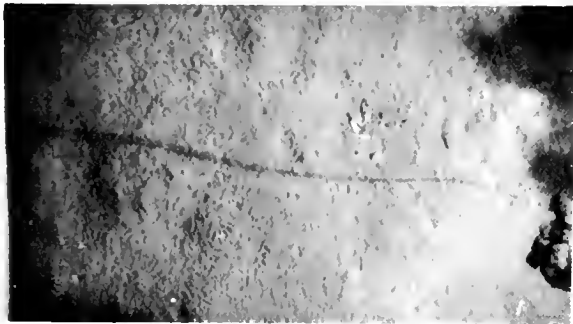
B



C



D



E



F

PLATE 18

Figs. A-F.—Station 32, slope, east of canyon, 530-550 fms.

A-F, Muddy, largely clayey, bottom (note sediment clouds in A and B). Bottom entirely covered by tracks and trails ("lebensspuren") and burrows. Paired track (arrow in B, C, and D) are probably produced by bottom-living fish. Shrimp resting on bottom in B and Macrourid fish swimming in F. Starfish in lower left corner of A. Irregular muddy cloud in E probably produced by burrowing organisms.



A



B



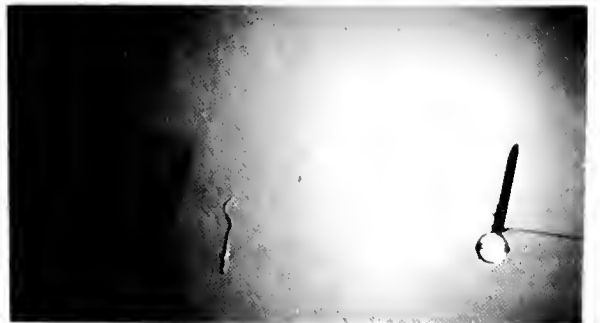
C



D



E



F

PLATE 19

Figs. A-F.—Station 33, slope, near canyon axis, 680-750 fms.

A-F, Muddy, largely clayey, bottom (note sediment trailing and clinging to compass in A and D). Bottom entirely covered by tracks and trails ("lebensspuren") and burrows. Note unidentified fish in E and sea urchins in E and F.

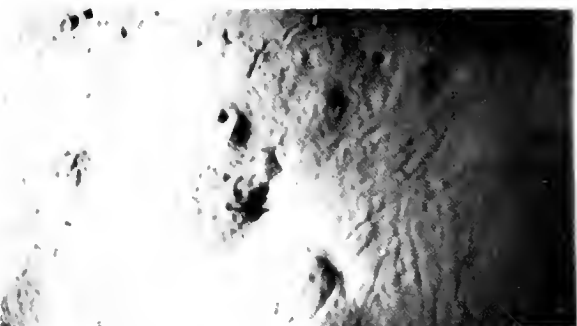




A



B



C



D



E



F

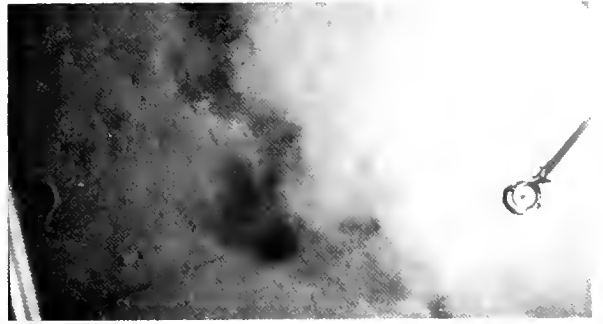
PLATE 20

Figs. A-F.—Station 34, mid-slope, on Nyckel Ridge south of canyon, 610–625 fms.

A-F, Muddy, largely clayey, bottom (see sediment clouds in A, B, and F). Granular texture, well developed in A, D, and E, may be produced by faecal pellets or muddy clasts. Large steep-sided depressions of unknown origin in lower part of E. Subcircular shallow depressions (“fish-nest” type) are common (see arrow in D) and probably produced by benthic flat fish (see C and D). Sea-spider (*Colossendeis sp.*) present (arrow 2) in D. Large dark circular object in F may be a sea urchin. Note also probable Macrourid fish in F.



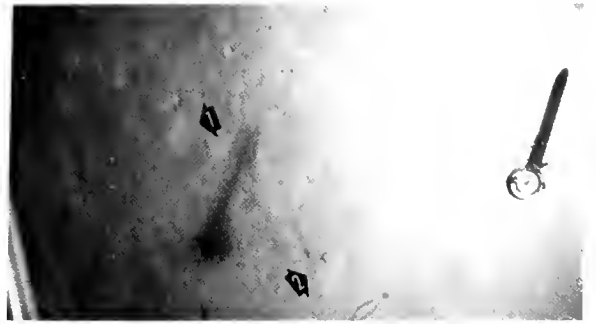
A



B



C



D



E



F

PLATE 21

Figs. A-F.—Station 36, lower slope, south of Nyckel Ridge, 810–815 fms.

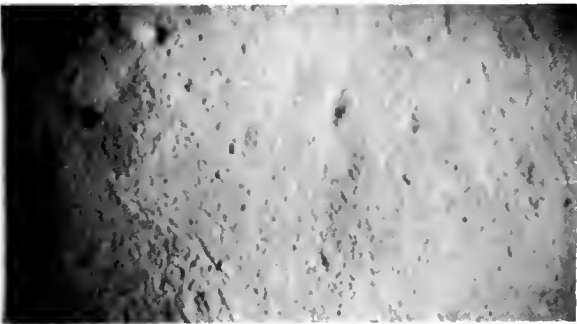
A-F, Muddy, largely clayey, bottom (see clouds in A and B). Granular texture, particularly apparent in C and E, may be produced by faecal pellets or sediment clasts. Halosaur fish, such as that in B, may produce linear tracks of the type shown in B and C (arrow). Burrow in lower left corner of E. Sediment clouds in center of F (arrow) may be produced by burrowing organisms. Sea urchin is present in D.



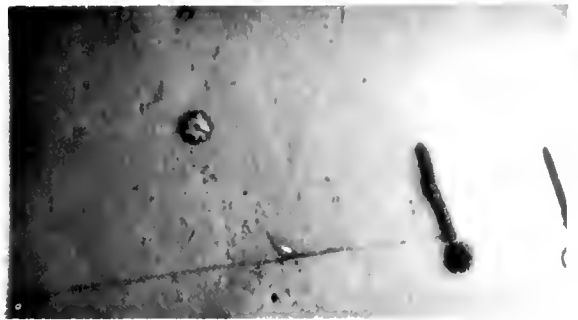
A



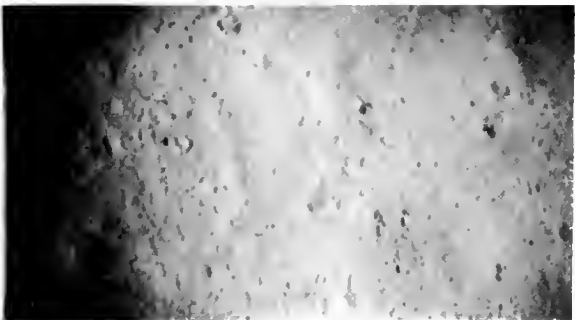
B



C



D



E



F

PLATE 22

Figs. A-F.—Station 37, on lower slope, on Nyckel Ridge south of canyon, 725–745 fms.

A-F, Muddy, largely clayey, bottom (see clouds in A and B). Granular texture, apparent in E, may be produced by faecal pellets or sediment clasts. Burrows are common; large steep-sided depressions of unknown origin in D (arrow). Elasi-podid holothurian (arrow 1) and probable faecal remains (arrow 2) in C. Morid fish and eel in D and sea urchins in D and F.



A



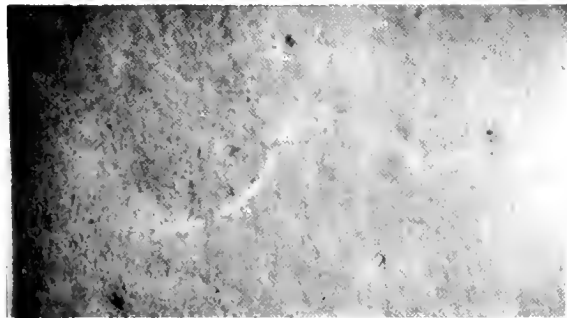
B



C



D



E



F

PLATE 23

Figs. A-F.—Station 37—A, lower slope, near canyon axis, 820–960 fms.

A–F, Silty mud bottom (see cloud in D). Local concentration of large elongate granules (arrow 2 in A, B, C), are probably faecal pellets of worm-like organisms (arrow 1 in A, B, E). Burrows and mounds are present; small worm tubes (?) (circled in D) heel over in same direction (towards north). Ophiuroid brittle stars (*?Ophiomusium*) are common; sea spider (*Colossendeis sp.*) in F (arrow 3); eel in E.

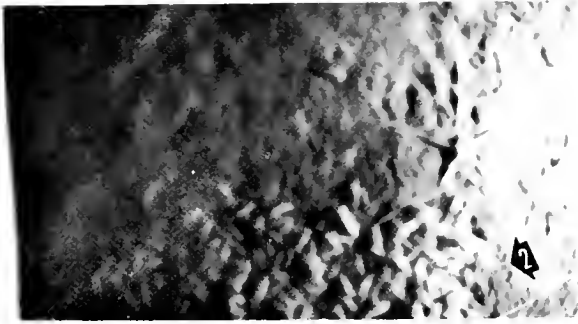




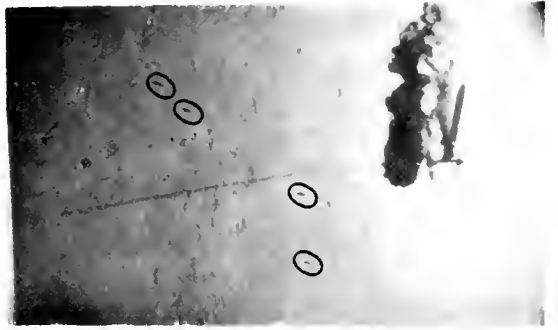
I



B



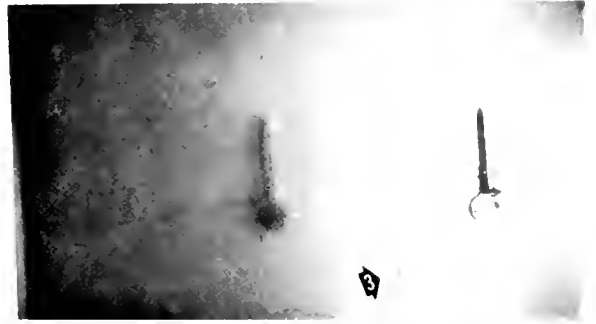
C



D



E



F

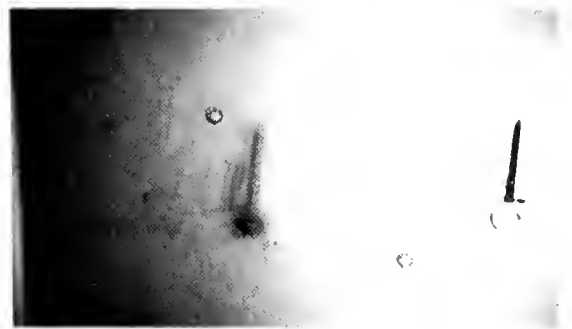
PLATE 21

Figs. A-F.—Station 38, lower slope, north of canyon, 695–735 fms.

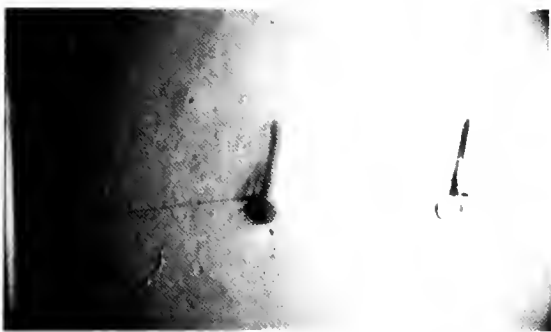
A-F, Soft silty mud bottom (see clouds in A, D, and E). Bottom covered by numerous tracks, trails and burrows. Morid fish in A, B, and hagfish or eel in C, and Lalosaur in D together with sea urchins (in A and B) are probably responsible for some of the bottom markings. Tube of polychaete worm (circled in E) projecting from bottom. Present bottom current activity negligible.



