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DISPOSAL AREA MONITORING SYSTEM

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IV. Field Verification Program (FVP)
Monitoring Surveys

Edited By:

R. W. Morton
J. H. Parker
W. H. Richmond

Science Applications International Corporation
Admiral's Gate, 221 Third Street
Newport, Rhode Island 02840

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IV. FIELD VERIFICATION PROGRAM MONITORING SURVEYS

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IV. FIELD VERIFICATION PROGRAM (FVP) MONITORING SURVEYS

AUTHORS:

Robert W. Morton - SAIC

Joseph D. Germano - MSI

Gary D. Paquette - SAIC

Donald C. Rhoads - MSI

IV. FIELD VERIFICATION PROGRAM (FVP) - MONITORING SURVEYS

1.0 INTRODUCTION

Through the Disposal Area Monitoring System program (DAMOS), the New England Division of the Corps of Engineers has been supporting a joint EPA-COE project at the CLIS disposal site since March 1982. A description of the Field Verification Program (FVP), the baseline surveys and subsequent disposal site selection have been presented in DAMOS Contribution #23. To briefly summarize the conclusions of that report, the proposed FVP site (Fig. I-1-2) at the northeast corner of the CLIS open water disposal area (41°9.39'N, 72°51.75'W) was characterized by a flat, gently sloping topography with the typical Central Long Island Sound mud bottom. The disposal site was considered to be very homogenous and typical of natural sediments in the region. These conclusions were reached based on sediment chemistry, diver observations and the REMOTS interface camera. Suspended sediment measurements indicated that the potential impact on the FVP site of other proposed disposal operations in the southwest corner of the CLIS disposal area would be negligible.

Continuing DAMOS operations occurred in three phases: the pre-disposal surveys, the disposal operation itself, and the immediate post-disposal surveys that were conducted through September 1983. The data included bathymetry and side scan sonar measurements, diver observations, suspended sediment measurements, REMOTS profiling, sediment chemistry, density probe measurements and visual observations of cores, and were reported in DAMOS Contribution #46 (Volume II, Section III).

This section describes the work conducted between September 1983 and December 1984, which includes precision bathymetric surveys and REMOTS imagery.

2.0 BATHYMETRY

A survey grid (Fig. IV-2-1) was established consisting of 33 transects, 800 meters long oriented in an east-west direction and spaced 25 meters apart. When conducting the surveys, navigation control was provided by the SAIC Navigation and Data Acquisition System. All navigation control for surveys and REMOTS photography was provided by the SAIC Navigation and Data Acquisition System, a computerized control unit interfaced to a Del Norte 540 microwave positioning system. The SAIC system provides real time video displays of ship position relative to designated lanes or locations which substantially enhance the capability of the ship's helmsman to steer survey lanes within ±5 meters and to obtain replicate sediment samples within ±10 meters. This precision in ship control is an essential requirement for this program since the disposal mounds are quite small and spatial variability in measured parameters is relatively large. Using calibration techniques established under

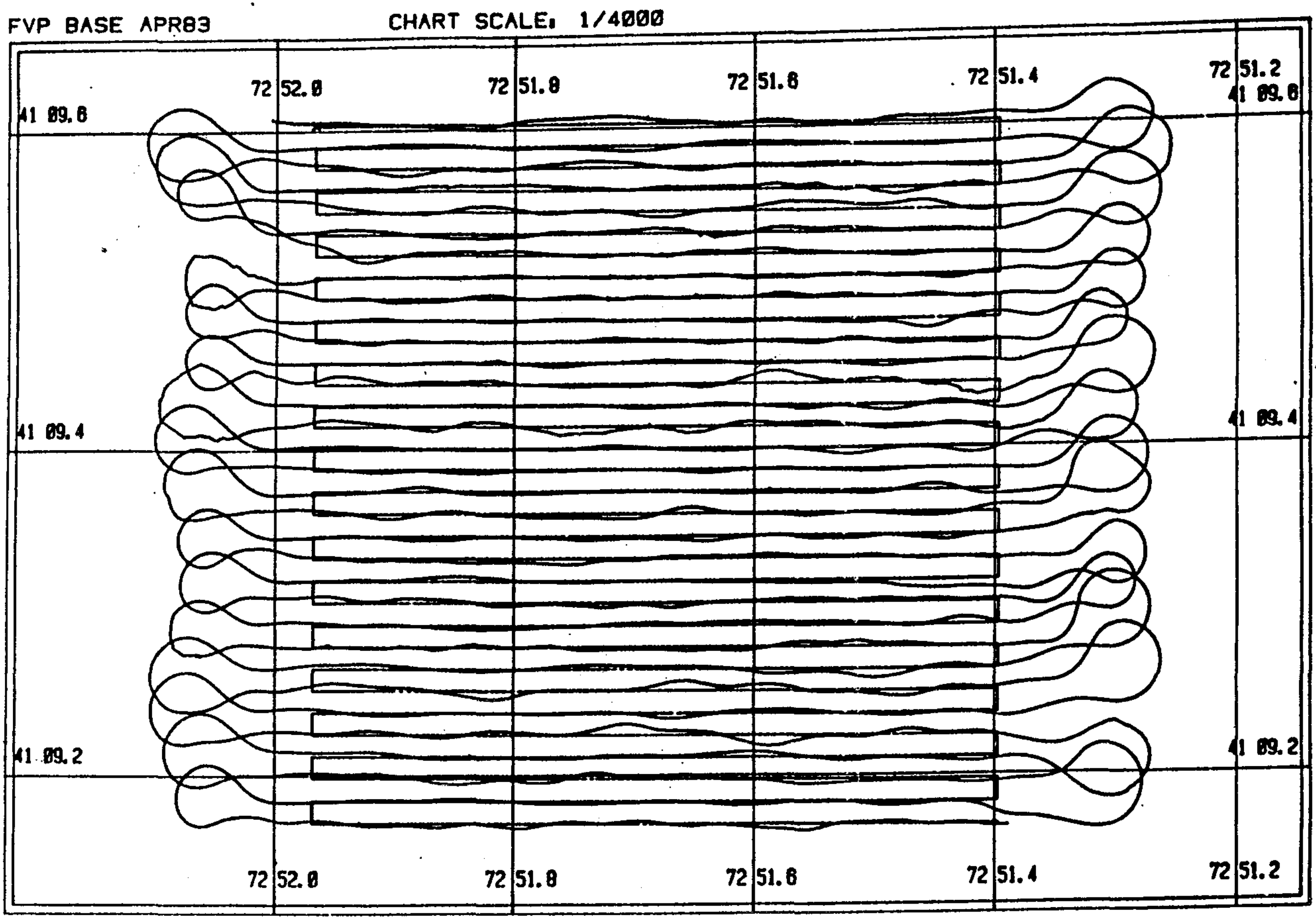


Figure IV-2-1. Ship's Track, FVP Base, April 1983.

the DAMOS program, recorded position accuracies within the CLIS disposal site are ±1-2 meters.

Disposal of contaminated Black Rock sediment was carefully monitored at the FVP site through a series of interim surveys in April and May 1983. The immediate post-disposal survey on 19 May revealed a relatively small deposit approximately 200m by 100m, with the major axis oriented in an east-west direction. When viewed on the contour difference chart, the topographic expression is slightly larger with a thin layer of material extending along a NE/SW direction. The maximum thickness of the mound is approximately 1.8 meters.

Three post-disposal surveys were conducted in June, July and August 1983. The mound initially experienced an apparent decrease in height, which is a likely result of initial reworking and consolidation of the dredged material. No further changes in the mound topography were apparent throughout August 1983.

The bathymetric surveys reported here were conducted in December 1983 and March, June and September 1984. Figures IV-2-2, 3, 4 and 5 are the bathymetric contour charts for these surveys, respectively. Examination of the depth at the center of the dredged material mound in December 1983 reveals a slight increase of between 0.2 and 0.4 m, indicating continued consolidation of the disposed material. The bathymetric surveys in 1984 depicted a stable mound configuration with no significant changes occurring. Figure IV-2-6 presents the individual lane records for all the surveys conducted at the FVP disposal site. The solid lines indicate the baseline and immediate post-disposal surveys, while the points demonstrate the bathymetry of the later monitoring surveys.

3.0 REMOTS SURVEYS

REMOTS survey procedures were utilized at the FVP site on five occasions, approximately 8, 10, 13, 16 and 19 months after the disposal operations. Results from the analyses of the REMOTS photographs serve to monitor potential change in the distribution of deposited dredged material, to document the process of successional recovery at the FVP disposal site, and to monitor changes in the ambient fauna and sediments adjacent to the site.

As discussed in the previous section (Section III), the replicate bathymetric surveys provide a reasonable approach to remote sensing of disposal mound stability over time, but are somewhat restricted in their ability to detect small vertical changes in depth (±20 cm) on a point by point basis. While they can define the extent of the disposal mound and the total volume of material present, the bathymetric surveys cannot delineate the apron of finer material that surrounds the disposal mound. As this apron becomes finer, detection by acoustic measurement becomes impossible and other methods must be used.

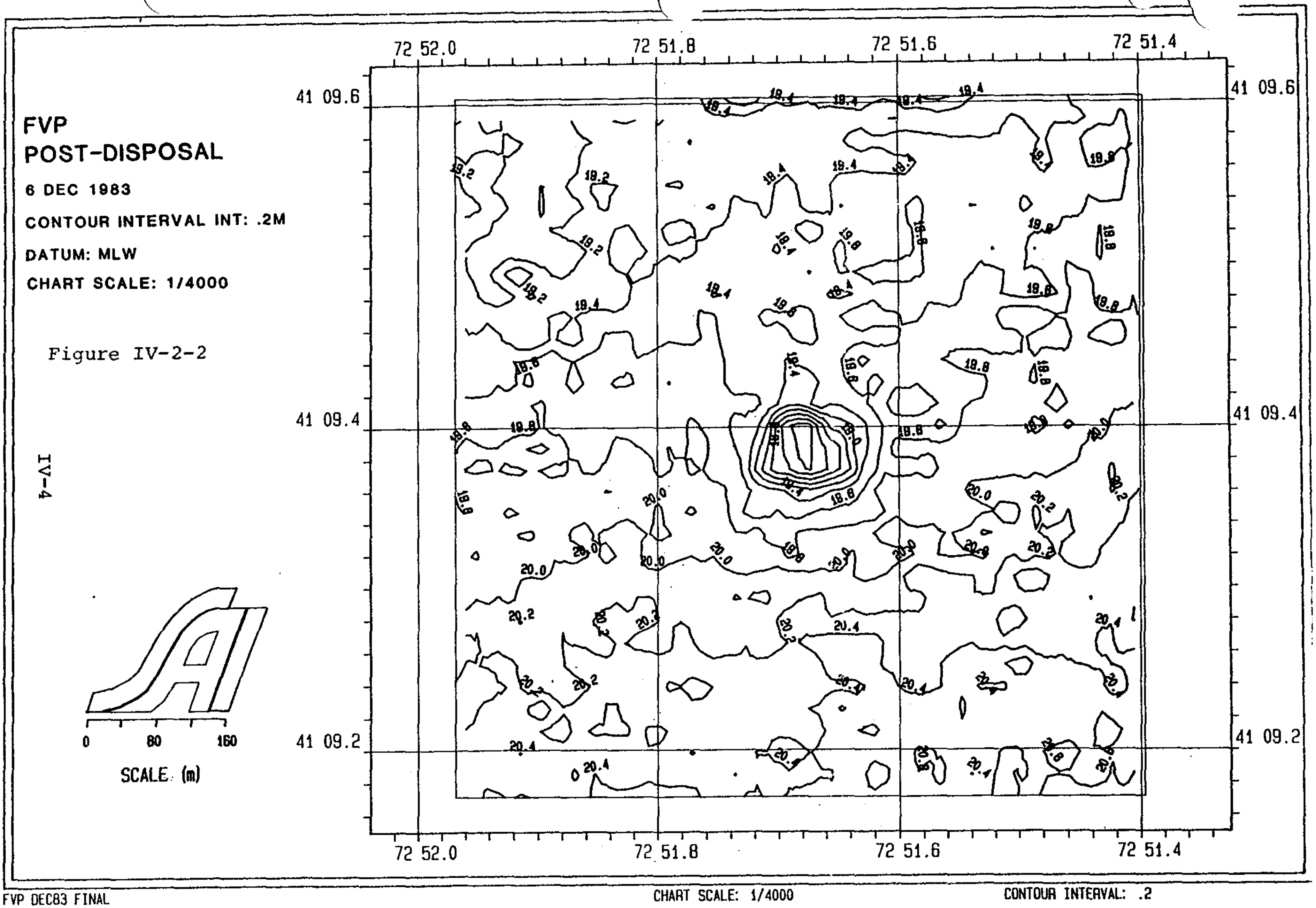

FVP
POST-DISPOSAL
6 DEC 1983
CONTOUR INTERVAL INT: .2M
DATUM: MLW
CHART SCALE: 1/4000
72 52.0
72 51.8
72 51.6
72 51.4
41 09.6
41 09.4
41 09.2
0
80
160
SCALE (m)
FVP DEC83 FINAL
CHART SCALE: 1/4000
CONTOUR INTERVAL: .2

Figure IV-2-2

FVP
POST-DISPOSAL

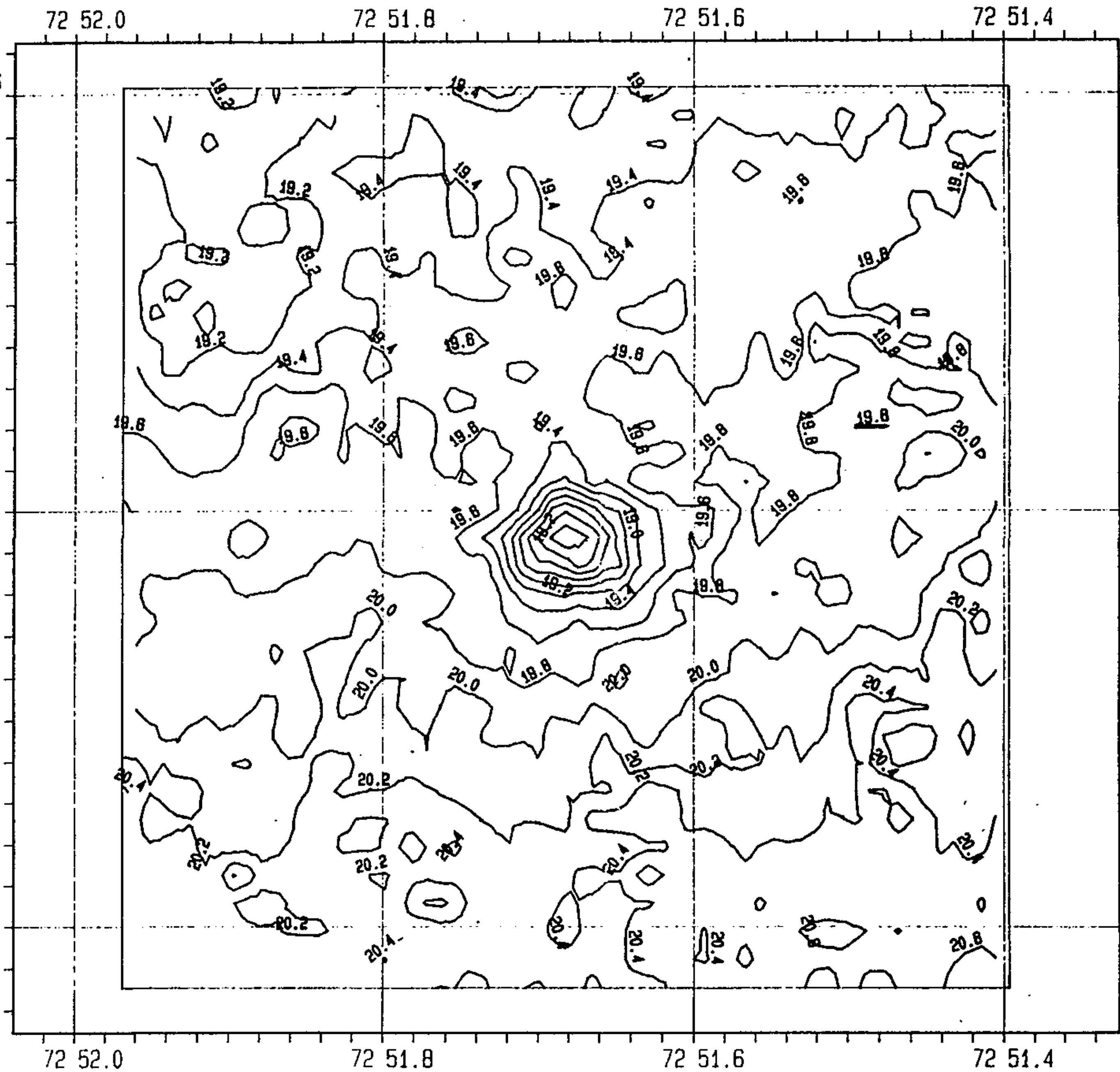
12 MAR 1984

CONTOUR INT: .2M

DATUM: MLW

CHART SCALE: 1/4000

Figure IV-2-3



0 80 160

SCALE (m)

FVP 12 MARCH 1984 TIDE CORRECTED

CHART SCALE: 1/4000

CONTOUR INTERVAL: .2

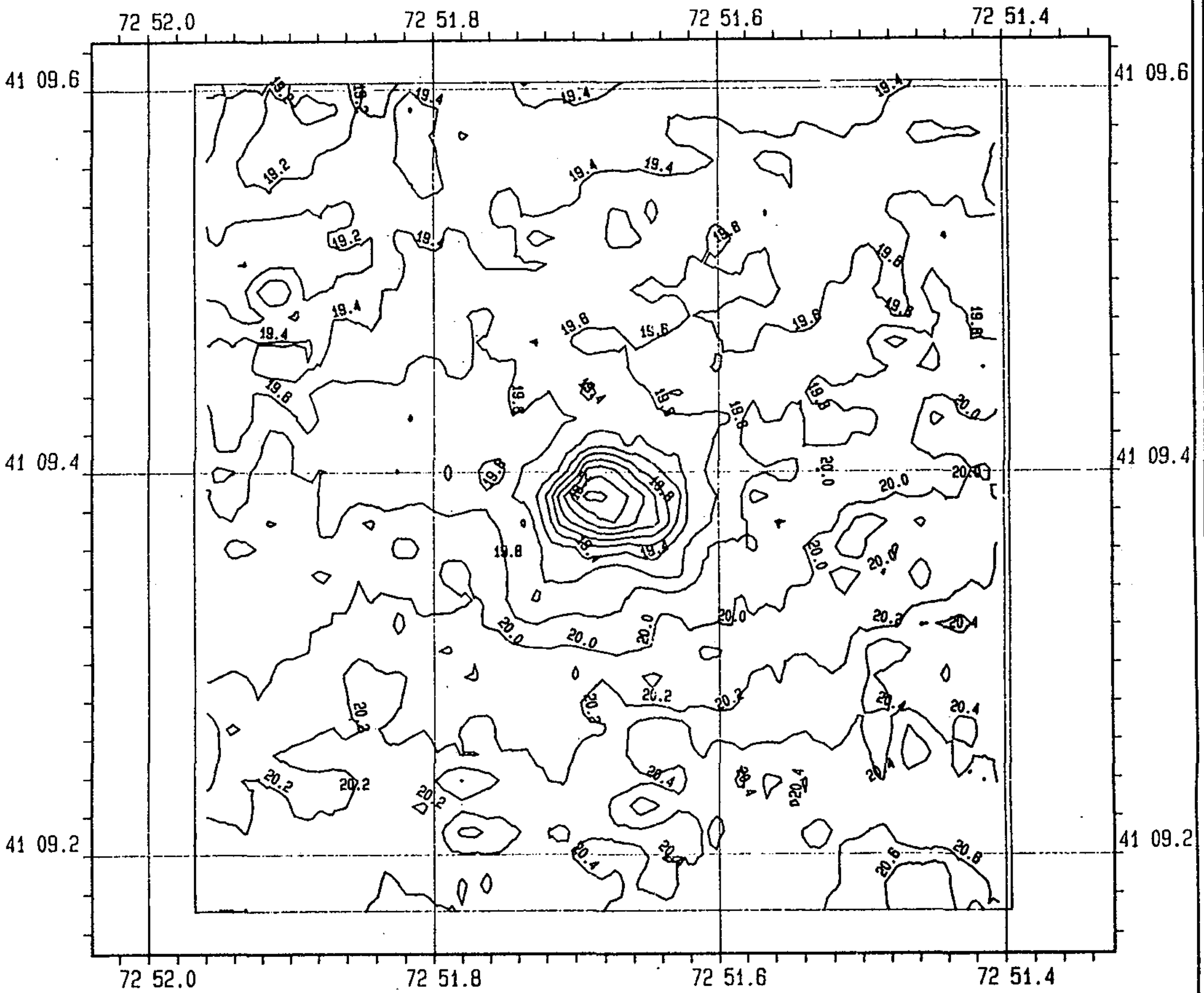
FVP
21 JUNE 1984

INTERVAL: 0.2m

SCALE: 1/4000

DATUM: MLW

Figure IV-2-4



0 80 160
SCALE (m)

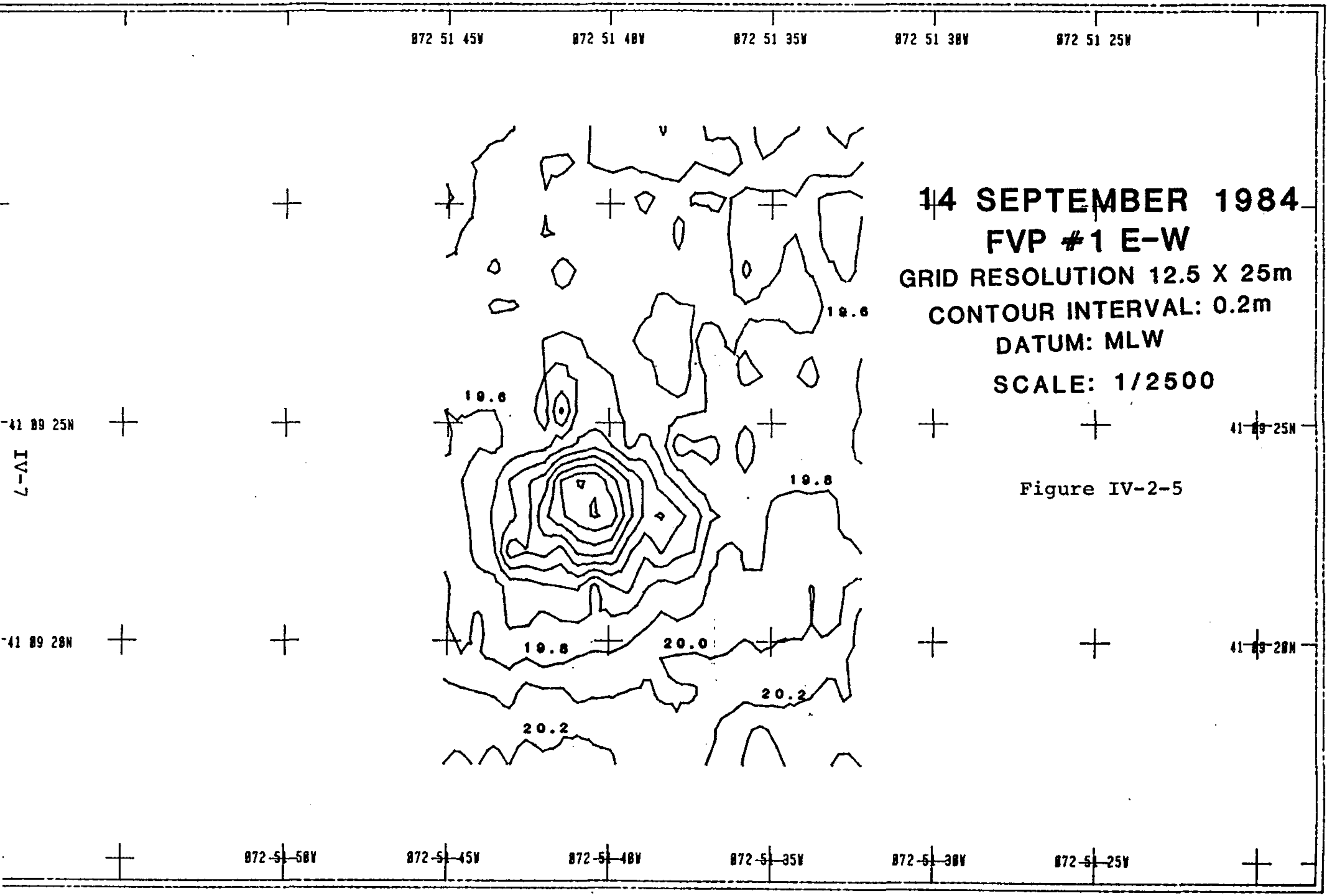

14 SEPTEMBER 1984
FVP #1 E-W
GRID RESOLUTION 12.5 X 25m
CONTOUR INTERVAL: 0.2m
DATUM: MLW
SCALE: 1/2500
072 51 45W
072 51 40W
072 51 35W
072 51 30W
072 51 25W
072 51 50W
41 09 25N
41 09 20N
19.6
19.8
20.0
20.2

Figure IV-2-5

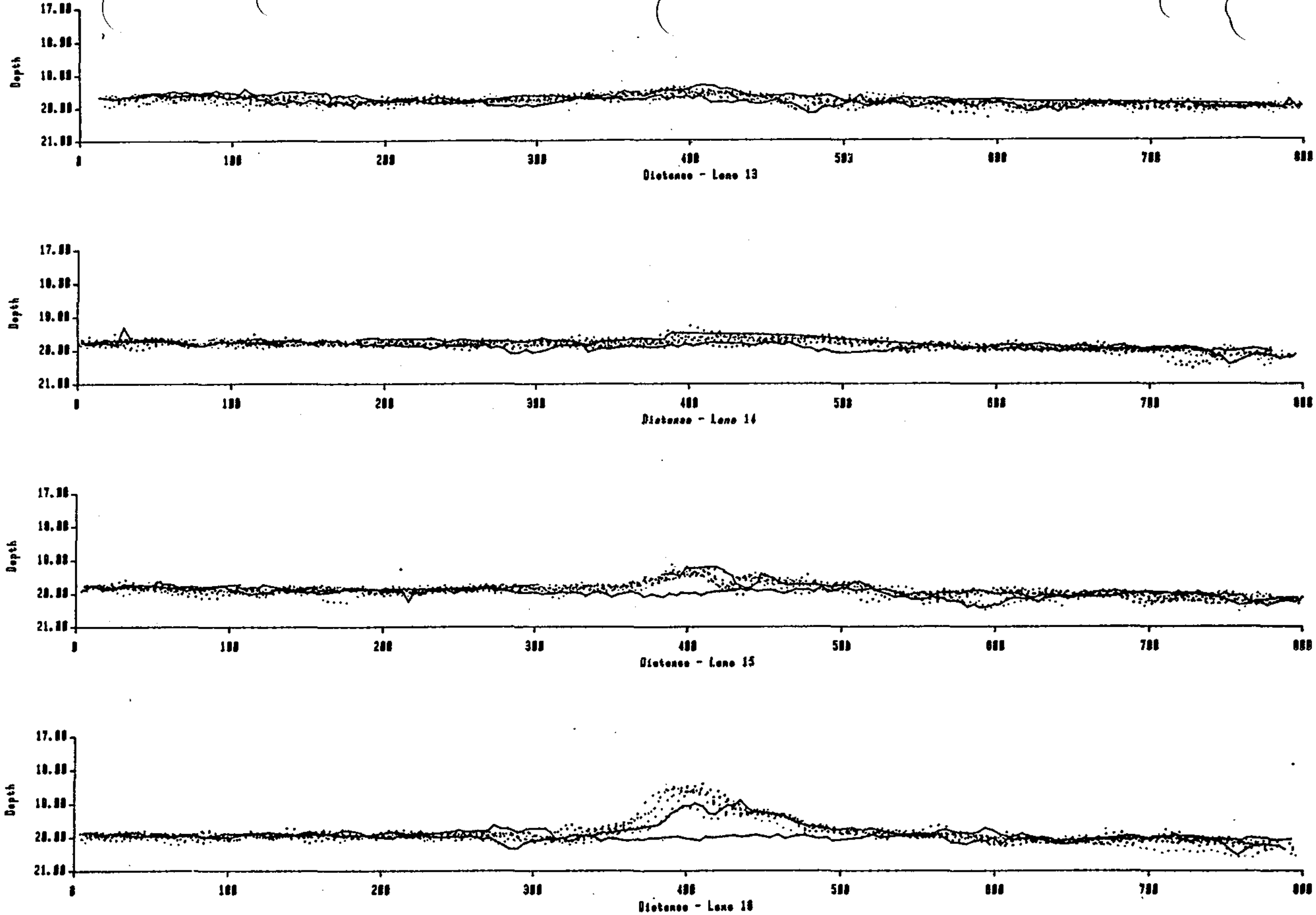


Figure IV-2-6a. Vertical profiles at FVP for all surveys.

