DECEMBER 1995 INVESTIGATION OF BENTHIC RECOLONIZATION AT THE MIRS BAY DISPOSAL SITE

GEO REPORT No. 84

Binnie Consultants Limited

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

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J.B. Massey
Ag. Principal Government Geotechnical Engineer
January 1999

FOREWORD

This report documents the findings of a survey at the Mirs Bay disposal site (MBDS), using sediment-profile photography and benthic grab sampling/taxonomic analysis, to assess the degree of colonisation by benthic organism since the cessation of mud disposal.

This report was prepared by Binnie Consultants Limited (currently known as Binnie Black & Veatch Hong Kong Ltd.) in association with Science Applications International Corporation for Geotechnical Engineering Office (GEO) of the Civil Engineering Department under Agreement No. CE42/90. Mr P.G.D. Whiteside of GEO coordinated the study and reviewed the report.

D.C.H. Chang

Chief Geotechnical Engineer/Fill Management (Ag)

CONTENTS

List of Tables

List of Figures

List of Plates

Plate 5. REMOTS image from station 65 showing Type 3 dumped material, consisting of relatively well-sorted fine to medium sand.

Plate 6. A thin surface lag deposit of sand and shell fragments overlies blue-grey cohesive clay (Type 1 material) in this REMOTS image from station 76.

Plate 7. REMOTS image from station 77 showing a surface layer of sand and shell fragments overlying silt-clay sediments at depth.

Plate 8. REMOTS image from station 15 at the north control area, showing light-colored, homogenous silt-clay with few distinguishing features.

Plate 9. Polychaetes (arrow) are visible within a sedimentary matrix consisting of disposed silt-clay (Type 1 dumped material) in this REMOTS image from station 55.

Plate 10. REMOTS image from station 88, with small branched tubes created by amphipods (family Corophidae?) visible at the seabed surface.

Executive Summary

Disposal of dredged material at the Mirs Bay disposal site (MBDS) ceased in 1993. Sidescan sonar and REMOTS seabed profiling surveys performed at the end of 1995 confirmed the presence of dumped material on the seabed near the southwestern corner of MBDS, both within and outside the gazetted site boundaries.

The December 1995 REMOTS seabed profiling survey was performed in conjunction with benthic grab sampling/taxonomic analysis to assess the degree, if any, to which the dumped material has become colonized by benthic organisms. This assessment involved comparing benthic community structure at dumped material stations versus nearby control (reference) stations located in areas unaffected by dredged material disposal.

REMOTS showed that a poorly-sorted mixture of rocks, pebbles, sand, mud and shell fragments comprised the dumped material, while homogenous mud characterized the control stations. Surface tubes, worms and feeding voids were visible in the REMOTS images and provided evidence that benthic organisms were present both on the dumped material and in the control areas.

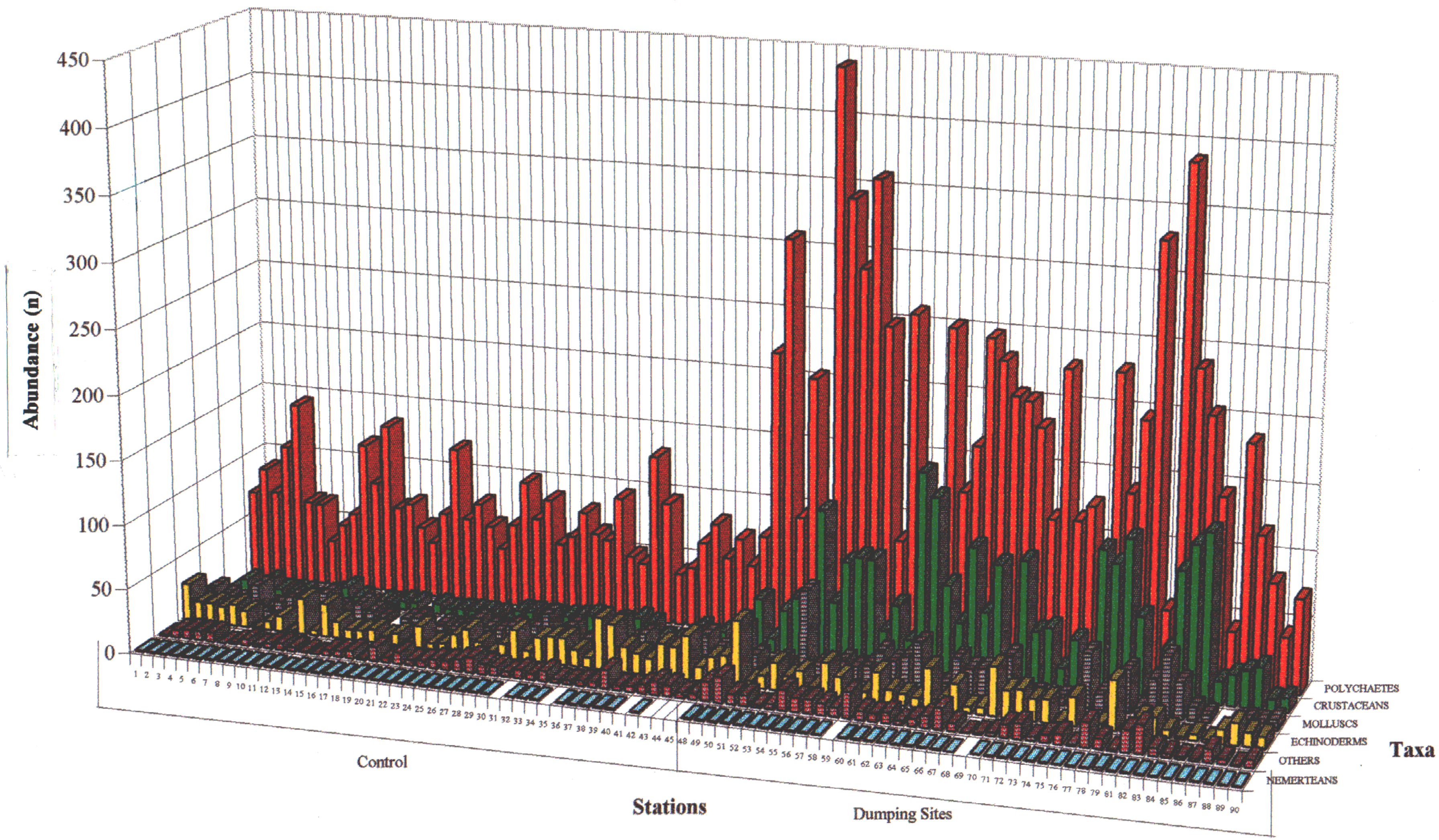
The benthic grab results supported the REMOTS findings in showing that benthic organisms were present both on the dumped material and in the control areas. At the phylum-level, a higher abundance of polychaetes and crustaceans was found in the grab samples from the 43 dumped material stations compared to the 45 control stations. This is illustrated clearly in Figure A.

Non-parametric statistical tests confirmed that the dumpsite community exhibits a significantly higher abundance of significantly smaller organisms than the control site community.

Two multivariate statistical techniques (clustering and non-metric multidimensional scaling, MDS) and the ANOSIM significance test were used to compare the family-level data. These tests showed that the benthic community characterizing the dumped material stations was significantly different from the control community, due to the higher abundance and diversity of benthic organisms inhabiting the dumped material.

It was concluded that benthic organisms have been successful in colonizing the dumped material at MBDS. By providing increased stability and habitat diversity relative to the surrounding seabed, the dumped material apparently has been functioning as the seabed equivalent of an artificial reef for benthic macrofauna.

Figure A. Total Abundance of six faunal groups at each Mirs Bay Station



1.0 Introduction

1.1 Hong Kong regulations stipulate that sediments must be tested before being dredged to determine the levels of certain compounds known to be toxic to marine organisms. Sediments with chemical levels below a specified limit are classified as uncontaminated and, once dredged, can be disposed at specially-designated open-water sites. While such disposal does not pose a toxicological threat to marine organisms, there can be deleterious physical effects, such as smothering and changes in critical habitat variables (e.g., sediment particle size or water content). Considerable concern therefore exists that dredged material disposal in Hong Kong is having a negative long-term ecological impact, particularly on communities of benthic organisms on the seabed in and around the gazetted disposal sites. Some of the perceived negative consequences include reductions in benthic organism abundance and community diversity, secondary impacts on fisheries, and, at the extreme, creation of "biological deserts" on the seabed.

1.2 This report presents the results of a study designed to address such concerns. During the 1980's and early 1990's, dredged material and assorted construction wastes were dumped from barges at a gazetted open-water marine disposal site located in central Mirs Bay, Hong Kong (Figure 1). Disposal at this site (Mirs Bay disposal site, or MBDS) ceased in 1993. A November 1995 bathymetric and sidescan sonar survey (EGS 1995) confirmed that dumped material was present on the seabed around the southwestern corner of MBDS, both within and outside the gazetted site boundaries (Figure 2). Interpretation of the sidescan sonar records resulted in mapping of the following types of dumped material: graded dumped material with sand waves, seabed with high reflectivity, and individual mounds of dumped material resulting from single disposal events (Figure 2). The dumped material occurs as a relatively thin and flat surface layer, because no bathymetric high points were detected by the swath bathymetry system, which has a resolution of about ± 50 cm.

1.3 A survey involving REMOTS sediment-profile photography in combination with benthic grab sampling/taxonomic analysis was performed in December 1995 to assess the degree, if any, to which the dumped material has become colonized by benthic organisms since disposal ceased in 1993. The REMOTS sediment-profile camera obtains high-resolution, undisturbed images of the upper 20 cm of the seabed, providing insights on physical and biological seabed processes. Benthic grab sampling is a standard technique which provides additional information on the taxonomic identification and abundance of benthic organisms inhabiting surface sediments imaged by REMOTS. The two techniques are thus complimentary in allowing a comprehensive assessment of physical and biological seabed characteristics and overall benthic habitat quality.

1.4 Given the concerns about dredged material disposal impacts on benthic communities in Hong Kong, the REMOTS/benthic grab survey was designed to address the following questions:

1) At the MBDS, are benthic organisms recolonizing areas of the seabed covered by dumped material?

2) What is the taxonomic composition and abundance of the benthic community, if any, found to be recolonizing the dumped material (as measured by grab and REMOTS)?

3) How does the benthic community inhabiting the dumped material compare with the communities found on the ambient seabed in nearby areas unaffected by disposal?

4) Are potential differences in benthic communities among areas and/or stations attributable to physical/chemical parameters?

2.0 Methods

2.1 The benthic grab and REMOTS sampling took place over the period 17-25 December 1995. Samples were taken at forty-five "dumped material" stations, as well as at forty-five "control" (reference) stations located roughly 1 to 1.5 km east of the dumped material deposit, where the sidescan sonar survey showed no evidence of dumped material on the seabed (Figure 3). Electronic and Geophysical Services Ltd. (EGS) provided vessel and logistic support, and stations were located using a differential GPS (dGPS) navigation system with an accuracy of ±1 m.

2.2 There were three separate control areas, with 15 stations each, to assess spatial variability in benthic communities both within and among areas (Figure 3). For sampling the dumped material, 15 stations were allocated to each of the three bottom types defined by sidescan sonar:

- graded dumped materials with sand waves,
- high reflectivity seabed, and
- disseminated dumped materials.

2.3 Station spacing within each control area was roughly similar to that for the dumped material, except in the "disseminated dumped material" areas which were smaller and required tighter station spacing (Figure 3). Station allocations among different areas are summarized in Table 1.

Table 1. Allocation of stations among different areas for the December 1995 REMOTS/benthic grab survey. Stations where taxonomic identifications were to family level are underlined

Dumped Material (as defined by sidescan sonar)			Controls		
"Graded dumped materials w/ sand waves" stations	"High reflectivity seabed" stations	"Disseminated dumped material" stations	North Control Area stations	East Control Area stations	South Control Area stations
50	48	46	**1**	16	**31**
53	49	47	2	17	32
54	52	**51**	3	**18**	**33**
55	**57**	60	**4**	19	**34**
56	66	61	5	**20**	35
58	**70**	62	**6**	21	36
59	**71**	**64**	**7**	**22**	**37**
63	**72**	**67**	8	23	38
65	**73**	68	9	24	39
69	**74**	**75**	**10**	**25**	40
76	**78**	79	11	**26**	**41**
77	81	80	**12**	27	42
82	85	83	13	**28**	43
86	**87**	**84**	**14**	29	**44**
88	90	**89**	15	**30**	**45**

2.4 A Model 3731 Sediment Profile Camera (Benthos, Inc., North Falmouth, MA) was used to obtain the REMOTS images in this survey. REMOTS images were obtained at all 45 dumped material stations but only half of the control stations. The control areas were sampled less intensely because relatively little small-scale spatial heterogeneity in sediment physical features was expected. The camera was lowered multiple times at each station so as to obtain at least three replicate images suitable for subsequent computer analysis.

2.5 The REMOTS parameters measured in this study were derived using formal and standardized techniques for computer image analysis, interpretation and mapping (Rhoads and Germano 1982, 1986). Complete descriptions of methods for REMOTS field operations, computer image analysis and interpretation, and associated QA/QC are provided in Appendix A.

2.6 A single benthic grab sample was obtained at 43 of the 45 dumped material stations and at all 45 of the control stations, using a Van Veen sampler with bucket dimensions 30 cm x 30 cm x 21 cm deep (maximum sample volume = 18,900 cm^3). Weights and "mud doors" were added or removed from the grab as necessary to ensure a consistent volume of sediment collected at each station. Benthic samples could not be obtained at dumped material stations 46 and 47 because large rocks prevented the grab from closing properly.

2.7 At most of the dumped material and half of the control stations, small surface subsamples were taken from the grab immediately upon retrieval and placed in plastic bags for laboratory analysis of particle size distribution (PSD) and total organic carbon (TOC). The remainder of each grab sample was washed through a 500 μm sieve, and the residue and organisms were transferred to a 10% Borax-buffered formalin fixative solution with Rose Bengal added to stain the organisms pink.

2.8 For laboratory analysis of TOC, a dried sample aliquot was homogenized by grinding, treated with HCl to remove inorganic carbon, and combusted at high temperature. Organic carbon concentration was then determined by infrared spectrophotometric detection of the evolved CO_2. An abbreviated PSD method involving wet sieving and weighing was used to determine the following: percent gravel, percent sand, and the percentage of silt and clay as a combined fraction (percent silt-clay) in each sample.

2.9 The biomass of benthic invertebrates was measured by air-drying the samples on paper towels for about 10 minutes to absorb the ethanol preservative. The samples were weighed on an electronic balance to $\pm$0.0005g. The average body mass for phyla level groups was determined by dividing the biomass by the abundance for each group. The average body size was also calculated for all animals by dividing the total biomass by the total number of individuals.

2.10 In the benthic laboratory, the sieved samples from each grab were washed over a 250 μm sieve, and the residue was sorted by eye. All visible organisms were removed and preserved in 70% ethanol pending further identification. For all 45 control and 43 dumped material stations, the sorted individuals were divided into major taxonomic groups (phyla) and counted. Identifications to family level were performed on a subset of stations (20 dumped material and 21 controls, see Table 1).

2.11 Most specimens were identified using an existing reference collection. Unidentified or tentatively-identified specimens were mailed to Qinqdao (PRC), where identifications were confirmed under the supervision of Professor Wu Bao Ling of The Marine Ecology and Polychaete Laboratory of the First Institute of Oceanography, State Oceanic Administration.

2.12 During benthic sorting in the laboratory, all benthic invertebrates were sorted to phylum and counted. Phylum Annelida consisted of polychaetes exclusively, so the annelid group is referred to as polychaetes. Similarly, the phylum Arthropoda consisted entirely of crustaceans, so the group is referred to as crustaceans. Individuals of the phyla Sipunculida, Echiura, Cnidaria, and Vertebrata were rare and were lumped together as "other".

2.13 Because the phylum-level designations were limited to just 6 groups, multivariate statistical methods were not used to analyze these data. Phylum level abundance and biomass data failed to meet the assumptions of normality and homogeneity of variance therefore the non-parametric Mann-Whitney U test was used for the univariate comparisons. Following non-parametric anova to show no differences among the three sub-areas at both the dump and control sites the data were pooled for the above test.

2.14 Two complimentary multivariate techniques were used to assess the family-level benthic community data: clustering and non-metric multi-dimensional scaling (MDS). Clustering was used to classify (cluster) the stations into mutually-similar groups based on benthic community composition. Hierarchical agglomerative clustering with group-average linking was performed on a similarity matrix derived from double square root transformed family abundance data (Clarke 1993), using the Bray-Curtis similarity index (Bray and Curtis 1957).

2.15 MDS attempts to provide an ordination, or "map", of the stations such that distances between stations reflect corresponding (dis)similarities in community structure: nearby stations on the map have similar communities, while those that are far apart have few taxa in common or the same taxa at different levels of abundance or biomass. Like the cluster analysis, non-metric MDS ordination (Kruskal and Wish 1978) was performed on a similarity matrix derived from double square root transformed family abundance data (Clark and Green 1988, Clarke 1993), using the Bray-Curtis similarity index (Bray and Curtis 1957).

2.16 Clustering and MDS are non-parametric methods which do not require that the data be transformed to meet underlying statistical assumptions. However, transformations do play an important role in these techniques, that of defining the balance between contributions from common and rarer species in the measure of similarity among samples. The double square root transformation which was applied to the abundance data prior to clustering and MDS is relatively severe in that it markedly downweights the contribution of the most abundant taxa while increasing the contribution of rarer taxa in assessing the degree of similarity among samples. The net effect is to provide a ***deeper*** view and more holistic comparison of the benthic communities inhabiting the dumped material and control areas. This is preferable, given the study objectives, to the ***shallow*** comparison which would result from using untransformed abundance data, where the emphasis would primarily be on the dominant taxa.

2.17 The ANOSIM randomisation test was used to test for statistical differences in benthic communities among areas; ANOSIM is based on a non-parametric permutation procedure applied to a (rank) similarity matrix underlying the ordination of samples (Clarke and Green 1988; Clarke 1993). This procedure is analogous to standard parametric analysis of variance (ANOVA) and was used to test for differences in benthic communities: 1.) among the three control sites, 2.) among the three putative bottom types comprising the dumped material (as defined in the sidescan sonar map), and 3.) between the control and dumped material stations. These tests were based on the rank Bray-Curtis similarity matrices constructed using double square root transformed family abundance data.

2.18 Following the ANOSIM test for differences between the pooled dumped material and pooled control stations, the average Bray-Curtis dissimilarity between all pairs of inter-group samples was calculated and then broken down into the separate contributions from each taxa, following the computational procedures of Clarke (1993) and Clarke and Ainsworth (1993). The taxa were then ordered by their percent contribution to the total dissimilarity to identify those which were the best ***discriminators*** between the two groups of samples.

2.19 The relationship between the benthic community data and two of the environmental variables measured in this study (PSD and TOC) was assessed as follows: the environmental variables were represented as symbols of differing size (using a simple linear function) and superimposed on the 2-D MDS ordination of the benthic community data (Warwick et al. 1990; Clarke and Ainsworth 1993). The PSD values were expressed as percent silt-clay. Samples for TOC and PSD analyses were not obtained at stations 1, 4, 11, 31, 37, 41, 45 and 84. For these stations, estimated TOC values based on group averages and estimated percent silt-clay values based on the REMOTS results were used for superimposing on the MDS ordination.

3.0 Results

3.1 Physical Characteristics of the Seabed

3.1.1 The REMOTS images showed that the dumped material consisted of fine to very fine sand (phi size 4 to 2) mixed with varying amounts of silt-clay (phi size >4, Figure 4). In contrast to the relatively high proportion of sand at most dumped material stations, silt-clay with minor fractions of very fine sand was the predominant particle size in all three of the control areas (Figure 4). The particle size distribution analysis of the grab subsamples confirmed that silt-clay was the dominant fraction at control stations: percent silt-clay ranged from 62% to 96%, with most values above 85% (Table 2). In contrast, the dumped material stations generally had much higher percentages of both sand and gravel (Table 2). TOC concentrations ranged from 0.5% to 1% at the control stations, compared to a range of 0.2% to 1% for the dumped material stations. In general, TOC concentrations were higher and less variable at the control stations compared to the dumped material stations (Table 2).

