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Comparison of Sediment Landscapes in Chesapeake Bay as Seen by Surface and Profile Imaging

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INTRODUCTION

The sediment-water interface is the boundary layer between the water column and sediments. It is involved in virtually all processes and cycles within aquatic and estuarine ecosystems. Interactions and reactions at the sediment-water interface are of particular importance in regulating processes involving nutrient regeneration-remineralization (Boynton and Kemp 1985), fate of toxicants (Olsen, Cutshall and Larsen 1982), development of hypoxia-anoxia (Garber 1987), sediment mixing (Schaffner et al. 1987a, b), and sediment transport (Wright et al. 1987). Much effort has and is being expended to provide details of these processes which will eventually be used in management plans for water quality, sediment quality, and fisheries resources.

Generally, field methods for investigating sediment-water interface processes or fluxes are time and labor intensive. Complementary methods are needed to support detailed studies and allow for better comprehension of these dynamic processes. Rhoads and Cande (1971) proposed the use of sediment profile cameras as a means of quickly collecting data on the character of the sediment-water interface. Rhoads and Germano (1986) outlined a scheme using sediment profile cameras to assess the character of the sediment-water interface relative to benthic community succession. Day, Schaffner, and Diaz (in press), in addition to using a sediment profile camera, also advocated the use of bottom surface cameras in conjunction with the profile camera to provide a more complete evaluation of the sediment-water interface.

Sediment profile and bottom surface cameras provide a unique *in situ* view of the sediment-water interface yielding both qualitative and quantitative data on its biological, chemical, and physical character. This *in situ* photographic approach and subsequent image analysis can quickly and cost effectively cover large areas of bottom defining biological, sediment fabric, and energy gradients or other spatial patterns. Natural or anthroprogenic events (i.e. storms, high flows, dredged material disposal) through time can also be easily followed and recovery rates measured.

In this paper we will demonstrate the utility of using a surface and profile imaging camera system to provide a broad characterization of the sediment-water interface from selected tributaries and mainstem of the Chesapeake Bay. Emphasis will be placed on defining the redox potential discontinuity and its depth in the sediment relative to biological and geochemical factors.

METHODS AND MATERIALS

A modified Benthos model 3731 sediment profile camera and Benthos model 371 standard camera and 372 standard flash were combined into a photographic system for evaluating sediment quality and benthic habitat complexity. The sediment profile camera provides images of the sediment column 15 cm wide and up to 20 cm deep. The profile camera does not provide comprehensive resolution of surface features, particularly if the prism penetration exceeds the optical axis of the camera lens. The standard camera is used to provide information on the surface by photographing an area approximately 20 x 30 cm in front of the profile camera. In combination this Surface and Profile Imaging (SPI) camera system provides a high resolution quick look into the character of the sediment water interface. The configuration of cameras in the SPI system can be seen in Figure 1.

Data from 359 SPI images collected in the Patuxent River, York River, and Lower Chesapeake Bay (Fig. 2) between April 1986 and February 1988 were used in this evaluation of sediment landscapes. Each image was analyzed using an International Imaging Systems I25 image processor interfaced to a Prime 9955 computer. Of the 14 major parameters measured from each image (Table 1) surface relief, depth of apparent RPD, void area, and sediment grain size were selected for evaluation.

Surface relief is maximum point of prism penetration minus the minimum point across the 15 cm width of the prism face plate. Apparent RPD depth is the area of the image visually discerned as being aerobic divided by the width of the analyzed image. We use the term apparent in describing this parameter because no actual measure is made of the redox potential. An assumption is made that, given the complexities of iron and sulfate reduction-oxidation chemistry, the reddish-brown color tones in sediments are indications of sediments that if not aerobic are not intensely reducing. This is in accordance with the classical concept of RPD depth which associates it with sediment color (Fenchel 1969). The area of an image occupied by voids and the type of voids are good indications of subsurface biological and physical processes. Void area is expressed as a percent of the total analyzed image area. All images are then standardized to a constant 15 cm prism penetration to avoid over or under weighting images that were less than or greater than 15 cm. Sediment grain size was estimated by comparing each image to sediments of known grain size. Sediment types followed the Wentworth classification as described in Folk (1974) and represent modal class for each image.

The entire data set was stratified *a posteriori* by sediment type (as described above), salinity at each location (from Stroup and Lynn 1963), and depth (recorded at time of collection) (Table 2). Broadscale patterns and trends were then evaluated using SPSSX (SPSS 1986).