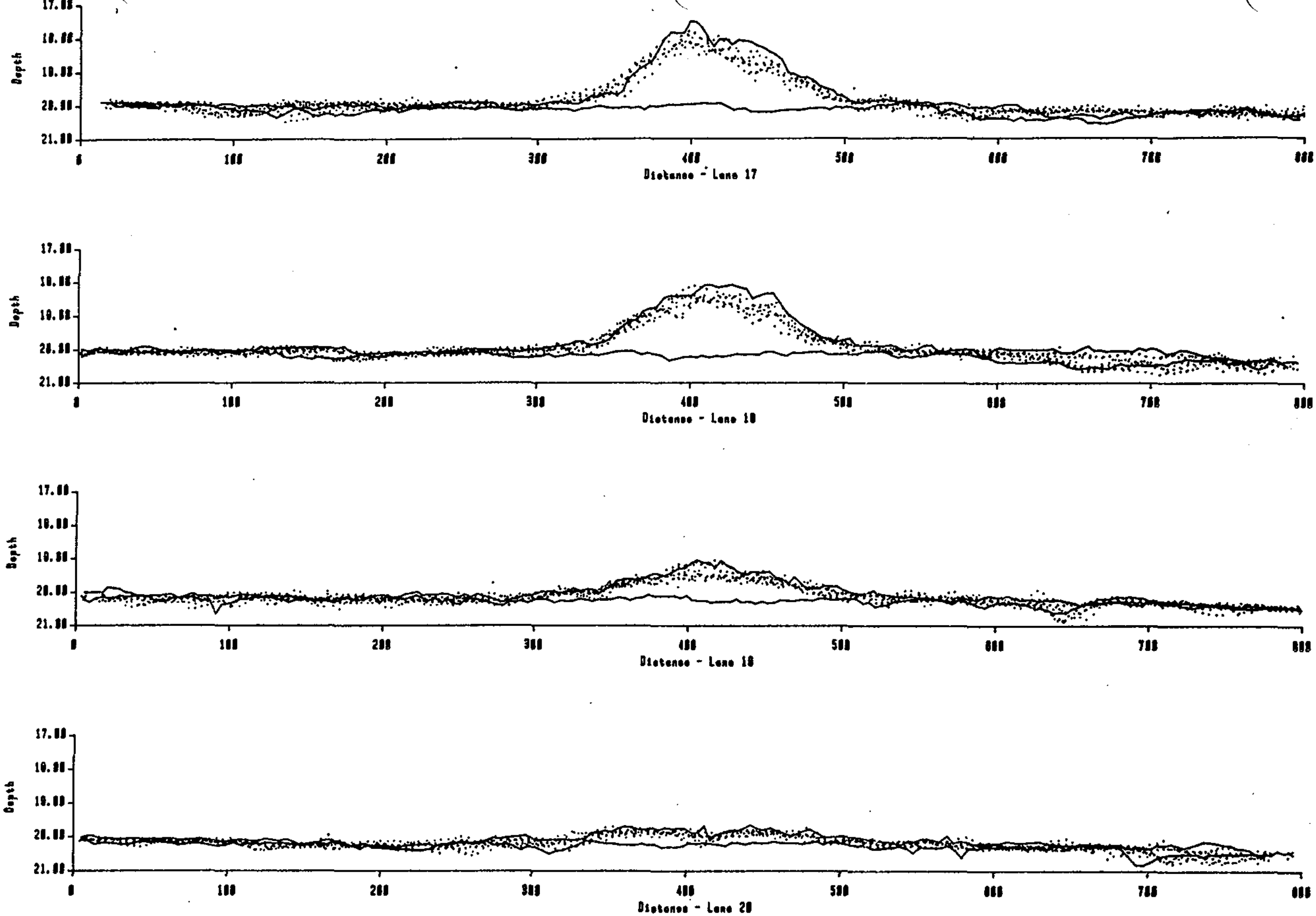


Figure IV-2-6b.

The REMOTS camera provides vertical photographic images of the sediment/water interface to a nominal depth of 18 cm and can be used to map specific parameters such as dredged material thickness, surface boundary roughness, oxidation depth, modal grain size and other more general information related to benthic biology, including faunal succession and bioturbation effects. The primary advantage of the REMOTS camera is its ability to accurately measure small thicknesses of dredged material over the fringe areas when used in conjunction with excellent navigation control and replication of measurements.

3.1 Methods

On 23 January 1984, twenty stations were occupied at the FVP site. These were the same stations occupied during the 1983 REMOTS monitoring study. For this survey and the others that followed, three replicates were taken at each station and six station replicates were taken at the CLIS-REF station. Methods of image interpretation are outlined in earlier FVP reports and are not repeated here.

On 16 March 1984, twenty-two stations were occupied at the FVP site, including two stations not included in previous REMOTS monitoring studies, 400E and 1000E/50N.

On 7 June 1984, twenty-one stations were occupied at the FVP site. These stations correspond to those monitored during the March 1984 survey, except for station 1000E/50N, which was not monitored during the present study.

On 4-6 September 1984, 57 stations were occupied at or adjacent to the FVP site. These stations correspond to those occupied during the first FVP post-disposal REMOTS survey. The thirty central stations in this array (see Fig. IV-3-10) are considered to be on the main disposed dredged material mound or flanks as defined by REMOTS and bathymetric surveys conducted immediately after the disposal operation in May 1983. The surrounding 27 stations are classified as edge and ambient stations. Three REMOTS images were taken at each station and 8 images were taken at the CLIS-REF site.

On 18 December, 21 stations were occupied at or adjacent to the FVP site. These stations correspond to those monitored during the March 1984 survey. The twelve central stations are considered to be on the main dredged material mound or flanks based on REMOTS and bathymetric surveys conducted immediately after the FVP disposal operation (see Figure IV-3-13). The surrounding nine stations are classified as edge and ambient stations. Three REMOTS images were scheduled to be taken at all stations. However, due to camera strobe failure, only one replicate image was obtained at stations 250E, 100W, and 250W, while two replicates were obtained at 400E, 300S, 200N/300E, and 200N/300W. On 17 December, twenty-one REMOTS images were taken at the CLIS-REF site compared to six replicates in previous surveys. Increased sampling at the CLIS-REF site was done to facilitate statistical comparisons between the reference site and the disposal area.

3.2 Results

3.2.1 Grain Size

During the January 1984 survey, most stations, as reported in earlier surveys, show a grain-size distribution of $>$4-3 Φ (silt-clay). Minor additions of 3-2 Φ (fine-sand) occurred primarily in pelletized fecal layers at the water-sediment interface and within feeding voids. Station CTR had a surface layer of fine to medium sand (3-1 Φ) overlying silt-clay mud ($>$4 Φ) which may represent a scour surface. This surface layer of fine sand can be seen in the photograph in Figure IV-3-1.

The apparent grain-size distribution at most stations remained $>$4 Φ (silt-clay) in March 1984 with some minor additions of 3 to 2 Φ (fine sand). Coarser particles in the form of shell debris were also present, but this component was not reflected in the above grain-size characterization. Station CTR showed no change in grain size.

During the June 1984 survey, all stations, except for CTR, show an apparent grain-size distribution of $>$4-3 Φ (silt-very fine sand), with the major component being $>$4 Φ (silt-clay). Station CTR again consisted of a surface layer of fine to medium sand (3-1 Φ) which overlies silt-clay.

The surveys conducted in September and December 1984 showed no change in grain size from the previous surveys.

3.2.2 Boundary Roughness

Figure IV-3-2 shows the boundary roughness class frequency distribution from small-scale topographic relief during the January 1984 survey. The major mode is at 0.41 to 0.80 cm and the overall shape of the frequency distribution is comparable to values obtained at the CLIS-REF station. The boundary roughness distribution remained unchanged from that described in the August 1983 survey.

Figure IV-3-3 shows the frequency distribution of boundary roughness values for the March 1984 survey. The major mode is at the 0.4 cm class interval. One replicate at station 250N had an exceptionally high boundary roughness value of 5.3 cm (Fig. IV-3-4). The average boundary roughness value of the three replicates at station 400E, which was not occupied in earlier FVP REMOTS surveys, was 1.54 cm. Station 400E is the deployment site of Dr. Bohlen's DAISY array and Dr. Bedford's profilometer. The mean roughness value for this station falls above the major mode for the overall FVP site and is also greater than the mean of boundary roughness values found at the CLIS-REF station (0.76 cm). Photos from this station are shown in Figure IV-3-5.

Figure IV-3-6 shows the boundary roughness class

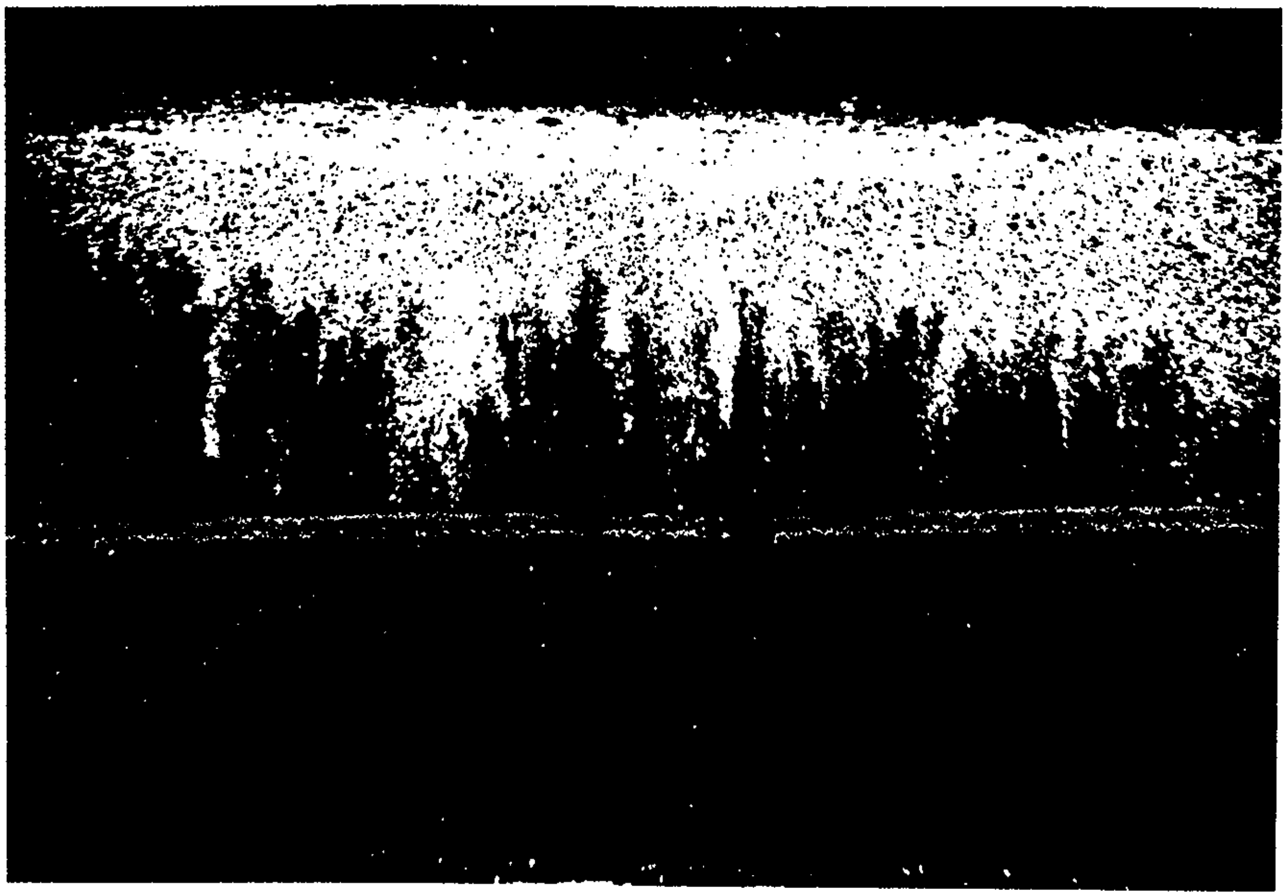


Figure IV-3-1. REMOTS image of the FVP CTR station, showing the surface layer (1-2 cm) of fine to medium sand overlaying a silt-clay mud.

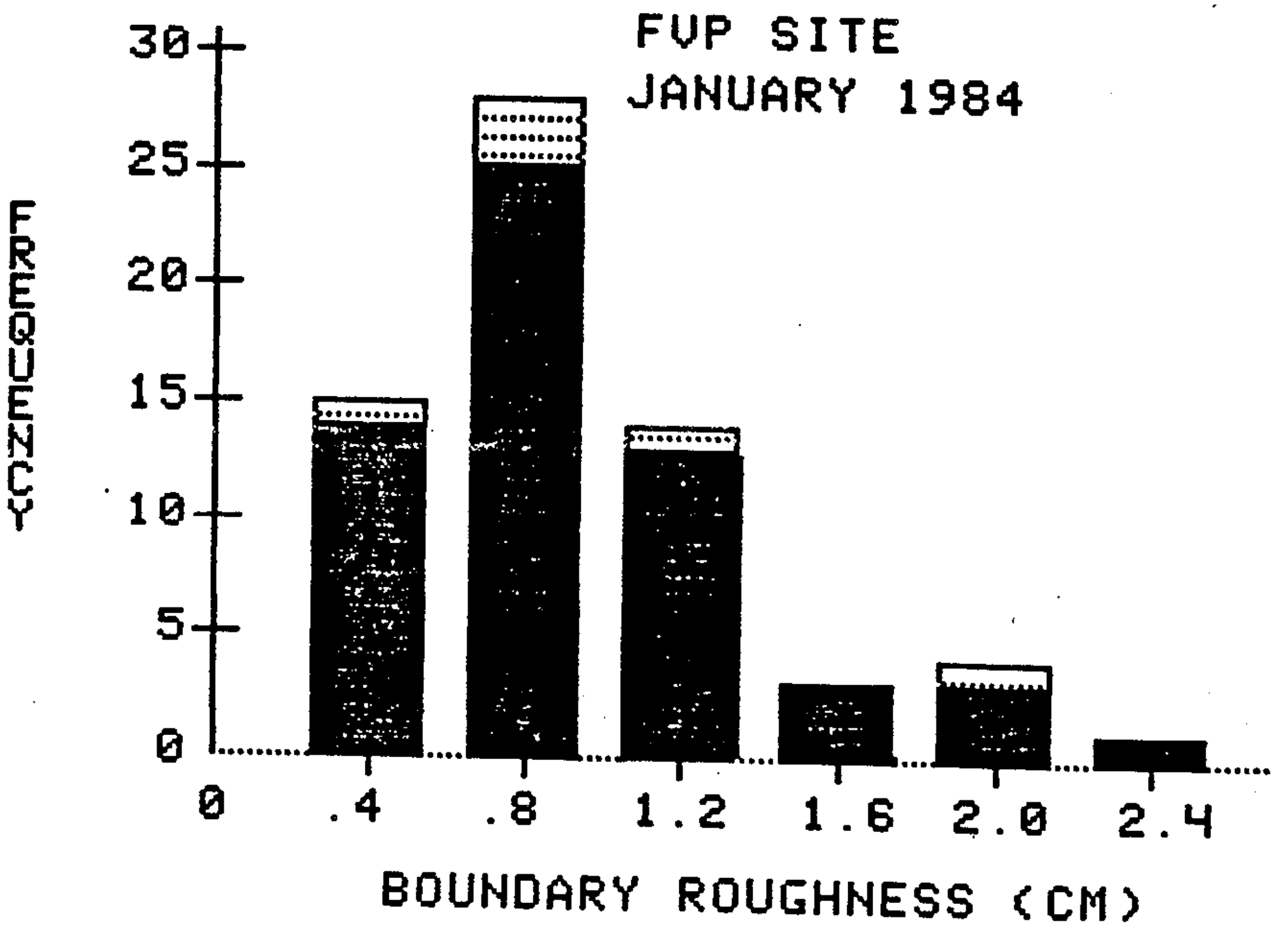


Figure IV-3-2. Frequency distribution for surface boundary roughness values at the FVP site in January, 1984. Stippled bars indicate values for the CLIS-REF station.

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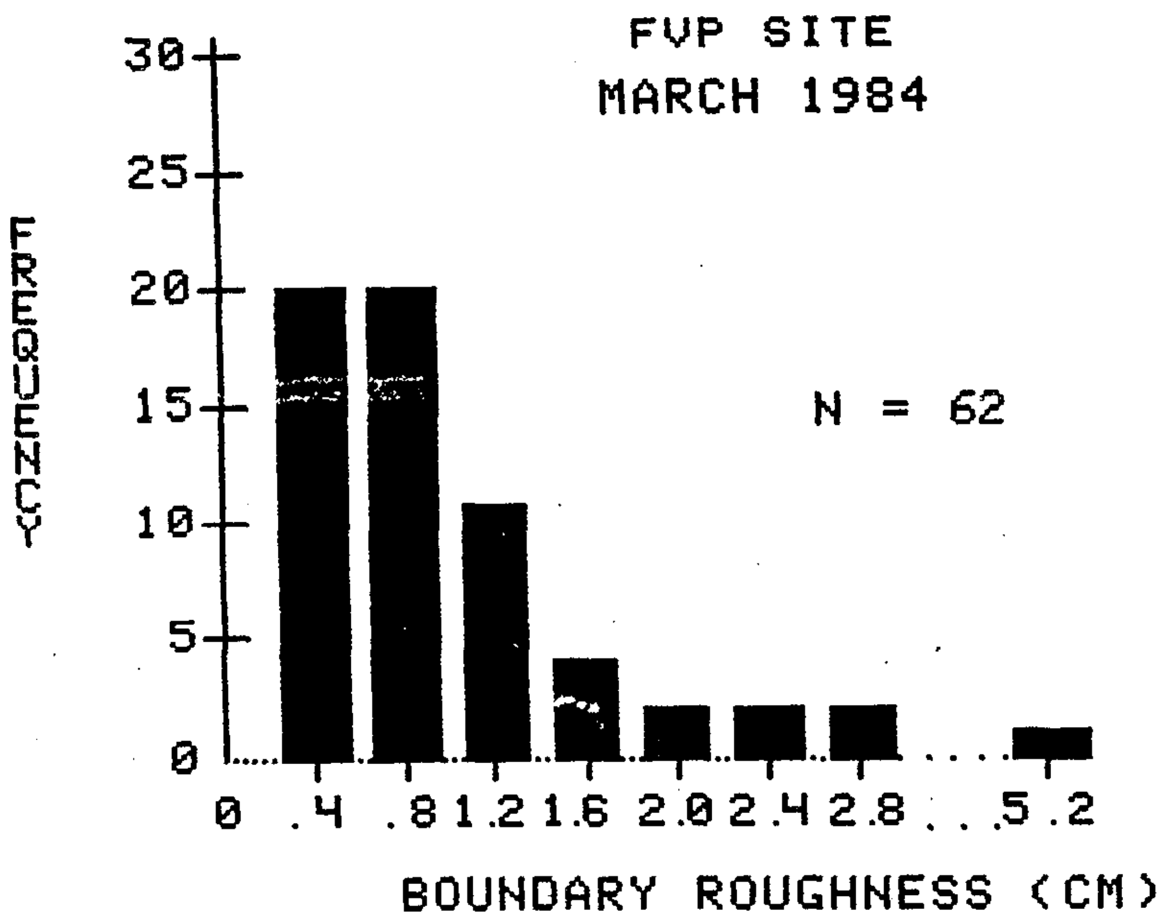

Figure IV-3-3. Frequency distribution of boundary roughness values at the FVP site in March 1984.

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Figure IV-3-4. REMOTS image from Station 250N with an exceptionally large surface boundary value (5.3 cm).

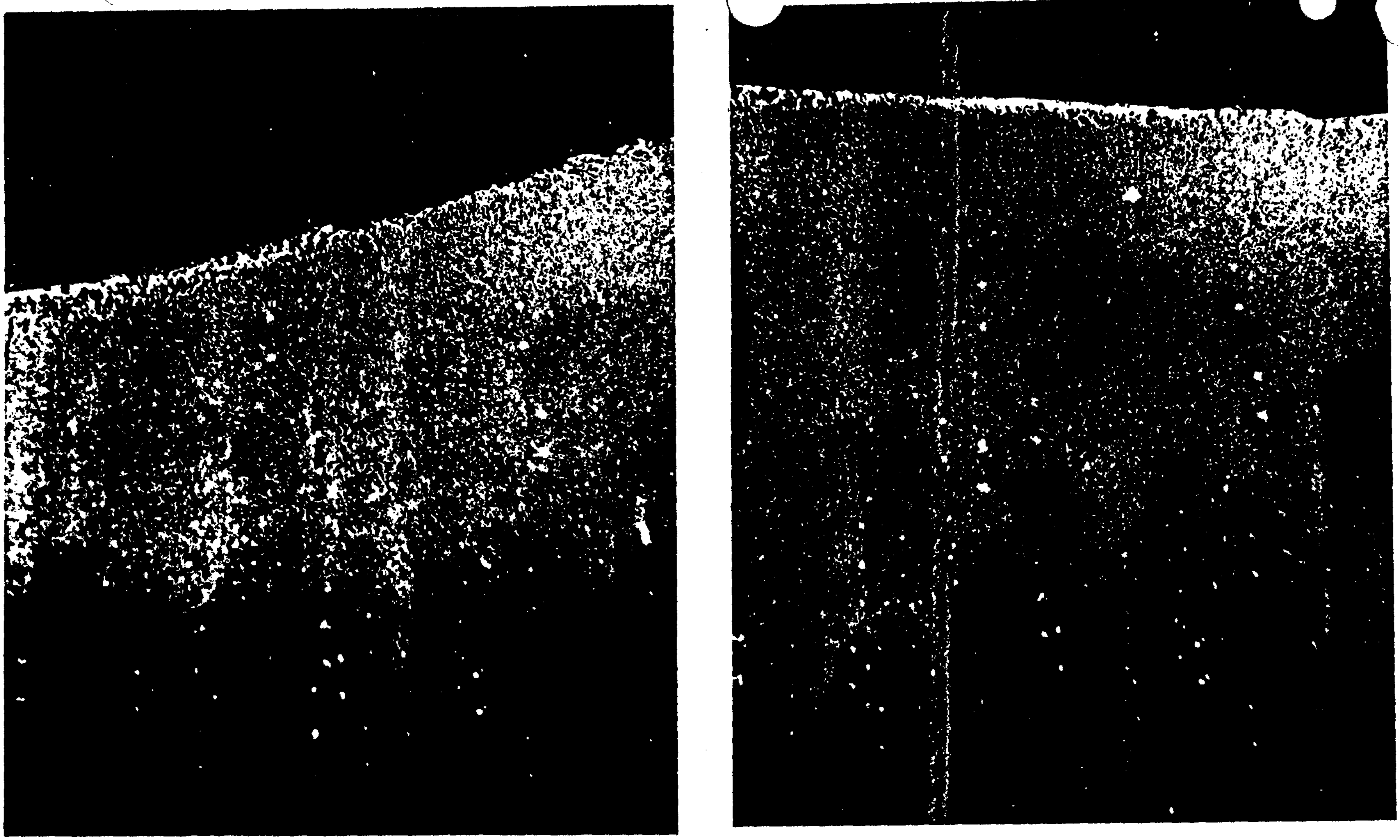

Figure IV-3-5. Two replicate images from Station 400E; note the difference in large and small scale sediment surface texture and roughness due to variation in meiofaunal and macrofaunal bioturbation.

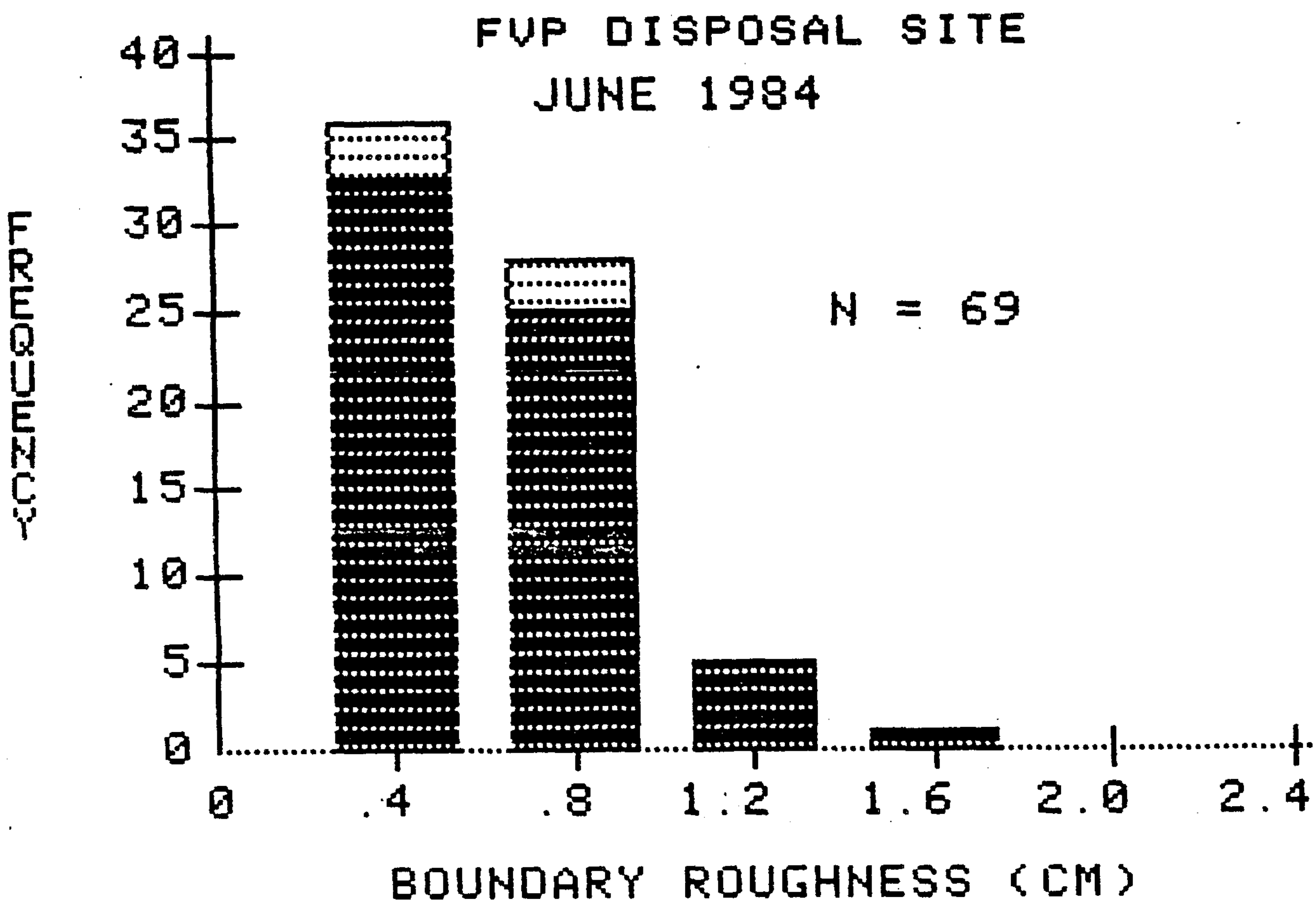

Figure IV-3-6. Frequency distribution for surface boundary roughness values at the FVP site in June 1984. Light stippled bars indicate values for the CLIS-REF station.

frequency distribution for the June 1984 survey. The major mode is again at the 0.4 cm interval. There has been a slight shift towards lower relief since the August 1983 and January 1984 surveys (major mode was at 0.8 cm).