3.1.2 Three types of dumped material were observed in the REMOTS images:

Type 1: This type of material was observed in seventy-five percent (75%) of all dumped material REMOTS images. The material consisted of poorly-sorted sandy mud or bluish-brown silt-clay, with significant amounts of small shell fragments (Plate 1). At many stations, the dumped clay appeared to be cohesive and had a characteristic mottled or streaky appearance (Plate 2). The average penetration depth of the REMOTS camera prism in this material was 12.9 cm, with most penetration depth values falling in the range 12 to 20 cm (Figure 5). These are deep penetration values indicative of relatively high-water content sediments.

Type 2: This type of material was observed in fourteen percent (14%) of the REMOTS images from dumped material stations. The material consisted of a poorly-sorted mixture of small-sized rocks, pebbles, and brown silt-clay with shell fragments; Gorgonian coral colonies (sea whips) were frequently observed growing on the rocks (Plates 3 and 4). The average REMOTS prism penetration depth in this material was 5.6 cm, with values ranging from 0 to 12 cm (Figure 5). Such low prism penetration is due to the relative hardness of this coarse sediment mixture.

Table 2. Sediment particle size distribution and total organic carbon concentration at dumped material and control stations (all values are percentages)

Area	Station	TOC	Gravel	Sand	Silt-clay
North Control	2	0.9	0	11	89
	4	0.9	0	9	91
	6	1	0	5	95
	8	0.9	0	10	90
	10	0.9	0	14	86
	12	0.8	0	6	94
	14	1	0	8	92
	avg.	**0.9**	**0**	**9**	**91**
East Control	16	0.9	0	5	95
	18	0.7	0	10	90
	20	1	0	30	70
	22	1	0	4	96
	24	1	0	6	94
	26	0.7	0	16	84
	28	0.9	0	12	88
	30	1	0	13	87
	avg.	**0.9**	**0**	**12**	**88**
South Control	32	0.8	1	12	87
	34	0.6	0	14	86
	36	0.5	0	38	62
	38	0.7	0	12	88
	40	0.9	0	16	84
	42	0.9	0	9	91
	44	0.7	0	19	81
	avg.	**0.7**	**0**	**17**	**83**
Dumped Material	51	0.7	3	29	68
	60	0.4	10	57	33
	62	0.5	18	62	20
	64	0.9	11	28	61
	67	0.7	22	54	24
	68	0.7	20	66	14
	75	0.3	34	41	25
	79	0.6	8	34	58
	83	0.6	8	27	65
	89	0.8	2	16	82
	avg.	**0.6**	**14**	**41**	**45**
High Reflect. Seabed	48	0.7	6	46	48
	49	0.7	3	35	62
	52	0.9	5	19	76
	57	0.6	4	53	43
	66	0.4	12	63	25
	70	0.5	4	39	57
	71	0.6	4	48	48
	72	0.7	3	39	58
	73	0.3	1	49	50
	74	0.8	4	24	72
	78	0.4	0	41	59
	81	0.4	4	65	31
	85	0.6	2	35	63
	87	0.6	1	48	51
	90	0.6	6	48	46
	avg.	**0.6**	**4**	**43**	**53**
Graded Dumped Material w/ Sand Waves	50	0.1	75	23	2
	53	0.9	11	34	55
	54	0.6	6	55	39
	55	0.4	6	45	49
	56	0.6	7	52	41
	58	0.2	44	43	13
	59	0.6	22	49	29
	63	0.3	18	69	13
	65	0.5	38	31	31
	69	0.4	17	66	17
	76	0.2	39	54	7
	77	0.6	27	42	31
	82	0.3	38	38	24
	86	1	4	51	45
	88	0.2	6	32	62
	avg.	**0.5**	**24**	**46**	**31**

Type 3: This type of material was observed in eleven percent (11%) of the REMOTS images obtained at the dumped material stations. This material consisted of bedform ripples composed of well-sorted very fine to medium sand mixed with shell fragments, with animal tubes protruding at the sediment surface (Plate 5). The sand/shell mixture in some images appeared as a lag deposit at the sediment surface, overlying disposed silt-clay sediment (i.e., Type 1 material) at depth (Plates 6 and 7). The average REMOTS prism penetration depth in this material was 9.0 cm, with values ranging from 4 to 16 cm (Figure 5). This is intermediate penetration typical of sandy bottoms.

3.1.3 Because the mixtures of sand, mud, small rocks, pebbles and shell fragments characterizing the dumped material stations were poorly sorted, there is some degree of overlap among the three material "types". At roughly one-third (15 of 45) of the dumped material REMOTS stations, two different dumped material types were observed in the replicate images. This reflects small-scale spatial heterogeneity (patchiness) in the distribution of the different REMOTS dumped material types, in general agreement with the sidescan sonar results. However, the REMOTS map (Figure 6) suggests that the three types of dumped material have a different distribution across the site compared to the patches mapped using sidescan sonar (Figure 3).

3.1.4 The average thickness of the surface layer of dumped material, as measured in the REMOTS images, varied from 2 to greater than 15 cm (Figure 7). At many stations, the REMOTS measurement represents a minimum estimate because the thickness of the dumped material layer exceeded the prism penetration depth. In the absence of pre-dumping bathymetric data, it is difficult to determine the thickness of the dumped material layer precisely. However, the deposit was not detected relative to the surrounding, flat seabed in the November 1995 swath bathymetry survey (EGS 1995). Assuming some settling and compaction of the deposited material, its maximum thickness is estimated to be no more than a few meters.

3.1.5 The REMOTS images showed that homogenous, light-colored silt-clay with few distinguishing features was distributed uniformly across all three control areas; this is classified as seabed Type 4 in Figure 6. Such light-colored, homogenous, muddy sediments (Plate 8) typify the seabed over most of the Eastern Waters region of Hong Kong, in areas unaffected by dredging or disposal activities (SAIC/BCL 1994a; BCL/SAIC 1996). The average REMOTS prism penetration depth at the control stations was 16.1 cm, with values ranging from 12.2 to 19.6 cm. These are high prism penetration values, and the fine-grained sediments at control stations are inferred to have relatively high water content due in part to the bioturbation activities of infaunal organisms.

3.1.6 Low prism penetration depths occurred with higher frequency in the dumped material REMOTS images compared to those from the control areas (Figure 8). Small-scale surface boundary roughness in excess of 3 cm also was found in a higher proportion of dumped material REMOTS images compared to the controls (Figure 9). These results reflect both the wider range of different sediment types and the coarser, harder nature of the dumped material, compared to the loose, homogenous, fine-grained sediments distributed uniformly across the three control areas.

3.1.7 The average RPD depth for all dumped material stations was 1.6 cm, compared to an overall average of 1.3 cm at the control stations. Most of the REMOTS images from both the dumped material and control stations had relatively shallow RPD depths in the range 0 to 2 cm (Figure 10), with no clear patterns in the spatial distribution of RPD values among stations or areas.

3.2 Biological Characteristics of the Seabed

Benthic Communities at Dumped Material and Control Stations

3.2.1 Both the dumped material and control stations were characterized by a mixture of Stage I and Stage I on Stage III successional stages, as defined by REMOTS (see Appendix A). In the control areas, the primary evidence of Stage III organisms was in the form of feeding voids at depth (e.g., Plate 8). At dumped material stations, evidence of biological activity was in the form of subsurface feeding voids, surface tubes (e.g., Plate 5), polychaetes visible down within the sediment (Plate 9), and surface amphipod tubes (Plate 10). Surface tubes and subsurface polychaetes were observed more frequently in the REMOTS images from dumped material stations compared to the controls, while feeding voids occurred with higher frequency in the control station images (Figure 11).

3.2.2 Appendix B contains the complete taxonomic list and organism count for each dumped material and control station. A total of 5,661 individuals belonging to 96 taxa were collected by grab at the 20 dumped material stations, compared with 2,257 individuals in 77 taxa at the 21 control stations (Table 3). Both the mean number of taxa and mean number of individuals per station (grab) were higher at the dumped material stations compared to the control stations. Polychaetes were the numerical dominants, accounting for 67% and 68% of all individuals collected at the dumped material and control stations, respectively. Crustaceans were proportionately much more abundant at the dumped material stations (20%) compared to the controls (6%), while the controls exhibited slightly higher proportions of echinoderms (13% versus 5%) and molluscs (7% versus 4%). There was a higher total number of individuals in each organism group at the dumped material stations compared to the control stations. This is illustrated in

Figure 12, which shows that the difference in abundance between dumped material and control stations is most pronounced for the polychaetes and crustaceans.

Table 3. Summary of benthic grab data

	Dumped material stations	Control stations
Number of stations (grabs)	20	21
Total number of taxa (all stations combined)	96	77
Total abundance (all stations combined)	5661	2257
Mean number of taxa per grab (± 1 std. deviation)	38 ± 7	26 ± 5
Mean abundance per grab (± 1 std. deviation)	283 ± 145	107 ± 26
Percentage of total number of individuals which are: Polychaetes Crustaceans Echinoderms Molluscs Sipunculans Other	 67% 20% 5% 4% 2% 2%	 68% 6% 13% 7% 3% 3%
Ten most-abundant taxa (% of total abundance):	Capitellidae (19%) Spionidae (10%) Corophidae (9%) Paraonidae (9%) Cirratulidae (6%) Ampelisciidae (5%) Amphiuridae (5%) Pilargiidae (3%) Glyceridae (2%) Maldanidae (2%)	Cirratulidae (13%) Amphiuridae (12%) Spionidae (8%) Nephtyidae (8%) Capitellidae (8%) Pilargiidae (8%) Paraonidae (4%) Polynoidae (4%) Sipuncula (3%) Hesionidae (3%)

3.2.3 The polychaete families Capitellidae, Spionidae, Paraonidae, Cirratulidae, Pilargiidae, Glyceridae and Maldanidae were numerically most abundant at the dumped material stations. Two families of amphipod (Corophidae and Ampelisciidae) and the echinoderm family Amphiuridae were also among the numerical dominants on the dumped material (Table 3). Several of the polychaete families which were numerically abundant at the dumped material stations (ie, Cirratulidae, Spionidae, Capitellidae, Pilargiidae, Paraonidae) also were among the numerical dominants at the control stations. In contrast to the dumped material stations, the control stations had much higher numbers of the polychaete family Nepthyidae and a higher relative proportion of the echinoderm family Amphiuridae.

Comparison of Dumped Material and Controls

3.2.4 In the family-level cluster analysis dendogram (Figure 13), two groups of stations can be distinguished at the 52% similarity level: 1.) a group consisting of all 20 of the dumped material stations and two control stations (stations 31 and 41), and 2.) a group consisting of the remaining 19 control stations. This indicates that the dumped material stations are largely similar in terms of benthic community composition, and almost all the control stations are likewise similar in forming a distinct group, but there is a basic difference in benthic community composition between the dumped material and control stations.

3.2.5 This clear distinction was confirmed by the MDS ordination: when the two groups of stations from the cluster analysis are circled (Figure 14a), the group containing the 20 dumped material stations and 2 control stations occurs on the left side, while the group containing the remaining 19 control stations occurs on the right side of the two-dimensional MDS plot. This basic consistency between the cluster analysis and MDS results is more apparent when only the symbols "C" and "D" are used to denote the control and dump stations in the MDS plot (Figure 14b).

3.2.6 Greater variability in benthic community structure among control stations is reflected in greater distances between these stations in the MDS plot, in contrast to the dumped material stations which generally form a tighter group (Figure 14a and b). The MDS plot has a moderately high stress level of 0.20, indicating some 3-D or higher dimensionality in the relationship among the 41 stations.

3.2.7 The MDS plots in Figure 14 do not reveal any strong station groupings beyond the separation of the control and dumped material groups. In particular, there are no groupings to suggest any differences among the three control areas or among stations representing the three putative types of dumped material (i.e., graded dump material, high reflectivity seabed, disseminated dump material).

3.2.8 Both the sampling design and statistical design for this survey were based on the results of the side-scan sonar survey which distinguished three reflectance signatures interpreted to indicate the presence of three types of dumped material. It is important to determine if there were biologically important differences in the material represented by the three reflectance signatures distinguished by side-scan sonar, because this would affect the design of the univariate statistical analyses. In particular, if biologically important differences were detected, then the data from the three areas should not be pooled.

3.2.9 The results of physical tests (PSD), REMOTS image analyses and multivariate analyses of biological grab results are in agreement. They do not show any evidence of three different types of material corresponding to the locations of the three material types distinguished by side-scan sonar.

3.2.10 The ANOSIM test confirms these results: there was no statistically significant difference in benthic communities among the three putative bottom types comprising the dumped material (test statistic R = 0.04, corresponding to a significance level p = 0.27). Therefore it was deemed appropriate to pool the data from all dumped material stations prior to statistical analyses. ANOSIM also showed there was no significant difference in benthic communities among the three control areas (R = 0.095, p = 0.09). Based on these results, a final ANOSIM test was performed using pooled station groups (i.e., all 20 dumped material stations versus the 21 control stations). This test showed that benthic community structure at dumped material stations was significantly different from that which characterized the control stations (R = 0.637, p < 0.01).

3.2.11 Because it is highly unlikely that any two benthic samples will have identical taxa and abundance, all taxa contribute to some extent in multivariate calculations of dissimilarity among different stations. However, certain taxa typically contribute more than others in discriminating between groups of samples. This includes, for example, a taxon which is highly abundant in one group of samples and extremely rare or non-existent in others, thereby uniquely characterizing the group in which it is abundant (i.e., it serves to ***discriminate*** that group in comparison to other station groups).

3.2.12 The taxa accounting for over 50% of the difference in benthic community structure between the dumped material and control stations are presented in Table 4. This table shows both the average abundance of these taxa at the control and dumped material stations, as well as how much each taxon contributes to the overall dissimilarity detected between the dumped material and control station groups (expressed as their "percent contribution" both on an individual and cumulative basis). This list of the principal ***discriminator*** taxa includes the following:

1) Taxa which were extremely rare at the control stations but occurred in relatively high numbers at the dumped material stations. These include the Corophid and Ampeliscid amphipods and the polychaete family Glyceridae.

2) Taxa which were very rare at the control stations but occurred in low to moderate numbers at the dumped material stations. This includes a number of polychaete families: Eunicidae, Phyllodocidae, Nereidae, Ampharetidae, Poecilochaetidae, Lumbrineridae, Onuphidae, Magelonidae, and Maldanidae. Also included in this group are the bivalve families Corbulidae and Tellinidae, the crustacean families Callianassidae, Goneplacidae, Mysidae and Cumacea, and the Phylum Phoronida.

3) Taxa which were relatively abundant at both the dumped material and control stations, but with much higher average abundance at the dumped material stations. These include the polychaete families Capitellidae, Paraonidae and Spionidae.

4) Taxa with moderate to high average abundance at the controls and low average abundance at the dumped material stations (e.g., the polychaete families Nephtyidae, Polynoidae, and Sternaspidae).

Table 4. Average abundance of different taxa at dumped material and control stations. The contribution of each taxon to the total dissimilarity between dumped material and control station groups is expressed as a percentage (both individual and cumulative percentages are shown). This is only a partial listing which was arbitrarily cut off at the 50% cumulative percent level; there are many additional taxa which contributed in ever decreasing percentages to the total dissimilarity.

Taxa	Average number of individuals per station		Percent contribution	Cumulative % contribution
	Dumped material stations	Control stations		
Corophidae	26.8	0.7	3.8	3.8
Glyceridae	6.8	0.2	3.3	7.1
Ampelisciidae	14.9	0.8	3.1	10.1
Eunicidae	4.2	0.1	2.7	12.8
Phyllodocidae	3.3	0.3	2.4	15.2
Capitellidae	53.7	8.5	2.2	17.4
Ampharetidae	3.3	1.1	2.1	19.5
Maldanidae	6.2	1.7	2.0	21.5
Nereidae	1.7	0.1	2.0	23.6
Paraonidae	25.8	4.7	1.9	25.5
Poecilochaetidae	2.4	0.5	1.9	27.4
Lumbrineridae	3.6	0.6	1.9	29.2
Nepthyidae	1.9	8.9	1.8	31.0
Corbulidae	2.8	1.3	1.8	32.8
Callianassa	2.9	0.8	1.8	34.6
Onuphidae	1.5	0.0	1.7	36.3
Polynoidae	2.9	4.4	1.7	38.0
Sternaspidae	0.6	1.6	1.7	39.7
Magelonidae	2.2	0.6	1.7	41.4
Tellinidae	1.4	1.3	1.6	43.0
Goneplacidae	2.3	0.8	1.6	44.6
Spionidae	29.1	9.1	1.6	46.2
Phoronidae	1.1	0.8	1.5	47.7
Mysidacea	1.5	0.7	1.5	49.2
Cumacea	1.6	0.1	1.5	50.8

Association between Benthic Community and Physical Variables

3.2.13 When the values for percent silt-clay are scaled and superimposed on the MDS plot of the benthic community data, there is a broad correlation between the two (Figure 15a and b). It is readily apparent that the control stations which form a group on the right side of the MDS plot have a consistently high percentage of silt-clay (larger circles), while lower silt-clay content (smaller circles) generally characterize the dumped material stations on the left side of the MDS (Figure 15b). The pattern for TOC is less clear (Figure 15c). It appears that differing sediment organic carbon concentrations bear less relation to the family-level biotic structure, in that stations having similar benthic communities, particularly the dumped material stations, are at opposite extremes of the range in TOC values.

Phylum-level Comparison

3.2.14 The phylum-level abundance data for all 88 stations match the results of the family-level comparisons (Figure 16). The abundance of polychaetes and crustaceans was significantly higher at the dump sites than at the control sites (Table 5). The total biomass (wet weight) of six phylum-level groups at each station is shown in Figure 17. The mean biomass per grab (and thus per station) of polychaetes, crustaceans, echinoderms and "others" was significantly higher at the dump sites than the control sites (Table 6).

Table 5. Comparison of mean abundance of major taxonomic groups at the dump and control sites (Mann-Whitney U test).

	Dumping sites	Control sites	p-value
polychaetes	190.571	74.289	0.000
crustaceans	63.429	6.911	0.000
molluscs	17.024	10.022	0.169
echinoderms	14.143	15.911	0.268
others	8.286	5.733	0.070
nemerteans	0.976	0.867	0.393
total	294.429	113.733	0.000

Table 6. Comparison of biomass (g wet weight) per grab of major taxonomic groups at the dump and control sites (Man-Whitney U test).

	Dumping sites	Control sites	p-value
polychaetes	1.857	0.646	0.000
crustaceans	0.481	0.103	0.000
molluscs	0.091	0.723	0.073
echinoderms	0.540	1.155	0.001
others	0.138	0.505	0.033
nemerteans	0.005	0.006	0.604
total	3.110	3.138	0.337

Table 7. Comparison of mean body weight (g wet weight) of major taxonomic groups at the dump and control sites (Mann-Whitney U test).

	Dumping sites	Control sites	p-value
polychaetes	0.015	0.009	0.959
crustaceans	0.009	0.018	0.016
molluscs	0.008	0.078	0.007
echinoderms	0.038	0.065	0.001
others	0.020	0.097	0.009
nemerteans	0.005	0.006	0.653
total	0.015	0.022	0.005

3.2.15 The mean body weight of all organisms at each station is plotted in Figure 18. Clearly, there were many larger animals at the control sites than at the dump site stations. The mean body weight was significantly higher for crustaceans, molluscs, echinoderms and "others" at the control site than at the dump site (Table 7).

4.0 Discussion

4.1 The results are discussed below in relation to the questions which this study was designed to address.

1) **At MBDS, are benthic organisms recolonizing areas of the seabed covered by dumped material?**

4.2 Both the REMOTS and benthic grab results clearly demonstrate that the dumped material at MBDS has become inhabited by a relatively diverse and abundant community of benthic organisms. The physical REMOTS results are particularly valuable because they provide confirmation that the benthic grab samples came from areas of the seabed covered by dumped material. Both the REMOTS images and the physical sediment analyses demonstrate that the dumped material at MBDS is distinguished by a much higher sand content and greater small-scale spatial heterogeneity in grain size/seabed type compared to the homogenous and muddy ambient seabed.

