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Benthic habitat mapping for living resources

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by

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INTRODUCTION

Much of the development activity in Chesapeake Bay involves modification to subtidal bottoms. Bottom sediments are also the final sinks for most of the particle reactive substances discharged into the Bay (Olsen et al., 1982). In view of this, managers that make decisions on permit applications, or assess past or potential impacts of projects need accurate detailed information on the extent and quality of benthic habitats that could be affected. Additionally, prudent management of living resources requires knowledge of how those resources are distributed within the Bay's habitats.

Much effort during the EPA Chesapeake Bay Program was focused on mapping sediment distributions (Byrne et al., 1982). This proved to be very valuable to resource managers. Recently, Wright et al. (1987) incorporated data on sediments, side-scan sonar, hydrodynamics, and biogenic activity into a classification scheme for characterizzing broad scale patterns in lower Bay bottoms. While both of these habitat characterizing studies provide accurate data on the physical nature of an area, they fall short of assessing the Bay's bottoms as habitat for living resources. More information on the biotic communities that are associated with any particular type of bottom needs to be incorporated into a benthic habitat classification that would reflect kinetic and potential resource value of the Bay bottom. Schaffner et al. (1987b) did exactly this for the lower Chesapeake Bay.

It would be cost prohibitive and very labor intensive to actually collect community data over broad areas of the Bay. To overcome this problem we have developed methods for remote sensing the bottom using sediment surface and sediment profile cameras (Diaz and Schaffner, 1988). From the photographs we can, through a combination of visual and computer image analysis, quickly obtain information on the biological and physical nature of the bottom, at the sediment water interface, that directly relates to the quality of habitat.

CONCEPTUAL APPROACH

The sediment profile camera provides a unique in situ view of the sediment-water interface and subsurface sediments, down to as much as 40 cm from the sediment surface, yielding both quantitative and qualitative data on their biological, chemical, and physical character. This in situ photographic approach and subsequent computer image analysis can quickly and cost effectively cover large areas of bottom defining biological, sediment, or energy gradients, and other spatial patterns. Rhoads and Cande (1971) first 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. Diaz and Schaffner (1988) related sediment geochemistry to sediment grain size and biological activity, using a sediment profile camera.

The benthic layer in the vicinity of the sediment-water interface is selected for defining benthic habitats because it involves virtually all processes and cycles within aquatic and marine ecosystems that affect living resources. Interactions and reactions at the sediment-water interface are of particular importance in regulating processes involving nutrient regeneration and remineralization (Boynton and Kemp, 1985), fate of toxicants (Olsen et al., 1982), development of hypoxia-anoxia (Garber, 1987), sediment mixing (Schaffner et al., 1987a, 1987b), and community succession (Rhoads and Germano, 1986). All of these benthic processes influence the quality of the bottom for living resources.

The technology of sediment profile photography has allowed the development of better understanding of the complexity of sediments from both a biological and physical point of view. It is a new approach to evaluating the environment, and potential impacts, that is on the cutting edge of impact and habitat assessment. Benthic habitat maps can easily be generated from the images and verified by cross referencing with our benthic community data base.

METHODS

As an example of habitat mapping, contour and data plots of a section of the lower York River were generated using profile image data currently in our data base. These plots were evaluated as to their usefulness in contributing to the development of geographical maps of benthic habitats.

A total of thirty stations in the lower York River were chosen from three different projects. Eighteen stations were from a study of low dissolved oxygen effects during the summer of 1989, three stations were from a depth comparison study (30 ft, 50 ft, and 60 ft) in November of 1987, and nine additional stations were chosen from a lower Bay study in April of 1987.

Using image and visual analysis data, collected as described in Diaz (1990) (See Appendix I), four parameters were selected for plotting: prism penetration, sediment grain size, depth of the RPD, and evidence of biological activity. Contour and data plots contained in this report were created using the SURFACE II Graphics System with existing data files.

Station positions are shown in Figure 1, and listed in Table 1, which includes additional descriptive information. Although a gridded sample format is more desirable for contour plotting, the stations selected from the three studies provide adequate areal coverage to effectively demonstrate the usefulness of this approach. Computer image analysis data are listed in Table 2, including replicates. Data from the visual analysis of the profile images are shown in Table 3, which includes an explanation of abbreviations used.

RESULTS

Prism Penetration

Camera prism penetration provides a qualitative measure of sediment compaction and sediment type. Prism penetration is reduced in sands and coarse silts (< 8 cm), and especially in well sorted, compacted fine sands (< 5 cm). Coarse silts and mud (fine silts and clay) generally show an intermediate level of penetration (8 - 12 cm). Values greater than 12 cm generally indicate sediments consisting primarily of muds. Clay sediments are usually very dense and compact, and produce reduced prism penetration. A contour plot of prism penetration values taken from Table 4 is shown in Figure 2.

Soft-bottom sediments are located in and around the main navigational channel for the lower York River, while areas to the north and south of the channel show varying patterns of penetration.

Sediment Grain Size

Based on visual analysis data, sediment grain-size was assigned a numerical range according to the Wentworth size classification for description of sediments (Folk, 1968). Texture of sediments in the images was compared to images of known grain size. The average phi value (ϕ) for each range was then assigned to each image, as shown below:

Sediment Type	ϕ Range	Average ϕ
Fine Sand	3- 4	3.5
Fine Sand/Silt	3- 5	4.0
Silt	4- 5	4.5
Silt/Mud	4- 8	6.0
Mud	5- 8	6.5
Silt/Clay	4-14	9.0
Mud/Clay	5-14	9.5
Clay	8-14	11.0

A contour plot of the average ϕ for each station sediment type is shown in Figure 3, with the corresponding data listed in Table 4. Similar patterns of sediment type can be seen here, compared with Figure 2. Soft-bottom sediments appear to follow the main channel, and more coarse-grained sediments can be found to either side.

RPD

The depth of the apparent color redox-potential-discontinuity (RPD) layer can be used as an indication of the level of oxygenation in surrounding sediments. Many factors can have an effect on the depth of the RPD, including: type of sediment; amount and type of biological and physical activities; oxygen levels of the near-bottom water; chemical processes in the sediments and the water column; and chemical and physical flux processes across the sediment-water interface. A contour plot of RPD depths is shown in Figure 4, and station data are listed in Table 4. Although these data are from different studies conducted at different times, Figure 4 demonstrates the potential for tracking spatial and temporal patterns of sediment oxygen levels.

BIOLOGICAL ACTIVITY

The amount and type of biological activity can be used as short and/or long term indicators of environmental conditions. Evidence of this activity at the sediment surface can be seen in many forms, including presence of organisms, feeding mounds, fecal material, pits, tube structures, and burrow openings. Sub-surface activity can be identified by the presence of organisms, burrows, and active feeding voids, which are generally well oxygenated. Two parameters of biological activity, density of surface worm tubes, and presence of sub-surface worms, are plotted in Figures 5 and 6, respectively. Other evidence of organism activity can be seen at many York River stations (Table 3).

CONCLUSIONS

Surface and profile imagery (SPI) does have the ability to map and define broad scale patterns in benthic habitats that can be related to living resources that utilize these habitats. In the lower York River, the example we have chosen, two basic habitats were delineated. One being a deep channel habitat characterized by soft muddy sediments, a shallow RPD layer, and the presence of surface and subsurface fauna. The second habitat was characterized as shallow shoal with sandy or mixed (sand, silt, clay) sediments, a deeper RPD layer, and fewer surface and subsurface faunal traces. From the SPI data we concluded that both of these habitats hold good resource value to fisheries species (bottom feeding fish and crabs), with the channel habitat having a relatively higher value. Ground truth data collected during the same period as the SPI data support this conclusion (Diaz et al., in prep.).

Contour mapping has many limitations for expressing patterns in complicated data bases, such as SPI. A geographic information system (GIS) would best handle questions of bottom habitat value based on SPI data. The next step is to apply the GIS approach to bottom habitat evaluation, and if successful, start collecting data to provide spatial coverage for the Bay and tributaries.

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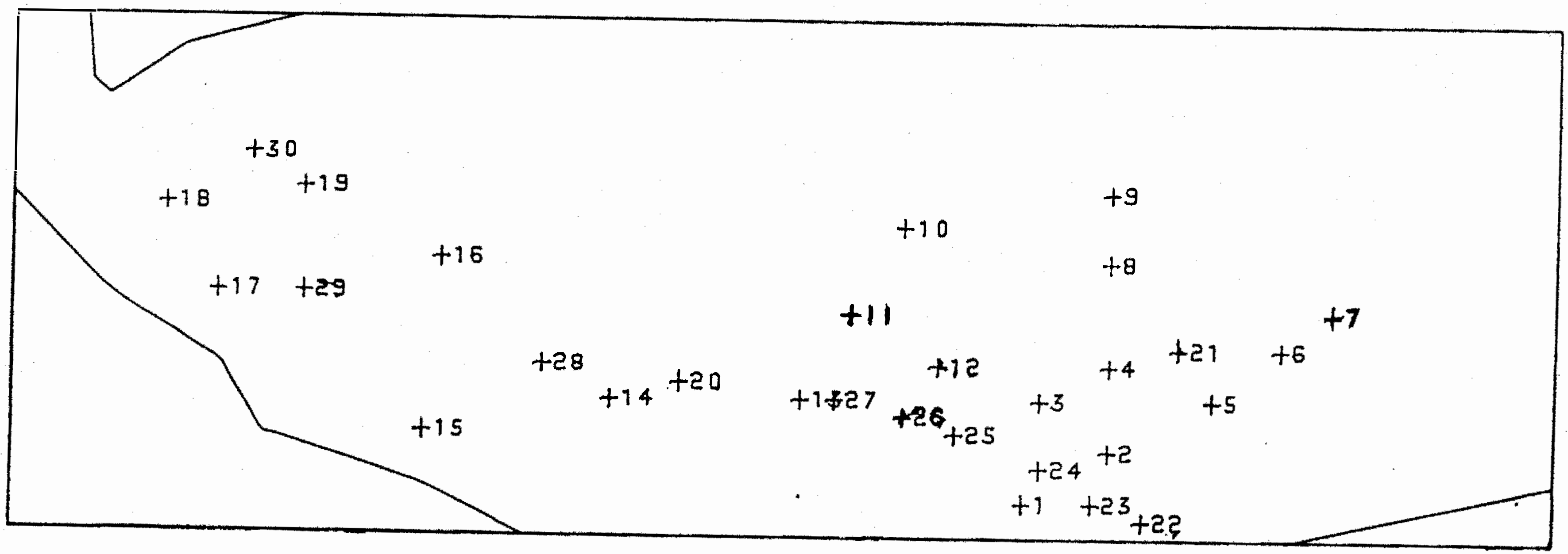

Figure 1. Location of stations in the lower York River, VA.

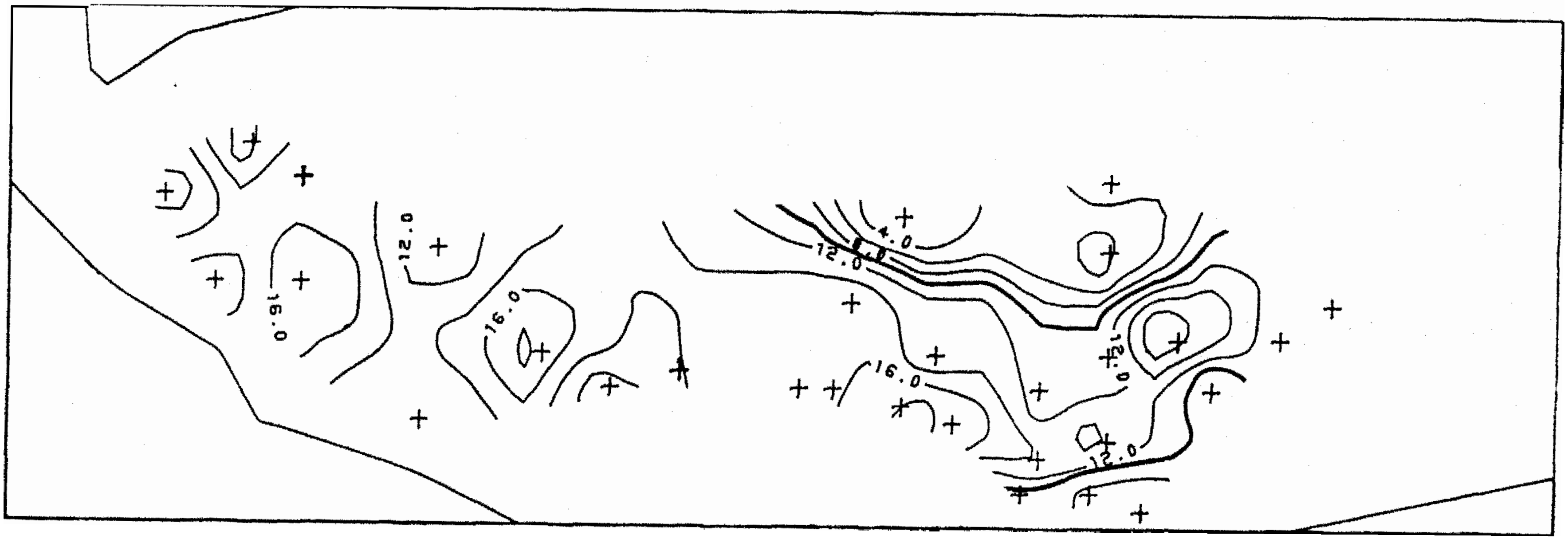

Figure 2. Contour of average prism penetration depth (cm), at lower York River stations, as determined from sediment profile images.

