Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 36

A RADIOGRAPHIC EXAMINATION OF PHYSICAL AND BIOGENIC SEDIMENTARY STRUCTURES IN THE CHESAPEAKE BAY

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Eli Reinharz, Karl J. Nilsen, Donald F. Boesch,
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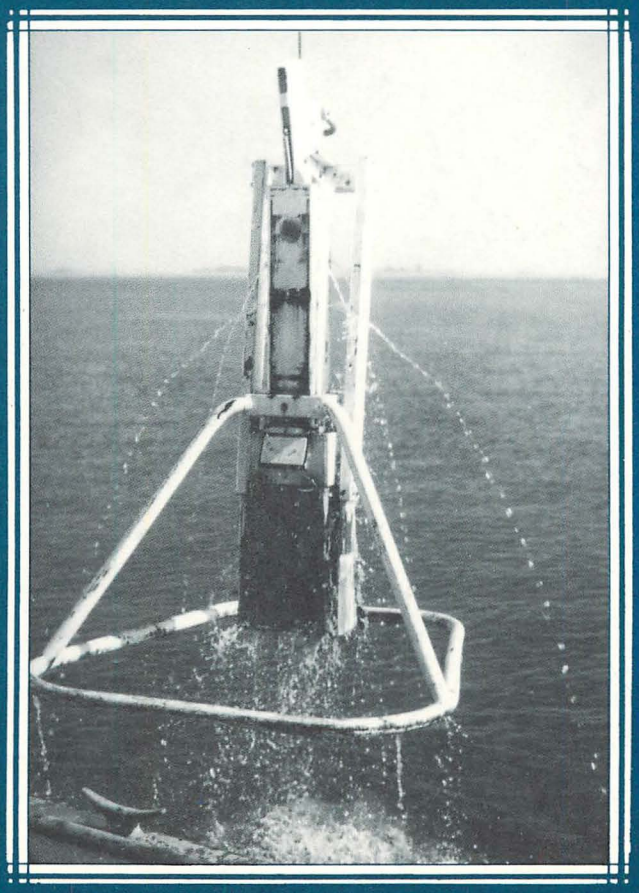

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Prepared in cooperation with the
College of William and Mary
Virginia Institute of Marine Science
School of Marine Science
Gloucester Point, Virginia 23062

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Cover Photograph:
The spade box corer recovering a bottom sample in the Chesapeake Bay. Photograph courtesy of Dr. Owen P. Bricker, III, United States Geological Survey, Reston, Virginia.

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A Radiographic Examination of Physical and Biogenic Sedimentary Structures in the Chesapeake Bay

by

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Rodney Bertelsen[4] and Arthur E. O'Connell[5]

ABSTRACT

Radiographs of box cores collected from nearly 200 stations serve as a basis for a descriptive study of the Chesapeake Bay bottom. Eighteen plates of characteristic sedimentary environments are included in this paper, identifying pertinent physical and biogenic features.

Prominent physical sedimentary structures include large-scale cross-bedding in medium to coarse sands, small-scale cross-bedding in fine sands, interbedded mud and sand in mixed sediments and laminated mud bedding in fine-grained sediments.

Almost all of our cores showed some evidence of biogenic sedimentary structures. Salient features include tubes and burrows as well as bioturbated textures. Many of these structures are associated with polychaetous annelids.

Biological activities dominate physical processes throughout much of Chesapeake Bay bottom. The prevalence of physical structures over biological features occurs in the upper Bay and in the deep-water channel regimes. Heterogenously textured mud environments are produced by sedentary tube inhabitants and relatively permanent burrow-dwelling species, primarily occupying the sediment surface. The more motile deep-burrowing fauna in sands tend to create homogenous fabrics. The composition of the benthic community is an essential aspect in the assessment of biological effects on the sedimentary environment.

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INTRODUCTION

The estuarine sedimentary environment is governed by a complex of physical, biological and chemical conditions. The examination of features preserved in the sedimentary record, particularly the physical and biogenic structures, is fundamental for the interpretation of contemporary and paleo-environmental changes. Documentation of these features is not only important for environmental reconstruction, but is also pertinent for studies of ongoing diagenetic processes.

Although a great deal of research has been directed to the study of estuaries (Lauff, 1967; Cronin, 1975), little attention has been given to specific structural components of the sedimentary environment. The development of X-ray radiography as a diagnostic tool (Hamblin, 1962) facilitated the analysis of textures and subtle structures of unconsolidated sediments (Calvert and Veevers, 1962; Bouma, 1964; Coleman, 1966; Howard, 1969; Hopfinger, 1974). The efforts of Howard and Frey (1972, 1975) provided the first complete examination of physical and biogenic sedimentary features in pristine estuaries. In essence, the use of radiography in field surveys and laboratory experiments has fostered a broad understanding of the genesis and post-depositional alterations of various sediment fabrics (see review of Reineck and Singh, 1975).

Textural and biotic patterns of the Chesapeake Bay sediments have been well described in prior studies (Sediments: Ryan, 1953; Palmer, 1975; Shideler, 1975. Biota: Boesch, 1972 and 1973; Roberts, et al., 1975; Boesch, et al., 1976; Boesch, 1977; Holland, et al., 1977; Mountford, et al., 1977; Loi and Wilson, 1979). Biggs' (1967) endeavor to determine sedimentation and diagenetic processes of the mid-Bay area has revealed a number of gross physical structures. The only radiographic analysis of the sedimentary record of this estuarine system is that of Schubel and Zabawa's (1977) investigation in the upper Bay.

Growing interest in the accumulation of toxic substances in the Chesapeake Bay on the part of the Environmental Protection Agency-Chesapeake Bay Program (Environmental Protection Agency, 1979) has in turn provided a rare opportunity to examine the variability of sedimentary structures of Recent bottom sediments. An integral part of the program focused on suspended and deposited sediments because of the affinity of many contaminants for particulate matter. Investigations of the benthic biota were also undertaken because these organisms play an important role in the deposition, mixing and resuspension of the sediments, and in the exchange of dissolved materials across the sediment-water interface. An extensive survey of the macrofauna and their relationship to sediment texture and structure was conducted by the Maryland Geological Survey and the Virginia Institute of Marine Science in conjunction with studies of sediment patterns, geochemical profiles and toxic-material content. Presented in this paper are radioigraphic analyses of diverse sedimentary environments in the Chesapeake Bay which are intended to serve as a framework for current research as well as a prospectus for future studies in this and other estuaries.

METHODS

Sampling

We have collected cores from nearly 200 stations in the Chesapeake Bay estuarine system, including embayments and tributaries. The 18 cores illustrated in this paper represent the spectrum of sedimentary environments encountered principally in the main stem of the Bay (Figure 1).

Cores were taken with a modified United States Navy Electronics Laboratory spade box corer (Bouma and Marshall, 1964). This device recovers a relatively undisturbed sample that has a surface area of 0.063 m^2 (21 $\times$ 30 cm) with a maximum depth of penetration of 60 cm. Two box cores were retrieved at each station; the first for radiographic analysis, dissection and visual observations, and the second for determining benthic distribution patterns. The bottom topography and vertical profiles were also recorded and photographed for each core.

Upon dismantling one of the box cores at each station, a 6 cm vertical slice was removed and sealed in

a plexiglass tray for subsequent radiographic procedures. The samples were refrigerated at 4°C to preserve the quality of the sediment. The remainder of the sediment was dissected to determine the placement and penetration of the biota. These observations were then compared with a more quantitative assessment of the benthic community in the second core (refer to Nilsen, et al., 1980, and Reinharz and O'Connell, 1981 for details). Subsamples for grain-size analysis taken along the vertical axis of each core provided additional textural information.

Radiographic Procedures

X-ray radiography provides an inexpensive and nondestructive method of obtaining a permanent record of the sedimentary environment (Bouma, 1969). Variations in the composition (density) of the sediment produces corresponding differences in X-ray attenuation, thus recording various amounts of radiation on photographic film. This technique allowed us to identify physical and biogenic sedimentary structures which are not readily discernible in slabbed cores. Radiography can also be utilized to estimate the percentage of biotic reworking of the sediment, otherwise referred to as bioturbation. Our bioturbation index follows the classification scheme proposed by Howard and Reineck (1972*a*): 0%, trace, <30%, 30-60%, 60-90%, 90-99%, 100%.

Methods for radiographic processing are presented in detail by Howard and Frey (1975). The 6 cm sections were subsequently trimmed to 2 cm and retained in plastic containers during X-ray exposure. Optimal resolution of the sediment fabric was achieved in this manner. The radiographs were made on Kodak AA-5 industrial film using a Torr 120 kv X-ray unit. The exposure data is as follows: focal distance, 95-120 cm; amperage, 3 ma; voltage exposure, 50-65 kv; time exposure, 60-210 sec.

Positive and negative images were produced on Kodak Rapid Polycontrast print paper. In positive reproductions mud is identified by dark colors, whereas sand is manifested as a lighter tone. A number of radiographs display horizontal (white or black) bands at the center of the photograph, indicating the splicing of top and bottom transparencies of that particular core to form a complete print.

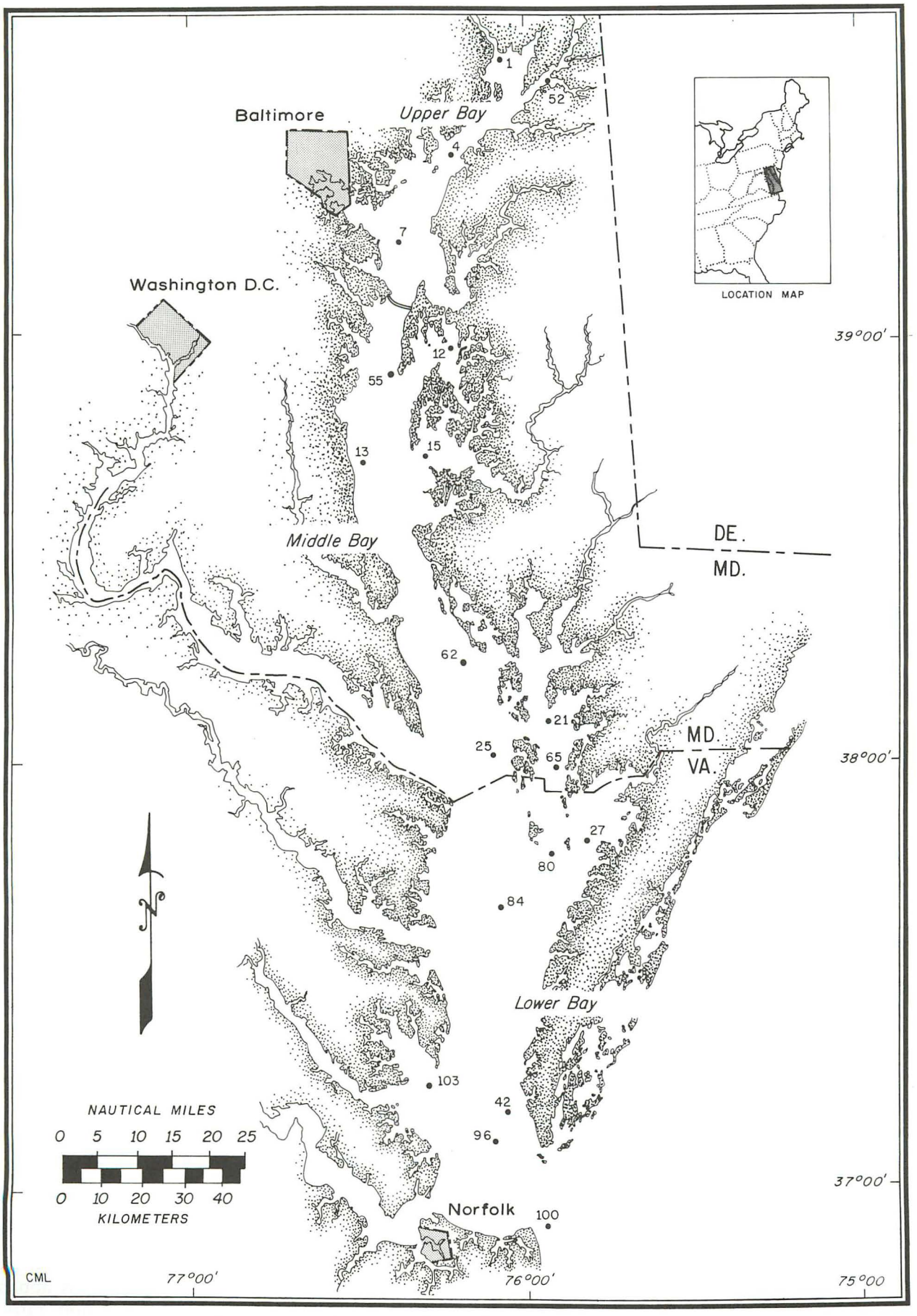

Figure 1: Location of sampling stations in the Chesapeake Bay.

SEDIMENT TEXTURES AND PHYSICAL STRUCTURES

The distribution of sediments and the formation of physical sedimentary structures in estuaries is controlled by hydrodynamic conditions and the availability of sediment. The sediments of the Chesapeake Bay are primarily derived from the suspended load of major tributaries (e.g.—Susquehanna and Potomac Rivers) and shoreline erosion (Ryan, 1953; Guilcher, 1967; Schubel, 1968 and 1971; Palmer, 1975; Shideler, 1975). Secondary sources include small riverine branches, oceanic influx, bottom resuspension and biogenic products. Since the abiotic and biotic components of the substratum are inextricably bound, physical structures formed at the time of deposition are subject to destruction, thus resulting in bioturbated textures.

Sedimentary environments in the Chesapeake Bay were characterized on the basis of sediment textures and biotic indicators (Nilsen, et al., 1980; Reinharz and O'Connell, 1981). According to this approach, the following substrate categories were established: (a) mud ($>90\%$ mud), (b) mixed sediment (15-90% mud), (c) fine sand ($<15\%$ mud), and (d) medium to coarse sand ($<15\%$ mud). The descriptive terminology used in delineating sedimentary structures relies on the classification proposed by Reineck and Singh (1975).

Mud Environment

Estuarine sediments dominated by silts and clays, or mud, tend to accumulate in low energy regimes, beyond the influence of a sand source. This fine-grained material comprises approximately 80% of all the sediments carpeting the Chesapeake Bay bottom (Ryan, 1953). Mud sinks are concentrated mainly along the central basin of the estuary north of the Rappahannock River and at tributary outlets.

The prevailing sedimentary feature in the mud facies is laminated silt and clay. Examination of set boundaries reveals both planar and wavy layering. These layers may have resulted from recurrent deposition of sediment on a planar or irregularly sculptured surface. Wavy sequences may also develop due to the unstable nature of muddy sediments (Katuan and Ingram, 1974). Mud beds are occasionally bounded by coarser-grained sandy material, suggesting interruptions in sediment deposition. These sand partings are produced by temporary high energy surges which transport sand into the basin or winnow the sand leaving a lag.

Sediments containing intercalated silts, clays and minimal amounts of fine sand are prevalent in the upper Bay (Plate 3). The bedding sequence of this area is indicative of considerable sediment loading and the intense dynamics of storm events (Schubel and Zabawa, 1977). The formation of these laminae may occur to a lesser degree when inputs from normal spring freshets or anthropogenic activities combine with the movements of the turbidity maximum zone (Schubel, 1968; Riggs, 1969; Schubel, 1971). The laminated sediments of the upper Bay are subject to low or moderate levels of bioturbation.

Laminated silts and clays are also located further south in the deepwater channels of the mud regime (Plates 5 and 9). Accumulations of mud beds which may be interlayered with poorly sorted sand are found in this area. As in the upper Bay, these beds are probably attributed to physical episodes such as storms which cause a substantial increase in the suspended-sediment load (McCave, 1970). The depositional rate of the channel regime is much higher than that of the upper Bay (Setlock, 1980, personal communication), resulting in thick mud sequences. These physical processes are signaled by the absence of bioturbated markers.

The physical structures common to fine sediments are often obliterated along the shallow fringes of the mud regime (Plates 7 and 15). Sedimentation rates are generally lower in these particular areas than in other regions of the mud environment. Nondepositional intervals are long enough to allow the biota to significantly modify the sediment, resulting in a mottled sediment fabric.

Gas-expansion bubbles are intimately associated with muddy sediments. Reducing bacteria produce methane in great quantities in the organic-rich environments of the upper Bay (Plate 3) and the channel (Plates 5 and 9) areas. These gases coalesce to form bubble features which migrate to the sediment-water interface (Martin and Val Klump, 1980). Migration of methane gas is facilitated at the sites of biogenic structures. The upward movement of these expansion bubbles causes some sediment disruption.

Shells are often among the sedimentary inclusions in the mud environment. Shells are dispersed or are found in discrete beds throughout the sediments. Benthic assemblages, especially those of the mactrid bivalve mollusc, *Mulinia lateralis*, represent episodes of mass mortality with some individuals preserved in the living position. The ongoing maintenance of benthic populations is apparently prevented because of high deposition rates, the presence of fluid mud and/or periodic anoxia (Biggs,

1967; Schubel and Cronin, 1977; Setlock, 1980, personal communication).

Anthropogenic inclusions are also found in the mud regime. Deposits of slag from coal-burning vessels are the most conspicuous human input. Unlike the ubiquitous nature of biogenic products, foreign components such as this occur only in localized areas.

Mixed-Sediment Environment

Mixed-sediment environments are produced as a result of highly diverse energy conditions. These sediments represent a transitional zone between the mud and fine sand facies in the Chesapeake estuary, becoming quite prominent in the lower Bay. The variable transport of sediments from both facies results in a broad range of textural composites.

Interbedded mud and sand comprise the dominant physical pattern in mixed-sediment environments. These mud-sand alternations may be thin or thick bedded, displaying a certain regularity. Because of the changeable dynamics of this sedimentary regime, a corresponding array of physical structures is generated.

Mud-sand sequences are modified by various processes throughout the Chesapeake Bay estuarine sediments. The presence of numerous interlaminations indicate continuous changes in tidal and current energies (Plate 14). Most mixed-sediment cores display marked post-depositional alterations (Plates 8 and 16). Physical sedimentary structures are often disrupted. Extensive bioturbation of the sediment fabric usually results in a mottled texture where sedimentary features are almost completely obscured. Where gross structural units are visible, relative changes in sedimentation patterns can be inferred (Plates 8 and 10).

Anthropogenic as well as natural influences are evident in the mixed-sediment environment. Human activity may be destructive, resulting in the massive deformation of physical structures (Plate 2). Physical mixing at this station is attributed to propeller-generated turbulence from concentrated ship traffic. Anthropogenic processes may also produce layered bed sets (Plate 4), created by the episodic dumping of dredged material.

Shell aggregations are abundant in mixed-sediment substrates. These assemblages may be homogeneous, possibly reflecting mass mortalities of benthic species. High-energy currents within certain mixed-sediment regimes produce heterogeneous shell concentrations.

Fine Sand Environment

Clean, well-sorted fine sands are generally found in high energy regimes. These fine sands are the most prevalent of the total sand-size fraction (Palmer, 1975; Shideler, 1975) and are concentrated along the estuarine margins of the Chesapeake Bay. Extensive sand facies development occurs along the eastern shoreline whereas more patchy sand shoals are located along the western sector. Sheets of fine sand, which may be as much as 20 cm thick, usually overlie a hard clay substratum (Plate 13).

Small-scale cross-bedding is the most common sedimentary structure of fine sand environments. Ripple laminae are frequently trough-shaped, and are produced by migrating currents and waves. Heavy minerals generally mark the rippled boundaries. Some of the rippled surfaces may be lined with silts and clays, thus forming mud flasers. Much of this fine-grained material originates as biodeposits (feces and pseudofeces) which are subsequently reworked by the physical regime.

Station 12 (Plate 6) displays the best preservation of small-scale cross-bedding observed in the Bay. The ripple laminae are found intact only in the uppermost sediment stratum. With the passage of time, biogenic activity may destroy these features and homogenize the sediment fabric, as seen at Stations 25 and 27 (Plates 11 and 13).

Shell concentrations are usually heterogeneous in composition. In most cores, shells and shell fragments are scattered throughout the sediment.