A



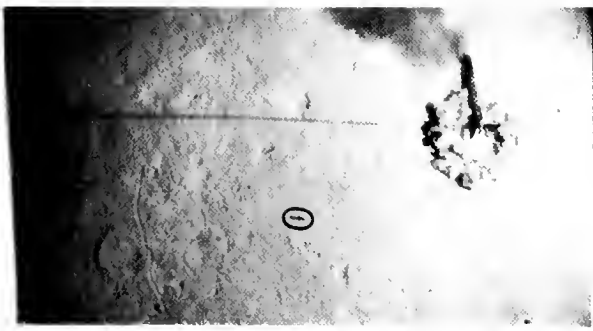
B



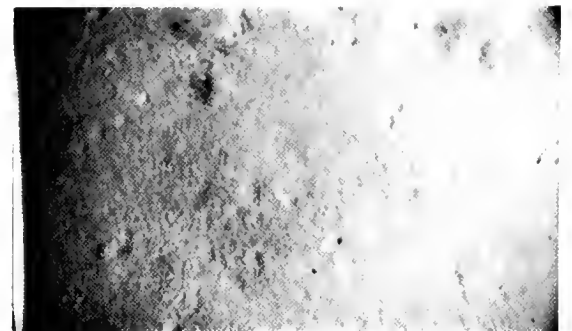
C



D



E



F

PLATE 25

Figs. A-C.—Station 39, lower slope, north of canyon, 1000–1050 fms.

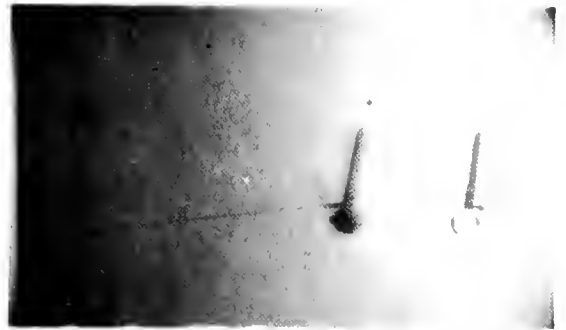
Figs. D-F.—Station 41, lower slope, Nyckel Ridge south of canyon, 925–935 fms.

A-C, Muddy, largely clay, bottom covered by resting traces of brittle stars (arrow in C) and deep burrows. Bladder-like organism in upper A (arrow) is probably an elasipodid holothurian.

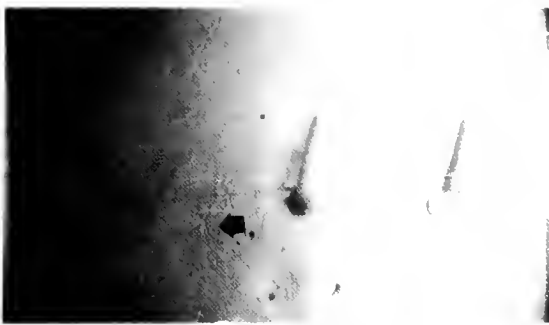
D-F, Silty mud bottom (cloud in D), slightly undulatory, covered by resting traces of brittle stars. Large, steep-sided depression of unknown origin (E), some of them 25 cm. in diameter, indicate cohesive nature of bottom. Subtle east-west ripple crest orientations in E and F suggest possible north-south bottom current movement. Probable worm-like organism (arrow) in upper part of F.



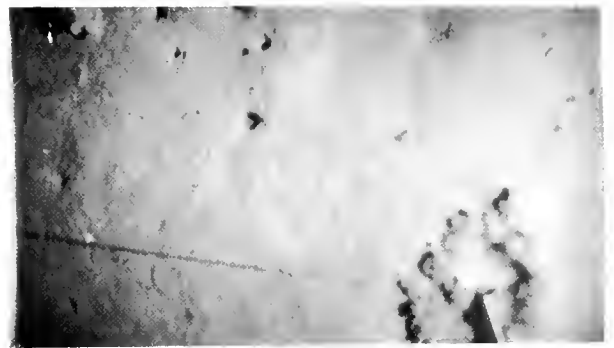
A



B



C



D



E



F

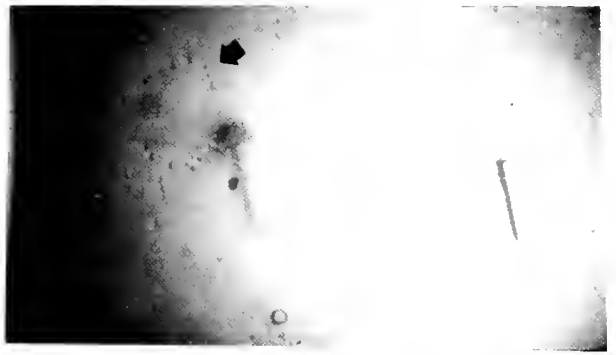
PLATE 26

Figs. A-F.—Station 12, lower slope, south of Nyckel Ridge, 990–1200 fms.

A-F, Silty muddy, slightly undulatory, bottom (see cloud in A) covered with resting traces of brittle stars, mounds, and burrows, tracks and trails. Sub-circular rings of small depressions in B (arrow) may be sunstar resting trace. Some depressions may also be produced by sea urchins (in A, B, and C). Possible holothurian or worm in D.



A



B



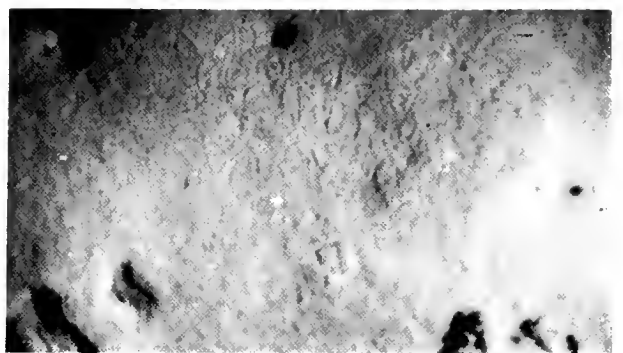
C



D



E



F

PLATE 27

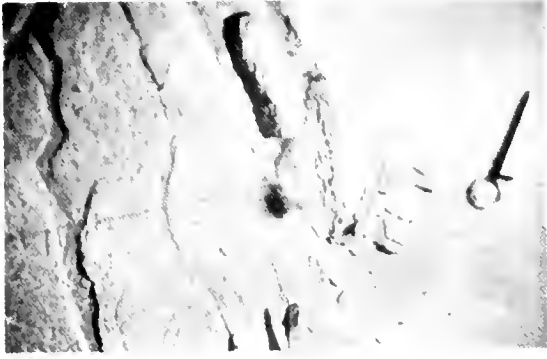
Figs. A-F.—Station 13, upper rise, Nyckel Ridge south of submarine valley, 1190–1215 fms.

A, Margin of fractured rock ledge on a slope. Main fracture direction ENE–WSW. Rock outcrop, possibly of consolidated sandstone, is at least 15–20 cm. thick. Fractures resemble joint pattern, possibly opened during slide and emplacement of rock mass. Rock seems to be resting on flat sandy bottom (right of photo).

B–D, Sand bottom in front of rock ledge shown in A, with numerous angular blocks of well jointed rock broken off ledge. Note appearance of *in situ* rupture of rock (arrow in C). Blocks resting on sand rippled by currents moving towards NW. Dark pebbles are also noted near blocks and in ripple troughs. Ophiuroid brittle stars, eel and Macrourid fish in D.

E&F, Sandy gravel bottom locally covered with silt as shown by clouds. Dark pebbles and subrounded cobbles. Unidentified fish, brittle stars and regular sea urchins (arrow) present in F.

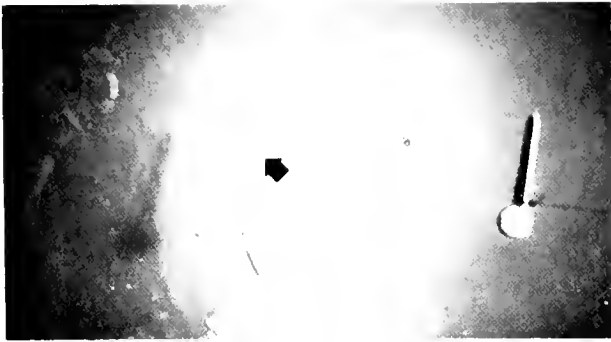




A



B



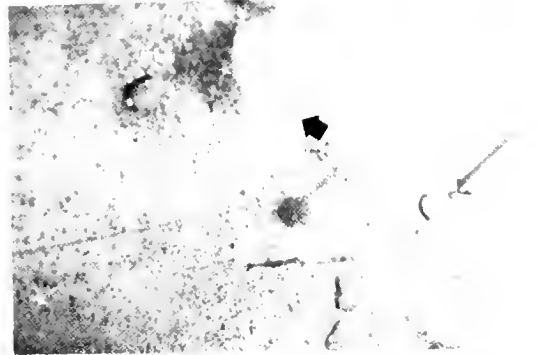
C



D



E



F

PLATE 28

Figs. A-F.—Station 43, upper rise, Nyckel Ridge south of submarine valley, 1190–1215 fms.

A, Broad outcrop of consolidated sediment veneered by silt (see cloud). Brittle star indicates scale.

B–D, Rippled sand (current towards NW) carrying patches of dark pebbles, cobbles, and occasional larger angular blocks of rock, similar to that in Plate 27. Blocks appear to have broken *in situ* (arrow in B). White circular objects in left of C and D may be regular sea urchins; ophiuroid brittle stars in C and D.

E&F, Sandy gravel bottom veneered by silt (cloud in F) with occasional cobbles. Pebbles appear to be relatively well-sorted suggesting current activity. Brittle star in top of E partially covered by cobble. White specks in F may be sea urchins.



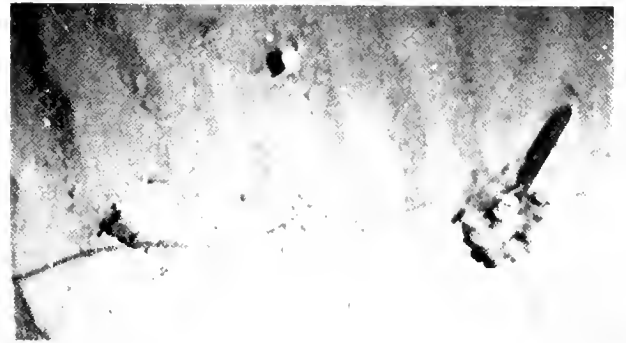
A



B



C



D



E



F

PLATE 29

Figs. A-C.—Station 11, upper rise, immediately south of submarine valley, 1185–1200 fms.

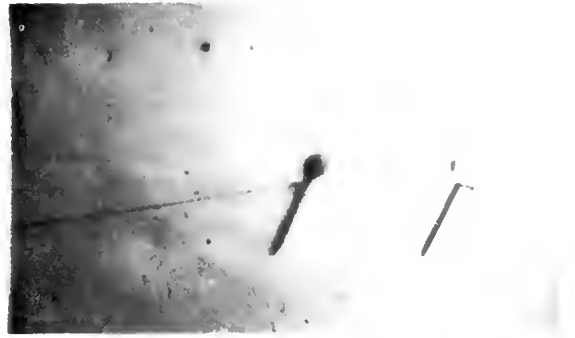
Figs. D-F.—Station 45, upper rise, north of submarine valley, 1190–1200 fms.

A-C, Silty mud bottom (cloud in A) with burrows, low mounds, trails and tracks. Moving ophiuroid brittle star (arrow in C) and regular sea urchins in B.

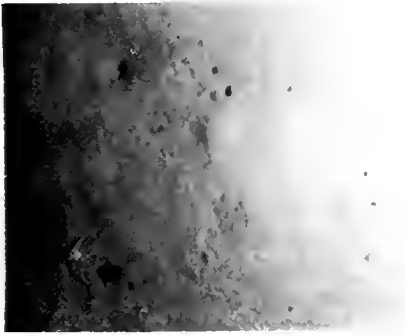
D-F, Clayey bottom (cloud in E) entirely covered with tracks, trails, resting places, and burrows. Granular appearance possibly due to faecal pellets or sediment clasts. Aspidochirotid holothurian (arrow 1) and Morid fish (arrow 2) in D.