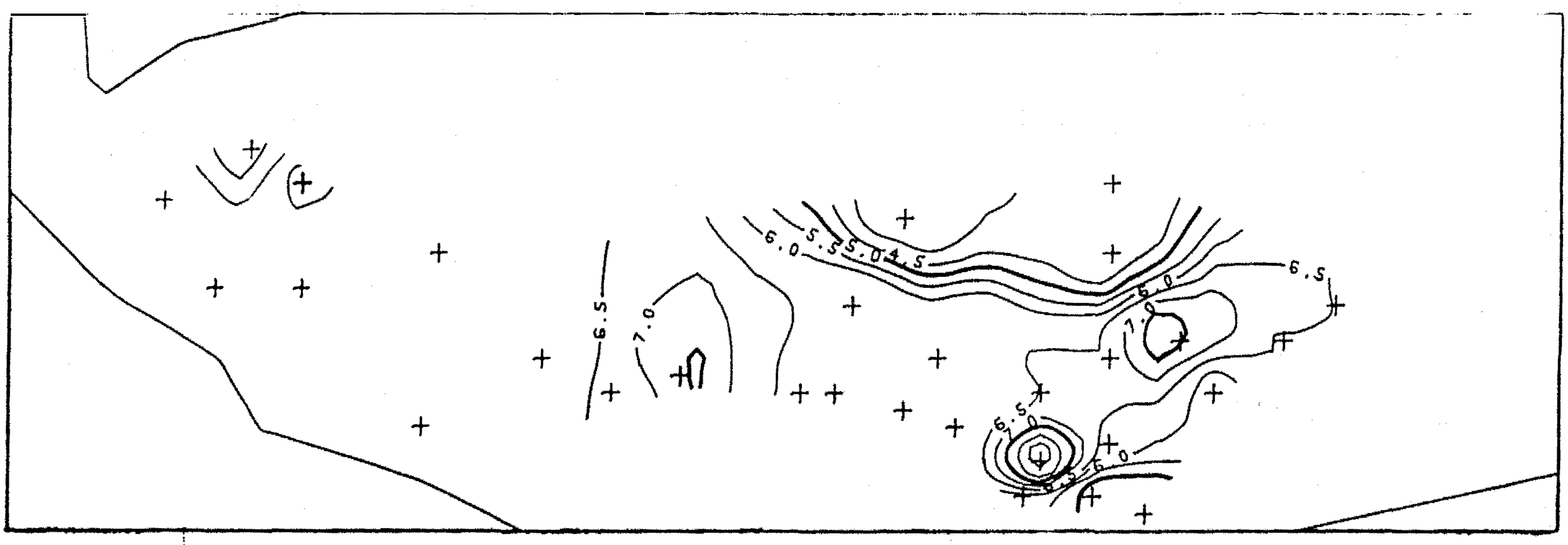

Figure 3. Contour of average Ø values, at lower York River stations, as determined from sediment profile images.

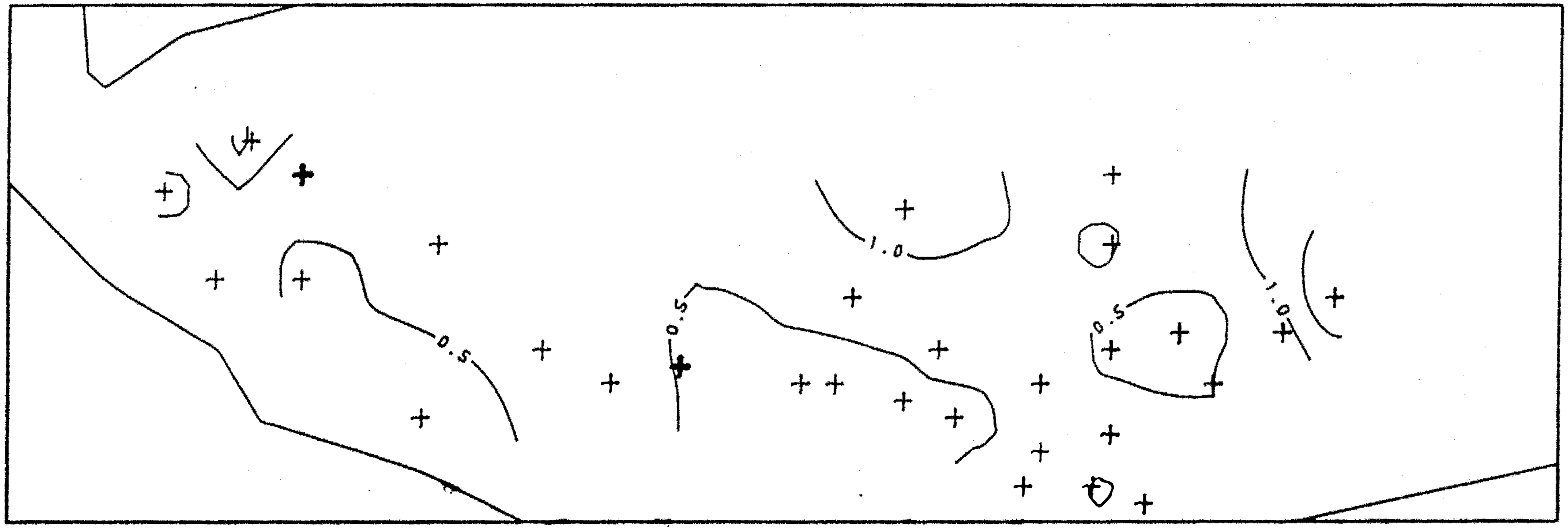

Figure 4. Contour of apparent color RPD depth (at 0.5 cm intervals), at lower York River stations, as determined from sediment profile images.

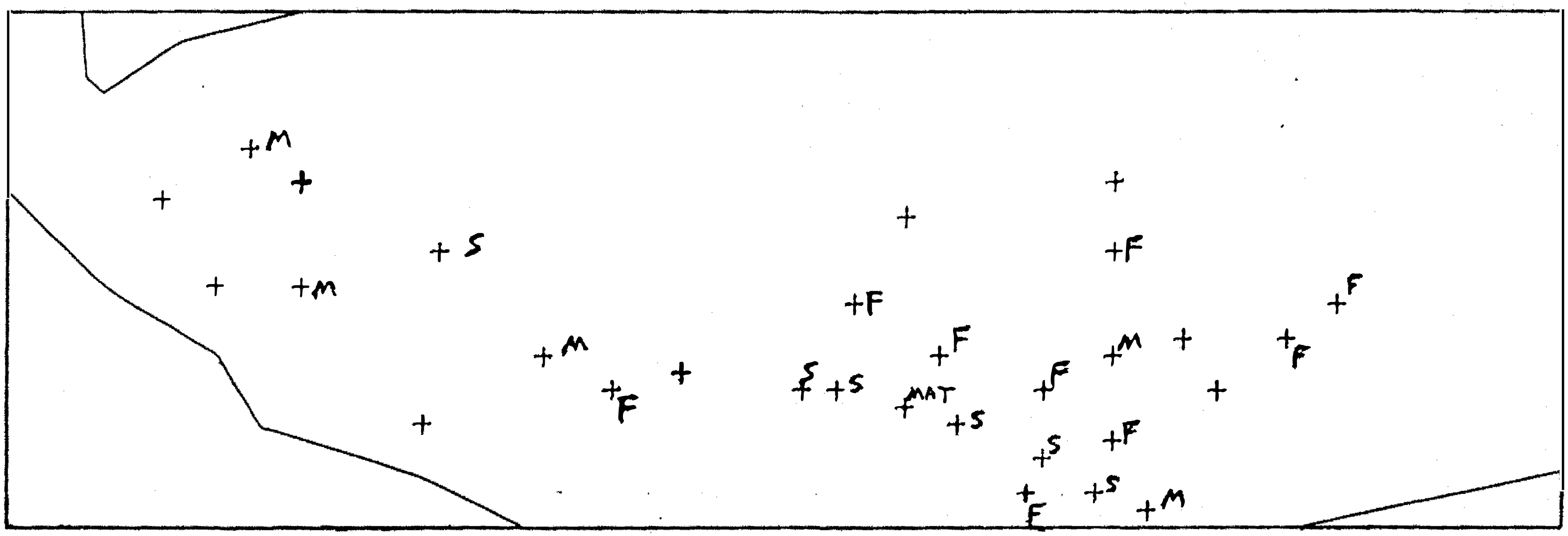

Figure 5. Density of surface worm tubes, at lower York River stations, from sediment profile images.
F = Few, <6 tubes/image; S = Some, 6-24 tubes/image;
M = Many, >24 tubes/image;
MAT = Dense tube mat on surface.

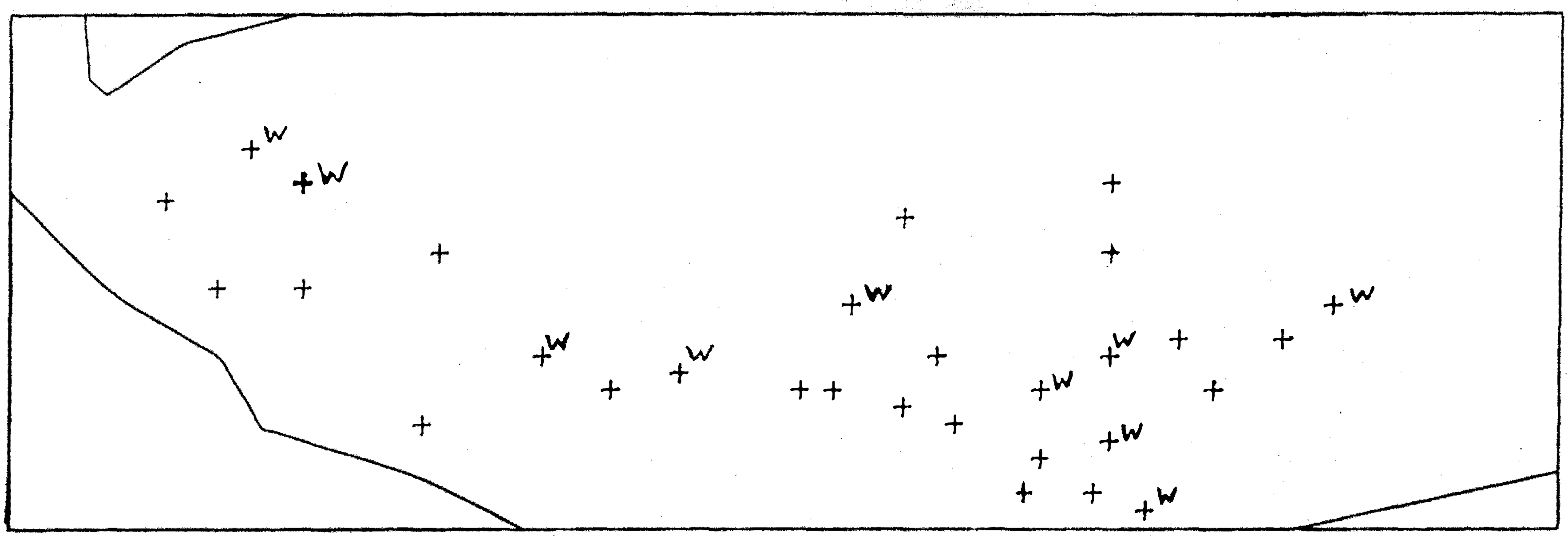

Figure 6. Presence of subsurface worms (W), at lower York River stations, from sediment profile images.

Table 1. Station position information for benthic habitat mapping of the lower York River. Plot # refers to the station labels used in Figure 1.

STATION	PLOT#	DATE	TIME	DEPTH	LORAN X	LORAN Y	LAT. N	LONG. W
A5	1	6/22/89	1434	25ft	27318.20	41433.90	3713.34	7627.06
B4	2	6/22/89	1442	34	27317.30	41436.20	3713.50	7626.75
C4	3	6/22/89	1455	50	27318.60	41438.30	3713.70	7626.97
D4	4	6/22/89	1507	60	27318.00	41439.90	3713.81	7626.76
B5	5	6/22/89	1520	45	27316.20	41439.10	3713.69	7626.37
C5	6	6/22/89	1530	62	27315.70	41441.20	3713.84	7626.16
D5	7	6/22/89	1541	68	27315.20	41443.30	3713.99	7625.96
A5	1	7/20/89	1057	26	27318.20	41433.90	3713.34	7627.06
B4	2	7/20/89	1108	34	27317.50	41436.10	3713.49	7626.80
C4	3	7/20/89	1116	52	27318.70	41438.40	3713.71	7626.98
D4	4	7/20/89	1124	62	27318.20	41440.10	3713.83	7626.80
B5	5	7/20/89	1135	47	27316.40	41440.20	3713.78	7626.37
C5	6	7/20/89	1142	62	27315.90	41441.60	3713.88	7626.19
D5	7	7/20/89	1148	69	27315.30	41443.50	3714.01	7625.98
B3	8	7/20/89	1158	35	27318.80	41443.80	3714.14	7626.78
A3	9	7/20/89	1205	22	27319.30	41446.70	3714.38	7626.77
A2	10	7/20/89	1213	28	27321.90	41444.80	3714.31	7627.46
B2	11	7/20/89	1220	39	27322.10	41440.70	3713.99	7627.68
D3	12	7/20/89	1227	58	27320.50	41438.70	3713.79	7627.39
C3	13	7/20/89	1236	54	27322.20	41436.90	3713.70	7627.87
C2	14	7/20/89	1252	49	27324.60	41435.70	3713.67	7628.48
B4	2	8/08/89	1328	33	27317.36	41436.01	3713.48	7626.77
C4	3	8/08/89	1333	46	27318.50	41438.27	3713.70	7626.94
D4	4	8/08/89	1348	60	27318.06	41439.99	3713.82	7626.77
B5	5	8/08/89	1403	43	27316.20	41439.22	3713.70	7626.37
C5	6	8/08/89	1414	51	27315.82	41441.08	3713.84	7626.20
D5	7	8/08/89	1427	72	27315.18	41443.41	3714.00	7625.95
B3	8	8/08/89	1442	36	27318.65	41443.97	3714.15	7626.74
A2	10	8/08/89	1505	29	27321.92	41444.70	3714.30	7627.47
B2	11	8/08/89	1517	41	27321.97	41440.68	3713.99	7627.65
D3	12	8/08/89	1527	60	27320.28	41438.19	3713.74	7627.36
C3	13	8/08/89	1543	56	27322.08	41436.71	3713.68	7627.85
C2	14	8/08/89	1557	50	27324.87	41435.79	3713.69	7628.54
A4	15	8/08/89	1611	22	27327.24	41433.55	3713.58	7629.19
B1	16	8/08/89	1623	41	27328.04	41440.26	3714.13	7629.09
D2	17	8/08/89	1706	62	27330.97	41438.00	3714.04	7629.88
D1	18	8/08/89	1718	64	27332.33	41441.63	3714.36	7630.04

Table 1. cont'd.

STATION	PLOT#	DATE	TIME	DEPTH	LORAN X	LORAN Y	LAT. N	LONG. W
30	19	11/19/87	1430	20ft	27330.37	41443.71	3714.43	7629.58
50	20	11/19/87	1330	47	27323.47	41437.03	3713.74	7628.25
60	21	11/19/87	1200	61	27317.23	41440.82	3713.87	7626.54
49	22	4/30/87	1159	10	27316.50	41433.60	3713.27	7626.67
50A	23	4/30/87	1202	15	27317.20	41434.00	3713.32	7626.82
51	23	4/30/87	1206	20	27317.30	41434.20	3713.34	7626.83
54	24	4/30/87	1214	35	27318.30	41435.30	3713.46	7627.02
55	25	4/30/87	1220	40	27319.70	41436.50	3713.59	7627.30
56	26	4/30/87	1224	45	27320.60	41436.70	3713.63	7627.50
57	27	4/30/87	1229	50	27321.40	41436.70	3713.66	7627.69
58	28	4/30/87	1238	55	27325.90	41437.00	3713.81	7628.73
61	29	4/30/87	1253	70	27329.90	41438.80	3714.07	7629.59
65	30	4/30/87	1308	30	27331.40	41443.90	3714.51	7629.73
66	30	4/30/87	1312	18	27331.60	41444.90	3714.60	7629.73

Table 2. SPI measurement data for the lower York River stations, in cm.