Medium-Coarse Sand Environment

Environments composed of medium to coarse sands are characterized by extremely high energy conditions. These sands are particularly common in the upper and lower reaches of the Chesapeake Bay and along certain estuarine margins. Local concentrations of medium to coarse sand are also found wherever subaqueous outcrops are present.

Large-scale cross-bedding is the predominant sedimentary feature of the medium-coarse sand environments. Both trough and planar bed sets are present. Ascertaining the prevalence of one bed type over another is difficult because the size of these structures is greater than the dimensions of the box core. Cross-laminated sets are produced by large

current and wave ripples. Heavy minerals commonly enhance these laminae. Although mud comprises a small percentage of the overall sediment, mud flasers are nevertheless apparent in some cores.

The best development of large-scale cross-bedding is found in the Susquehanna sand flats (Plate 1). The physical energy in this area is strong and repetitive enough so that the substrate is continually reworked and biogenic structures are not preserved. Bioturbation becomes more significant within the mouth of the Bay and in some local areas (Plates 12 and 17) where the sediments are thoroughly homogenized. Cross-laminated beds are also present towards the perimeter of the Bay mouth (Plate 18).

Sedimentary inclusions consist of pebbles, shells and mud balls. Most of these materials are randomly distributed through the sediments. Anthropogenic products, especially coal, are found only in the uppermost sand flats of the Chesapeake estuarine system.

BIOGENIC STRUCTURES AND PROCESSES

The benthic macrofauna have a significant effect on the bottom environment where physical processes do not prevail. The types of biogenic structures produced are, in part, indicative of the biota's influence on the sediment. Biogenic features in the Chesapeake Bay (Table 2) include (a) dwelling tubes, (b) well-defined burrows which serve as dwelling or feeding structures, and (c) feeding traces

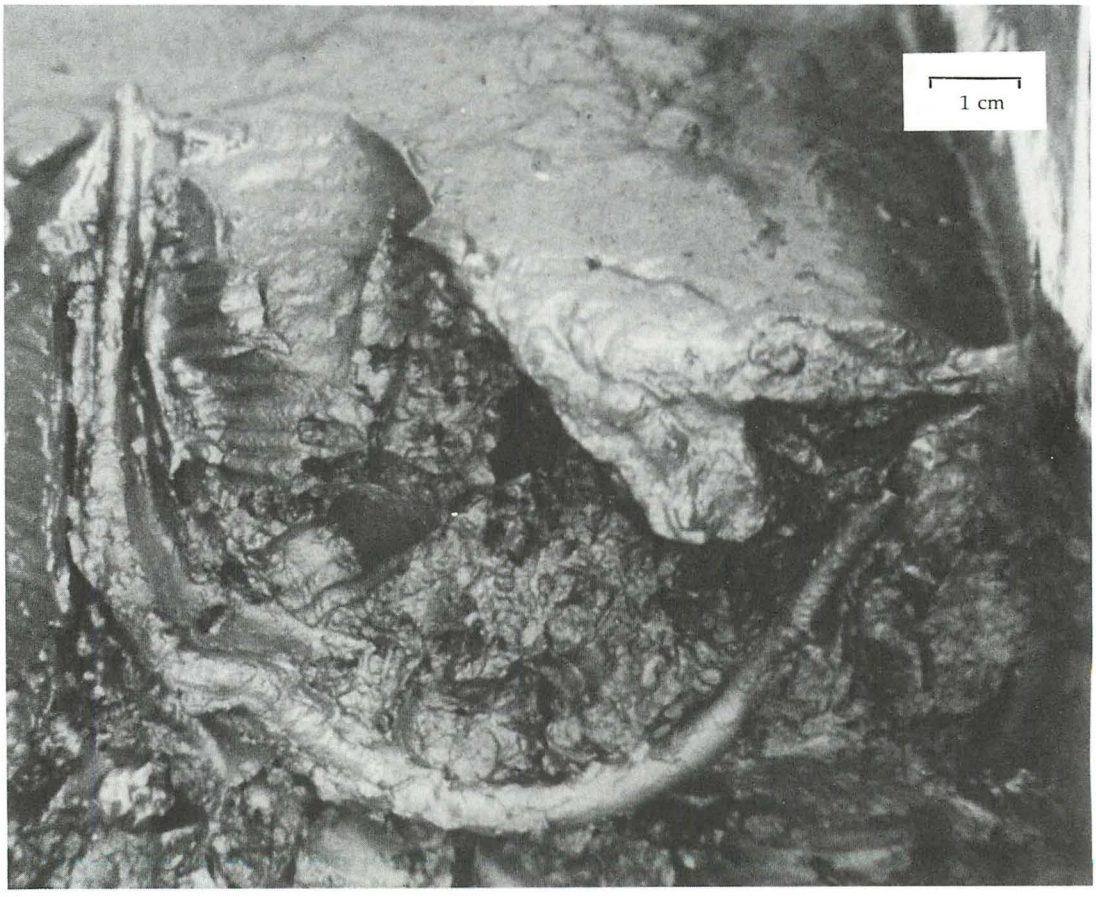

Figure 2: Photograph of a U-shaped mucus tube of the terebellid polychaete, *Loimia medusa*.

which facilitate the general bioturbation of the substratum. Depending on their life habits, organisms bioturbate the sediment by burrowing and/or rework it by feeding, biodeposition and irrigation.

Tubes

The impact of tube-dwelling organisms on sediment textures and physical structures varies considerably along the estuarine gradient. Tube construction ranges from fragile mucus to parchment-like, shell-covered forms. The sedentary nature of tube-builders precludes active bioturbation of the sediment. Species that occupy tubes can, however, modify the substratum through other biological processes, primarily by feeding. Tubes are also important because at high densities, they stabilize the sediment. Polychaetes are the predominant tube inhabitants recovered from the box cores.

The spionid polychaetes are one of the most abundant tube-dwelling groups in the Chesapeake Bay. Commonly represented among the spionids is the eurytopic organism, *Streblospio benedicti*. This species constructs shallow, limp mucus tubes which function as useful current indicators (Frey, 1970). Dense assemblages are readily apparent from surficial profiles. Tubes of this species are often abandoned when the organisms are disturbed (Foster, 1971). Deserted structures are subsequently degraded by microbial processes and eroded by currents. The temporary nature of these tubes as well as their minute size explain the lack of preservable biotic traces in the sediments. The transience of *Streblospio* and their dense tube concentrations also suggests that these polychaetes serve only as temporary stabilizing agents.

Other spionids construct firmer mucus tubes which extend deeper into the sediment. *Scolecolepides viridis* is predominant in the upper reaches of the Chesapeake Bay (Plates 2 and 34), whereas *Paraprionspio pinnata* is most prevalent in the lower zones of the estuary (Plates 6, 15 and 17). Both of these organisms produce characteristic galleries that penetrate the sedimentary beds without disrupting surrounding physical structures. High densities of these tubes ensure the cohesiveness of the sedimentary environment.

The terebellid, *Loimia medusa* (Plates 12 and 14; Figure 2) and the maldanid, *Asychis elongata* (Plate 15; Figure 6) polychaetes are only mildly disruptive to the sediment fabric. These species and their mucus-lined tubes are most conspicuous in the lower Bay. *Loimia* forms a moderately deep, U-shaped tube. In contrast, *Asychis* tubes are fairly straight but penetrate to a much greater depth. Since the box core often slices part of the tube of *Loimia*, its tube may easily be mistaken for that of *Asychis* in the radiographs. These species tend to penetrate as well as create slight bending of the laminated features where physical stratification is present (Plate 14). High densities of *Asychis* are reported to have a significant stabilizing effect in the San Francisco Bay area (Nichols, 1979). Because of their low population in the Chesapeake Bay, *Asychis* as well as *Loimia* alone probably do not act to enhance sediment stabilization here.

Some tube-building polychaete species are known to have a more significant impact on the sediments than others. Among these sediment-modifying organisms is the maldanid polychaete, *Clymenella torquata*, which frequently occurs at the lower regime of the Chesapeake system (Plate 16; Figure 3). The sand-encrusted tubes of *Clymenella* project deep into the sediment. This "conveyor-belt" species feeds on fine-grained material at the lower end of its tube and deposits its excretory products at the sediment surface. The vertical transport of these particles results in a biogenic graded bed (Rhoads and Stanley, 1965). Such beds were not found in this study. Assemblages of this tube-dweller are likely to be responsible for extensive sediment sorting which in turn disrupts laminated structures, thus creating mottled textures. Densities of this maldanid species in the Chesapeake estuary are similar to those reported for the Minas Basin (Featherstone and Risk, 1972) and are known to induce comparable stabilization of the sediments.

Unlike *Clymenella*, the effect of the amphictenid polychaete, *Pectinaria gouldii*, is more like that of a shallow burrowing bivalve (Plates 5, 12, 14 and 17). This species is generally found in the lower Chesapeake Bay. *Pectinaria* constructs a tapered conical sand tube with which it ploughs through the sediment. As with other "conveyor-belt" species, *Pectinaria* feeds on fine particles at the base of its tube (wide anterior end) and deposits rejected material at the sediment-water interface. Uptake of sediment creates feeding traces in the form of small cavities (Plates 12 and 14) which constantly collapse and provide the animal with new food resources. Rhoads (1967) indicated that *P. gouldii* has the potential to create biogenic graded beds. However, our radiographs do not reveal such beds in association with these polychaetes. The sediment reworking rate of *Pectinaria* is exceptionally high compared to other organisms (Gordon, 1966; Rhoads, 1967). Therefore, where this species is concentrated (Plate 12), the combination of its feeding activities and

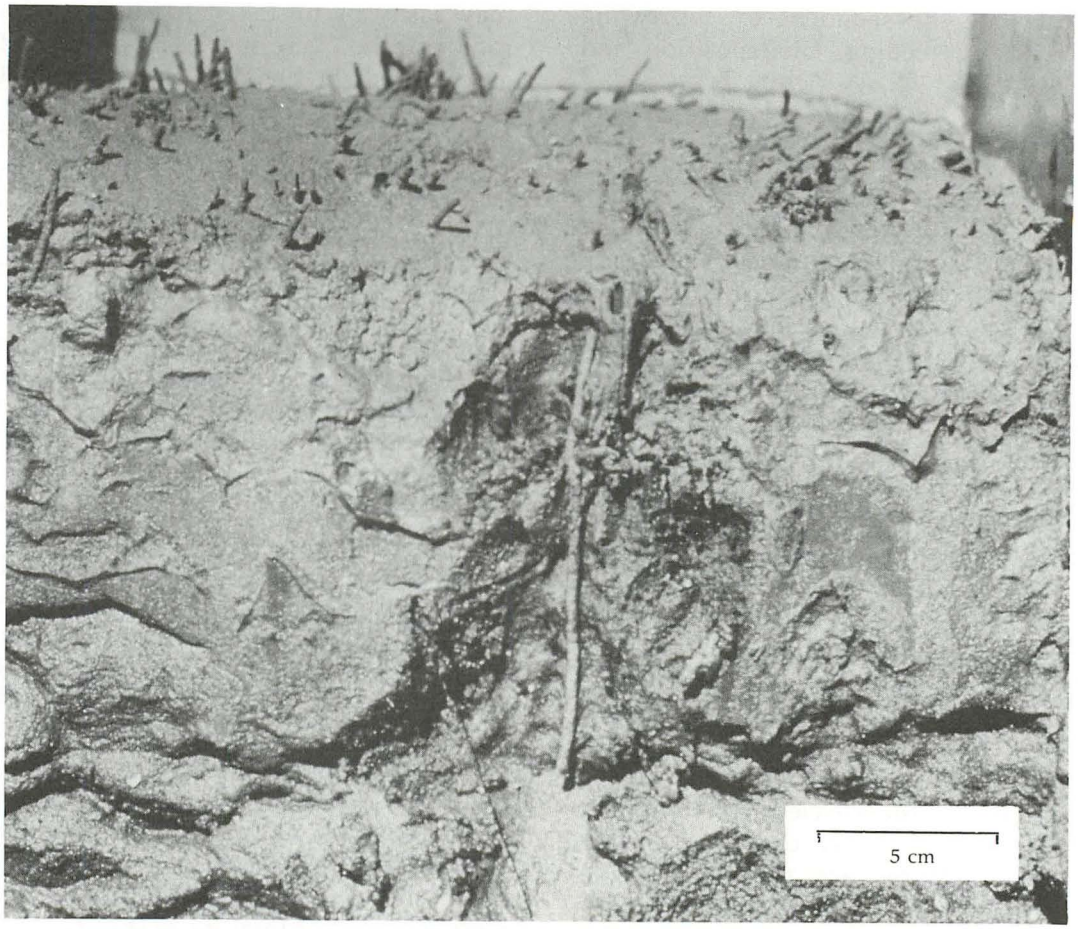

Figure 3: Photograph of sand tubes of the maldanid polychaete, *Clymenella torquata.*

mobility can result in the complete mixing of the sediment surface in a short period of time.

A number of polychaetes and other worm-like species affect the sediments in ways that may not be apparent, such as sediment disruption during tube construction. This type of sediment sorting is best exemplified by the deep-penetrating onuphid polychaete, *Diopatra cuprea* (Plate 17). The assortment and extent of materials incorporated into their agglutinated tubes has been used to ascertain transport and sedimentation rates. The orientation of these tubes has also provided valuable information regarding current direction (Myers, 1972). Smaller-scale sorting is performed by the deep-dwelling onuphid, *Onuphis eremita* (Plate 18), the maldanid, *Clymenella torquata*, and the amphictenid, *Pectinaria gouldii*, polychaetes, and the phoronid, *Phoronis* sp. (Plate 11). The onuphid and phoronid species are frequently found in the high-energy environments of the lower portions of the estuary. These species most likely do not function as sediment stabilizers in the Chesapeake Bay due to their low densities. Surface scour marks surrounding some tubes (e.g.—*Phoronis* sp.) may, in fact, indicate destabilizing effects.

Tube-dwellers of other taxa also influence sediment dynamics in a manner similar to that of certain polychaetes. The ampeliscid amphipod crustacean, *Ampelisca abdita*, is abundant in the lower Chesapeake estuary (Plates 12 and 14; Figure 4) and can facilitate sediment stabilization (Mills, 1967). These amphipods project their tubes above the sediment surface, trapping fine-grained materials. Sediment accumulation rates may substantially increase in areas of extremely high densities of this species (Lynch and Harrison, 1969). *Ampelisca* tube assemblages in fluid mud layers, moreover, allow deeper tube-dwellers (e.g.—*Loimia medusa*) to establish themselves. However, these benthic populations may be ephemeral. One box core contained an amphipod mat at the sediment surface and a second layer buried 40 cm beneath the surface. These alternating biological and physical layers serve as a useful indicator of environmental conditions.

Cerianthid anemones were among the other taxa also encountered in our study. The tube-dweller, *Ceriantheopsis americanus*, is known to inhabit the fine-grained environment of the lower Chesapeake Bay regime. The backfilled cerianthid structure depicted at Station 84 (Plate 15) exceeded the penetration of the box corer and appears to have been highly disruptive.

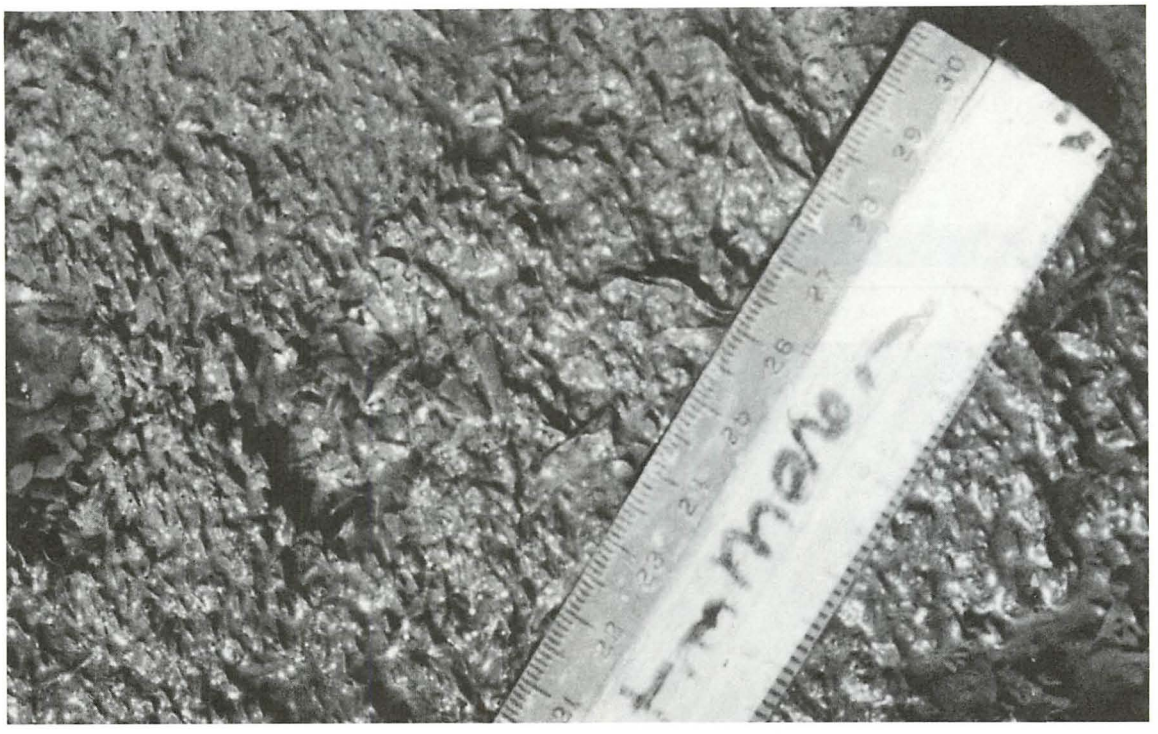

Figure 4: Photograph of a dense assemblage of ampeliscid amphipod crustacean mucus tubes, *Ampelisca abdita*.

Burrows

Burrow-builders are as significant as tube-builders in the modification of the Chesapeake Bay bottom. Distinct burrow networks of varying complexity are found in the sediments. New burrow components may be created as extensions of more permanent systems or as temporary structures which are intermittently excavated. The preservation of burrows is due to mucus secretions and compacted fine-grained sediment. Most burrow structures are formed by polychaetes which influence the sediments in varying degrees.

The capitellid polychaetes are one of the most prevalent burrowing groups in the Chesapeake estuarine system, leaving distinctive traces in the substratum. One of the more striking biogenic features is that of the eurytopic organism, *Heteromastus filiformis*, which forms a straight or bifurcating, mucus-lined structure (Plate 8). Surface bifurcation of the burrow occurs when food is plentiful. Decreased food availability forces this species to excavate deeper into the substratum (Howard, et al., 1973). The "conveyor-belt" feeding mode of *Heteromastus* contributes to biogenic graded bedding (Caddée, 1979). Although no such beds have been noted in this study, fecal casts are occasionally evident at the sediment surface (Figure 5). Capitellids sharply penetrate laminar structures wherever such features are present (Plate 18).

More extensive alteration of the sedimentary environment is accomplished by the eurytopic nereid polychaete, *Nereis succinea* (Plates 3 and 7; Figure 6). The burrow complex consists of a well-constructed dwelling stem in connection with less developed offshoots formed as the worm searches for food. Highly irregular patterns are produced as a result of this process. Fine-grained sediment is

cemented to the burrow walls, forming a multi-layered mucus sheath (Mayou and Howard, 1975). Active burrow systems may extend to great depths. In several box cores, *Nereis* is responsible for the creation of fecal mounds at the sediment-water interface. Sediment processing rates by this organism are reported to have a considerable impact on the substratum (Cammen, 1980). *Nereis* has been found to be an important bioturbator in a New Hampshire estuary (Winston and Anderson, 1971). Likewise, this species appears to have significantly contributed to sediment reworking in the Chesapeake Bay.