4.3 These results are significant because they provide solid proof that in Hong Kong, benthic organisms are capable of recolonizing areas where dredged material has been disposed. This is the first detailed study of the benthos at MBDS since disposal began in the early 1980's, making it impossible to determine the time scale and successional sequence involved in establishing the present community. It should be noted that the community at MBDS has not been subjected to dumping disturbance since disposal operations ceased in 1993, and the dumped material is characterized by a high proportion of sand. Therefore, the present findings may not necessarily be applicable to other disposal sites in Hong Kong where dumping is ongoing and/or the disposed material is predominantly silt-clay.

2) What is the taxonomic composition and abundance of the benthic community found to be recolonizing the dumped material?

4.4 Compared with recent REMOTS surveys in Eastern Waters and elsewhere in HK territorial waters (BCL/SAIC 1995; 1996), a higher proportion of replicate images at the dumped material stations had polychaete or amphipod tubes at the sediment surface (e.g., Plates 5 and 10) and/or animals visible within the sediment matrix (e.g., Plate 9). These results suggest that benthic organisms have attained higher densities on the dumped material than typically found in most seabed areas of HK. Based on the taxonomic results, candidate taxa for the surface tubes observed in the REMOTS images include the polychaete families Maldanidae and Spionidae, which are known to have tube-building members (Fauchald and Jumars 1979), while the amphipod tubes probably indicate the presence of the families Corophidae or Ampeliscidae. Polychaetes observed burrowing at depth most likely belong to the families Capitellidae, Paraonidae, Cirratulidae, Pilargiidae or Glyceridae, which are known to include free-living, burrowing members (Fauchald and Jumars 1979).

4.5 The benthic grab results confirm that polychaetes were the most abundant group at the dumped material stations. Not surprisingly, the families Capitellidae and Spionidae were the two most abundant polychaete taxa; these are traditionally regarded as representative "opportunists" (surface-dwelling, tubicolous, REMOTS "Stage I" taxa) which colonize seabed habitats rapidly following physical disturbance or in response to excessive organic enrichment (Pearson and Rosenberg 1978; Rhoads et al. 1978). These two groups obviously continue to be successful at exploiting the "new" seabed habitat provided by the dumped material since disposal ceased in 1993.

4.6 The benthic community on the dumped material is not limited to opportunistic polychaete taxa; polychaete families representing more advanced successional stages, as well as crustaceans, echinoderms, molluscs, and even gorgonian corals, also are present at moderate to high abundance. The families Maldanidae, Paraonidae and Cirratulidae are late successional (i.e., subsurface deposit-feeding, REMOTS "Stage III") polychaete taxa found in high abundance on the dumped material. Several families of carnivorous polychaetes, most notably the Glyceridae and Pilargiidae (Fauchald and Jumars 1979), as well as the amphipod families Corophidae and Ampeliscidae, the brittlestar family Amphiuridae, and the bivalve families Corbulidae, Semelidae, Montacutidae, and Nuculanidae, also were relatively abundant.

4.7 Overall, the benthic community inhabiting the dumped material consists of a diverse mixture of taxa. Polychaetes are the numerical dominants, as is typical of benthic communities throughout Hong Kong, but the dumped material community also includes both early and late successional taxa representing several different phyla.

3) How does the benthic community inhabiting the dumped material compare with the communities found on the ambient seabed in nearby areas unaffected by disposal?

4.8 The benthic community inhabiting the dumped material was found to differ significantly from that found nearby on the ambient seafloor. In this study we are interested in the response of the <u>whole</u> benthic community following the cessation of dumping at MBDS. In addition, we applied a double square root transformation to the abundance data to downweight the numerically dominant taxa and allow those with less abundance to contribute to the determination of overall community (dis)similarity among stations. For the family-level dataset, we based our assessment on multivariate techniques encompassing all taxa, while for the phylum-level dataset we used univariate tests of common taxa.

4.9 The stress value of 0.20 for the MDS plot (Figure 14) is fairly high and suggests that this 2-dimensional representation of the relationships among stations has higher dimensional components. In such instances, it is advisable to avoid placing too much reliance on the detail of the plot, and its interpretation should be cross-checked against the results from an alternative technique. We superimposed the groups from the cluster analysis on the MDS plot to provide such a cross-check and found mutual consistency between the two: the control and dumped material stations generally form separate groups in both representations. This indicates the adequacy of the MDS plot despite the high stress value.

4.10 The high stress value is partly a consequence of our decision to apply the double square root transformation to the abundance data, thereby allowing many more taxa to contribute toward determining the overall community pattern. The resulting increase in the "dimensionality" of the data makes it more difficult to display in a 2-dimensional MDS plot. For the sake of comparison, we re-ran the analysis using untransformed abundance data, and the resulting MDS plot showed a similar station grouping (separation of controls and dumped material stations in two distinct groups) with a much lower stress value of 0.13. Overall, the MDS results demonstrate the basic difference in benthic community structure between control and dumped material stations.

4.11 The REMOTS results showed that most of the dumped material was Type 1 (Plates 1 and 2), with much small-scale spatial heterogeneity within and among stations (Figure 6). We designed the survey based on the sidescan sonar interpretation of three dumped material types. Analysis of REMOTS images, however, showed the presence of three dumped material types which do not correspond to the sidescan interpretation. Therefore, the original station allocation appears to be less relevant with respect to ecology. The ANOSIM test confirmed a lack of significant difference in benthic communities among the three "sidescan sonar" bottom types, and a similar lack of difference among the three control sites. However, the ANOSIM using pooled stations (21 controls versus 20 dumped material) demonstrated a statistically significant difference in benthic community structure between the dumped material and the ambient seafloor.

4.12 The results presented in Table 4 are particularly important in this study because they show which taxa are principally responsible for the statistically significant difference in community structure between dumped material and control stations. The difference is principally due to the following (see Table 4):

- Corophid and Ampeliscid amphipods and Glycerid polychaetes were relatively abundant at dumped material stations and quite rare on the ambient seabed.

- Many other polychaete families (e.g., Eunicidae, Phyllodocidae, Nereidae, Ampharetidae, Poecilochaetidae, Lumbrineridae, Onuphidae, Magelonidae, and Maldanidae) occurred, on average, in moderate numbers on the dumped material, but were extremely rare on the ambient seabed.

- Polychaete families like Capitellidae, Paraonidae, and Spionidae were relatively abundant at all stations, but occurred at higher average densities on the dumped material compared to the ambient seabed.

- Polychaete Families Nephtyidae, Polynoidae, and Sternaspidae were relatively abundant on the ambient seabed but occurred at very low densities on the dumped material.

4.13 It is notable that the percent contributions of individual taxon to the overall dissimilarity have a narrow range from 1.5% to 3.8% (Table 4). It is not unusual in studies of this kind for a relatively small number of taxa to contribute disproportionately to the overall dissimilarity (for example, greater than 90% of the dissimilarity might be contributed by only 5 or 10 key discriminating taxa). The results from this study indicate a lack of such key discriminators. Rather, there are many individual taxon which contribute in small and relatively even proportions to the overall difference between the dumped material and control stations.

4.14 The phylum-level data for all sites are in agreement with the results of the family-level analysis. The dumpsite community exhibits a significantly higher abundance of significantly smaller animals than the control site community. It is not known if the difference in mean body size is due to recent disturbance at the dumpsite, or whether species with larger body size prefer the finer sediment environment at the control area.

4.15 In attempting to understand why this difference exists, we turn to the fourth and final question posed at the beginning of this study.

4) Are potential differences in benthic communities among areas and/or stations attributable to physical/chemical parameters?

4.16 One of the main physical differences found in this survey is the much higher proportion of fine and medium sand in the dumped material compared to the seabed nearby. In addition, the dumped material exhibited a much wider range of sediment particle size classes (rocks, gravel, coarse/medium/fine sand and silt-clay) and greater small-scale patchiness compared to the controls.

4.17 There appears to be an association between sediment particle size and benthic community composition (Figure 15a and b), while correlations between the biota and sediment TOC are much less apparent (Figure 15a and c). Two of the stations in the southern control site had very fine sand as the dominant particle size fraction, while most of the other control stations had high silt-clay content. This probably explains why, in terms of benthic community structure, these two stations (31 and 41) were grouped together with the dumped material stations in both the cluster analysis and the MDS plot. The occurrence of very fine sand at these control stations is somewhat anomalous given that sediments at the other control stations and throughout the region are generally muddy (i.e., silt-clay is typically the dominant particle size). The increased sand content found at stations 31 and 41 may simply reflect naturally-occurring heterogeneity in the composition of surface sediments in this region, or it may be either a direct or indirect result of dumping in and around MBDS.

4.18 The increased sand content and greater variety of sediment types characterizing the dumped material apparently have stimulated increased diversity and abundance of the benthic community relative to the ambient seabed. Several explanations for this stimulatory effect are proposed. First, there are some taxa which require sand to build essential structures (e.g., tubes or burrows), or else have a preference for ingesting sand-sized particles while feeding. The Corophid and Ampelisicid amphipods, which were relatively abundant on the dumped material and rare on the ambient seafloor, are examples of taxa with a strong preference for sand. Second, the coarser, more-compact sediments comprising the dumped material are likely to be less susceptible to erosion, while sediments elsewhere in Eastern Waters are known to experience frequent disturbance due to high energy storm events (Shin 1989; SAIC/BCL 1994b). The REMOTS images confirm that in many places, finer sediments have been selectively removed from the exposed surface of the dumped material, leaving an armoured surface (i.e., a lag deposit) consisting of coarser sediment and shell hash (see Plates 6 and 7). Thus, the dumped material probably provides a much more stable habitat compared to the surrounding area, allowing both common and relatively rare taxa to reach much higher abundances than they normally achieve in soft-bottom areas subject to frequent physical disturbance.

4.19 The poorly-sorted mixture of different sediment types comprising the dumped material creates greater habitat diversity than normally found on the muddy seabed, providing a third explanation for increased organism diversity and abundance at MBDS. For example, the many small rocks, pebbles, and shell fragments provide a solid surface for organism attachment and better support for structures such as tubes, compared to the soft, loose mud which typifies the ambient seabed. Another factor accounting for the different benthic community on the dumped material is the increased abundance of secondary consumers (i.e., carnivorous, predatory polychaetes like the Glyceridae and Pilargiidae) in response to the increased abundance and diversity of prey. Finally, the higher average abundance of polychaete families like Nephtyidae, Polynoidae and Sternaspidae at the control stations may reflect a preference for the softer, looser sediments there compared to the controls. Members of the Family Nephtyidae have been reported as head-down, subsurface deposit feeders (Fauchald and Jumars 1979), which may explain the greater number of feeding voids observed in the control station REMOTS images (Figure 11).

4.20 This study demonstrates that since the cessation of dumping at MBDS in 1993, the dumped material has been colonized by an assemblage of benthic organisms which is both diverse and abundant compared to the communities in nearby areas where there was no dumping. Taxa which are abundant on the ambient seafloor are also abundant on the dumped material, where they have managed to achieve comparatively higher numbers. In addition, several taxa which are rare or uncommon on the surrounding seafloor have come to inhabit the dumped material in relatively high numbers. Thus, the ecological effect of past dredged material disposal at MBDS appears to be the creation of a locally-unique seabed environment which is proving to be a highly favourable habitat for a variety of benthic and epibenthic organisms. By providing stability and structure within a dynamic region, the dumped material deposit represents the seabed equivalent of an artificial reef for benthic macrofauna.

4.21 Additional work would be needed to determine if succession of the benthic community at MBDS is still proceeding, or if it has reached a point of relative stability. The results from this study will provide a useful basis for comparison should future studies of benthic recolonization be undertaken at MBDS or any of the other Hong Kong disposal sites.

5.0 Conclusions

1) Dredged material dumped at the Mirs Bay Disposal Site (MBDS) up until 1993 occurs as a relatively thin surface deposit located on the seabed near the southwestern corner of MBDS, both within and outside the gazetted site boundaries. Both sidescan sonar and REMOTS seabed profiling surveys performed in late 1995 confirmed the continuing discrete existence of the dumped material deposit.

2) REMOTS images and benthic grab samples obtained in December 1995 indicate that a diverse community of benthic organisms has come to inhabit the dumped material deposit.

3) Polychaetes are the most abundant group of organisms comprising the benthic community on the dumped material. There are also considerable numbers of crustaceans and lesser numbers of echinoderms, molluscs, sipunculans and several other groups.

4) The benthic community on the dumped material is significantly different from the community in areas of the surrounding seabed assumed to be unaffected by dumping. One of the main differences is in terms of organism abundance: there are a number of taxa, principally polychaetes, which occur in much higher numbers on the dumped material than in nearby areas. Some taxa, such as the Corophid and Ampeliscid amphipods, are found almost exclusively on the dumped material. Other taxa, like the Nephtyid polychaetes, have very low densities on the dumped material but are relatively common in nearby areas. The dumpsite community exhibits a significantly higher abundance of significantly smaller organisms than the control site community.

5) There is evidence that the coarser sediment texture and the greater variety of sediment types (rocks, gravel, sand, shell fragments, mud) which characterize the dumped material may account for the difference in benthic communities. The greater variety of sediment types creates a varied habitat leading to increased organism diversity. The coarser sediments, being less susceptible to erosion, also provide physical stability which enables benthic populations to increase.

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FIGURES

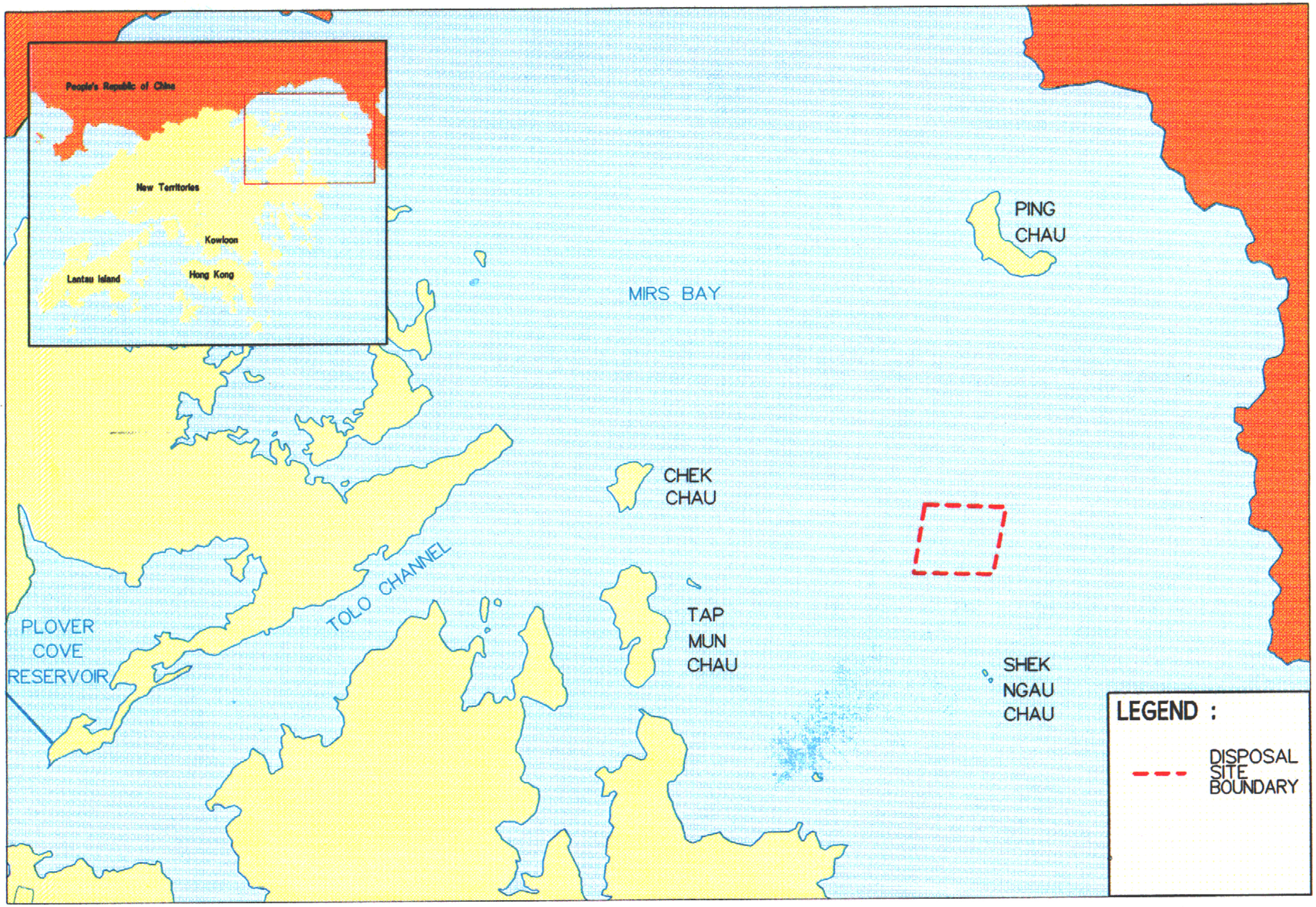


Figure 1. Location of the disposal site in central Mirs Bay, Hong Kong.

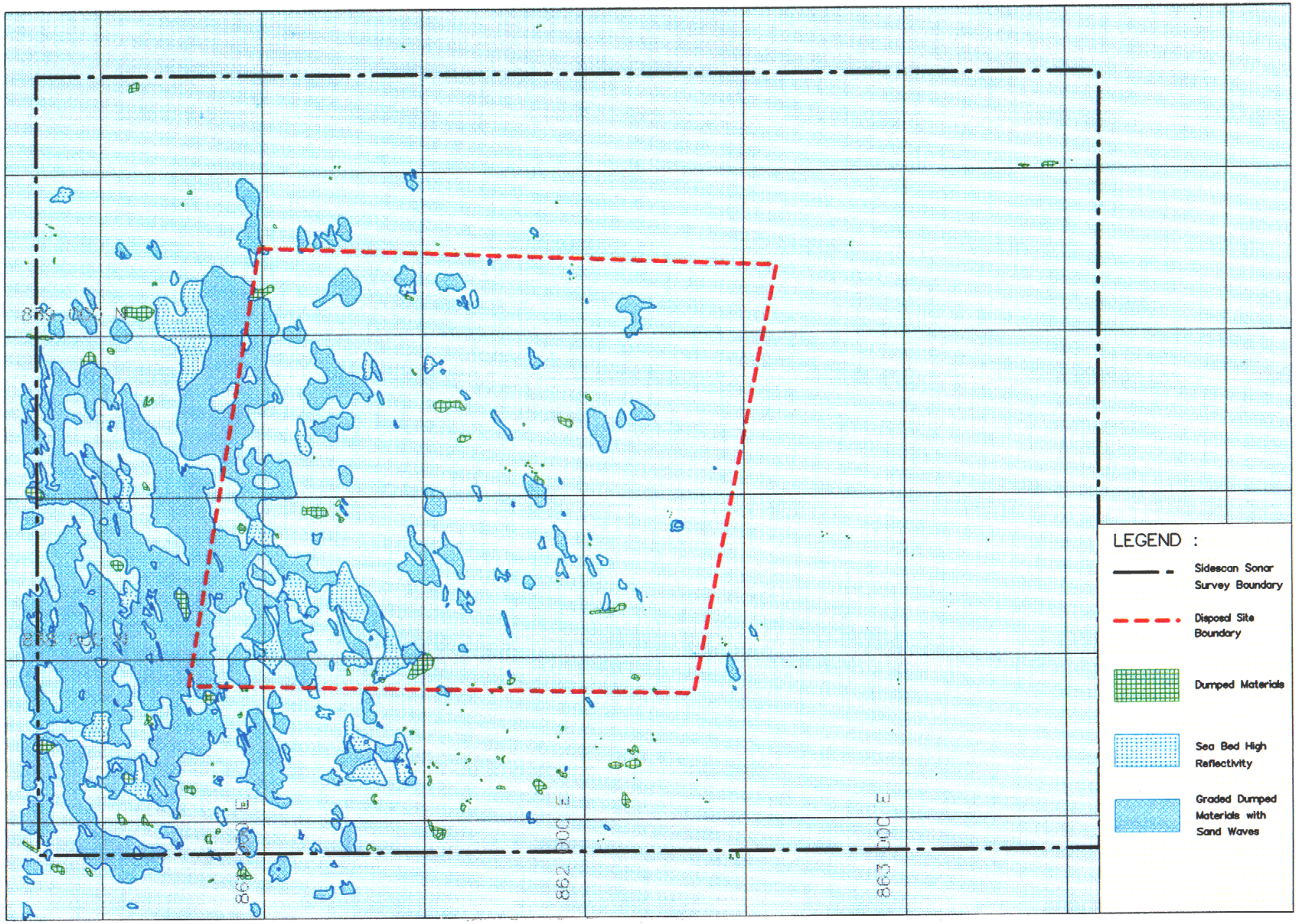


Figure 2. Results of November 1995 sidescan sonar survey showing dumped material concentrated in the southwestern corner of the MBDS boundaries and to the west (outside) of the MBDS.