STATION	TIME	PENETRATION MIN	PENETRATION MAX	PENETRATION AVE.	SURFA. RELIEF	RPD DEPTH MIN	RPD DEPTH MAX	RPD DEPTH AVE.
A5	1434	10.8	12.3	11.0	1.4	0.1	1.2	0.6
B4	1442	15.6	16.6	14.0	0.8	0.3	2.1	0.8
C4	1455	15.7	16.2	14.3	0.7	0.2	1.1	0.6
D4	1507	14.3	15.2	14.0	1.0	0.1	0.9	0.6
B5	1520	3.6	4.7	7.4	1.2	0.0	0.5	0.5
C5	1530	12.2	15.3	14.4	1.6	0.1	1.2	0.6
D5	1541	12.7	13.2	13.2	1.4	0.3	0.9	0.5
A5	1057	4.6	6.1	5.4	1.8	0.2	1.2	0.8
B4	1108	13.3	13.8	13.6	0.8	0.2	1.2	0.8
C4	1116	14.7	15.5	15.3	0.6	0.6	1.9	1.7
D4	1124	12.9	14.8	12.4	1.2	0.0	0.9	0.5
B5	1135	12.4	13.0	12.9	0.6	0.2	0.6	0.6
C5	1142	16.0	17.4	14.8	1.0	0.0	2.8	1.1
D5	1148	16.0	17.5	16.2	1.2	2.7	4.4	5.3
B3	1158	3.7	5.0	3.6	2.0	0.7	3.1	1.6
A3	1205	8.0	9.0	6.5	1.2	0.0	2.0	0.8
A2	1213	1.8	3.1	2.8	1.4	0.3	2.9	1.9
B2	1220	15.4	16.3	13.8	0.8	0.6	1.6	1.0
D3	1227	13.5	15.0	13.0	1.4	0.0	1.3	0.8
C3	1236	12.6	13.2	13.7	0.8	0.1	0.7	0.4
C2	1252	9.3	10.3	9.8	0.8	0.1	1.5	0.8
B4	1328	15.0	16.3	15.7	1.3	0.1	0.9	0.4
C4	1333	2.7	3.5	2.9	0.7	0.1	0.6	0.6
D4	1348	3.6	4.1	3.8	0.6	0.0	0.6	0.2
B5	1403	4.1	4.6	4.5	0.5	0.0	0.3	0.4
C5	1414	4.1	4.5	4.2	0.4	0.0	0.4	0.2
D5	1427	4.4	4.9	4.8	0.4	0.0	0.4	0.1
B3	1442	2.1	3.5	2.9	1.4	0.1	0.9	0.5
A2	1505	1.3	1.8	1.5	0.5	0.1	0.9	0.5
B2	1517	15.9	16.6	16.0	0.7	0.3	1.0	0.6
D3	1527	12.7	13.4	13.0	0.6	0.1	0.7	0.3
C3	1543	13.0	14.2	13.0	1.2	0.0	0.8	0.4
C2	1557	10.0	11.4	11.2	1.4	0.1	0.5	0.4
A4	1611	11.8	12.6	12.0	0.8	0.0	0.3	0.2
B1	1623	10.8	11.6	11.3	0.8	0.1	1.0	0.7
D2	1706	11.8	13.2	12.9	1.5	0.1	1.8	0.8
D1	1718	19.1	19.6	18.9	0.5	0.0	0.8	0.4

Table 2. cont'd.

STATION	TIME	PENETRATION MIN	PENETRATION MAX	PENETRATION AVE.	SURFA. RELIEF	RPD DEPTH MIN	RPD DEPTH MAX	RPD DEPTH AVE.
30-01	1412	16.1	16.2	15.7	0.0	0.3	0.7	0.5
30-02	1417	20.1	20.3	19.7	0.2	0.4	1.1	0.7
30-03	1419	19.7	20.5	19.5	0.9	0.4	1.0	0.6
30-04	1422	15.1	16.0	15.0	0.9	0.2	0.7	0.5
30-05	1424	15.5	16.0	15.5	0.6	0.2	0.5	0.4
30-06	1428	16.0	16.6	15.9	0.6	0.1	0.7	0.5
30-07	1431	13.8	14.1	13.8	0.3	0.4	0.9	0.7
30-08	1434	17.1	17.6	16.7	0.5	0.2	0.6	0.4
30-09	1436	14.7	15.3	14.5	0.5	0.3	1.0	0.5
30-10	1440	19.7	20.4	19.5	0.7	0.5	1.1	0.5
30-11	1443	13.3	14.4	13.6	1.1	0.3	0.8	0.5
30-12	1445	15.1	15.6	15.2	0.5	0.4	1.0	0.5
30-13	1447	15.5	15.7	14.9	0.2	0.2	1.2	0.5
30-14	1449	15.9	16.5	15.6	0.6	0.1	0.4	0.2
30-15	1451	16.1	16.9	16.0	0.8	0.1	1.0	0.5
30-16	1454	14.6	14.9	14.3	0.3	0.2	0.6	0.4
30-17	1456	15.3	15.8	15.1	0.5	0.6	1.1	0.5
50-01	1304	15.7	16.1	15.6	0.5	0.2	0.5	0.3
50-02	1307	17.7	17.8	17.7	0.1	0.2	0.7	0.3
50-03	1310	8.2	10.0	8.8	1.8	0.2	0.9	1.1
50-04	1314	7.9	8.7	8.2	0.8	0.6	1.2	0.7
50-05	1317	14.7	14.8	14.6	0.1	0.3	0.9	0.5
50-06	1322	11.9	13.0	12.4	1.1	0.2	0.7	0.6
50-07	1325	18.8	19.4	18.8	0.6	0.2	0.7	0.3
50-08	1329	15.5	15.9	15.7	0.4	0.4	0.7	0.4
50-09	1331	15.5	16.4	15.6	1.0	0.1	1.4	0.6
50-10	1334	18.8	19.2	18.4	0.4	0.1	0.7	0.3
50-11	1339	17.7	18.5	17.9	0.8	0.1	0.4	0.2
50-12	1342	19.3	19.9	19.4	0.6	0.1	0.4	0.2
50-13	1345	9.9	11.7	10.6	1.8	0.4	1.3	0.6
50-14	1348	11.3	11.8	11.3	0.5	0.2	0.5	0.2
50-15	1354	18.8	19.4	18.8	0.6	0.2	0.7	0.4
50-16	1357	8.7	9.0	8.6	0.3	0.4	0.9	0.7
60-09	1157	17.5	18.4	17.5	0.8	0.3	0.7	0.4
60-11	1202	19.7	20.3	19.6	0.5	0.2	0.5	0.3
49	1159	6.6	7.4	6.3	0.8	0.4	1.4	0.9
50A	1202	0.7	2.5	1.7	1.8	0.7	2.5	1.6
51	1206	12.4	13.9	12.7	1.4	0.1	1.3	0.5
54	1214	14.5	15.3	14.0	0.8	0.1	1.5	0.7
55	1220	18.9	19.2	18.1	0.4	0.1	0.9	0.3
56	1224	19.4	20.5	19.2	1.1	0.2	1.8	0.5
57	1229	16.6	17.5	16.2	0.9	0.1	0.5	0.2
58	1238	18.8	19.9	18.6	1.0	0.2	1.3	0.7
61	1253	18.4	19.2	17.9	0.8	0.1	0.6	0.4
65	1308	16.3	16.9	16.1	0.6	0.2	2.0	0.6
66	1312	6.2	6.6	5.9	0.4	0.9	3.3	2.7

Table 3. Visual analysis data for the lower York River stations.

STATION	TIME	PENET-RATION	SEDI. LAYERS	SEDI. TYPE	SURFACE INTER.	TUBES	SUBSURFACE FAUNA	VOIDS	BURROW	BIOL. STATE, COMMENTS
JUNE 22, 1989										
A5-A-3	1434	12		SI,MU	U,M?					
A5-B-3	1436	12		SI,MU	U,P,CA					
B4-A-3	1442	17		MU	E,CA			2A		
B4-B-3	1446	17		MU	E	SOME		2A		
B4-C-3	1448	14		MU	U,M?,CA		1WR@5			
C4-A-2	1455	22	COLOR	MU	E,CA			BF		FP IN WATER COL. 4cm lb/lg,15cm mg/lg, rest dg. LG AREA BF VOIDS
C4-B-3	1459	20	COLOR	MU	E,FP	FEW?				3cm lb/lg,13cm mlg,rest dg.
C4-C-3	1502	17		MU	U,M?,CA	?				FP
D4-A-3	1507	15		MU	E,FP,CA	FEW		1BF		
D4-B-3	1510	19		MU	D	-	1WR@11			NO IMAGE ANALYSIS
D4-C-3	1513	18		MU	U,CA,FP			1A		
B5-A-3	1520	4		SI	U,M,FP	FEW?				
B5-B-3	1522	9		SI,MU	E,CA,FP	FEW?				
B5-C-3	1524	10		SI,MU, CL?	U,M,CA, BU			10	1	FP
C5-A-2	1530	20	COLOR	MU	U,P,CA					FP. 4cm lb,9cm mg/lg,rest dg
C5-B-3	1532	18		MU	E,P,CA			10		FP
C5-C-2	1536	22	COLOR	MU	E,CA,FP	?				4cm lb/lg,7cm mg/lg,rest dg
D5-A-3	1541	19	COLOR	MU	E,M,CA	FEW?				FP. 1cm lb,15cm mg,rest dg
D5-B-3	1544	20		MU	U,CA,FP					
D5-C-3	1546	14		MU,CL?	U,P,FP	?		1BF	1?	SEDS AROUND PIT DIST. HYDROIDS?
AUGUST 8, 1989										
B4-A-3	1328	18		MU	U,P,CA	FEW?				FP
C4-A-1	1333	4		MU	E,CA,FP	?				NO SHOT #2 OR #3
D4-A-1	1348	5		MU	E,CA,FP	?				NO SHOT #2 OR #3
B5-A-3	1403	5		SI	U,CA,FP	?				
C5-A-1	1414	5		MU	E,CA,FP					NO SHOT #2 OR #3
D5-A-1	1427	5		MU	E,CA,FP		1??@2		1?	NO SHOT #2 OR #3
B3-A-3	1442	4		SI,SF	U,M?					HYDROID STEM?
A3-A-1	1453	NO PENETRATION - NO ANALYSIS								
A2-A-3	1505	2		SF	E					
B2-A-3	1517	18		MU	U,M?,CA	FEW	1WR@2	1A	1	FP
D3-A-3	1527	14		MU	E,CA,FP			1A,2BF		
C3-A-3	1543	15		MU	U,M,CA	SOME				FP
C2-A-3	1557	12		MU	U,P?,CA	FEW				FP
A4-A-3	1611	14		SI,MU	E/U,CA			10		FP
B1-A-3	1623	12		SI,MU	E,FP	SOME				
A1-A-3	1635	NO PENETRATION - NO ANALYSIS								
C1-A-1	1653	5		MU	U,D,CA	-				FP. NO IMAGE ANALYSIS
D2-A-3	1706	14		MU	U,M,CA	?				FP
D1-A-3	1718	21	COLOR	MU	E,CA,FP					<1cm lb,6cm lb/lg,9cm mg,rest dg SHOT #2 NO IMAGE

Table 3. cont'd.

STATION	TIME	PENET-RATION	SEDI. LAYERS	SEDI. TYPE	SURFACE INTER.	TUBES	SUBSURFACE FAUNA	VOIDS	BURROW	BIOL. STATE. COMMENTS
JULY 20, 1989										
A5-A-3	1057	6		SI	U					
A5-B-3	1100	6		SI	U,P	FEW		30		
B4-A-3	1108	16		MU	E,P,CA			1A		
B4-B-3	1110	18		MU	E/U,CA					FP
C4-A-3	1116	20		MU	U,CA,FP		1WR@6			
C4-B-2	1119	22		MU	E,CA,FP			1BF		
D4-A-3	1124	17		MU	U,D,CA					FP
D4-B-3	1127	16		MU	E,FP	MANY	1WR@6			
B5-A-3	1135	18	COLOR	MU	E,CA					1cm lb,3cm mlg,2cm lg, 10cm mg/lg, rest dg
B5-B-3	1136	19		MU	U,CA					
C5-A-2	1142	21		MU	U,D,CA					
C5-B-3	1143	19		MU	E,CA,CO	FEW		1BF		
D5-A-2	1148	23		MU	U,P?,D?					
D5-B-2	1151	23		MU	U,D?,FP		1??@2			
B3-A-3	1158	4		SI,SF	U,M?,FP	FEW			1?	DIOPATRA TUBE?
B3-B-3	1200	4		SI,SF	U,FP	?				
A3-A-3	1205	9		SI,SF	U,M	1?			1	
A3-B-3	1206	6		SI,SF	U,M?,FP			10		
A2-A-3	1213	3		SI,SF	U,P,FP					
A2-B-3	1214	<1		SF	U,P,SH					NO IMAGE ANALYSIS
B2-A-3	1220	16		MU	U,M?,CA			1A		
B2-B-3	1222	16		MU	E,CA,FP					
D3-A-3	1227	19		MU	U,CA,FP	FEW		1A,2BF		
D3-B-3	1230	18		MU	E/U,CA	?		1A		FP
C3-A-3	1236	16		MU	E,CA,FP			1A,1BF		
C3-B-3	1238	15		MU	E,CA,FP	FEW				
C2-A-2	1252	10		MU	E,CA,FP					NO SHOT #3
C2-B-2	1254	11		MU	E,CA,FP			20		NO SHOT #3

Table 3. cont'd.