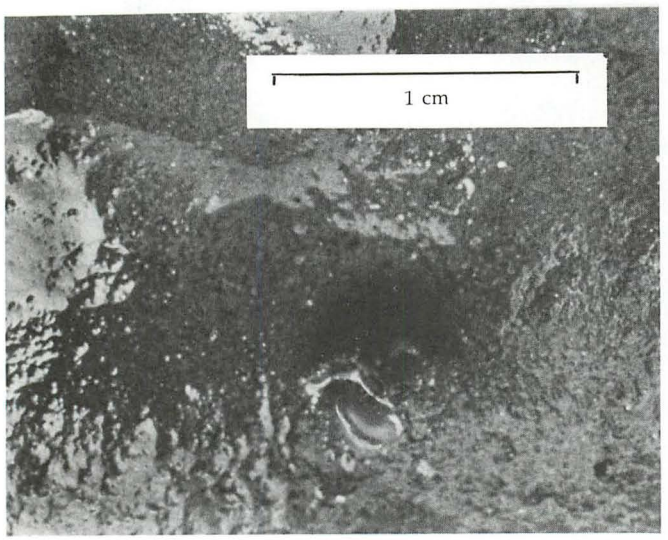

Figure 5: Photograph of a biodeposit (dark-grained sediment) produced by the capitellid polychaete, *Heteromastus filiformis*.

The glycerid polychaetes, *Glycera dibranchiata* and *Glycera americana*, are also effective sediment modifiers (Plates 10 and 11; Figure 7). Both species occupy the middle and lower estuarine regimes. The burrow systems of *Glycera* spp. are as complex as those of *Nereis* and may occasionally be misidentified. Unlike the nereid burrow, only a simple coat of mucus is secreted against the interior wall of the glycerid structure. Laminar disruptions are associated with glycerid burrow sites, primarily the result of excavation and feeding activities. Despite its numerical insignificance, the deep-dwelling nature of *Glycera* spp. seems to be a principle biogenic factor in the reworking of various substrates.

Several other taxonomic groups may be responsible for the modification of the sediments. Among the most important mollusc species is the tellinid bivalve, *Macoma balthica*, which is most prevalent in the middle region of the Chesapeake Bay (Plates 3, 4, 7 and 8). *Macoma* often constructs vertically-oriented, funnel-shaped burrows which are reinforced by compacted fine-grained materials. Maintenance of deep permanent burrows by adult individuals serves as an escape pathway from unfavorable environmental conditions. *Macoma* will occasionally migrate in a horizontal direction (Plate 7). This bivalve is known to intensively rework the sediments (Bubnova, 1972) and large populations can pelletize the sediment surface (Risk and Moffat, 1977). Densities and sedimentary disturbances noted in this study were similar to those of the aforementioned investigations. However, biodeposits were not discernible in any of the box cores.

The solenid bivalve, *Ensis directus*, is also a deep-burrowing mollusc (Plate 17) and a common inhabitant of coarser-grained sediments of the lower estuary. The burrow is narrow or elliptical in cross-section and is usually oriented in a vertical position. Extensive penetration by this species has been previously reported for the Chesapeake Bay (Allen, 1954). The depth of burrowing and extent of sediment disruption is related to environmental limitations and the size of the individual organism (Frey, 1968).

Unlike *Macoma* and *Ensis*, the activity of the ubiquitous mactrid bivalve, *Mulinia lateralis*, is restricted to the sediment surface. Under laboratory conditions, these molluscs produce funnel-shaped "resting traces" (Frey and Howard, 1972). A few such funnel-like structures have been observed in several radiographs.

Crustaceans are also well represented in the sediments. Biogenic features of the anthurid isopod, *Cyathura polita* (Plate 4), and the corophiid amphipod, *Leptocheirus plumulosus*, are especially noticeable. Both species are quite prevalent in the upper reaches of the Chesapeake estuary. *Cyathura* constructs simple straight or sinuous burrows with mud accumulations at its base. On the other hand, the structures of *Leptocheirus* are more irregular in form. The burrows of these species are shallow and unlined. Significant sediment alterations may result from *Leptocheirus* by virtue of its high population levels.

Biogenic features produced by small crustaceans are usually obscured elsewhere in the lower Bay. Only the massive burrows of the callianassid decapod, *Callianassa atlantica*, are evident. This species is confined to high-energy environments. *Callianassa* is highly disruptive, producing a large branching structure with several openings at the surface (Howard and Frey, 1975).

Figure 6: Photograph of a burrow system of the nereid polychaete, *Nereis succinea* (at surface), and the backfilled tube trace of the maldanid polychaete, *Asychis elongata* (at depth).

General Bioturbated Textures

Disturbance of the sediment matrix can also be attributed to the mobility of general bioturbators. The random burrowing and feeding activities of polychaetes, molluscs, crustaceans and other taxa can substantially rework the substratum. Sedimentary features may be altered but not obliterated at low levels of activity (Plate 14). On the other hand, destruction may be so extensive that the once stratified sediments are completely turbated with only well-maintained biogenic structures left intact (Plates 8, 11, 12 and 17).

TRENDS

It is necessary to examine the relationship between physical and biogenic structures in order to assess the various processes active in the sedimentary environments of the Chesapeake Bay. Prominent physical sedimentary structures include large-scale cross-bedding (medium to coarse sands), small-scale cross-bedding (fine sands), interbedded mud and sand (mixed-sediments) and laminated mud bedding (fine-grained sediments). These sedimentary features may be modified or destroyed by biological activity. However, physical structures may still be identifiable despite disruptive benthic processes and suggest the original depositional environment.

Most of the sediments of the Chesapeake estuarine complex are thoroughly bioturbated. Similar observations are noted for other regions (Rhoads, 1967; Winston and Anderson, 1971; Rhoads, 1974; Howard and Frey, 1975*a*; Featherstone and Risk, 1977; Robbins, et al., 1979). Benthic populations are influenced by the salinity gradient, type of sediment, sedimentation rate, stability of the substratum and the occurrence of anoxic conditions. Winston and Anderson (1971) and Howard and Frey (1975*a*) indicate that the degree of bioturbation follows the salinity gradient, with the least amount of biological activity at the head and the greatest at the mouth of an estuary. Bioturbation levels within similar sedimentary environments are uniformly high throughout the length of the Chesapeake Bay, becoming substantially reduced in the upper reaches of the system as a result of very active sedimentation processes (Schubel and Zabawa, 1977) and low salinities. Biogenic activity is also greatly diminished in the deep-water channel regime of this estuary

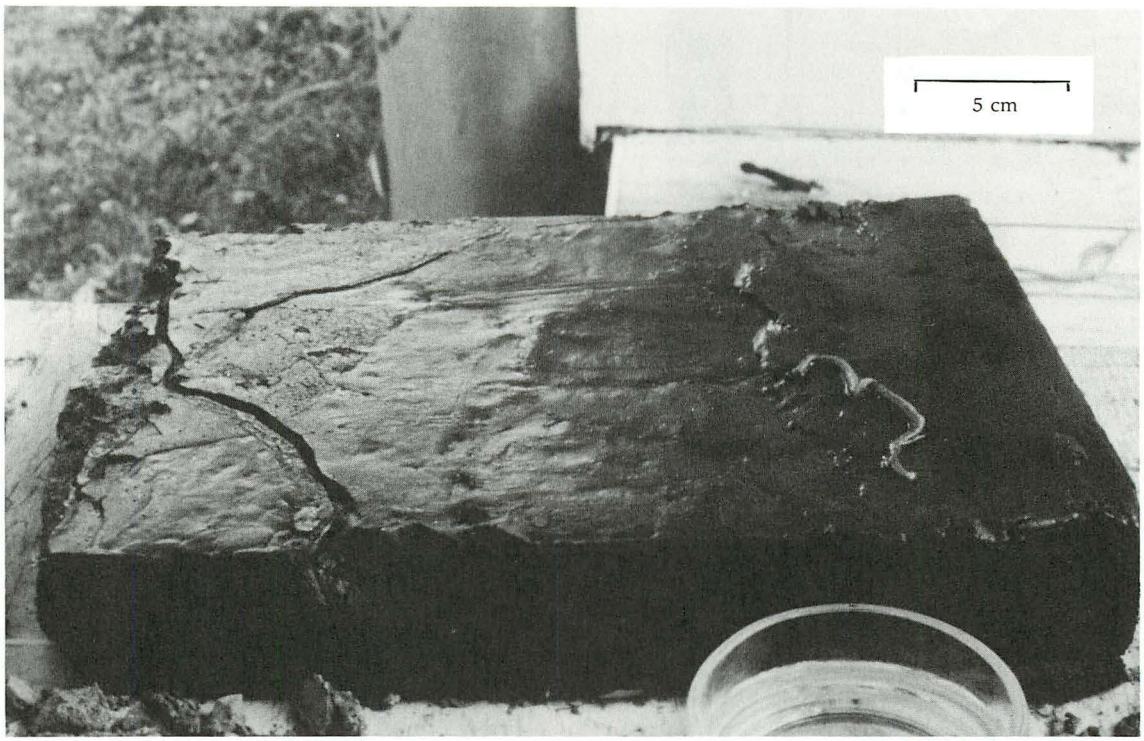

Figure 7: Photograph of the glycerid polychaete, *Glycera americana*, and its burrow system.

because of the combined effects of high deposition, the unstable nature of fluid mud and periodic anoxia (Biggs, 1967; Schubel and Cronin, 1977; Setlock, 1980, personal communication).

It is possible to distinguish biogenic features in many substrates and associate these structures with specific members of the benthic community. Most tube and burrow structures are formed by polychaetes. Where bioturbation is extensive, biotic traces become less obvious because members of one species may destroy features produced by those of another taxonomic group. Occasional biodepositional accumulations at the sediment-water interface are also discernible in the box cores. The paucity of these features is probably due to their rapid bacterial and physical breakdown, and subsequent transport by tidal currents.

The stable mud environment is inhabited mainly by sedentary tube-builders and relatively permanent, burrow-dwelling species, primarily occupying the sediment surface. Food resources are abundant in this regime; however oxygen is of limited supply since it is confined to a surface layer of a few mm in thickness. Therefore, a connection with the sediment-water interface and constant irrigation of tubes and burrows is necessary for survival because of the small reserve of oxygen. The transition from oxidizing to reducing conditions at the sediment surface and around irrigated structures may also result in the precipitation of various iron-rich substances as well as other compounds. These chemical products show up in the photographs as a clearly defined, rust-colored lining and as halos in the radiographs (indicated as iron oxide halos). Some biogenic structures are backfilled with fine-grained material upon the abandonment or death of the organism. Other features remain open, serving as conduits for inorganic and/or organic substances at depth. The heterogeneous character of muddy sediments is known to produce complex chemical gradients (Aller, 1977; Aller and Yingst, 1978).

Unlike the mud regime, sands are characterized by a more motile deep-burrowing fauna. Sandy substrates are usually saturated with oxygen, but have a limited food supply. Therefore, free-burrowing organisms are allowed to penetrate deeper into the sediment in order to maximize food procurement. Only well-maintained biogenic structures are visible since unoccupied features are quickly obliterated. Bioturbation activities result in a homogeneous texture, suggesting more uniform chemical profiles.

Examination of the radiographs indicate that the benthic biota are quite capable of destroying the detailed sedimentary record of the Chesapeake Bay.

The degree of biological disturbance is determined by the faunal composition in space and time (Rhoads, 1974; Tevesz, et al., 1980). Current data (Nilsen, et al., 1980; Reinharz and O'Connell, 1981) and other previous reports (Davis, 1974*a*&*b*; Aller, 1977; Goldhaber, et al., 1977; Rhoads, et al., 1977; McCall and Fisher, 1979) also demonstrate that benthic organisms are a prominent source of change in the physical and chemical properties of the sediments. Our investigations should provide a qualitative input to the interpretation of such diagenetic processes. A more quantified study of sedimentary mechanisms is recommended for future development of "real-world" models. The resultant information is likely to have important implications regarding the distribution and fate of natural and anthropogenic constituents in the sediments of the Chesapeake estuarine system.

REFERENCES

Allen, J. F., 1954, The influence of bottom sediments on the distribution of five species of bivalves in the Little Annemessex River, Chesapeake Bay. Nautilus, Vol. 68, p. 56-65.

Aller, R. C., 1977, The influence of macrobenthos on chemical diagenesis of marine sediment. Ph.D. Dissert., Yale Univ., New Haven, Connecticut, 600 pp.

Aller, R. C. and J. Y. Yingst, 1978, Biogeochemistry of tube-dwellings, A study of the sedentary polychaete, *Amphitrite ornata* (Leidy). Jour. Mar. Res., Vol. 36, p. 201-254.

Army Corps of Engineers, 1980, Operations Division, Baltimore, Maryland 21201.

Biggs, R. B., 1967, The sediments of the Chesapeake Bay. *In:* G. H. Lauff (ed.) Estuaries, Am. Assoc. Sci., Washington, D.C., Publ. No. 83, p. 239-260.

Boesch, D. F., 1972, Species diversity of marine macrobenthos in the Virginia area. Chesapeake Sci., Vol. 13, p. 206-211.

Boesch, D. F., 1973, Classification and community structure of macrobenthos in the Hampton Roads area, Virginia. Marine Biology, Vol. 21, p. 226-244.

Boesch, D.F., 1977, A new look at the distribution of benthos along the estuarine gradient. *In:* B. C. Coull (ed.), Ecology of marine benthos. Univ. of South Carolina Press, p. 245-266.

Boesch, D. F., M. L. Wass and R. W. Virnstein, 1976, The dynamics of the estuarine benthic communities. *In:* M. Wiley (ed.), Estuarine processes, Academic Press, New York, p. 177-196.

Bouma, A. H., 1964, Notes on X-ray interpretation of marine sediments. Marine Geology, Vol. 2, p. 278-309.

Bouma, A. H., 1969, Methods for the study of sedimentary structures. Wiley-Interscience, New York, 458 pp.

Bouma, A. H. and N. F. Marshall, 1964, A method for obtaining and analyzing undisturbed oceanic sediment samples. Marine Geology, Vol. 2, p. 82-99.

Bubnova, N. P., 1972, The nutrition of the detritus-feeding mollusks, *Macoma balthica* (L.) and *Portlandia arctica* (Gray), and their influence on bottom sediments. Oceanology, Vol. 12, No. 6, p. 899-905.

Caddée, G. L., 1979, Sediment reworking by the polychaete, *Heteromastus filiformis*, on a tidal flat in the Dutch Wadden Sea. Netherlands Jour. Sea Res., Vol. 13, No. 314, p. 441-456.

Calvert, S. E. and J. J. Veevers, 1962, Minor structures of unconsolidated marine sediments revealed by X-radiography. Sedimentology, Vol. 1, p. 296-301.

Cammen, L. M., 1980, A method for measuring ingestion rate of deposit feeders and its use with the polychaete, *Nereis succinea.* Estuaries, Vol. 3, No. 1, p. 55-60.

Coleman, J. M., 1966, Ecological changes in a massive fresh-water clay sequence. Gulf Coast Assoc., Geol. Soc., Trans., Vol. 16, p. 159-174.

Cronin, L. E. ed., 1975, Estuarine research. Academic Press, Inc., New York, Vols. 1 & 2.

Davis, R. B., 1974*a*, Stratigraphic effects of tubificids in profundal lake sediments. Limnol. Oceanogr., Vol. 19, p. 466-488.

Davis, R. B., 1974*b*, Tubificids alter profiles of redox potential and pH in profundal lake sediments, Limnol. Oceanogr., Vol. 12, p. 342-346.

Environmental Protection Agency, 1979, Chesapeake Bay Program: Summary of projects. EPA-600/8-79-030, 72 pp.

Featherstone, R. P. and M. J. Risk, 1977, Effect of tube-building polychaetes on intertidal sediments of the Minas Basin, Bay of Fundy. Jour. Sed. Petrol., Vol. 47, No. 1, p. 446-450.

Foster, N. M., 1971, Spionidae (Polychaeta) of the Gulf of Mexico and the Caribbean Sea. Studies on the fauna of Curacao and other Caribbean Islands, Vol. 36, No. 129, p. 1-183.

Frey, R. W., 1968, The lebensspuren of some common marine invertebrates near Beaufort, North Carolina. I. Pelecypod burrows. Jour. Paleont., Vol. 42, p. 570-574.

Frey, R. W. and J. D. Howard, 1972, VI. Radiographic study of sedimentary structures made by beach and offshore animals in aquaria. *In:* Georgia coastal region, Sapelo Island, U.S.A.: Sedimentology and biology. Senckenbergiana Marit., Vol. 4, p. 169-182.

Goldhaber, M. B., R. C. Aller, J. K. Cochran, J. K. Renfeld, C. S. Martens and R. A. Berner, 1977, Sulfate reduction, diffusion and bioturbation in Long Island Sound sediments. Report of the FOAM group, Amer. Jour. Sci., Vol. 277, p. 193-237.

Gordon, D. C., Jr., 1966, The effects of the deposit feeding polychaete, *Pectinaria gouldii*, on the intertidal sediments of Barnstable Harbor. Limnol. Oceanogr., Vol. 11, p. 327-332.

Guilcher, A., 1967, Origin of sediments in estuaries. *In:* Lauff, G. H. (ed.), Estuaries: Am. Assoc. Adv. Sci., Publ., Vol. 83, p. 149-157.

Hamblin, W. K., 1962, X-ray radiography in the study of structures in homogenous sediment. Jour. Sed. Petrol., Vol. 32, p. 201-210.

Holland, A. F., N. K. Mountford and J. A. Mihrusky, 1977, Temporal variation in upper bay mesohaline benthic communities. I. The 9-m mud habitat. Chesapeake Sci., Vol. 18, No. 4, p. 370-378.

Hopfinger, C., 1974, Textures and structures of Lake Erie sediment cores as revealed by X-ray radiography and continuous X-ray scanning. Unpubl. M. S. Thesis, Univ. of Toledo, Toledo, Ohio, 304 pp.

Howard, J. D., 1969, Radiographic examination of variations in barrier island facies, Sapelo Island, Georgia. Gulf Coast Assoc. Geol. Soc., Trans., Vol. 19, p. 217-232.

Howard, J. D. and R. W. Frey, 1972, Georgia coastal region, Sapelo Island, U.S.A.: Sedimentology and biology, Senckenbergiana Marit., Vol. 4, 222 pp.

Howard, J. D. and H. E. Reineck, 1972*a*, IV. Physical and biogenic sedimentary structures of the nearshore shelf. *In*: Georgia coastal region, Sapelo Island, U.S.A.: Sedimentology and biology, Senckenbergiana Marit., Vol. 4, p. 81-123.

Howard, J. D. and R. W. Frey, 1975, Estuaries of the Georgia coast, U.S.A.: Sedimentology and biology. Senckenbergiana Marit., Vol. 7, 305 pp.

Howard, J. D. and R. W. Frey, 1975*a*, II. Regional animal-sediment characteristics of Georgia estuaries. *In*: Estuaries of the Georgia coast, U.S.A.: Sedimentology and biology. Senckenbergiana Marit., Vol. 7, p. 33-103.

Howard, J. D., R. W. Frey and H. E. Reineck, 1973, Holocene sediments of the Georgia coastal area. *In*: R. W. Frey (ed.), The Neogene of the Georgia coast, Georgia Geol. Soc., Guidebook 8th Ann. Field Trip, p. 1-58.

Katuan, M. P. and R. L. Ingram, 1974, Sedimentary structures of a modern lagoonal environment, Pamlico Sound, North Carolina. Sea Grant Publ. UNC-SG-74-14, 122 pp.

Lauff, G. H., ed., 1967, Estuaries. Am. Assoc. Adv. Sci., Washington, D.C., Publ. No. 83, 757 pp.

Loi, T-N and B. J. Wilson, 1979, Macroinfaunal structure and effects of thermal discharges in a mesohaline habitat of Chesapeake Bay, near a nuclear plant. Marine Biology, Vol. 55, p. 3-16.

Lynch, M. P. and W. Harrison, 1969, Sedimentation caused by a tube-building amphipod. Jour. Sed. Petrol., Vol. 40, p. 434-435.

Martin, C. S. and J. Val Klump, 1980, Biogeochemical cycling in an organic-rich coastal marine basin. I. Methane-sediment-water exchange processes. Geochemica et Cosmochimica Acta, Vol. 44, No. 3, p. 481-490.