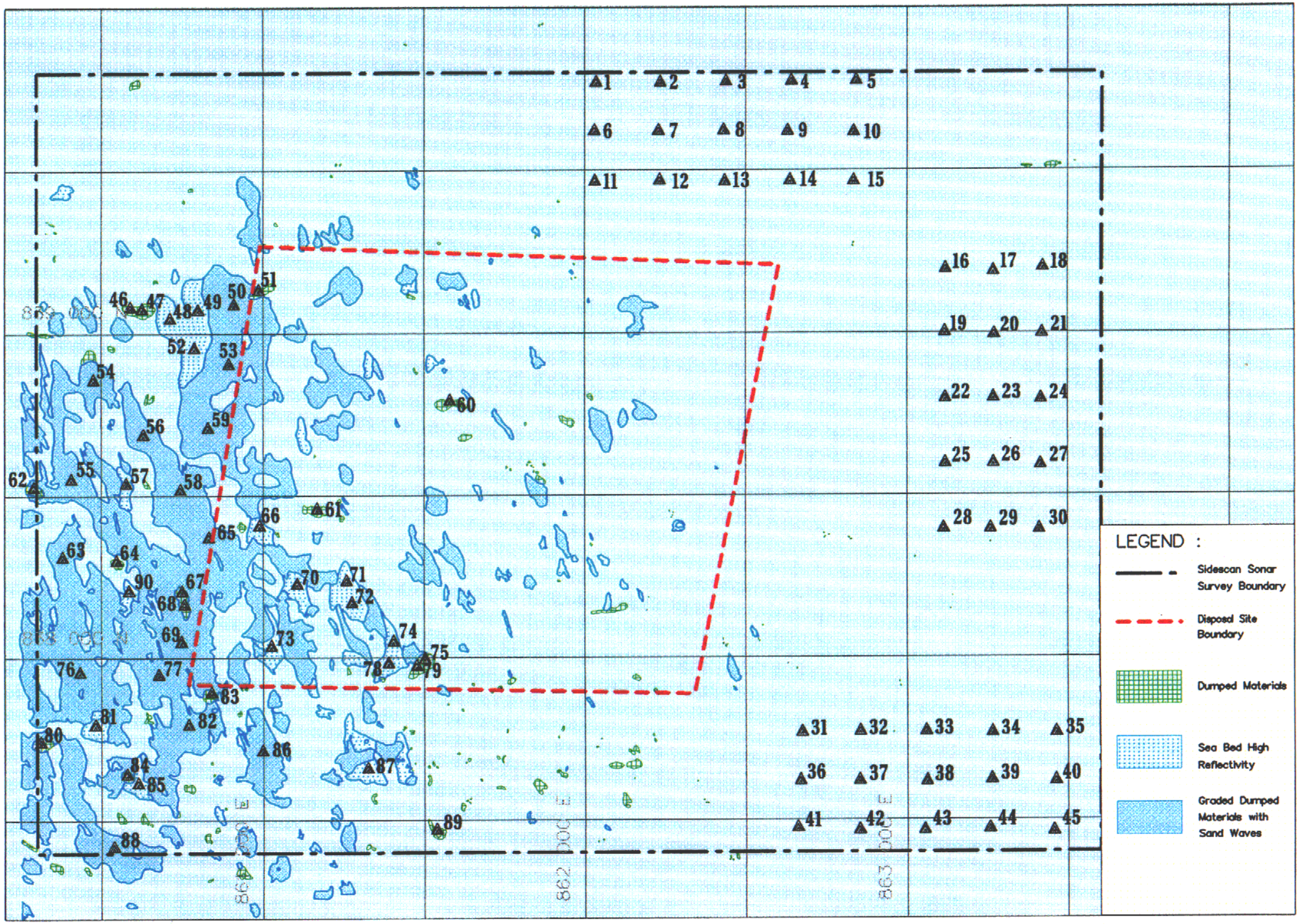


Figure 3. Station locations for the December 1995 REMOTS/benthic grab survey.

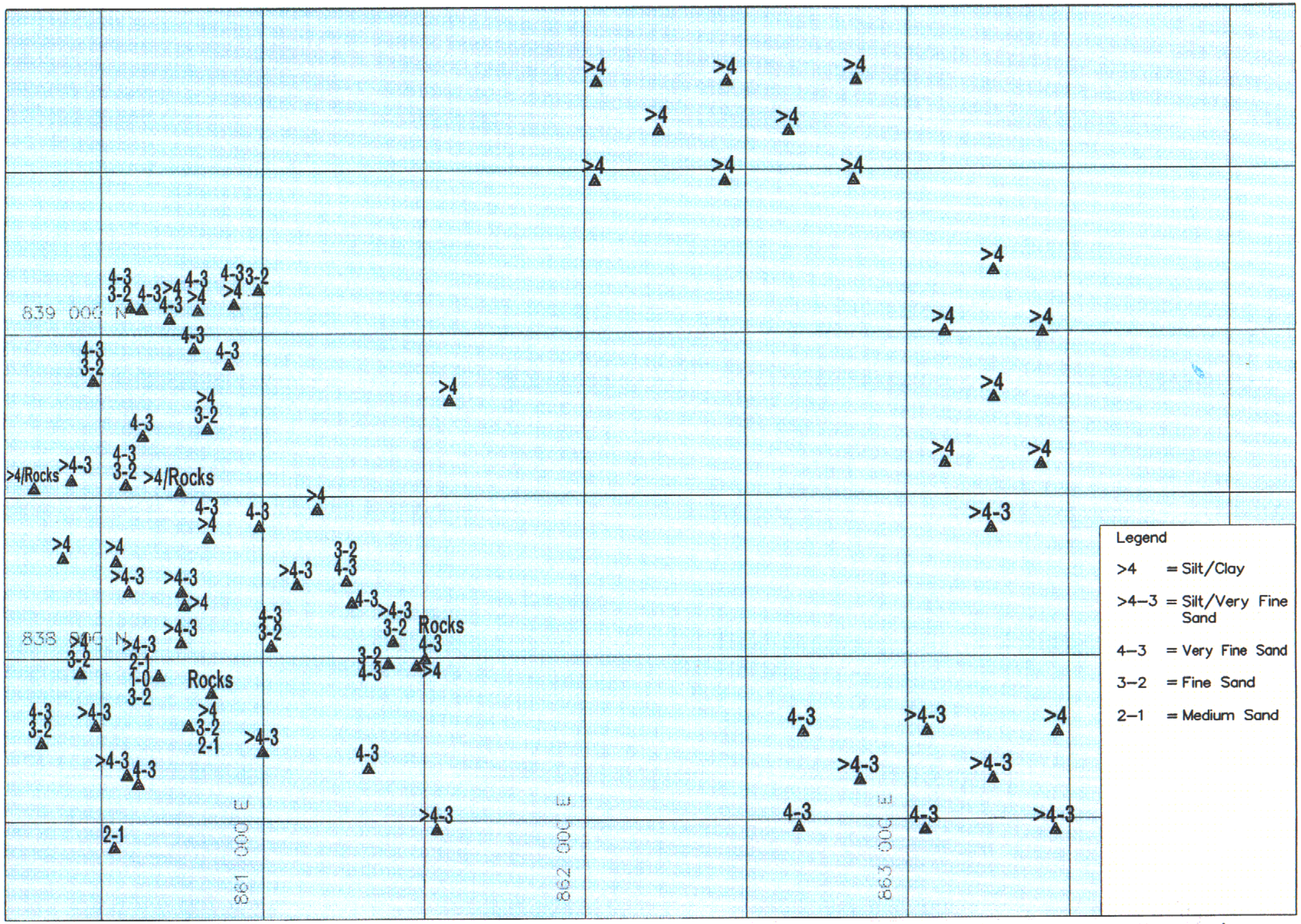


Figure 4. REMOTS grain size major mode (in phi units) at dumped material and control stations. Replicate images showed different grain sizes at some dumped material stations.

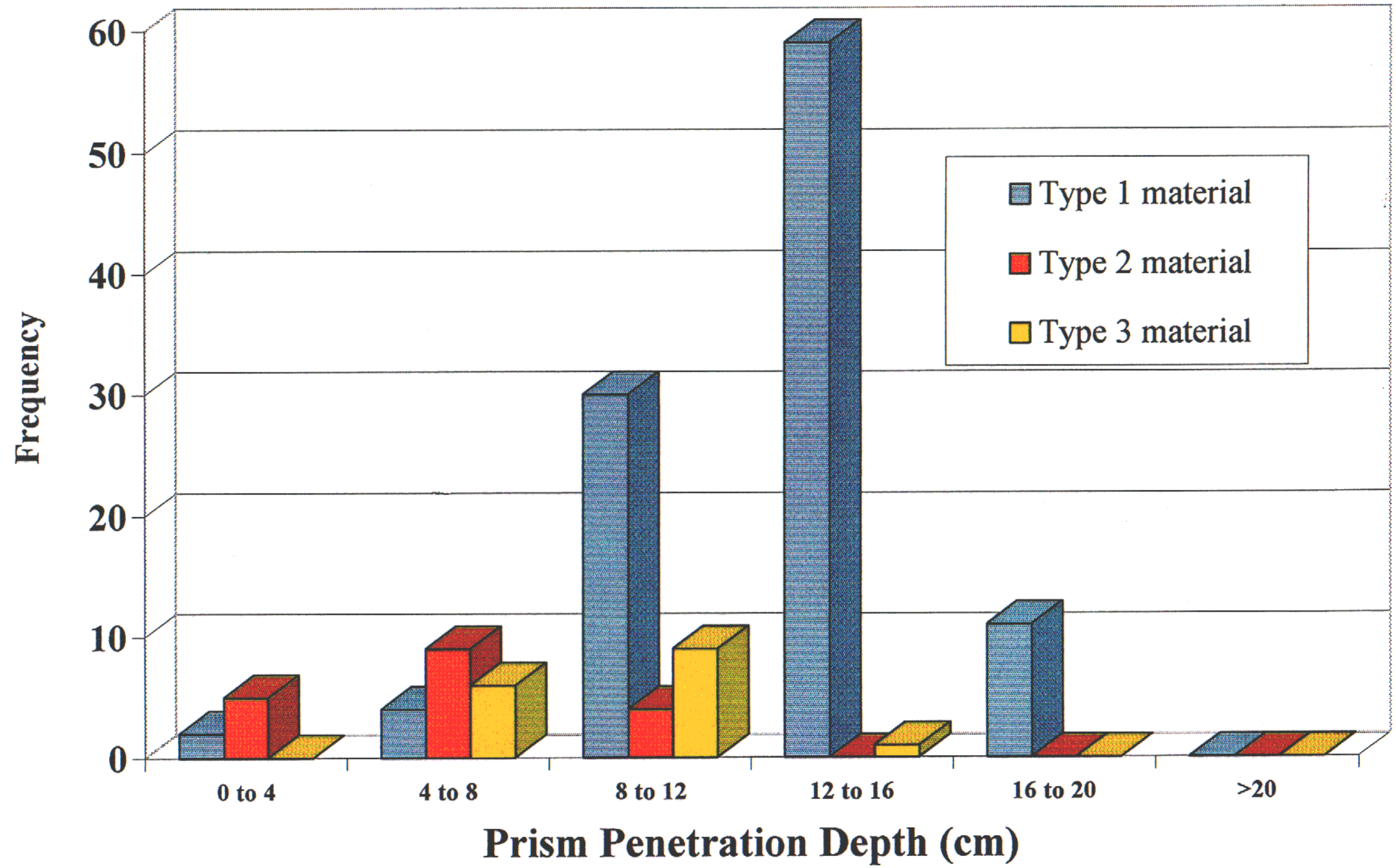


Figure 5. Frequency distributions of REMOTS prism penetration depths for replicate images obtained on three different types of dumped material.

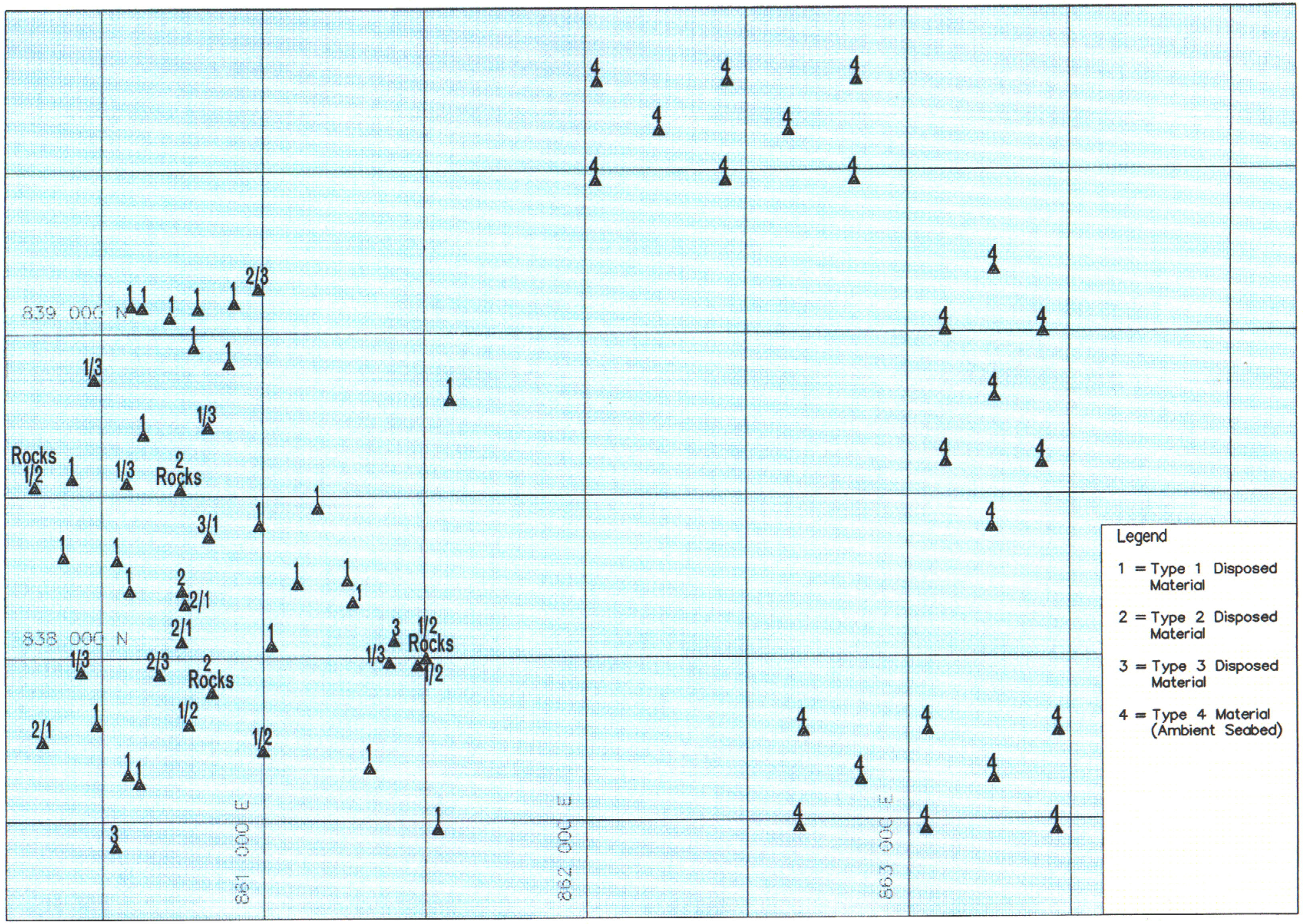


Figure 6. Mapped distribution of different types of dumped material observed in the REMOTS images.

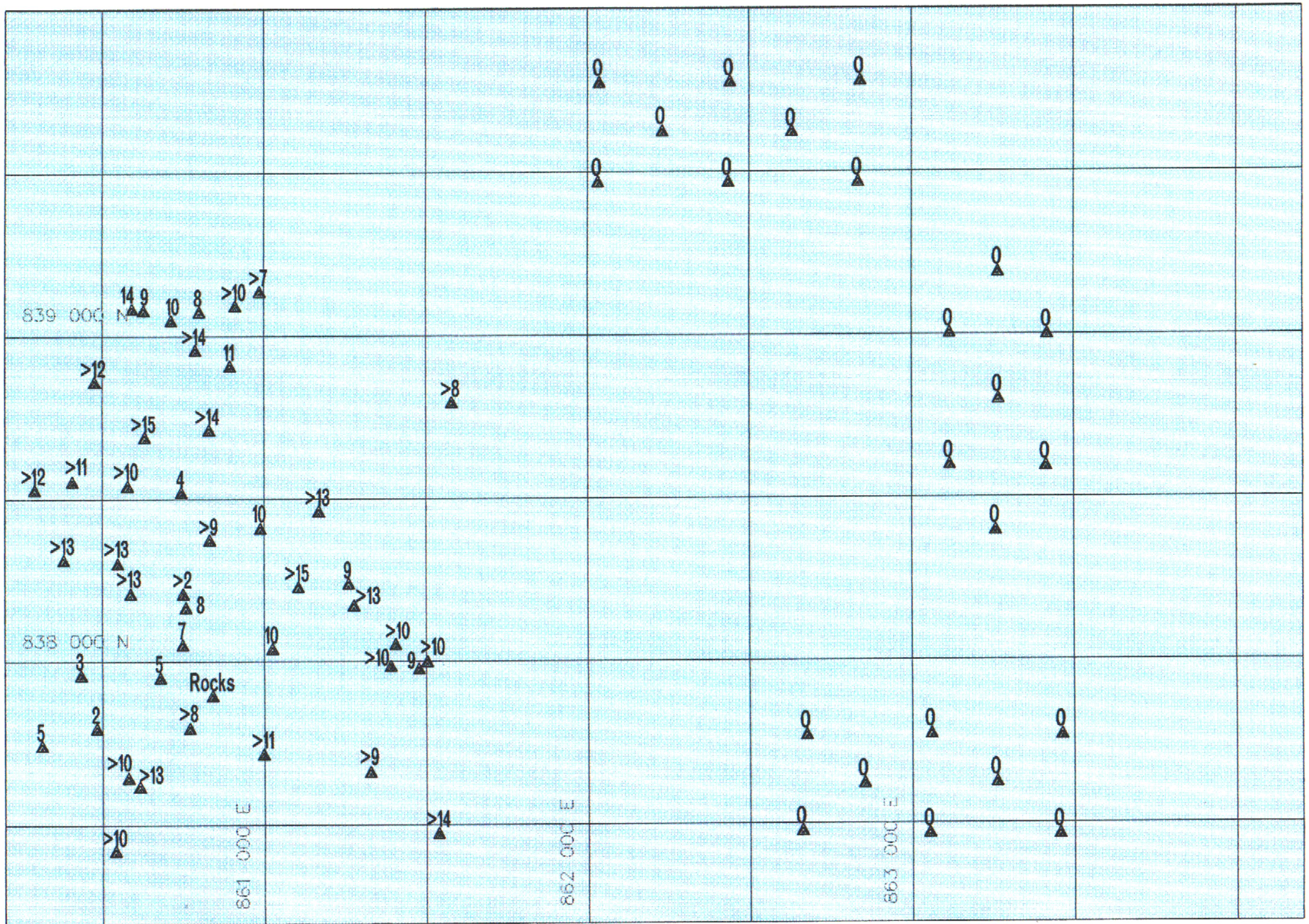


Figure 7. Average thickness (in cm) of dumped material layers observed in REMOTS images. A "greater than" symbol indicates the thickness of the dumped material layer exceeded the prism penetration depth.