STATION	TIME	PENET-RATION	SEDI. LAYERS	SEDI. TYPE	SURFACE INTER.	TUBES	SUBSURFACE FAUNA	VOIDS	BURROW	BIOL. STATE, COMMENTS
YR30-01A	2:12	24		MU	E,CO			1-0,2-?		
YR30-02B	2:17	20		MU	E,CO			2-0		VOID PARTIALLY FILLED WITH DARKER SEDMNTS
YR30-03B	2:19	20		MU	E,CO		WR@12	3-0,1-?		
YR30-04A	2:22	22		MU	E,CO			4-0		
YR30-05A	2:24	21		MU	E,C?			3-0		
YR30-06A	2:28	22		MU	E,CO				1	
YR30-07B	2:31	13		MU	E		WR@8	2-0		
YR30-08A	2:34	23		MU	E		WR@12	2-0,1-?		1 VOID AREA FILLED WITH DARKER SEDMNTS
YR30-09A	2:36	23		MU	E		WR@4	2-0,1-?		
YR30-10B	2:40	20	MU>CL?	MU,CL?	E,C?			2-0	1	1 VOID HIGHLY OXIDIZED
YR30-11A	2:43	22		MU	E			1-0		
YR30-12A	2:45	22		MU	E			1-0,2-?	1?	
YR30-13A	2:47	24		MU	E			3-0		
YR30-14A	2:49	22		MU	E			2-0		
YR30-15A	2:51	23		MU	E,CO			3-0		
YR30-16A	2:54	21		MU	E			2-0		
YR30-17A	2:56	21		MU	E,CO			1-0,2-?	1	
YR50-01A	1:04	25		MU	E,C?			2-A		VOIDS BACKFILLED
YR50-02B	1:07	17		MU	E,CO			2-0,4-A	1	4 LG VOID AREAS FILLED W/ DARKER SEDIMENTS
YR50-03B	1:10	9		MU,SH	U	MANY				HYDROIDS,ULVA,CLUMPS OF SABELLID TUBES
YR50-04B	1:14	8		MU,SH	E,C?		WR@7			
YR50-05B	1:17	14	MU>CL	MU,CL	E,CO		WR@10	4-0		
YR50-06B	1:22	12		MU	U		WR@9 WR@3	2-0		
YR50-07B	1:25	19		MU	E,CO			4-0		
YR50-08B	1:29	15	MU>CL	MU,CL	E,CO			4-0,1-?		1 VOID FILLED WITH DARKER SEDIMENTS
YR50-09B	1:31	16	MU>CL	MU,CL	E,C?			2-?	1	
YR50-10A	1:34	23		MU	E			3-0		
YR50-11A	1:39	23		MU	E			2-0	?	
YR50-12A	1:42	24		MU	E,CO					
YR50-13B	1:45	15		MU	U,CO, B?	1?		1-0		HYDROZOA
YR50-14B	1:48	11	MU>CL	MU,CL	E,CO					A SHOT NO IMAGE
YR50-15B	1:54	19	MU>CL	MU,CL	E,CO			1-0		
YR50-16B	1:57	8	MU>CL	MU,CL	E,CO					
YR60-09A	11:57	26	CL>MU?	MU,CL	E	2?		1-0	1?	
YR60-11A	12:02	27		MU	E			1-0		

Table 3. cont'd.

STATION	TIME	PENETRATION	SEDI. LAYERS	SEDI. TYPE	SURFACE INTER.	TUBES	SUBSURFACE FAUNA	VOIDS	BURROW	BIOL. STATE, COMMENTS
YR-49B	11:59	6		SI	E	MANY	WR@ 4?			
YR-50B	12:02	2		SI?	U,SH					MANY LG SHELLS ON SURFACE.
YR-51B	12:06	13		SI	U,CO	SOME		3-0		1 LG WORM TUBE
YR-54B	12:14	15	SI>CL	SI,CL	E,CO	SOME		5-0		2 COLOR LAYERS, FP/PA IN WATER COL.
YR-55A	12:20	19		SI,MU	E,CO	SOME		1-0,2-?		B SHOT IS GREEN. 3 COLOR LAYERS.
YR-56A	12:24	21		SI,MU	E	MAT		1-0		3 COLOR LAYERS
YR-57B	12:29	17		SI,MU	U	SOME		1-0		A SHOT IS GREEN
YR-58A	12:38	20		SI,MU	E	MANY	WR@ 7	2-0,1-A		
YR-61A	12:53	22		SI,MU	E	MANY				2 COLOR LAYERS
YR-65B	1:08	16		SI,MU	E,CO	SOME		1-0,2-?		2 COLOR LAYERS
YR-66B	1:12	6		SI,SF	E	MANY	WR@ 3			

Table 4. Average prism penetration (cm), average RPD depth (cm), and average phi values for the lower York River stations.

STATION	AV. PEN.	AV. RPD	AV. PHI
A5	8.2	0.7	5.2
B4	14.4	0.7	6.5
C4	10.8	1.0	6.5
D4	10.0	0.4	6.5
B5	8.3	0.5	5.7
C5	11.1	0.6	6.5
D5	11.4	2.0	6.5
B3	3.2	1.0	4.0
A3	6.5	0.8	4.0
A2	2.2	1.2	3.5
B2	14.9	0.8	6.5
D3	13.0	0.6	6.5
C3	13.4	0.4	6.5
C2	10.5	0.6	6.5
A4	12.0	0.2	6.0
B1	11.3	0.7	6.0
D2	12.9	0.8	6.5
D1	18.9	0.4	6.5
30	15.9	0.5	6.7
50	14.5	0.5	7.6
60	19.4	0.4	8.0
49	6.3	0.9	4.5
50A	7.2	1.0	4.5
54	14.0	0.7	9.0
55	18.1	0.3	6.0
56	19.2	0.5	6.0
57	16.2	0.2	6.0
58	18.6	0.7	6.0
61	17.9	0.4	6.0
65	11.0	1.6	6.0

APPENDIX I

USE OF SEDIMENT PROFILE CAMERAS FOR DREDGE MATERIAL DISPOSAL MONITORING

by

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USE OF SEDIMENT PROFILE CAMERAS FOR DREDGE MATERIAL DISPOSAL MONITORING

INTRODUCTION

Environmental issues are part of every dredging project and can be broadly categorized into concerns for living resources, that are associated with a project site, and physical stability of the site. Collection and analysis of field data to address these environmental concerns is both time consuming and expensive. Recent advances in photographic and video technologies for underwater remote sensing of the bottom provide a new approach to evaluating dredged material disposal impacts that can quickly provide data on impacts. Sediment profile cameras can be used to directly look at thickkness and spread of dredged material layers, or as a tool for aiding in the development of more efficient sample designs for collection of other field data, such as sediment or biological samples, or to augment the results of precision bathymetry or side scan sonar in areas where their resolution is limited.

This report is an introduction to the application of this remote technology, from both a physical and biological perspective, to monitoring of dredged material disposal.

THEORY AND PRINCIPALS OF SEDIMENT PROFILE CAMERA OPERATION

The sediment profile camera (Figure 1) was developed to collect data on sediments at and below the sediment-water interface. Sediment profile cameras provide a unique _in situ_ view of the sediment-water interface and subsurface sediments (Figure 2), down to as much as 40 cm from the sediment surface, yielding both quantitative and qualitative data on the biological, chemical, and physical character of the sediments.

The sediment profile camera is composed of two parts; 1 - the camera, encased in a pressure housing, and 2 - a 45° prism, with approximately a 15 x 23 cm clear plexiglass face plate and mirror to reflect the image of the sediment up to the camera lens. The bottom edge of the prism is sharpened to neatly cut through the sediment. The prism is filled with clear fresh water to prevent hydrostatic pressure from distorting the face plate as the prism is lowered below the sea surface. The lens and light source (strobe for still and incandescent bulbs for video) used to illuminate the sediment are both contained inside the clear water filled prism (Figure 1). The camera is focused on the prism faceplate and records sediment features pressed against the faceplate. This configuration allows the camera to work in complete darkness with image clarity independent of turbidity.

For deep water deployment the camera and prism are attached to a cradle held by a larger stabilizing frame to insure the prism enters the sediment at a 90° angle (Figure 3). The entire frame is lowered to the bottom by winch. Once on the bottom a hydraulic piston regulates the descent of the prism and camera cradle into the bottom. This prevents excessive disturbance of the sediment-water interface. The profile camera is externally triggered on contact with the bottom. Electronic circuits in the camera control the exposure timing to allow the prism to penetrate the sediment after contacting the bottom. Delay times usually range from 1 sec. in soft mud to 15 sec. in hard sand. The number of exposures taken on a single deployment can range from one or two, for the Benthos sediment profile camera, to up to five, for the Hulcher profile camera.

APPLICATION

Collection and analysis of sediment profile photographs, using both visual and computer assisted image analysis (see companion volume), can quickly and cost effectively cover large areas of bottom to define spatial patterns in dredged material, background sediments, biological conditions, or other energy and pollution gradients. Almost any activity that disturbs the sediment-water interface can be evaluated using sediment profile cameras. Dredged material disposal monitoring is particularly suitable for the use of these techniques. Impacts, on the surface sediments, from natural or anthropogenic events (e.g. storms, hypoxia, anoxia, eutrophication, point discharges, toxic spills) can be easily followed through time using a sediment profile camera. One of the strongest applications of this technology is measuring the rate and sequence of recovery of benthic communities and sediment conditions after a disturbance.

Rhoads and Cande (1971) first 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. Diaz and Schaffner (1988a) related sediment geochemistry to sediment grain size and biological activity using a sediment profile camera. Rhoads and Germano (1982) and Boyer and Hedrick (1985, 1989) developed video profile cameras, but problems of low resolution currently limit their usefulness, except in special applications (Boyer and Hedrick 1989, Boyer et al. 1988).

The technology of sediment profile photography was first applied to dredging and disposal impact assessment for the U.S. Army Corps of Engineers (SAIC 1985, Morton et al. 1985, Diaz et al. 1985, Diaz et al. 1987, Diaz and Schaffner 1988b, Nichols et al. in press). As its potential for quickly assessing environmental conditions was realized sediment profile cameras were applied to areas experiencing oxygen stress (SAIC 1987) by the U.S. Environmental Protection Agency. The National Oceans and Atmospheric Association has also used sediment profile photography to look at sediment quality and habitat evaluation in major U.S. tributaries (San Francisco Bay - Revelas et al. 1987; Long Island Sound - Day et al. 1988). Boyer and Shen (1988) used sediment profile photograpahy to map spatial patterns in sediments and infaunal communities in the Great Lakes.

The sediment-water interface is a critical boundary between the water column and sediments, and is involved in virtually all processes and cycles within aquatic and marine ecosystems. Interactions and reactions at the sediment-water interface are of particular importance in regulating processes involving nutrient regeneration and remineralization (Boynton and Kemp 1985), fate of toxicants (Olsen et al. 1982), development of hypoxia-anoxia (Garber 1987), and sediment mixing (Schaffner et al. 1987a, 1987b).

The technology of sediment profile photography has allowed the development of a better understanding of the complexity of sediments, from both a biological and physical point of view, that is needed to properly evaluate and manage dredged material disposal. This approach to evaluating the environment and potential impacts is on the cutting edge of impact and habitat assessment.

DATA

The images captured by sediment profile cameras (Figure 2) are the primary data used in interpretation. Whether still or video cameras are used, the analysis and interpretation steps follow the same path. First, the images are analyzed visually to provide a general impression of the area surveyed and to record data on features of importance. The visual analysis is done from slides, videotape, or hard copy. It also sets the stage for computer assisted image analysis, being used as a guide for setting the limits on many parameters (Table 1). Typical examples of data from visual and computer assisted image analysis are found in Tables 2 and 3.

SIGNIFICANCE OF DATA

In this section we explain the significance and usefulness of the data produced from analysis of profile images. Details of how these data are actually obtained can be found in the companion volume.

A. Digitized image statistics.

These statistics are the actual pixel (picture element) densities from the digitized image. They are used to compare the color and contrast changes that occur within an image and between sets of images. Changes in pixel density are very important for delineating boundaries in the sediment between layers of different mineralogy, of different biogeochemical reaction rates, and of different sediment type. If black and white film or video is the recording medium, the image contrast is set at the time the image is taken to a single band. Black and white mediums condense the original color to a single band image. Color film or video (either composite or red-green-blue) contain more information on the subtle changes in the color of sediments. Color images often facilitate and at times are the only medium that clearly can identify layers of dredged material (Diaz et al. 1986) or the depth of oxidized sediment (Diaz et al. 1987, Day et al. 1988).

Useful quantitative measures of color or image intensity are the 10% and 90% pixel density values (first and ninth deciles). They are the points in the frequency distribution, of all the pixels from an image, that bound the central 80% of the pixels. They are convenient measures that can be used to compare images between stations and evaluate color of sediments, which has been found to be related to habitat quality (Diaz and Schaffner 1988a). In temperate estuaries very dark black sediments are associated with habitats that are recently disturbed or sinks for labile organic matter that do not support advanced successional stage communities (Rhoads and Germano 1986). Lighter colored grey-green-brown sediments have been shown to support more diverse and abundant communities (Diaz and Schaffner 1988a).

B. Prism Penetration.

This parameter provides a geotechnical estimate of sediment compaction with the profile camera prism acting as a dead weight penetrometer. The further the prism enters into the sediment the softer the sediments, and likely the higher the water content. Penetration is simply measured as the distance the sediment moves up the face plate of the prism. Prism penetration provides a means for assessing the firmness of a habitat and identifying areas that are less consolidated. By using multiple exposures per deployment the camera can record overlapping photographas of the sediment as the prism penetrates. In unconsolidated mud up to 35 cm of the sediment has been photographed in the upper Chesapeake Bay (Diaz, unpublished data).

C. Surface Relief.

This parameter provides an estimate of the small-scale bed roughness, on the order of the prism face plate width (15 cm). Many times the causes of roughness can be determined from the images. In physically dominated sandy habitats surface relief is typically small sand waves or bed forms (Figure 2). In muddy habitats surface relief is typically irregular surfaces, from biological activity of benthic organisms (Figure 4), or smooth (Figure 5). In biologically dominated habitats surface roughness can range from small fecal mounds and tubes to large colonies of hydroids or seagrasses. Surface relief provides qualitative and quantitative data on habitat characteristics which can be used to evaluate existing conditions.

Surface relief is measured as the difference between the maximum and minimum prism penetration.

D. Apparent Redox Potential Discontinuity (RPD) Layer.

This parameter is an important measure of benthic habitat quality. The depth of the apparent RPD is defined as the area of the image discerned as being aerobic divided by the width of the digitized image. The term apparent is used in describing this parameter because no actual measurement is made of the redox potential. An assumption is made that, given the complexities of iron and sulfate reduction-oxidation chemistry in sediments, reddish-brown color tones (Diaz and Schaffner 1988a), (Figure 2), or in black and white images areas of high pixel intensity (Rhoads and Germano 1986), (whiter or lighter areas of the image), 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 the image with aerobic sediment is determined by digitally manipulating the image to enhance characteristics associated with aerobic sediment (greenish-brown tones). Then the enhanced area is computed from a density slice of the image.