Mayou, T. V. and J. D. Howard, 1975, VI. Animal-sediment relationships of a salt marsh estuary—Doboy Sound. *In*: Estuaries of the Georgia coast, U.S.A., Sedimentology and biology. Senckenbergiana Marit., Vol. 7, p. 205-236.

McCall, P. L. and J. B. Fisher, 1979, Effects of tubificid oligochaetes on physical and chemical properties of Lake Erie sediments. *In*: R. O. Brinkhurst and D. G. Cooke (eds.), Aquatic oligochaete biology, Plenum Press, New York, p. 253-317.

McCave, I. N., 1970, Deposition of fine-grained suspended sediment from tidal current. Jour. Geophys. Res., Vol. 75, p. 4151-4159.

Mills, E. L., 1967, The biology of an ampeliscid amphipod crustacean sibling species pair. Fish. Res. Board Canada, Vol. 24, No. 2, p. 305-355.

Mountford, N. K., A. F. Holland and J. A. Mihursky, 1977, Identification and description of macrobenthic communities in the Calvert Cliffs region of the Chesapeake Bay, Chesapeake Sci., Vol. 18, p. 360-369.

Myers, A. C., 1972, Tube-worm-sediment relationships of *Diopatra cuprea* (Polychaeta: Onuphidae). Marine Biology, Vol. 17, p. 350-356.

Nichols, F. H., 1979, Natural and anthropogenic influences on benthic community structure in San Francisco Bay. *In*: T. J. Conomos, A. E. Levitan and M. Berson, San Francisco Bay: The urbanized estuary, San Francisco, California, p. 409-426.

Nilsen, K. J., R. J. Diaz, D. F. Boesch, R. Bertelsen and M. Kravitz, 1980, The biogenic structure of lower Chesapeake Bay sediments. Final Report to Environmental Protection Agency-Chesapeake Bay Program, Annapolis, Maryland, Grant No. R805982, 103 pp.

Palmer, H. D., 1975, Upper bay survey: Estuarine sedimentology. Maryland Department of Natural Resources, Vol. 2, 63 pp.

Reineck, H. E. and I. B. Singh, 1975, Depositional sedimentary environments. Springer-Verlag, New York, 439 pp.

Reinharz, E. and A. E. O'Connell, 1981, Animal-sediment relationships of the upper and central Chesapeake Bay. Final Report to Environmental Protection Agency-Chesapeake Bay Program, Annapolis, Maryland, Grant No. R805964, 71 pp.

Rhoads, D. C., 1967, Biogenic reworking of intertidal and subtidal sediments in Barnstable Harbor and Buzzards Bay, Massachusetts. Jour. Geology, Vol. 75, p. 461-476.

Rhoads, D. C., 1974, Organism-sediment relations on the muddy sea floor. Oceanogr. Marine Biology Ann. Res., Vol. 21, p. 263-300.

Rhoads, D. C. and D. J. Stanley, 1965, Biogenic graded bedding. Jour. Sed. Petrol., Vol. 35, p. 956-963.

Rhoads, D. C., R. C. Aller and M. B. Goldhaber, 1977, The influence of colonizing benthos on physical properties and chemical diagenesis of the estuarine sea floor. *In*: B. C. Coull (ed.), Ecology of marine benthos, Univ. of South Carolina Press, p. 113-138.

Risk, N. J. and J. S. Moffat, 1977, Sedimentological significance of fecal pellets of *Macoma balthica* in the Minas Basin, Bay of Fundy. Jour. Sed. Petrol., Vol. 47, No. 4, p. 1425-1436.

Robbins, J. A., P. L. McCall, J. B. Fisher and J. R. Krizooki, 1979, Effect of deposit feeders on migration of ^{137}Cs in lake sediments. Earth and Planet. Sci. Letters, Vol. 42, No. 2, p. 227-287.

Roberts, M. H., D. F. Boesch and M. E. Bender, 1975, The Chesapeake Bay: A study of present and future water quality and its geological effects. Final report to National Commission on Water Quality, Virginia Institute of Marine Science, Gloucester Point, Virginia.

Ryan, J. D., 1953, The sediments of Chesapeake Bay. Maryland Dept. of Geology, Mines and Water Resources, Bull. 12, 120 pp.

Schubel, J. R., 1968, Suspended sediment of the northern Chesapeake Bay. Ph.D. Dissert., Johns Hopkins Univ., Baltimore, Maryland, 264 pp.

Schubel, J. R., 1971, Sources of sediments to estuaries. *In*: Schubel, J. R. (ed.), The estuarine environment, estuaries and estuarine sedimentation. Amer. Geol. Inst. Short Course Lecture Notes, VI-19.

Schubel, J. R. and W. B. Cronin, 1977, Effects of Agnes on the distribution of dissolved oxygen along the main axis of the bay. *In*: Davis, J. and B. Laird (eds.), The effects of tropical storm Agnes on the Chesapeake Bay estuarine system. The Johns Hopkins Univ. Press, Baltimore, Maryland, Publ. No. 54, p. 335-347.

Schubel, J. R. and C. F. Zabawa, 1977, Agnes in the geological record of the upper Chesapeake Bay. *In:* Davis, J. and B. Laird (eds.), The effects of tropical storm Agnes on the Chesapeake Bay estuarine system. The Johns Hopkins Univ. Press, Baltimore, Maryland, Publ. No. 54, p. 240-248.

Setlock, G., 1980, unpublished data, Univ. of Maryland, Department of Chemistry, College Park, Maryland 20742.

Shideler, G. L., 1975, Physical parameter distribution patterns in bottom sediments of the lower Chesapeake Bay estuary, Virginia. Jour. Sed. Petrol., Vol. 45, No. 3, p. 728-737.

Tevesz, M. J. S., F. M. Soster and P. L. McCall, 1980, The effects of size-selective feeding by oligochaetes on the physical properties of river sediments. Jour. Sed. Petrol., Vol. 50, No. 2, p. 561-568.

Winston, J. E., and F. E. Anderson, 1971, Bioturbation of sediments in a northern temperate estuary. Marine Geology, Vol. 10, p. 39-49.

Table 1: Physical structures found within various sedimentary environments of the Chesapeake Bay
(Based on the classification scheme of Reineck and Singh, 1975)

Sediment Textures	Dominant Physical Structures	Associated Physical Structures
Medium-coarse sand	Large-scale cross bedding (rippled trough and planar bed sets)	Mud flasers Inclusions (pebbles, shells, mud balls, coal)
Fine sand	Small-scale cross-bedding (rippled trough-shaped bed sets)	Mud flasers Inclusions (shell and shell fragments)
Mixed sediment	Interbedded mud and sand	Small-scale ripple lamination Mud flasers Wavy bedding Sand lenses Scour-and-fill structures Inclusions (shells and shell fragments)
Mud	Laminated mud bedding (planar and wavy bed sets)	Sand partings (laminae, lenses) Inclusions (shells, slag)

Table 2: Commonly Encountered Biogenic Structures in the Chesapeake Bay

Species	Environmental Preference	Feeding Mode	Biogenic Structure
Cnidaria			
Ceriantheopsis americanus	1. Polyhaline zone 2. Mud	Suspension feeder	1. Thick, mucus tube composed of tough cnidae 2. Max. Diam: 3.5 cm Penetration: > 30 cm
Polychaeta			
Amphictenidae			
Pectinaria gouldii	1. High mesohaline to euhaline zone 2. All sediment types	Selective deposit feeder (subsurface): "conveyor-belt" species	1. Conical-shaped, slightly arcuate sand tube (mobile): forms cavity (feeding trace) at lower end 2. Max. Diam: 1 mm at top, 5 mm at base Penetration: 5 cm
Capitellidae			
Heteromastus filiformis	1. Euryhaline 2. All sediment types	Non-selective deposit feeder (subsurface): "conveyor-belt" species	1. Simple, straight or bifurcated mucus-lined burrow: produces surface fecal mounds 2. Max. Diam: 1 mm Penetration: 40 cm
Glyceridae			
Glycera spp. *G. americana* *G. dibranchiata*	1. High mesohaline to euhaline zone 2. All sediment types	Non-selective deposit feeder: omnivorous forager	1. Winding, simple mucus-lined burrow 2. Max. Diam: 6 mm Penetration: 40 cm
Maldanidae			
Asychis elongata	1. High mesohaline to polyhaline zone 2. Mud to sandy mud	Selective deposit feeder (surface)	1. Mucus, mud-covered cylindrical tube 2. Max. Diam: 5 mm Penetration: 50 cm
Clymenella torquata	1. High mesohaline to polyhaline zone 2. Sandy mud to fine sand	Selective deposit feeder (subsurface): "conveyor-belt" species	1. Cylindrical, sand-encrusted tube 2. Max. Diam: 3 mm Penetration: 20 cm
Nereidae			
Nereis succinea	1. High oligohaline to euhaline zone 2. All sediment types	Non-selective deposit feeder: omnivorous forager	1. Simple (U-shaped) to complex burrow (irregular lined with mucus sheath: produces surface fecal mounds 2. Max. Diam: 4 mm Penetration: 50 cm
Onuphidae			
Diopatra cuprea	1. High polyhaline to euhaline zone 2. Muddy sand to medium-coarse sand	Carnivore	1. Heavy, parchment-like tube encrusted with sand, shells and hydroids 2. Max. Diam: 2 cm Penetration: 30 cm
Onuphis eremita	1. Euhaline 2. Fine to medium-coarse sand	Carnivore	1. Cylindrical sand tube 2. Max. Diam: 4 mm Penetration: > 15 cm
Spionidae			
Paraprionspio pinnata	1. Mid-mesohaline to polyhaline zone 2. All sediment types with preference for mud environments	Selective deposit feeder (surface)	1. Mucus, mud-covered tube 2. Max. Diam: 1 mm Penetration: 15 cm
Scolecolepides viridis	1. Oligohaline to low mesohaline zone 2. All sediment types with preference for mixed-sediment environments	Selective deposit feeder (surface)	1. Mucus, mud-covered tube: easily fragmented 2. Max. Diam: 1 mm Penetration: 20 cm

Table 2: Commonly Encountered Biogenic Structures in the Chesapeake Bay (cont.)

Species	Environmental Preference	Feeding Mode	Biogenic Structure
Polychaeta (Cont.)			
Spionidae			
Streblospio benedicti	1. Euryhaline 2. All sediment types	Selective deposit feeder (surface)	1. Limp, fragile, mucus tube 2. Max. Diam: 0.5 mm Penetration: 5 cm
Terebellidae			
Loimia medusa	1. High mesohaline to polyhaline zone 2. All sediment types	Selective deposit feeder (surface)	1. U-shaped, mucus mud and sand-covered tube 2. Max. Diam: 6 mm Penetration: 15 cm
Mollusca			
Mactridae			
Mulinia lateralis	1. Mid-mesohaline to euhaline zone 2. All sediment types, more common in muddier environments	Suspension feeder	1. Funnel-shaped features 2. Penetration: 5 cm
Solenidae			
Ensis directus	1. Polyhaline to euhaline zone 2. Muddy sand to medium-coarse sand	Suspension feeder	1. Narrow or elliptical in cross-section, smooth-walled burrow; usually has vertical or inclined orientation 2. Penetration: > 30 cm
Tellinidae			
Macoma balthica	1. High oligohaline to mesohaline zone 2. All sediment types with preference for muddier environments	Selective deposit feeder (surface): occasionally suspension feeds	1. Funnel-shaped, smooth-walled burrow: generally with vertical or inclined orientation but may also burrow in horizontal direction 2. Penetration: 30 cm
Crustacea			
Amphipoda			
Ampeliscidae			
Ampelisca abdita	1. High mesohaline to polyhaline zone 2. Mud to fine sand	Selective deposit feeder (surface)	1. Thin mucus tube 2. Max. Diam: 2 mm Penetration: 3 cm
Corophiidae			
Leptocheirus plumulosus	1. Oligohaline to mesohaline zone 2. Mud to muddy sand	Omnivore	1. Simple, irregularly-shaped, unlined burrow 2. Max. Diam: 2 mm Penetration: 10 cm
Decapoda			
Callianassidae			
Callianassa atlantica	1. Polyhaline 2. Muddy sand to medium-coarse sand	Omnivore	1. Large burrow with complex branching and several openings to surface 2. Max. Diam: 2 cm Penetration: > 20 cm
Isopoda			
Anthuridae			
Cyathura polita	1. Oligohaline to low mesohaline zone 2. Mud to muddy sand	Omnivore	1. Simple, straight to sinuous, unlined burrow: spherical mud accumulation at base of burrow 2. Max. Diam: 3 mm Penetration: 10 cm
Phoronida			
Phoronis sp.	1. High mesohaline to polyhaline zone 2. Fine sand	Suspension feeder	1. Chitinous, sand-encrusted tube builder 2. Max. Diam: 1 mm Penetration: 15 cm

Plate 1. Station 1, Medium-Coarse Sand Environment

Station 1: Mouth of the Susquehanna River
Latitude: 39°32′59.7″
Longitude: 76° 4′27.5″
Sampling Date: 7/5/79
Water Depth: 10.38 m
Radiographic positive print

Medium-Coarse Sand Environment:

The intense dynamics of the river-dominated, Susquehanna sand flat regime are reflected in this radiograph. Large-scale cross-bedding (trough and planar-shaped bed sets) characterizes these sediments. Cross-laminations are generally enhanced by heavy minerals, but may also be outlined by anthropogenic materials, such as coal. The print shows a unidirectional dip; up-river is presumably to the left. Horizontal laminations reflect planes of erosion which mark different bed units. Despite the scarcity of silt and clay in these sands, mud flasers are occasionally evident. The dynamic nature of the physical regime is further demonstrated by the absence of bioturbation.
Degree of Bioturbation: 0%

Special Features:

A. Homogenous bed unit
B. Trough-shaped bed set, delineated by heavy minerals (light grains)
C. Planar cross-bedding, defined by coal fragments (dark grains)
D. Heavy mineral rippled lamina
E. Heavy mineral erosional planes
F. Mud flasers
G. Pebbles
H. Structural cracks in the sediment

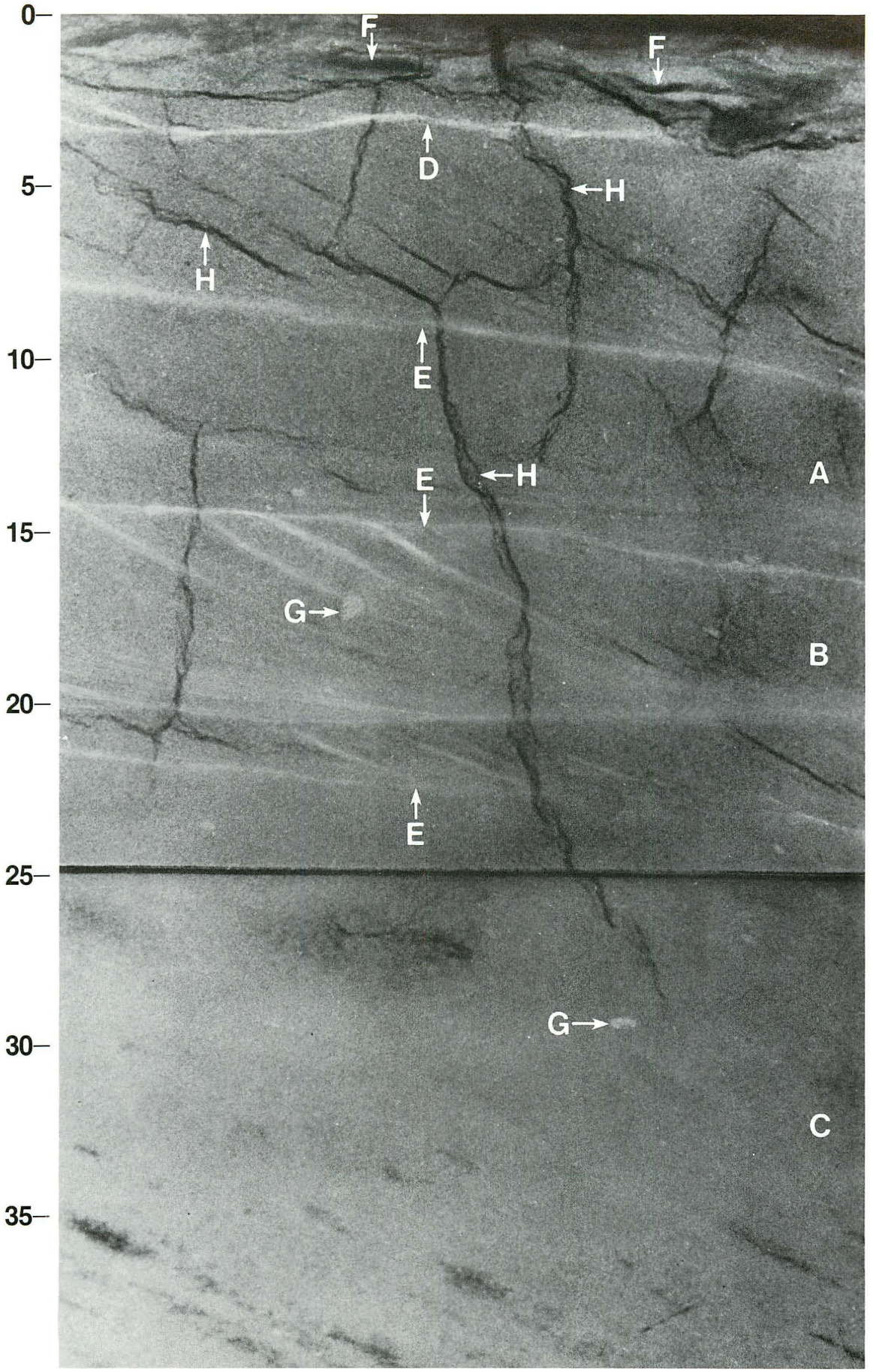

Plate 1. Station 1

Plate 2. Station 52, Mixed-Sediment Environment

Station 52: Confluence of the Elk and Bohemia Rivers
Latitude: 39°28′50.3″
Longitude: 75°56′20.9″
Sampling Date: 7/4/79
Water Depth: 4.40 m
Radiographic positive print

Mixed-Sediment Environment:

Massive destruction of bedding may occur in shallow areas subject to heavy ship traffic. Propeller-generated turbulence is probably the responsible turbating agent at this station. Thin mud-sand laminae and wavy bedding found at depth are the principal physical features here. Some evidence of these structures is seen in the upper sediment strata as disrupted laminae. The scattered shells of the bivalve mollusc, *Rangia cuneata* represent a death assemblage. Biogenic activities are relatively insignificant in this environment.
Degree of Bioturbation: $<30\%$

Special Features:

A. Silty sand bed containing disrupted mud laminae and flasers
B. Clayey silt bed, containing disrupted sand laminae and lenses
C. Interlaminated mud-sand bed
D. Wavy bedding
E. *Rangia cuneata* shells (disarticulated)
F. *Scolecolepides viridis* tube traces (active)
G. *Scolecolepides viridis* tube traces (remnant)
H. Fishing line