A



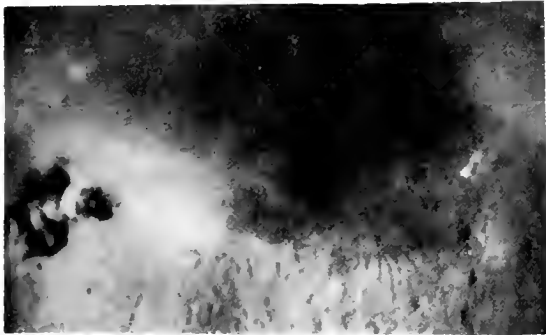
B



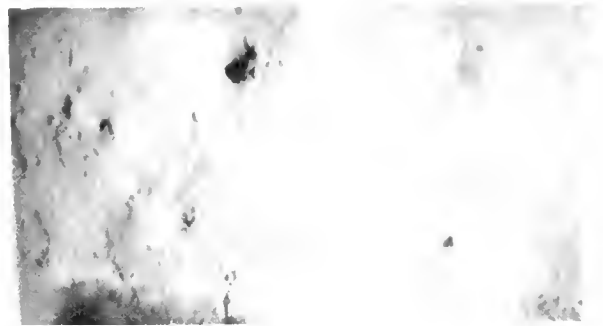
C



D



E



F

PLATE 30

Figs. A-C.—Station 46, upper rise, north of submarine valley, 1290-1300 fms.

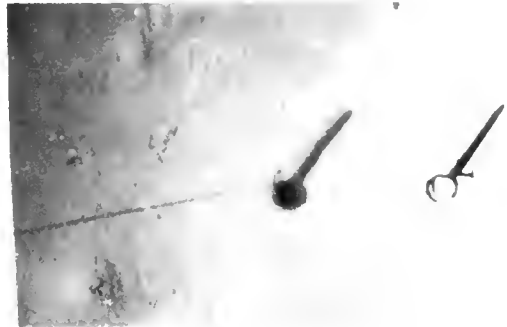
Figs. D-F.—Station 47, upper rise, south of submarine valley, 1340 fms.

A-C, Mud, largely clay, bottom with small depressions and burrows. Note large darker ovate patches. Bladder-like object in A (arrow 1) is probably an Elasi-podid holothurian. Unidentified sea-star or crinoid (arrow 2) in A. Linear trail in B. Ophiuroid brittle stars near base of C; also small worm tubes or small holothurians (circled) projecting from bottom.

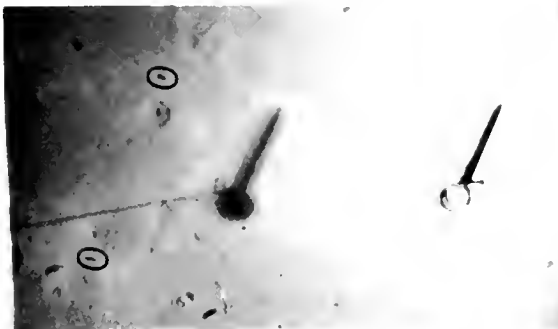
D-F, Silty mud bottom, slightly undulatory, covered by tracks, trails and burrows. Small worm tubes or small holothurians projecting from the bottom (circled in E and F) trend toward the east, suggesting current moving in that direction. Regular sea urchins in all three photographs.



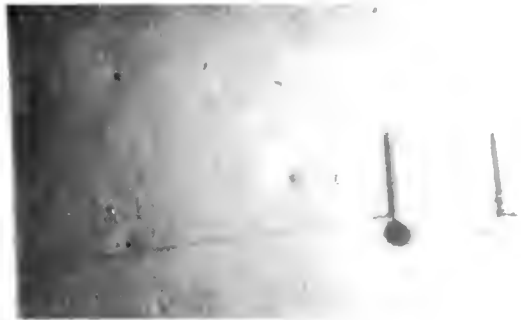
A



B



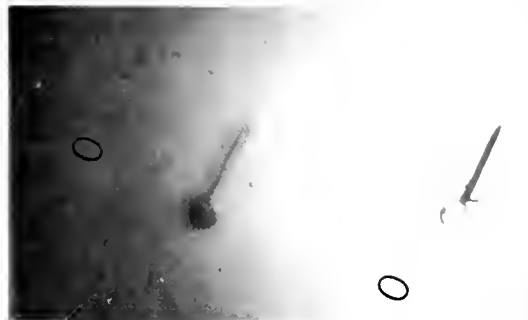
C



D



E



F

PLATE 31

Figs. A-C.—Station 18, upper rise, on Nyckel Ridge, 1300 fms.

Figs. D-F.—Station 19, upper rise, south of Nyckel Ridge, 1410 fms.

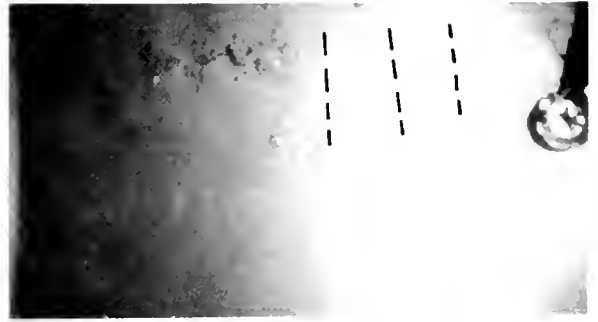
A-C, Gravelly, sandy mud with local concentrations of subrounded cobbles with diameters up to 40 cm. Trace of ripple crest orientation of  $035^{\circ}$ – $215^{\circ}$  in B. Ripples are buried under a veneer of silt. Regular sea urchins are represented by white specks in all photos.

D-F, Sandy mud bottom with gravel. Note organism-encrusted boulder between arrows (approximately 1 m in length) on left margin of F. Sublinguoid ripple marks indicate current movement towards SSW. Elaspodid holothurian in D.





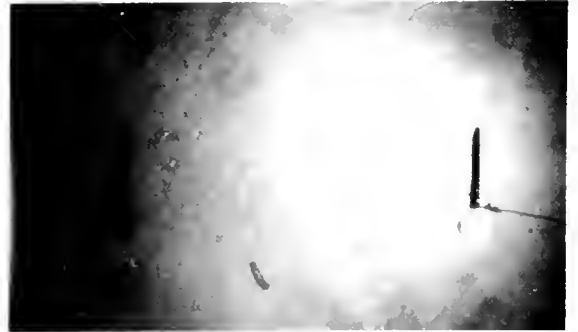
A



B



C



D



E



F

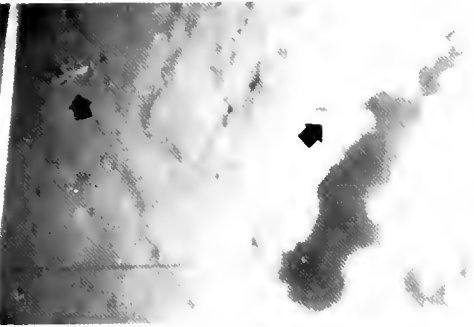
PLATE 32

Figs. A-C.—Station 50, upper rise, immediately south of submarine valley, 1420 fms.

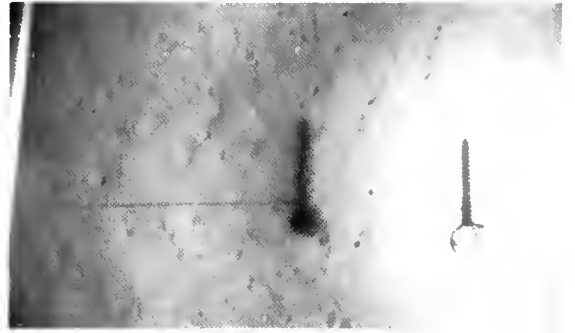
Figs. D-F.—Station 51, upper rise, north of submarine valley, 1400-1405 fms.

A-C, Sandy silty mud bottom (cloud in A). Interference ripple marks with dominant trend showing current movement towards SSW. Plant-like organisms (coelenterates?) depicted by arrows in A.

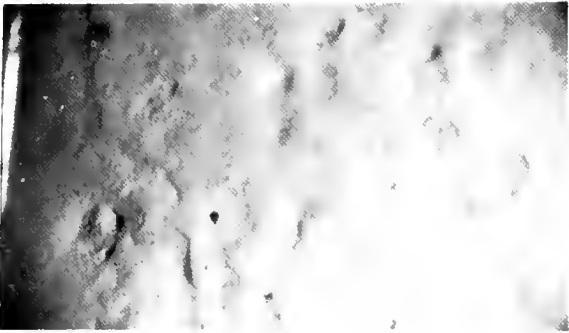
D-F, Mud, largely clay, bottom (cloud in D) covered with large tracks (arrow 1 in F) and some burrows and mounds. Asteroid seastars in D and E; plant-like organisms (coelenterates?) in E and F (arrow 2).



A



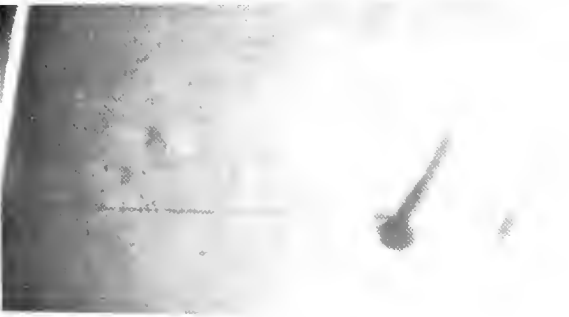
B



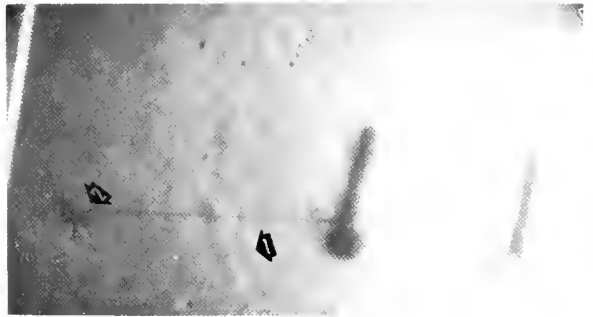
C



D



E



F

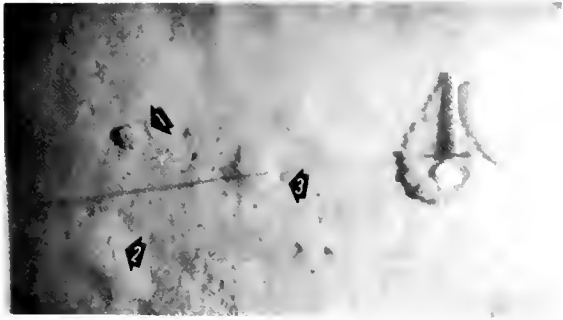
PLATE 33

Figs. A-B.—Station 52, outer part of upper rise, north of submarine valley, 1460-1465 fms.

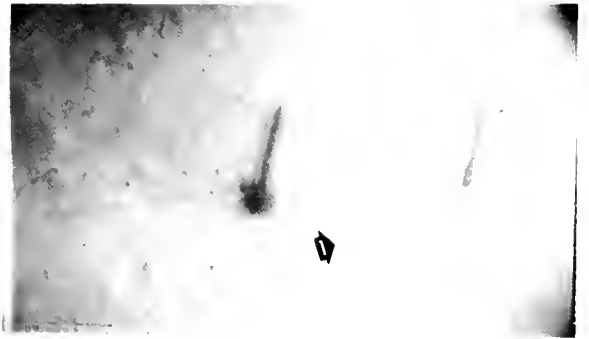
Figs. C-F.—Station 53, outer part of upper rise, adjacent to submarine valley, 1506 fms.

A&B, Silty mud bottom (cloud in A) with possible pebbles or unidentified organisms (arrow 1 in A and B). Bottom covered with burrows, mounds, tracks, trails, and resting places of brittle star (arrow 2 in A) and sun-star (arrow 3 in A). Elaspodid holothurian narrowly avoids striking the compass in A.