The frequency distributions of boundary roughness values for the dredged material, edge and ambient stations, and CLIS-REF area are shown in Figure IV-3-7. The distributions are similar for all three areas, with the major mode for small-scale topographic relief being 0.4 cm. A single unusually high boundary roughness value (4.80 cm) was recorded at station 300W and is not plotted in Figure IV-3-7. This anomalously high value was due to the presence of a large macrofaunal burrow at the sediment-water interface (Fig. IV-3-8). Boundary roughness values have not changed throughout 1984. Small-scale relief was slightly greater during 1983. This widespread decrease in relief at the FVP site may represent the progressive "smoothing" of the surface of dredged material by both currents and bioturbation.

Extensive meiofaunal tunnelling of the upper 1 cm of the sedimentary column, a feature not observed in previous FVP REMOTS surveys, was evident in approximately 50% of the images from the December survey (Fig. IV-3-9a). This fine scale biological reworking probably results from the feeding activities of small annelids and/or microcrustaceans. This activity potentially lowers critical erosion velocities by increasing micro-scale boundary roughness and by "loosening" the sedimentary fabric (i.e. disturbing the organic binding between particles). As illustrated in Figure IV-3-9a, this meiofaunal "fluffing" of the interface leads to the formation of small mudclasts. For reasons indicated above, these mudclasts are susceptible to erosional scour by fluid shear forces. Once mobilized, such features would tend to grow in size through a "snowballing" effect. This sequence of events could result in an interface strewn with larger mudclasts (Fig. IV-3-9b). Moreover, widespread meiofaunal tunnelling could result in significant redistribution of surface sediments and any associated contaminants. Consequently, this may be an important phenomena to monitor at disposal sites. In the present survey, extensive large mudclast formation (Fig. IV-3-9b) was not apparent. However, a number of images from both on mound and off mound stations revealed some thin recently deposited sedimentary intervals (Fig. IV-3-10) indicating that surface sediments have been resuspended and redeposited.

3.2.3 Extent of Observable Dredged Material

Dredged material was apparent in the REMOTS images from the following central FVP stations during the June 1984 survey: 250W, 100E, CTR, 150E, 250E, 200N and 200S. The dredged material layer was deeper than camera prism penetration at stations CTR, 100W and 150E. At the remaining four stations, the dredged material layer has been largely reoxidized due to infaunal recolonization. This pattern is illustrated in Figure IV-3-11, an image from station 250W.

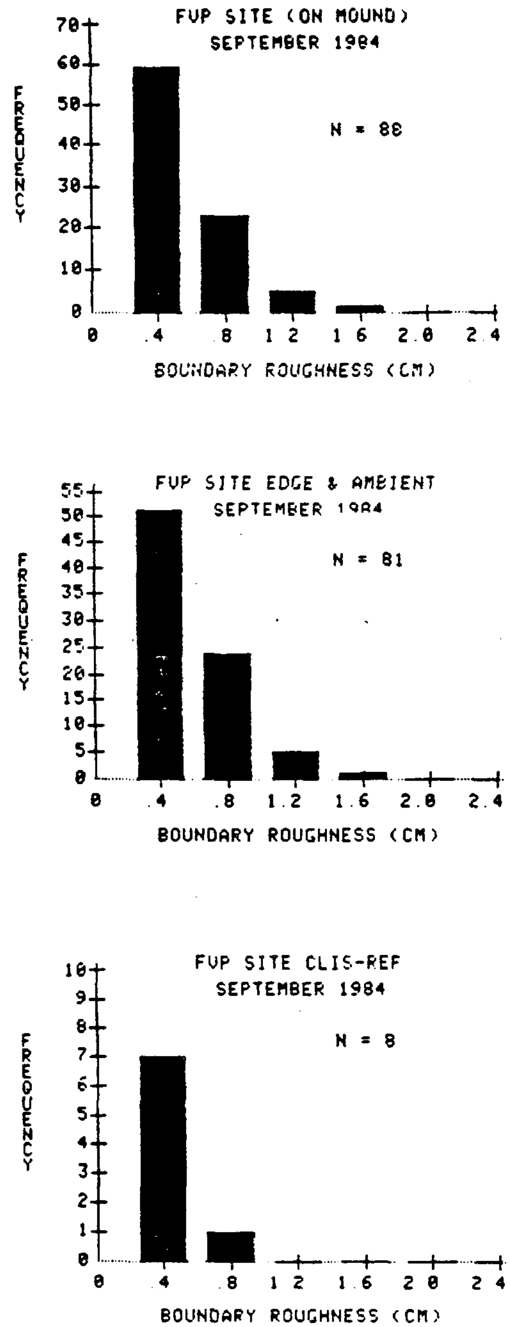

Figure IV-3-7. The frequency distribution of boundary roughness values for dredged material mound, edge and ambient, and CLIS-REF stations.

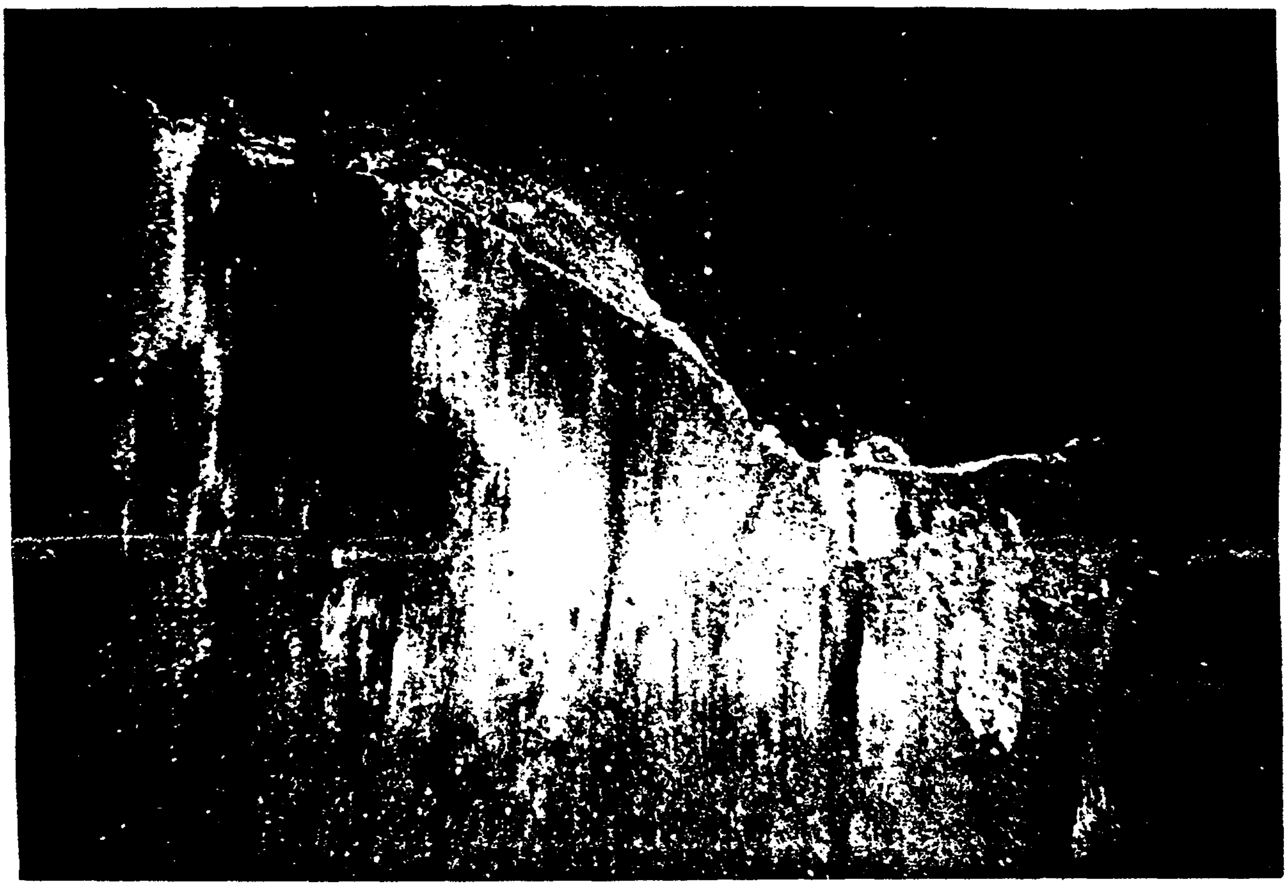

Figure IV-3-8. A REMOTS image from station 300W showing a large macrofaunal burrow at the interface. A distinct dredged material layer extending to the sediment surface is also present in the left side of the photo.

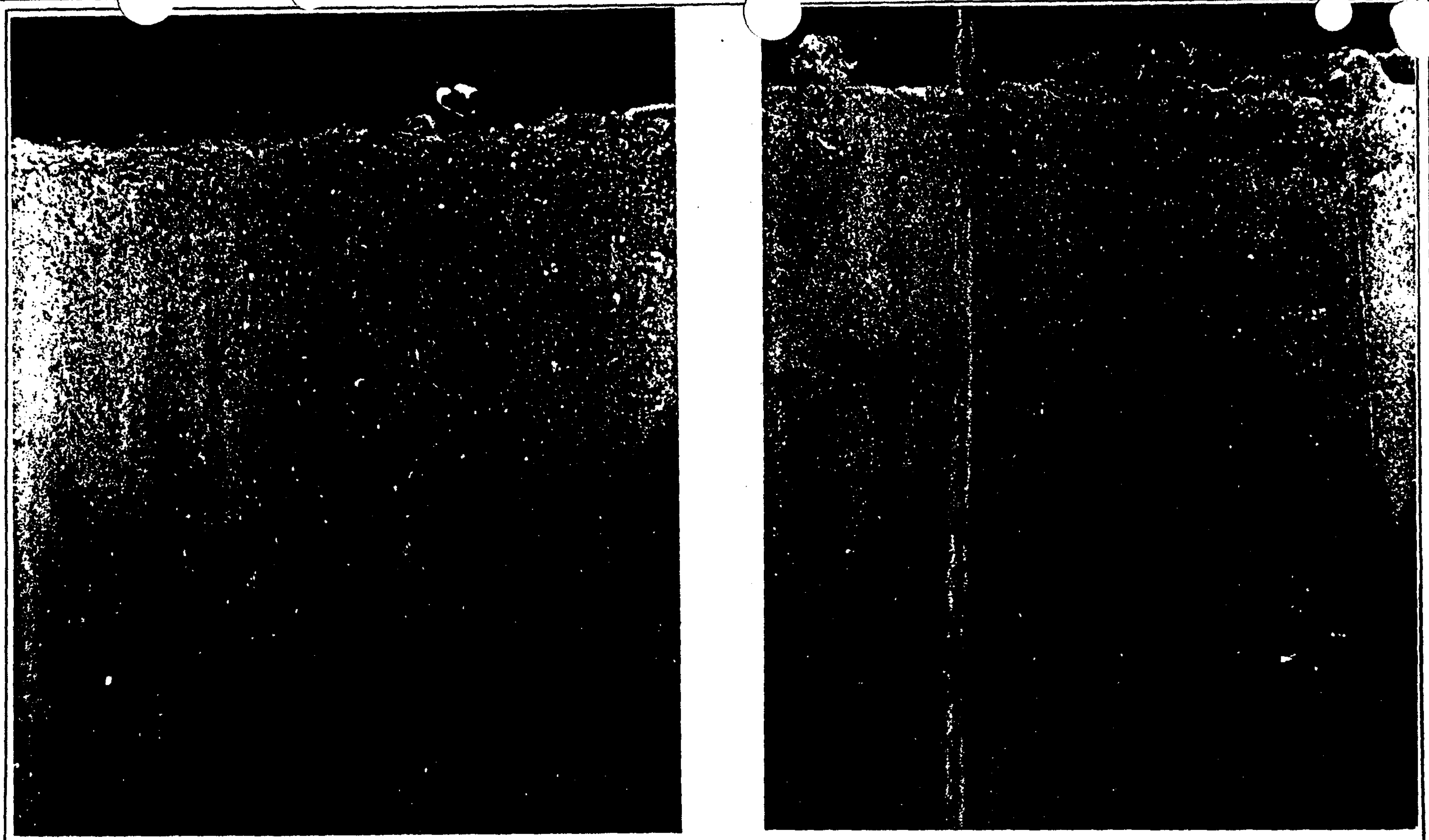

Figure IV-3-9. REMOTS® images from stations 250 W (A) and 200S/300E (B) showing meiofaunal tunneling in the upper 1cm of sediment.

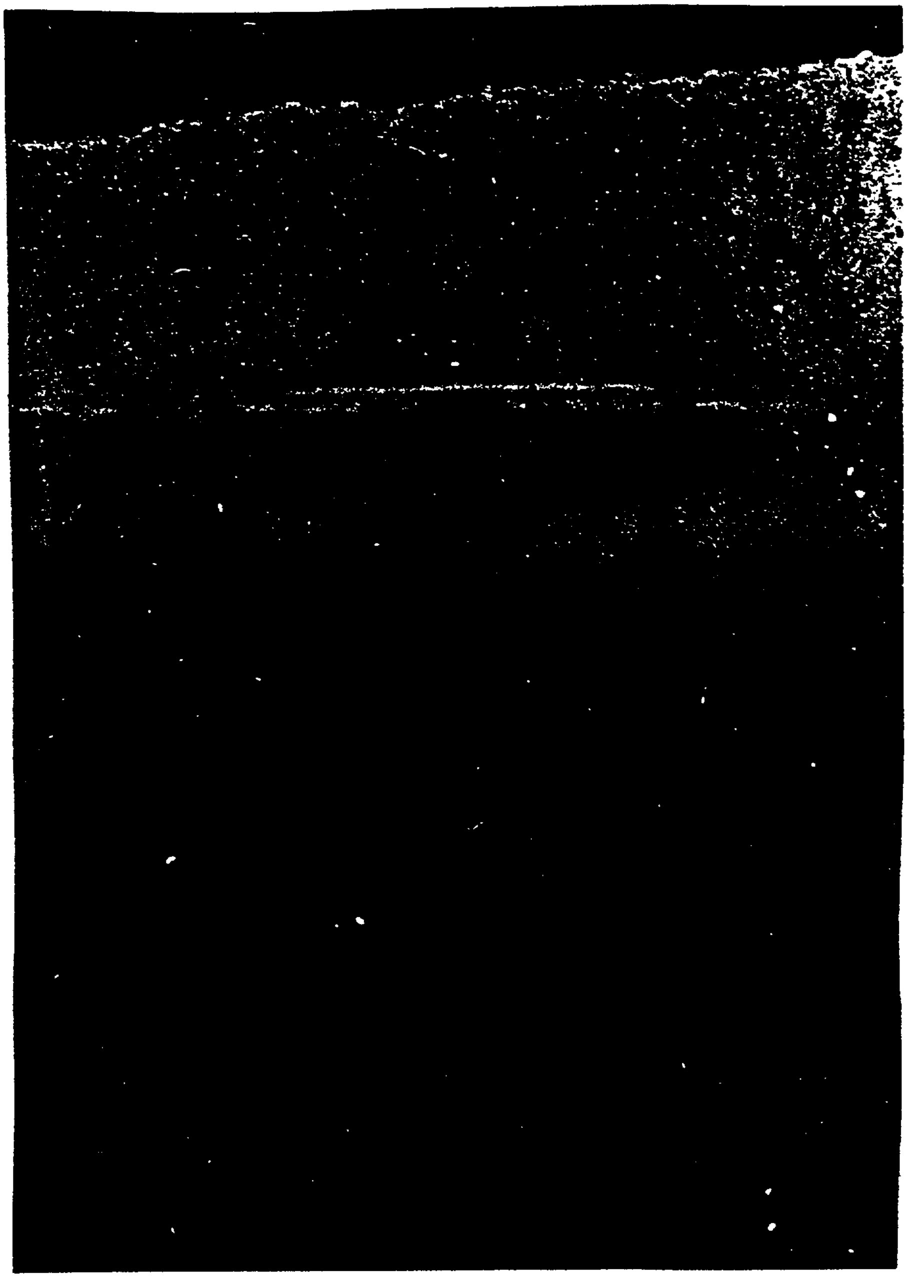

Figure IV-3-10. A REMOTS® image from station 400E showing a recently deposited sedimentary layer at the interface.

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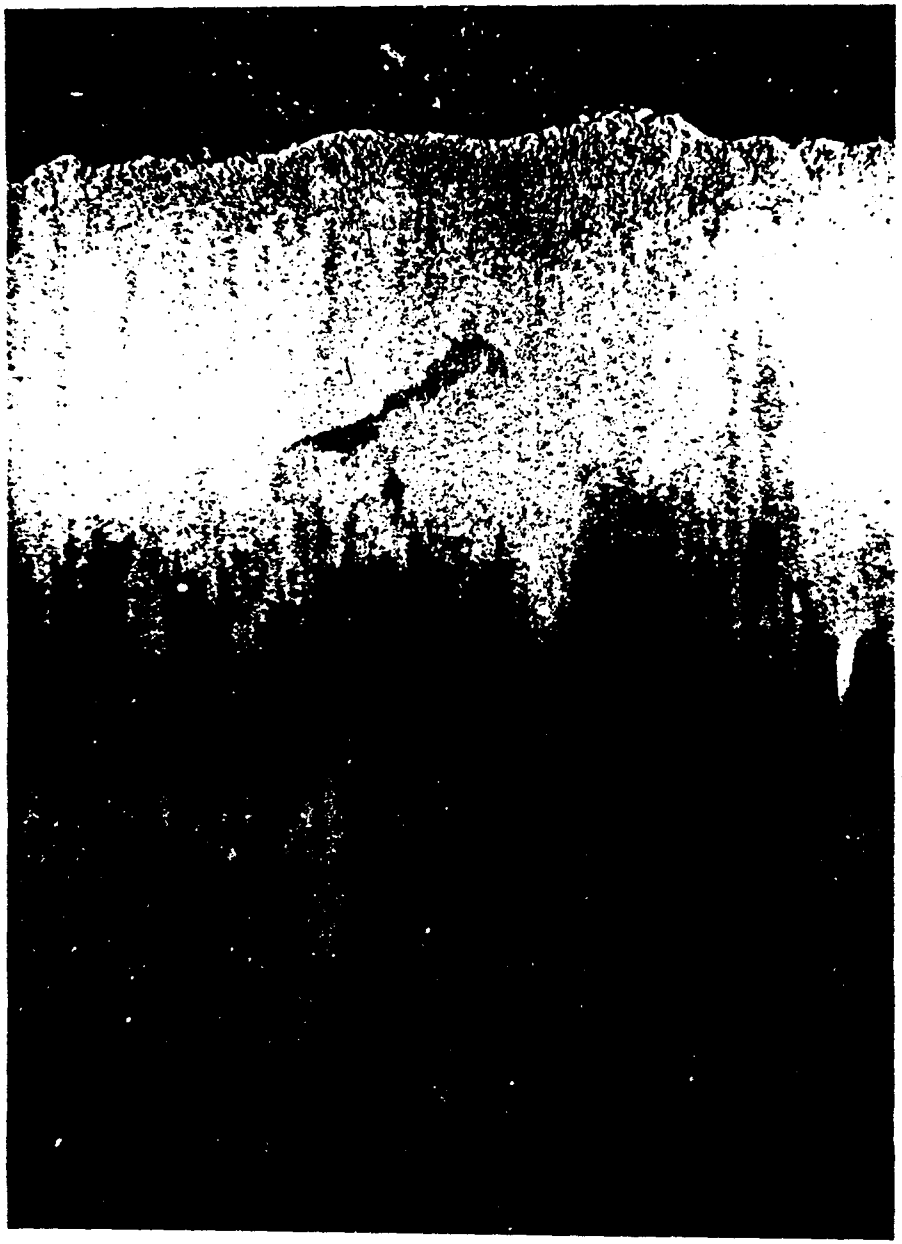

Figure IV-3-11. REMOTS® image of FVP 250W station, showing the reoxidation of the dredged material layer. The cavity in the center of the photo is probably a Nephtys burrow.

The distribution and thickness (cm) of observable dredged material at the FVP site in September 1984 is shown in Figure IV-3-12. The thickness of the layer is based on the presence of a high reflectance layer at depth (a buried "relict" redox which represents the predisposal sediment-water interface). The measurements of dredged material thickness are made from the present sediment-water interface downward to the top of this high reflectance layer. Resolution is best where the layer is between 4 and 18 cm thick, i.e. thicker than the mean bioturbational (mixing) depth but thinner than the height of the REMOTS window. Because particle mixing by bioturbation destroys the former record of a dredged material layer thinner than 4 cm, Figure IV-3-12 does not accurately define the thickness near the thin edge of the disposal area. The most accurate dredged material thickness maps are those made within the first year of the survey when bioturbation depths are ~1 cm.

The distributions of dredged material thickness for the September and December surveys are shown in Figures IV-3-12 and IV-3-13 and are comparable to that observed in previous REMOTS surveys. Dredged material was observed at three corner stations (200N/300W, 200S/300, 200S/300E) where it was not detected in the June 1984 survey. At these locations, dredged material is patchily distributed, i.e. not observed in all replicate photos.

3.2.4 Redox Potential Discontinuity Depths

The station means for RPD depths in January 1984 are mapped in Figure IV-3-14. Those stations with values less than the CLIS-REF station (3.53 cm) fall well within the zero isopleth for dredged material as mapped on 13 June 1983. One apparent exception exists at station 1000E. This is related to one replicate having a relatively high value (3.62 cm) while a second replicate has a value lower than the reference station (3.12 cm). The station mean of 3.37 is roughly only one millimeter less than the CLIS-REF station and this difference is not significant. Figure IV-3-15 shows the frequency distribution of the RPD depth classes. The distribution of values at stations located within the central area of dredged material have a nearly symmetrical distribution about a major mode of 2.6 to 3.0 cm (n=33). The mean of this population is 2.99 cm and the range is 1.38 to 4.23. Stations located on the ambient bottom, or near the edge of the deposit, have a major mode at 3.1 to 3.5 cm and a secondary or subordinate mode at 4.6 to 5.0 cm (n=22). The mean of this population is 4.01 cm with a range of 3.10 to 5.58 cm. Most of the CLIS-REF station values fall within the major mode of the ambient bottom stations.

Station means for RPD depths in March 1984 are mapped in Figure IV-3-16. Stations with values less than or equal to 3 cm (n=5) are also located within the zero isopleth for dredged material from the June 1983 survey. Stations 400N, 1000W, 400S, and 1000E have RPD values less than the mean value of the CLIS-REF station (3.64 cm). However, all of these stations have values greater than 3.0 cm, and this difference may not be significant. RPD depths at stations 400 N, 1000 W, and 400 S in

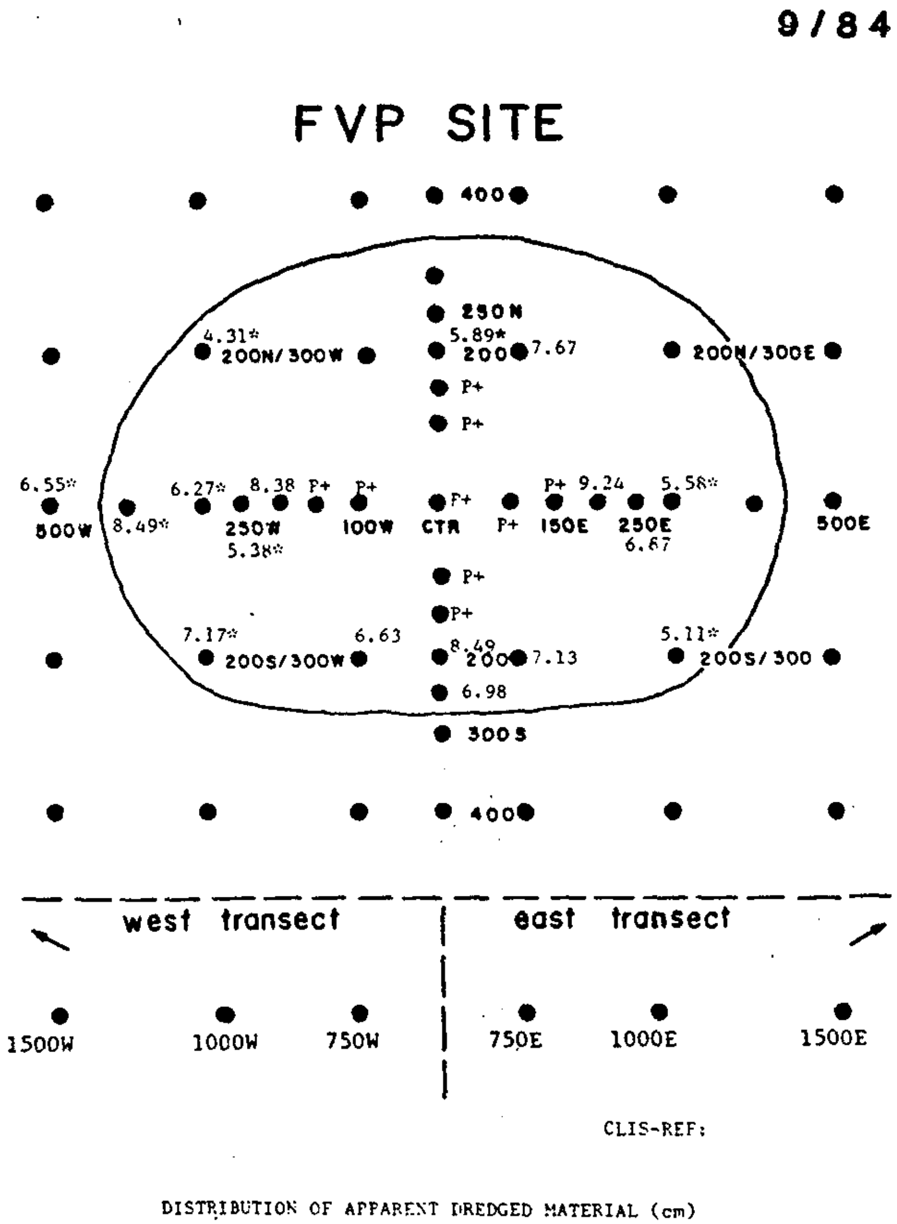

Figure IV-3-12. The apparent distribution and thickness (cm) of dredged material averaged by station, at the FVP site in September, 1984.