The apparent RPD is very useful in assessing the quality of a habitat for epifauna and infauna from both physical and biological points of view. Rhoads and Germano (1986), Revelas et al. (1987), SAIC (1987), Day et al. (1988), and Diaz and Schaffner (1988a) all found the depth of the RPD from profile images to be directly correlated to the quality of the benthic habitat. Areas with thin RPD's, on the order of a few millimeters, were always reported to be under some environmental stress, whereas areas with deep RPD's, over 3 cm, were usually found to have flourishing epibenthic and infaunal communities.

E. Sediment Grain Size.

This parameter is a geotechnical feature of the sediments and is used to determine the type of sediments present. From grain size the nature of the communities (flora and fauna) that can likely occur in a habitat can be inferred. Grain size is a key parameter in detecting the presence of dredged material layers, particularly if the dredged material is of a different grain size than the background sediments upon which it is placed.

The sediment type discriptors used follow the Wentworth classification as described in Folk (1974) and represent the major modal class for each layer identified in an image. Grain size is determined by comparison of collected images with a set of standard images for which mean grain size has been determined in the laboratory. Sediment grain size from gravels, to sands (Figure 2), to silts (Figures 4 and 5), and clays (Figure 6) can be accurately determined from the images.

F. Area of Dredged Material

Layering of dredged material over background sediments is easily seen in sediment profile images. If recently deposited, and not physically or biologically reworked, layers of dredged material thinner then 1 cm can be accurately identified (Figure 7). Generally, dredged material has different color tones (lighter grey) and texture (uniform or clearly laminated) when compared to undisturbed natural (mottled greys, mixed texture) sediments (Figure 6). Procedures similar to defining the apparent RPD area are used to calculate the area of dredged material. The dredged material is digitally enhanced and the area calculated from a density slice of the image.

Detecting thin layers (< 2 cm) of dredged material that are old, not recently deposited, and reworked is difficult because through time the dredged material takes on the character of the natural background sediments. Usually, there is no distinct signature retained by the dredged material once it is reworked and great care and experience is needed to properly interpret thin layers of dredged material through time.

G. Area of Special Interest.

At times layers of special interest may occur. These layers can be defined and measured much the same way apparent RPD is measured. For example, from a baseline survey of the benthic habitat in Nichupte Lagoon, Mexico (Sirrine Environmental 1988), for a dredge-and-fill project, shell hash was found to be a major component of the sediment fabric (i.e., physical structure and complexity of organization within the sediment). The area of each image occupied by shell hash was calculated by digitally manipulating the image to locally enhance the shell fragments, to make them much brighter than the surrounding sediment, and then compute the area of the bright pixel from a density slice of the image.

H. Surface Features.

These parameters are a variety of features ranging from seagrasses, worm tubes, epibenthic organisms, bacterial mats, shells, mud clasts, bed forms, to feeding pits and mounds. Each gives an indication of the type of habitat and its quality for supporting desired species. Desired species are those selected by ecosystem managers as being ecologically, recreationally, or aesthetically important. The presence of certain surface features is indicative of the overall nature of a habitat. For example, bed forms are always associated with physically dominated habitats (Figure 2), whereas the presence of worm tubes or feeding pits would be indicative of a biologically accommodated habitat (Figures 4, 5, and 6) (Rhoads and Germano 1986, Diaz and Schaffner 1988a).

Surface features are visually evaluated from each slide and compiled by type and frequency of occurrence. See Table 2 for examples of visual data analysis.

I. Subsurface Features.

These parameters can be a variety of features including burrows, feeding voids, rhizomes, infaunal organisms, gas bubbles or inclusions, shell debris, detrital layers, and sediment lenses of different grain size. Subsurface features also reveal a great deal about the physical-biological control occurring in a habitat. For example, the presence of methane gas inclusions (Figure 8) has been found to be an indication of anaerobic metabolism (Rhoads and Germano 1986) and associated with high rates of bacterial activity. Muddy habitats with large amounts of methane gas are generally associated with areas of oxygen stress or high organic loading (SAIC 1987, Day et al. 1988). On the other hand, habitats with burrows, infaunal feeding voids, and/or actual infauna visible are generally biologically accommodated and very "healthy" (Figures 5 and 6).

J. Derived Measurements.

The above image data (A through I) can be combined in many ways to summarize environmental conditions. Rhoads and Germano (1986) have developed an index that gives an impression of habitat quality for living resources. Their organism sediment index (OSI) is defined from both sediment profile image parameters and measurement of bottom dissolved oxygen. The lowest value of the OSI (-10) is given to habitats that have little or no dissolved oxygen, no apparent evidence of fauna (surface or subsurface data), and methane gas is present (subsurface data). Highest value of the OSI (+11) is given to habitats that have high dissolved oxygen, deep apparent RPD layer, evidence of fauna, and no methane gas.

Sediment profile data have also been used to estimate successional stage of the fauna in a habitat (Rhoads and Germano 1986). Characteristics that are associated with pioneering or colonizing (stage I) assemblages (in the sense of Odum 1969), such as dense aggregations of small polychaete tubes at the surface and shallow apparent RPD layers, are easily seen in sediment profile images. Advanced or equilibrium (stage III) assemblages also have characteristics that are easily seen in profile images, such as deep apparent RPD layers and subsurface feeding voids.

CASE STUDY

We have chosen the thin-layer open-water disposal project at the Fowl River, Mobile Bay, Alabama, to demonstrate the application of sediment profile cameras to monitoring of dredge material. Details of the project can be found in Mobile District documents and Blancher et al. (1988).

Briefly, maintenance material from the Fowl River channel was thin-layered over a shallow open-water disposal site in Mobile Bay. Less then 100,000 yd^3 of material was to be spread over the area with a thickness of approximately 6". Because of the high fisheries productivity of Mobile Bay many environmental concerns were raised as to the impacts from thin-layer disposal. An intensive monitoring program was implemented to document impacts that included sediment profile imaging along with traditional sampling techniques (water quality, precision bathymetry, macrobenthic communities, fisheries communities).

Sediment profile camera surveys, both pre- and post- disposal, were conducted to evaluate:

1- The general impacts of thin-layer disposal on the bottom.
2- Determine the stability of the dredged material once on the bottom and follow its spread through time.
3- Follow benthic recolonization of the dredged material.

4- Follow the reworking of the dredged material by biological and physical processes.

The field sampling design was a combination of fixed (6 x 10 station grid), random (6 stations within the gird), and float (6 stations located in areas of special interest) stations. The grid was larger then the disposal area and included disposal, fringe, and control areas (Figure 9). A pre- and four post-operation surveys were conducted between June 1986 to June 1987.

Data were collected using a modified Benthos Model 3717 sediment profile camera (Diaz et al. 1986). At each station one sediment profile photo was taken. On each deployment the profile cameras took two photographs. The first photograph was taken 4 sec. after bottom contact and the second after 15 sec. later. This timing sequence best captured the sediment-water interface in both hard and soft sediments.

Stations were initially photographed using both black and white and color slide film. Visual and computer image analysis, however, demonstrated that color film more accurately portrayed thickness of dredged material and other sediment features and use of black and white film was discontinued (Diaz et al. 1986). The original black and white or color slides were analyzed in two stages (visually and computer image analysis). In the visual analysis surface (type of surface layers, tubes, epifauna, bedforms, shell, clasts) and subsurface (sediment grain size, laminations, infauna, burrows, feeding voids, gas bubbles) features were identified and enumerated. After the visual analyses a computer image analysis was done in color using a red-green-blue Dage MTI series 68 instrumentation grade video interfaced to an International Imaging Systems I^2S Model 75 image processor. The image processor was interfaced to a Prime 9955 mainframe, which provides access to compilers and the operating system used to execute the I^2S software. (Details of the computer image analysis can be found in companion volume.)

Measurements obtained from computer image analysis include a number of digitized image statistics by red, green, and blue color planes, areas for various sediment layers (aerobic, anaerobic, voids), and linear measurements for penetration depth, surface relief, depth of various sediment layers, and depth of the apparent color redox-potential discontinuity (RPD).

The general character of the site, based on sediment profile imagery, was found to be basically dominated by physical disturbances. In sandy inshore areas wave generated ripples were dominant features. These bedforms were on the order of 1 to 2 cm in height and consistently found at the same stations each cruise (Figure 2). In muddy areas resuspension-deposition cycles, likely generated in the short term by shrimp trawling activities and in the long term by storms and seasonal inflow of freshwater. Muddy areas were characterized by a uniformly even surface and layering of subsurface sediments. Anywhere from three to five layers of different grey color tone sediments, each of which was from 2 to 6 cm thick, were seen at most stations (Figure 7). Little change occurred in these layers over the one year study.

The evidence for trawl induced resuspension-deposition was strongest in June 1986, from the predisposal photographs. Dozens of small boats were trawling for shrimp, in and around the study area, the entire time sediment profile photographs were collected. Furrows and mounds, likely caused by trawl doors, and thin layers of recently deposited sediment from trawl turbidity plumes were seen at many stations. During the remaining four cruises an occasional trawler was seen within the study area and none of the trawl attributed features occurred. Particularly absent were the thin layers of recently deposited sediments.

The apparent color redox-potential discontinuity (RPD) was on the order of 1 to 2 cm and did not change much between cruises. Apparent RPD's were slightly deeper in sandy areas (Figures 2, 6, and 7). Evidence for deep reworking of the sediments by infauna was seen in the form of Callianassa and possibly penaeid shrimp burrows (Figure 6). These burrows were found only at muddy stations and at times appeared active, being lined with a thin (1 to 2 mm) layer of brownish colored oxidized sediments. Other voids or inclusions were seen throughout the sediments but most appeared not to be oxidized and were either abandoned burrows or cracks in the sediment.

The entire study area was dominated by a pioneering or successional stage I community. The general nature of the infaunal community or successional stage did not change during the study. Even 3 weeks after disposal there was evidence that the fauna was burrowing through (up or down) and had recolonized the surface of the dredged material. Sediment profile imagery easily detected the broad scale recolonization event that occurred within two months after the July disposal operation (Figure 7). The entire surface of control, fringe, and disposal areas was colonized by the capitellid polychaete Mediomastus. The thickness of the tube mats made by these organisms varied from station to station but they were present at virtually all stations, except some of the inshore sandy areas (Figure 2). Areas that received dredged material were similar, with respect to recruitment, to control and fringe areas. By November (10 weeks post-disposal) the Mediomastus tube mat was gone. The entire study area was then sparsely covered with tubes and still no patterns were seen in tube distribution relative to dredged material (Figure 6).

Sediment profile images indicated that most of the disposal area was filled to a thickness of over 20 cm with dredged material. The western inshore fourth of the disposal area had no dredged material. Dredged material spread, or was placed, south of the disposal area in thicknesses similar to those measured in the disposal area. Spread of dredged material to thé north and east of the disposal area was limited. The basic thickness and distribution of dredged material did not change much after disposal, up to the January 1987 (20 week post-disposal) cruise.

When thicker then a few cm's dredged material was easily recognized by its lighter grey color tone and more uniform texture relative to background sediments (Figure 6). Thin layers of dredged material were at times difficult to identify because sediment reworking (mostly physical but also some biological) obscured the dredged material signature (Figure 7). This reworking of dredged material was seen in many of the 3 week post-disposal images and continued throughout the study.

Sediment profile imagery was able to resolve dredged material layers on the order 1 cm while precision bathymetry had a resolution of about 10 cm (0.3 ft). Table 4 compares dredged materials depths determined from both methods. It can be seen that sediment profile imagery provides a more accurate picture of thin-layers of dredged material, and its spread, relative to precision bathmetry (Figures 6 and 7). When the dredged material was thicker then the minimum resolution of precision bathymetry the sediment profile camera was unable to penetrate to the original sediment surface and could not determine the exact thickness of material.

ADVANTAGES

1 - A picture is worth a thousand worms (D.C. Rhoads, Per. Com.). Sediment profile camera provides a unique *in situ* view of the sediment water interface and dredged material disposal.

2 - A wide range of data on physical and biological processes are collected by sediment profile cameras. These data provide an integrated estimate of habitat conditions.

3 - Quickness with which it can be applied and analyzed. Sediment profile cameras provide a rapid screening tool for assessment of habitat conditions. On-station-time for three deployments of the sediment profile camera, typically takes from 5 to 15 minutes, depending on water depth. Depending on vessel speed and distance between stations, from 10 to 80 stations can typically be occupied in a ten-hour day. If necessary, sediment profile images can be evaluated within hours of collection. Typically, a complete analysis and interpretation of 100 images can be done in 2 to 4 weeks.

4 - Relatively low cost compared to traditional methods of impact assessment. Not counting the vessel costs, 100 images can be collected for about $1,000 and analyzed for about $4,000.

5 - Can be used to more efficiently design field sampling strategies. Sediment profile image data can be mapped and used to stratify a site forming homogeneous areas for positioning quantitative samples (grabs or box-cores) and reducing the total number of replicates needed to characterize the area. This has the added benefit of increasing statistical power for a given unit of effort.

LIMITATIONS

1 - The relationship of sediment proflie image data to biological parameters needs to be better defined. Proper interpretation of many image features requires ground truth data, particularly if the area sampled is new to the technology.

2 - Sensitivity of image quality to field conditions. The camera frame must be carefully deployed to avoid disturbing the sediment surface prior to taking the sediment profile image. Vessel size and general sea state in the study site must be carefully matched. Waves greater than 4 feet and working from vessels of less then 55 feet generally leads to a high rate of surface sediment disturbance from the camera frame landing on the bottom too hard or being dragged across the sediment surface after bottom contact. The type of winch is also very important to the quality of the profile images. A power-out-power-in winch (This is the typical hydraulic winch with controlled rate of load decent to the bottom.) causes fewer surface sediment disturbance artifacts then a power-in winch (This is most electric or mechanical brake winches that free-fall their load to the bottom.). Images taken from free-fall winches have a higher rate of disturbance artifacts (mud clasts, very irregular surfaces).

3 - Video technology has not yet overcome problems of low resolution, particularly with color, that limits the detail of profile camera images.

4 - Depth of sediment profiled is currently limited to about 20 to 40 cm.

5 - Recognition of surface features is limited because of the narrow depth of field. If surface features are of primary interest a standard underwater camera should be deployed with the profile camera.