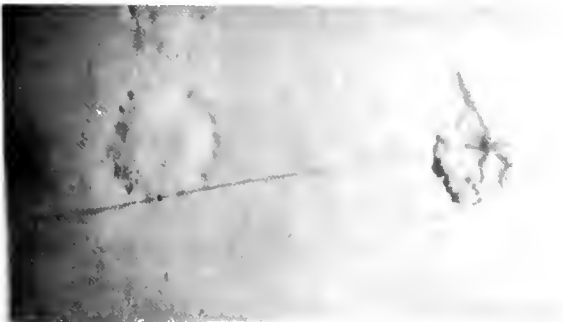
C-F, Silty mud bottom, slightly undulatory, with burrows and circular sun-star imprints. Track of unknown origin in F.



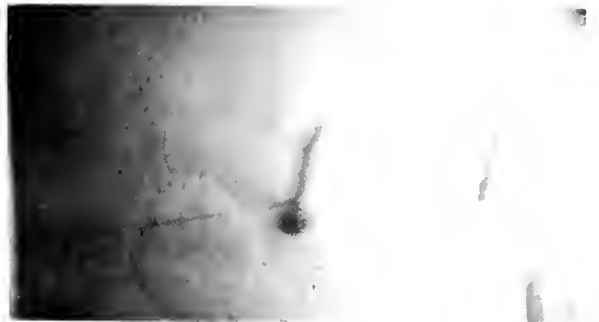
A



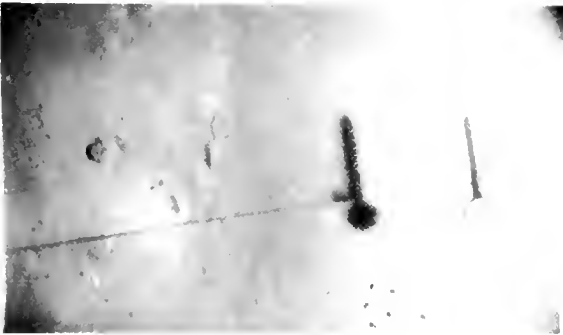
B



C



D



E



F

PLATE 34

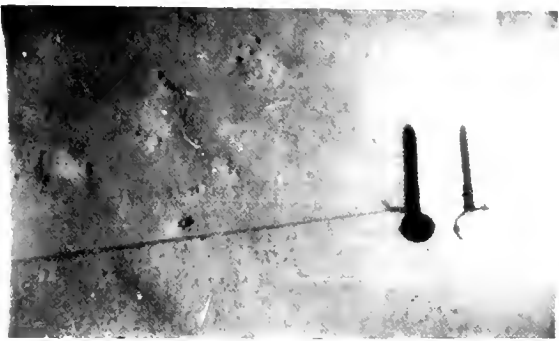
- Figs. A-F.—Station 54, outer part of upper rise, south of submarine valley, 1490 fms.  
A-E, Silty mud bottom (cloud in A), slightly undulatory. Tracks, trails, sunstar resting trace, burrows, and mounds common.  
F, Evidence of deep ocean *bacchanalia* at about 1500 fms.



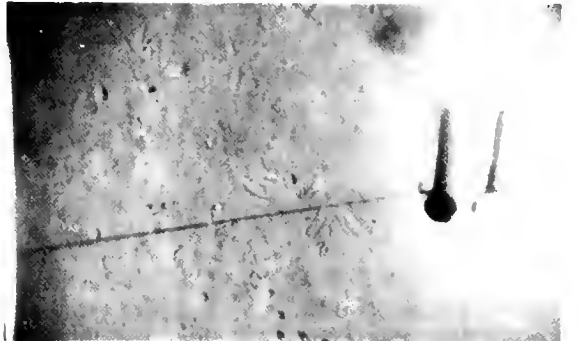
A



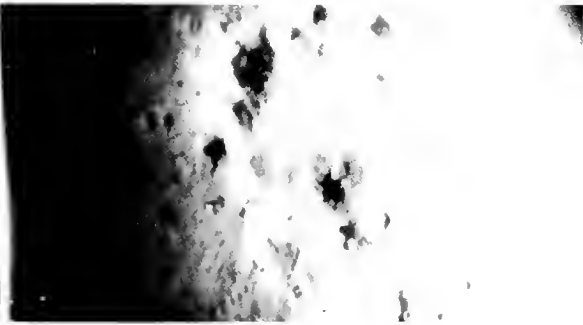
B



C



D



E



F





## IV. RESULTS

### *General*

A total of 1243 photos were taken at the fifty-four stations shown on Fig. 3. Of these, approximately two thirds, or about 800 frames, were close enough to the bottom to show some evidence of lithology, current activity or organisms. About one sixth or 200 of the frames, generally taken close to the bottom (within 1 fathom) could be categorized as good to excellent. The photographic information collected at each station is summarized in Table II.

This table includes the following data for each station studied: film roll and frame number, quality of photographs, bottom surface area covered, bottom textural types, ripple marks and other current indicators, organisms, and other pertinent observations. Selected representative photographs of the bottom at most of the stations are presented in Plates 1 to 34. A brief summary highlighting sediment texture, inferred bottom current directions, and organisms recorded on film is presented below. Figures 7 to 10 have been compiled by plotting data summarized in Table II.

### *Sediment Texture*

The contoured regional distribution of major sediment textural types (sediment grain size mixtures) is shown in Fig. 7. The textural terms used are those employed by sedimentologists (Pettijohn, 1957). Textural interpretations were verified by coring, where possible, and by comparison with sediment notations of Stetson (1949) and Hathaway (1966, 1967). Coarse to medium sand occurs near the outer shelf margin and the head of the Wilmington Canyon to depths somewhat in excess of 50 fms. Sandy silt and silty sand actually drapes the shelf edge and uppermost continental slope. This material also fills the upper canyon head and extends as a tongue down the axis to about 500 fms. Greater photographic coverage in the canyon could indicate that this tongue actually extends further downslope. Silt and clay admixtures (material finer than 0.0625

mm) increase and the relative percentage of sand (0.0625–2.0 mm) decreases substantially below 50 fathoms. However, local concentrations of sandy sediment are noted at greater depths, particularly on the Nyckel Ridge (Stations 43, 48, 50 and 52), to about 1500 fms.

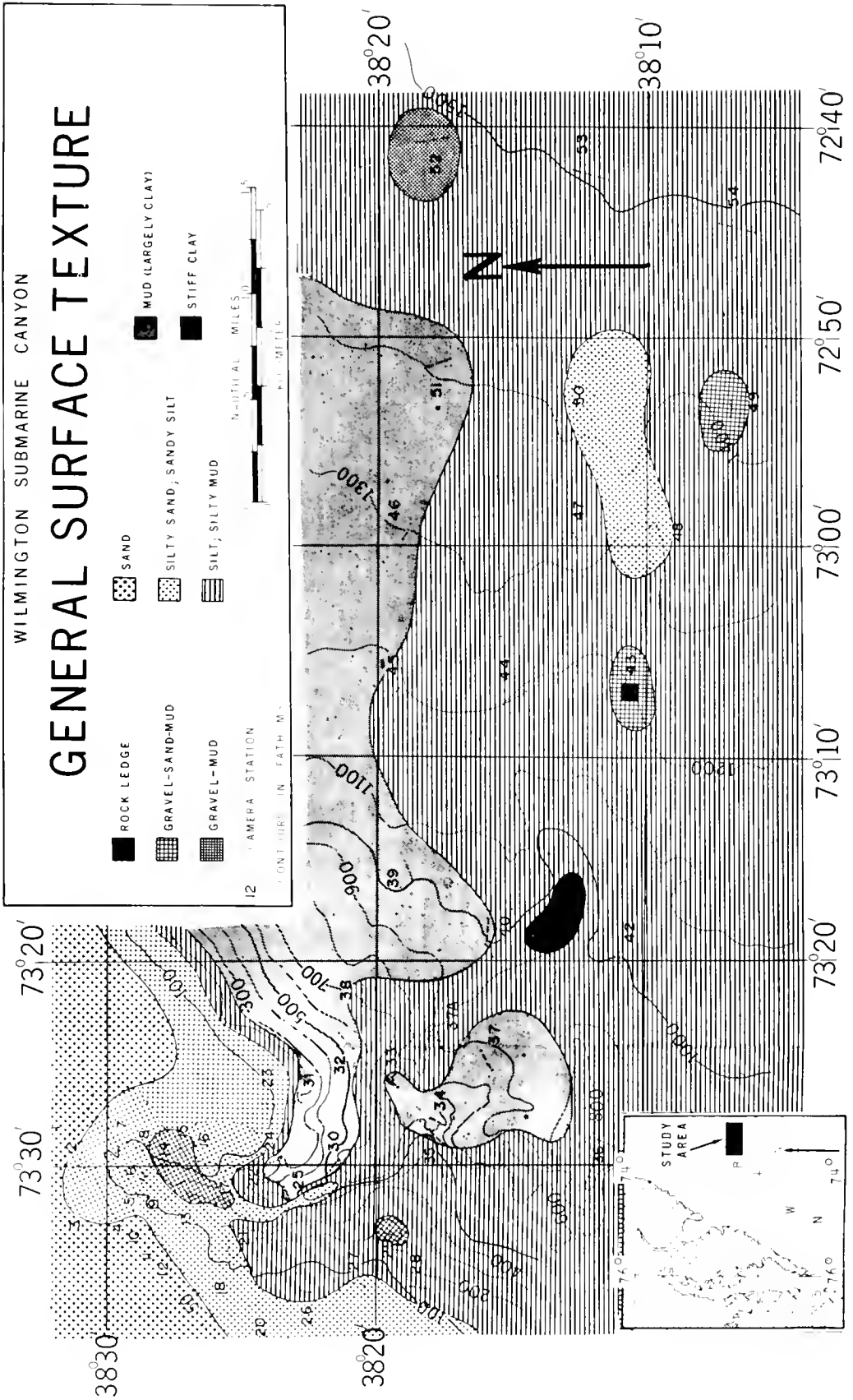
Pebble and cobble-sized material (coarser than 2.0 mm) appear to be concentrated in three areas. A tongue of coarse material on the steep east wall of the canyon head extends from the shelf edge to depths exceeding 300 fms. Boulders, some exceeding 1 m. in diameter, occur near the axis at Stations 13 and 17. An isolated gravel location (Station 29) was encountered on the southwest canyon wall at a depth of about 150 fms. Gravel, with sand and mud, also occur on the upper rise near the Nyckel Ridge at Station 49 and north of the canyon axis at Station 52.

Below about 100 fms silt and silty mud covers the canyon proper and the continental slope and rise. The slope east and north of the canyon tends to be covered with soft clayey mud. Stiff clay is noted at several deep stations particularly those on or near the Nyckel Ridge including Station 41 at 930 fms. Small muddy lumps of granule size in silt and clay sediments, common in some slope and rise stations, are probably of organic origin and may be faecal pellets (Table II).

A rock outcrop was noted at Station 43 on the Nyckel Ridge at the base of the slope. This large, parallel-bedded ledge is more than one meter thick and displays a series of distinct linear fractures (Plate 27, fig. A). Angular rock fragments broken from the leading edge of the ledge lie at the base of the outcrop (Plate 27, figs. B-D). The presence of a thin veneer of silt on the rock slabs is shown in Plate 28 (fig. A).