P+ = Dredged material thicker than REMOTS window penetration.
* = Dredged material not observed in all replicate images from that station.

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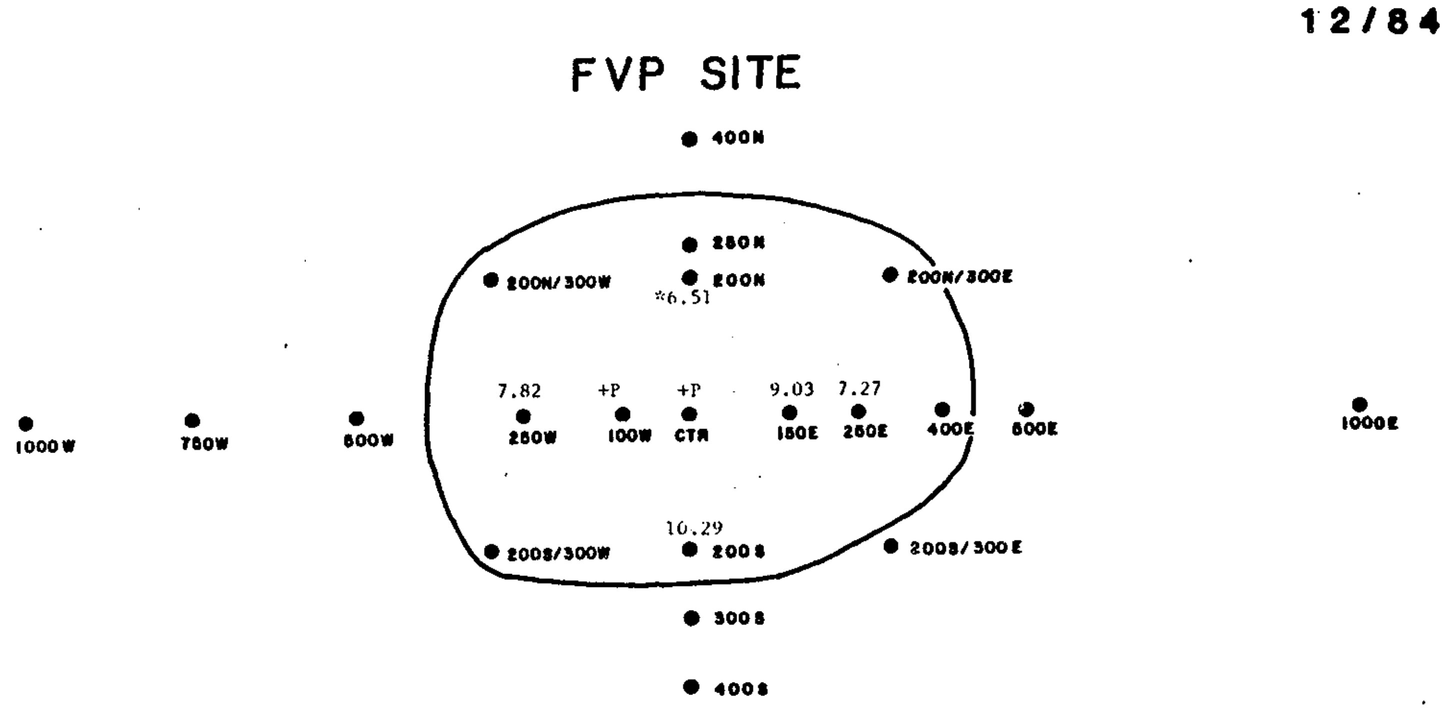

Figure IV-3-13. The apparent distribution and thickness (cm) of dredged material, averaged by station, at the FVP site in December 1984. The solid line encloses the twelve stations considered to be on the main dredged material mound or flanks.

P+ = Dredged material thicker than REMOTS® window penetration.

* = Dredged material not observed in all replicate images from that station.

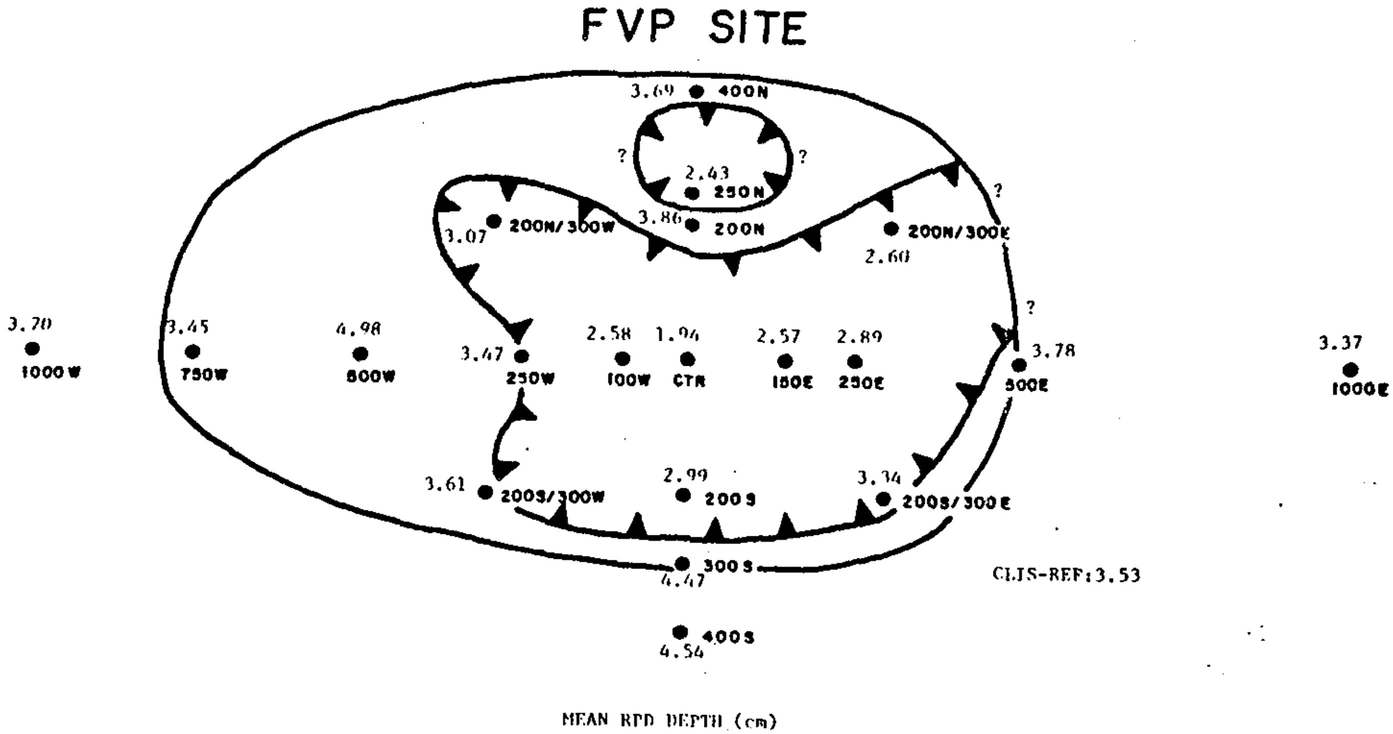

Figure IV-3-14. Mapped values for mean RPD depth at the FVP site. The zero isopleth for dredged material as measured in the June 1983 REMOTS survey is indicated. All stations with values less than the CLIS-REF are located on dredged material, with the exception of 1000E (see text for explanation).

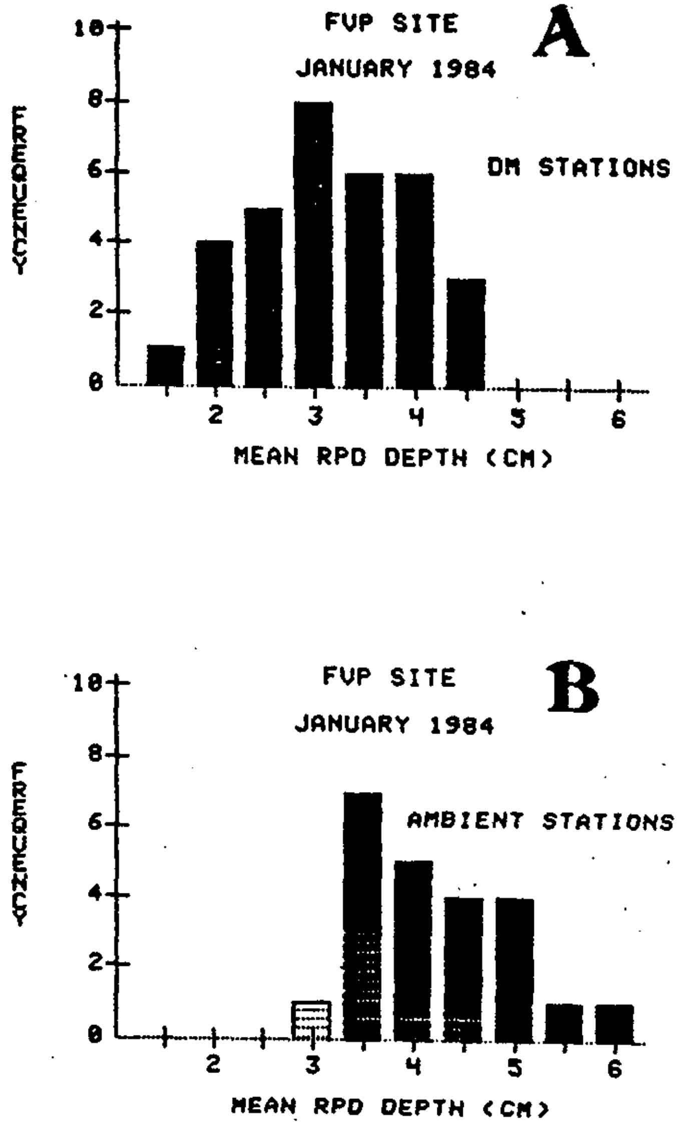

Figure IV-3-15. Frequency distribution of RPD values for stations located on dredged material (A) versus values for CLIS-REF (stippled portion) and stations located on the ambient bottom or near the edge of the dredged material (B).

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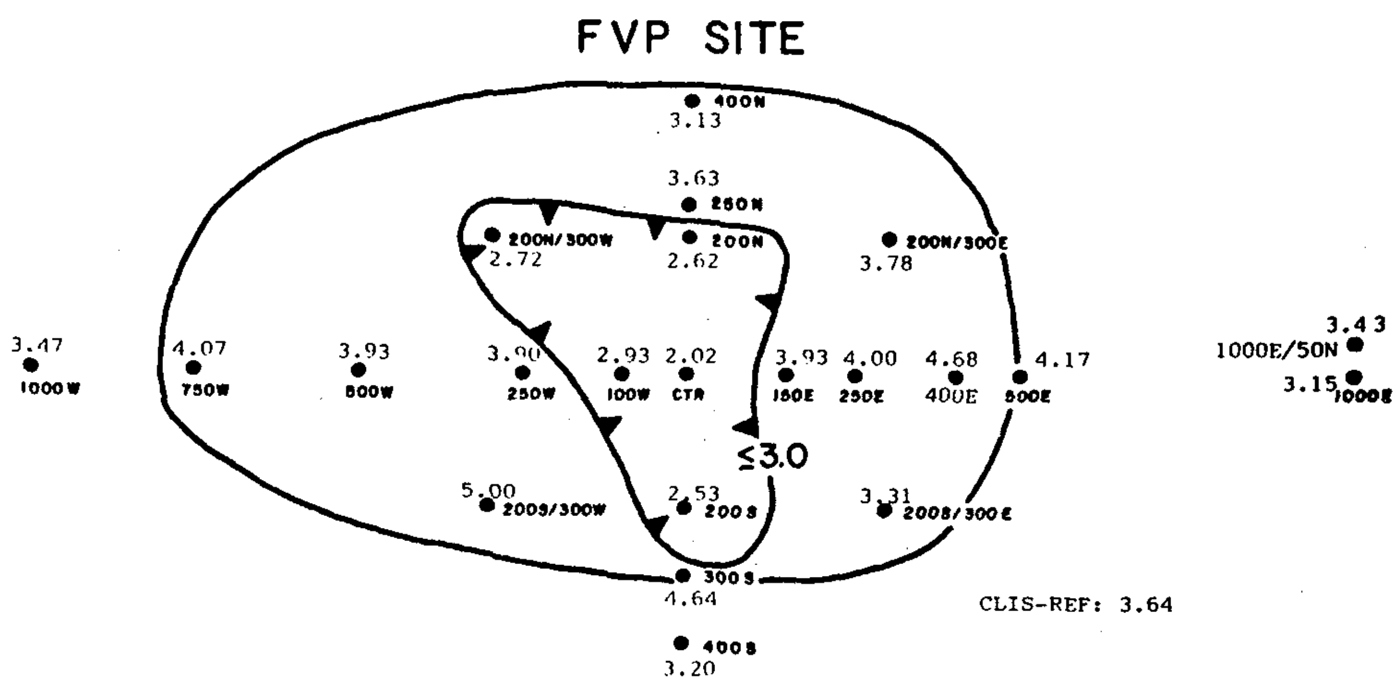

Figure IV-3-16. Spatial distribution of average RPD depth at the FVP site in March 1984. Outer line indicates limits of dredged material as determined in our June 1983 survey.

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the January survey were greater than the mean value at the CLIS-REF station. The shallower RPD depths found at these stations in this survey do not seem to have resulted from the presence of dredged material but rather may reflect winter conditions, i.e. reduced tube and burrow irrigation rates.

Figure IV-3-17 shows the frequency distribution of RPD depth classes. The major mode for stations located within the central area of dredged material and for stations near the edge of the deposit or on the ambient bottom, is 3.6-4.0 cm. This represents an increase for stations located on the central mound from a major mode of 2.6-3.0 cm as measured in January 1984 and an increase for stations on the edge of the deposit or on ambient bottom from a major mode of 3.1-3.5 cm as measured in January. Stations in the central dredged material area have approached ambient values for RPD depth. The mean RPD depth for stations located on the central mound (n=36) is 3.36 cm, as compared to 2.99 cm for January survey. For stations located on the edge or ambient bottom (n=26), the mean RPD depth is 3.83 cm, as compared to 4.0 cm for the January survey.

Figure IV-3-18 shows the average RPD depths for each station in June 1984. Only one station, CTR, exhibits a mean RPD $>$3.0 cm. This is a noticeable improvement over previous surveys; five stations in March 1984, seven in January 1984, and twelve in June 1983 had RPD depths $>$3.0 cm. This is the first post-disposal survey in which the RPD depths at the central dredged material sites conincide with the RPD values at the edge and ambient stations. The average RPD depth for all central stations (3.95 cm, n=36) does not differ significantly (t-test, $p < 0.5$) from the average RPD depth for edge, ambient and CLIS-REF sites (4.04 cm, n=33).

Since the March survey, the average RPD depth has increased for both the central region (from 3.37 to 3.95 cm), and the peripheral and ambient regions (from 3.63 to 4.04 cm). However, between August 1983 and March 1984 the RPD depths of the central dredged material sites increased steadily, while the RPD depths of the adjacent regions generally decreased. This pattern is apparently due to the recolonization and recovery of the central disposal area juxtaposed to the effects of winter conditions on the ambient benthic fauna.

The frequency distribution of the RPD depth classes is shown in Figure IV-3-19. Compared to previous surveys, the distribution for the central deposit area, the edge and ambient sites, and the CLIS-REF station are relatively evenly distributed around a central mode of approximately 3.6-4.0 cm.

The depth of the apparent RPD in September 1984 is mapped (averaged by station) in Figure IV-3-20. Two central stations, CTR and 100W, have anomolously shallow RPD's ($<$2.00 cm), while five other central stations, 200N/300W, 150W, 150N, 200S/100W, and 150S, have RPD values $>$3.00 cm. Four of these seven stations clearly show a rebounded RPD, suggesting retrograde succession (Fig. IV-3-21). This decrease in apparent

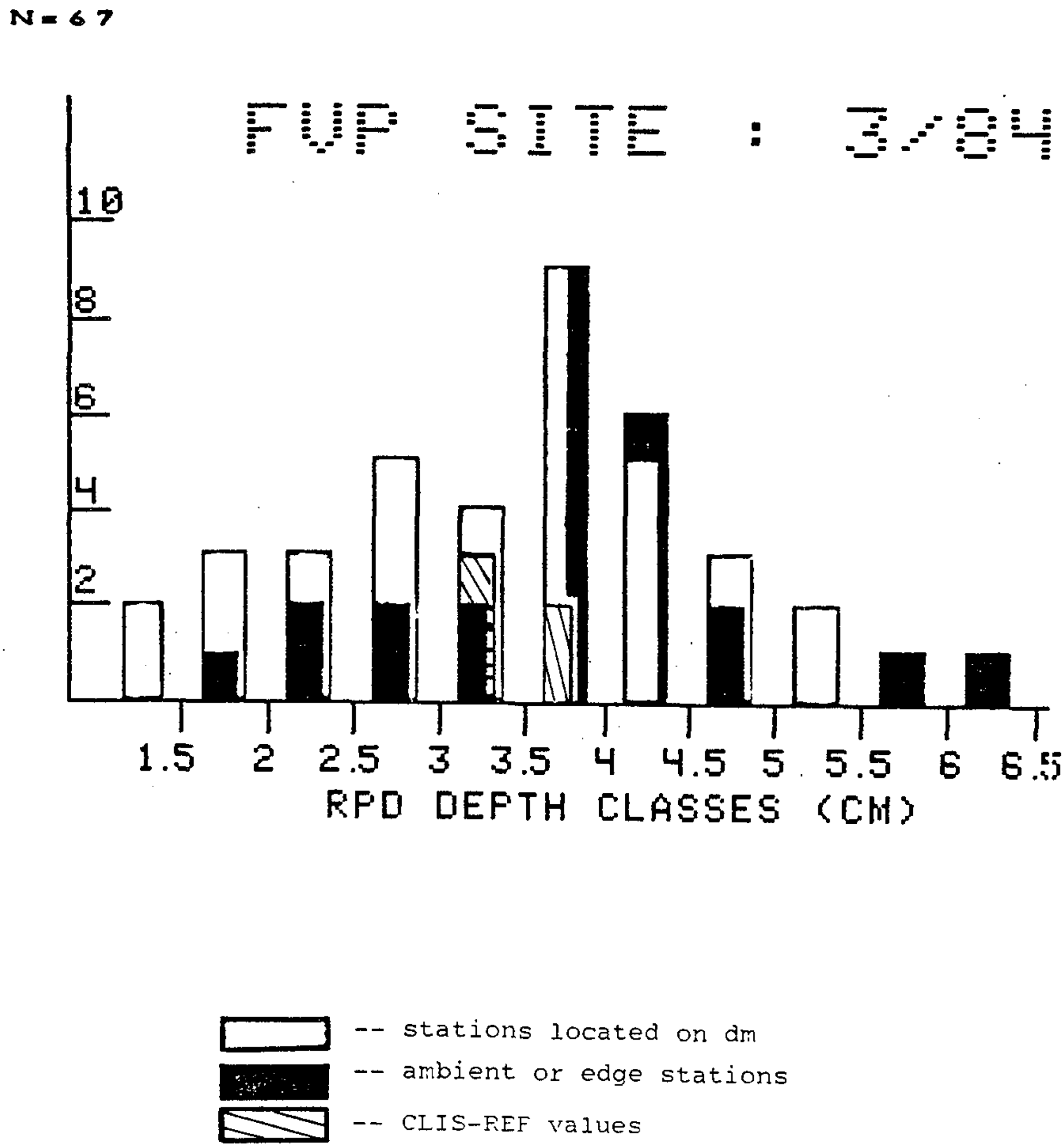

Figure IV-3-17. Frequency distribution of mean RPD depth for the FVP site in March 1983.

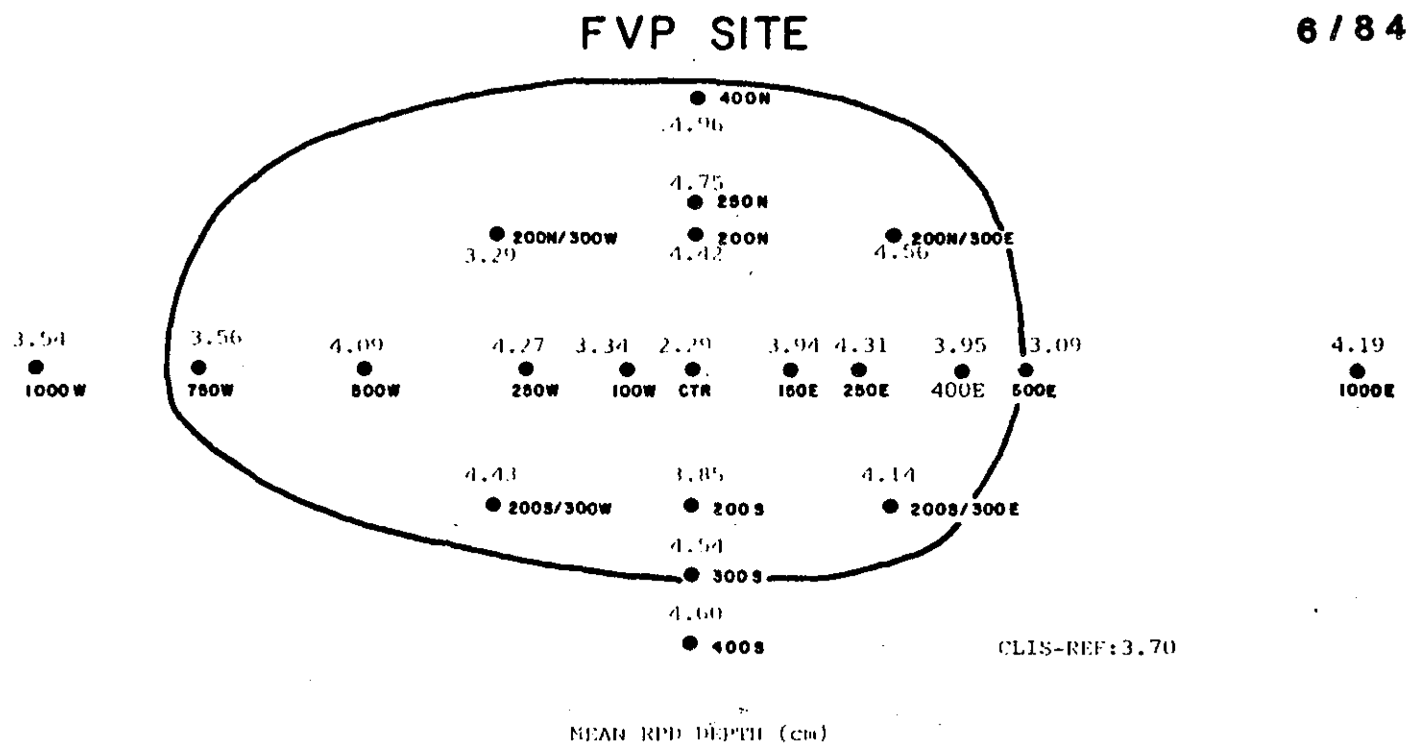

Figure IV-3-18. Mapped values for the average RPD depths at the FVP site. The zero isopleth for dredged material as measured in the June 1983 REMOTS survey is indicated.

N=69

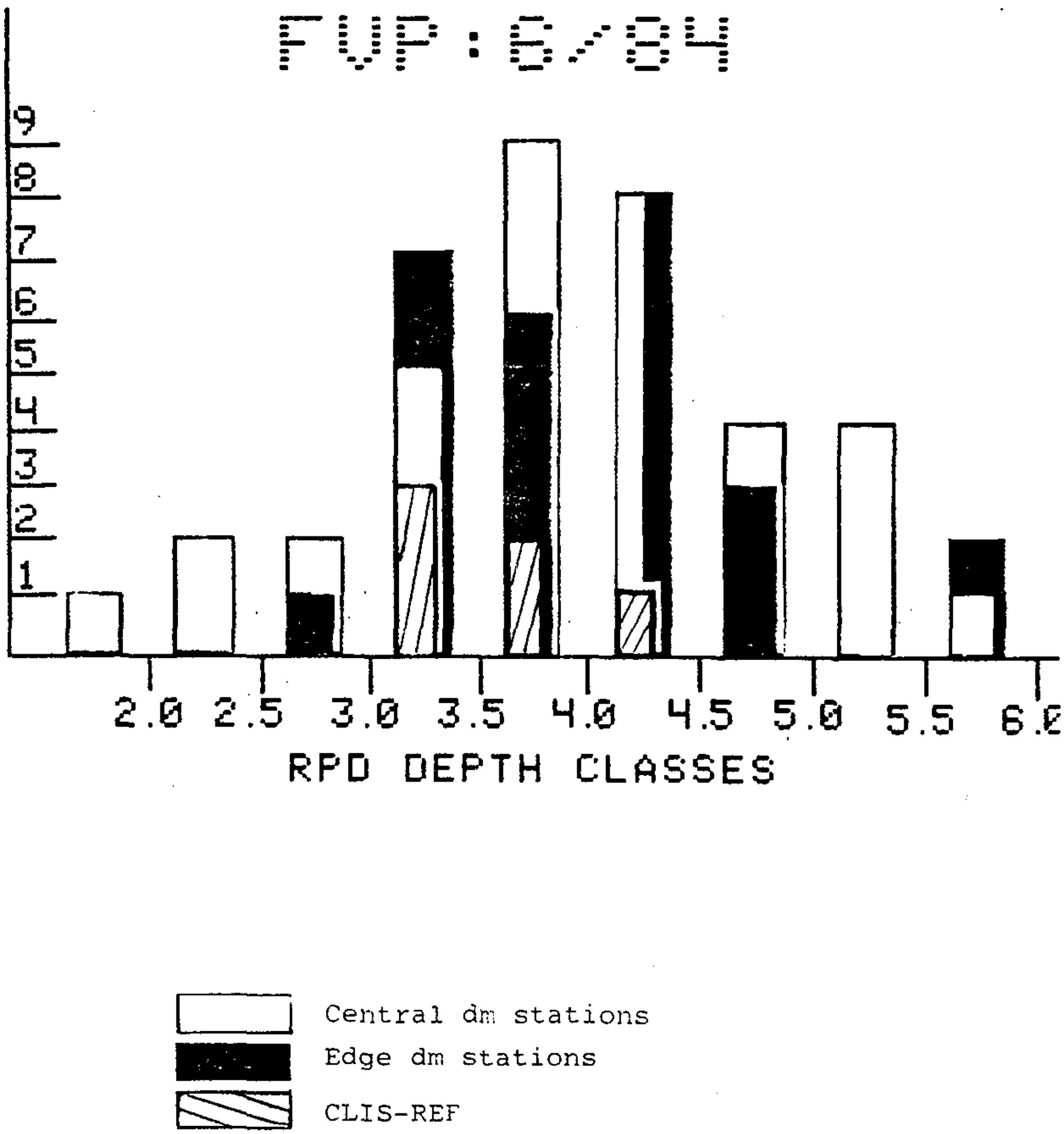

Figure IV-3-19. Frequency distributions of the RPD values for central dredged material, edge dredged material, and CLIS-REF stations.