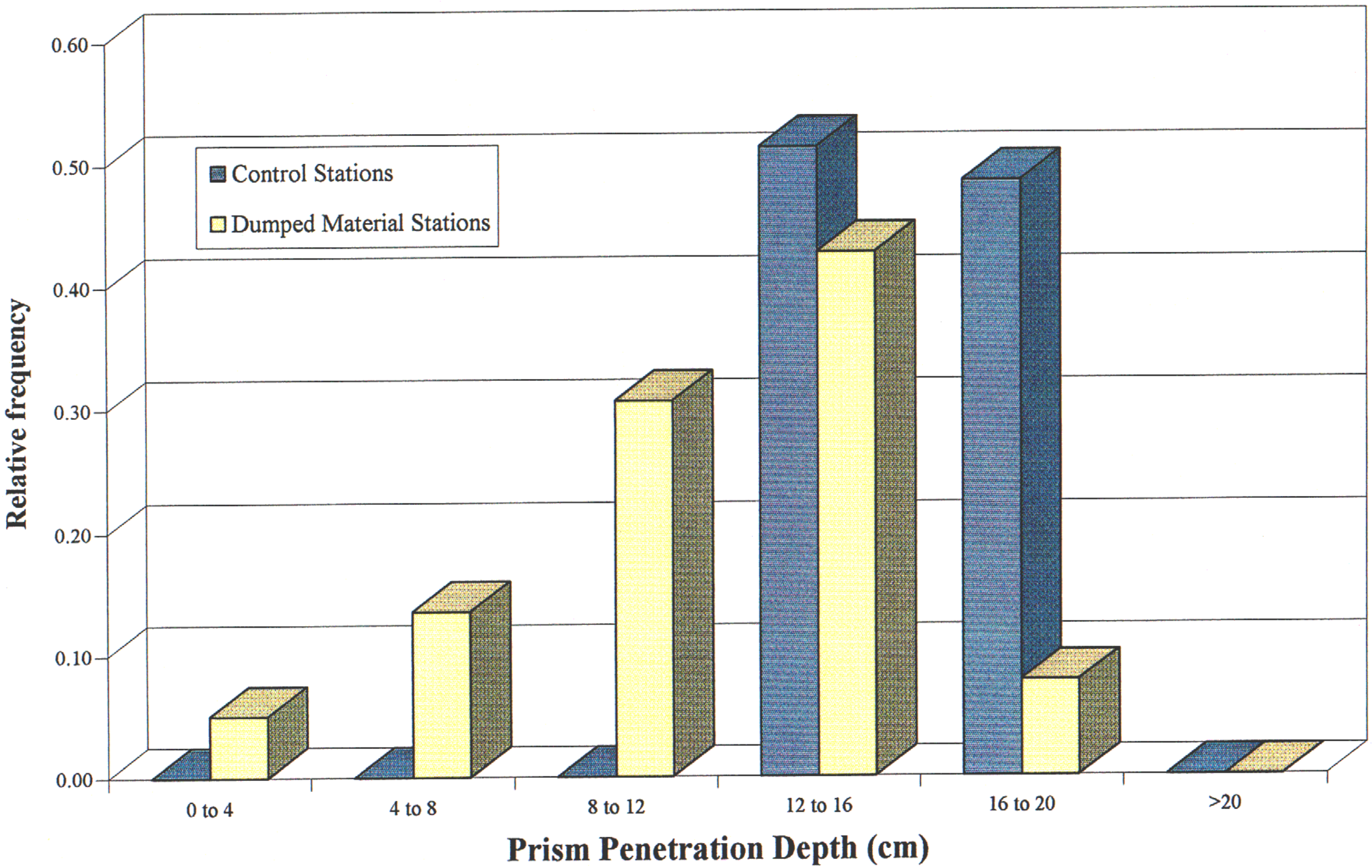


Figure 8. Frequency distributions of REMOTS prism penetration depths for replicate images obtained at the dumped material versus the control stations.

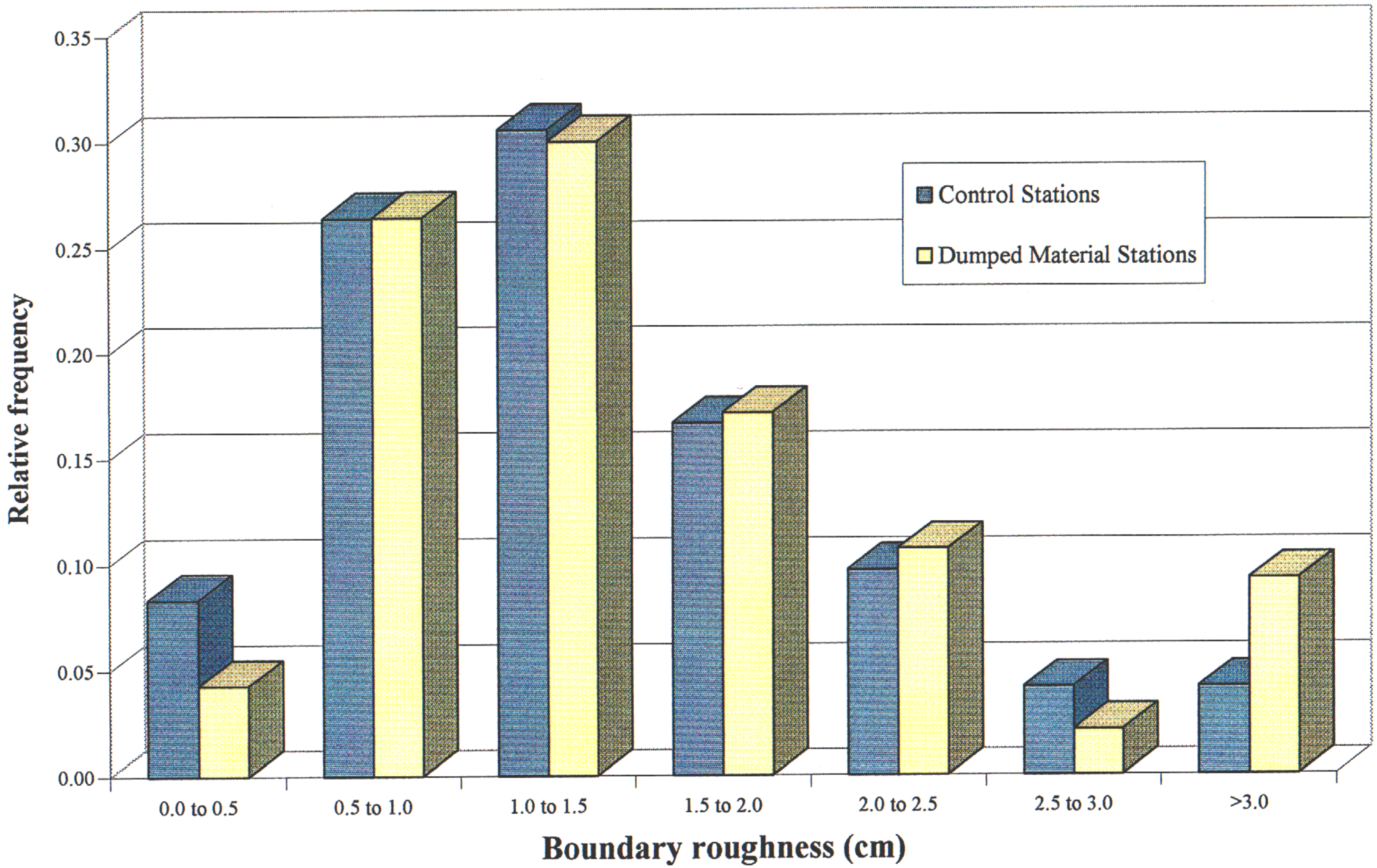


Figure 9. Frequency distributions of REMOTS small scale boundary roughness values for replicate images obtained at the dumped material versus the control stations.

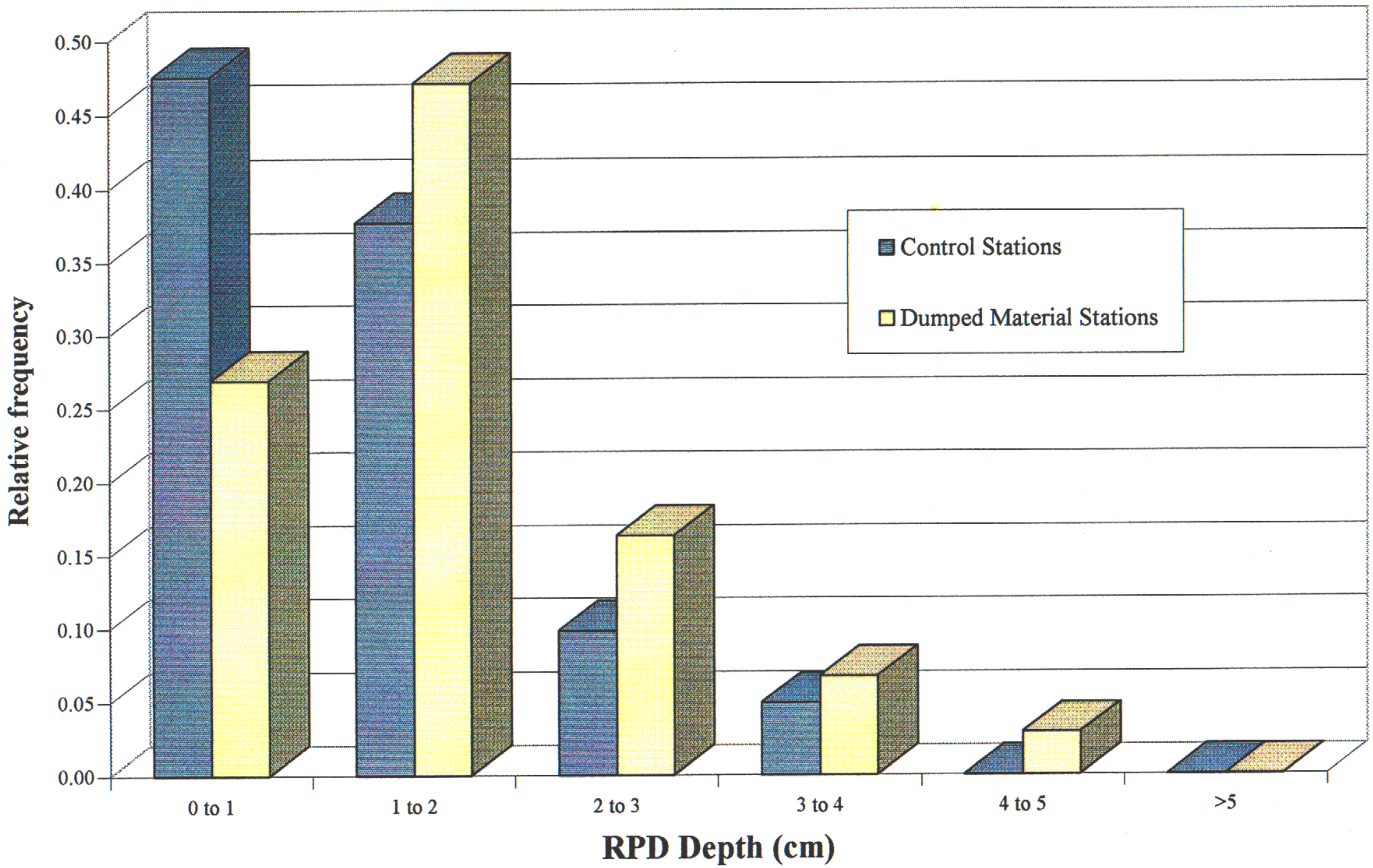


Figure 10. Frequency distributions of RPD depths for replicate REMOTS images obtained at the dumped material versus the control stations.

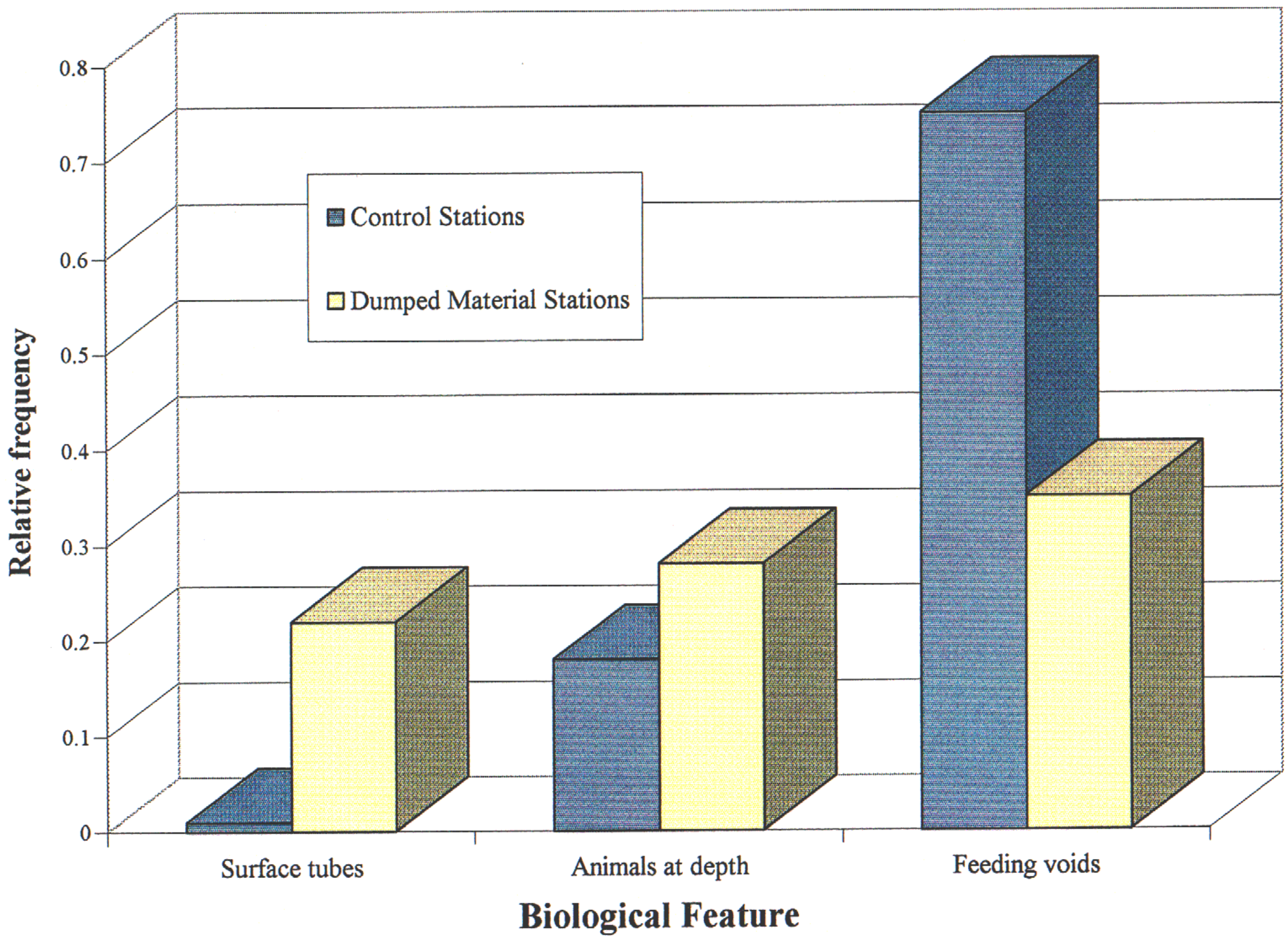


Figure 11. Frequency of occurrence of different biological features in replicate REMOTS images obtained at the dumped material versus the control stations.

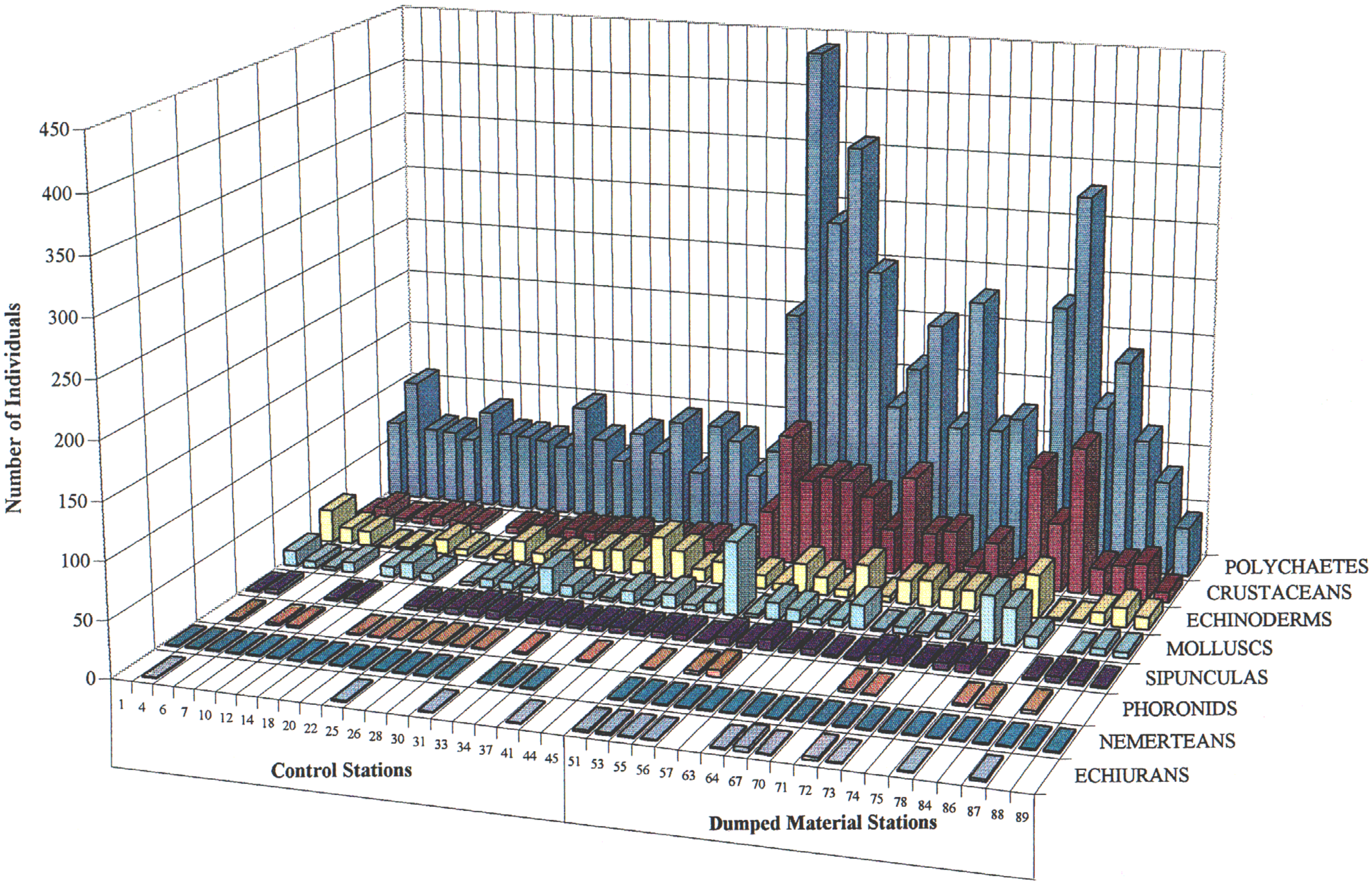


Figure 12. Abundance of different groups of benthic organisms at the control and dumped material stations.