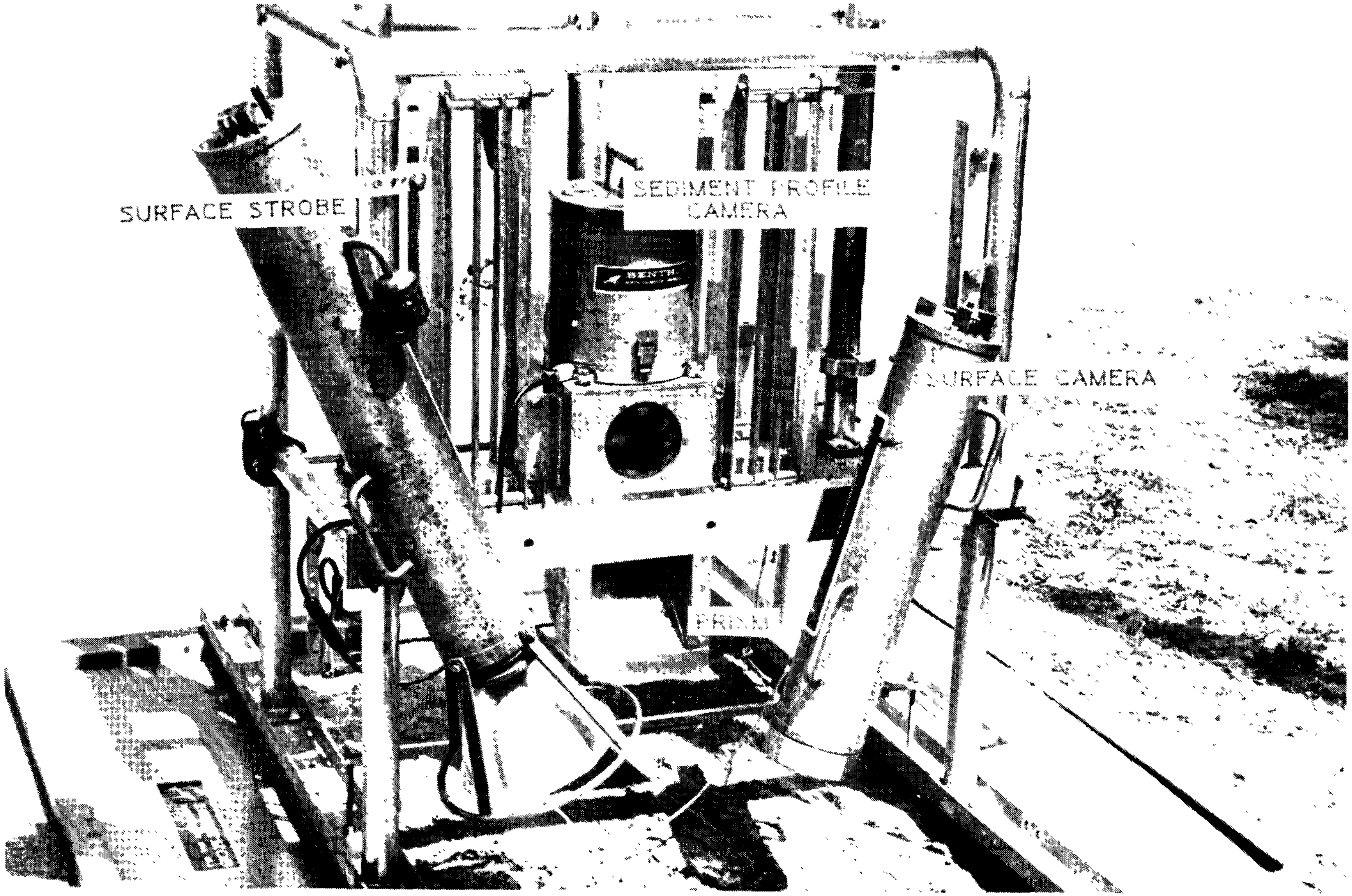


Figure 1. Surface and Profile Imaging (SPI) camera system.

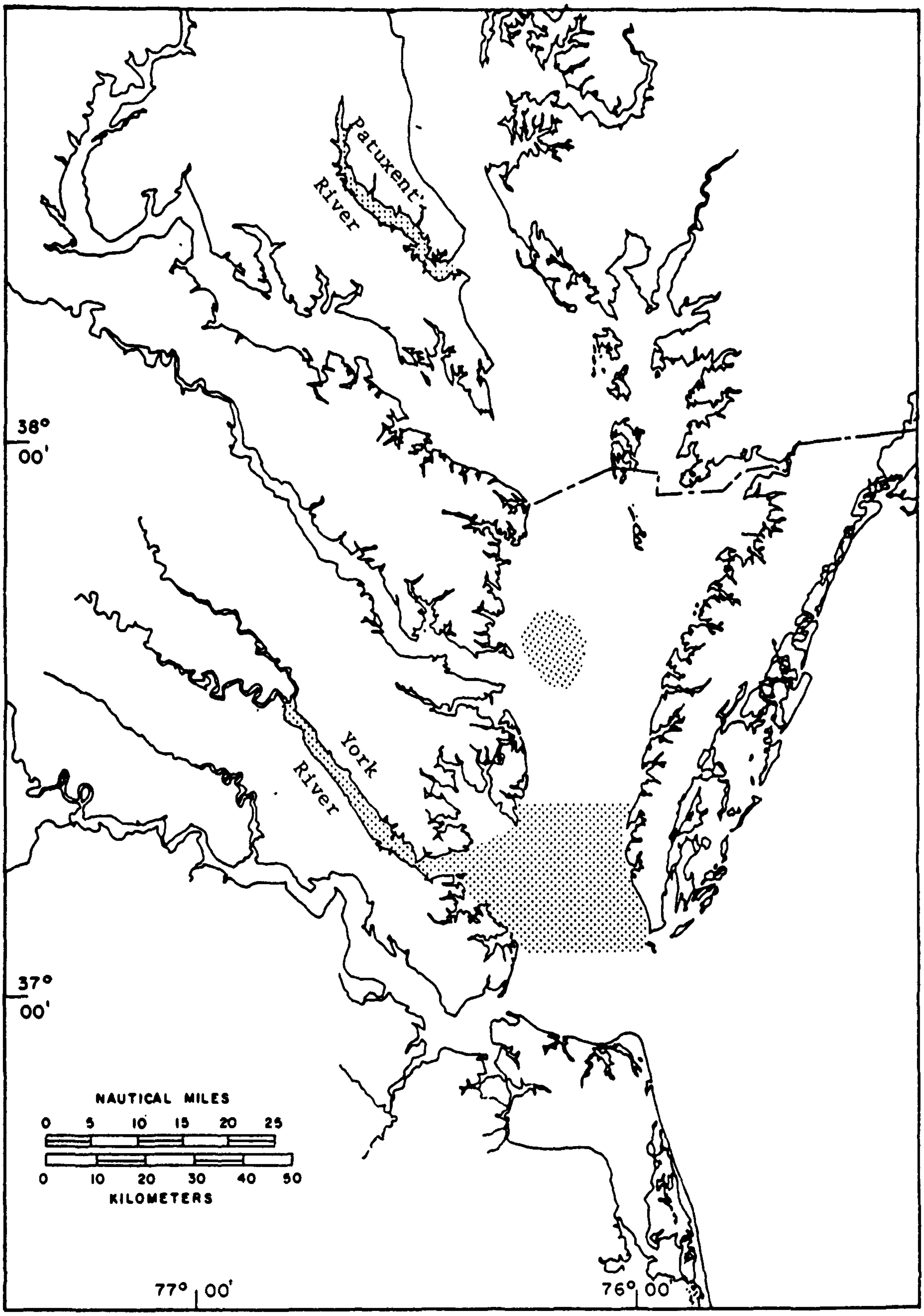


Figure 2. Location of areas around the Chesapeake Bay from which SPI data were collected.