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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 minimum depth of penetration.	If the camera is level this is a good measure of small scale bed roughness, on the order of 15cm (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 biogenetics activity in muddy sediments. In 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 biogenetic activity.
i -Other Inclusions	Number counted, depth from surface of each delineated. area of each 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, depth from	Burrow presence is a good indication of deep living fauna and high biogenic activity.
k -Surface Features		Presence of these features is indicative of recent biological and physical processes.
1. Tubes	Counted and speciated.	
2. Epifauna	Counted and speciated.	
3. Pelletized Layer	Thickness and area delineated.	
4. Shell	Qualitative estimate of coverage.	
5. Mud Clasts	Qualitative estimate of coverage.	
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 -Dredge Material or other	Measure thickness above original sediment surface and area delineated.	Location of dredge material and measuring its thickness provide quantitative measure for relating impacts to the benthos of any disposal project.

Table 2. Example of data from computer image analysis of sediment profile photographs from Rappahannock Shoals, Chesapeake Bay. See figures 2 and 3 through 7 for the images.

IMAGE AREA STATISTICS

STATION	IMAGE AREAS IN CM^2 TOTAL	AERO	ANERO	VOIDS	DM	% IMAGE AREAS STAND. TO 15 CM TOTAL	AERO	ANERO	VOIDS	DM
NS-1-8 10:38	71.0	16.4	54.6	0.0	0.0	42.0	10.0	90.0	0.0	0.0
RAC206C 1:07	131.7	21.9	109.8	0.0	0.0	63.1	10.5	89.5	0.0	0.0
RAN104B 9:12	228.1	24.8	193.9	9.3	0.0	110.4	12.0	83.4	4.5	0.0
EW-7 6:09	218.7	8.4	204.3	6.0	77.1	110.0	4.0	92.9	3.1	36.7
NS-4-8 3:09	183.5	10.0	173.5	0.0	15.2	115.3	6.0	94.0	0.0	6.7

IMAGE LINEAR STATISTICS

STATION	PENETRATION MIN	PENETRATION MAX	PENETRATION AVE.	SURFA. RELIEF	RPD MIN	RPD MAX	AVE. DEPTH	DM LAYER MIN	DM LAYER MAX	DM LAYER AVE
NS-1-8 10:38	5.8	7.0	6.3	1.2	1.3	2.1	1.5			
RAC206C 1:07	9.0	10.0	9.5	1.0	0.5	2.8	1.6			
RAN104B 9:12	16.9	17.4	16.6	0.5	1.0	3.1	1.8			
EW-7 6:09	16.1	16.9	16.5	0.8	0.1	2.4	0.6	4.5	7.5	5.5
NS-4-8 3:09	16.9	17.6	17.3	0.7	0.4	1.4	0.9	0.8	1.2	1.0

PIXEL DENSITIES FROM DIGITIZED IMAGES

	TOTAL IMAGE AREA						AEROBIC IMAGE AREA					
	RED		GREEN		BLUE		RED		GREEN		BLUE	
STATION	10	90	10	90	10	90	10	90	10	90	10	90
RAN104B 9:12	74	156	81	165	78	129	142	174	148	178	108	130
EW-7 6:09	61	126	62	138	67	130	112	148	102	140	88	116

	VOID IMAGE AREA						DM LAYER AREA					
	RED		GREEN		BLUE		RED		GREEN		BLUE	
STATION	10	90	10	90	10	90	10	90	10	90	10	90
RAN104B 9:12	62	100	65	110	61	97						
EW-7 6:09	52	73	50	74	54	72	83	138	92	149	94	139

DEPTH TO VOIDS

STATION	DEPTH TO VOIDS (CM)
RAN104B 9:12	12.4, 16.3, 12.8, 14.1
EW-7 6:09	13.0
5A-B-4 12:01	25.0, 28.3, 28.5, 28.5

Table 3. Example of visual analysis of sediment profile images from Wolf Trap open-water disposal area, Chesapeake Bay.

STATION	TIME	PENET-RATION	SEDI. LAYERS	SEDI. TYPE	SURFACE INTER.	TUBES	SUBSURFACE FAUNA	VOIDS	BURROW	OTHER
NS-1-8	10:38	6 cm		FS	B				1	Clear RPD layer
RAC206C	13:07	10		SI	U,M	SOME				2-3 Lg tubes w/hydroids
RAN104B	9:12	16		MU	E		2WR@10	2-OX		
EW-7	6:09	17	DM	CL/MU	E,M	SOME		2-OX		DM light grey
NS-4-8	3:09	17	DM	MU	E,M,P	MANY	WR@3,WR@5			DM thin, light grey
5A-B-4	12:01	>30	@20	MU	E					4 Methane bubbles

KEY TO ABBREVIATIONS:

INTERFACE

- E - SMOOTH,EVEN - < 1 CM OF RELIEF
- U - UNEVEN OR IRREGULAR - > 1 CM OF RELIEF
- D - DISTURBED
- OVRP - OVERPENETRATED
- ST - STREAKED (SURFACE SHOTS)
- C - CLASTS - NOTE AS:
  - OX - OXIC (AEROBIC)
  - AX - ANOXIC (ANEROB
- M - MOUNDS
- B - BEDFORMS (SAND WAVES OR RIPPLES)
- P - PIT
- BU - BURROW OPENINGS
- R - ROCKS AT SURFACE
- F - FLOCK LAYER
- DT - DETRITUS
- FP - FECAL PELLETS PRESENT
- PA - FEEDING PALPS PRESENT
- SH - SHELLS, OR PIECES ON SURFACE

TUBES

- FEW - 1 TO <6
- SOME - 6 - 24
- MANY - >24
- MAT - VERY DENSE LAYER OF TUBES
- LR - LARGE
- SM - SMALL

SEDIMENT TYPE

- MU - MUD
- SI - SILT
- CL - CLAY
- S - SAND AS:
  - C - COARSE
  - M - MEDIUM
  - F - FINE
- MS - MUDDY SAND
- GR - GRAVEL
- R - ROCKS
- SH - SHELL

Table 4. Thickness of dredged material, at post-disposal time intervals, as determined by sediment profile imagery and precision bathymetry from the Fowl River, Mobile Bay, Alabama thin-layer open water disposal site grid stations (See Blancher et al. 1987 for a complete evaluation.).

Station	Sediment Profile Imagry 3 Weeks	10 Weeks	20 Weeks	Precision Bathymetry 10 Weeks
NS- 2-03	2-4 cm	2-3 cm	9 cm	15-30 cm
NS- 2-04	>20	17	ND*	15-30
NS- 2-05	>20	>16	9	30-45
NS- 2-06	>20	>17	>18	30-45
NS- 2-07	>20	>14	5	15-30
NS- 2-09	ND	ND	ND	15-30?
NS- 3-04	16-17	16-17	>20	15-30
NS- 3-05	>20	>16	>20	30-45
NS- 3-06	>20	>16	8	15-30
NS- 3-07	>20	>16	>16	15-30
NS- 3-08	>20	?	ND	ND
NS- 3-09	?	1-2?	ND	ND
NS- 4-04	>20	>17	?	ND
NS- 4-05	>20	?	?	ND
NS- 4-06	>20	>13	>15	15-30
NS- 4-07	>20	>16	>16	15-30
NS- 4-08	1-4	ND	ND	ND
NS- 4-09	1-2	ND	ND	ND
NS- 4-10	1-2	ND	ND	ND
NS- 5-06	>20	ND	6	ND
NS- 5-07	10-13	10-14	?	ND
NS- 5-08	ND	ND	?	ND

* ND - Dredged Material Not Detected
? - Possable Dredged Material Signature
> - Indicates Dredged Material Was Thicker Then Sediment Profile Camera Prism Penetration.

Figure 1. Diagram of Hulcher model Minnie sediment profile camera. The cutting edge contacts the sediment first then the 45° angle of the prism displaces sediment away from the cutting edge as the entire unit penetrates below the sediment surface.

Figure 2. Sediment profile camera image from Mobile Bay, Alabama, (Station NS-1-9 see Figure 9, Benthos profile camera, Kodachrome 64 film). The sediment-water interface is marked by the edge of the cross-section of the fine sand ripple. The water column has many sand grains susspended from deployment of the camera frame. Notice the light brown aerobic sand layer over the dark grey aerobic sediments. The area between these aerobic and anaerobic sediments is know as the redox-potential discontinuity layer (RPD). There is also a burrow located under the crest of a sand ripple. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 3. Hulcher sediment profile camera, model Minnie, deployed in aluminum frame. Base is approximately 80 X 120 cm.

Figure 4. Sediment profile camera image from Rappahannock Shoals, Chesapeake Bay (RAC206C-3, Hulcher profile camera, Fujichrome 100 film), with various size worm tubes and hydroid colonies at the surface. These biogenic structures are indicative of "healthy" habitats. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 5. Sediment profile camera image from Rappahannock Shoals, Chesapeake Bay (RAN104B, Benthos profile camera, Fujichrome 100 film), with even sediment-water interface and a series of active head down deposit feeding maldanid polychaete feeding voids. These deep feeding voids are key features in determining the advanced successional stage of the benthic communities. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 6. Sediment profile camera image from Mobile Bay, Alabama (Station near NS-2-5 see Figure 9, Benthos profile camera, Kodachrome 64 film), taken on the edge of a open-water disposal site showing a 6 cm layer of dredged material over "natural" sediments. The dredged material has been recolonized by small tube building capitellid polychaetes. The dark grey band at 6-7 cm is the original water-sediment likely darkened from the aerobic metabolism of organic matter present at the surface when it was covered by dredged material. The apparent RPD is less then 1 cm thick. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 7. Sediment profile camera image from Mobile Bay, Alabama (Station NS-4-8 see Figure 9, Benthos profile camera, Kodachrome 64 film), taken in the fringe area surrounding the disposal site and showing a thin, about 1 cm, layer of dredged material. The surface is covered by small tube building capitellid polychaetes. At 3 and 5 cm below the sediment surface there are worms pressed against the prism faceplate. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 8. Sediment profile camera image from the edge of the deep natural channel in Chesapeake Bay, south of Annapolis, MD (Station RAN104B, Hulcher profile camera, Fujichrome 100 film), showing methane gas bubbles 25-30 cm below the sediment surface. This is the fourth slide of a sequence of four. Because the sediments were of low bulk density the camera was set to take the first photograph 1 sec. after bottom contact with the three subsequent photographs at 2 sec. intervals. See Tables 2 and 3 for the image analysis statistics that pertain to this image.

Figure 9. Field sampling design for the Fowl River, Mobile Bay, Amabama, thin-layer open-water disposal study.

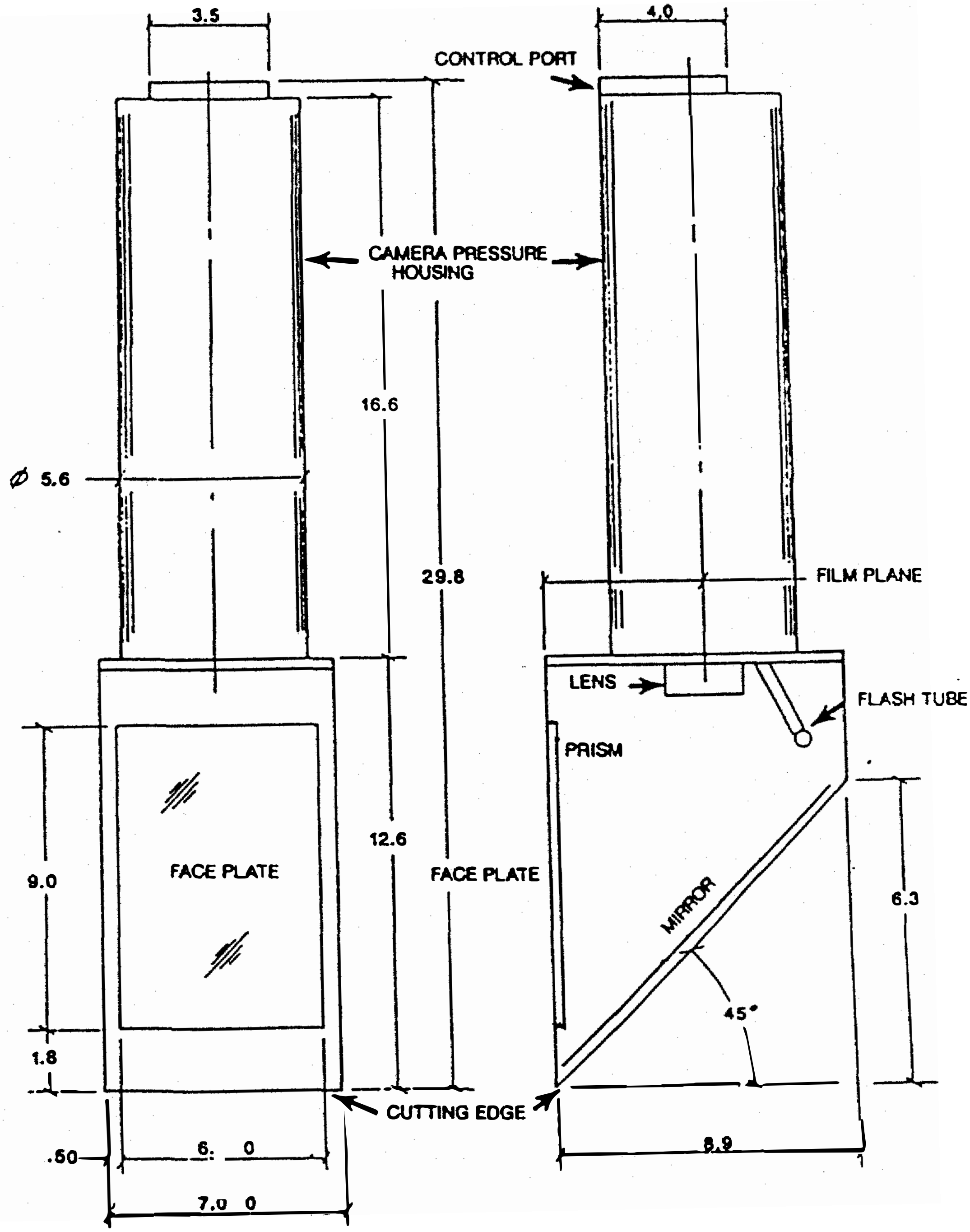
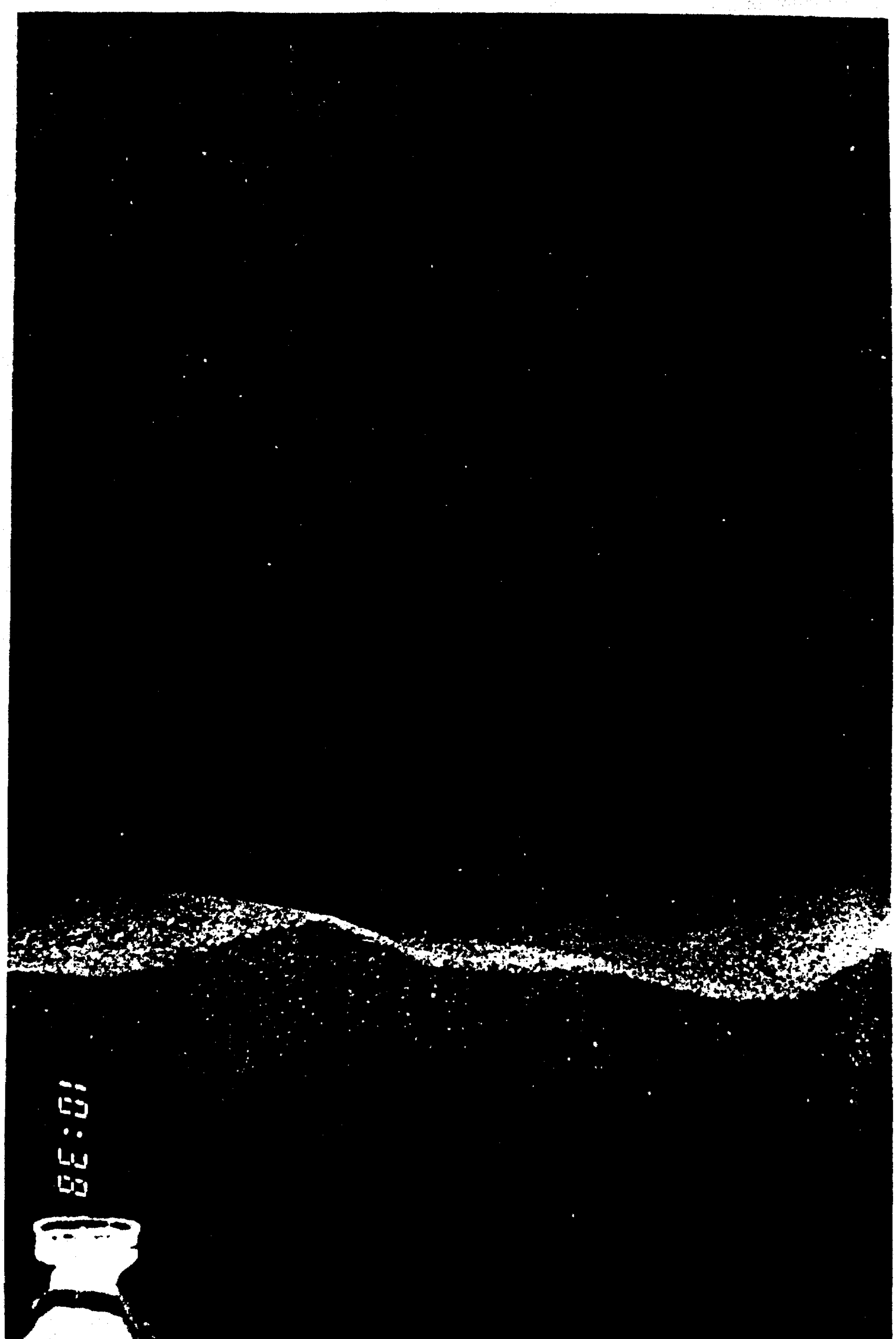