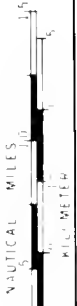
### *Inferred Bottom Currents (Neocurrents) and Sediment Movement*

The photographic survey makes it possible to detect the evidence of recent bottom current

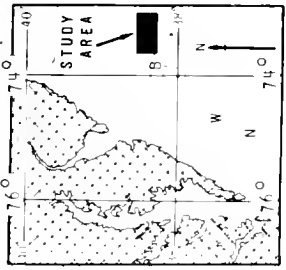
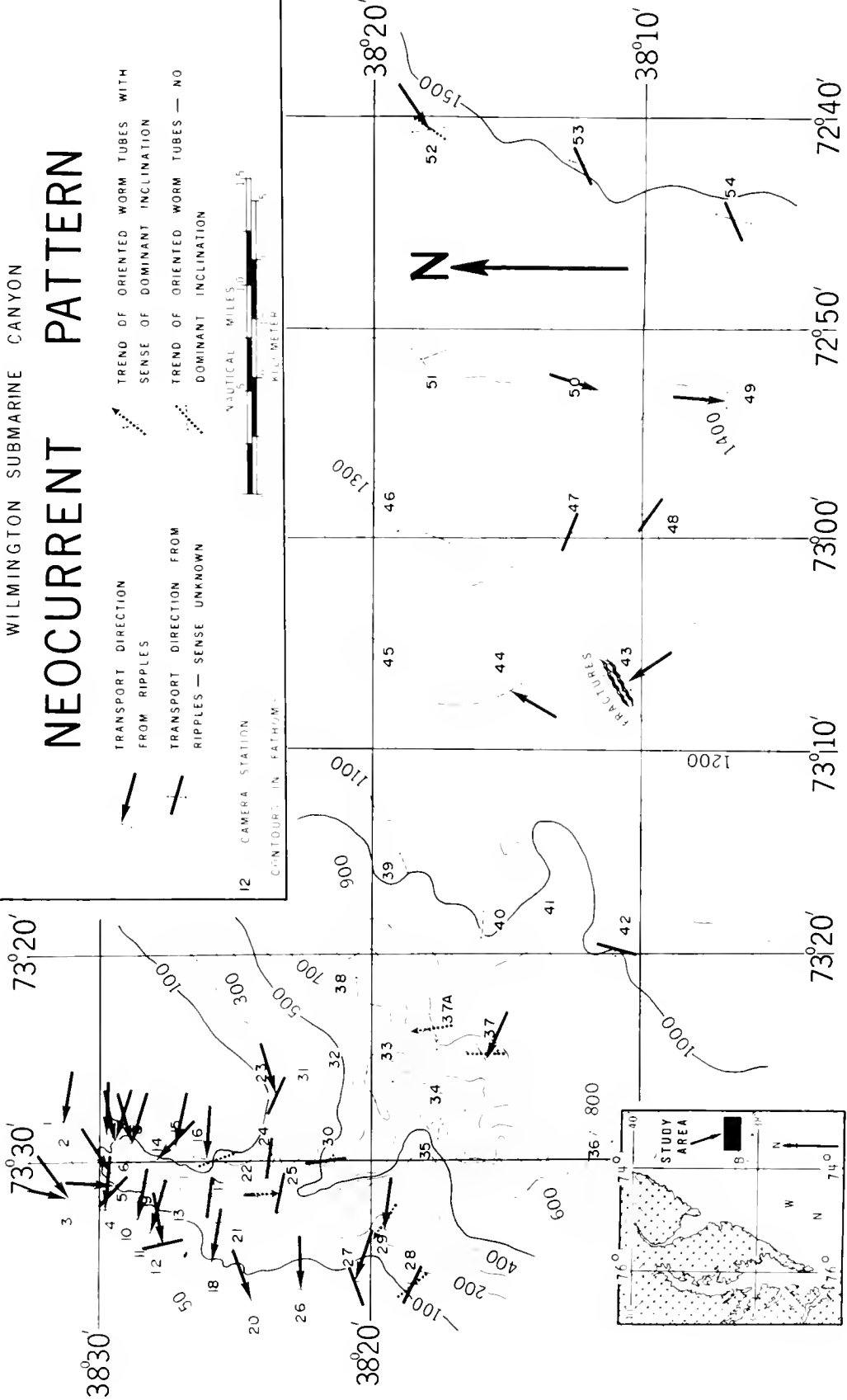


# NEOCURRENT PATTERN

- TRANSPORT DIRECTION FROM RIPPLES
- TRANSPORT DIRECTION FROM RIPPLES — SENSE UNKNOWN
- TREND OF ORIENTED WORM TUBES WITH SENSE OF DOMINANT INCLINATION
- TREND OF ORIENTED WORM TUBES — NO DOMINANT INCLINATION



12 CAMERA STATION  
CONTOUR IN FATHOM



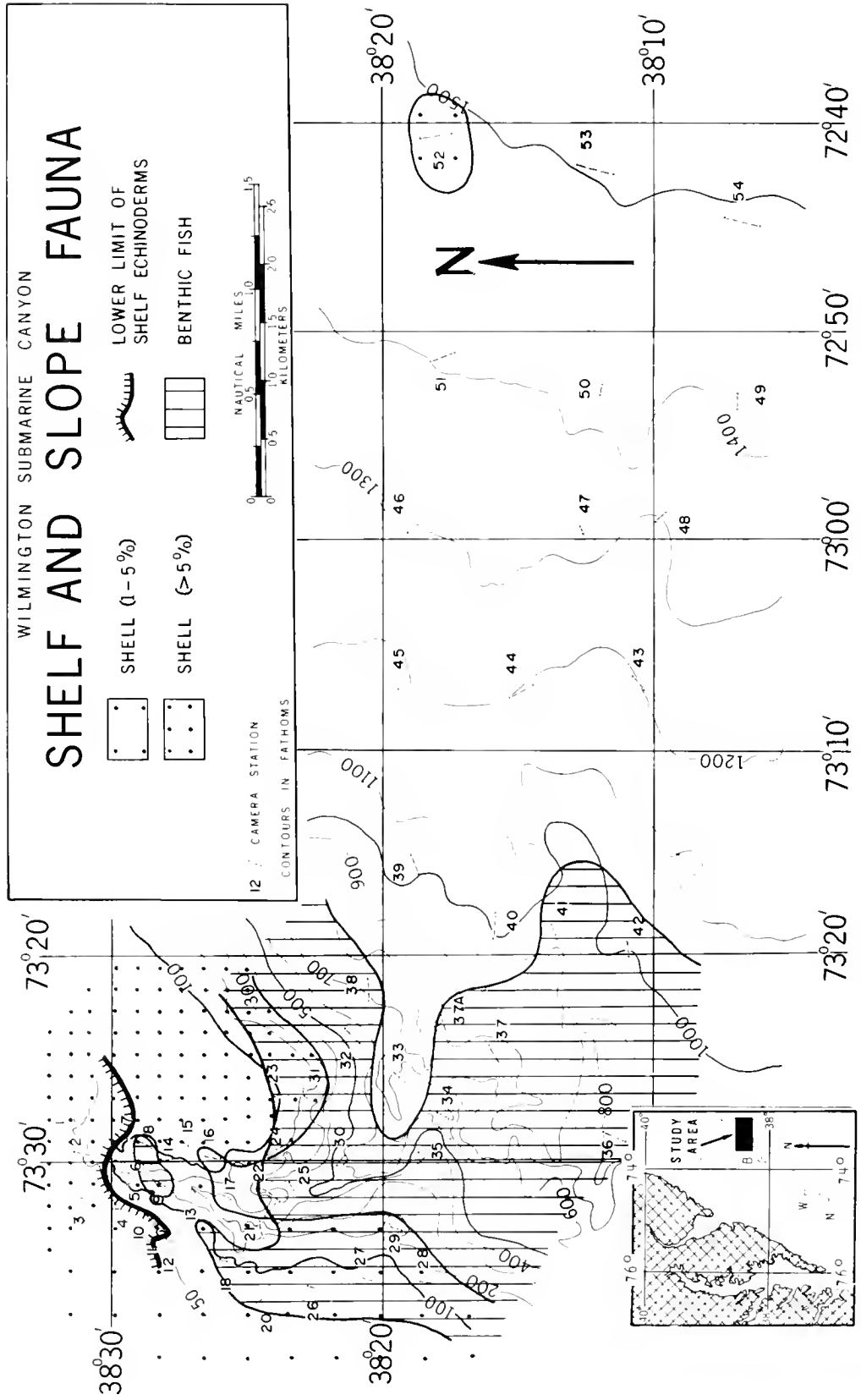


Figure 9. Distribution of major groups of organisms affecting bottom sediment on the shelf and slope of the Wilmington submarine canyon area. Data obtained during RoS, 4-10 December, 1967.

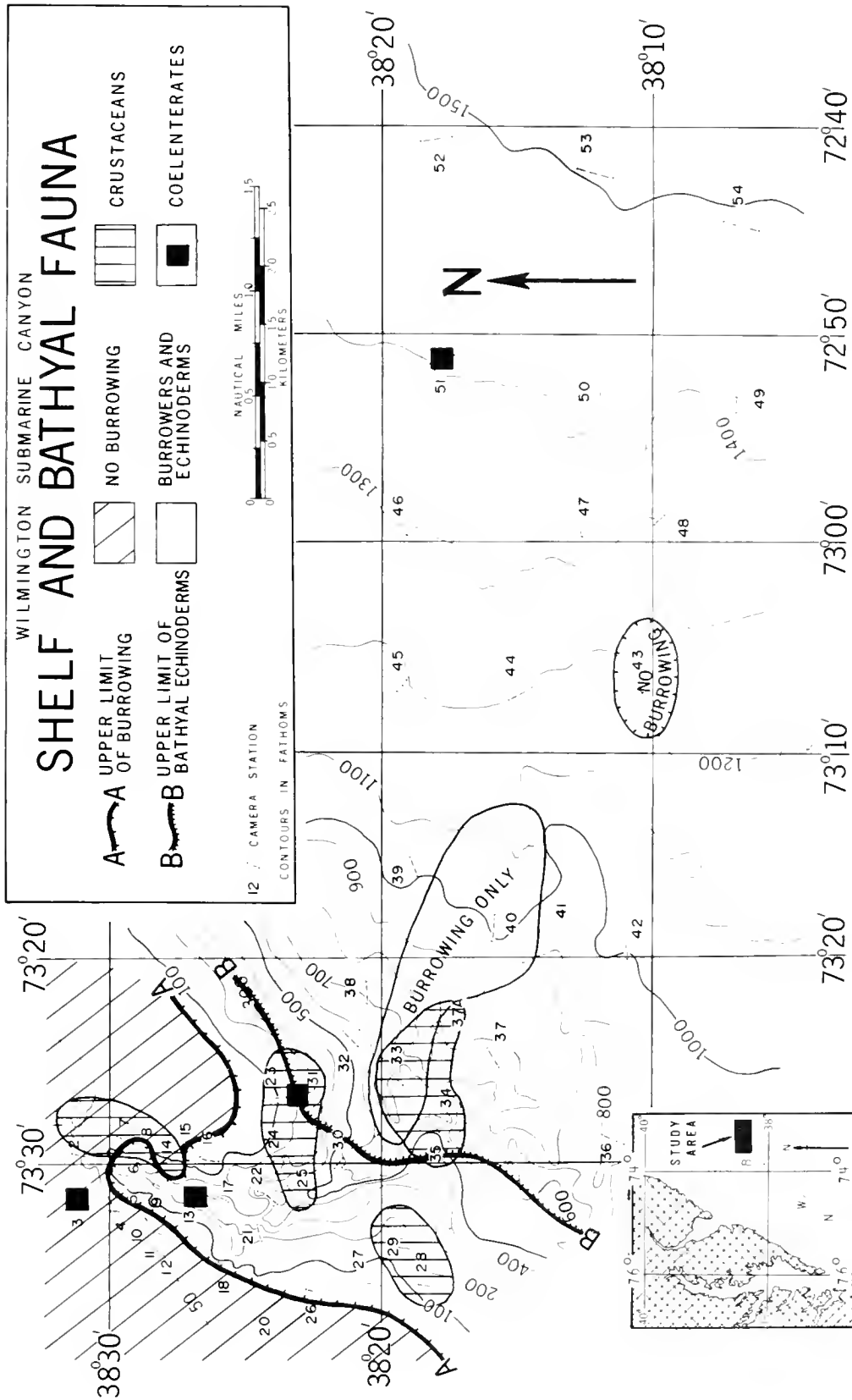


Figure 10. Distribution of major groups of organisms affecting bottom sediment on the shelf and bathyal regions in the vicinity of Wilmington submarine canyon. Data obtained during RoS, 4-10 December, 1967.

activity (neocurrent patterns) and to infer the dominant current trends in the area of study. Most of this evidence is derived from an examination of current-formed sedimentary structures, principally ripple marks, and the attitude of certain marine organisms, principally worm tubes, on the compass-oriented photographs (Table II). The patterns of dominant current movement in the Wilmington Canyon and adjacent continental shelf, slope and rise are depicted on Fig. 8.