Table 1. Image analysis measurements from sediment profile camera photographs.

Measurement	Method	Usefulness
a - Depth of Penetration	Average of maximum and minimum distance from sediment surface to bottom of prism window.	Penetration depth is a good indicator of sediment compaction.
b - Surface Relief	Maximum minus nimimum depth of penetration.	If the camera is level, this is a good measure of small scale bed roughness, on the order of 15mm (prism window width).
c - Digitized Image Statistics 1. Pixel densities for total image 2. Pixel densities for areas of interest	Actual range of densities the digitizing camera detects from the sediment profile image.	For cross comparisons of images, it is necessary to have measurements relying upon image pixel density done on a similar intensity range.
d - Depth of apparent RPD Layer	Area of apparently oxic layer (g) divided by width image. Maximum and minimum distance from sediment surface to top of RPD layer are also measured.	Gives a good indication of DO conditions in the bottom waters and the degree of biogenic activity in muddy sediments. In sands will be related to porosity and turbulence.
e - Color Contrast of apparent RPD	Contrast between oxic and anoxic layers is determined from light intensity level density slicing of digitized and specially enhanced image.	Establishes boundary of RPD. Depending upon whether the RPD is straight or convoluted will be of use in understanding the biologic and physical process.
f - Area of Anoxic Sediment	Select desired pixel density for boundary between oxic and anoxic, count anoxic pixels, and convert to area.	When calculated to a constant depth of penetration and combined with oxic layer area a good understanding of RPD dynamics can be obtained.
g - Area of Oxic Sediment	As in f, except use oxic pixel count.	When calculated to a constant depth of penetration and combined with anoxic layer area a good understanding of RPD dynamics can be obtained.
h - Voids	Number counted, depth from surface of each measured, area of each delineated.	Presence of oxic voids is a good indicator deep living fauna and high biogenic activity.
i - Other Inclusions (Methane Bubbles, Mud Clasts, Shells)	Number counted, depth from surface of each measured, area delineated.	Often other inclusions such as methane or mud clasts are indicative of certain processes and are helpful in understanding recent events.
j - Burrows	Number counted, area delineated.	Burrow presence is a good indication of deep living fauna and high biogenic activity.
k - Surface Features 1. Tubes 2. Epifauna 3. Pelletized Layer 4. Shell 5. Mud Clasts	 Counted and speciated. Counted and speciated. Thickness and area delineated. Qualitative estimate of coverage. Qualitative estimate of coverage.	Presence of these features is indicative of recent biological and physical processes.
l - Sediment Grain Size	Determined from comparison of image to images of known grain size.	Provides modal estimate of grain size and sediment layering.
m - Dredged Material or other Layers	Measure thickness above original sediment surface and area delineated.	Location of dredged material and measuring its thickness provide quantitative measure for relating impacts to the benthos of any disposal project.

Table 2. A. posteriori strata definition by sediment type, salinity, and depth.

Sediment strata (Wentworth Size Classes)

Clayey Mud
Silty Mud
Silt
Silty Sand
Fine Sand
Fine-Medium Sand
Medium Sand

Salinity range (ppt)

0 to 5
5 to 15
15 to 20
20 to 25
>25

Depth interval (feet)

<15
15-30
30-45
45-60
>60

RESULTS

The *a posteriori* stratification of image data by sediment type, salinity, and depth showed that most of the variation in surface relief, apparent RPD depth, and percentage of void area could be explained by sediment type alone. For example, the pattern of the apparent RPD depth was similar with regard to sediment type by salinity range (Fig. 3). Therefore, the data were restratified and reanalyzed by only sediment type.

Surface relief

Surface relief tended to increase with increasing grain size (Fig. 4). From clayey mud to silty sand the increase in surface relief was due to biogenic activities of the benthic fauna. In sands the surface relief was due to current generated bed forms. The magnitude of surface relief in fine sediments averaged 0.7 cm in clayey mud to 1.1 cm in silty-sand. This corresponds to surface slopes of 2.7^{0} and 4.2^{0}, respectively. Bed forms in sands averaged 1.4 to 1.7 cm in height, or 5.3^{0} to 6.5^{0} in slope.

Apparent RPD depth

The depth of the apparent RPD, as measured by brown and reddish-brown color tones of the sediment, tended to increase with increasing grain size (Fig. 5). The higher mean value for RPD in clayey mud over silty mud was due to several highly reworked low salinity stations. Median values for the apparent RPD were the same for both of these sediment types (0.5 cm). The increase in RPD depth in silt and silty sand was due to biogenic reworking of sediments by infauna. In sand sediments porosity was the major determinant of RPD depth.

The thin apparent RPD depths in clayey and silty mud sediments were clearly defined from the grey color tones of the subsurface sediments. Apparent RPD layers less than 1 cm thick in muddy sediments, while not smooth, were more uniform than deeper RPD layers. The complexity in the form of the RPD was highest in silt and silty sand sediments from biogenic activities of infauna. In sands the apparent RPD was simplest in form being close to a uniform surface between aerobic and anaerobic sediments.

Percent void area

The average and median percentage of void area, standardized to 15 cm of prism penetration, was low. Void area in fine and predominantly fine grained sediments averaged 1.3 to 2.1% with median values being much less at 0.0 to 0.8% for the same sediments (Fig. 6). In sands voids were not major subsurface features. At times voids do occur in sands, but they tend to be small. In fine sediments about 15% of the images have voids that were much larger than average, being up to 22% of the sediment area. The majority of these large voids appeared to be active biogenic structures from subsurface deposit feeding. Except in clayey muds many of the largest voids resulted from physical cracking of the sediment caused by the camera prism.