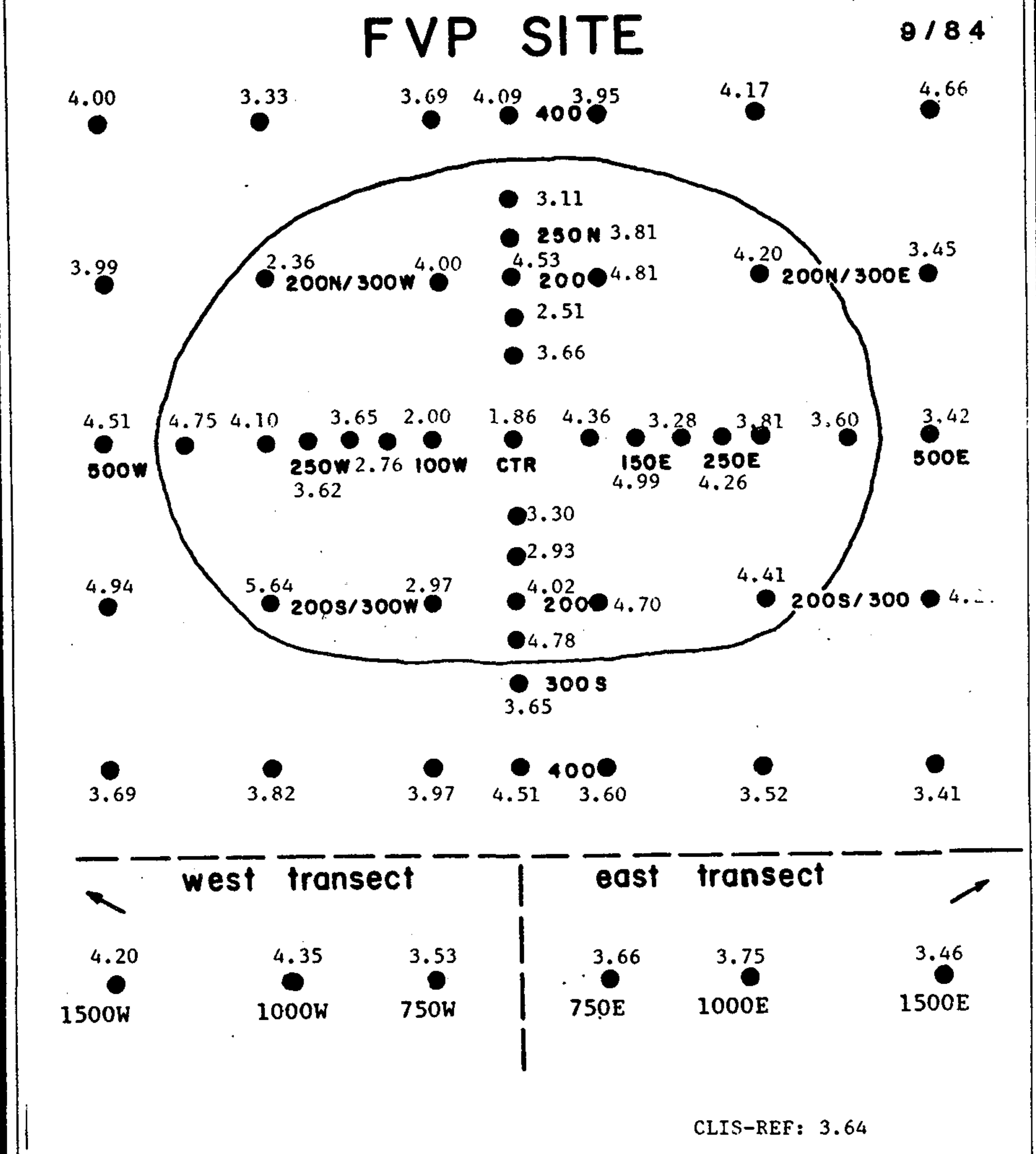

Figure IV-3-20. Mapped average RPD values at each station.

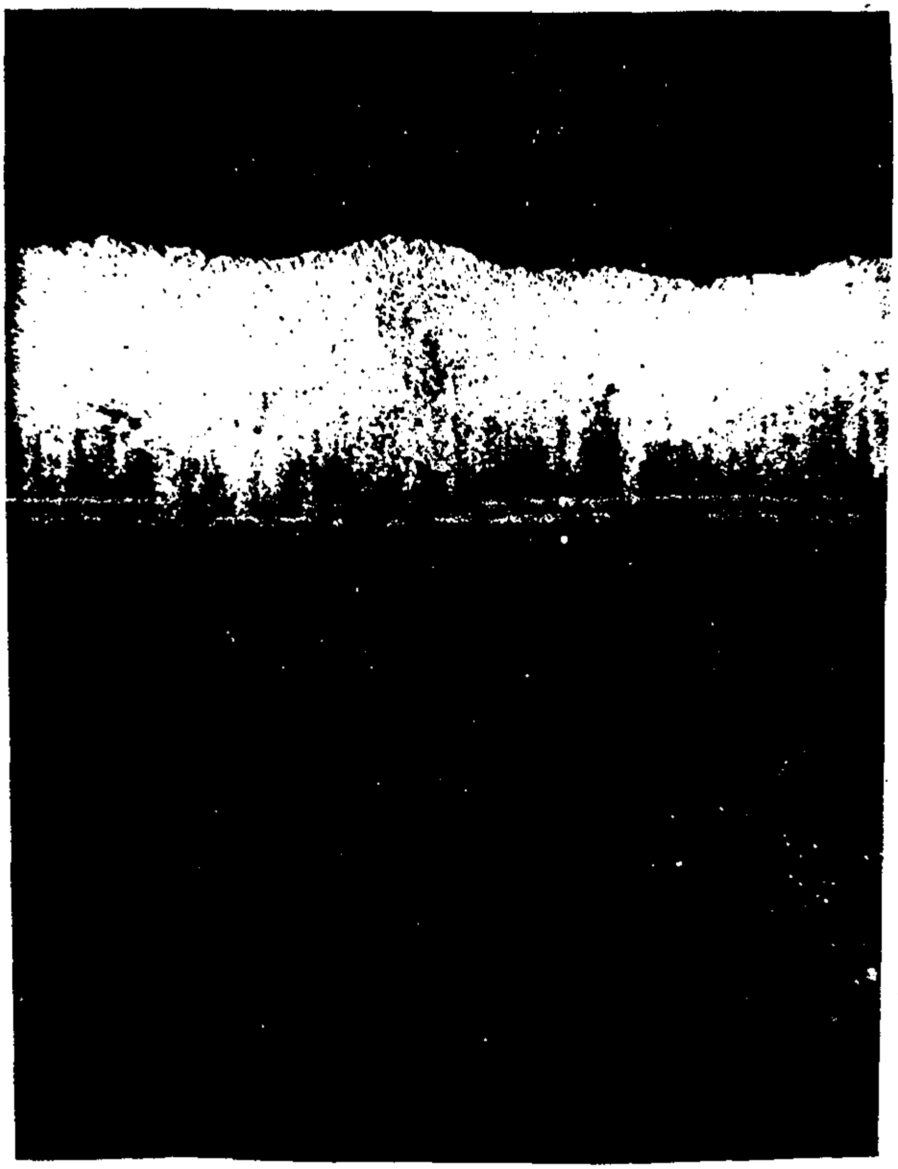

Figure IV-3-21. A REMOTS image from station 100W showing a rebounded RPD. Oxygenated sediment (the region of highest reflectance) formerly extended to approximately 5 cm (scale of photo is 1X); the RPD has rebounded to its present depth, producing a region of intermediate reflectance.

RPD depths from the June survey at some centrally located dredged material stations suggests that this part of the FVP site is experiencing stress factors which are not apparent at other stations.

Taken as a whole, however, RPD values within the central region (x = 3.75, N=88) were not significantly different ($p < .05$; Mann-Whitney U-test) from RPD depths at edge and ambient stations (x = 3.90, N = 81) nor from the CLIS-REF site (x = 3.64, N = 8). Figure IV-3-22 shows the frequency distribution for mean RPD depths for the three regions of the study site. All three distributions have a central mode at 4.0 cm. Between the June and September surveys, average RPD values at the FVP site have not changed significantly ($p < .05$; t-test). In June, the mean RPD depth for central dredged material station was 3.95 cm; for edge and ambient stations the mean RPD depth was 4.04 cm. Also, both regions exhibited RPD frequency distributions with a major mode approximately centered at 4.0 cm.

Figure IV-3-23 shows the average depth of the apparent RPD for each station in December 1984. Only station CTR continues to exhibit an anomalously shallow RPD (< 3.00 cm). Overall, the average RPD value for mound stations is 4.97 cm; this is not significantly different from the average RPD value of 5.28 cm for edge and ambient stations (p = .4398, Mann-Whitney U-test). Figure IV-3-24 shows the frequency distributions of mean RPD depths for mound stations, edge and ambient stations and the CLIS-REF site. Mound stations and edge and ambient stations have a distribution centered around 5.0 cm. The RPD's in both of these areas have deepened significantly since the September survey, when the major modes were centered at 4.0 cm ($p < .001$, Mann-Whitney U-test). This increase in RPD depths at the FVP site represents renewed benthic recovery after a stasis in RPD depths observed from June to September 1984.

The major modal RPD depth at the CLIS-REF site is 2.00 cm (Fig. IV-3-24). CLIS-REF RPD depths are significantly shallower than RPD depths at the mound and the edge and ambient region ($p < .001$, Mann-Whitney U-test). In September, the RPD depths at CLIS-REF were comparable to the RPD depths at the FVP site. It is evident that the CLIS-REF site has been subject to stress factors not occurring in the FVP region, e.g. predation or bottom trawling.

A plot of mean RPD depths for on mound and off mound (edge, ambient, and CLIS-REF stations from the August 1982 baseline survey through all post-disposal surveys is shown in Figure IV-3-25. A convergence of RPD values from the two regions has been observed since the March 1984 survey, nine months after the disposal operation. Since that time, on mound and off mound RPD depths have tracked each other closely. The slight (p = .06, Mann-Whitney U-test) divergence shown in the last sampling point on the graph is due to the current retrograde condition apparent at CLIS-REF.

3.2.5 Successional Stage

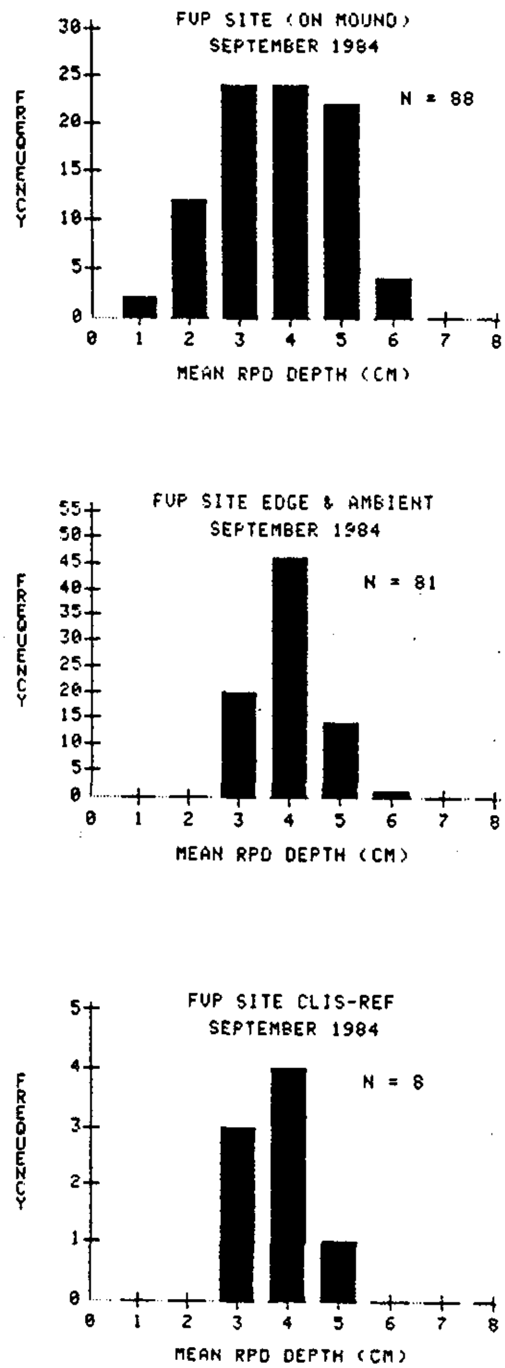

Figure IV-3-22. The frequency distributions of mean RPD depths for dredged material mound, edge and ambient, and CLIS-REF stations.

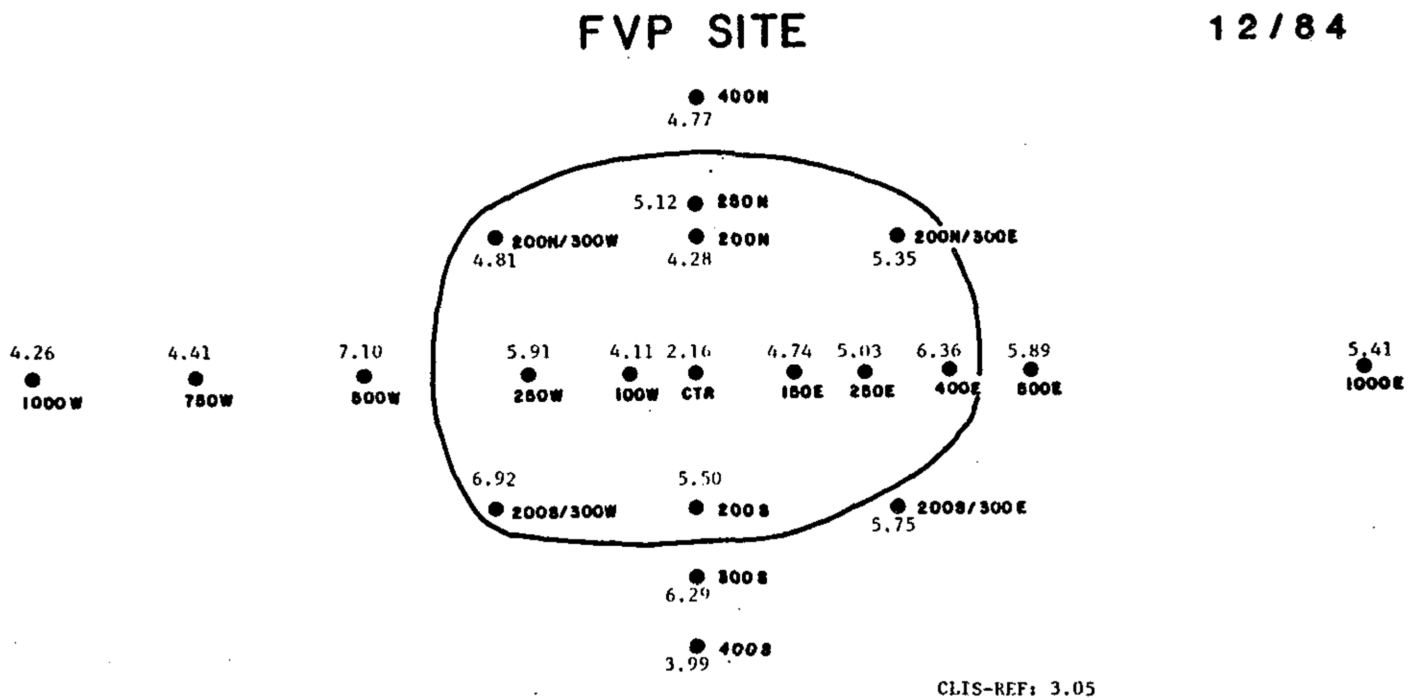

Figure IV-3-23. Mapped average RPD values at each station.

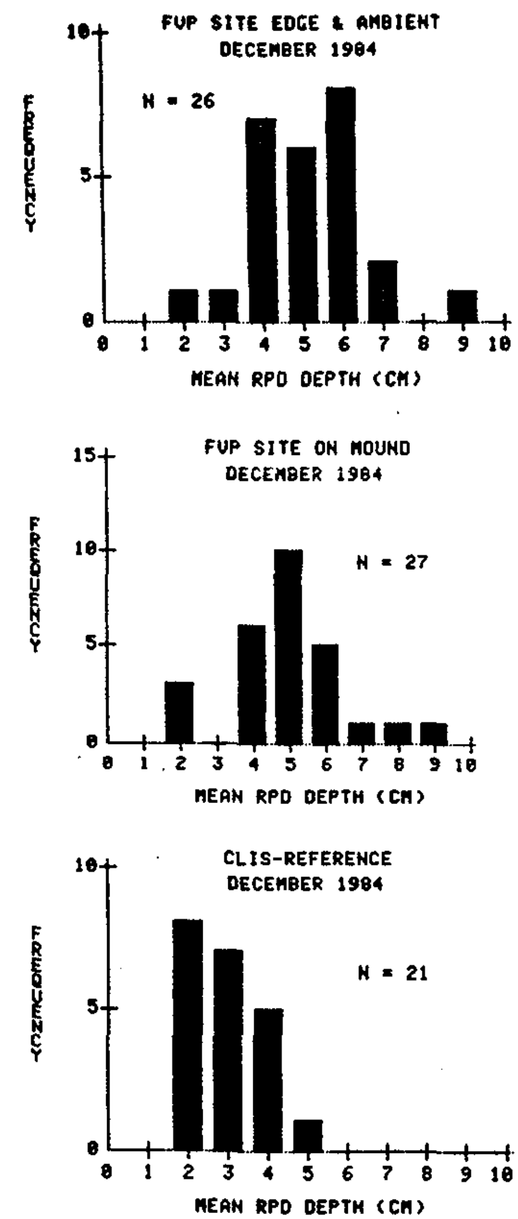

Figure IV-3-24. The frequency distributions of mean RPD depths for edge and ambient, mound and CLIS-REF stations.

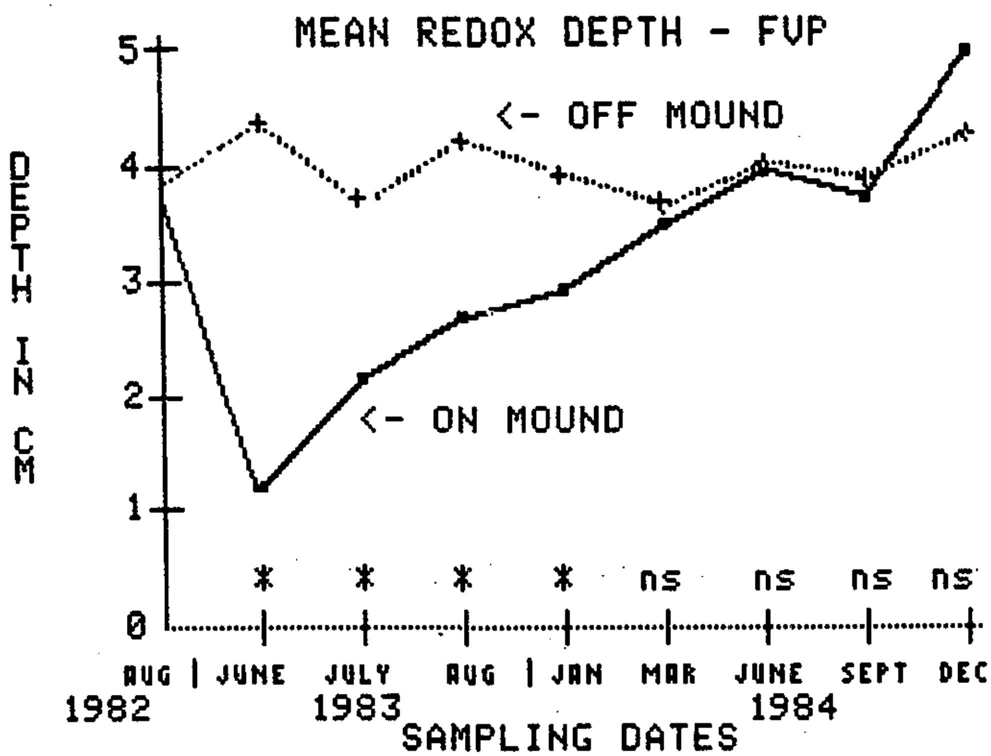

Figure IV-3-25. Average RPD depth for on mound and off mound (edge, ambient, and CLIS-REF) stations from August 1982 baseline through all post-disposal surveys. Significant differences ($P < .05$, Mann-Whitney U-test) between the on mound and off mound value are indicated by an "*" along the x-axis.

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Figure IV-3-26 shows the mapped distribution of successional stages for each station replicate in January 1984. Seventy-six percent of the station replicates that are located well within the boundaries of the zero dredged material isopleth are in Stage I while only 36% of the ambient bottom or edge stations are in Stage I. In the August 1983 REMOTS survey, 83% of the dredged material station replicates were in Stage I while only 22% of the ambient bottom station were in Stage I (Fig. IV-3-27).

Compared to the August 1983 survey, the January 1984 survey showed a slight increase in dredged material replicates that are in Stage III-I. However, this survey also revealed a few more ambient bottom station replicates in Stage I sere. This condition is also true for the CLIS-REF station, where half of the 6 replicates are in Stage I and the other half in Stage III-I. The retrograde status of some of the ambient and CLIS-REF stations relative to the August 1983 survey may be caused by winter conditions. One important criterion for identifying Stage III infauna is the presence of feeding voids at depth (produced by head-down conveyor-belt deposit feeders; see Fig. IV-3-28). As bottom water temperatures decrease in the winter, infaunal feeding rates also decrease. Feeding voids can then collapse, giving the impression that no head-down feeders are present. Because of this temperature effect on the formation and preservation of feeding voids, the apparent shift from a Stage III-I to a I may not necessarily indicate the loss of an infaunal trophic type. For this reason, the most accurate characterization of successional stage is done with summer sampling, when metabolic rates are high and feeding voids are abundant and well developed.

Figure IV-3-29 shows the mapped distribution of successional stages for each station replicate for the March 1983 survey. Eighty-nine percent of the station replicates located on the central area of dredged material are in Stage I (included in this percentage is one replicate at station 100 W that appears to be in Stage I-II). Sixty-eight percent of stations located near the edge or on ambient bottom are in Stage I. In both station subsets, the percentage of station replicates in Stage I has increased since the January 1984 survey; by 13% for centrally located stations, and 32% for edge or ambient bottom stations. The successional status of the CLIS-REF station replicates has not changed significantly since January 1984. This general increase in the number of replicates showing a Stage I successional sere may also reflect winter conditions as mentioned above.

Figure IV-3-30 shows the mapped distribution of successional stage for each station replicate in June 1984. The distribution is more uniform than in previous post-disposal surveys. Ninety-seven percent of the central dredged material replicates are in Stage I, compared to 76% of the edge and ambient bottom images. This difference is significant (G-test for independence, $p < .01$), indicating that there are fewer Stage

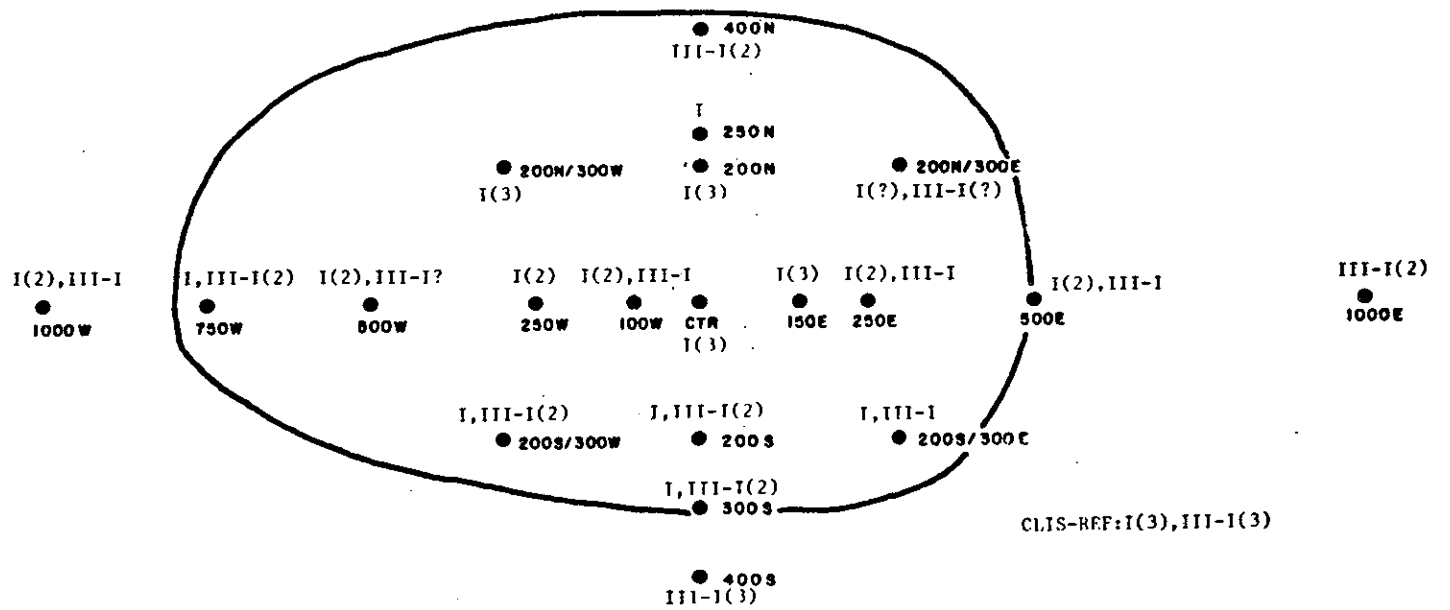

Figure IV-3-26. Mapped values for successional stage at the FVP site.