3.5
4.0
CONTROL PORT
CAMERA PRESSURE HOUSING
16.6
Ø 5.6
29.8
FILM PLANE
LENS
FLASH TUBE
PRISM
12.6
FACE PLATE
FACE PLATE
9.0
MIRROR
6.3
45°
1.8
CUTTING EDGE
.50
6.0
8.9
7.0

Figure 1



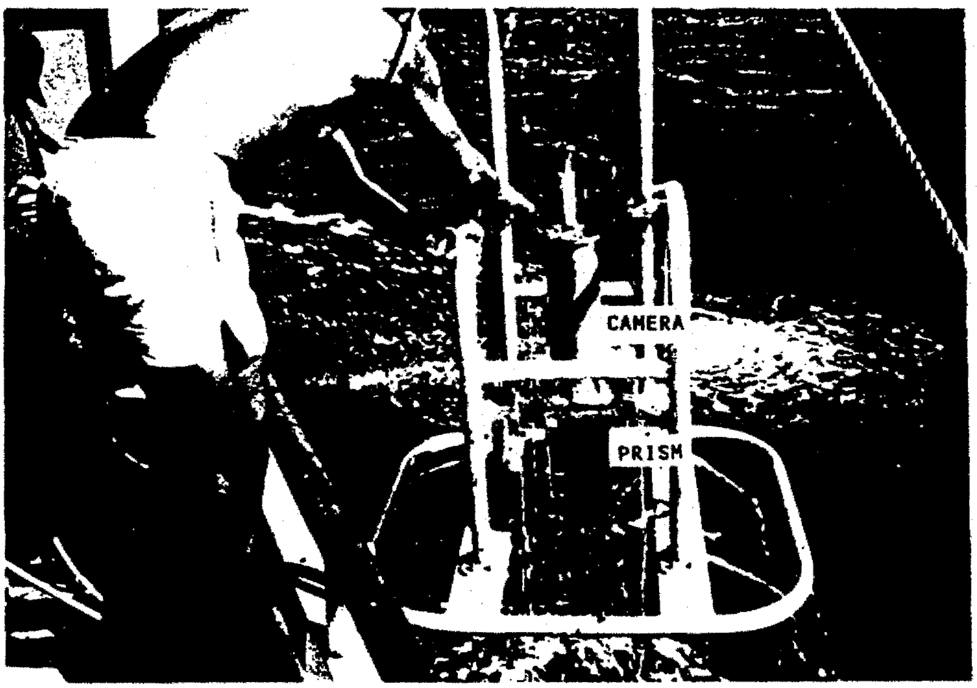


Figure 3 . Hulcher sediment profile camera, model Minnie, deployed in aluminum frame. Base is approximately 80 X 120 cm.

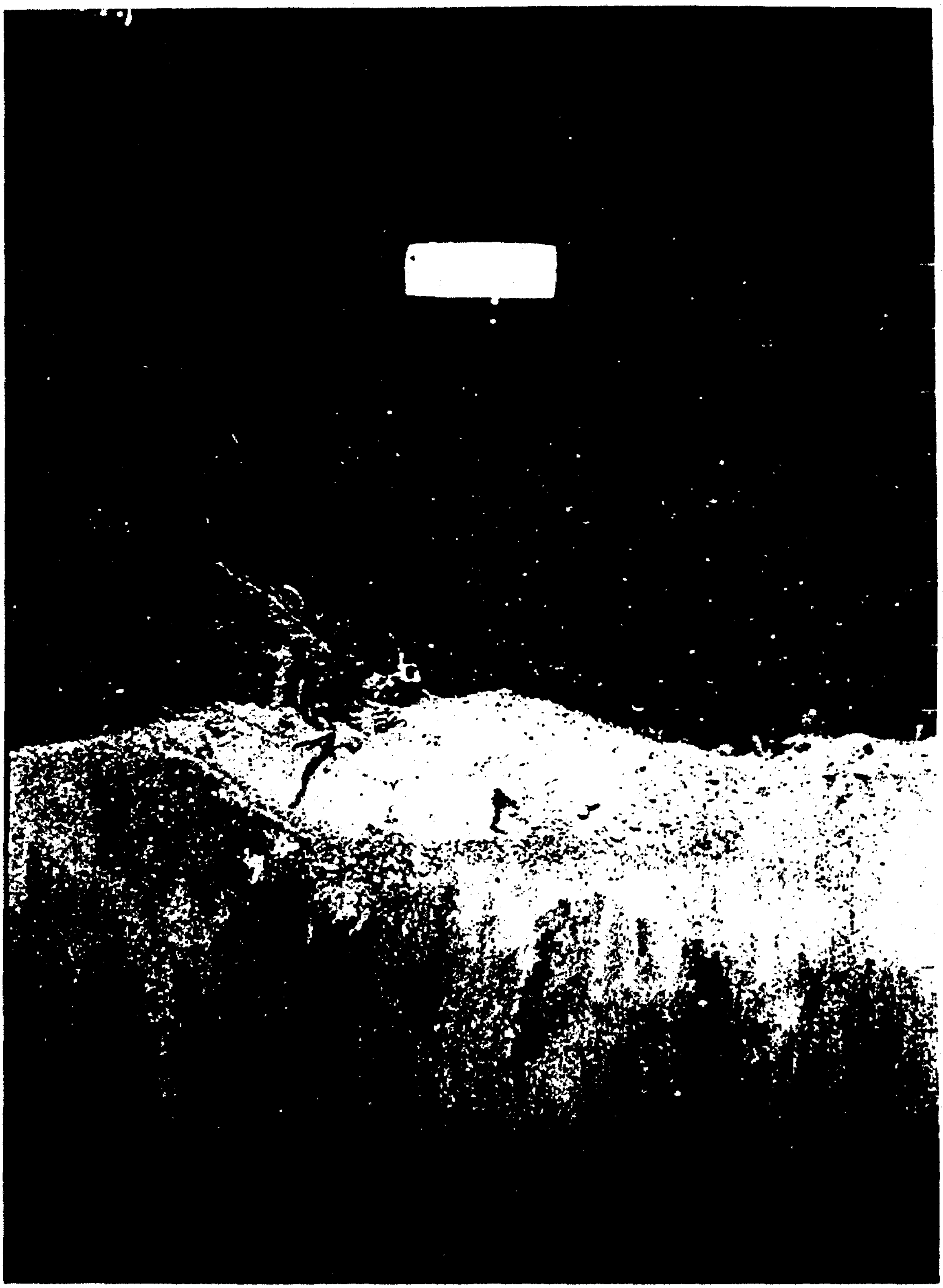
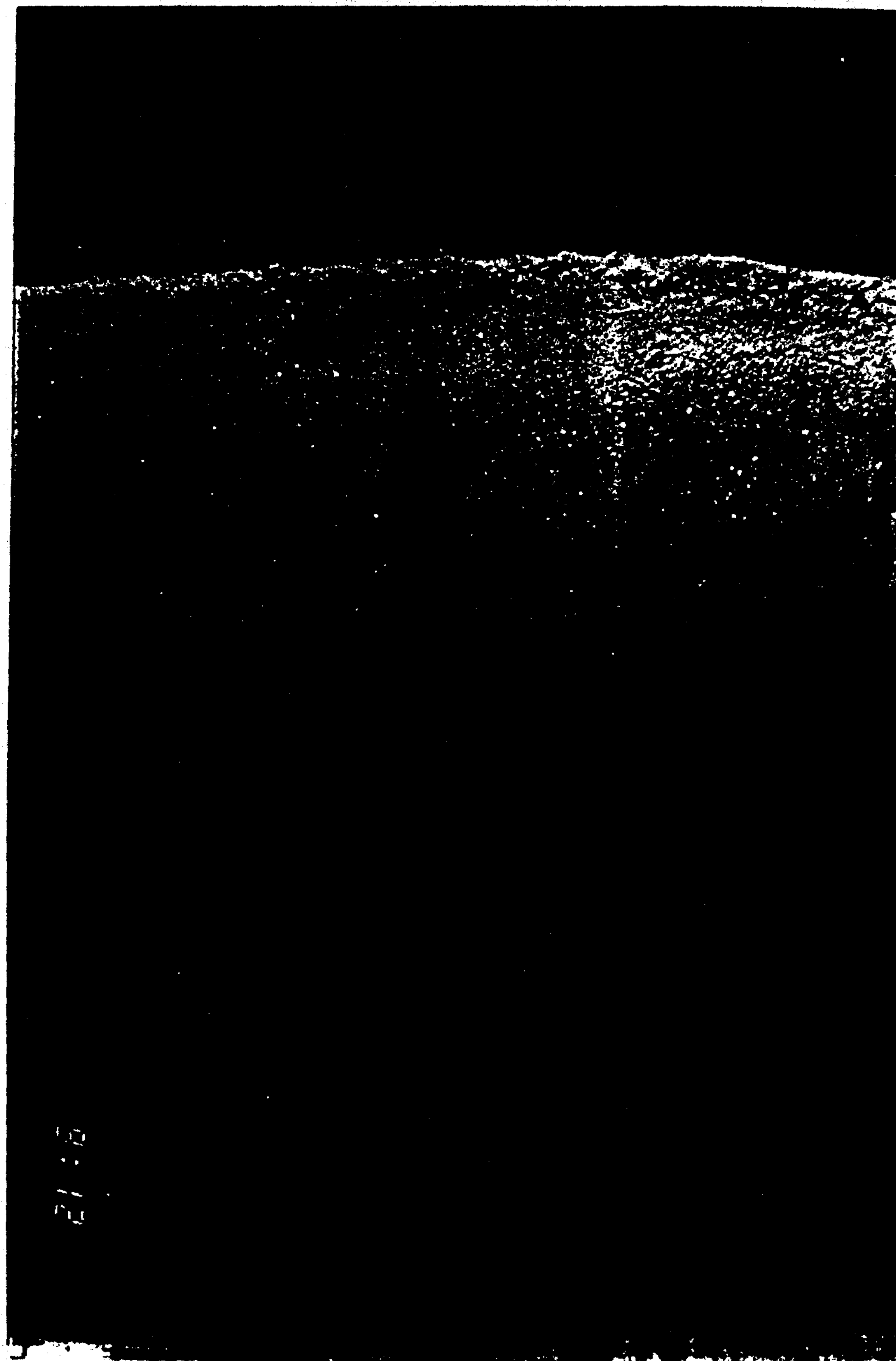