DISCUSSION

Sediment landscapes in the Chesapeake Bay exhibit broadscale patterns related mainly to sediment grain size and secondarily to salinity, which are a primary determinant of the character of infaunal

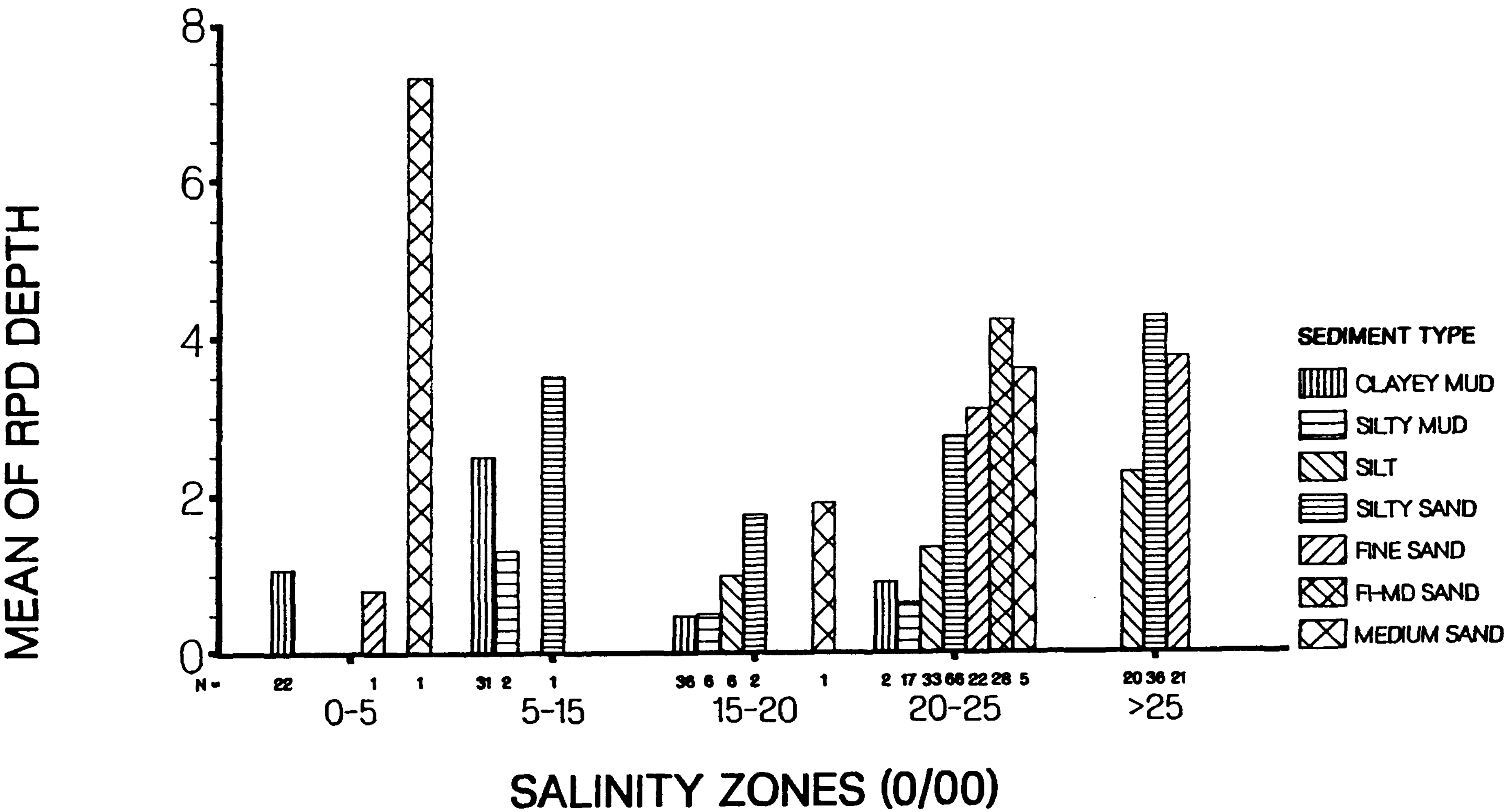


Figure 3. Depth of the apparent RPD, from profile camera images, by salinity zone and sediment type.