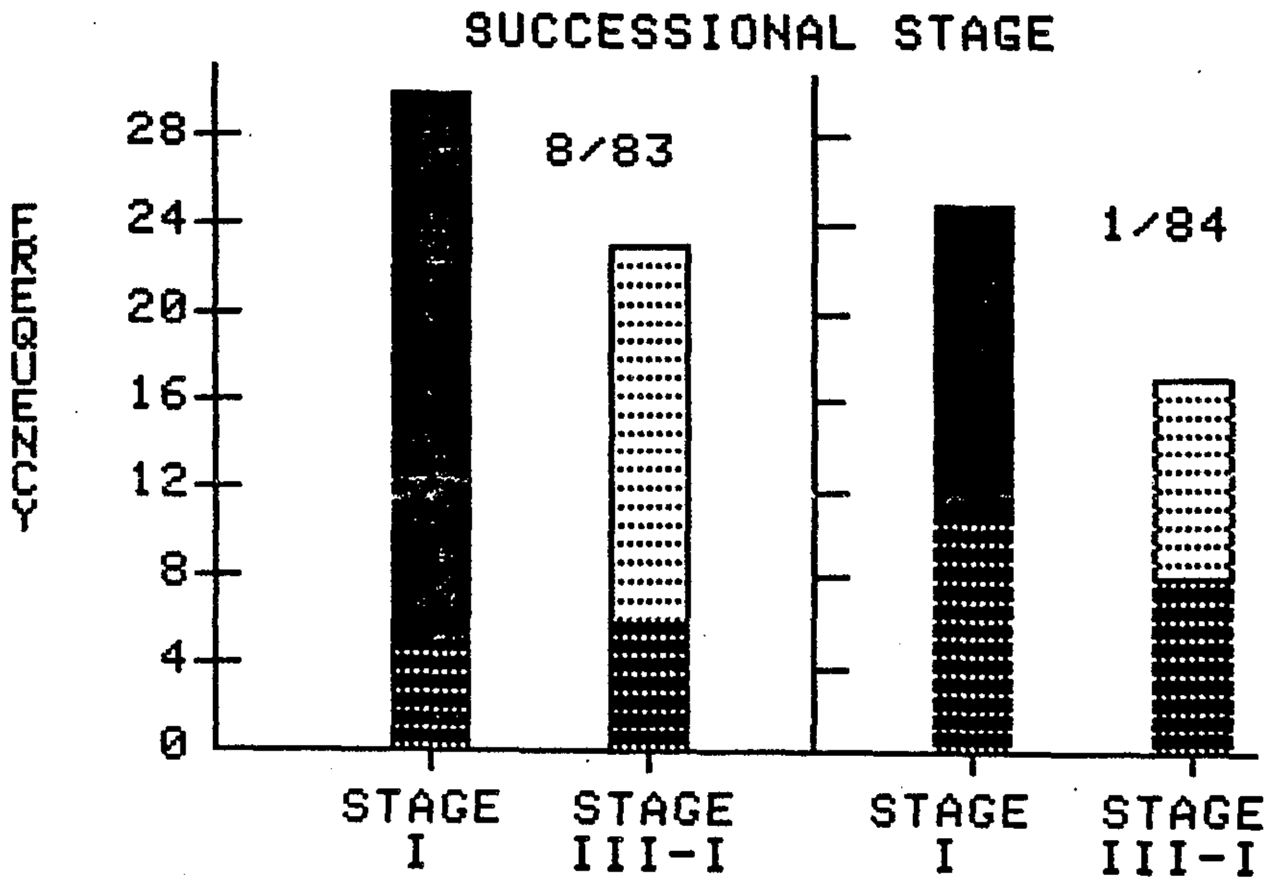

Figure IV-3-27. Comparison of successional stage seres for stations on and off dredged material in August 1983 and January 1984. Solid bars represent values of stations located on dredged material; stippled portion represents values of ambient and CLIS-REF stations.

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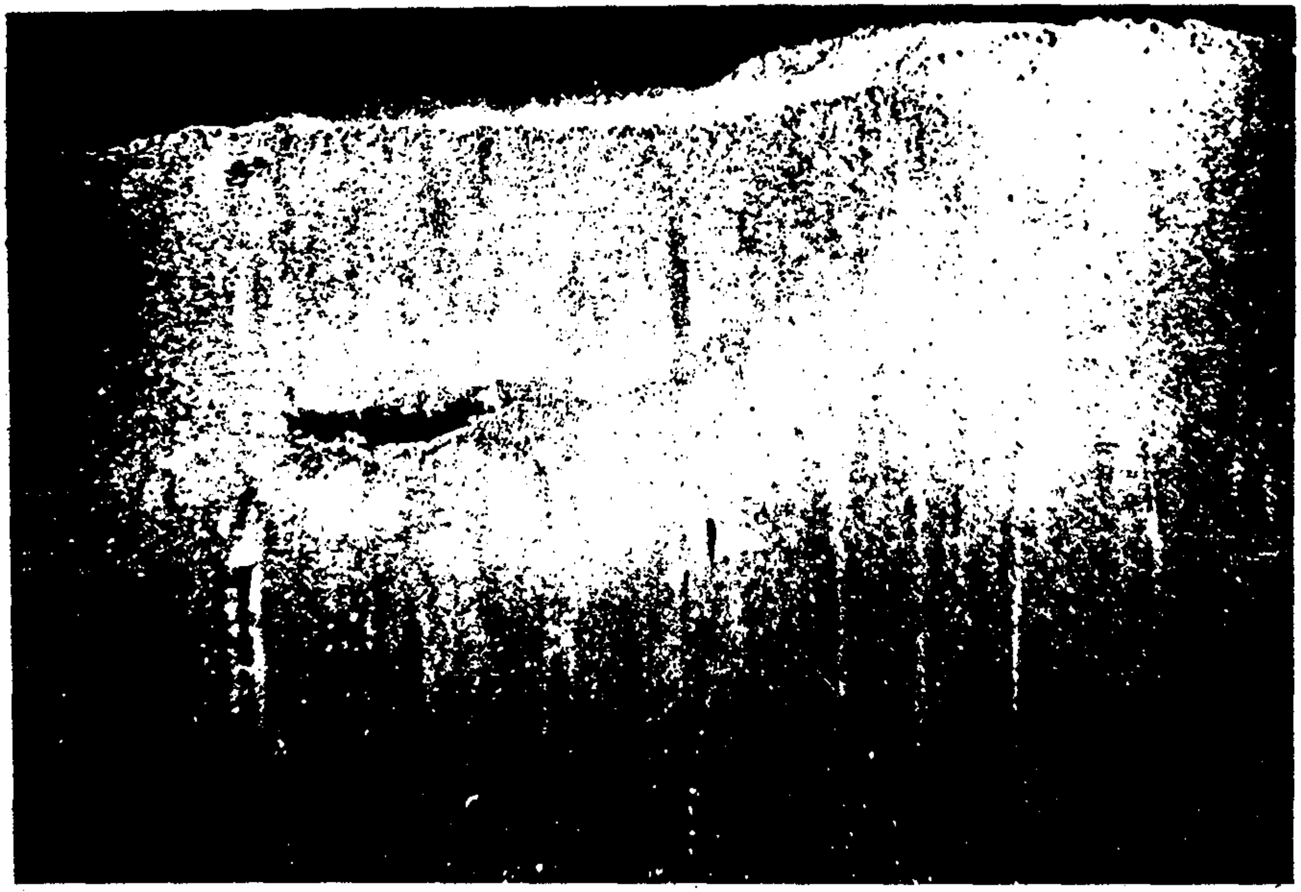


Figure IV-3-28. REMOTS image from station 400S; note feeding void in sediment, indicating presence of head-down deposit-feeders.

3/84

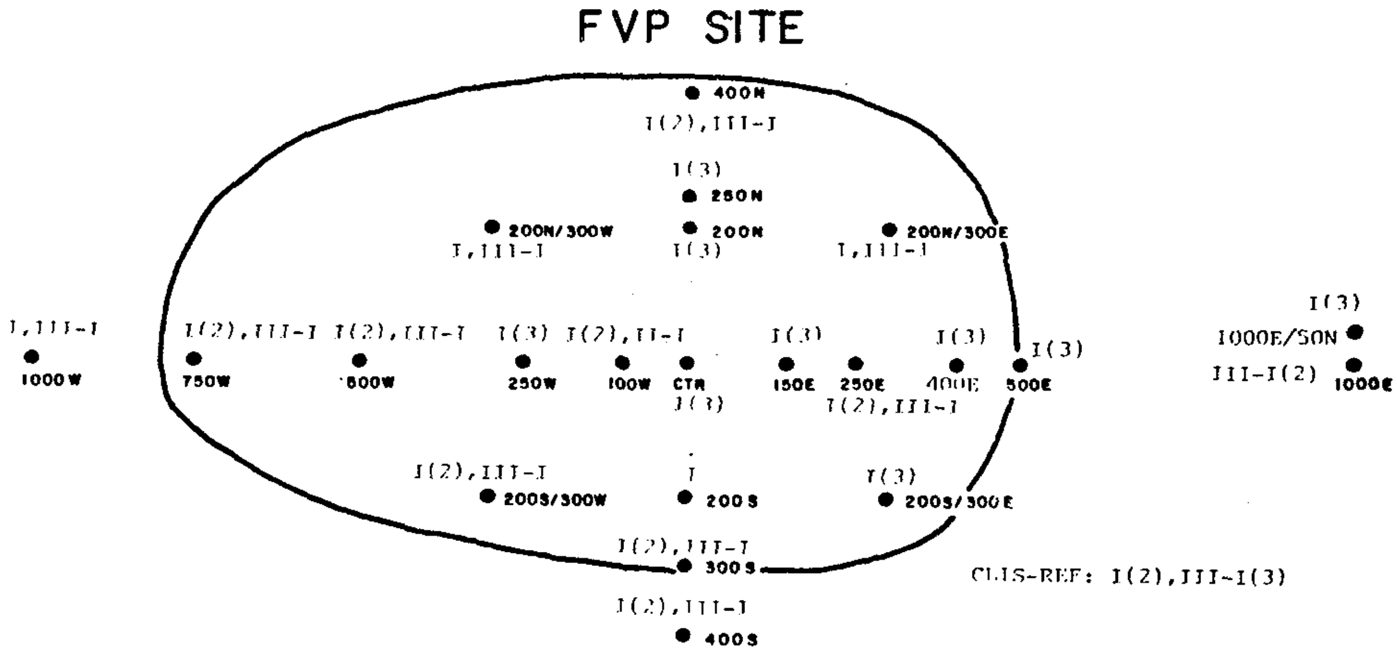


Figure IV-3-29. Spatial distribution of successional stage values at the FVP site in March 1984. The number in parentheses indicates the number of replicates with the corresponding value.

6/84

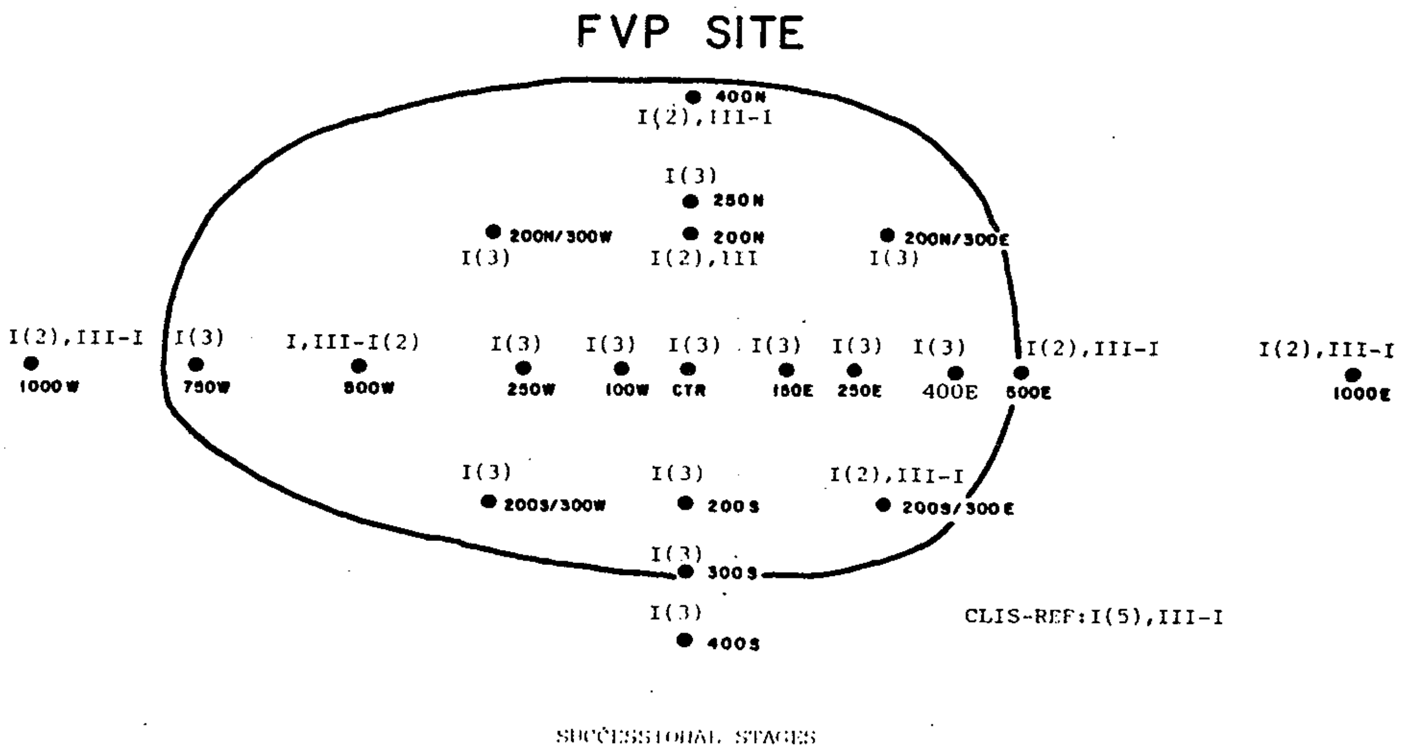


Figure IV-3-30. Mapped values for successional stages at the FVP site. The zero isopleth for dredged material in the June 1983 REMOTS survey is indicated.

III assemblages (i.e. head-down deposit feeders) at central stations than on the surrounding seafloor. Overall, the survey area exhibits a higher proportion of Stage I seres than previously observed. Table IV-3-1 shows the trend since August 1983. As noted above, the apparent retrograde succession in recent months reflects the effect of winter conditions on the benthos. Also, the paucity of Stage III seres has persisted somewhat longer than expected based on surveys in 1983. As shown in Table IV-3-1, only 57% of edge and ambient stations were in Stage I in June 1983 compared with 76% this year. This discrepancy may be due to annual variability in the timing of primary successional events.

The areal distribution of successional stages in September 1984 is shown in Figure IV-3-31. Stage I seres comprise 71% of the area affected by dredged material, as compared with 62% and 38% on the ambient and CLIS-REF stations respectively. A chi-square test shows the central area to have significantly more Stage I seres than those located on the ambient seafloor (p .05). Few head-down deposit feeders have apparently been able to successfully colonize Black Rock dredged materials. For the first time, low densities of Stage II tube-dwelling amphipods (Ampelisca sp.) were observed at the FVP site, both on dredged material and the ambient bottom. These amphipods co-occur with Stage I polychaetes, and so this association is tentatively designated as a I-- II transition stage.

The mapped distribution of successional stages in December 1984 is shown in Figure IV-3-32. Of the mound stations, 63% exhibit Stage III seres; this compares with 77% of the edge and ambient stations and 81% of the CLIS-REF replicates. A series of chi-square tests shown that these discrepancies between areas are not significant ($p < .05$). In September, only 21% of the mound stations, 34% of the edge and ambient stations, and 50% of the CLIS-REF site exhibited Stage III seres. Since that survey, the abundance of Stage III fauna has increased significantly throughout the FVP area ($p = .001$, chi-square test).

An important criterion for identifying Stage III fauna is the presence of feeding voids at depth. However, as water temperature decreases in winter, infaunal feeding rates also decrease; feeding voids can then collapse giving the impression that no head-down feeders are present (Fig. IV-3-33). Because a collapsed void is indicative of recent head down feeding activity, REMOTS images with such features are given a Stage III designation. As the winter progresses, it becomes increasingly difficult to discern collapsed voids. Therefore, as mentioned in previous FVP reports, the most accurate characterization of Stage III faunal abundances is achieved during the warmer months.

This is the first FVP post-disposal survey in which the abundance of Stage III fauna (head-down deposit feeders) on the main disposal area is comparable to their abundance on the surrounding seafloor. Nineteen months after the disposal of Black Rock Harbor dredged materials at the FVP site, high-order

Table IV-3-1

PERCENTAGE OF STAGE I SERES

DATE	6/83	7/83	8/83	1/84	3/84	6/84
CENTRAL (on dredged materal)	97	82	85	78	88	97
AMBIENT	57	64	22	37	70	76

9/84

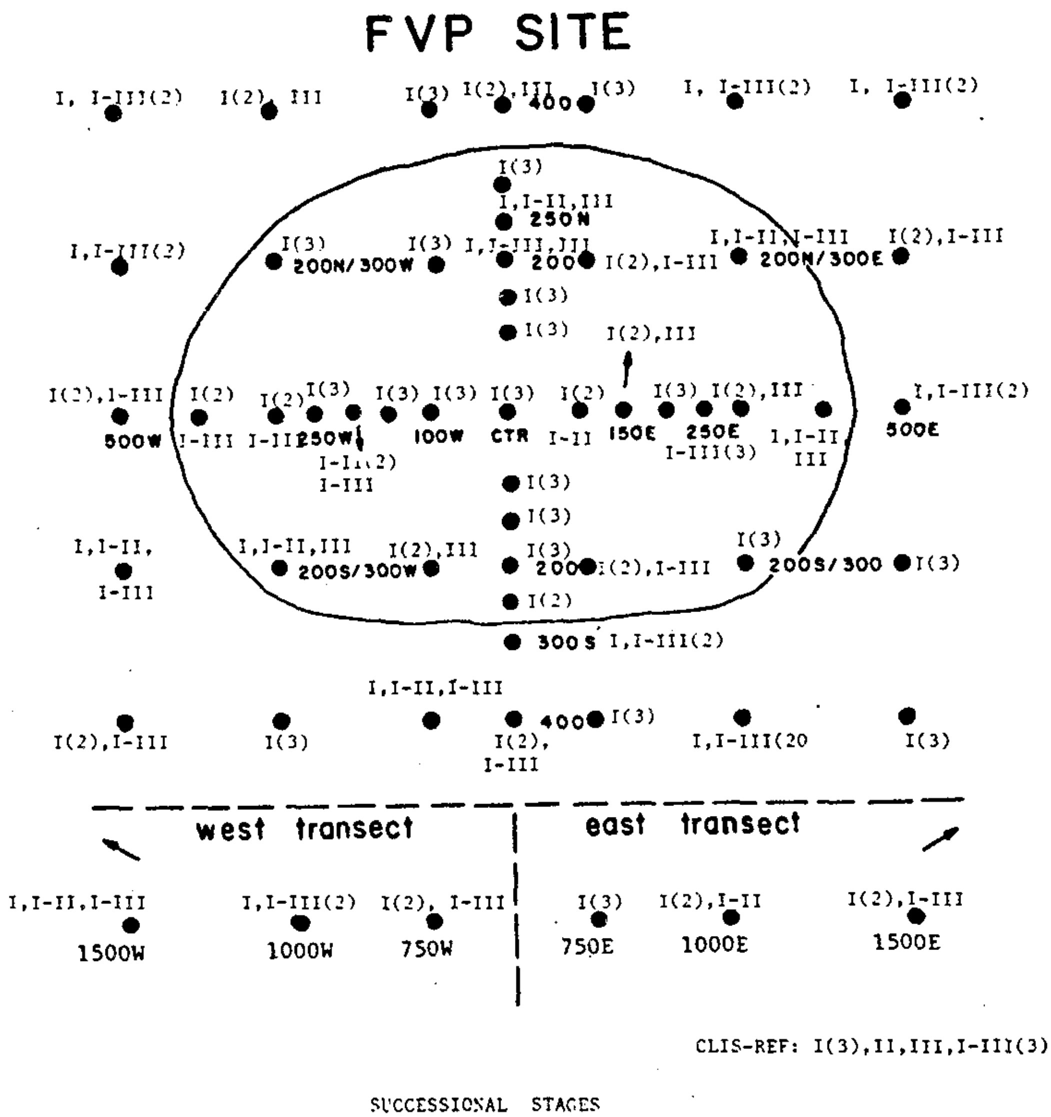


Figure IV-3-31. The mapped distribution of infaunal successional stages at the FVP site.

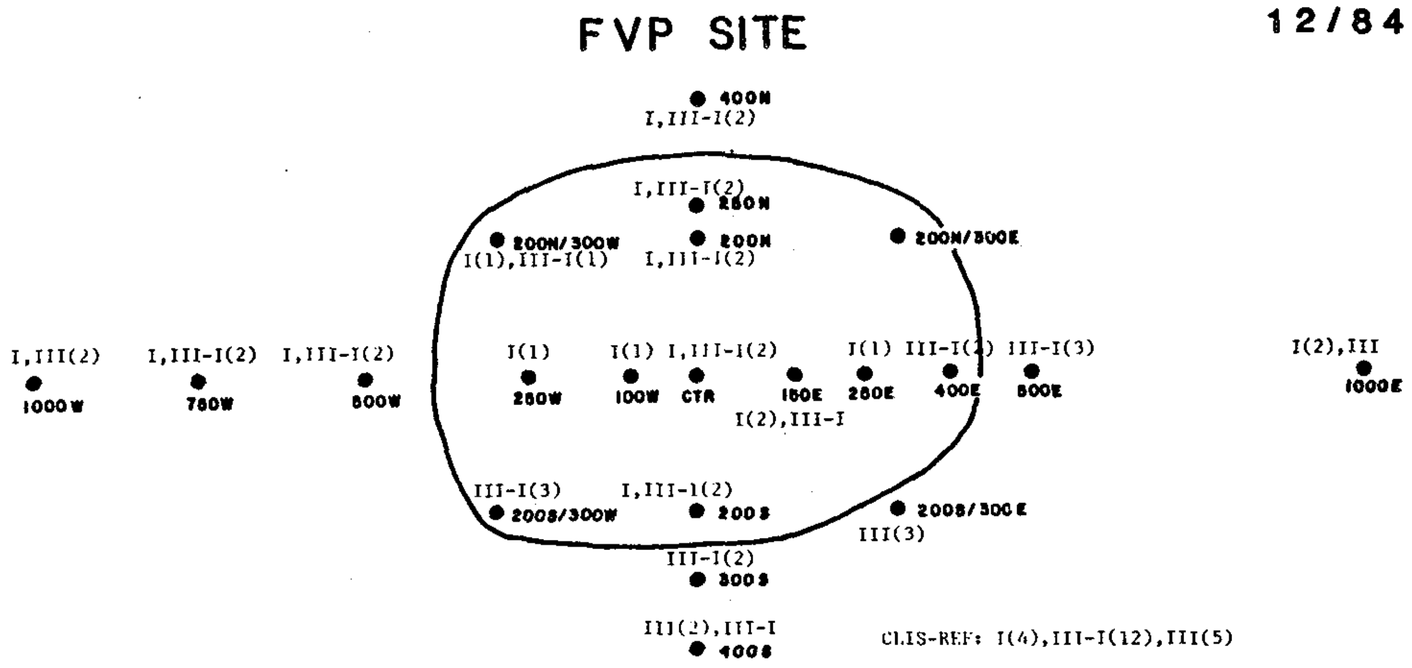


Figure IV-3-32. The mapped distribution of infaunal successional stages at the FVP site.

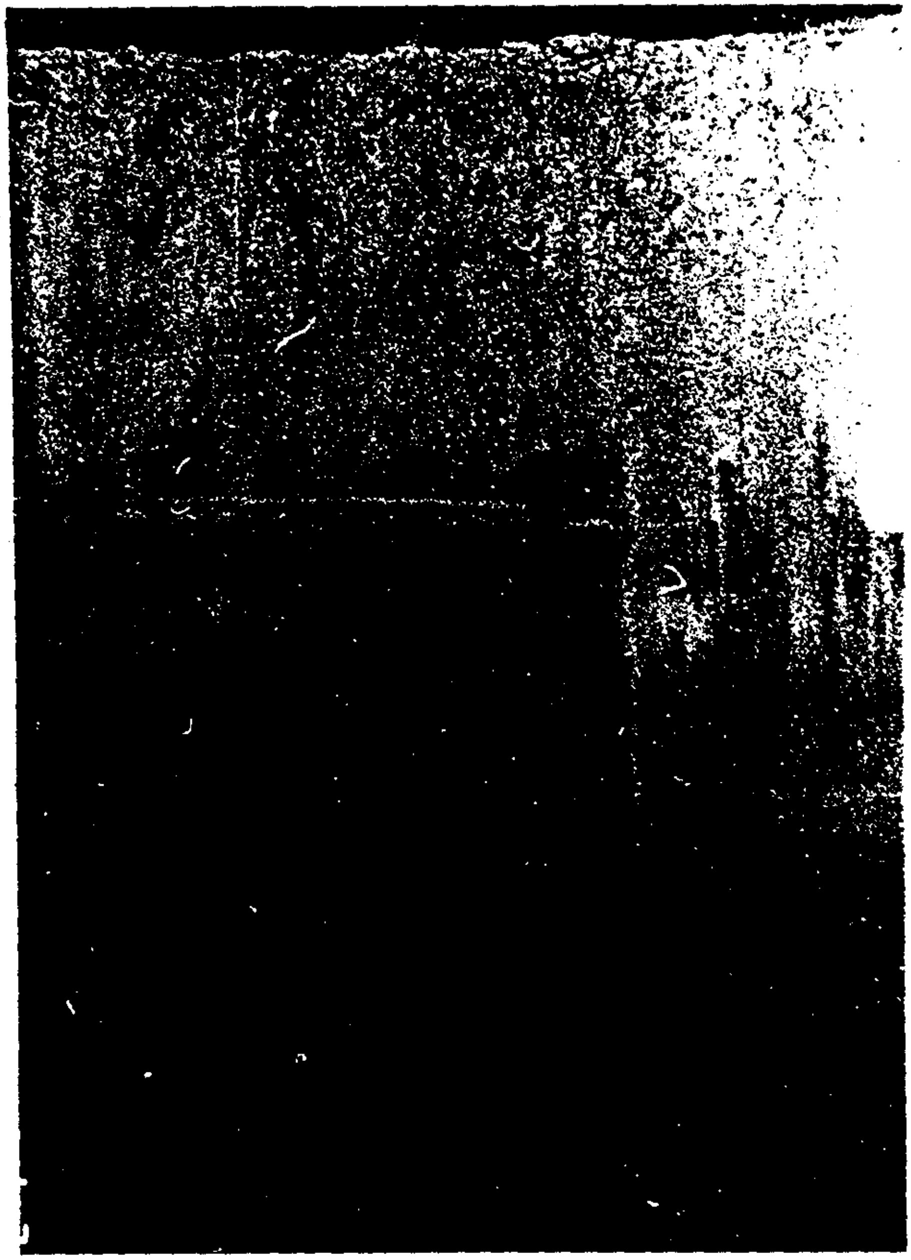


Figure IV-3-33. REMOTS® image from station 200S/300W showing a "collapsed" feeding void, the dark elleptical structure below the RPD in the left side of the image.

successional stage fauna have apparently colonized the dredged materials.

3.2.6 Benthic Indices

The mapped habitat indices for the January 1984 survey are shown in Figure IV-3-34, most station replicates located on dredged material have values within the range of 4 to 6. Stations located near the edge of the deposit, or on the ambient seafloor, have values ranging between 6 and 11 (Fig. IV-3-35). The CLIS-REF station values range between 5 and 11, related to the apparent retrograde condition of some ambient bottom stations as described earlier. This may, or may not, represent a real decrease in successional status. The August 1983 survey also showed the habitat indices to be bimodally distributed, with stations located on dredged material having a major mode at the index value of 5 and ambient stations at 11 (Fig. IV-3-36).

Mapped benthic indices for the March 1984 survey are shown in Figure IV-3-37. Figure IV-3-38 shows the frequency distribution of benthic index values for all stations. The major mode for stations located on dredged material is 6 and is unchanged from the January survey. However, more central station replicates have a benthic index value of 7 (n=10) than recorded in the January survey (n=3). This largely reflects the increase in RPD depths at many of these staions. The frequency distribution of benthic indices for edge and ambient stations is bimodal with peaks at 7 and 11 (Fig. IV-3-38). Fewer values are in the 9-11 range for this survey (n=8) than in the January survey (n=12), again reflecting the apparent retrograde successional status of some of these stations. The CLIS-REF station values range from 6 to 11. Figure IV-3-39 shows a contour map of benthic index values, visually emphasizing the fact that lower values are centrally located on the dredged material mound.