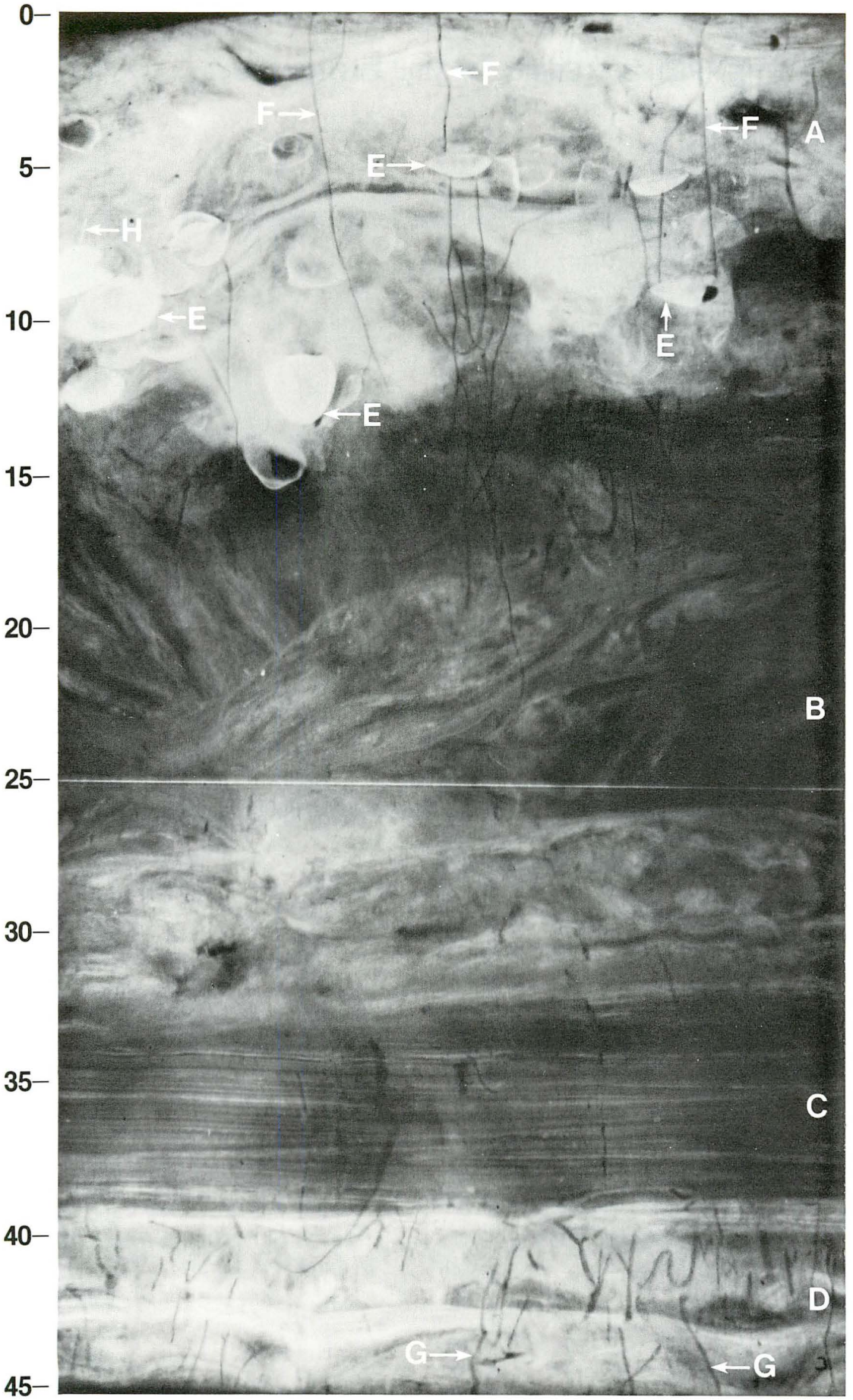

Plate 2. Station 52

Plate 3. Station 4, Mud Environment

Station 4: Middle of the Chesapeake Bay just north of Pooles Island
Latitude: 39°18′42.6″
Longitude: 76°13′56.7″
Sampling Date: 9/26/78
Water Depth: 6.40 m
Radiographic negative print

Mud Environment:

Laminations of clay (dark on print) and silts with some fine sand (light on print) is the characteristic feature in the sedimentary environment of the upper Chesapeake Bay. Interlayered sediments are subject to some bioturbation in this core. The homogenous surface bed appears to represent a single event and may possibly be anthropogenic in origin. Methane production is commonplace in these organic-rich sediments. Such gas bubbles appear to concentrate along burrow structures.

Degree of Bioturbation: $<30\%$

Special Features:

A. Homogenous mud bed
B. Interlaminated mud and fine sand bed
C. Juvenile *Nereis succinea* burrow (active)
D. *Scolecolepides viridis* tube traces (some are active)
E. *Macoma balthica* shell and burrow with methane bubble concentration (inactive)
F. *Rangia cuneata* shell (disarticulated)

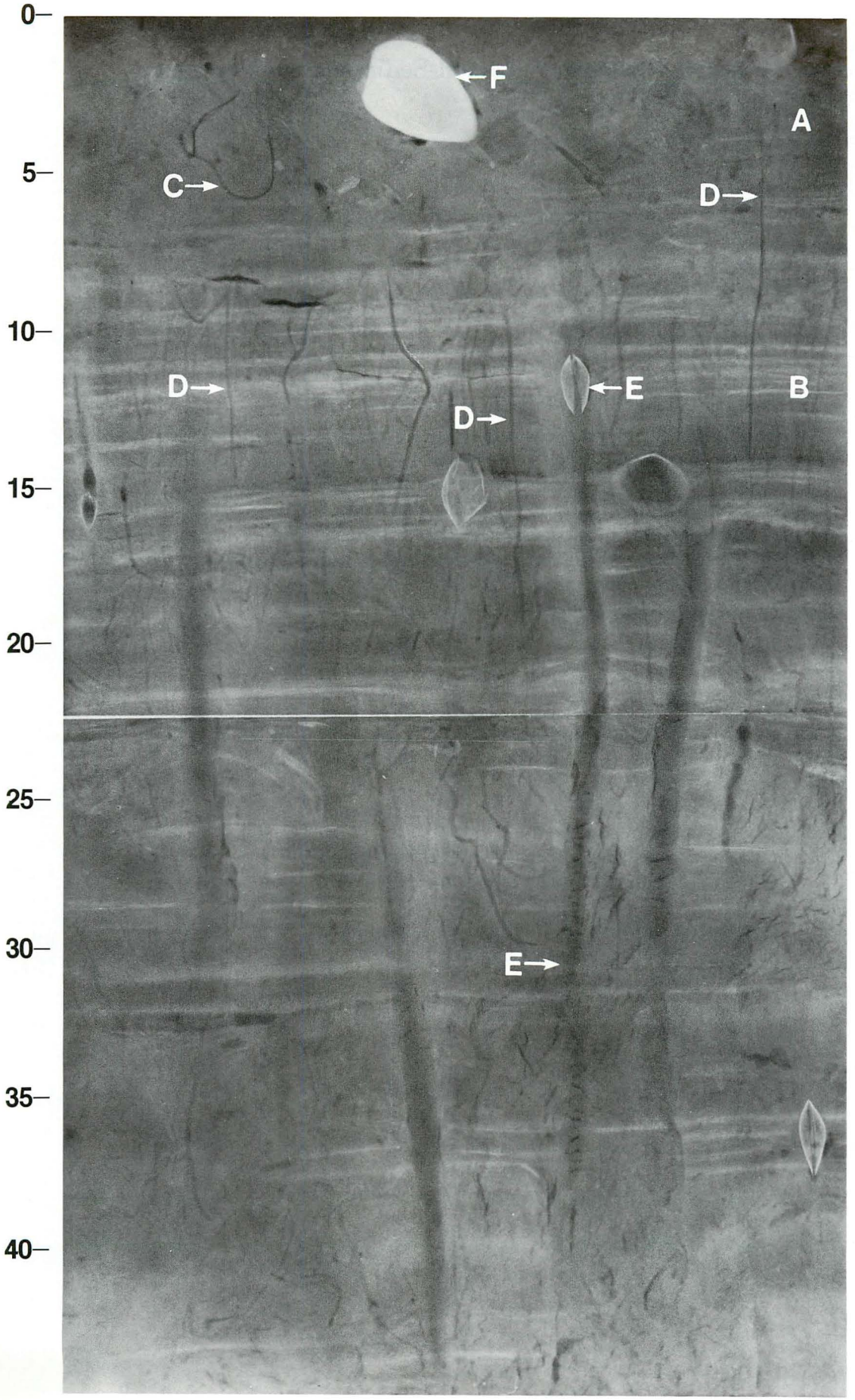

Plate 3. Station 4

Plate 4. Station 7, Mixed-Sediment Environment

Station 7: Belvedere Shoals near the Patapsco River
Latitude: 39° 7′16.3″
Longitude: 76°21′52.8″
Sampling Date: 7/3/79
Water Depth: 5.03 m
Radiographic positive print

Mixed-Sediment Environment:

Anthropogenic activities occasionally create discrete bed formations, as at this station. The interbedded sequence at depth is attributed to dredge and spoil disposal episodes. The most recent disposal (25-30 cm) was due to the dredging of Baltimore Harbor in 1965 by the Army Corps of Engineers (personal communication). Subsequently, the biota were able to repopulate and rework the sediment. Shell concentrations reflect mass mortalities of benthic species and the influence of current transport.

Degree of Bioturbation: 60-90% (top half)
0% (bottom half)

Special Features:

A. Bioturbated sandy mud bed with heterogenous shell concentration
B. Clayey silt bed
C. Fine sand bed
D. Compacted clay bed
E. Coarse-medium sand bed
F. *Rangia cuneata* shells (boxed and disarticulated)
G. *Crassostrea virginica* shell fragment
H. Pebbles
I. *Cyathura polita* burrow with mud accumulation at its base (active)
J. *Macoma balthica* burrows (active)

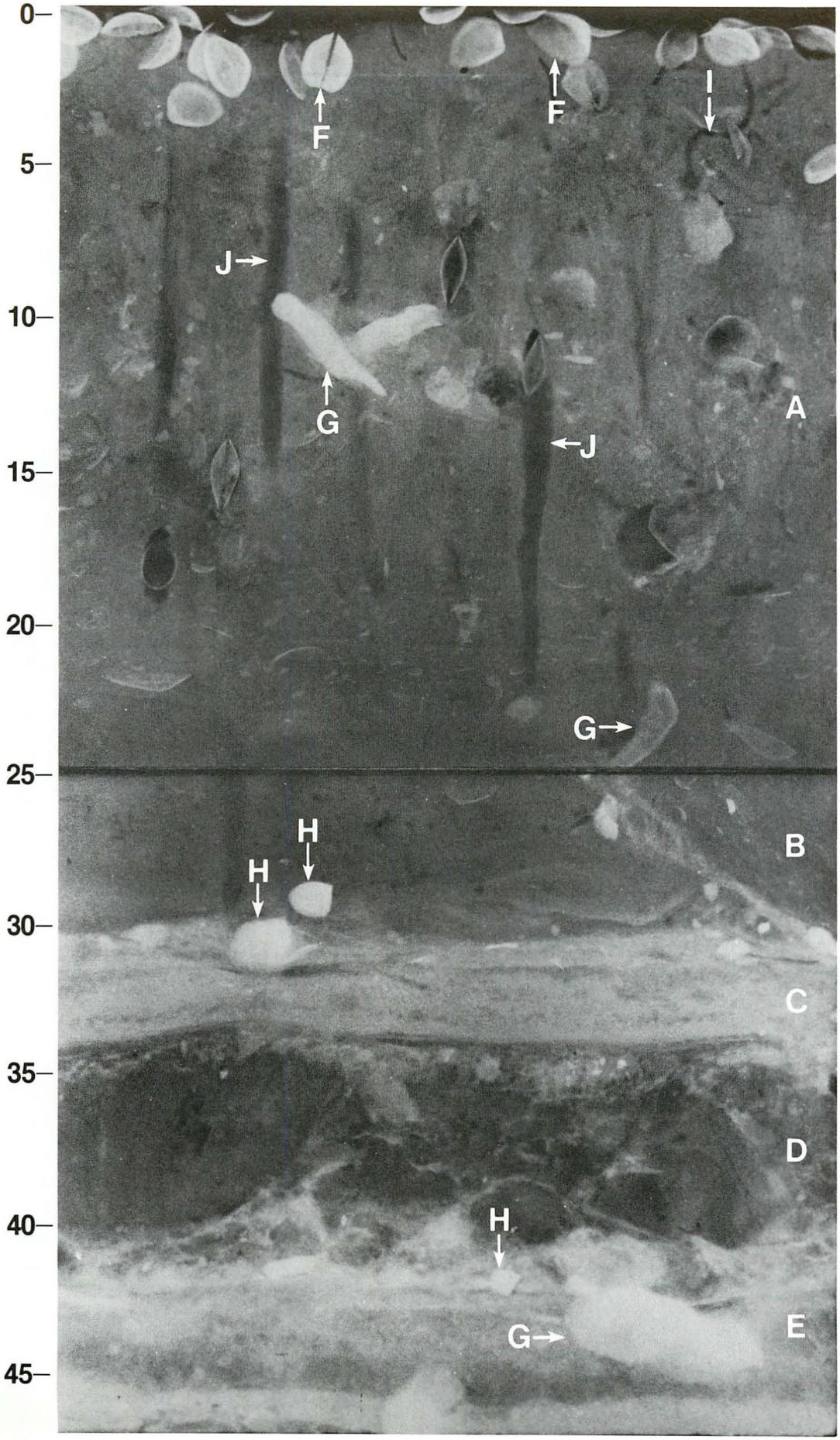

Plate 4. Station 7

Plate 5. Station 55, Mud Environment

Station 55: Channel ridge near Bloody Point area
Latitude: 38°47′50.4″
Longitude: 76°23′38.2″
Sampling Date: 7/3/79
Water Depth: 31.45 m
Radiographic positive print

Mud Environment:

Channel regimes are generally characterized by thick accumulations of mud which may be interbedded with coarser-grained materials. The lower sedimentary sequence depicted in this radiograph is conjectured to represent coastal plain deposits. The pockets are methane bubbles which may be mistaken for burrow structures. Unsuccessful colonization episodes of benthic species, namely that of the bivalve mollusc, *Mulinia lateralis*, are commonly found in these areas.

Degree of Bioturbation: trace

Special Features:

A. Mud bed with silt-clay foreset laminae
B. Homogenous mud bed
C. Fine sand bed
D. Sand lamina
E. Sand lenses
F. Methane bubbles
G. *Mulinia lateralis* shell laminae
H. *Pectinaria gouldii* tube remnants in fine sand bed
I. Unidentified polychaete burrows

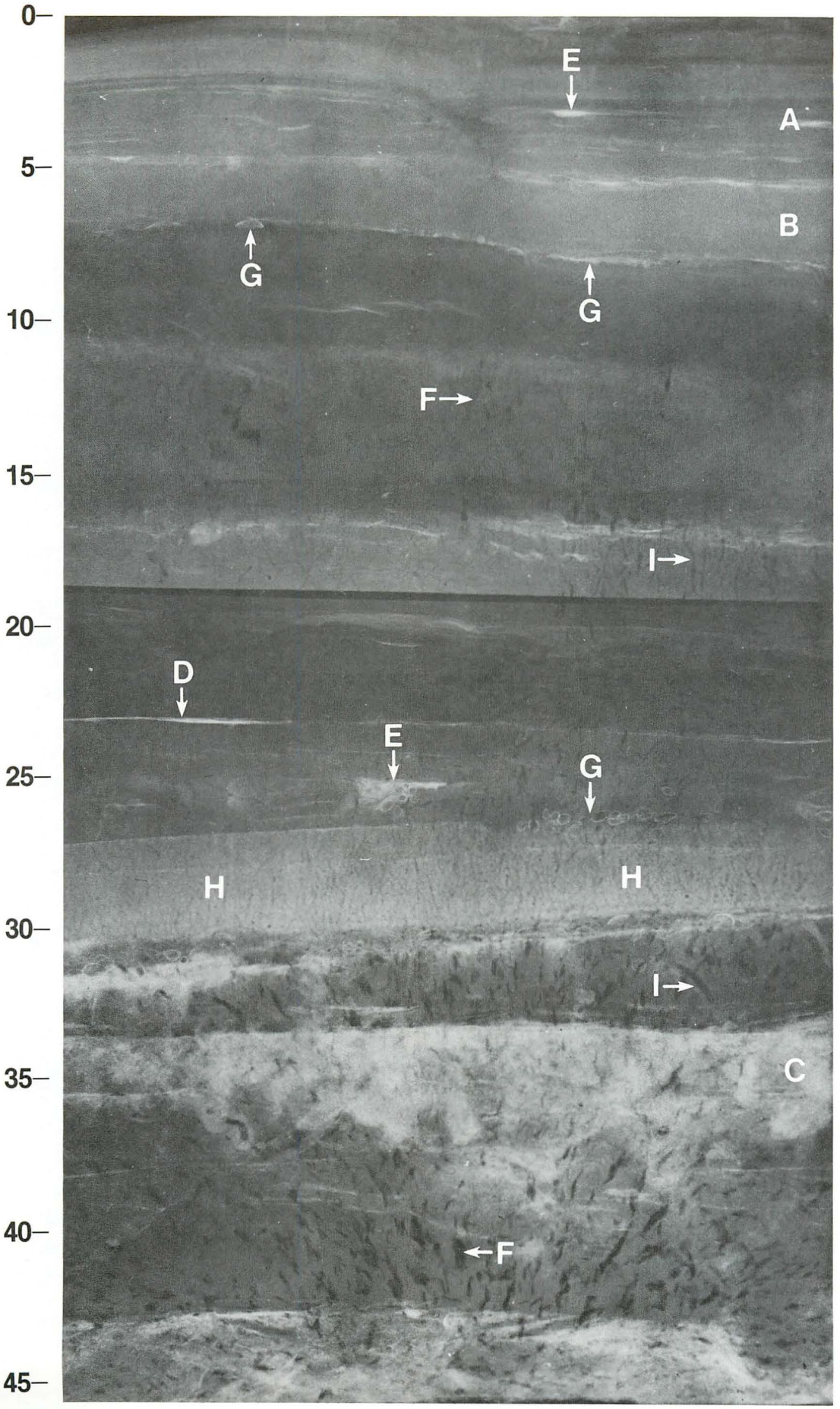

Plate 5. Station 55

Plate 6. Station 12, Fine Sand Environment

Station 12: Eastern shore of Eastern Bay
Latitude: 38°53′ 6.5″
Longitude: 76°13′23.9″
Sampling Date: 10/2/78
Water Depth: 6.10 m
Radiographic positive print

Fine Sand Environment:

Small-scale cross-bedding is a characteristic sedimentary feature of mobile, fine sand environments. Ripple laminations are usually enhanced by heavy minerals. Less frequently, such layers are coated by silts and clays, thus producing mud flasers. The preservation of these sedimentary structures is rare in most other fine sand regimes.