The form of ripple marks (straight, sinuous, interference types) and the orientation of dominant crests were recorded, and the direction of steeper faces was measured wherever possible. The vertical position of the camera and slight oblique illumination employed, however, made this determination impossible in some instances. A two-directional trend is depicted in those cases where symmetrical ripple-marks are present or where the appearance of symmetry does not allow interpretation of the sense of current transport. The mean value of current direction or trend has been determined for each station; this value, in some cases, represents the orientation of current patterns measured over as much as two miles of sea floor. In several cases the large number of photos obtained over an extensive distance requires that the data be grouped into two or more sub-stations. Stations 7 and 8, for instance, extending from the shelf margin into the canyon head, display several mean vectors (Fig. 8). Two transport directions are also depicted at those stations where interfering groups of ripple marks differ in orientation by more than 30°.

Ripple marks on the shelf and upper slope tend, in general, to be asymmetrical, straight to slightly sinuous and possess sharp to somewhat rounded crests. Two or more sets of cross-cutting ripples are not infrequent at shallow stations, but distinct cell-like interference patterns have not been observed here. Interfering ripple-sets usually differ in dimensions or form, and it is generally possible to demonstrate that one set post-dates the others. Ripples on deeper silty and mud bottoms tend to be more sinuous and discontinuous with low amplitudes and soft rounded crests. Many ripples appear relatively fresh and are probably of recent origin. A veneer of mud, however,

covering crests and partially filling troughs, may be detected at some deeper stations.

Additional evidence of current transport is obtained in a number of stations from the alignment of shell debris or gravel, and of worm tubes lying upon the bottom. Scour lineations and pockets are generally absent except for Station 22 (Plate 10) in the canyon axis and at Station 43 (Plate 28) at the base of the slope. Similar scour lineation markings on the continental slope have been reported by Owen and Emery (1967, Fig. 15-4).

Direct evidence of prevailing near-bottom current activity is provided by the preferred orientation of worm-tubes that appear stalk-like and project obliquely from the sea-bed to a maximum height of 10 cm. These structures, presumably geotropic in character, locally display a random orientation. More frequently these tubes show a preferential alignment, i.e., a dominant sense of inclination, as if heeling over in response to a current. It is assumed that such an inclination is in a down-current sense. This assumption is borne out at Station 29 where preferentially inclined worm tubes and asymmetric ripples are associated (Plate 15).

The regional current transport pattern as inferred from photographs is evidently a composite one. Landward of the shelf edge currents flow uniformly towards the west both on the shelf proper and in the canyon head. In a small area northwest of the canyon (Stations 3 and 5) currents appear to flow towards the south and southwest. Observation of large sand waves and dunes to depths exceeding 50 fms suggest that sedimentation on this outer shelf may be active, not relict, at present.

Evidence of southerly current movement down the canyon axis between 400 and 600 fms is observed at Stations 22 and 30 (Plate 10). Little evidence of current activity is noted on the lower slope and adjacent parts of the upper continental rise away from the canyon; the sea-floor in this area is one dominated by biological reworking of bottom sediments. A renewal of current activity on the outer sector of the upper rise is noted at depths greater than 1400 fms; current flow at this depth tends to be directed consistently towards the southwest and south-southwest (Fig. 8).

Conspicuous current activity is also associated with the Nyckel Ridge forming the south (right) bank of Wilmington Canyon. Water movement on the upper part of this ridge appears to be directed up-slope (west and west-northwest). A northerly current sense is indicated on the more deeply submerged portion of this ridge at depths of 1000 to 1200 fms. Additional evidence of current activity on this outer ridge are provided by the observation of a firm bottom of stiff clay at Station 41. Samples of similar lithology have been recovered from this region by the Woods Hole Oceanographic Institution (Sample 2109B, in Hathaway, 1966) suggesting removal or non-deposition of recent finegrained sediment in this sector. Strong northwest-flowing currents capable of moulding sand and gravel into ripples are also noted on the Nyckel Ridge at Station 43 (Plates 27, 28).

#### *Benthic Organisms*

Benthic organisms, like bottom currents, appear to modify bottom sediments in the Wilmington submarine canyon and adjacent areas. The lateral distribution of the more important groups of organisms detected in the photographic survey are shown on Figures 9 and 10.

Shell material forms a large part of the coarse sediment fraction on the shelf edge at depths less than 100 fms, particularly on the northern and eastern margins of the canyon head (Fig. 9). Shell material of coarse sand to pebble size is often aligned in bands concentrated in ripple mark troughs. Many of the shells, sometimes distinct enough to be recognized as pelecypod valves of scallops and other forms, lie concave up and are often partially buried or filled with sediment. The shell content decreases from over 30 percent on sectors of the shelf to about 1 percent at depths of about 200 to 300 fms. Pelecypod valves of probable shelf origin have, however, been en-

countered in cores collected in the canyon and on the continental rise (Stanley and Kelling, 1968b, Fig. 8).

Echinoderms are also locally important on the shelf and include starfish, sand dollars and sea urchins (Fig. 9). Crabs and lobsters also abound in this area (Fig. 10). This environment is one of high sand and shell content. Crustaceans appear to be more abundant in the immediate vicinity of the canyon area than on the adjacent slope.

The area covered by burrowing organisms increases progressively at depths greater than 75 fms. Burrows, tracks, mounds, and other forms of bioturbation are recorded at almost every station below this depth, with the exception of Station 43 (Fig. 10). Pencil-like tubes of polychaete worms [probably *Hyalinoecia tubicola* (Müller)], a common form on the continental slope of northeast North America (Wigley and Emery, 1967), are locally important. Numerous forms of bathyal echinoderms (Fig. 10), including brittle stars and asteroid starfish, become important below depths of about 500 fms. These, as well as crabs and sea spiders leave distinctive markings in the soft mud bottom and otherwise modify the sediment as a result of their movement and their feeding habits.

Equally spectacular are bottom markings produced by benthic fish (Fig. 9); these appear to be most abundant on the slope between 100 to 1000 fms. The soft undulating mud at some localities has been entirely moulded by fish that form shallow depressions (resting-places or "nests"), and by fin marks. Holothurians are important because of the trails they make and because of the abundance of their faecal deposits which cover extensive areas of the bottom (Table II). Coelenterates, including sea-anemones and possible soft corals, are recorded at four localities but are generally less common than the preceding forms (Fig. 10).

## V. DISCUSSION

Most of the submarine canyons off the east coast of the United States previously have been regarded as relatively inactive so far as sedimentary processes are concerned (Stetson, 1949; Shepard, 1965a, p. 327) because they head far out on the shelf in deep water in tectonically stable area. This contrasts sharply with submarine canyons in other areas which serve to funnel sediments from shelf areas to the deep sea. Shepard (1965a, p. 322-323) lays particular stress on supply of longshore-drifted detritus to canyons heading close inshore on tectonically active borderlands, as in the area off southern California. In those canyons, sediment is transferred from the head to the deep-sea fans at their base by processes which include slumping, creep, sand flows and turbidity currents. The surface texture in the vicinity of these Californian canyons apparently reflects the present activity of the processes outlined above although a thin cover of 'pelagic' mud occurs in areas more remote from active channels (Shepard and Dill, 1966, p. 68). A submarine canyon on the northwest Atlantic margin, The Gully off Nova Scotia, which has been described by Stanley (1967) displays a spectrum of processes similar to those observed in canyons on the Pacific margin.

In the Wilmington canyon area, the sum of photographic observations shows that textural types are more closely related to geographic proximity to the canyon depression and other major features of the slope than to depth *per se*. However, the distribution of relatively fine-grained bottom surface sediments in the proximity of the Wilmington canyon (an observation also made by Stetson, 1949) and the abundance of burrowing activity in all but the most shallow portions of the canyon suggest a relatively inactive role for sedimentation at the present time. Similarly, the pattern of current movement in the vicinity of the canyon, where examined, shows only minor evidence of axial transport (unlike more active canyons de-

scribed by Shepard, 1965b; Shepard and Dill, 1966; Ross, 1968 and others).

Photographic evidence, however, must be interpreted cautiously in evaluating the role of the Wilmington Canyon in Holocene (post-Pleistocene to modern) sedimentation. It is important to note, for instance, that textural varieties at the surface often conceal very different sediment types just a few millimeters or centimeters below the surface. An examination of cores collected in the same areas as photo Stations 33, 34 and 46 (Fig. 3) indicates that the surface veneer recorded in bottom photographs is generally finer-grained than the sediment lying below it (Stanley and Kelling, 1968b). The textural pattern as mapped in Figure 7 is thus a composite reflecting both recent depositional activity and, locally, relict (pre-Recent) sediment patterns. These local pockets of relict sediment may represent areas which are not receiving sediments at the present time or they may indicate removal of the veneer of recent sediment by erosion.

It is also important to note that the textural map indicates only the most recent sediment activity and masks the results of processes operating in the recent past. Examination of the bottom photographs suggests that, at present, benthic organisms are reworking the sediment cover over much of the slope and rise. Cores show distinct laminations of somewhat coarser sediment below a mottled uppermost sediment veneer. This indicates that at most localities periods of active deposition have alternated with quieter periods (perhaps like the present) when the entire sediment horizon is reworked by bottom-living organisms.

The hypothesis that sedimentation in the Wilmington submarine canyon has been active within the recent past, and perhaps even today on a local scale, is supported by several observations:

- (1) The present study indicates that there



is strong current activity on the outer shelf in this region (see Fig. 8). The siting of the Wilmington Canyon is such that sediment being transported westward across the outer shelf (in accord with the direction of non-tidal bottom drift noted by Bumpus, 1965, Fig. 5) would be intercepted by the canyon head. The tongues of gravel, coarse sand and shell debris which extend down the eastern flanks of the canyon head (Fig. 7) evidently result from this process of entrapment, since materials of comparable grade are lacking on the sheltered western walls. The first prerequisite for active canyon sedimentation—a continuing supply of sediment to the head—is thus fulfilled.

(2) A narrow tongue of silty sand extends down the canyon axis to a depth of about 500 fms suggesting down-slope movement of coarser detritus, at least to this depth, at the present time.

(3) While clay muds cover the continental slope and upper continental rise in areas remote from the canyon, the distribution of silt follows the trend of the major depressions associated with Wilmington canyon (compare Figs. 1 and 7). The pattern of silt distribution closely resembles that discovered by Stanley (1967, Figs. 7 and 8) in The Gully Canyon.

(4) Patches of gravel and sand presently exposed on the upper rise may be relict deposits swept clear of recent mud by the deep-sea currents detected in their vicinity. On the other hand, they may indicate active, if periodic, supply of coarse detritus to the upper rise via the Wilmington Canyon complex. Ample evidence of such periodic influxes of debris within the recent past is provided by the presence of sand and shell debris in cores (Stanley and Kelling, 1968b, Fig. 8).

One point is clear: the supply of coarse shelf sediment moving toward the west and, thus, toward the head of the canyon is such that most of the material must be transferred quickly to the deep sea. Were it not, the head would soon be filled.

The fine-grained veneer that floors much of the area of the slope and rise is being contributed, in part, by a rain of pelagic material settling to the bottom. The origin of this material is unknown at present. Muds could originate

from deposition of suspended matter concentrated in the water column by deep turbulence. This *nepheloid layer* on the slope and rise north of the Wilmington Canyon has been described by Ewing and Thorndike (1965). Geostrophic contour bottom currents of the type recognized at the base of the Atlantic margin by Heezen et al. (1966) and Schneider et al. (1967) may also play an important role in the transport and deposition of sediments.

Evidence from bottom photographs of southwest and south-southwest flowing currents on the outer sector of the upper rise are compatible with the geostrophic contour patterns recorded by these other workers. However, in this study area, flow also occurs at a level on the upper continental rise, which Schneider et al (1967, p. 358) regard as a tranquil, current-free region. Strong, northwest-flowing currents that are capable of moulding sand and gravel at station 43 (Plate 28) may form part of an eddy system developing counter to the main Western Boundary Under Current. The location of this eddy is probably controlled, in part, by the presence of the southeast-northwest trending Nyckel Ridge. Observation of this ridge shows that bottom currents are capable of moving material of fine to coarse sand grade and that they may well play an important role in modifying the dispersal pattern of sediment emanating from the Wilmington Canyon on the lower slope and rise.