The benthic indices for June 1984 are mapped in Figure IV-3-40. Only station CTR exhibits obviously depressed values. Figure IV-3-41 shows the benthic index value frequency distribution for the central stations and the edge and ambient stations. The major mode for stations located on the central region is 7 (range = 4-11). The major mode for the surrounding seafloor is also 7 (range 5-11). This is the first post-disposal survey in which the major modes for both regions coincide. On the ambient bottom, there is a subordinate peak at 11 which does not occur at the central dredged material sites. This divergence in index values is due largely to the lack of Stage III assemblages in the central region. Since January and March 1984 the major mode of the central sites has increased from 6 to 7. This increase in the benthic index values reflects increasing RPD depths. At the ambient and edge stations, there are fewer values in the 9=11 range in this survey (n=8) than in January 1984 (n=12) or August 1983 (n=24). This is due to the apparent retrograde succession at these sites due to winter conditions.

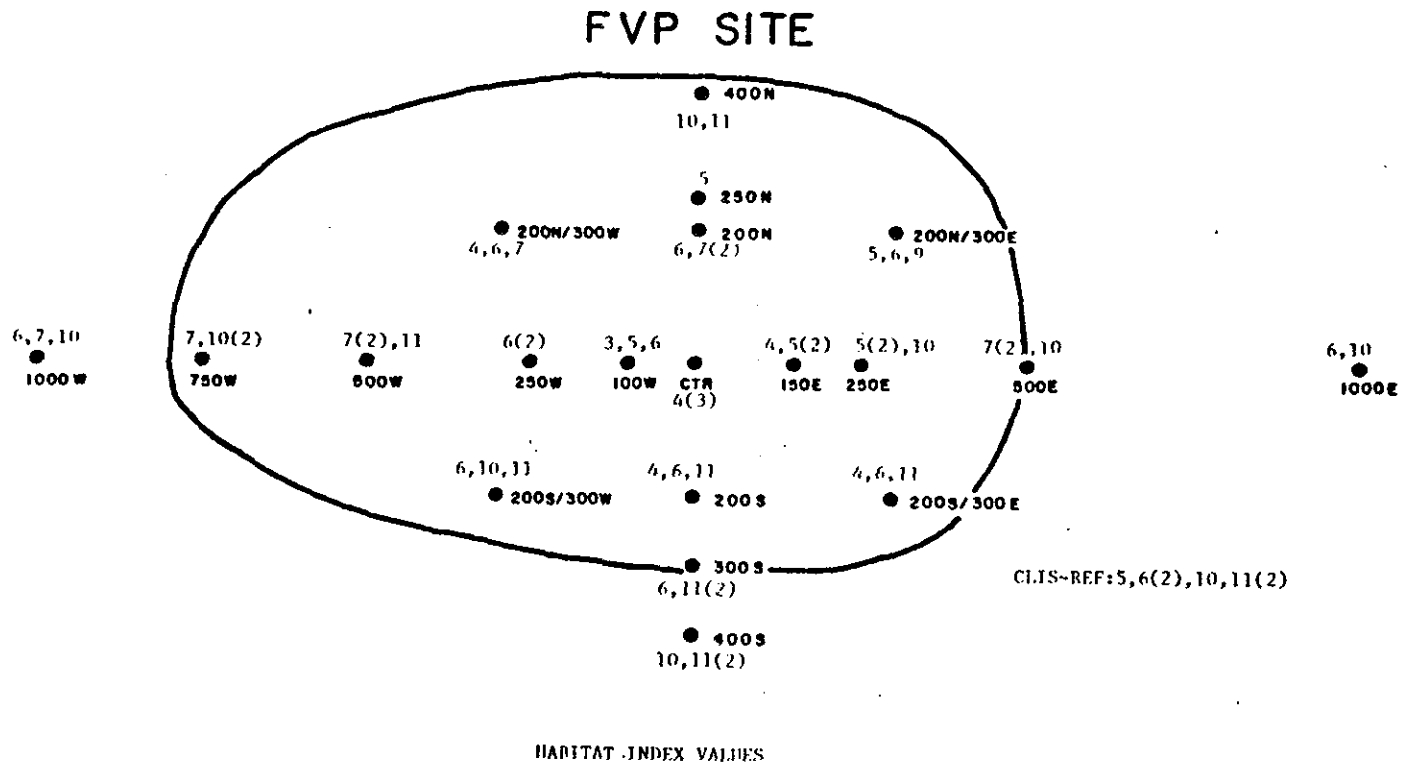


Figure IV-3-34. Habitat index values at FVP site in January 1984.

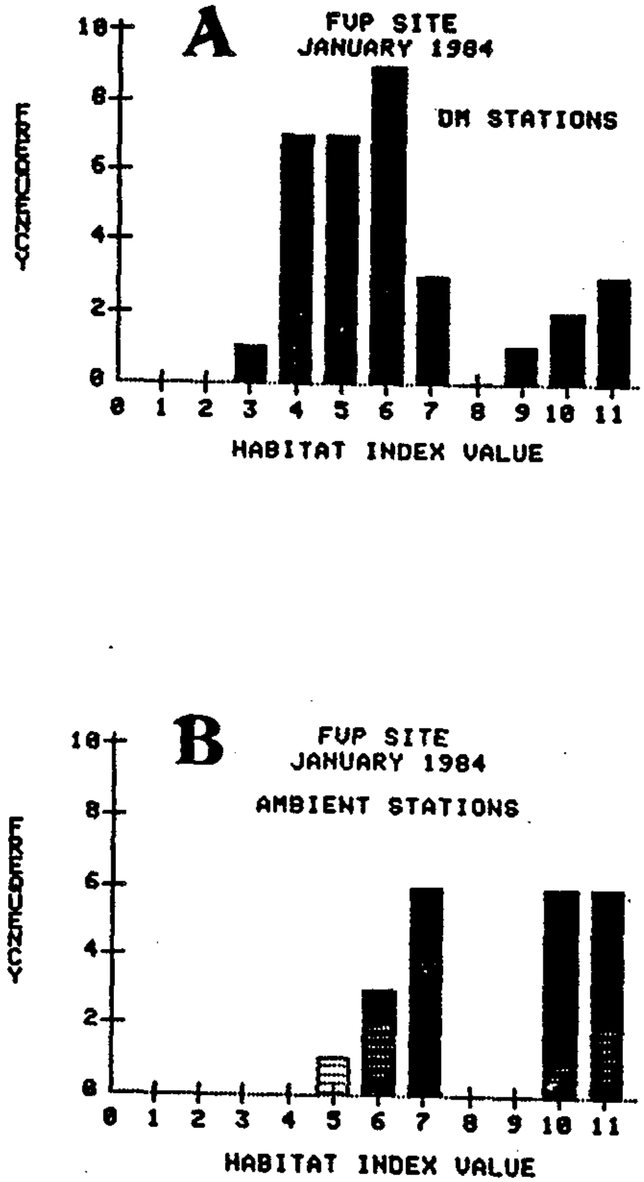
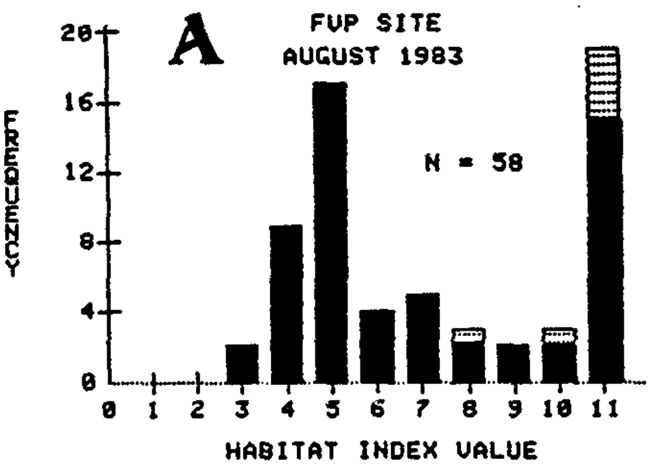


Figure IV-3-35. Frequency distribution of habitat index values for stations located on dredged material versus values for CLIS-REF (stippled portion) and stations located on amient bottom.



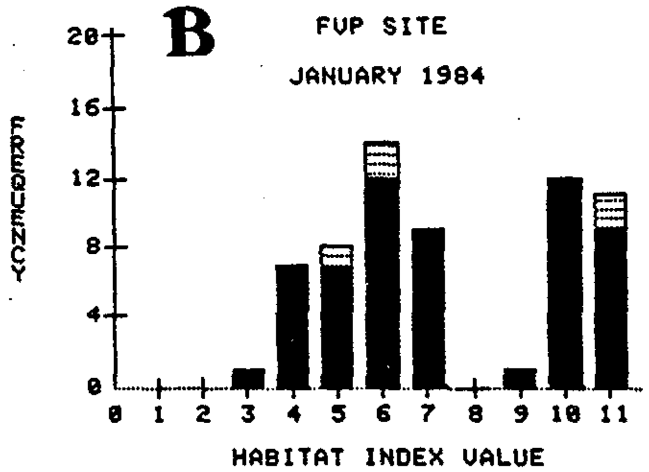


Figure IV-3-36. Frequency distribution of habitat index values August, 1983 (A) versus values in January, 1984(B).

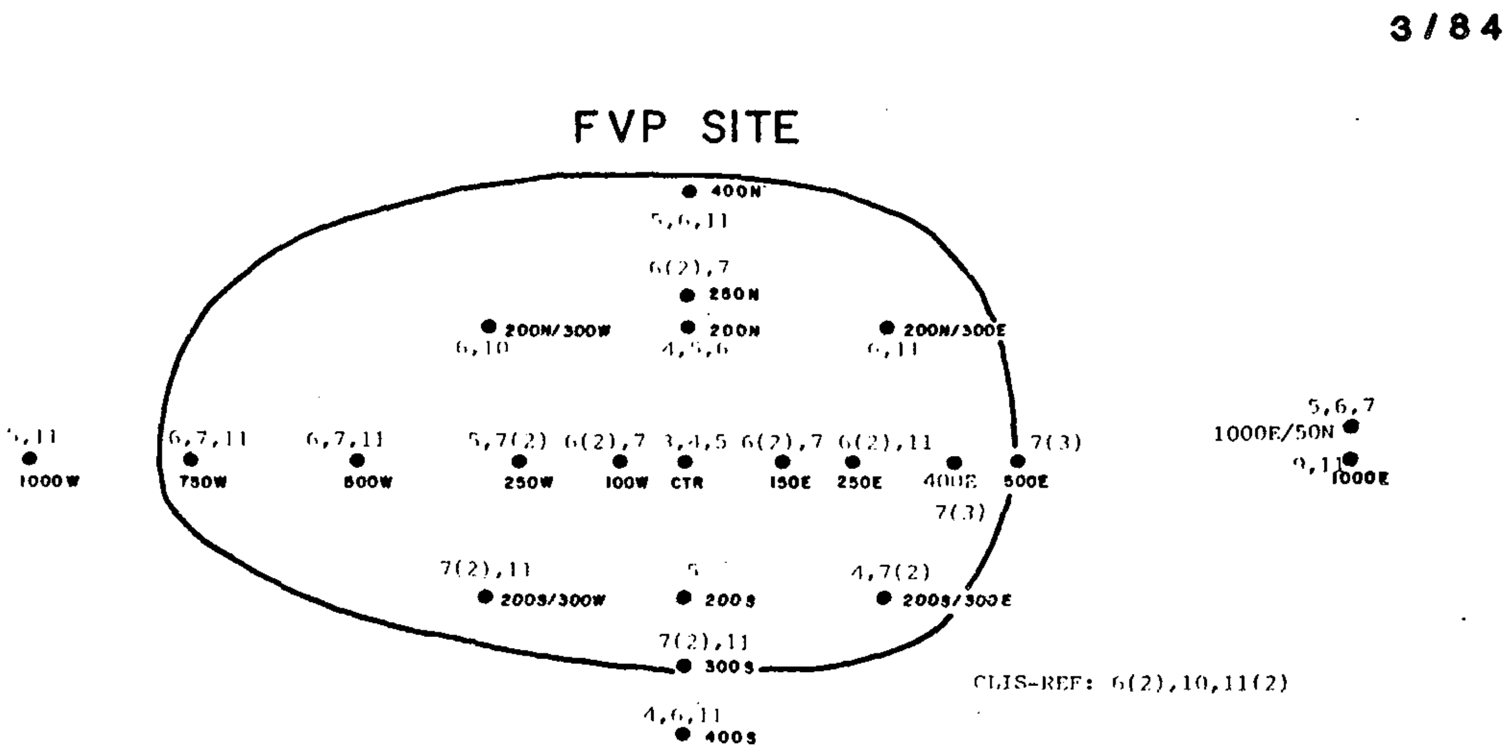


Figure IV-3-37. Spatial distribution of benthic index values at the FVP site in March 1984. The number in parentheses indicates the number of replicates with the corresponding value.

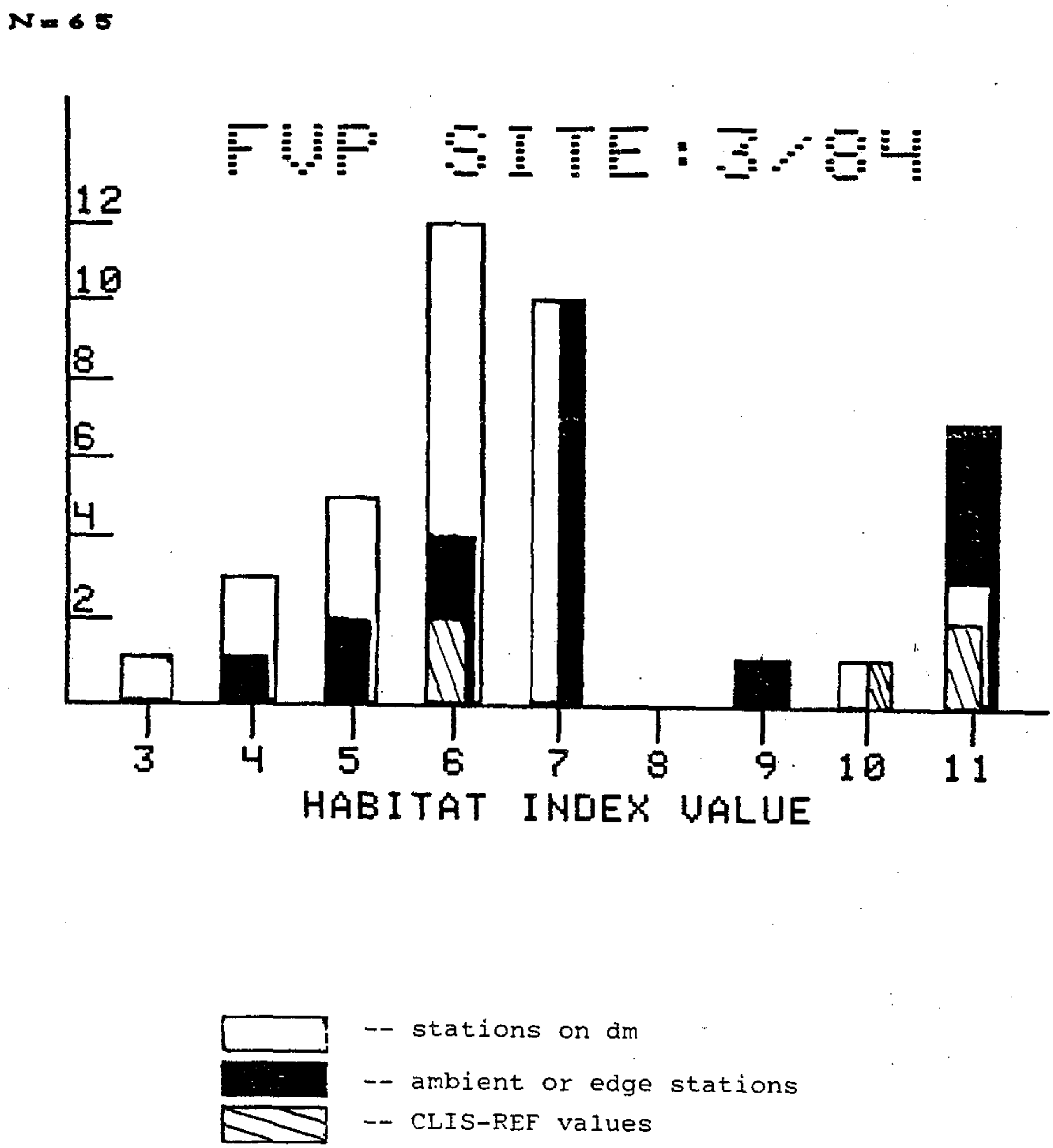


Figure IV-3-38. Frequency distribution of benthic index values at the FVP site in March 1984

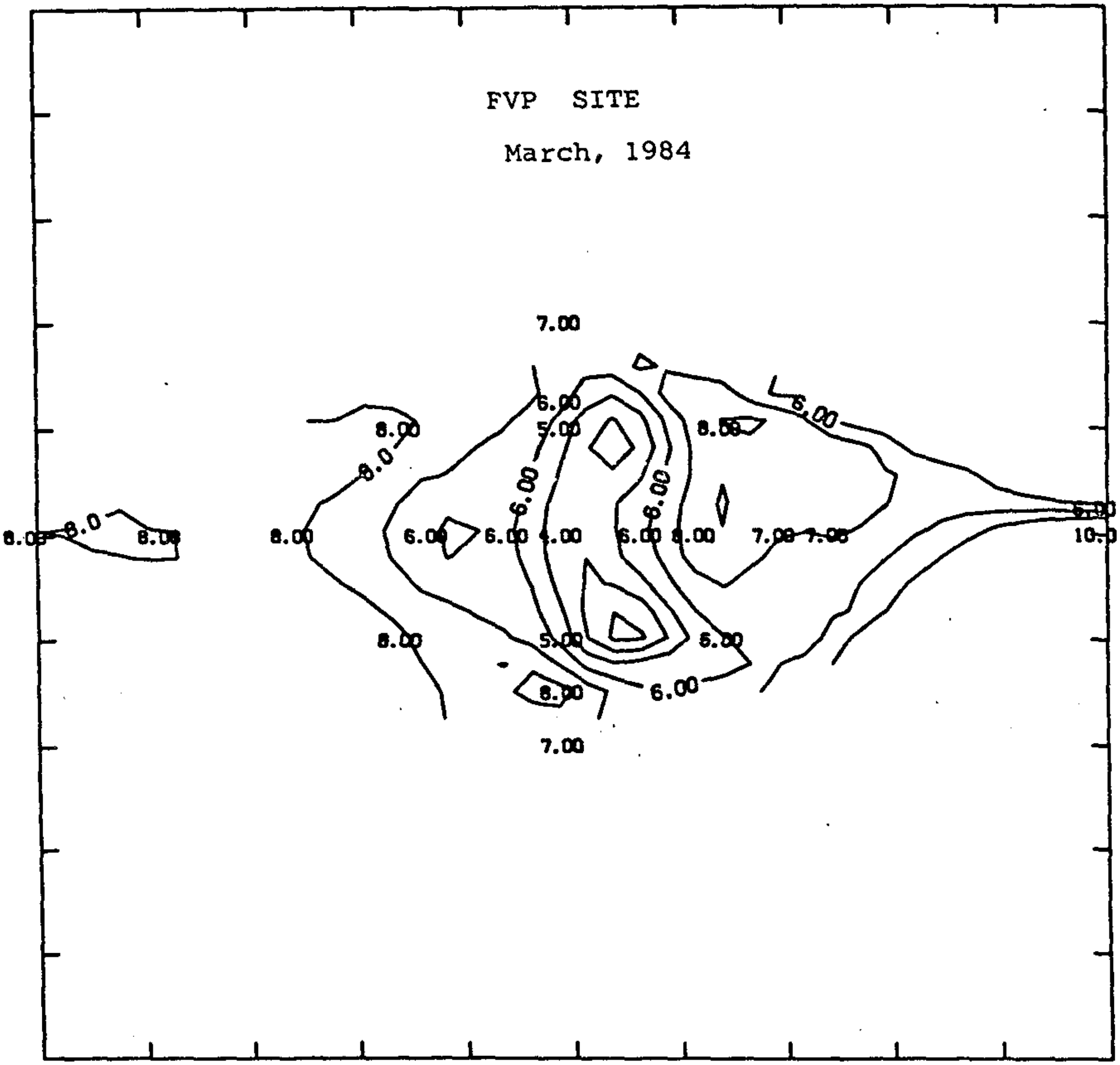


Figure IV-3-39. Contour map of the average benthic index values at the FVP site in March 1984.

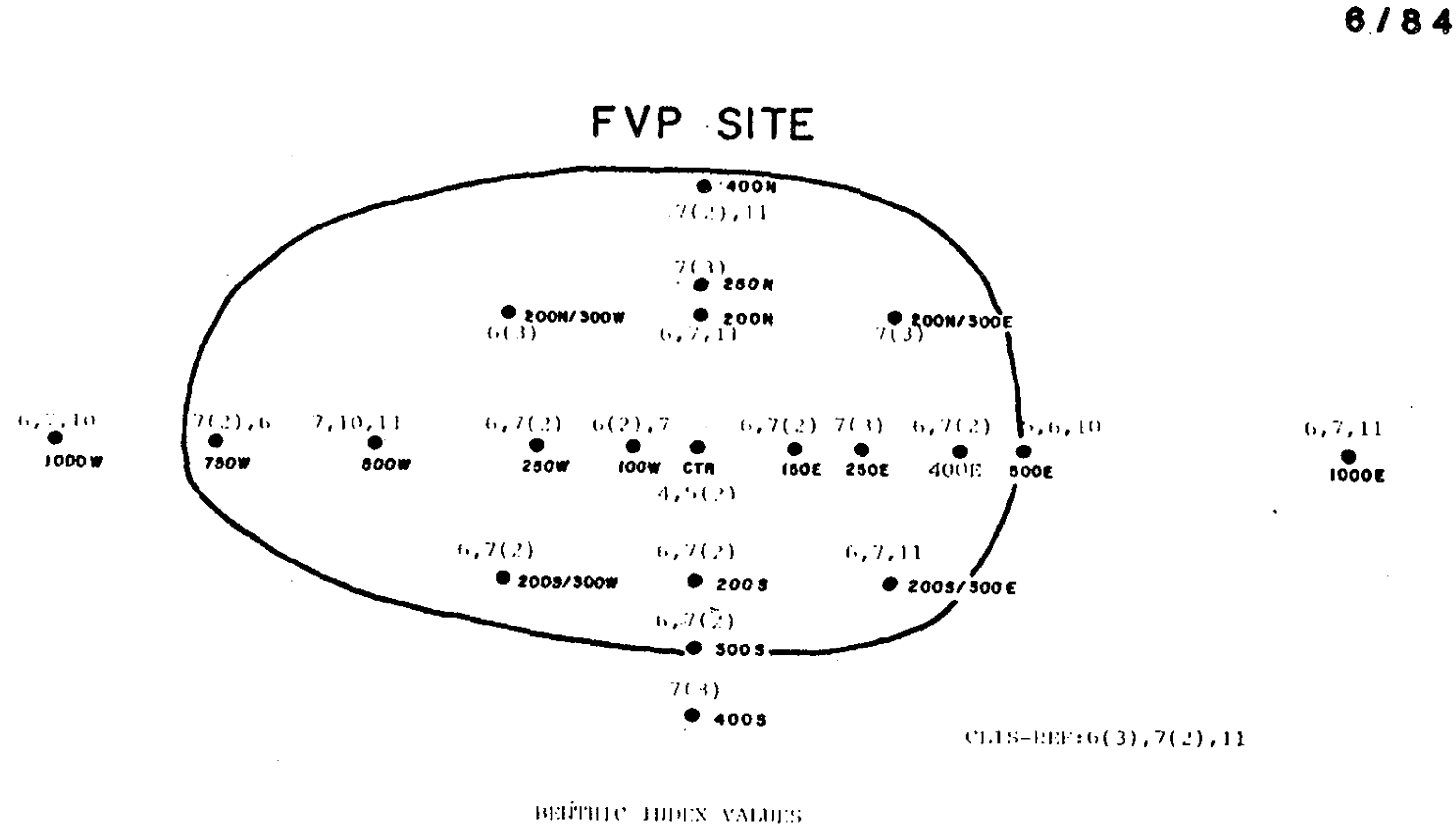


Figure IV-3-40. Mapped benthic index values for the FVP site. The zero isopleth for dredged material as measured in June 1983 is indicated. Only station CTR exhibits obviously depressed values.

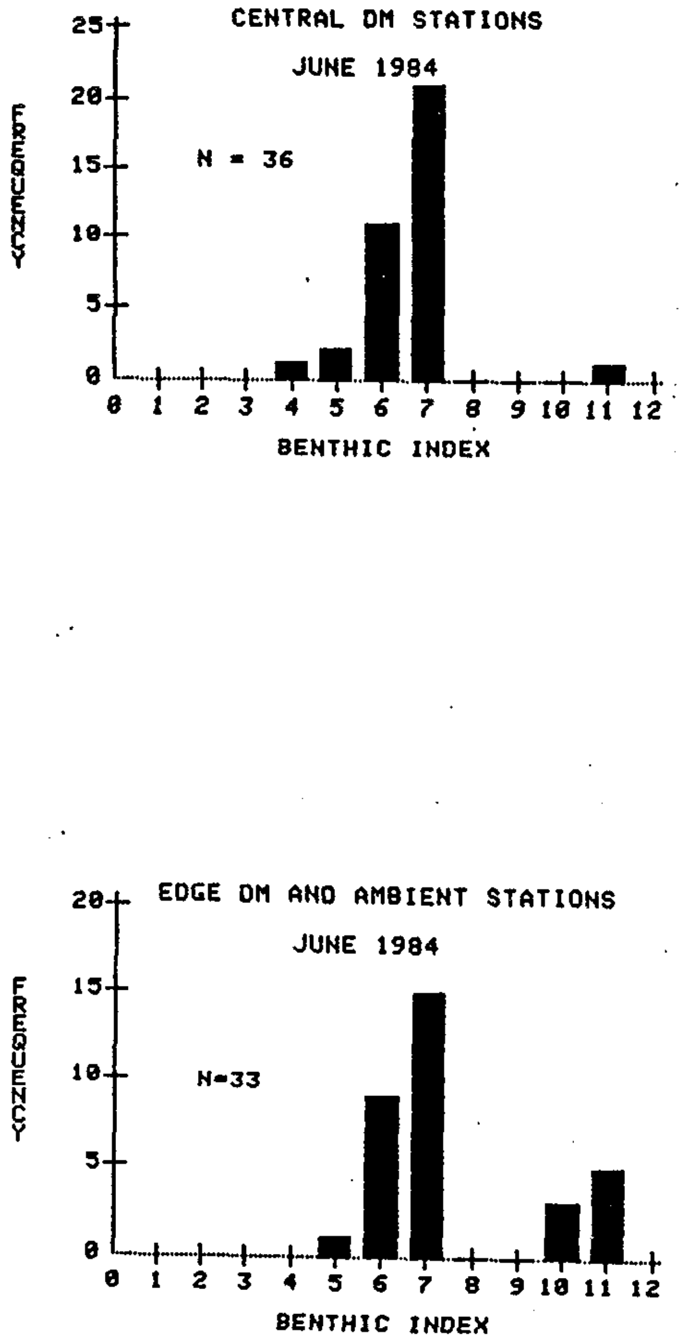


Figure IV-3-41. Comparison of benthic index frequency distributions for the central dredged material and the edge dredged material and ambient stations.