Degree of Bioturbation: $<30\%$

Special Features:

A. Small-scale, trough-shaped ripple laminae outlined by heavy minerals (light grains)
B. Mud flasers
C. *Paraprionspio pinnata* tube traces (active)
D. Assorted shell fragments
E. *Crassostrea virginica* shell fragments
F. Structural cracks in the sediment

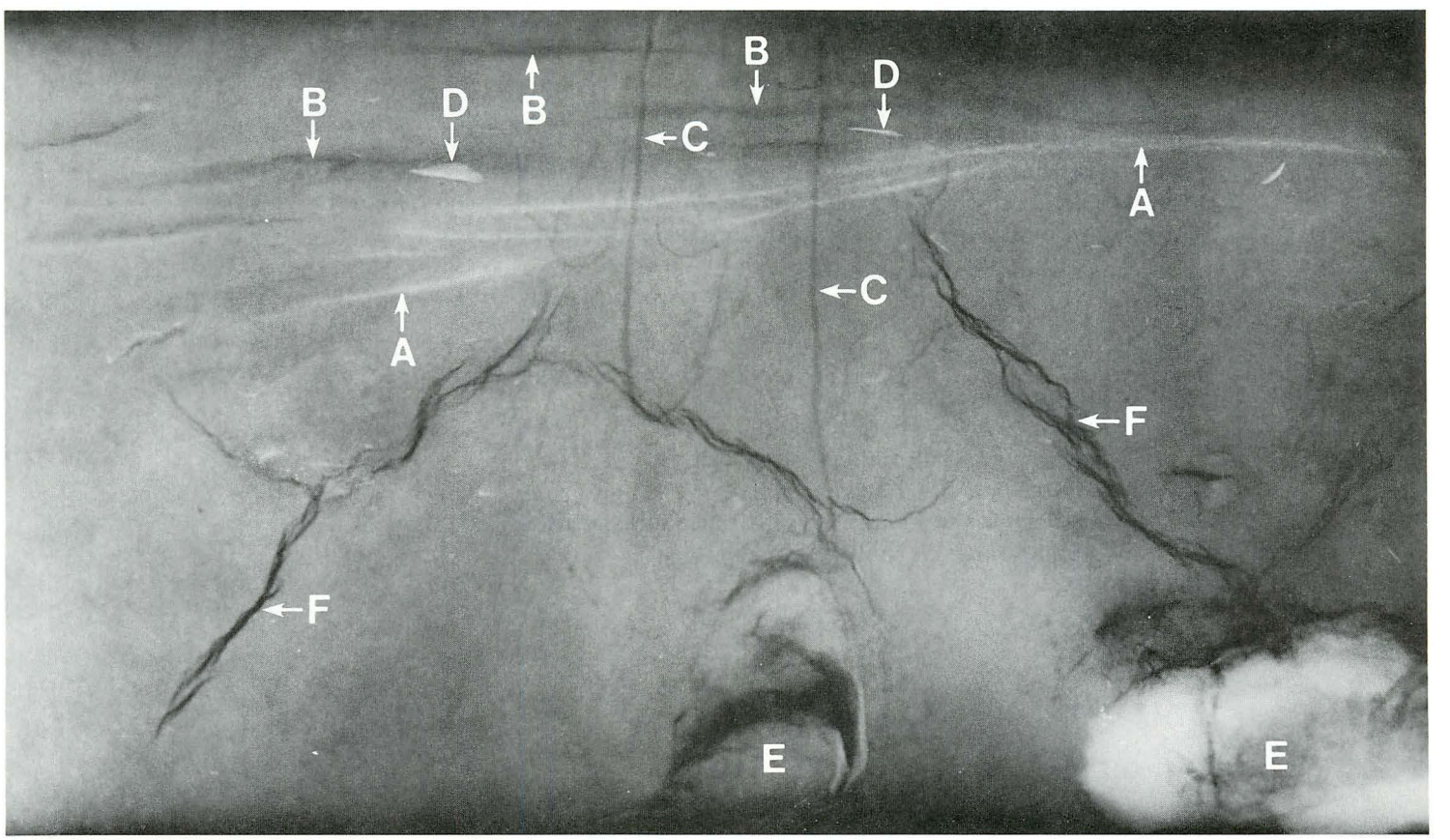

Plate 6. Station 12

Plate 7. Station 13, Mud Environment

Station 13: Western shore just south of Chesapeake Beach
Latitude: 38°39′ 4.9″
Longitude: 76°29′34.4″
Sampling Date: 7/11/79
Water Depth: 9.75 m
Radiographic positive print

Mud Environment:

This bioturbated silty clay station is representative of many shallow-water, mud-fringe environments in the middle regime of the Chesapeake Bay. Intense bioturbation has destroyed any trace of physically-produced sedimentary structures. Shell aggregates, representing death assemblages of the bivalve mollusc, *Mulinia lateralis*, are commonly found here.

Degree of Bioturbation: 90-99%

Special Features:

A. *Mulinia lateralis* shell lamina
B. *Mulinia lateralis* shell pocket
C. *Nereis succinea* burrow system (active)
D. *Macoma balthica* burrow (active)
E. *Macoma balthica* burrow with horizontal attitude (inactive)
F. *Macoma balthica* shell (disarticulated)

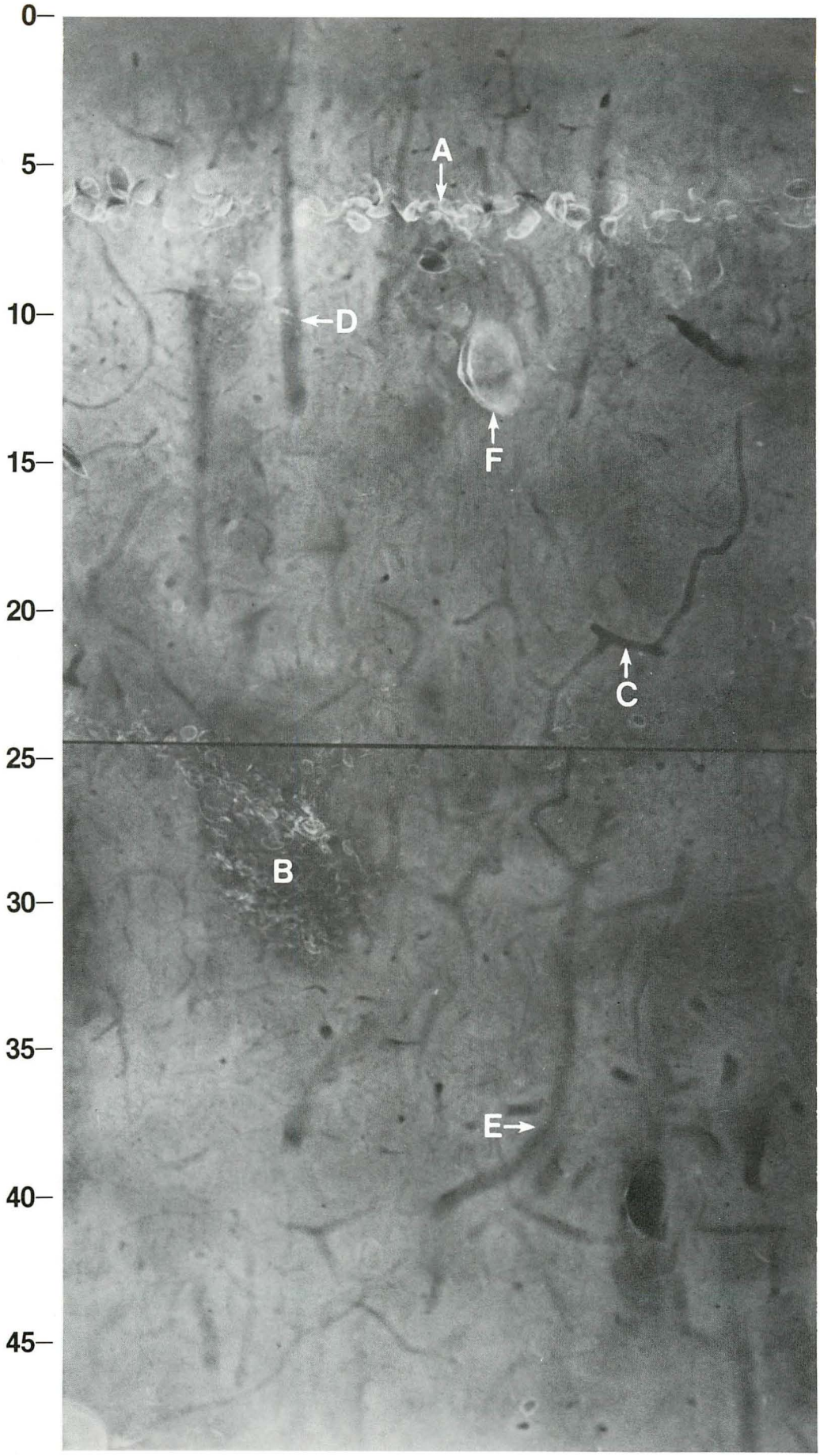

Plate 7. Station 13

Plate 8. Station 15, Mixed-Sediment Environment

Station 15: Mouth of the Choptank River
Latitude: 38°39′21.3″
Longitude: 76°18′47.5″
Sampling Date: 11/8/78
Water Depth: 7.01 m
Radiographic positive print

Mixed-Sediment Environment:

Mixed-sediment environments may display definite gradational changes. The intensely bioturbated zone in the top half of this print appears to indicate a decrease in depositional rates. Only minimal disruption is evident below the biologically mixed bed.

Degree of Bioturbation: 90-99% (top half)
trace (bottom half)

Special Features:

A. Bioturbated sandy mud bed
B. Parallel-laminated mud bed
C. *Crassostrea virginica* shell fragment
D. *Heteromastus filiformis* burrow (active)
E. *Macoma balthica* shells (live)

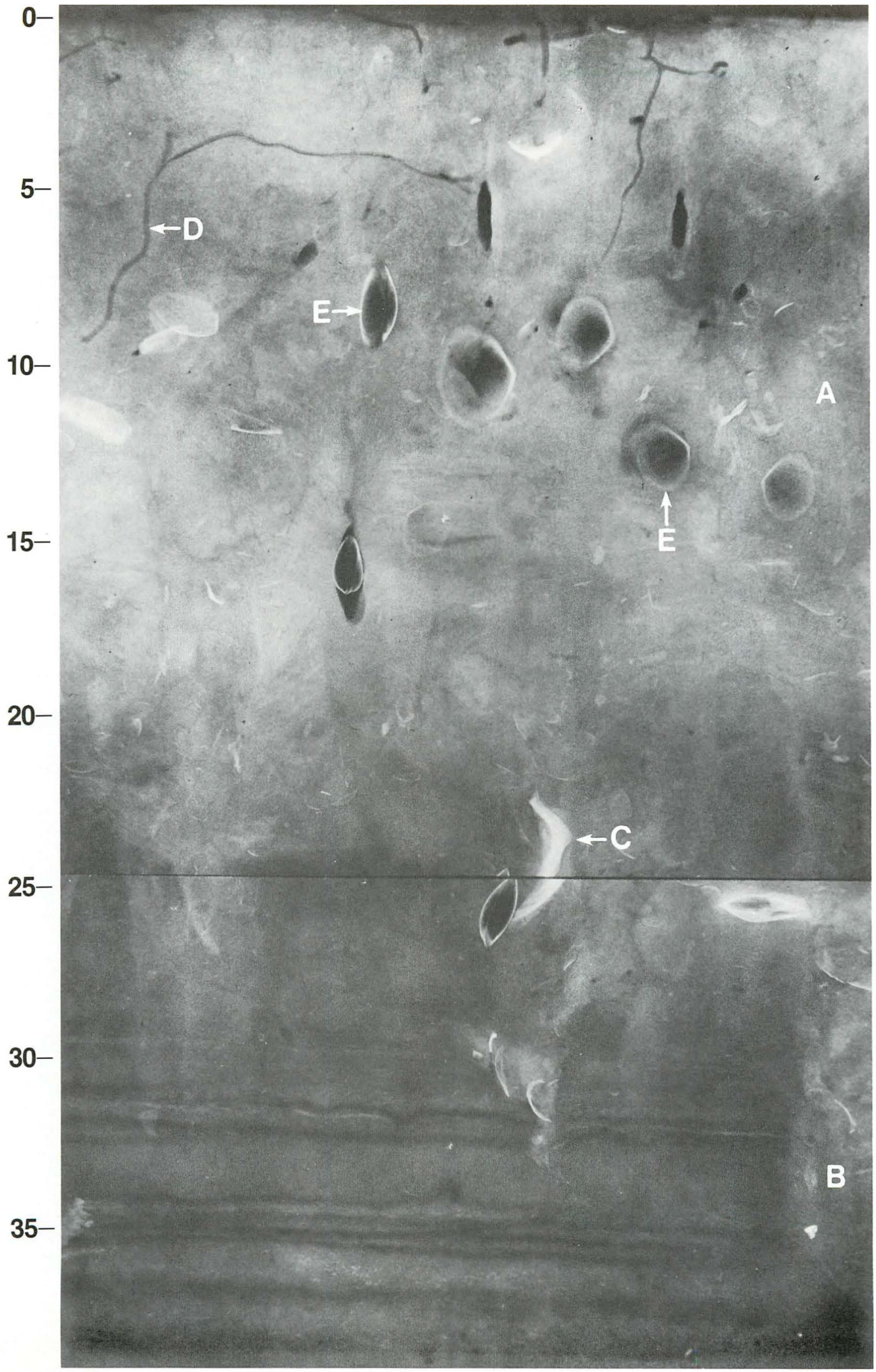

Plate 8. Station 15

Plate 9. Station 62, Mud Environment

Station 62: Channel regime east of Hooper Strait
Latitude: 38°11′15.2″
Longitude: 76°13′41.1″
Sampling Date: 6/28/79
Water Depth: 31.45 m
Radiographic positive print

Mud Environment:

Thick mud sequences are often found in the channel environment. Methane is produced in such great quantities here that laminated sedimentary features may be obscured. *Mulinia lateralis* shell concentrations represent death assemblages.

Degree of Bioturbation: trace

Special Features:

A. Homogenous mud bed
B. Laminated mud bed
C. *Mulinia lateralis* shell laminae
D. Methane bubbles
E. Unidentified polychaete burrow (inactive)

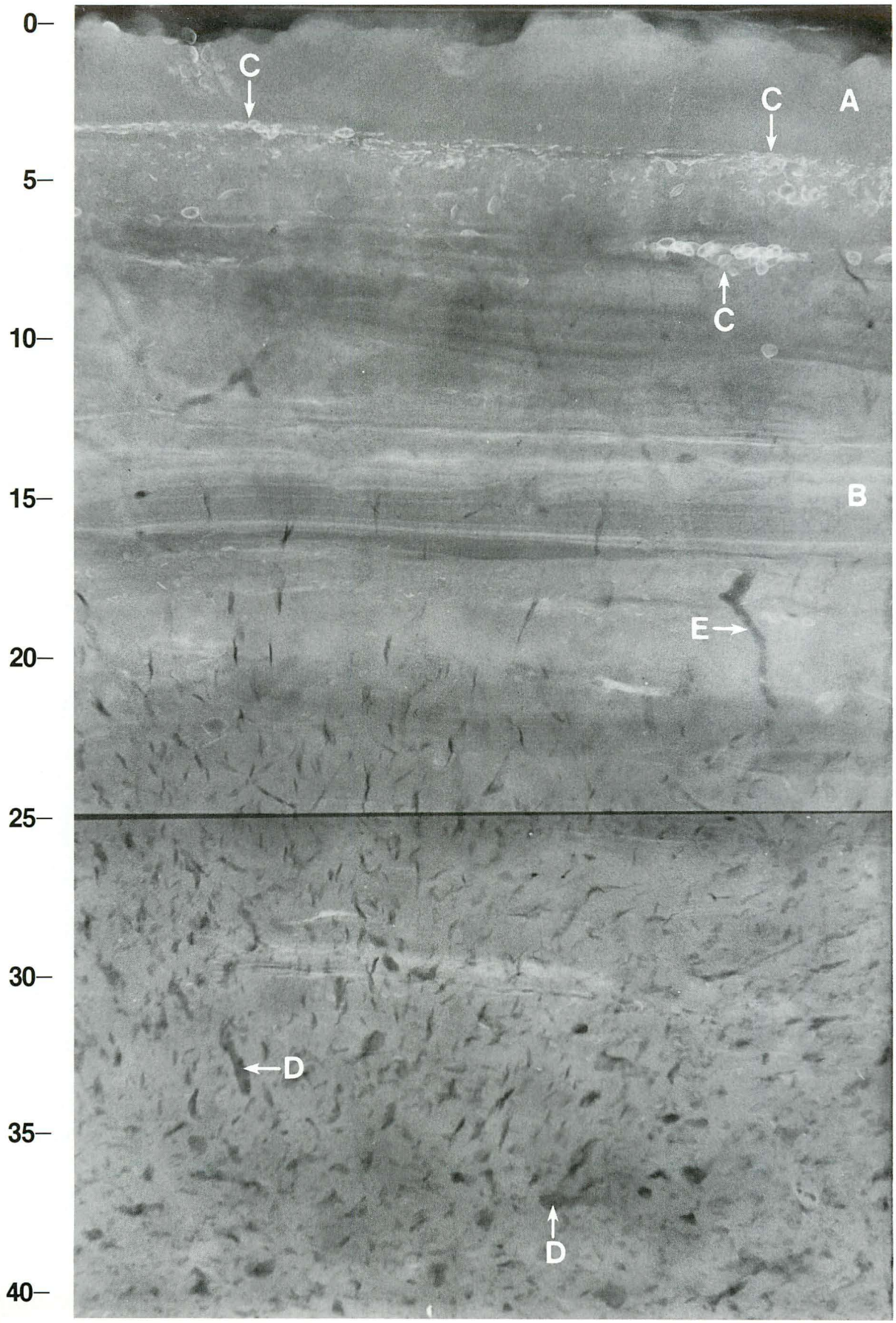

Plate 9. Station 62

Plate 10. Station 21, Mixed-Sediment Environment

Station 21: Tangier Sound midway between Kedges Straits and the Manokin River
Latitude: 38° 4′54.8″
Longitude: 75°58′17.8″
Sampling Date: 6/26/79
Water Depth: 9.75 m
Radiographic positive print

Mixed-Sediment Environment:

Gradational sequences in mixed-sedimentary environments may vary considerably. Increased sedimentation has decreased bioturbation and produced the mud-sand-shell banding and scour-and-fill structure of this core. Faint mud-sand layers are also present in the intensely bioturbated zone. Excavation and back-filling of the large central burrow system of the polychaete, *Glycera dibranchiata*, has resulted in some disruption of bedding.

Degree of Bioturbation: $<30\%$ (top half)
90-99% (bottom half)

Special Features:

A. Faint, interbedded mud-sand and shell (*Mulinia*) cross-banding
B. Bioturbated sandy mud bed
C. Scour-and-fill structure
D. Backfilled *Glycera dibranchiata* burrow system, partially with iron oxide halo (inactive)
E. Unidentified polychaete burrows (probably juvenile *Glycera*)
F. *Mulinia lateralis* shells (boxed)
G. *Ilyanassa vibex* shell (remnant)

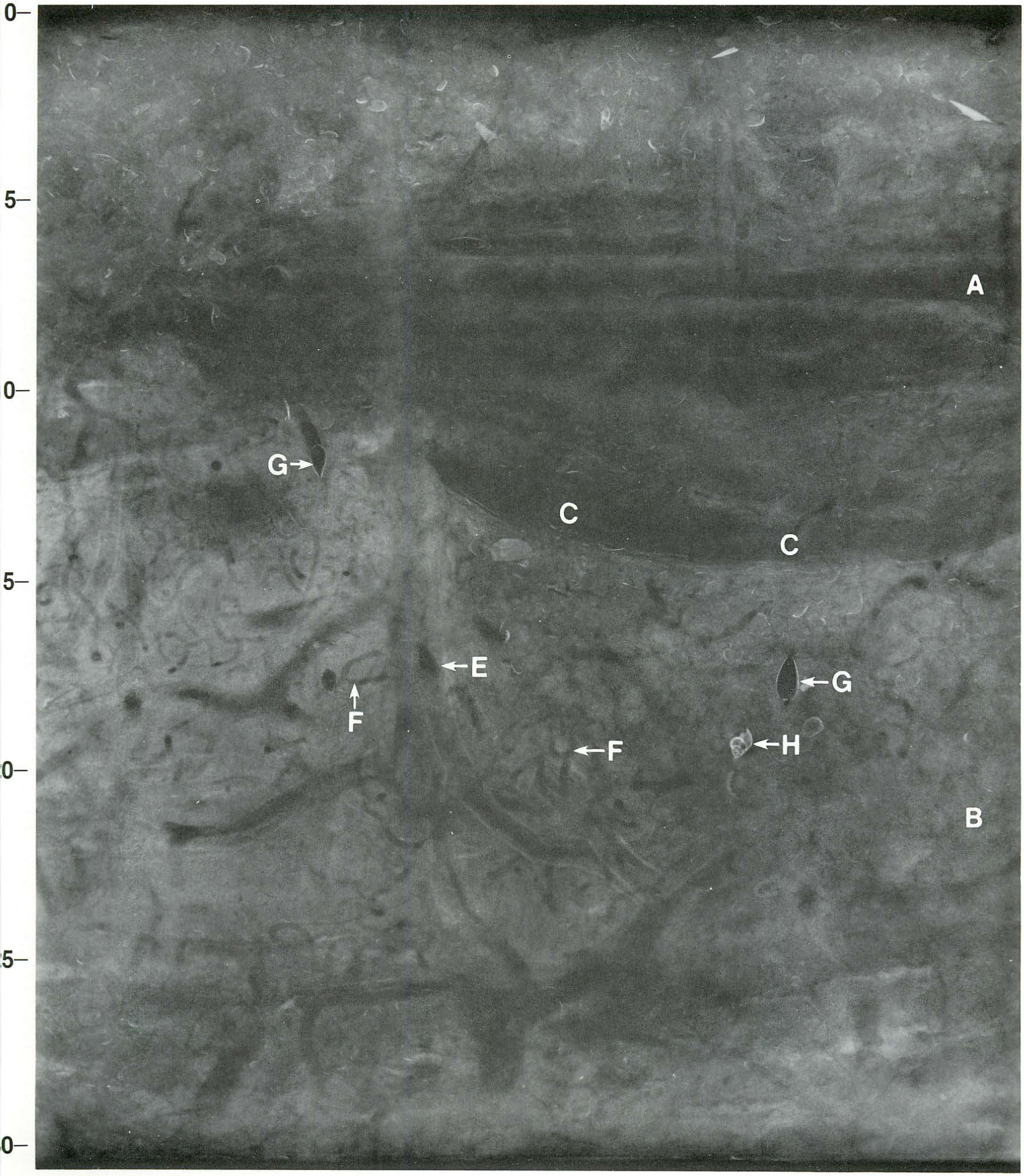

Plate 10. Station 21

Plate 11. Station 25, Fine Sand Environment

Station 25: Eastern Shore near Smith Island
Latitude: 37°59′27.0″
Longitude: 76° 7′34.5″
Sampling Date: 11/3/78
Water Depth: 9.15 m
Radiographic positive print

Fine Sand Environment:

Biotic reworking usually destroys any trace of physically-produced structures in fine sand regimes. Only well-maintained biogenic features remain, as portrayed at this station. Scour marks surround the tubes of the phoronid, *Phoronis* sp., and may be indicative of sediment destabilization at the surface.