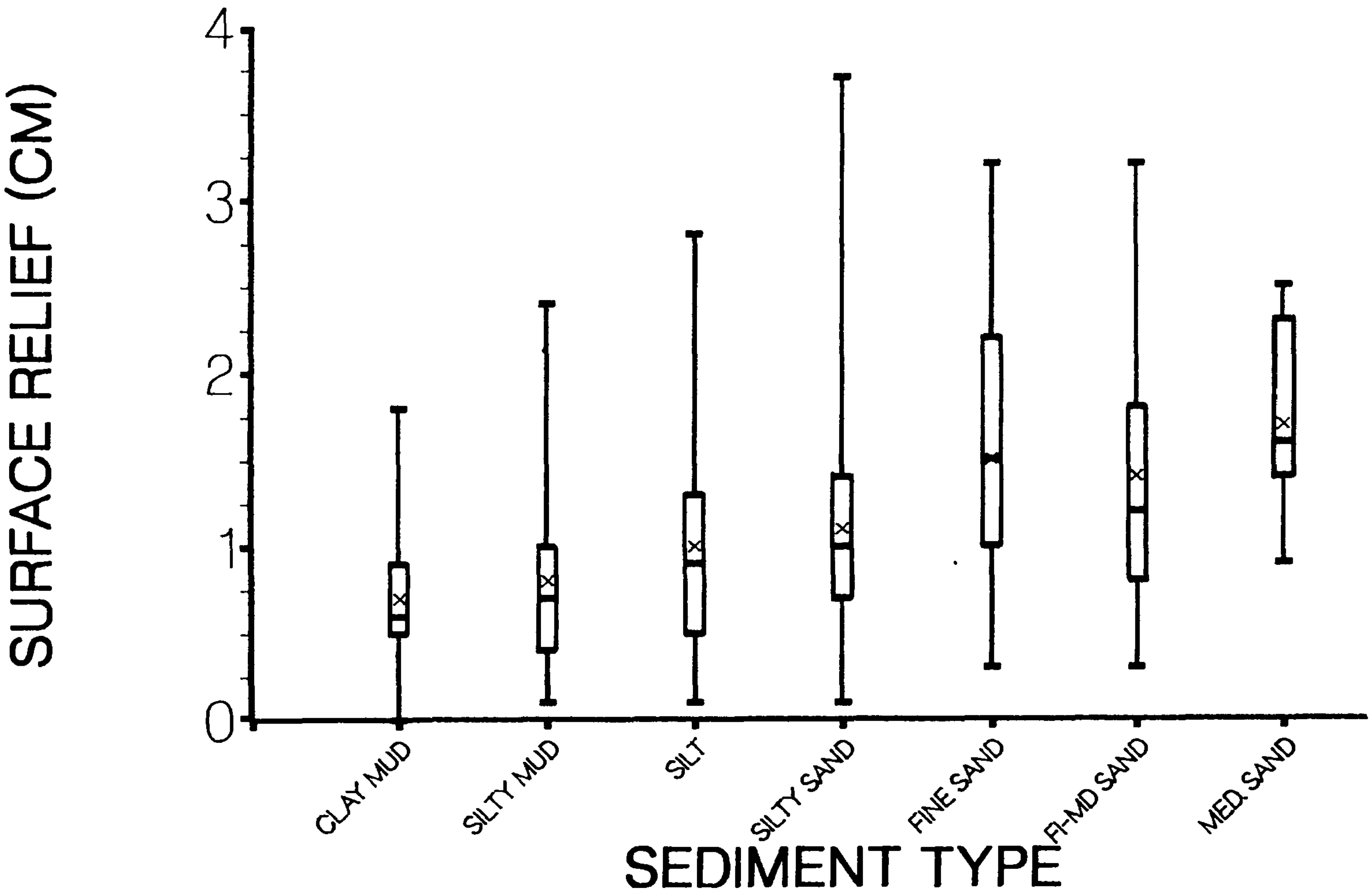


Figure 4. Surface relief, from profile camera images, by sediment type. Bar is median, x is mean, box is interquartile range, and end bars are total range.

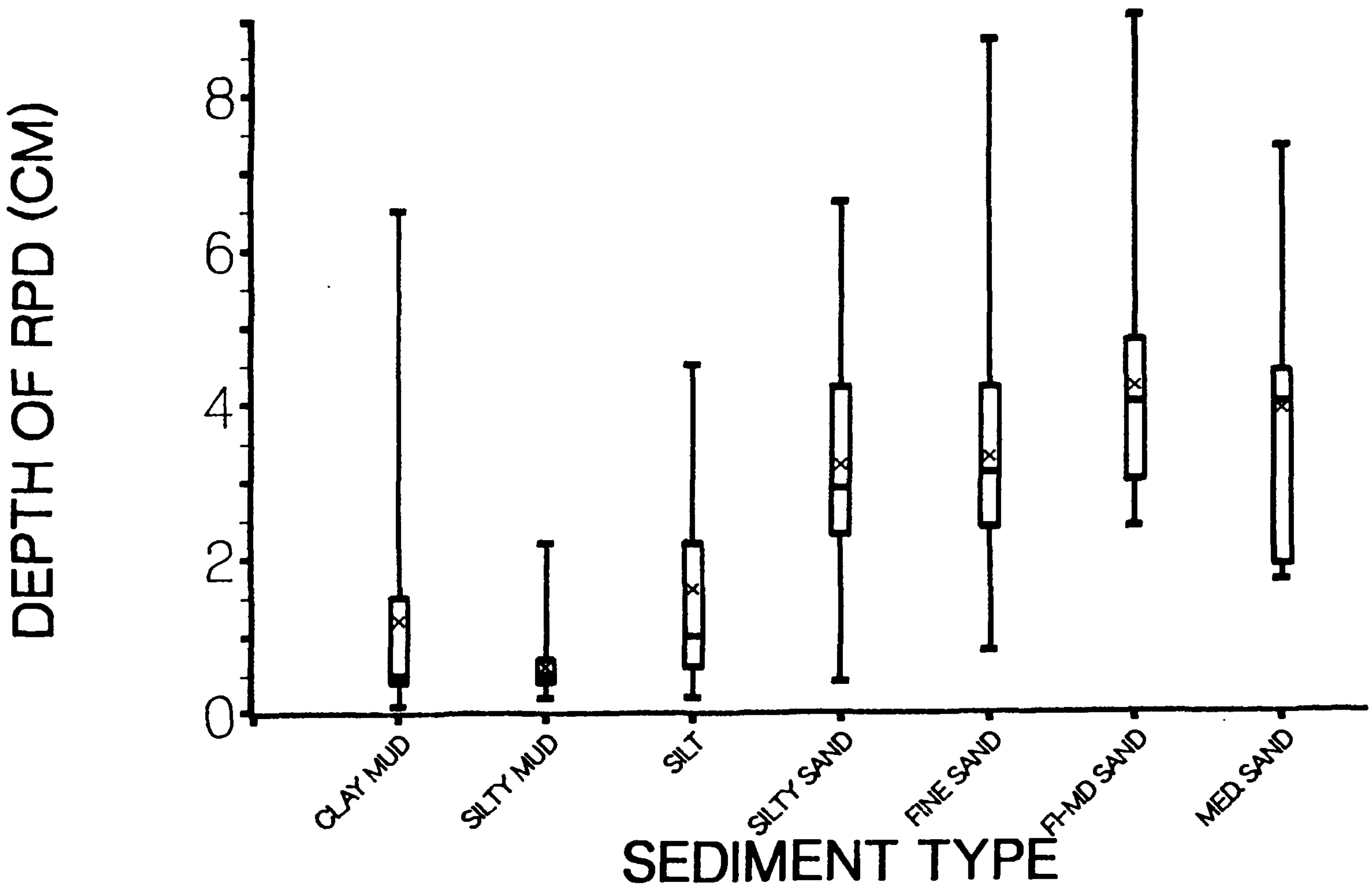


Figure 5. Depth of apparent RPD, from profile camera images, by sediment type. Bar is median, x is mean, box is interquartile range, and end bars are total range.