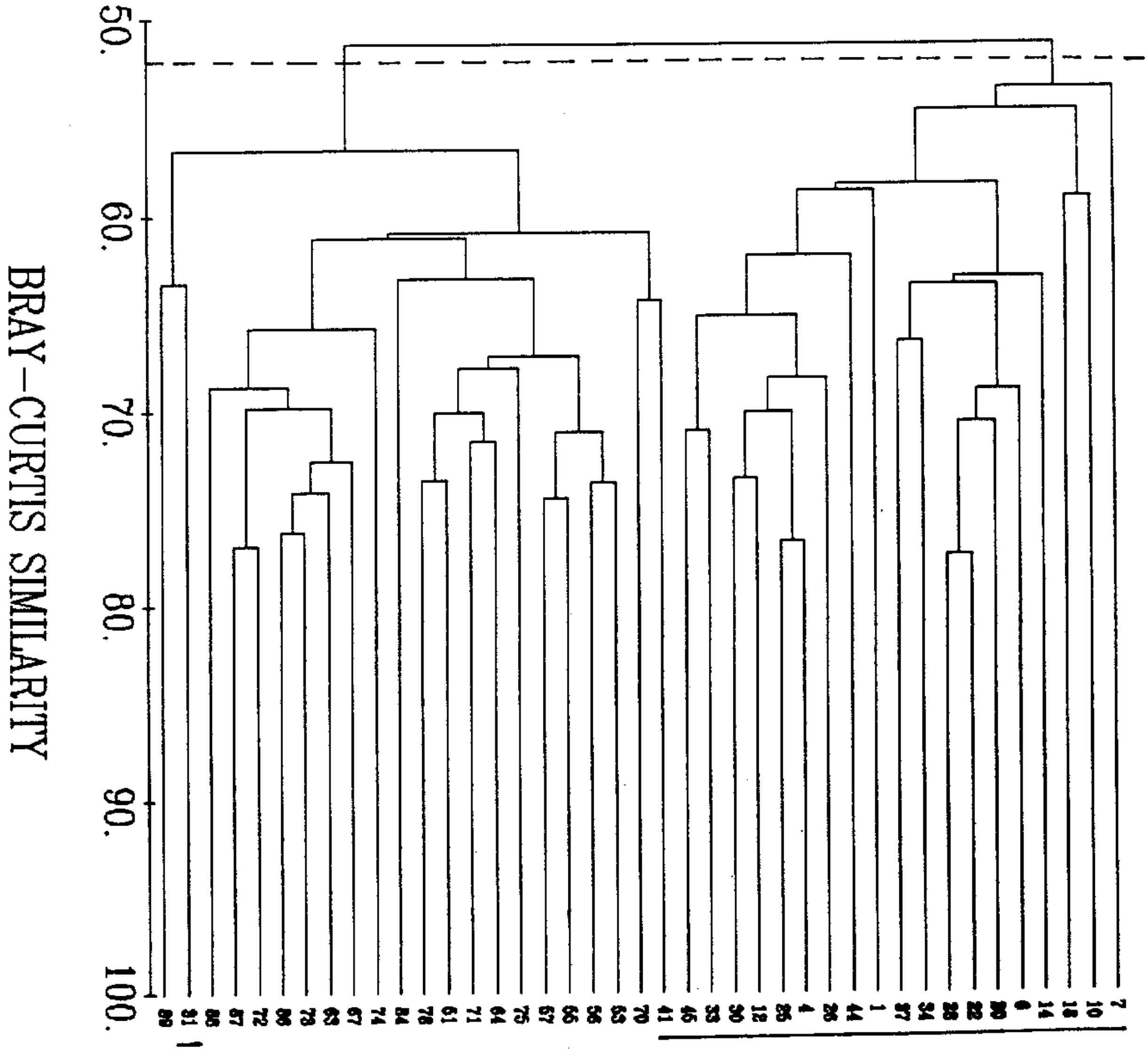
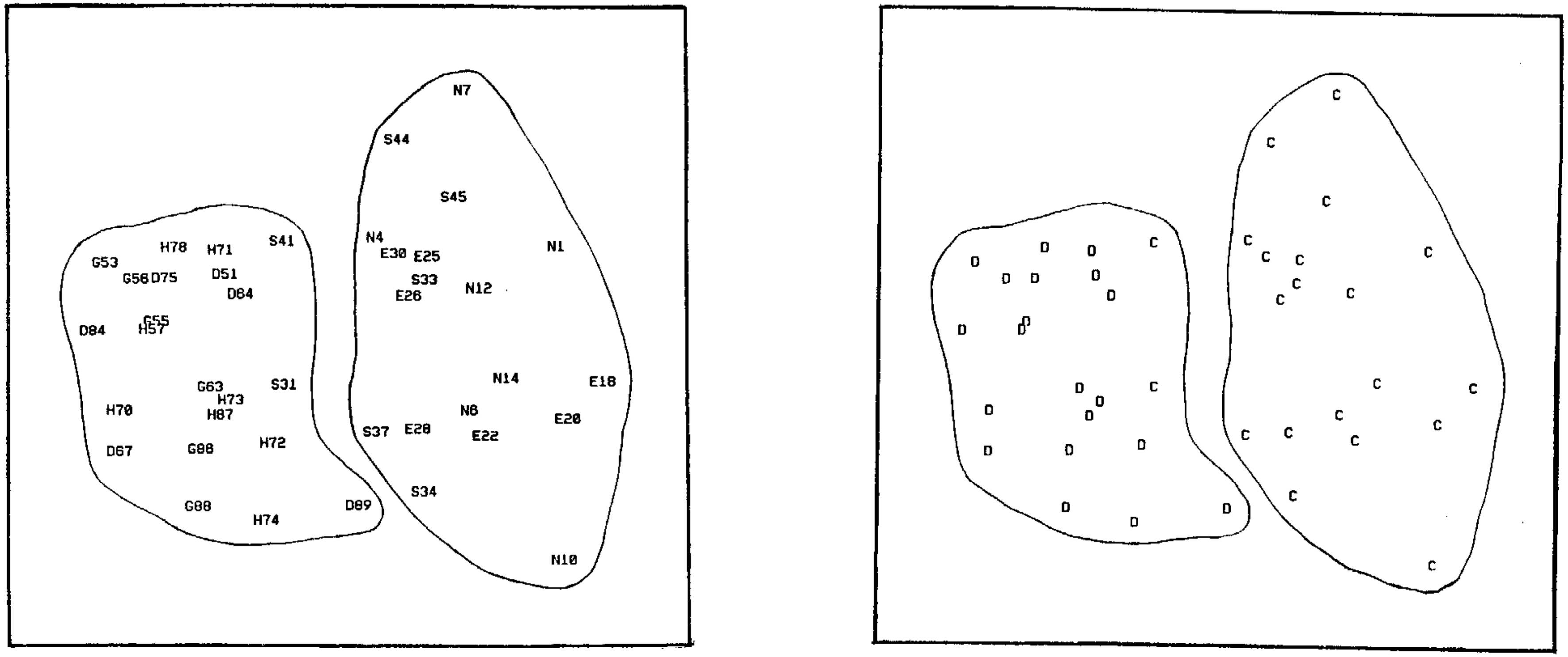


Figure 13. Dendogram for hierarchical clustering of the 41 stations, using group-average linking of Bray-Curtis similarities calculated on double square root transformed abundance data. At the 52% similarity level (dashed line), two clusters are shown representing the dumped material stations and control stations 31 and 41 (left) and the remaining control stations (right). The control stations are underlined.

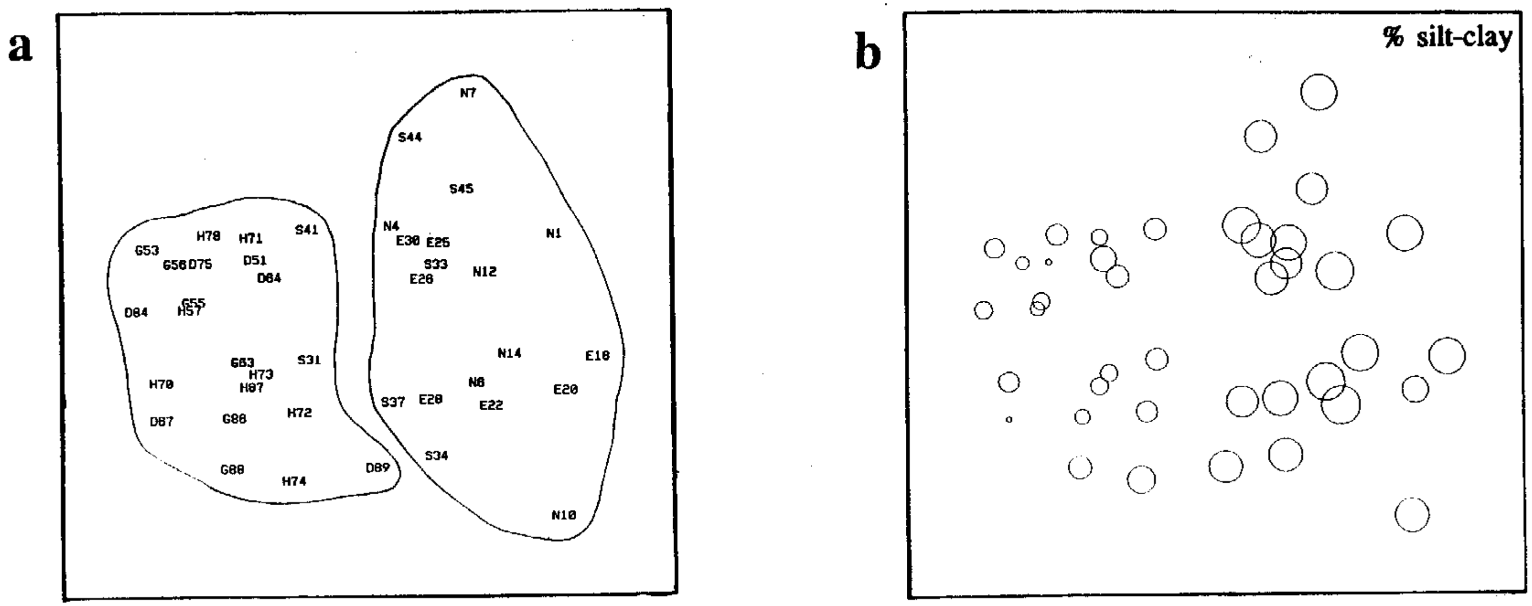


a

b

Figure 14. a.) 2-dimensional MDS configuration of the 41 stations based on double square root transformed abundances and Bray-Curtis similarities, with results from the cluster analysis (Figure 13) superimposed (stress = 0.20). Station prefixes as follows: D = dumped material, G = graded dumped material, H = high reflectivity seabed, N = north control, E = east control, S = south control.

b.) the same MDS plot but with only the letters D and C used to denote dumped material and control stations.



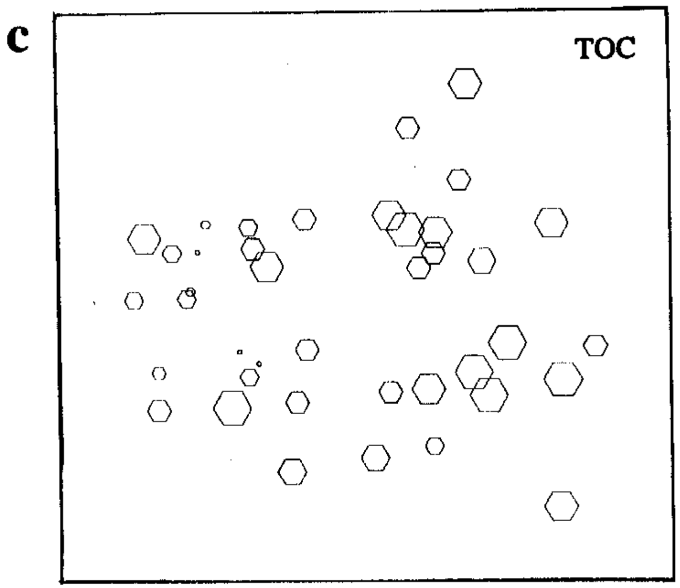


Figure 15.

a.) MDS of Bray-Curtis similarities from double square root transformed abundance data at the 41 stations, with cluster analysis results superimposed (stress = 0.20).

b.) the same MDS plot but with superimposed circles of increasing size representing increasing proportions of silt-clay in the sediment.

c.) the same MDS plot but with superimposed hexagons of increasing size representing increasing amounts of sediment organic carbon.

Figure 16. Total Abundance of six faunal groups at each Mirs Bay Station

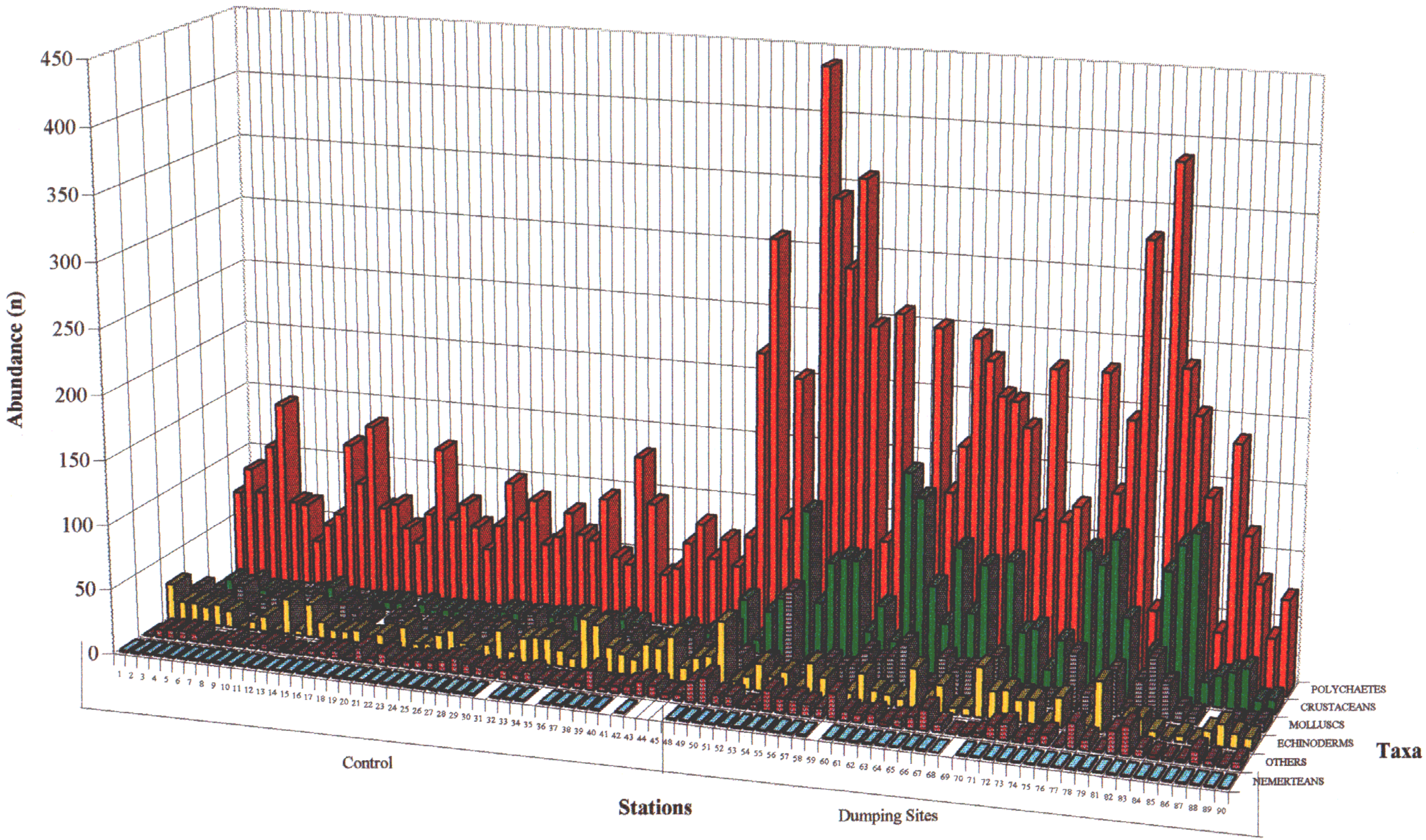


Figure 17. Total biomass of each faunal group at each Mirs Bay Station

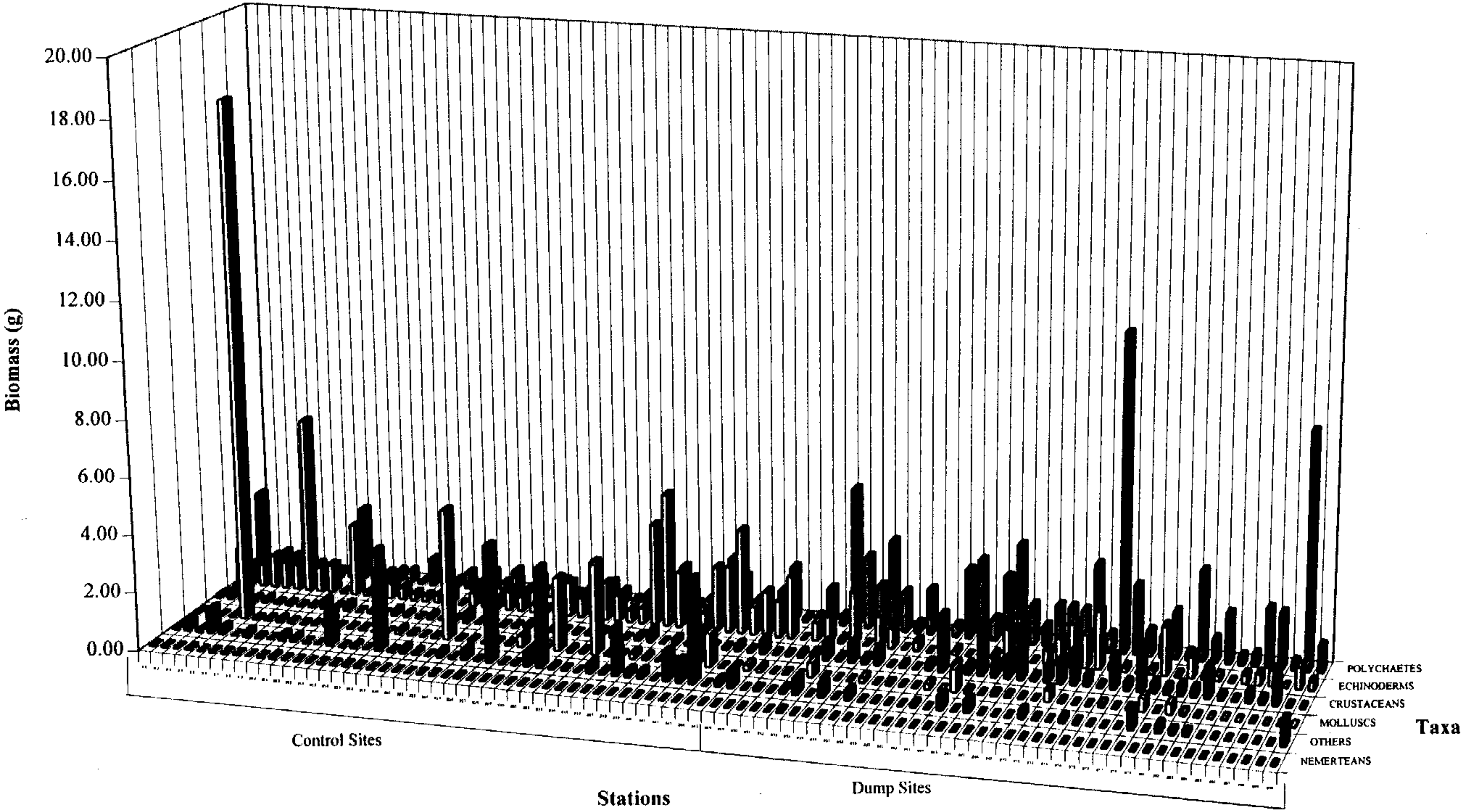
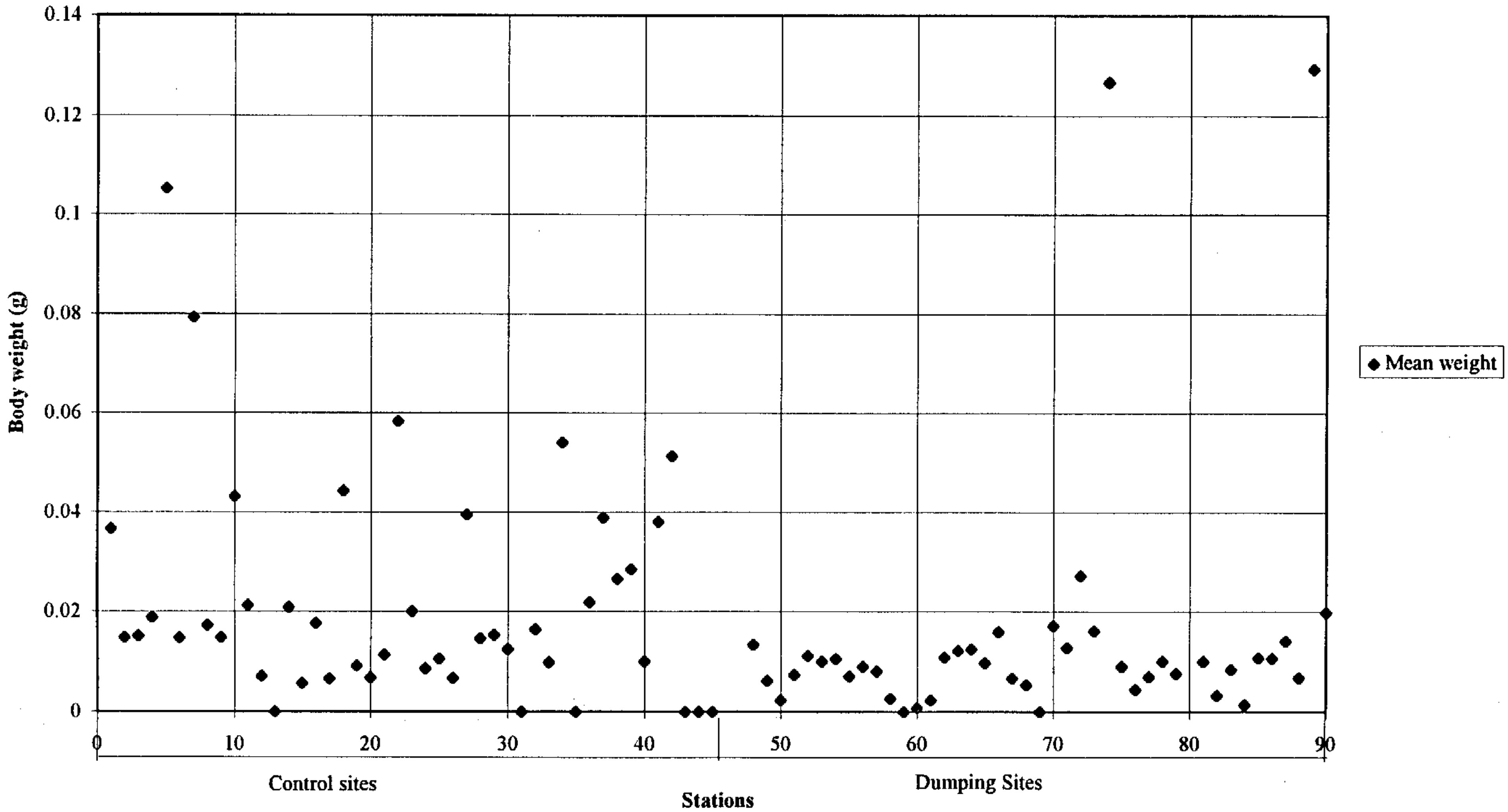