Degree of Bioturbation: 90-99%

Special Features:

A. Surface scour marks
B. *Phoronis* sp. tubes (active)
C. *Glycera dibranchiata* burrow (active)
D. Unidentified polychaete burrows (active)

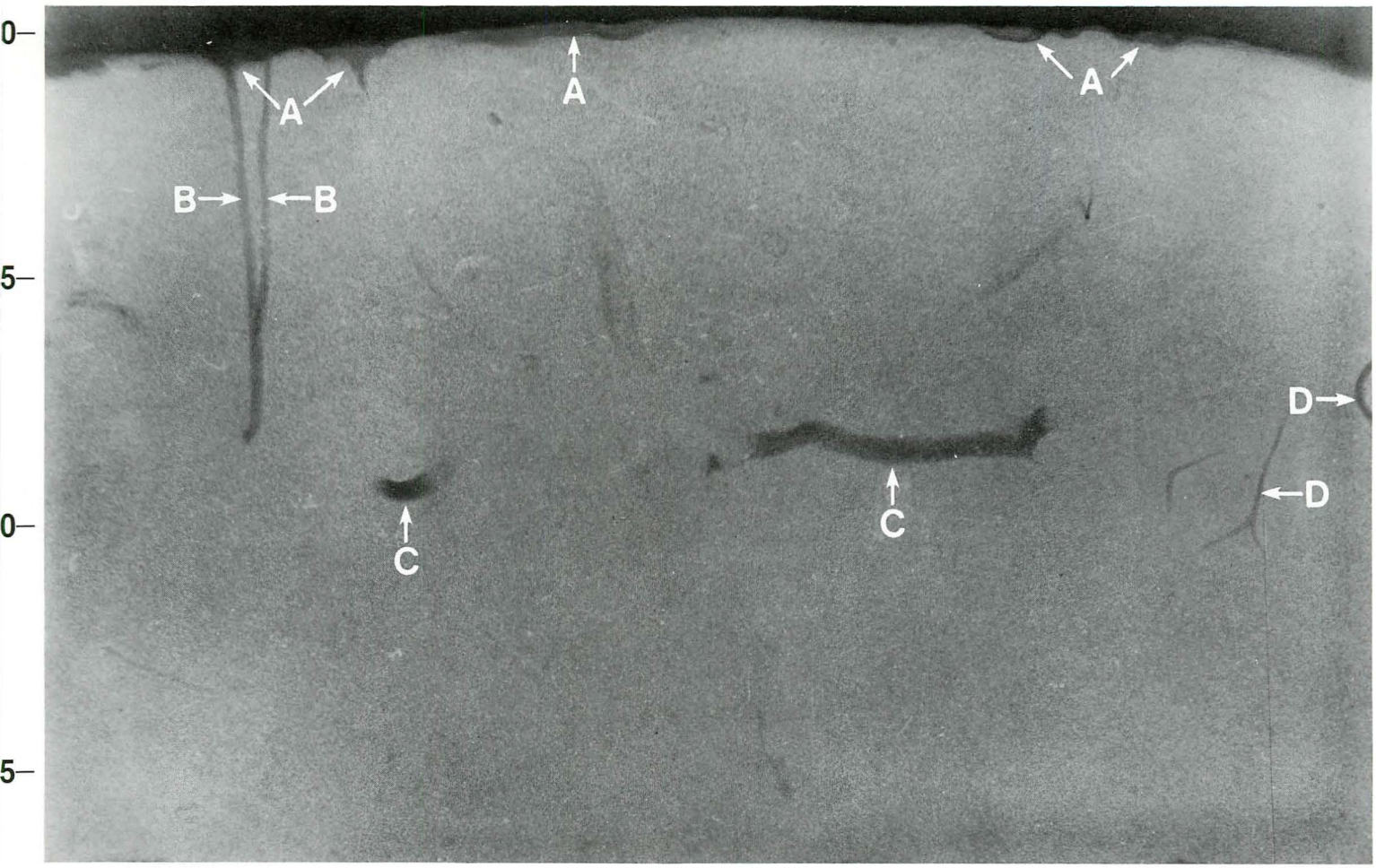

Plate 11. Station 25.

Plate 12. Station 65, Medium-Coarse Sand Environment

Station 65: Tangier Sound near Crisfield, Maryland
Latitude: 37°58′18.2″
Longitude: 75°55′35.9″
Sampling Date: 6/29/79
Water Depth: 27.36 m
Radiographic positive print

Medium-Coarse Sand Environment:

This station is representative of reworked subaqueous Pleistocene outcrops. High densities of the tube-building polychaete, *Pectinaria gouldii*, are primarily responsible for processing the top 5 cm of the substratum. General bioturbation activities by other organisms have resulted in further mixing of the sediment fabric.

Degree of Bioturbation: 90-99%

Special Features:

A. Mud pockets
B. *Pectinaria gouldii* tube (active)
C. *Pectinaria gouldii* tube with feeding trace (active)
D. *Mercenaria campechiensis* shell (live)
E. *Ampelisca abdita* tube (active)
F. *Mulinia lateralis* shell (live)
G. *Loimia medusa* tube (active)
H. *Ilyanassa vibex* shell (remnant)
I. *Macoma balthica* shell (disarticulated)
J. *Crassostrea virginica* shell fragment

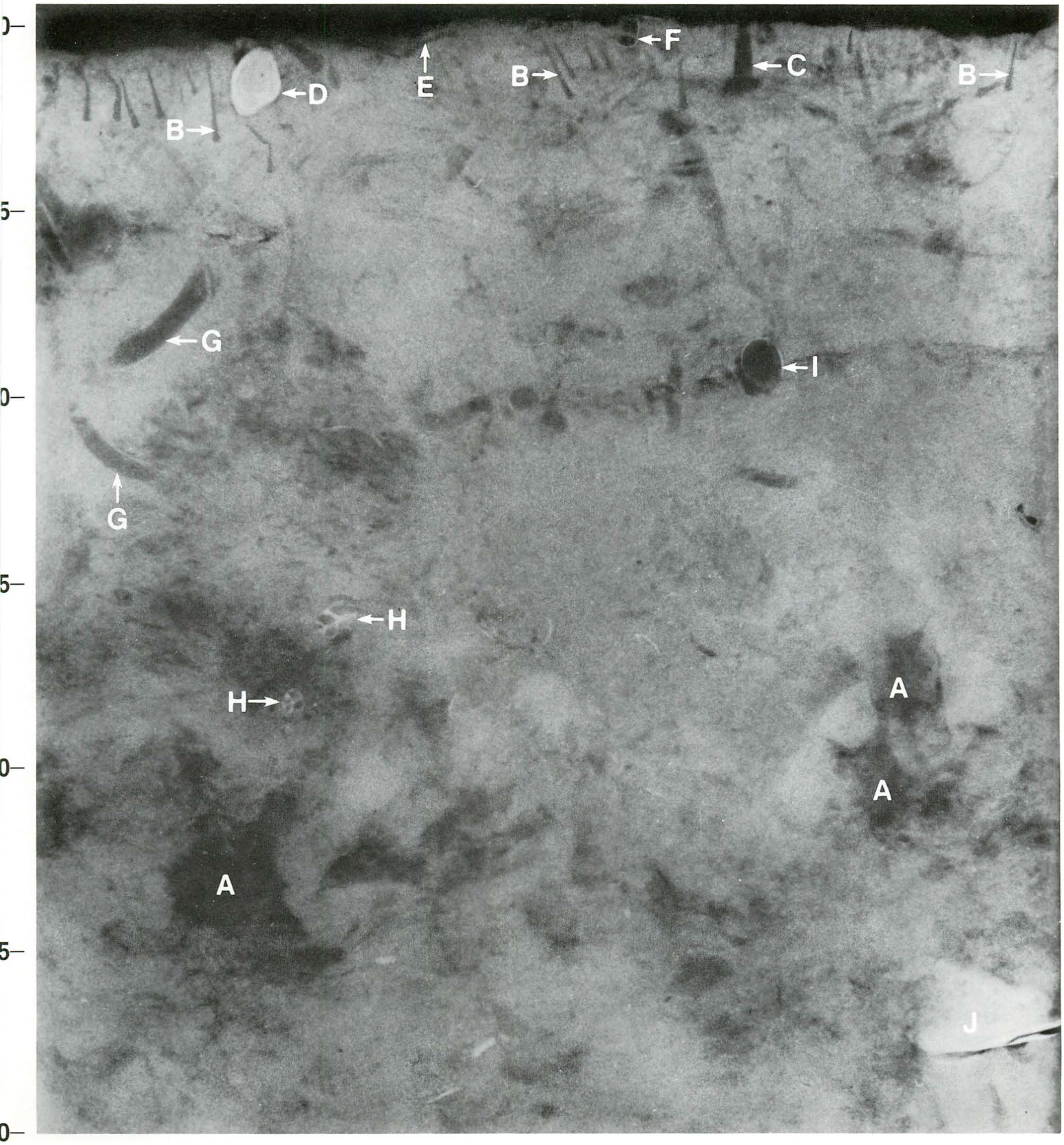

Plate 12. Station 65.

Plate 13. Station 27, Fine Sand Environment

Station 27: Pocomoke Sound
Latitude: 37°49′54.1″
Longitude: 75°50′ 7.4″
Sampling Date: 9/20/78
Water Depth: 4.88 m
Radiographic negative print

Fine Sand Environment:

General bioturbation activities in this core have disrupted the ripple laminae and will eventually result in complete homogenization of the sediment. The underlying hard clay substratum is generally found along many nearshore, fine-sand margins of the Chesapeake Bay.

Degree of Bioturbation: 60-90% (above 15 cm)
0% (below 15 cm)

Special Features:

A. Bioturbated fine-sand bed with homogeneously scattered heavy minerals (dark grains)
B. Mud layer
C. Consolidated clay bed
D. Heavy mineral ripple laminae
E. Unidentified polychaete burrows (active)
F. *Ilyanassa vibex* shell (remnant)

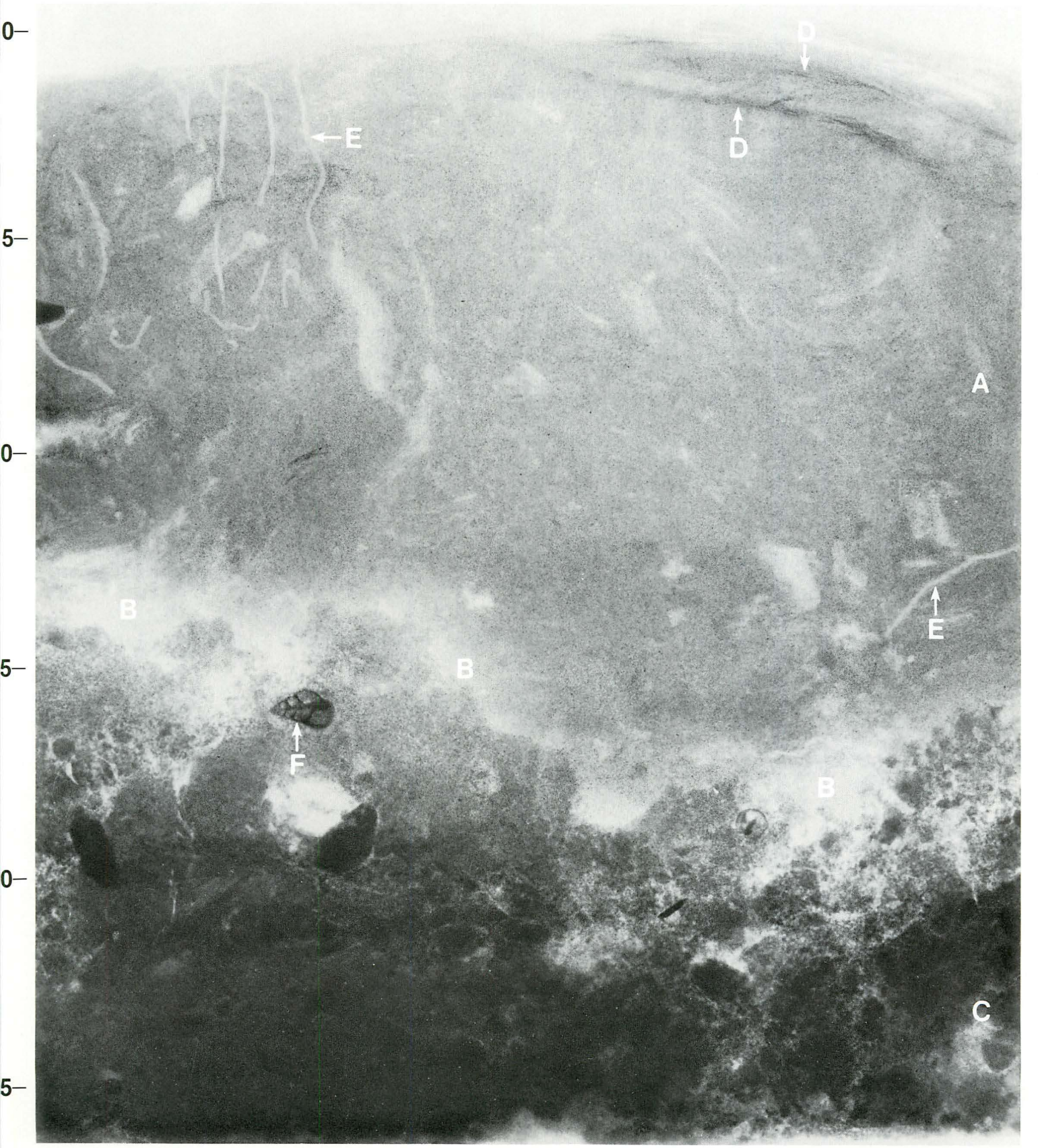

Plate 13. Station 27.

Plate 14. Station 80, Mixed-Sediment Environment

Station 80: Southeast of Tangier Island
Latitude: 37°46′52.6″
Longitude: 75°58′ 5.2″
Sampling Date: 6/23/79
Water Depth: 17.68 m
Radiographic negative print

Mixed-Sediment Environment:

Interbedded mud (dark on print) and sand (light on print) sequences are characteristic sedimentary features of the mixed-sediment environment. Numerous intercalations are usually the result of continuous fluctuations in transport energies. Physically laminated beds alternate with biologically mixed zones at this station. The most recent mud layer is due to the entrapment of fine-grained sediments by dense populations of the tube-building crustacean, *Ampelisca abdita*. Substrate stabilization has consequently allowed other species (e.g.—*Loimia medusa*) to establish themselves at depth. Disruption and destruction of layered sediments appears to be linked with such biotic activities.

Degree of Bioturbation: 30-60%

Special Features:

A. Bioturbated muddy sand zone
B. Interbedded mud and sand bed
C. Biologically reworked muddy sand layer containing remnant *Mulinia lateralis* shells
D. *Pectinaria gouldii* tubes (active)
E. *Pectinaria gouldii* tube with feeding trace (active)
F. *Loimia medusa* tubes (active)

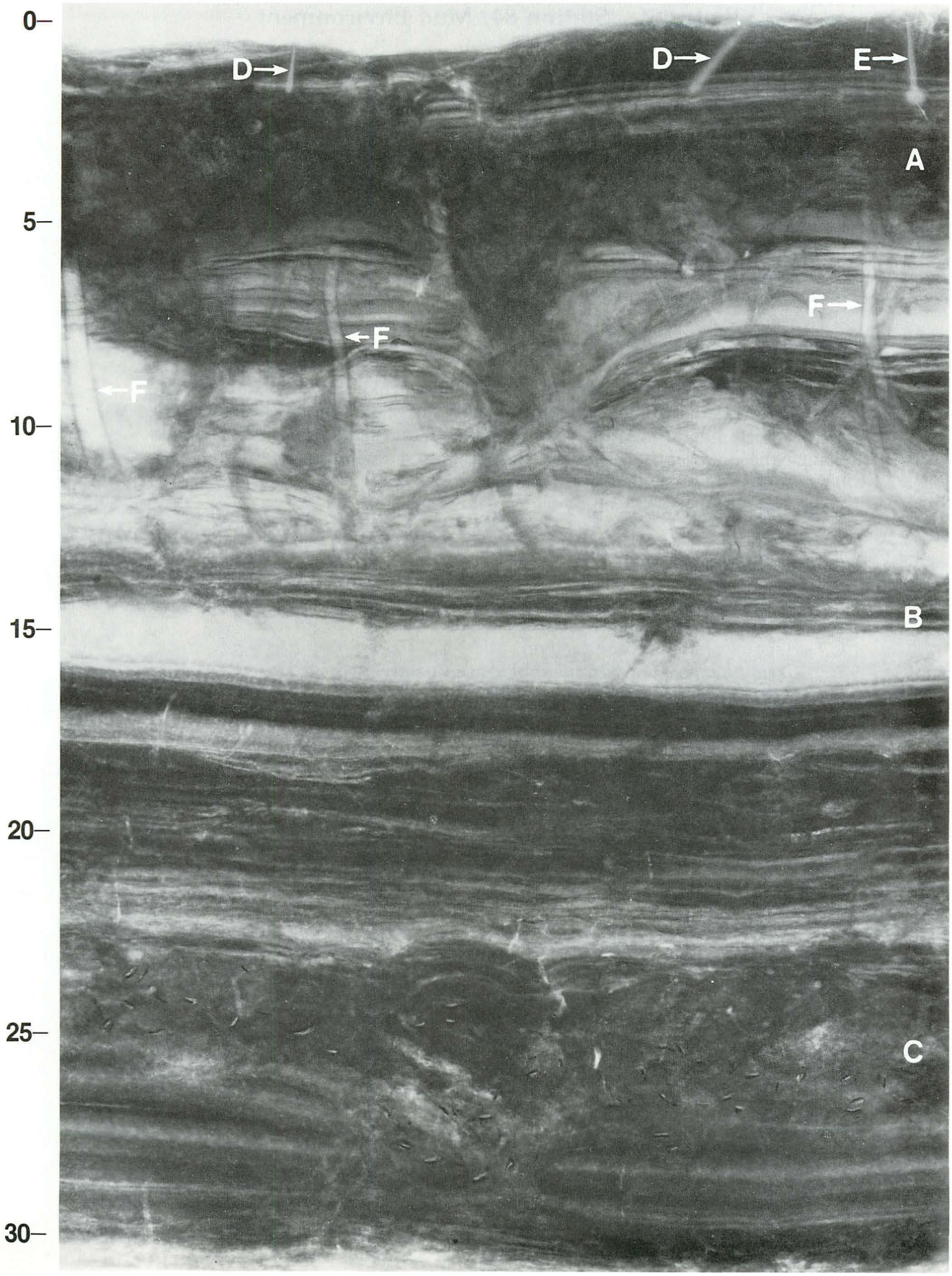

Plate 14. Station 80.