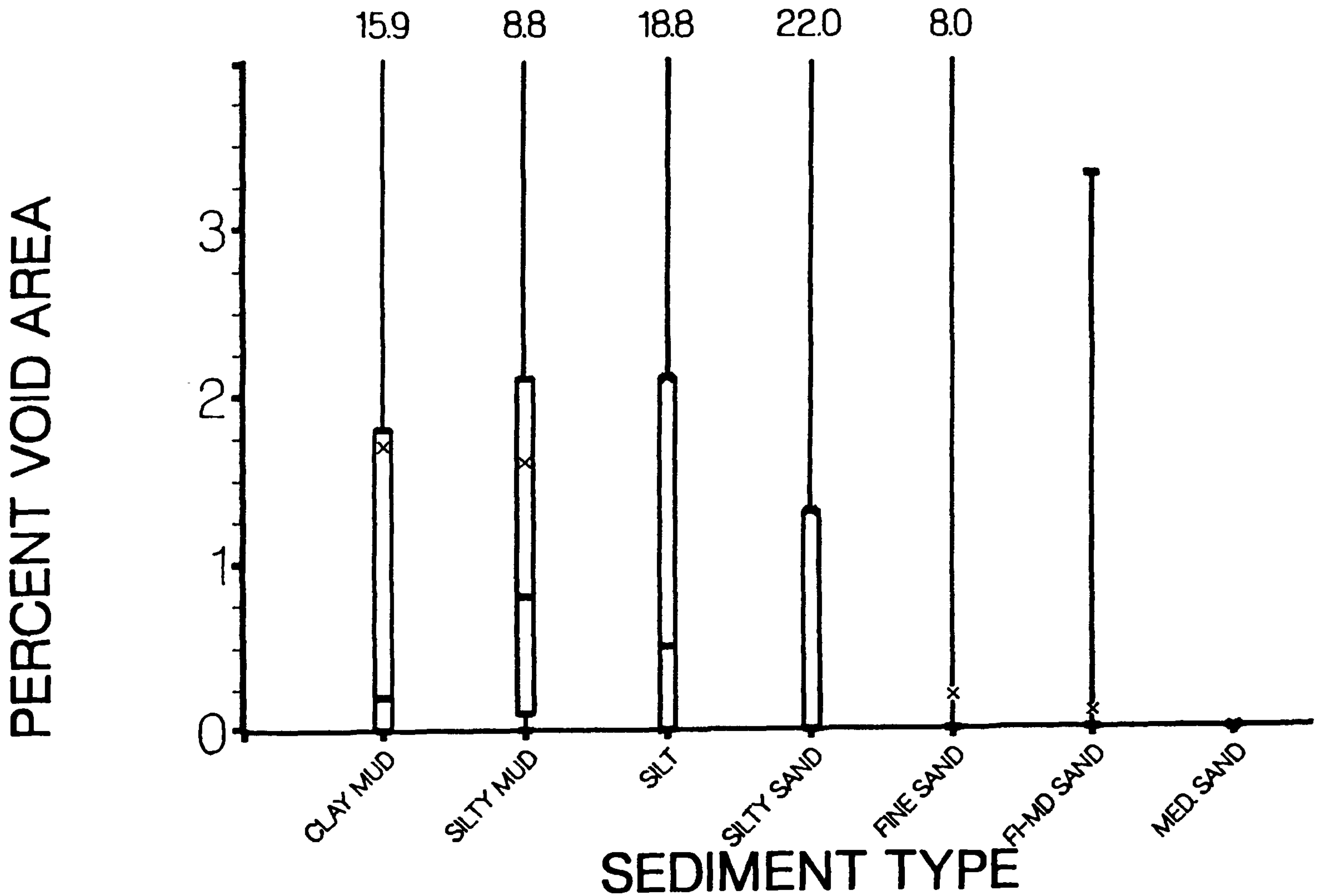


Figure 6. Percentage of image area that was voids, standardized to 15 cm prism penetration. Bar is median, x is mean, box is interquartile range, and end bars are total range.

communities. Within each salinity zone, as defined, the basic patterns of surface relief and apparent RPD depth were similar by sediment type. At salinities above 5 ppt patterns in void area by sediment type were also similar. At salinities less than 5 ppt functional groups of infauna capable of producing subsurface feeding voids are limited in abundance (Schaffner et al. 1987a). See Figure 7 for representative images.

In sediments ranging from mud to silty sands, the complexity of surface relief and apparent RPD depth increases with increasing grain size. This is due mainly to the increasing dominance of infauna in sediment mixing processes along this sediment gradient (Schaffner et al. 1987b). With the transition to sand sediments physical forces dominate surface relief and RPD depth. In sands, bed forms are the predominant surface relief and the apparent RPD layer tends to be more uniform, not following the surface contours provided by bed forms. Apparent RPD layers in clayey and silty muds tended to be broadly uniform, following the contour of the surface sediments, upon which a smaller scale (on the order of mm's) convolution is superimposed. In silts and silty sands the apparent RPD is most complex and convoluted providing a greatly increased biologically reactive interface.

The degree of biogenically-induced structural complexity in Chesapeake Bay surface sediments, as documented by surface and profile imagery, might have important effects on cycling of dissolved and particulate substances at and through the sediment water interface. For example, consider the processes associated with geochemical cycling across the RPD layer. While flux rates are typically based on simple areal measurement and the RPD is considered to be a simple contact plane between aerobic and anaerobic environments (Fenchel 1969), over most of the Chesapeake Bay's sediment landscape this assumption would lead to an underrepresentation of the actual area of the RPD layer. The results of numerous studies clearly demonstrate that biogenic structures are regions of enhanced biological and geochemical activity (Aller 1982, Aller and Yinst 1978, Aller and Aller 1986) and that the activities of infaunal organisms can increase flux across the oxic-anoxic sediment interface (Henriksen, Hanson and Blackburn 1980, Aller and Yinst 1978). Our documentation of the apparent RPD layer, a complicated surface much greater in actual area than a simple areal measurement would estimate, strongly suggests the need for further evaluation of the effects of infaunal benthos on sediment-water interface flux processes in the Chesapeake Bay.