Figure 18. Mean body weight (all organisms) at each Mirs Bay Station



PLATES

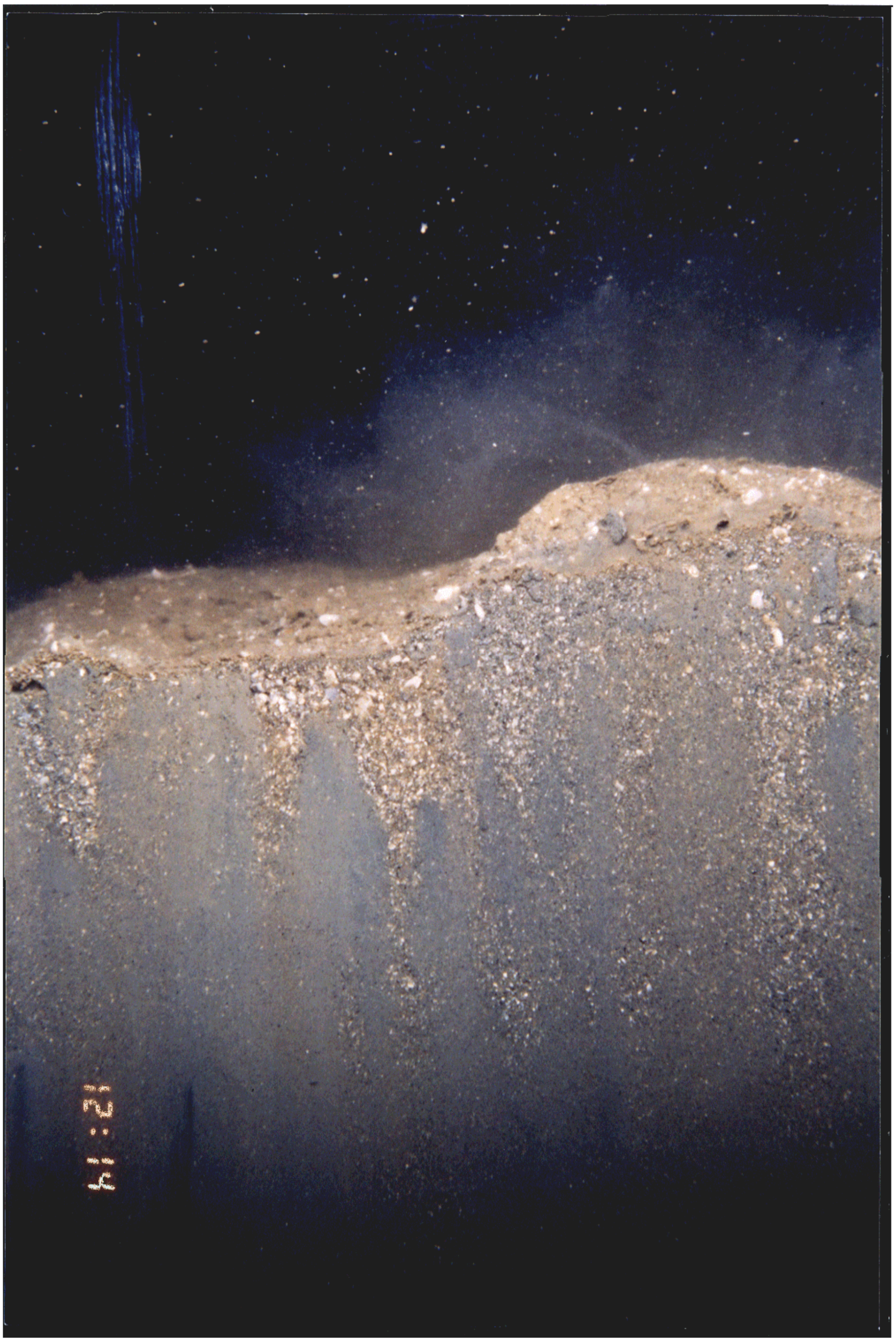


Plate 1. REMOTS image from Station 59 showing Type 1 dumped material, consisting of blue-grey silt/clay with a significant fraction of fine sand & small shell fragments.
Scale: Image Width is 15cm

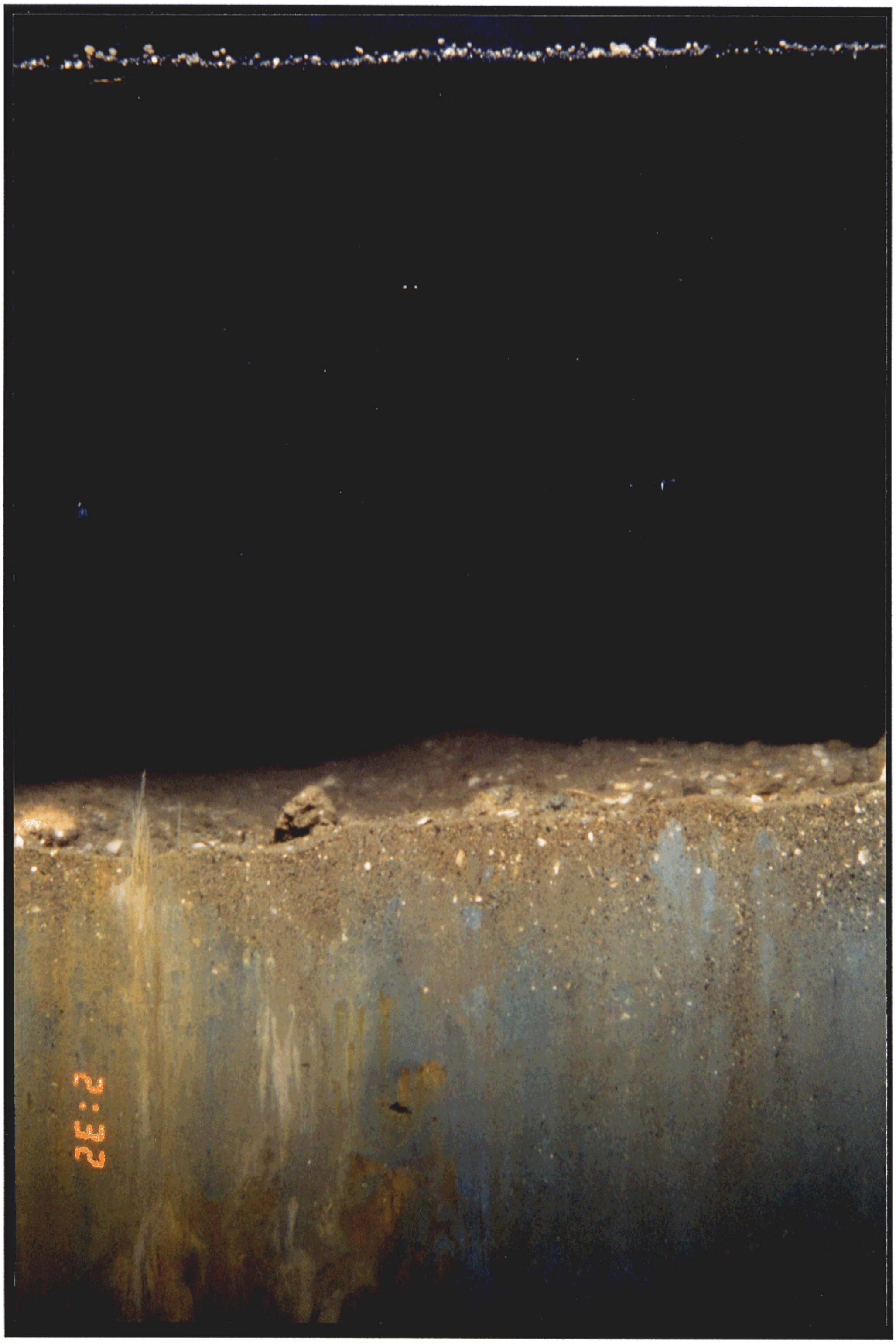


Plate 2. Type 1 dumped material at Station 69, consisting of cohesive silt-clay with mottled colouring (white, orange and blue-grey streaks).
Scale: Image Width is 15cm

Plate 3. REMOTS image from Station 82 showing dumped material Type 2, consisting of a poorly-sorted mixture of pebbles, rocks and brown mud with shell fragments. A sea whip is growing on the rock at left.
Scale: Image Width is 15cm

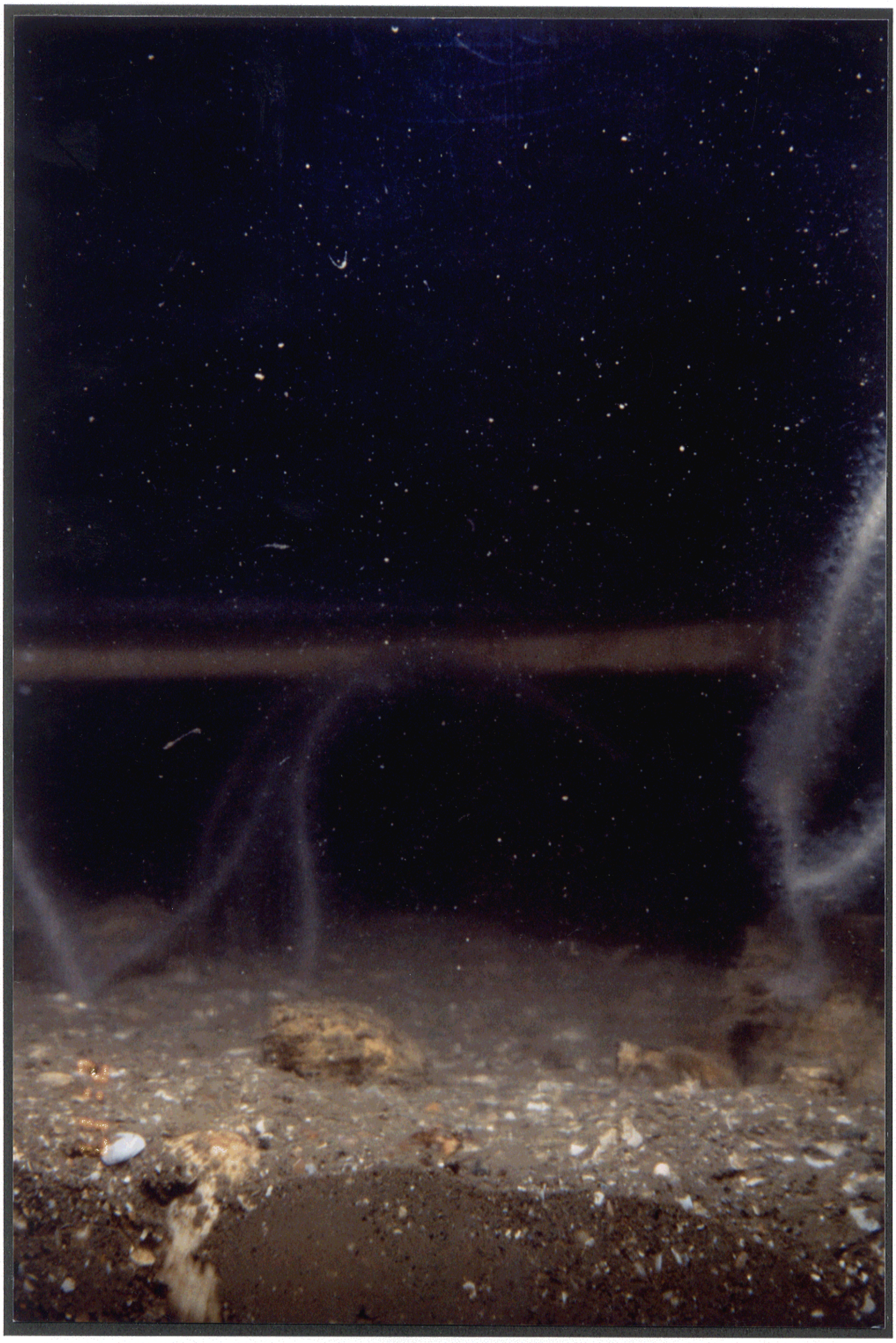


Plate 4. Example of Type 2 dumped material at Station 67. Small rocks with attached sea whips are visible in the background, while the sediment consists of a poorly-sorted mixture of shells and brown mud. Note the poor penetration of the REMOTS prism in this type of material.
Scale: Image Width is 15cm

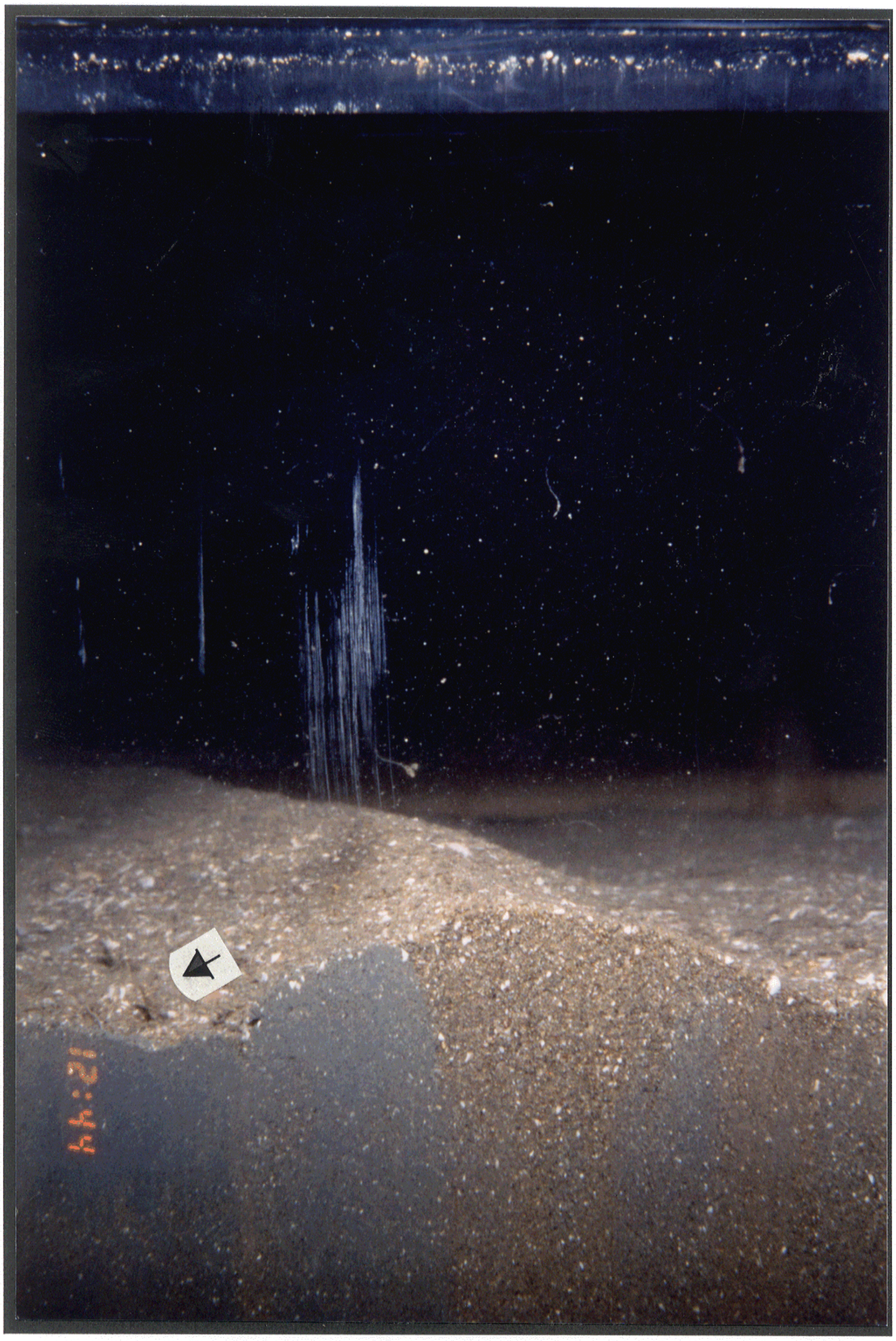


Plate 5. REMOTS image from Station 65 showing Type 3 dumped material, consisting of relatively well-sorted fine to medium sand. A bedform ripple has been transected in this image and polychaete tubes can be seen protruding from the sediment surface at left (arrow). The grey clay on the camera faceplate is probably an artifact from a previous image.
Scale: Image Width is 15cm