At present, the Nyckel Ridge bounding Wilmington Canyon on its south side forms an important locus of current activity and of probable slope instability, i.e. slumping and gravitational gliding, perhaps of the type described by Rona and Clay (1967) and Uchupi (1968). The occurrence of large angular slabs of rock with talus at Station 43 suggest either active erosion of outcropping rock as described by Schneider et al. (1967, p. 358) or slumping and sliding of large rockmasses off the adjacent Nyckel Ridge onto a sand-silt bottom. Evidence for displacement of these blocks is provided by a series of linear fractures in the rock ledge proper (Plate 27). The general trend of main fractures affecting these rocks is N50°E, i.e. parallel with local isobaths. The breaks are not unlike crevasses in glaciers or in areas of incipient avalanches such as steep snow-covered

hills. The rock mass illustrated in Plate 27 represents an allochthonous slab moved into place at this locality.

The present photographic investigation, coupled with an earlier subbottom survey during RoS<sub>1</sub>, indicates that the Nyckel Ridge is not simply a deep-sea levee (Stanley and Kelling, 1968a). This topographic high developed as a structural feature and serves as an important internal source of sediment as a result of exposure to bottom current activity, erosion, and slumping. In effect, it plays a dominant role in intrabasinal sedimentation.

Evidence gathered on the basis of the photographic study does not allow a categorical answer to the problem of the Wilmington Canyon's contemporary funneling role. An evaluation of the past present functions of the canyon in the context of deep sea sedimentation off the Atlantic margin clearly requires further investigation. A comparison of the dominant patterns in the Wilmington Canyon with those of adjacent features including Baltimore, Washington, and Norfolk Canyons should eventually lead to the creation of a sedimentation model for canyons of this type.

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## REFERENCES

- Bumpus, D. F., 1965. Surface circulation on the Continental Shelf. Summary of Investigations conducted in 1964. Woods Hole Oceanographic Institution Ref. 66-13, p. 158.
- Daly, R. A., 1936. Origin of submarine "canyons". Amer. Jour. Science, Ser. 5, v. 31, p. 401-420.
- Edgerton, H. E., 1967. The instruments of deep-sea photography, in *Deep Sea Photography* (J. B. Hersey, Ed.). The Johns Hopkins Press, Baltimore, p. 47-54.
- Ewing, M. and E. M. Thorndike, 1965. Suspended matter in deep ocean water. *Science*, v. 147, p. 1291-1294.
- Hathaway, J. C., 1966. Data file. Continental margin program, Atlantic coast of the United States, Vol. I, Sample collection data. Woods Hole Oceanogr. Institution Ref. 66-8, 184 p.
- , 1967. Data file, Continental margin program, Atlantic coast of the United States, Vol. I, Sample collection data, Supplement I. Woods Hole Oceanogr. Institution Ref. 67-21, 108 p.
- Heezen, B. C., C. D. Hollister and W. F. Ruddiman, 1966. Shaping of the continental rise by deep geostrophic contour currents. *Science*, v. 152, p. 502-508.
- Hersey, J. B., 1967. The manipulation of deep-sea cameras, in *Deep-Sea Photography* (J. B. Hersey, Ed.). The Johns Hopkins Press, Baltimore, p. 55-67.
- Johnson, D. W. 1939. *The Origin of Submarine Canyons*. Columbia University Press, New York, 126 p.
- Kuenen, Ph. H., 1950. *Marine Geology*. John Wiley and Sons, Inc., New York, p. 485-526.
- Lawson, A. C., 1893. *The Geology of Carmelo Bay*. Bull. Univ. Calif. Dept. Geology, 1, 59 pp.
- Owen, D. M. and K. O. Emery, 1967. Current markings on the continental slope, in *Deep-sea Photography* (J. B. Hersey, Ed.). The Johns Hopkins Press, Baltimore, p. 167-172.
- Pettijohn, F. J., 1957. *Sedimentary Rocks*. Harper & Sons, N.Y. 718 p.
- Pruvot, G., 1894. Essai sur la topographie et la constitution des fonds sous-marins de la région de Banyuls, de la plaine du Rousillon au Golfe de Rosas. Arch. Zool. Exp. Gén., v. 2, p. 599-672.
- Rona, P. E. and C. S. Clay, 1967. Stratigraphy and structure along a continuous seismic reflection profile from Cape Hatteras, North Carolina, to the Bermuda Rise. Jour. Geophys. Research, v. 72, p. 2107-2130.
- Ross, D. A., J.V.A. Trumbull and C. D. Hollister, 1968. Geologic observations in Corsair canyon from DSRV Alvin (Abstract). Geol. Soc. America Northeastern Section, Program 3rd Ann. Meeting, Washington, D.C., p. 52.
- Schneider, E., P. J. Fox, C. D. Hollister, H. D. Needham and B. C. Heezen, 1967. Further evidence of contour currents in the Western North Atlantic. *Earth and Planetary Sci. Letters*, v. 2, p. 351-359.
- Shalowitz, A. L., 1930. Slope corrections for echo soundings. U. S. Coast and Geodetic Survey Spec. Pub. No. 165.
- Shepard, F. P., 1963. Submarine canyons, in *The Sea* (M. N. Hill, Ed.). Interscience Publishers, New York, p. 48-506.
- , 1965a. Importance of submarine valleys in funneling sediments to the deep sea, in *Progress in Oceanography*, v. 3 (M. Sears, Ed.) Pergamon Press, Oxford, p. 321-332.
- , 1965b. Submarine canyons explored by Cousteau's Diving Saucer, in *Submarine Geology and Geophysics* (W. F. Whittard and Bradshaw, Eds.) Butterworth, London, p. 303-311.
- , and R. F. Dill, 1966. *Submarine Canyons and other Sea Valleys*. Rand McNally, Chicago. 381 p.
- Stanley, D. J., 1967. Comparing patterns of sedimentation in some modern and ancient submarine canyons. *Earth and Planetary Sci. Letters*, v. 3, p. 371-380.
- , and G. Kelling, 1968. Interpretation of a levee-like ridge and associated features, Wilmington submarine canyon, eastern U.S.A., in *Les Méthodes Sismique-Réflexion et les Cartes de Géologie Sous-Marine* (L. Glangeaud, Ed.). C.N.R.S. Symposium, Villefranche-sur-Mer and Monaco (in press).
- , 1968b. Sedimentation patterns in the Wilmington Submarine Canyon area, in *Ocean Sciences and Engineering of the Atlantic Shelf*. Trans. Mar. Tech. Society, Philadelphia, p. 127-142.
- Stetson, H. C., 1949. The sediments and stratigraphy of the east coast continental margin; Georges Bank to Norfolk Canyon. Papers Phys. Oceanogr. Meteorology, v. II, Mass. Inst. Technology and Woods Hole Oceanogr. Institution, 60 p.
- Uchupi, E., 1968. Slumping on the continental margin southeast of Long Island, New York. *Deep-Sea Research*, v. 14, p. 635-639.
- Veatch, A. C. and P. A. Smith, 1939. Atlantic submarine valleys off the United States and the Congo Submarine Valley, Geol. Soc. America Spec. Paper 7, 101 p.
- Wigley, R. L. and K. O. Emery, 1967. Benthic animals, particularly *Hyalinoecia* (Annelida) and *Ophiomusium* (Echinodermata), in sea-bottom photographs from the continental slope, in *Deep-Sea Photography* (J. B. Hersey, Ed.). The Johns Hopkins Press, Baltimore, p. 235-249.

Table I. Station positions and depths on USCGC ROCKAWAY-SMITHSONIAN Cruise (RoS<sub>2</sub>).  
(December 4-10, 1967)

Station Number	Beginning of station			End of station		
	Latitude	Longitude	Depth in fathoms	Latitude	Longitude	Depth in fathoms
1	38°31'27.0"	73°27'50.7"	46	38°31'9.5"	73°28'19.7"	51
2	38°31'20.6"	73°29'33.8"	45	38°30'39.7"	73°29'48.0"	74
3	38°31'21.5"	73°31'39.2"	36	38°30'58.8"	73°31'51.5"	39
4	38°29'58.3"	73°32'15.0"	47	38°29'22.0"	73°32'18.0"	52
5	38°29'44.0"	73°31'31.4"	60	38°29'12.8"	73°31'9.4"	107
6	38°29'46.4"	73°30'33.7"	114	38°29'4.7"	73°30'48.6"	129
7	38°29'44.1"	73°28'44.7"	59	38°29'11.7"	73°29'12.7"	89
8	38°29'3.2"	73°29'6.2"	131	38°28'18.3"	73°29'31.3"	110
9	38°28'22.6"	73°30'57.2"	214	38°27'15.8"	73°31'47.7"	195
10	38°28'50.8"	73°32'37.7"	59	38°28'22.5"	73°33'8.8"	57
11	38°28'22.5"	73°33'22.7"	54	38°27'59.3"	73°33'28.6"	58
12	38°28'6.0"	73°33'43.8"	52	38°27'41.1"	73°34'5.0"	58
13	38°27'13.4"	73°31'11.6"	278	38°26'32.6"	73°32'4.2"	258
14	38°28'16.1"	73°30'0.7"	124	38°27'36.2"	73°29'53.9"	92
15	38°27'26.0"	73°29'7.9"	76	38°27'16.4"	73°29'36.8"	63
16	38°26'44.3"	73°29'44.1"	65	38°25'41.9"	73°29'50.6"	168
17	38°26'8.2"	73°31'44.1"	240	38°24'46.0"	73°32'41.4"	380
18	38°26'6.1"	73°34'51.4"	68	38°25'33.1"	73°35'19.6"	76
19	NO	STATION				
20	38°24'43.2"	73°36'57.2"	57	38°24'5.5"	73°36'25.4"	62
21	38°24'35.5"	73°32'57.2"	355	38°24'18.4"	73°34'6.4"	160
22	38°24'38.2"	73°31'19.8"	430	38°23'30.5"	73°32'11.7"	391
23	38°24'5.9"	73°27'5.5"	80	38°23'18.8"	73°26'51.5"	156
24	38°23'54.7"	73°29'35.9"	243	38°23'14.6"	73°29'23.8"	302
25	38°23'29.1"	73°31'5.5"	460	38°23'17.3"	73°31'52.6"	480
26	38°22'50.4"	73°36'9.6"	62	38°22'19.1"	73°36'16.0"	62
27	38°20'51.7"	73°35'43.1"	71	38°20'10.0"	73°36'0.5"	73
28	38°18'47.5"	73°35'56.8"	128	38°17'46.9"	73°36'16.0"	165
29	38°19'48.2"	73°33'10.9"	127	38°19'5.0"	73°33'42.0"	194
30	38°21'10.5"	73°29'32.7"	620	38°21'49.2"	73°30'36.2"	595
31	38°22'51.0"	73°26'21.8"	195	38°22'42.0"	73°27'4.0"	247
32	38°21'30.6"	73°23'22.9"	518	38°20'32.7"	73°24'30.4"	575
33	38°19'55.1"	73°25'37.8"	772	38°19'6.4"	73°26'14.9"	654
34	38°17'33.1"	73°28'17.0"	602	38°18'0.7"	73°27'52.4"	640
35	38°18'12.8"	73°27'52.2"	648	38°15'55.8"	73°30'15.9"	566
36	38°11'58.8"	73°28'27.5"	810	38°09'47.1"	73°36'23.4"	817
37	38°16'17.0"	73°34'05.7"	795	38°15'28.7"	73°35'35.1"	715
37A	38°17'46.4"	73°22'36.2"	909	38°17'31.4"	73°24'26.5"	808
38	38°20'35.8"	73°20'48.1"	786	38°20'30.1"	73°22'24.2"	692
39	38°19'7.3"	73°15'06.7"	1050	38°18'42.4"	73°16'53.1"	1000
40	38°15'49.8"	73°17'17.8"	1030	38°15'51.0"	73°19'49.6"	964
41	38°13'46.9"	73°18'08.1"	940	38°13'35.8"	73°19'24.3"	903
42	38°10'58.7"	73°19'18.1"	1029	38°10'48.6"	73°20'29.6"	990
43	38°10'47.0"	73°06'36.3"	1176	38°10'20.7"	73°07'24.8"	1222
44	38°14'24.1"	73°07'12.9"	1177	38°15'38.3"	73°07'46.6"	1208
45	38°18'48.5"	73°06'33.4"	1200	38°19'32.7"	73°07'24.5"	1181
46	38°19'19.5"	72°59'46.8"	1285	38°19'11.7"	72°59'22.1"	1308
47	38°12'41.0"	72°59'54.5"	1338	38°12'47.4"	72°59'32.2"	1340
48	38°10'15.7"	72°59'32.3"	1295	38°09'31.8"	72°58'41.5"	1325
49	38°07'6.2"	72°54'9.2"	1408	38°07'3.6"	72°53'07.9"	1413
50	38°11'57.9"	72°53'13.3"	1417	38°11'36.6"	72°52'26.5"	1421
51	38°18'21.4"	72°51'43.7"	1395	38°17'18.8"	72°51'02.0"	1408
52	38°18'47.9"	72°41'0.7"	1457	38°17'22.8"	72°40'28.4"	1470
53	38°12'59.5"	72°42'08.3"	1506	38°11'22.5"	72°42'50.4"	1507
54	38°07'37.6"	72°44'34.7"	1495	38°05'16.5"	72°45'20.8"	1483