CONCLUSIONS

There are broadscale patterns in the sediment landscapes of the Chesapeake Bay with regards to data collected by surface and profile imaging. General trends noted are:

- Biogenic voids are common and an integral part of sediment structure, except in sand and tidal freshwater and oligohaline habitats.

- Surface roughness increases concordant with increasing grain size. In fine grain sediments roughness is primarily biogenic and best developed in silts and silty-sands. In sands roughness is from current generated bed forms.

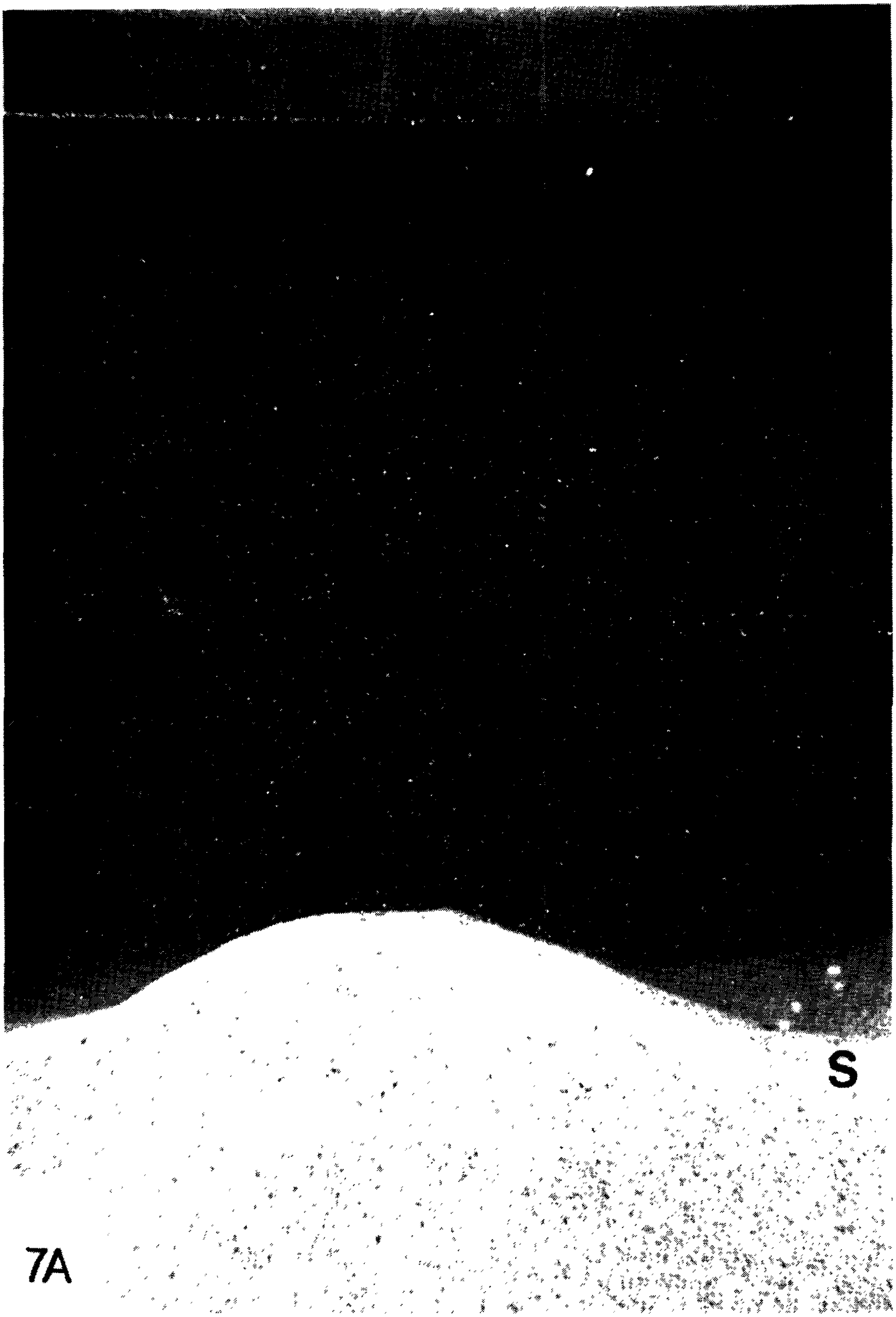
Figure 7. Examples of sediment profile images. Scale is 1X. S - sediment water interface, T - worm tube, V - feeding void.

a. 2 cm high bed form in medium sand at 5 m depth off Cape Charles in the Lower Chesapeake Bay.

b. Muddy sediments off Broome's Island, Patuxent River, showing thin (less than 1 cm) apparent RPD. Notice highly mottled appearance of subsurface sediment which may result from biogenic mixing. Also notice polychaete tubes at surface of sediment.

c. Silty sediments along Eastern Shore south of Cape Charles at 22 m depth. Apparent RPD is deeply convoluted and along the right of the image it extends down below the penetration of the camera prism. This type of apparent RPD is due to biogenic reworking by deep dwelling fauna. Surface relief in this image is all from biogenic activities. Notice small polychaete tubes at the surface.