The areal distribution of REMOTS benthic indices for the September 1984 survey is shown in Figure IV-3-42, and the index frequency distributions are shown in Figure IV-3-43. Benthic index values are lowest at stations located near, and west of, the FVP center: stations CTR, 100W, and 150W. This is related to their anomolously shallow RPD depths and Stage I status. Some stations located near the edge of the dredged material deposit are colonized by a few Stage III taxa and have relatively deep redox depths. The aforementioned gradients produce a bimodal distribution of benthic indices (Fig. IV-3-43, on mound). Bimodal distributions are also characteristic of stations located near the edge of the deposit, ambient bottom, and at the CLIS-REF site. In these areas, lower numerical indices probably represent local disturbances related to predation or bottom trawling. The benthic indices of the central stations are significantly different ($p < 0.05$; Mann- Whitney U-test) from those at the edge and ambient stations and CLIS-REF station. The edge and ambient station values are not significantly different from the CLIS-REF station at this probability level.

The mapped distribution of REMOTS benthic indices is shown in Figure IV-3-44. Reflecting the uniform RPD and successional stage values across the FVP site, there is no difference in benthic index values between the mound stations and edge and ambient stations ($p = .3825$, Mann-Whitney U-test). The combined benthic index values for the mound stations and the edge and ambient stations are greater than the index values at the CLIS-REF site ($p = .0474$, Mann-Whitney U-test). The depressed benthic index values at CLIS-REF reflect the anomalously shallow RPD depths at that site.

Figure IV-3-45 shows the frequency distributions of benthic index values for the three areas surveyed. The major modal benthic index value at mound stations and edge and ambient stations is 11. Both regions have significantly higher index values than in September ($p < .001$, Mann-Whitney U-test). This increase in benthic indices reflects both the deepened RPD values and the greater abundance of Stage III assemblages.

Figure IV-3-46 compares the benthic index distribution of the central stations (disposal site) and the edge and ambient stations (ambient bottoms) from all REMOTS surveys. The initial impact of the disposal operation as well as the subsequent, progressive recovery of the disposal site is clearly illustrated. During the first summer of colonization, the major modal benthic index at disposal stations increased one index value per month from June to August 1983 (2 to 5). The June 1984 REMOTS survey showed that the modal index had increased to a value of 7 and the disposal site appeared to be converging rapidly with the ambient seafloor. There had been no change in the benthic index frequency distribution in September. The rate of convergence of benthic indices of the disposal site and ambient seafloor has decreased during the second year of colonization. For the central mound area, the December REMOTS survey was the first in which the major modal benthic index value has reached the

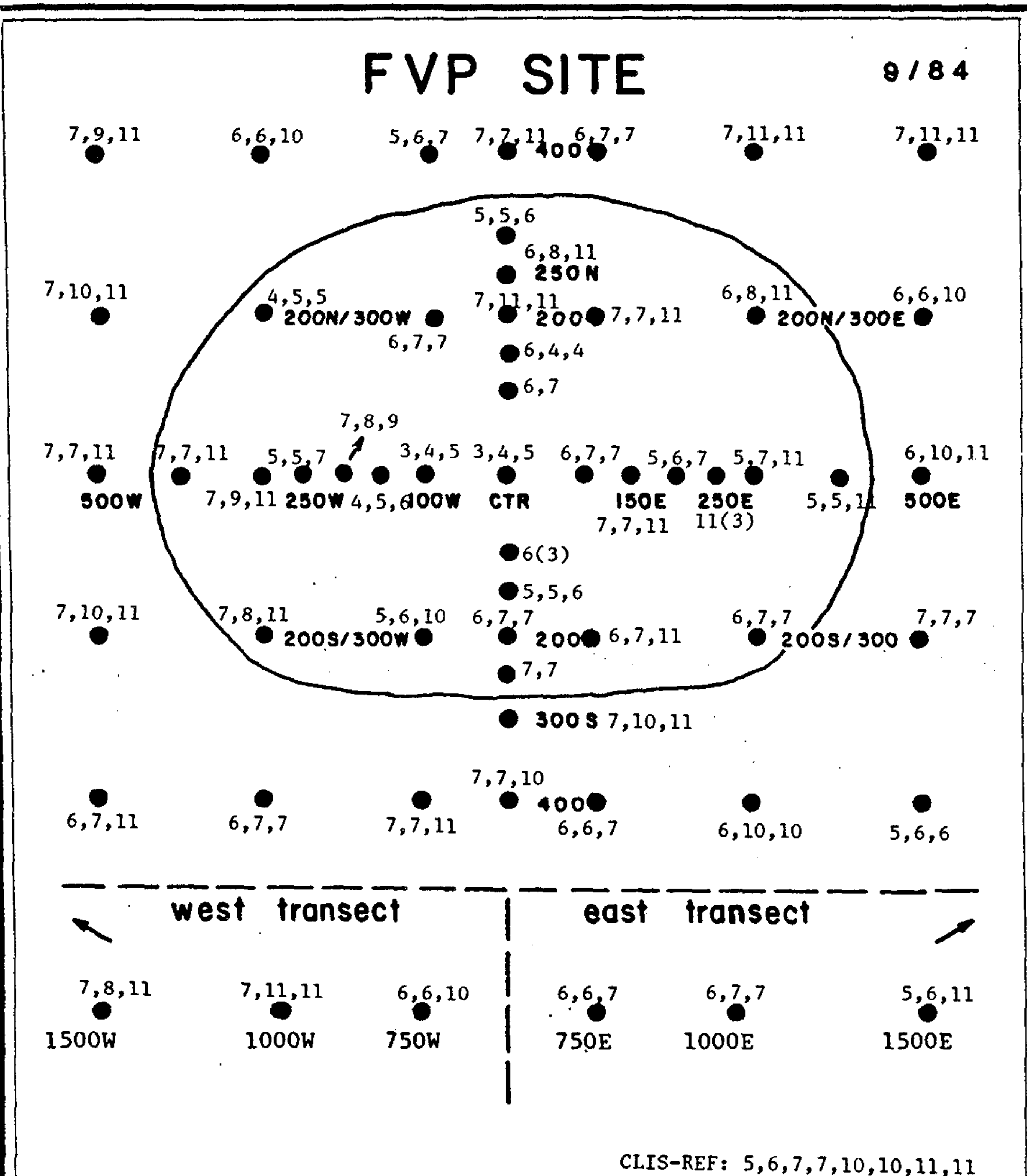


Figure IV-3-42. The mapped distribution of benthic indices.

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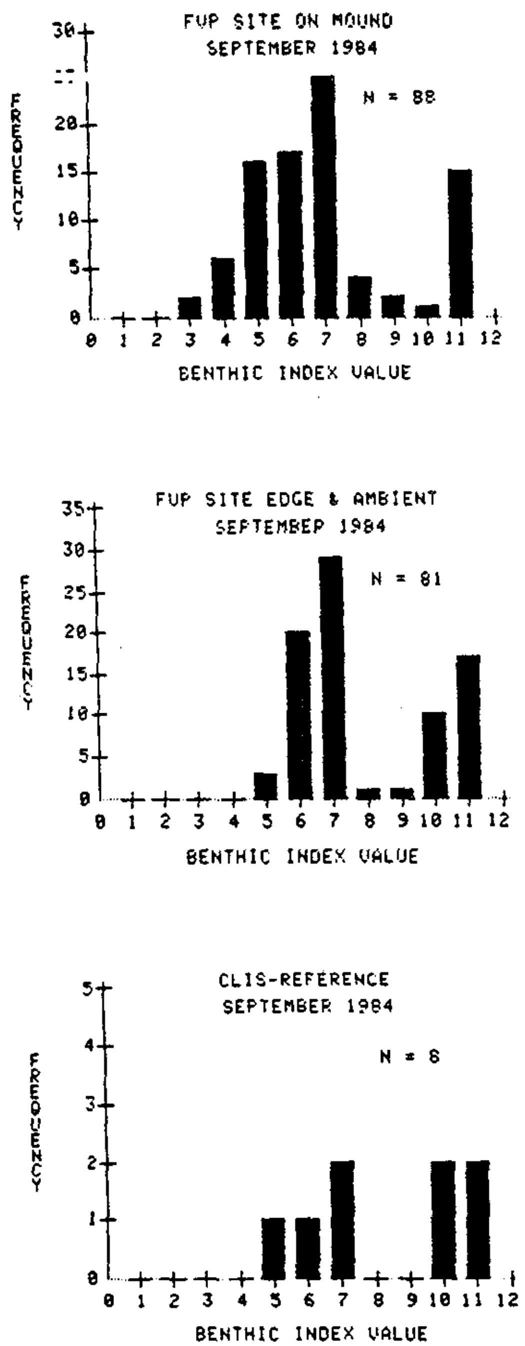

Figure IV-3-43. The frequency distributions of benthic index values for dredged material mound, edge and ambient, and CLIS-REF stations.

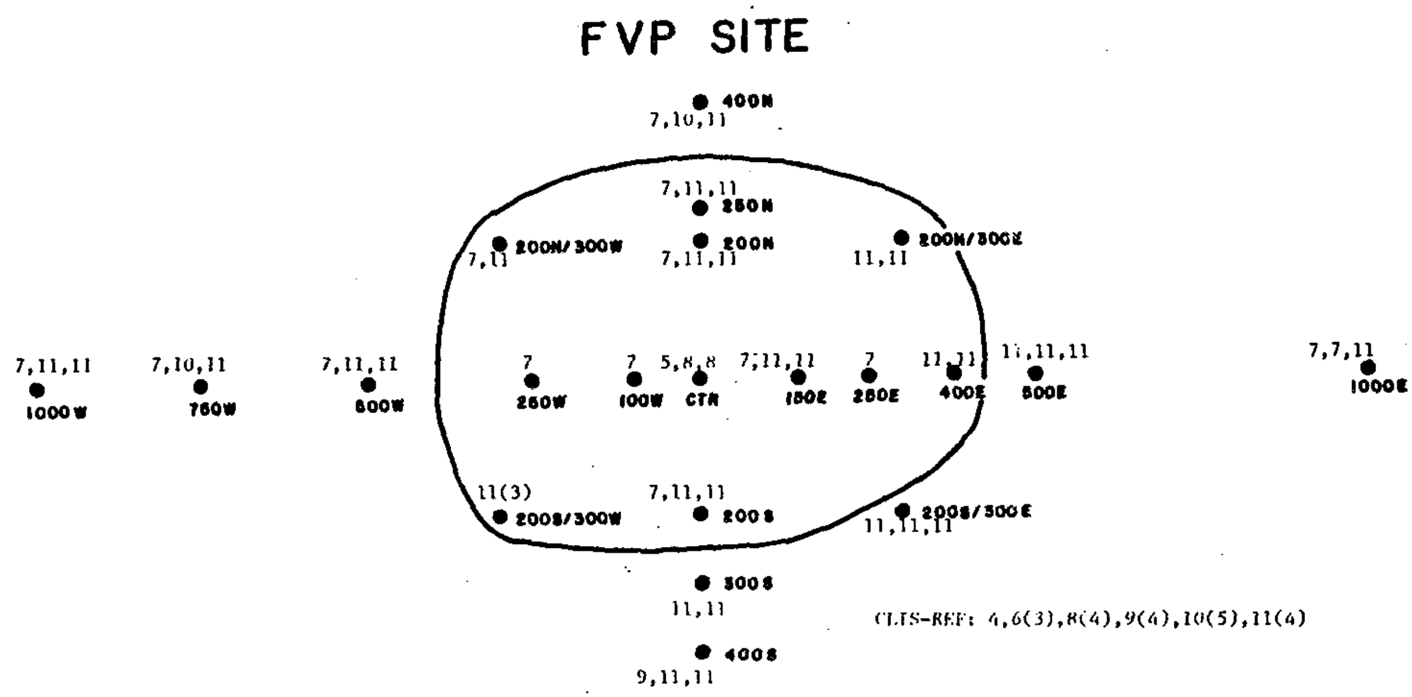

Figure IV-3-44. Mapped distribution of benthic indices for all replicates in the December survey.

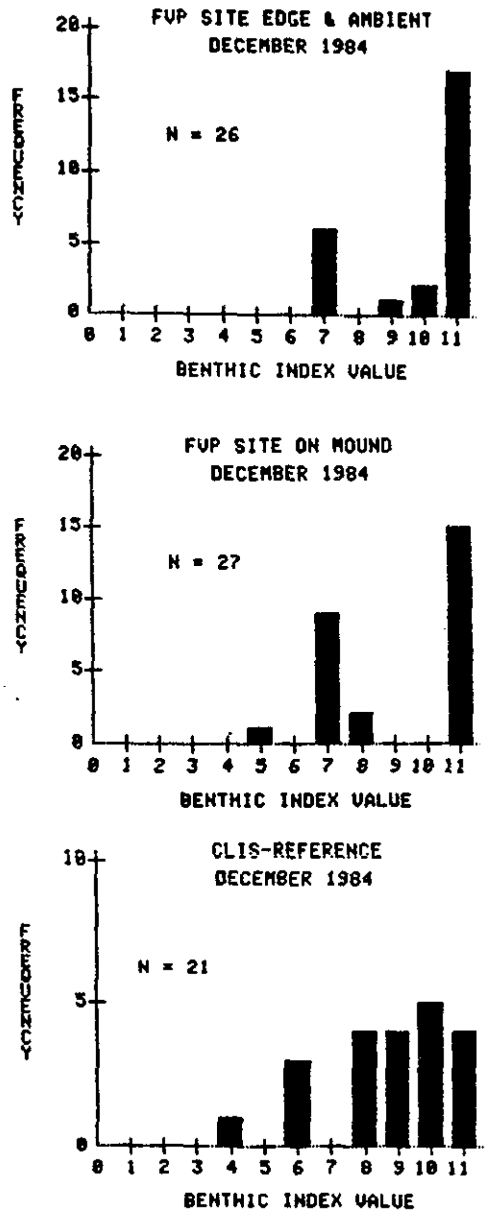

Figure IV-3-45. Benthic index frequency distributions for the edge and ambient, on mound, and CLIS-REF stations.

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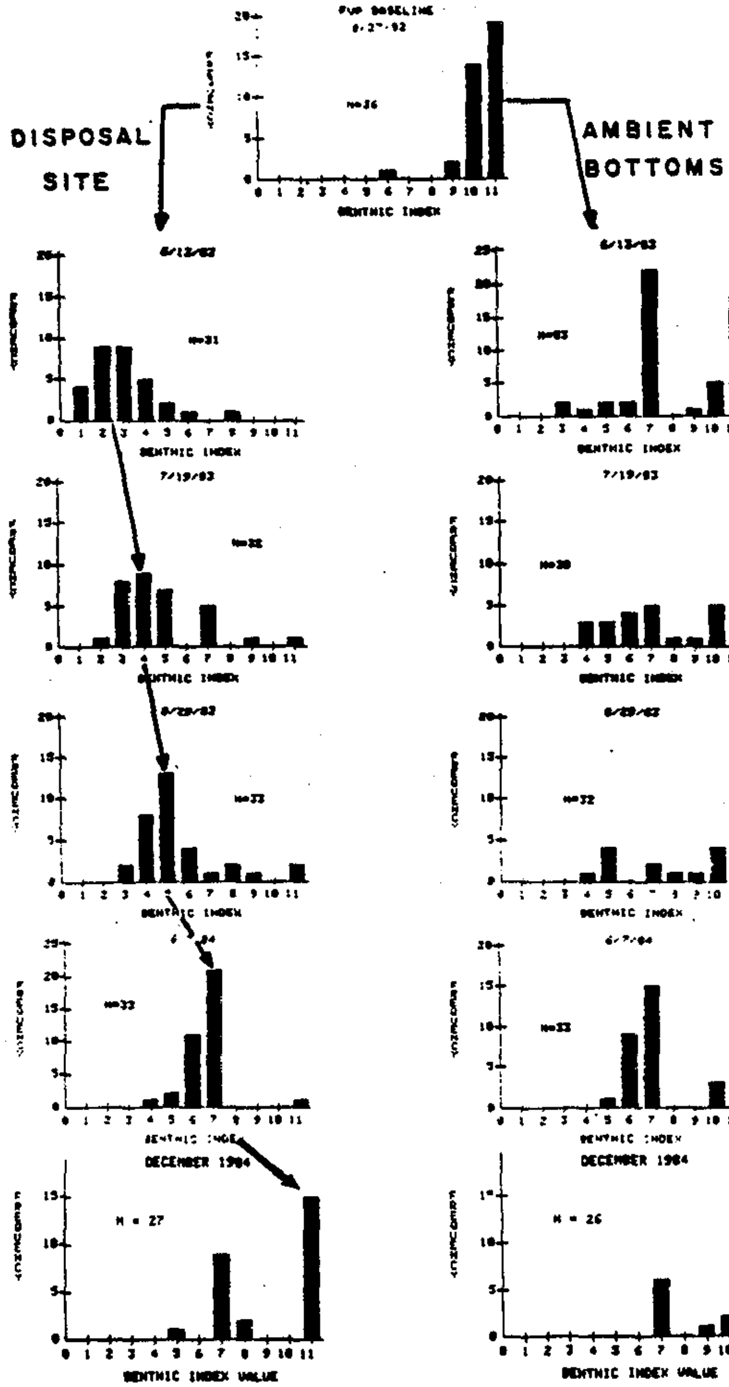

Figure IV-3-46. Selected benthic index frequency distributions for on mound stations and edge and amient stations (including CLIS-REF, except in December 1984) from the August 1982 baseline survey through December 1984.

baseline survey level of 11. Nineteen months after the disposal operation, the FVP site has returned, by and large, to its pre-disposal state.

4.0 SUMMARY

The series of bathymetric surveys conducted at the FVP disposal site since the placement of dredged material in April and May 1983 revealed initial decreases in mound height (increases in water depth) in July and December 1983. These changes are the likely results of consolidation with no indication of significant erosion (see Volume II, Section II, 4.0 for discussion of sediment transport).

These REMOTS surveys were conducted over the 19 months after disposal of Black Rock Harbor dredged materials at the FVP site. Black Rock material between 4 cm and 18 cm thick can still be mapped because the buried predisposal surface is still visible. Black Rock Harbor mud thinner than 4 cm has been mixed into the predisposal bottom by bioturbation and, hence, the low-reflectance dredged material "signature" has been lost. The areal distribution of dredged material thickness has remained the same except for the appearance of dredged material at three corner stations: 200N/300W, 200S/300W, and 200S/300E. It is unknown if this "new" appearance is related to an originally patchy distribution of dredged material in these quadrants or to some post-disposal dispersion.

The grain size distribution and boundary roughness values at the FVP site have remained unchanged and values for both the ambient seafloor and CLIS-REF station are comparable. The one exception is the appearance of a 1-2 cm layer of fine to medium sand at the CTR station; this may represent evidence of scour occurring at the mound apex, with the finer silt-clay fraction being winnowed away at the sediment surface. Boundary roughness values for March at station 400E, the DAISY deployment site (not sampled in previous surveys), are higher than the average FVP boundary roughness values. A progressive decrease in boundary roughness has been documented for the disposal site over time. This is attributed to "smoothing" of the surface by currents and/or bioturbation. Extensive meiofaunal tunnelling of the upper 1 cm of sediments, a feature not observed in previous FVP surveys, was evident in approximately 50% of the REMOTS images. By increasing micro-scale boundary roughness and "loosening" the sedimentary fabric, this phenomena leads to the formation of mudclasts and enhances the resuspension of surface sediments. Several images revealed recently deposited sedimentary layers indicating a redistribution of surface material.

Redox depths (depth to which bioturbation and diffusion supply oxygenated seawater to pore waters) at stations located on dredged material in January showed little change since August 1983. The average RPD value in August 1983 was 2.90 cm, compared to 2.99 cm in January 1984. Redox depths on the ambient seafloor decreased from 4.6 cm in August to 4.0 cm in January. This is related to the winter retrograde caused by decreased infaunal metabolic activity and increased physical disturbance. The frequency distribution of mean redox depths for the survey area as a whole in March 1984 became more uniformly distributed, reflecting an increase in the mean for centrally located dredged material stations (from 2.99 cm to 3.36 cm), and a slight decrease in the mean for edge and ambient bottom stations (from 4.00 to 3.83 cm). In June, the average RPD value for central dredged material sites (3.95 cm) was not significantly different from the average value for edge and ambient sites (4.04 cm). In September 1984, the survey indicated a major modal depth for mean RPD values of 4.0 cm. However, stations CTR and 100W show anomolously shallow RPD's (2 cm), which strongly suggests that penetration of infauna into the deposit at these stations is being impeded by some sediment associated factor(s). The mean RPD values in both regions have deepened significantly since the September 1984 survey. This increase represents renewed benthic recovery at the FVP site after a brief stasis in RPD values observed from June to September 1984. The major modal RPD depth at CLIS-REF decreased from 4.0 to 2.0 cm between September and December. This shallowing of RPD's suggests that CLIS-REF has been subject to stress factors not occurring at the FVP site, e.g. predation or bottom trawling.

Results from the January and March 1984 surveys indicated an improvement in the overall successional status at stations located on dredged material, with more replicates showing evidence of being colonized by head-down deposit feeders. The successional status of ambient stations decreased in a few replicates, a typical response to winter conditions. In subsequent surveys, stations located on dredged material had a significantly higher number of Stage I seres and fewer head-down deposit feeders (Stage III) than ambient and control stations. This suggests that dredged material associated factors may be inhibiting penetration of the deposit by those organisms that ingest buried detritus. During the September survey, low densities of Stage II taxa (ampeliscid amphipods) were observed for the first time at both ambient stations and edge stations.

In December, Stage III seres were abundant (~ 60% of all images exhibit Stage III fauna) throughout the FVP site. This represents a significant increase in the number of head-down deposit feeders throughout the survey area since September. Moreover, this is the first FVP post-disposal REMOTS survey in which the abundance of Stage III seres on the main disposal area is comparable to their abundance on the surrounding seafloor. High-order successional stage fauna have apparently colonized the Black Rock Harbor dredged materials nineteen months after the disposal operation.

The FVP disposal site benthic indices increased rapidly during the initial colonization of the Black Rock dredged materials in 1983. The modal benthic index value increased one index increment per month over the period June through August 1983 (+3 to +5). Throughout much of 1984, the colonization rate, as measured with this parameter, appeared to have reached a "stasis", increasing only one increment (+6 to +7) from January to September. In previous reports, this was attributed to the delay in recruitment of subsurface deposit feeders into the Black Rock sediment. In the present survey, the major modal benthic index has increased to the baseline survey level of +11. Thus, it appears that recruitment of subsurface deposit feeders at the FVP site has occurred. Nineteen months after the disposal operation, the FVP site has returned, by and large, to its pre-disposal state.

Initially, the benthic indices at the disposal site stations were significantly different from those of the ambient bottom and control station. In the December 1984 survey, the REMOTS benthic indices at the on mound stations were comparable to those at edge and ambient stations, reflecting the uniform RPD and successional stage values across the site. Both regions have significantly higher index values than in September. Depressed benthic indices at CLIS-REF relative to previous surveys result from the anomalously shallow RPD depths at the site.

At station 1000E, REMOTS monitoring in four post-disposal FVP surveys had never detected dredged material. Evidence from Dr. Feng's mussel cages located in this area (1000E/50N) indicated presence of dredged material. Three replicate REMOTS images were taken during the March survey at Dr. Feng's cage site, 50 meters north of 1000E. All three replicates show the presence of dredged material (Fig. IV-4-1). This station is located well outside of the zero isopleth for dredged material as defined in the June 1983 REMOTS survey. Apparently some isolated patches of dredged material exist outside of the main disposal mound.

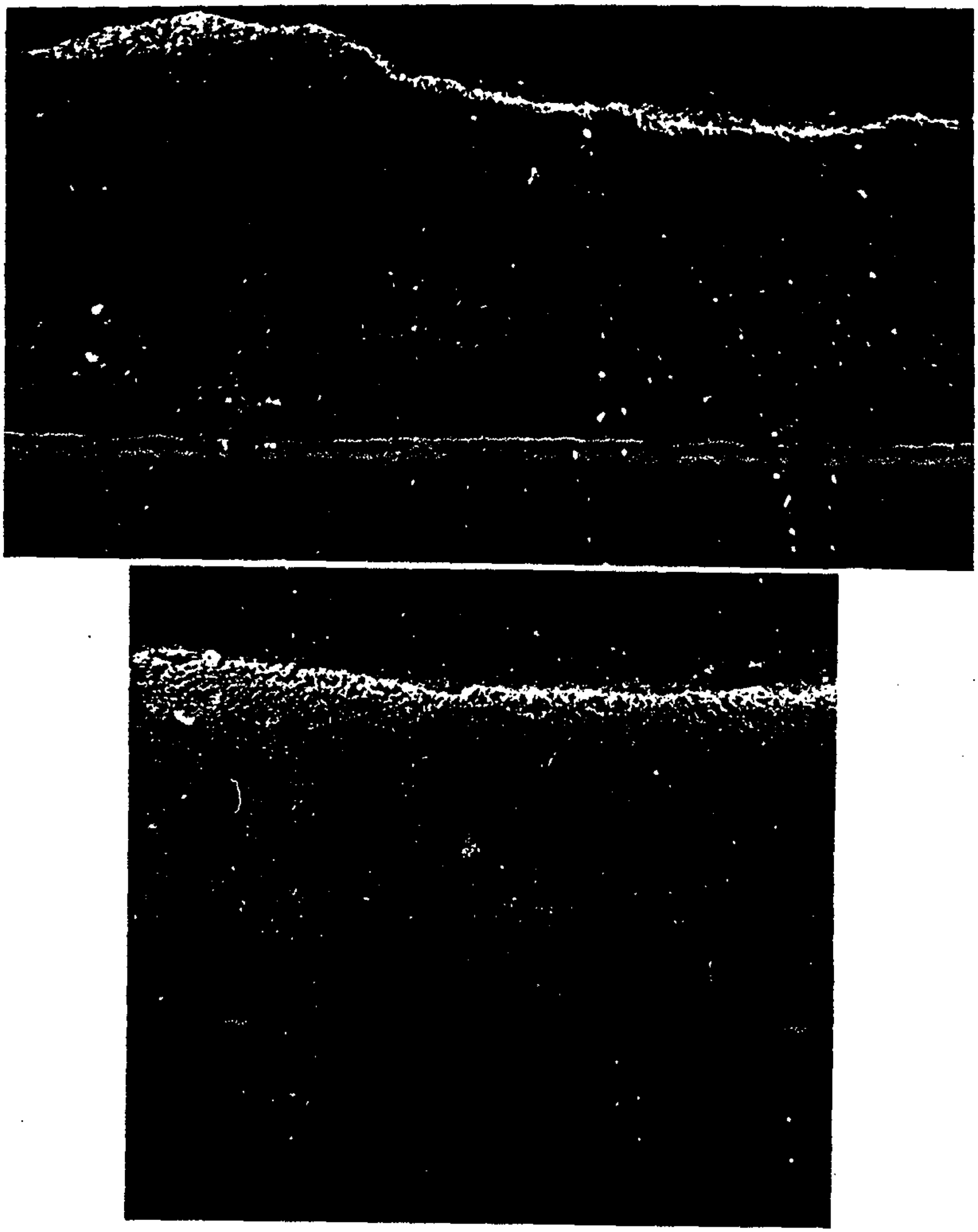

Figure IV-4-1. REMOTS images from 1000E(top) and 1000E/50N (bottom). Note contrast difference between the redox layer and underlying sediment in the bottom photograph, indicating presence of dredged material.

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