Table II. Summary of data from photographic investigation in the Wilmington subma

Station Number	Film Data		Photo Quality	Range of Bottom Surface Area Covered (in meters <sup>2</sup> )	Sediment Type ⊗ = Dominant type			Ripple Marks			Oriented Worm Tubes H = Heading direction A = Alignment trend			
	Roll Number	Frame Numbers of Photos on Bottom			Gravel	Sand	Mud (Silt + Clay)	Type				Inferred Current Movement (Mean direction or trend at station)	Wave Length (in cm.)	Amplitude (where available) (in cm.)
								⊕ = Asymmetric	⊖ = Symmetric	⊗ = Dominant type				
						Straight	Sinusuous	Interference						
1 2	1 1	192-227 260-305	Poor to Moderate Very Poor <sup>1</sup>	>4 >4		⊗ X		⊗ X	⊕,⊖ A,S		to 285° 25-35			
3 4	1 1	337-355 391-409	Poor to Good Poor to Moderate	1-1 1-4		⊗ ⊗		⊗ ⊗	⊕,⊖ A,S		to 200° <sup>1</sup> to 235° <sup>2</sup> to 275° to 185° 184°-314° to 240°	12.5-50 17.5-30	2.5-10	
5 6	1 1	451-472 536-550	Poor Poor to Good	1-1 <1-4		⊗ ⊗		⊗ ⊗	⊕ <sup>1</sup> A		17.5-50 12.5-30		4.2-10 1.25-5	
7	1	606-634	Moderate to Excellent	1-4		X	⊗	⊗	A A	A,S	to 270° <sup>1</sup> to 253° <sup>2</sup> to 285° <sup>3</sup>	15-55	1.25-7.5	
8	2	680-716	Moderate to Excellent	<1->4		X	⊗	⊗	A,S	A,S A,S	to 252° <sup>1</sup> to 283° <sup>2</sup>	12.5-25		
9 10 11	2 2 2	746-752 774-789 825-851	Moderate to Excellent Poor to Excellent Poor to Moderate <sup>1</sup>	<1 <1-2 2-4		X X X	⊗ ⊗ ⊗	⊗ ⊗ ⊗	A A A		to 260° <sup>1</sup> to 279° to 285°	10-17.5 15-20 17.5-25	2.5-3.75 1.25-2.5	
12 13	2 2	891-904 939-963	Poor to Excellent Moderate to Excellent	<1-1 <1-2	X <sup>1</sup>	X X	⊗ ⊗	⊕ ⊕		A	165°-345° to 258°	15-20		H: to 270°
14	2	001-016	Moderate to Good	1-4	X <sup>1</sup>	⊗	⊗	⊕		S	to 318°	17.5-25		
15	3	050-076	Moderate to Excellent	<1-4	X <sup>1</sup>	⊗	⊗	⊕		A	to 281°	12.5-20	1.25-2.5	
16 17 18	3 3 3	125-151 188-189 242-294	Good to Excellent Poor Moderate to Excellent	<1-2 1-2 1-4	X <sup>1</sup>	X X	⊗ ⊗	⊕ ⊕		⊕ A,S	to 272° 95°-275° to 271°	12.5-17.5 20-25 10-22.5	0.65-1.25 2.5-3.75	H: to 345°
19		NO STATION												
20	3	294	Moderate	2-4		X	⊗	⊗	A		to 250°	25		
21	3	332	Moderate	1-2		X	⊗	⊗						
22	3	369-406	Poor to Excellent	<1-4			X <sup>1</sup>	X <sup>1</sup>			to 180° <sup>2</sup>			H: to 180°
23 24 25	4 4 4	473-499 534-561 601-605	Moderate to Good Moderate to Excellent Good	<1-2 <1-2 <1		X X	⊗ ⊗	⊕ ⊕		S,A	to 254° 112°-292° 097°-277°	20-37.5 15 30	1.25-3.75 1.25	H: to WNW
26	4	678-698	Poor to Moderate	1-4		X	⊗	⊗		A	to 268° 070°-250° to 287° 121°-301° to 278° 175°-355°	17.5-20	1.25-2.0	
27 28 29 30	4 4 4 4	728-755 775-796 814-846 872-920	Moderate to Excellent Moderate to Excellent Moderate to Good Good to Excellent	1-2 <1-2 1-1 <1-2	X <sup>1</sup>	X X	⊗ ⊗	⊕ ⊕		⊕ S		15-25 15-22.5 10-25 25-30	1.25-2.0	
31 32 33 34 35 36 37 37A 38 39	5 5 5 5 6 6 6 6 6	979-004 049-085 133-168 270-286 401 460-485 544-578 628-670 747-766 837-846	Moderate to Excellent Good to Excellent Poor to Excellent Excellent Poor Moderate to Excellent Moderate to Excellent Poor to Excellent Good to Excellent Good	<1-2 <1-2 <1-1 <1-2 >4 <1-4 <1-2 <1-2 <1-2 1-2		X X X X	⊗ ⊗ ⊗ ⊗	⊕ ⊕ ⊕ ⊕		A	to 283°	10-15	<2.0	A: to 002°-182° H: to 350°
40	7	965-966 (color)	Poor	<1		X	⊗	⊗						
41	7	134-164 (color)	Moderate to Good	<1-2		X <sup>1</sup>	X <sup>1</sup>	X <sup>1</sup>	A(?)		010°-190°	10-12.5	1.-1.25	
42	7	254-282 (color)	Moderate to Good	<1-2		X	X	X	S		015°-195°	12.5-15		
43	7	383-421 (color)	Good to Excellent	<1-4	⊗ <sup>1</sup>	X	X	X	A		to 325°	10-20	1.5-3.0	
44 45	8 8	564-587 692-715	Moderate to Good Moderate	1-2 <1-4		X X	⊗ ⊗	⊗ ⊗		A	to 030°	15-25		
46 47 48	8 8 9	843-858 988-003 102-116	Moderate Moderate to Good Poor to Good	1-2 1-2 <1-2	X <sup>1</sup>	X X	⊗ ⊗	⊗ ⊗		S S	110°-290° 125°-305°	15-20 10-15	1.25-2.5	A: to 285°
49	9	185-200	Moderate to Good	1-2	X <sup>1</sup>	X	⊗	⊗		A	to 184°	20-25	2.0-3.0	
50 51	9 9	312-336 473-501	Moderate to Excellent Moderate to Excellent	<1-2 <1-2		X X	⊗ ⊗	⊗ ⊗	A	⊕	to 197°	10-15	1.25-2.50	
52 53 54	10 10 10	707-724 815-845 952-972	Moderate to Excellent Moderate to Good Moderate to Excellent	<1-2 <1-2 <1-2	X <sup>1</sup>	X X	⊗ ⊗	⊕ ⊕	S A	S S	to 240° 053°-233° 075°-255° 075°-255°	10-20 10-20 15-20		A: to 035°-215°

		Organisms										Remarks					
Lebensspuren P = Present C = Common A = Abundant		Shell (Mainly pelecypod Relative percent)	Coelenterates			Echinoderms					Polychaete Worms and Related Forms	Crustaceans			Fish		
Tracks, trails and resting places	Burrows and Mounds		Anemones	Soft Coral	Jelly Fish	Star Fish	Brittle Star	Sea Urchin	Sand Dollar	Sun Star		Holothurian	Crab	Lobster		Sea Spider	Shrimp
		3-12 <sup>1</sup>				X						X					<sup>1</sup> Large shells mainly concave up. <sup>1</sup> All photos too poor to interpret (camera too far off bottom). <sup>1</sup> Beginning of station. <sup>2</sup> End of station.
		5-12 2-5		(?)													
P	P	7-20 3-12						X							X		<sup>1</sup> Straight ripples probably younger than interference ripples. <sup>1</sup> Beginning of station, straight ripples dominant.
	P	1-7				X						X			X		<sup>2</sup> Middle of station, sinuous ripples dominant. <sup>3</sup> End of station, sinuous and interference ripples.
A	P	1-7									tubes <sup>3</sup>	X			X	X	<sup>1</sup> Beginning of station. <sup>2</sup> End of station. <sup>3</sup> Not oriented.
C	P	1 7-15 3-5				X	X				tubes				X	X	<sup>1</sup> In one photo only.
	P	0-3 1		(?)							tubes						<sup>1</sup> Murky nature of photos suggest material in suspension.
		15-30 <sup>2</sup>											X		X	X	<sup>1</sup> Large boulders observed (to > 60 cm in diameter). <sup>1</sup> Maximum diameter 25 cm. <sup>2</sup> NE-SW alignment of shell concentrations in ripple troughs.
	P	5-10									tubes	X			X		<sup>1</sup> Maximum diameter 30 cm.; gravel rare in later frames.
	P	1-2		X												X	<sup>1</sup> Maximum diameter 2-3 cm. <sup>1</sup> Granular nature may be due to faecal pellets or mud clasts.
	A	3									tubes						<sup>1</sup> Ibid. <sup>2</sup> Current direction obtained from scour lineation.
A	A										tubes	X			X	X	
A	A	3-11		X							tubes	X			X	X	<sup>1</sup> Granular texture may be due to faecal pellets or mud clasts.
P	P	2-3													X		
P	P	1-3		X							tubes	X			X	X	<sup>1</sup> Maximum diameter 20 cms.
A	P	1-3									tubes	X			X	X	<sup>1</sup> Granular texture may be due to faecal pellets or mud clasts.
C	P	1-5			X						tubes	X			X	X	<sup>1</sup> Ibid.
A	A	2-5		X							tubes	X		X	X	X	<sup>1</sup> Ibid.
A	A					X								X	X	X	<sup>1</sup> Ibid.
A	A					X		X						X	X	X	<sup>1</sup> Ibid.
A	A					X		X			worm (?)			X	X	X	<sup>1</sup> Ibid.
A	A					X		X			worm (?)		X		X	X	<sup>1</sup> Ibid.
A	A					X		X						X	X	X	<sup>1</sup> Ibid.
P	P					X		X			tubes				X		<sup>1</sup> Clay appears stiff.
A	A					X		X		X	tubes				X		
A	A					X		X		(?)	worm (?)						
	P					X		(?) <sup>2</sup>							X		<sup>1</sup> Large fractured rock ledge (see Plate 27A) and numerous angular blocks of rock at least 20 cm thick. <sup>2</sup> Ping-pong ball-like echinoid.
A	A					X		X							X		<sup>1</sup> Granular texture may be due to faecal pellets or mud clasts.
P	P					X		X									<sup>2</sup> Possible crinoid.
P	P					X		X		(?) <sup>1</sup>	worm?						<sup>1</sup> Maximum diameter 40 cms. Possible sponge observed.
P	P					X		X		(?)					X		<sup>1</sup> Maximum diameter at least 1 meter.
P	A					X		X			tubes						<sup>1</sup> Granular texture may be due to faecal pellets or mud clasts.
P	P	2				X		X		X	tubes						<sup>1</sup> Maximum diameter 7.5 cm (may be an unidentified organism).
P	P				X			X		X	tubes						<sup>1</sup> Maximum diameter 20 cm.







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ATLAS - GAZETTE COLLECTION