d. Silty sediments near York River entrance channel at 10 m depth. Apparent RPD is deep in sediments and convoluted from biogenic activities. Large void is from head down deposit feeding of maldanid polychaetes.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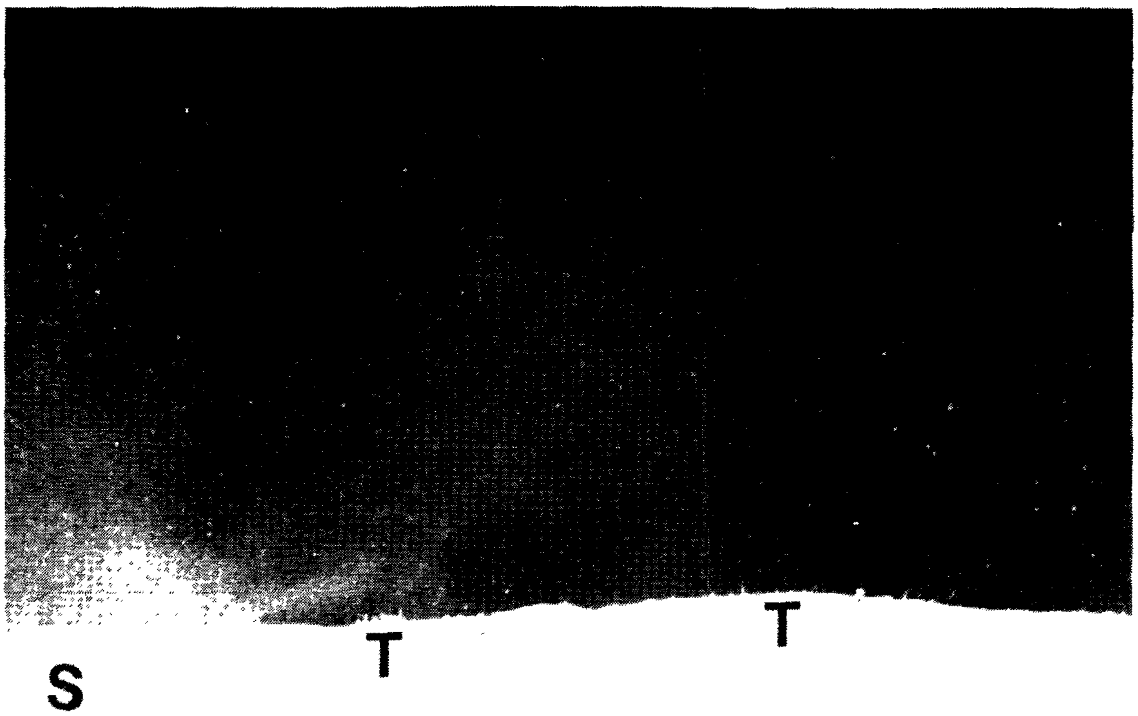
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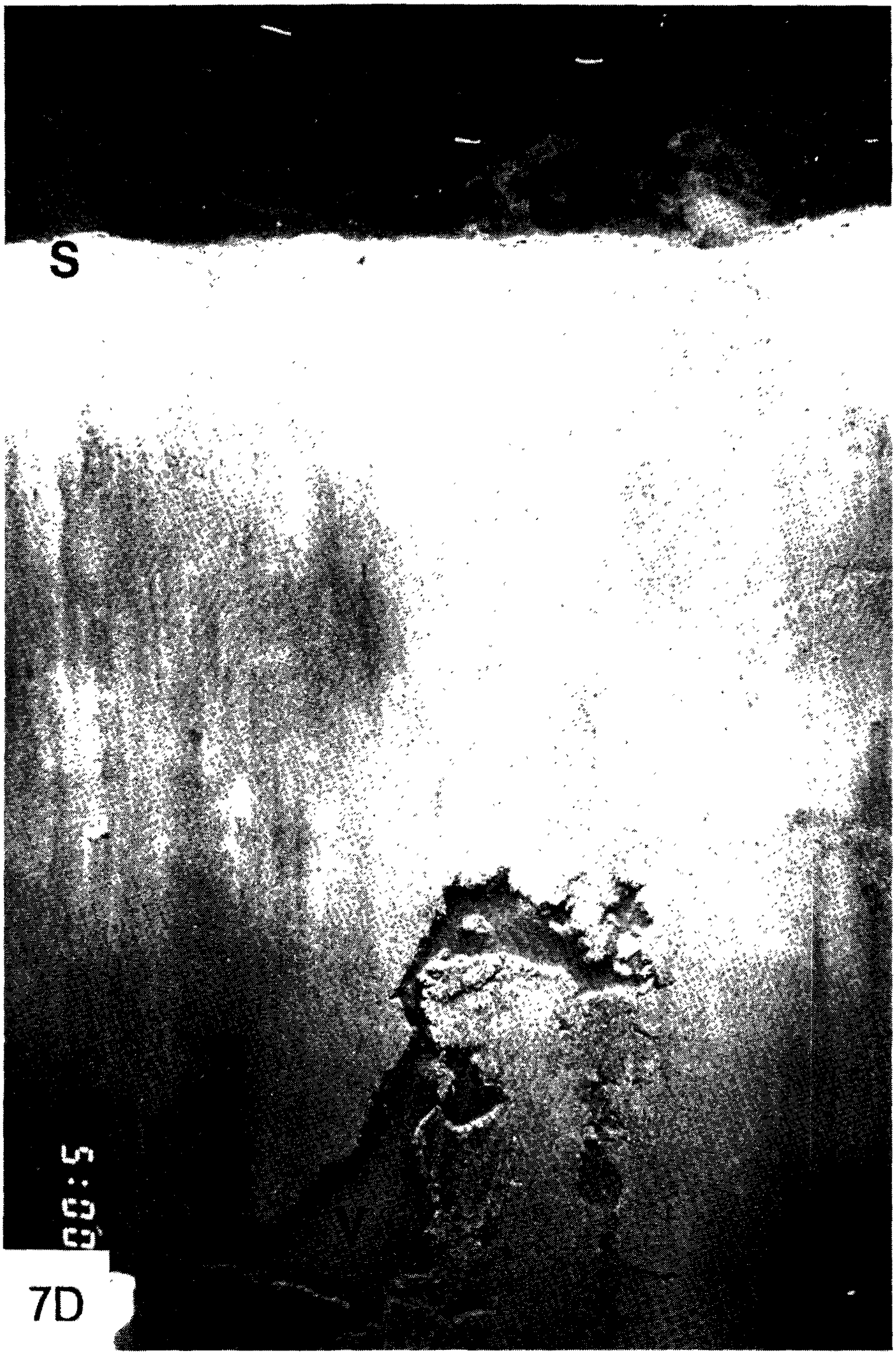

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- The biologically reactive interface, as represented by the apparent RPD, is greater than predicted by surface area alone. Deepest and most complex RPD's are found in silts and silty-sands at meso- and polyhaline salinities.

- Except when very thin (< 0.5 cm) and there is no deep biogenic activity, or in sand sediments, the apparent RPD layer is not a simple contact plane between aerobic and anaerobic environments. The actual RPD area could be many times that described by simple surface area.

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