Figure 4



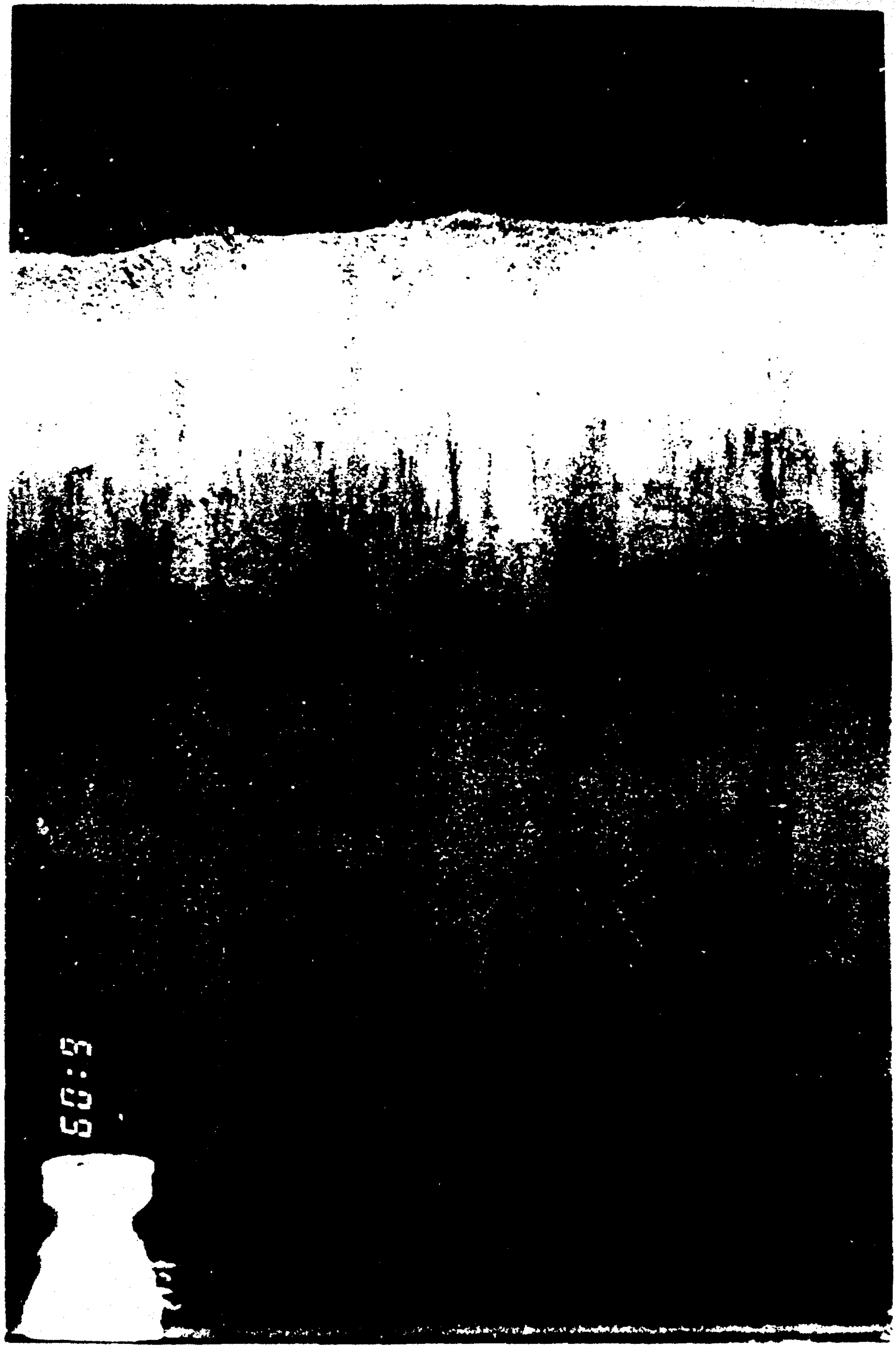


Figure 6

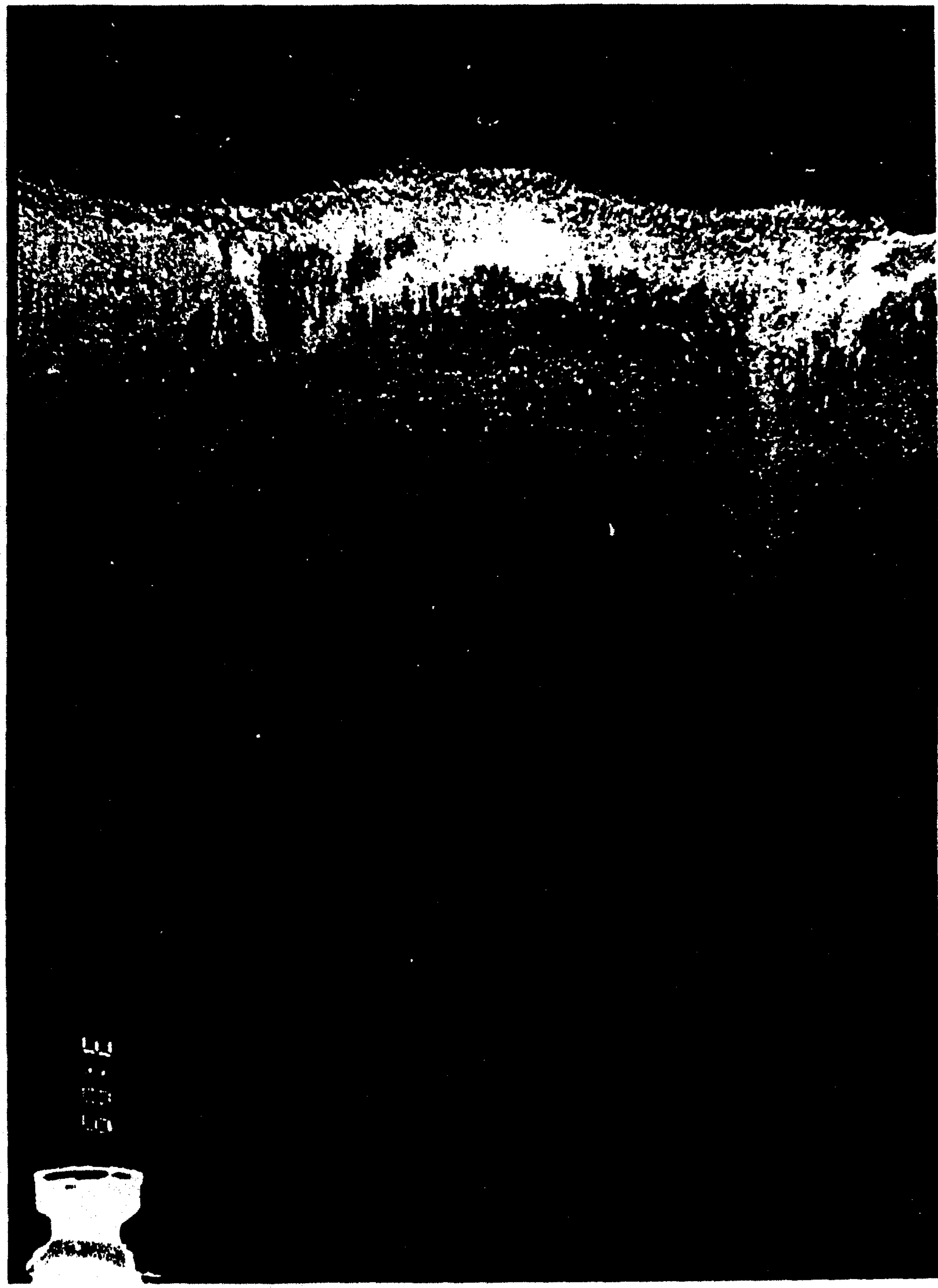


Figure 7

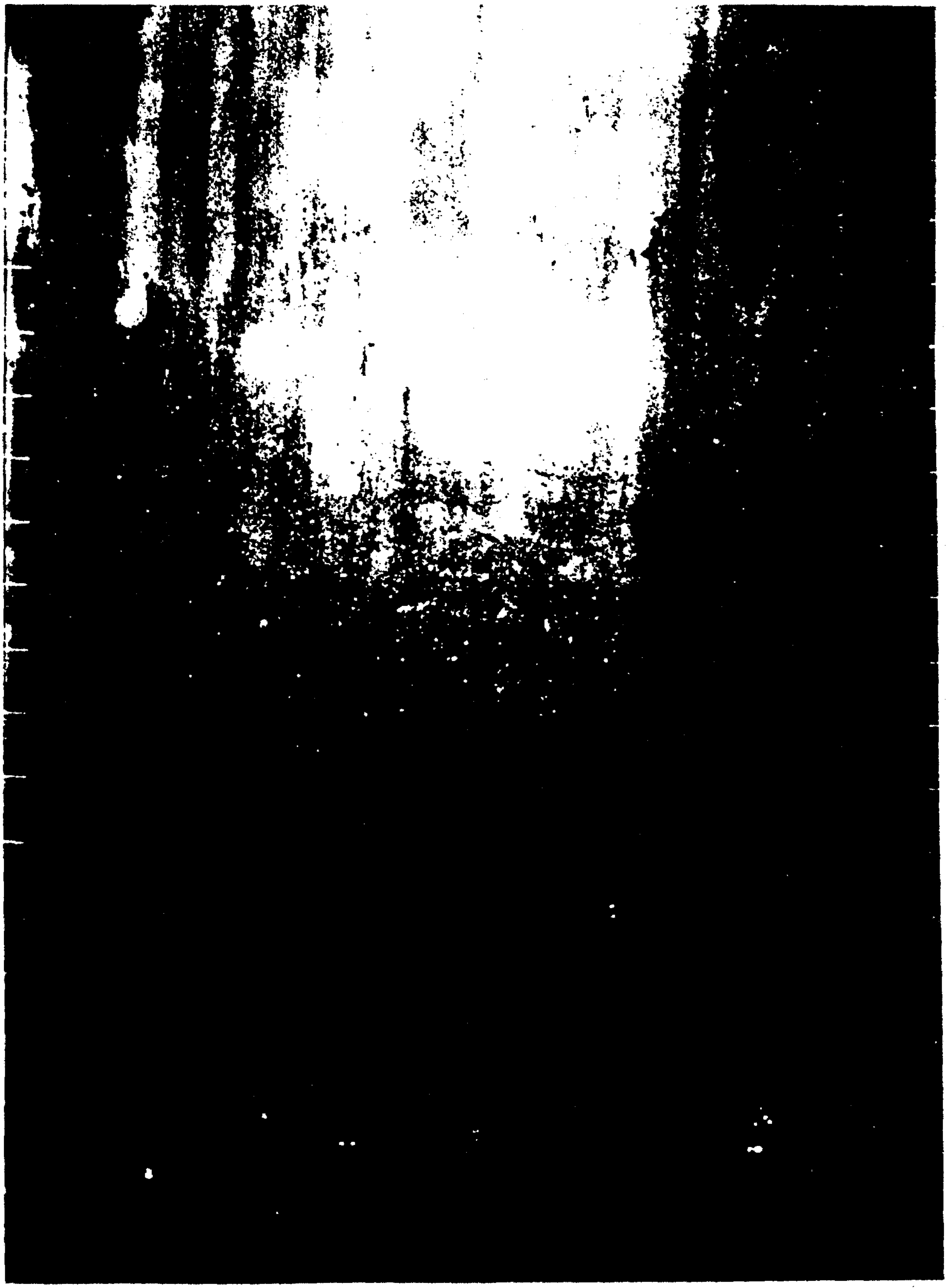


Figure 8

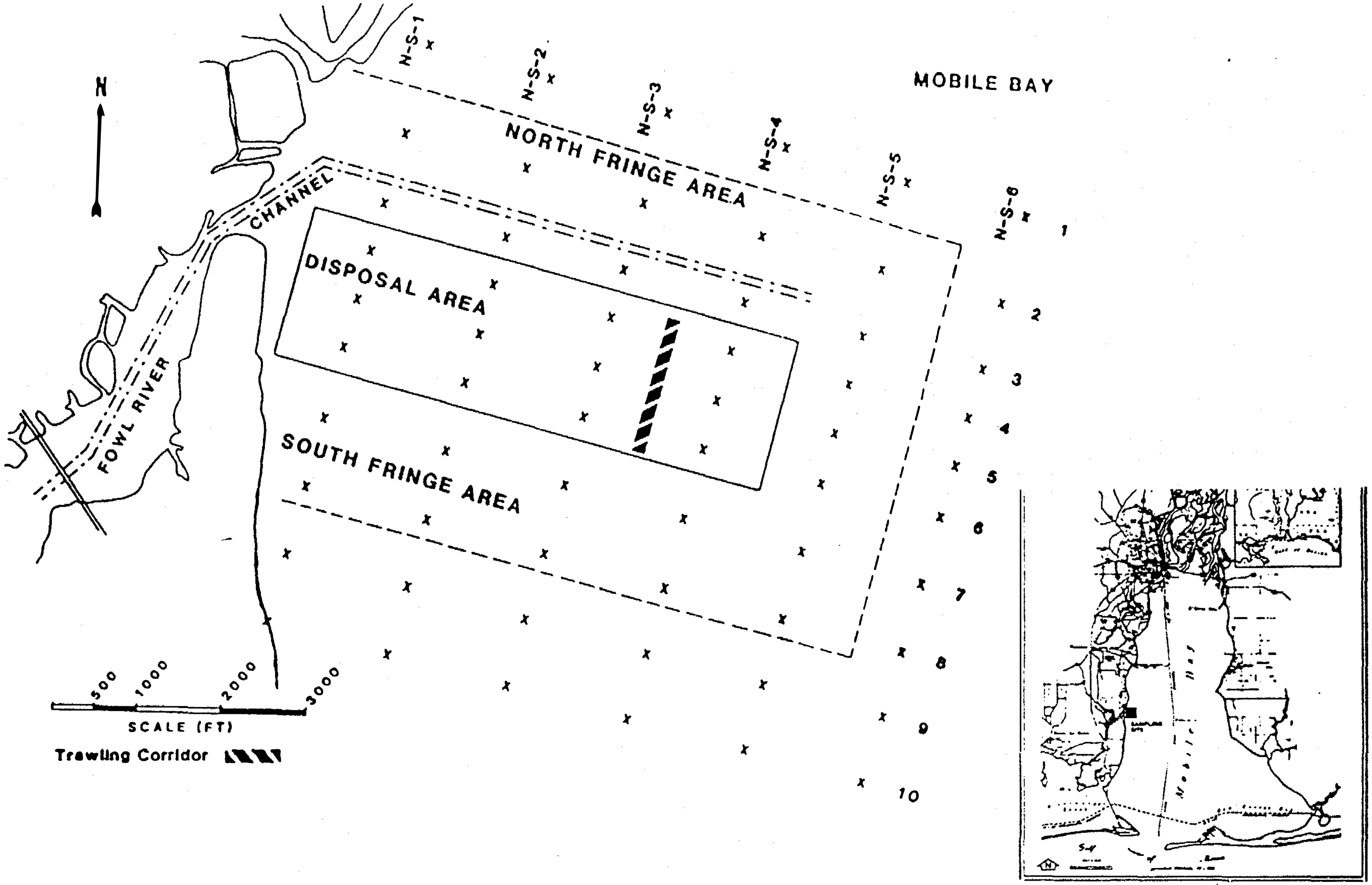

MOBILE BAY
N
N-S-1
N-S-2
N-S-3
N-S-4
N-S-5
N-S-6
NORTH FRINGE AREA
CHANNEL
DISPOSAL AREA
SOUTH FRINGE AREA
FOWL RIVER
1
2
3
4
5
6
7
8
9
10
500
1000
2000
3000
SCALE (FT)
Trawling Corridor

Figure 9