Plate 15. Station 84, Mud Environment

Station 84: Middle of the Chesapeake Bay just north of the Rappahannock River
Latitude: 37°40′20.2″
Longitude: 76° 7′55.8″
Sampling Date: 6/22/79
Water Depth: 12.80 m
Radiographic negative print

Mud Environment:

Fringing mud environments in the lower Chesapeake Bay tend to be extensively bioturbated. Biogenic activity in this silty clay core has destroyed all physical sedimentary features and produced a mottled texture. The massive disturbance at depth is due to the cerianthid anemone, *Ceriantheopsis americanus*, whose tube trace is backfilled.

Degree of Bioturbation: 90-99%

Special Features:

A. *Paraprionspio pinnata* tube traces (active)
B. *Mulinia lateralis* shells (live)
C. *Asychis elongata* tube (active)
D. *Ceriantheopsis americanus* tube trace (inactive)
E. *Macoma balthica* shell (disarticulated)

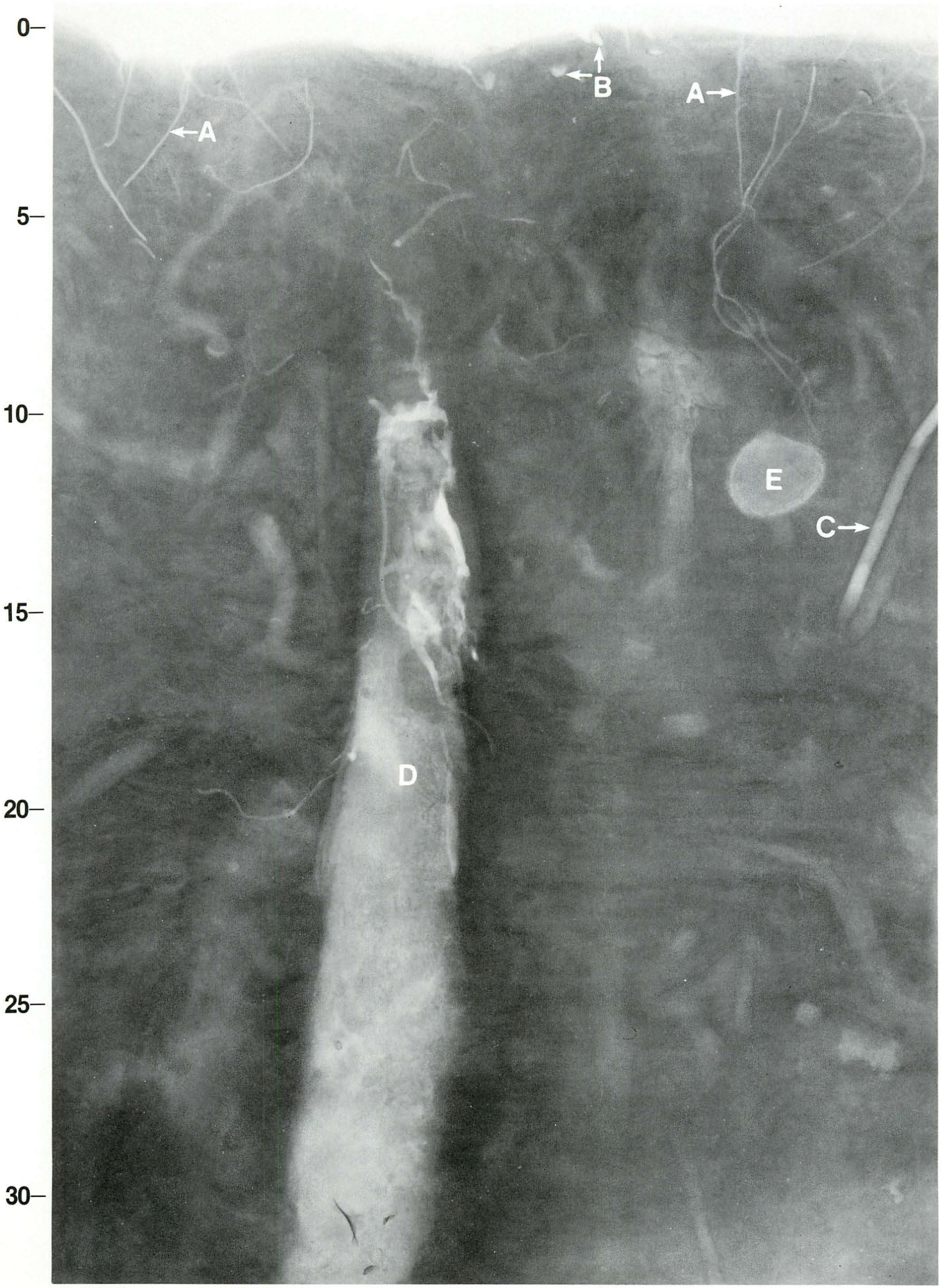

Plate 15. Station 84.

Plate 16. Station 42, Mixed-Sediment Environment

Station 42: Eastern Shore opposite the mouth of the York River
Latitude: 37°12′48.2″
Longitude: 76° 4′ 6.4″
Sampling Date: 9/15/78
Water Depth: 11.59 m
Radiographic negative print

Mixed-Sediment Environment:

Biogenic reworking in mixed sediments generally results in sediment disruption and mottling. The tube-building polychaete, *Clymenella torquata*, is thought to be primarily responsible for modifying the muddy sand fabric depicted in this print. High densities of this individual are able to stabilize the sediment.

Degree of Bioturbation: 90-99%

Special Features:

A. Disrupted mud layer
B. *Mulinia lateralis* shell layer
C. *Clymenella torquata* tubes (active)
D. *Clymenella torquata* tube (inactive)

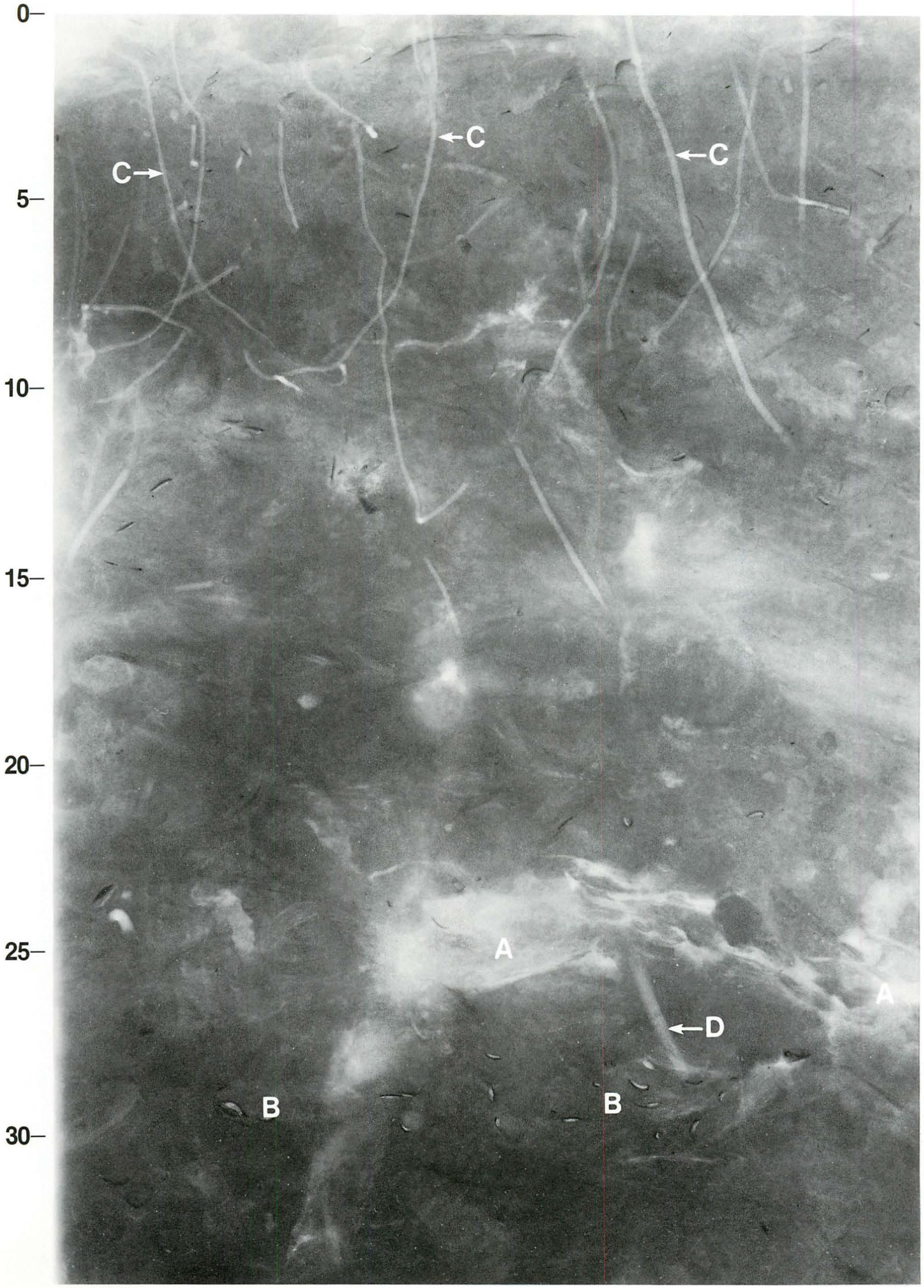

Plate 16. Station 42.

Plate 17. Station 96, Medium-Coarse Sand Environment

Station 96: North of Chesapeake Bay Bridge Tunnel
Latitude: 37°10′49.4″
Longitude: 76° 7′ 9.3″
Sampling Date: 6/14/79
Water Depth: 8.23 m
Radiographic negative print

Medium-Coarse Sand Environment:

The bioturbated nature of most ocean-derived sand environments within the mouth of the Chesapeake Bay is demonstrated by this print. A number of biogenic structures are evident, including a surface layer of *Pectinaria gouldii* polychaete tubes.

Degree of Bioturbation: 90-99%

Special Features:

A. Surface excavation of unknown origin
B. *Pectinaria gouldii* tubes (active)
C. Juvenile *Ensis directus* burrow (active)
D. *Paraprionspio pinnata* tube trace (active)
E. *Diopatra cuprea* tube (active)
F. *Ensis directus* shell (live)
G. Unidentified traces

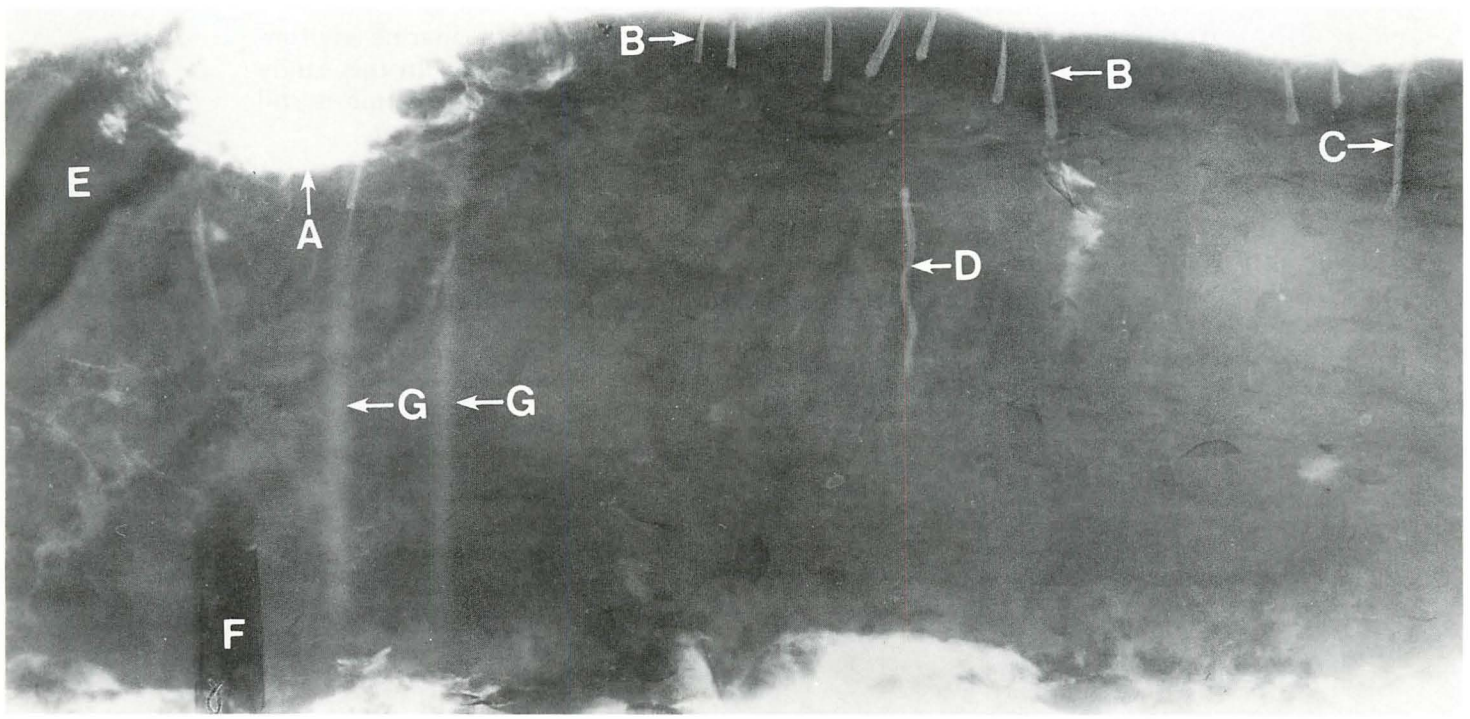

Plate 17. Station 96.

Plate 18. Station 100, Medium-Coarse Sand Environment

Station 100: Perimeter of the Chesapeake Bay mouth just off Cape Charles
Latitude: 36°55′45.5″
Longitude: 75°54′53.4″
Sampling Date: 6/13/79
Water Depth: 18.90 m
Radiographic negative print

Medium-Coarse Sand Environment:

At the entrance to the Chesapeake Bay, the influence of the marine environment is evident in the presence of large-scale cross-bedding. In this sandy core, as well as in others in the lower Bay, however, bioturbation is still predominant.

Degree of Bioturbation: 60-90%

Special Features:

A. Planar-shaped, cross-bed composed of heavy minerals (dark grains)
B. Bioturbated sand bed
C. Undescribed capitellid burrows (active)
D. *Onuphis eremita* tube (active)

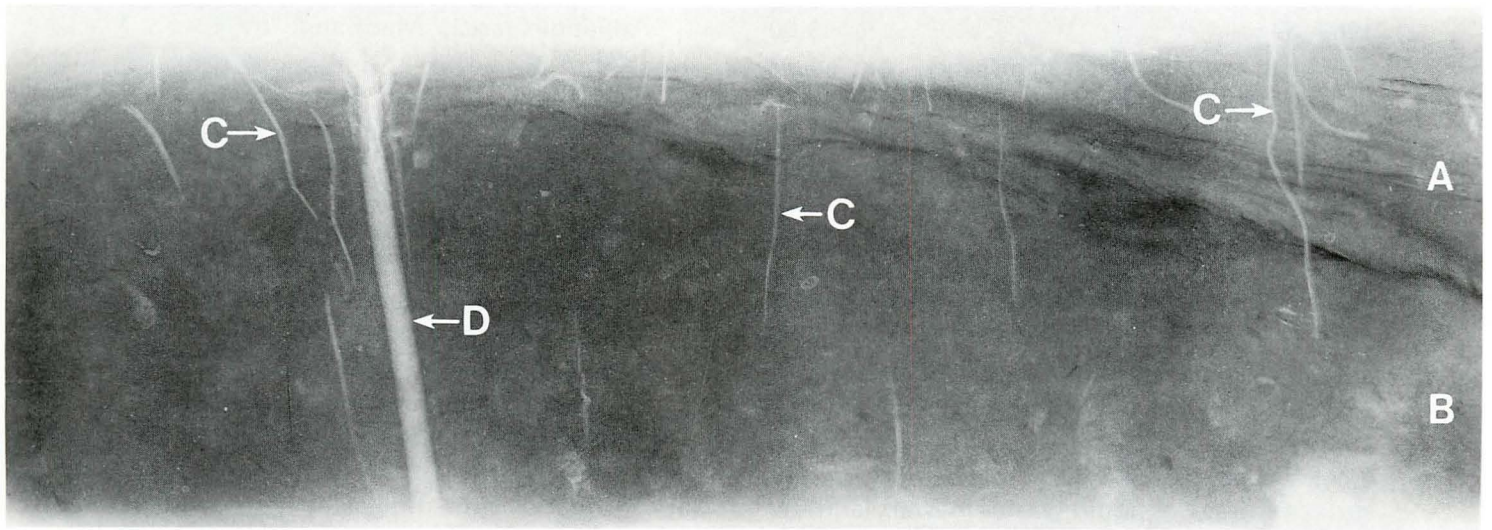

Plate 18. Station 100.

MARYLAND GEOLOGICAL SURVEY

Merryman Hall
The Johns Hopkins University
Baltimore, Maryland 21218

Selected Reports of Investigations:

1. Chemical quality of water and trace elements in the Patuxent River Basin, by S. G. Heidel and W. W. Frenier, 1965, 40 p. $3.50*
3. Water resources of the Salisbury area, Maryland, by D. H. Boggess and S. G. Heidel, 1968, 69 p. 3.00
5. Chemical quality reconnaissance of water of Maryland streams, by J. D. Thomas, 1966, 61 p. 2.00
9. Chemical and physical character of municipal water supplies in Maryland, by J. D. Thomas and S. G. Heidel, 1969, 52 p. 1.00
10. Ground-water occurrence in the Maryland Piedmont, by L. J. Nutter and E. G. Otton, 1969, 56 p. 2.50
13. Extent of brackish water in the tidal rivers of Maryland, by W. E. Webb and S. G. Heidel, 1970, 46 p. 1.50
14. Geologic and hydrologic factors bearing on subsurface storage of liquid wastes in Maryland, by E. G. Otton, 1970, 39 p. 2.75
16. Flow characteristics of Maryland streams, by P. N. Walker, 1971, 160 p. 2.50
17. Water resources of Dorchester and Talbot Counties, Maryland with special emphasis on the ground-water potential of the Cambridge and Easton areas, by F. K. Mack, W. E. Webb, and R. A. Gardner, 1971, 107 p. 5.25
18. Solid-waste disposal in the geohydrologic environment of Maryland, by E. G. Otton, 1972, 59 p. 3.00
19. Hydrogeology of the carbonate rocks, Frederick and Hagerstown Valleys, Maryland by L. J. Nutter, 1973, 70 p. 3.50
20. Hydrogeology of the formation and neutralization of acid waters draining from underground mines of western Maryland, by E. F. Hollyday and S. W. McKenzie, 1973, 50 p. 2.25
22. An evaluation of the Magothy Aquifer in the Annapolis area, Maryland, by F. K. Mack, 1974, 75 p. 3.00
24. Availability of fresh ground water in northeastern Worcester County, Maryland: With special emphasis on the Ocean City area, by J. M. Weigle, 1974, 64 p. 4.00
26. Hydrogeology of the Triassic rocks of Maryland, by L. J. Nutter, 1975, 37 p. 2.50
28. Digital simulation and prediction of water levels in the Magothy Aquifer in Southern Maryland, by F. K. Mack and R. J. Mandle, 1977, 42 p. 3.00
31. Simulated changes in water level in the Piney Point Aquifer in Maryland, by J. F. Williams III, 1979, 50 p. 6.25
33. A quasi three-dimensional finite-difference ground-water flow model with a field application, by G. Achmad and J. M. Weigle, 1979, 22 p. with appendix 6.50
34. The availability of ground water in western Montgomery County, Maryland, by E. G. Otton, 1981, 76 p. 5.75
35. Characteristics of stream flow in Maryland, by D. H. Carpenter. in press . . . . . .
36. A radiographic examination of physical and biogenic sedimentary structures in the Chesapeake Bay, by E. Reinharz, et al., 1982, 64 p. 8.25

*microfiche

A Radiographic Examination of
Physical and Biogenic Sedimentary Structures
in the Chesapeake Bay

R.I. No. 36 1982