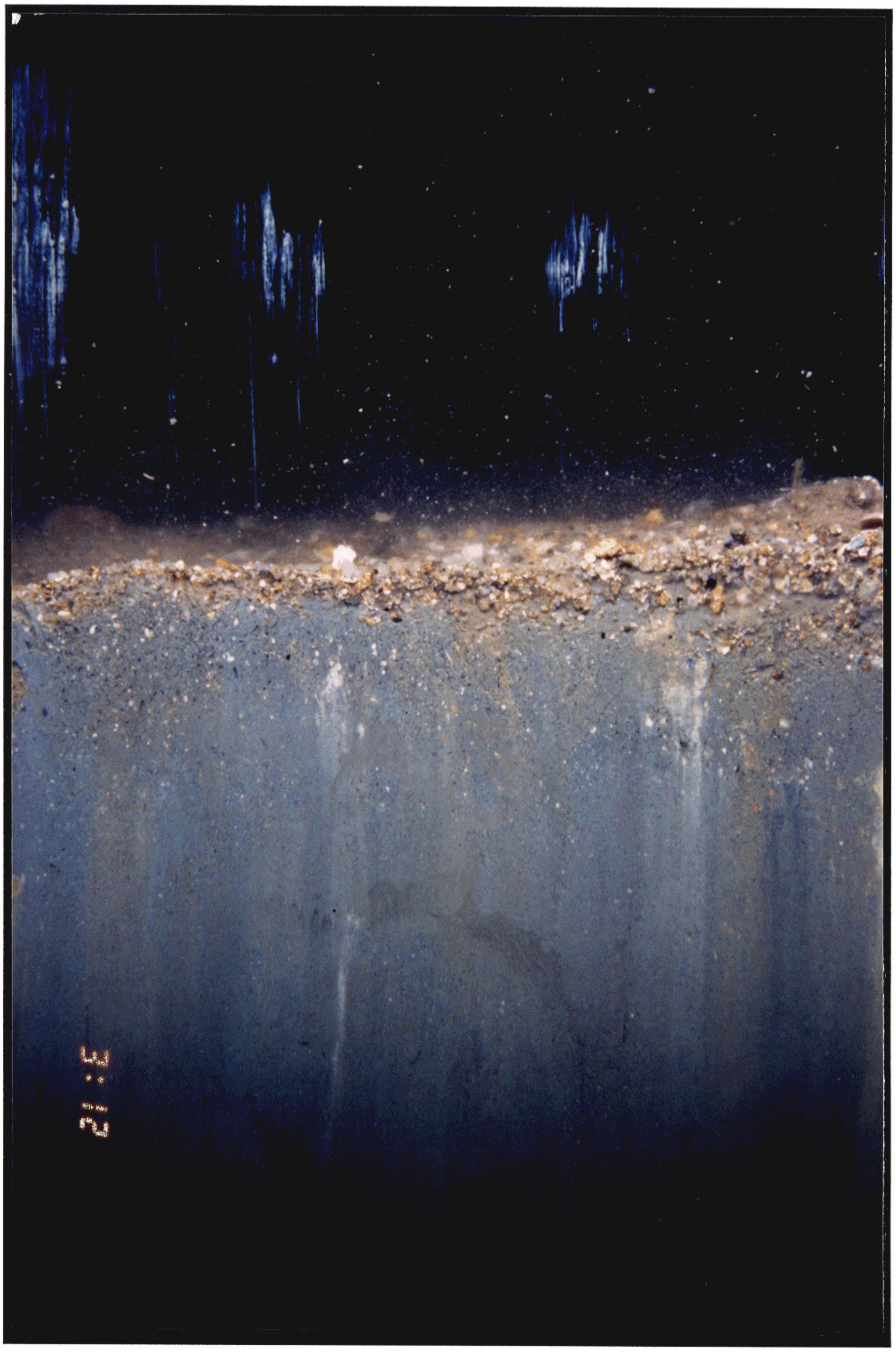


Plate 6. A thin surface lag deposit of sand and shell fragments overlies blue-grey cohesive clay (Type 1 material) in this REMOTS image from Station 76.
Scale: Image Width is 15cm

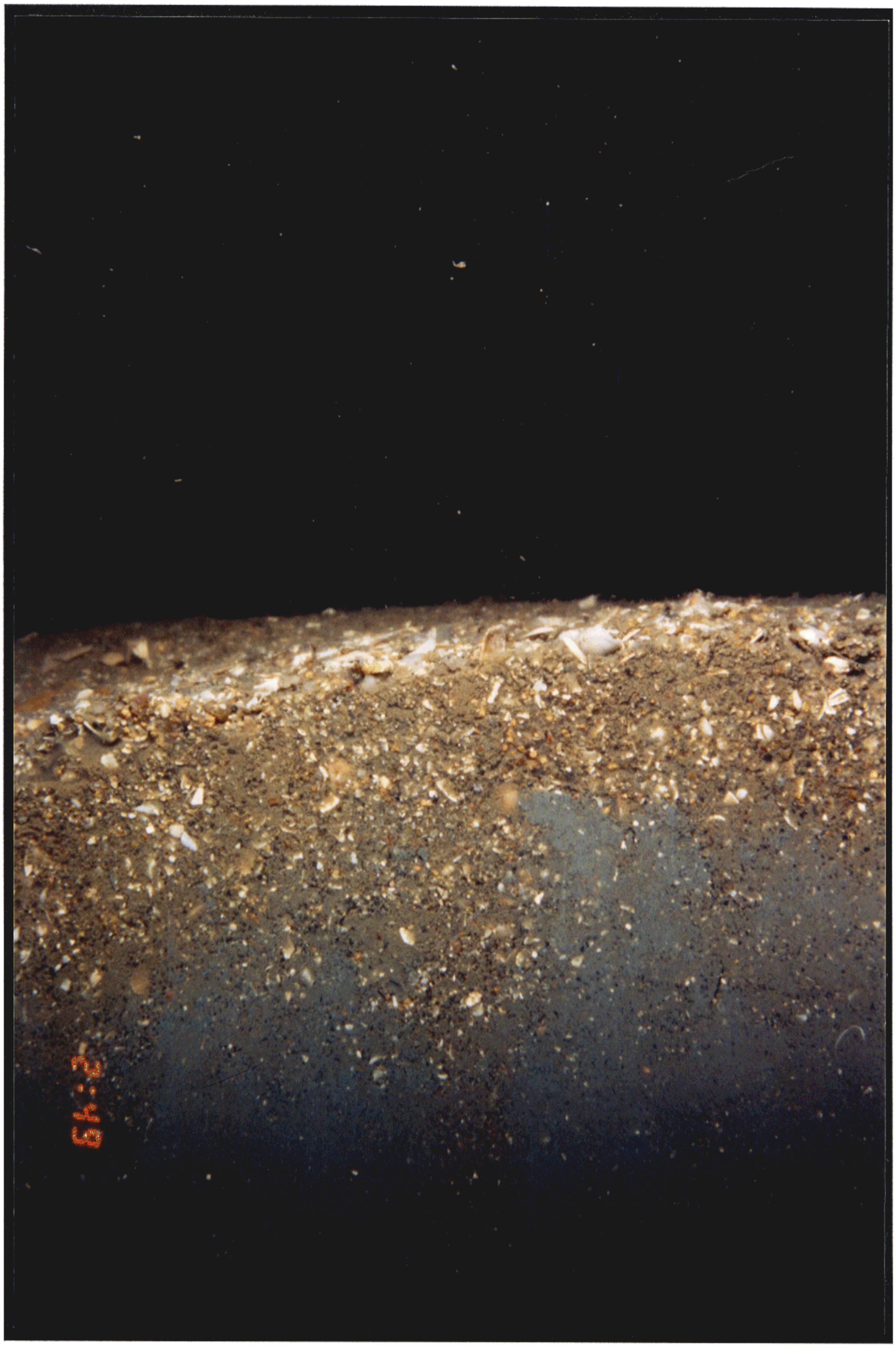


Plate 7. REMOTS image from Station 77 showing a surface layer of sand and shell fragments overlying silt-clay sediments at depth.
Scale: Image Width is 15cm

Plate 8. REMOTS image from Station 15 at the North Control Area, showing light-coloured, homogenous silt-clay with few distinguishing features. A feeding void is visible at depth (arrowed).
Scale: Image Width is 15cm

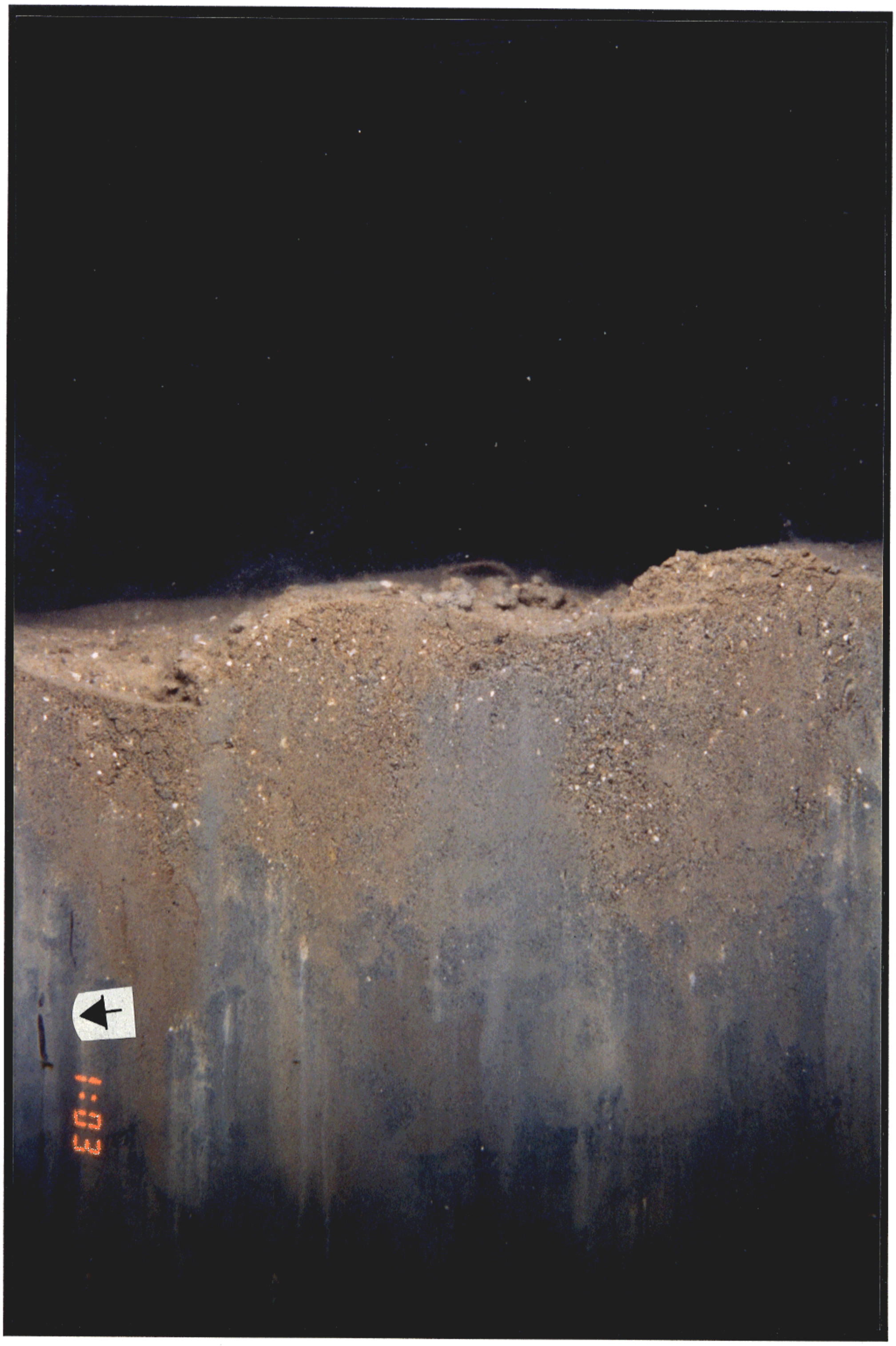


Plate 9. Polychaetes (arrowed) are visible within a sedimentary matrix consisting of disposed silt-clay (Type 1 dumped material) in this REMOTS image from Station 55.
Scale: Image Width is 15cm

Plate 10. REMOTS image from Station 88, with small branched tubes created by amphipods (Family *Corophidae?*) visible at the seabed surface. The underlying sediment consists of medium sand with shell fragments (Type 3 dumped material).
Scale: Image Width is 15cm

APPENDIX A

REMOTS® METHODS

APPENDIX A: REMOTS® METHODS

The methods employed in the December 1995 REMOTS® survey at Mirs Bay Disposal Site were the same as those employed in previous surveys conducted in 1993 (SAIC, 1994a) and 1994 (SAIC 1994b). A complete description of these methods and procedures is provided below.

1.0 Field Methods and QA/QC Procedures

The following technical description and QA/QC procedure for sediment-profile imaging and analysis is a formal and standardized technique called REMOTS® (Remote Ecological Monitoring Of The Seafloor; Rhoads and Germano, 1982 and 1986). The method of acquiring REMOTS® data and its subsequent analysis, interpretation, and synthesis is described together with QA/QC procedures for each of these steps. This mapping technique and QA/QC plan has evolved over the past 15 years as a result of the survey experience of SAIC scientists.

The REMOTS® field QA/QC procedures are follows: At the beginning of each survey day, the time on the data logger mounted on the REMOTS® camera is synchronized with the internal clock on the computerized navigation system used to locate sampling sites during the survey. Each REMOTS® station replicate is identified by the time recorded on the film and on disk along with vessel position. Even though multiple replicate images are taken at each location, each image is assigned a unique sample number in the precision navigation data file.

Redundant sample logs are kept by the field crew. Test shots are fired on deck at the beginning and end of each roll of film to verify that all internal electronic systems are working to design specifications. Spare cameras and charged batteries are carried in the field at all times to ensure uninterrupted sample acquisition. After retrieval of the camera at each station, the frame counter is checked to make sure that replicate images had been taken at each location. In addition, a prism penetration depth indicator on the camera frame is checked to see that the optical prism had actually penetrated the bottom to a sufficient depth to acquire a profile image. If images are missed (frame counter indicator) or the penetration depth is insufficient (penetration indicator), weights are removed or added, or the camera chassis "stops" are adjusted, and additional replicates are taken. Changes in prism weights and stop positions are noted in the log for each replicate image. Exposed film is developed at the end of every survey day to verify successful data acquisition; strict controls are maintained for development temperatures, times, and chemicals to ensure consistent density on the film emulsion so as to minimize interpretive error by the computer image analysis system. The film is then visually inspected under magnification. Any images that are of insufficient quality for image analysis are noted, and, if possible, the appropriate stations are reoccupied on subsequent survey days.

Thorough measurements of all physical parameters and some biological parameters are subsequently taken directly from the color film positives using a video digitizer and computer image analysis system. The actual film slides are used for analysis instead of positive prints in order to avoid changes in image density that can accompany the printing of a positive image. The full color image analysis system can discriminate up to 16.7 million different shades of color, so subtle features can be accurately digitized and measured. Proprietary SAIC software allows the measurement and storage of data on 21 different variables for each REMOTS® image obtained. All data stored on disks are printed out on data sheets for editing by the principal investigator and as a hard-copy backup; a separate data sheet is generated for each REMOTS® image. All data sheets are edited and verified by a senior-level scientist before being approved for final data synthesis, statistical analyses, and interpretation. Automatic disk storage of all parameters measured allows data from any variables of interest to be compiled, sorted, displayed graphically, contoured, or compared statistically. In addition, the integration of the REMOTS® analysis software with GIS software allows any REMOTS® measurement to be plotted (and contoured if desired) on a base map of the survey area.

2.0 Measurement of REMOTS® Parameters

2.1 Depositional layer thickness

Because of the camera's unique design, REMOTS® has proven invaluable in detecting depositional and dredged material layers ranging from 20 cm (the height of the REMOTS® optical window) to 1 mm in thickness. During image analysis, the thickness of the deposited sedimentary layers is determined by measuring the linear distance between the pre- and post-deposition sediment water interface. Recently deposited material is usually evident because of its unique optical reflectance, texture, fabric, and/or color relative to the underlying material representing the predisposal surface. Also, in most cases, the point of contact between the two layers, and a textural change in sediment composition in the new layer, are clearly visible, facilitating measurement of the thickness of the newly deposited layer.

2.2 Sediment type determination

The sediment grain size major mode and range are visually estimated from the images by overlaying a grain size comparator which is at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the REMOTS® camera. Seven grain size classes are on this comparator: $\geq$ 4 phi, 4-3 phi, 3-2 phi, 2-1 phi, 1-0 phi, 0-(-)1 phi, $<$ -1 phi. The lower limit of optical resolution of the photographic system is about 62 microns, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing our REMOTS® estimates with grain size statistics determined from laboratory sieve analyses. The REMOTS® analysis is most accurate when the major mode is distinctly different from the minor modes (i.e., the sediments are well sorted). If the major and subordinant modes are in adjacent size classes, the accuracy of the estimate decreases slightly.

2.3 Prism penetration depth

The REMOTS® prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of the film frame. The REMOTS® analysis software automatically averages these maximum and minimum values to determine the average penetration depth. All three values (maximum, minimum, and average penetration depth) are included on the data sheets. Prism penetration is potentially a noteworthy parameter; if the position of the stop collars and number of weights used in the camera are held constant throughout a survey, the camera functions as a static-load penetrometer. Changes in camera prism weight and stop positions are sometimes necessary to obtain acceptable data. In these cases, interpretation of penetration values considers the change in weight and/or stop positions. Comparative penetration values from sites of similar grain size give an indication of relative sediment water content and sedimentation rate. Highly bioturbated sediments and rapidly accumulating sediments tend to have the highest water contents and greatest prism penetration depths.

2.4 Small-scale surface boundary roughness

Surface boundary roughness is determined by measuring the vertical distance (parallel to the film border) between the highest and lowest points of the sediment-water interface. In addition, the origin of this small-scale topographic relief is indicated when it is evident (physical or biogenic). Boundary roughness is only accurately measured when the camera is level. In sandy sediments, boundary roughness can be a measure of sand wave height. On silt-clay bottoms, boundary roughness values often reflect biogenic features such as fecal mounds or surface burrows.

2.5 Mud clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour, faunal activity (e.g., decapod foraging), dredging, or deposition of cohesive muds from scows, intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in REMOTS® images. During analysis, the number of clasts is counted, the diameter of a typical population of clasts is measured, and the oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidized (in REMOTS® images, the oxidation state is apparent from their reflectance value; see section on apparent redox potential discontinuity depth below). Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6-12 hours (Germano, 1983). Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g., angular versus rounded, is also considered. Mud clasts may be moved about and broken-up by bottom currents and/or animals (macro- or meiofauna; Germano, 1983). Over time, fresh large angular clasts become smaller and rounded. Overall, the abundance, distribution, oxidation state, and angularity of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

2.6 Apparent redox potential discontinuity (RPD) depth

Aerobic near-surface marine sediments typically have higher reflectance values relative to underlying hypoxic or anoxic sediments. Surface sands washed free of mud also have higher optical reflectance than underlying muddy sands. These differences in optical reflectance are readily apparent in REMOTS® images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive or tan color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally grey to black. The boundary between the colored ferric hydroxide surface sediment and underlying grey to black sediment is called the apparent redox potential discontinuity (abbreviated as the RPD).

The relationship between the thickness of the high reflectance layer and the presence or absence of free molecular oxygen in the associated pore waters must be made with caution. The actual RPD is the boundary (or horizon) which separates the positive Eh region of the sediment column from the underlying negative Eh region. The exact location of this Eh=0 potential can only be determined accurately with microelectrodes; hence, the relationship between the change in optical reflectance, as imaged with the REMOTS® camera, and the actual RPD can only be determined by making the appropriate *in situ* Eh measurements. For this reason, we describe the optical reflectance boundary, as imaged, as the apparent RPD, and it is mapped as a mean value. In general, the depth of the actual Eh=0 horizon will be either equal or slightly shallower than the depth of the optical reflectance boundary. This is because bioturbating organisms can mix ferric hydroxide-coated particles downward into the bottom below the Eh=0 horizon. As a result, the apparent mean RPD depth can be used as an estimate of the depth of pore water exchange, usually through pore water irrigation (bioturbation).

Measurable changes in the apparent RPD depth using the REMOTS® optical technique can be detected over periods of one or two months. In sediment-profile surveys of ocean dredged material disposal sites sampled seasonally or on an annual basis throughout North America's northeastern (New England) region, SAIC repeatedly has documented a drastic reduction in apparent RPD depths immediately after dredged material disposal, followed by a progressive postdisposal apparent RPD deepening (barring further physical disturbance). Consequently, time series RPD measurements can be a critical diagnostic element in monitoring the degree of recolonization in an area by the ambient benthos.

The depth of the mean apparent RPD also can be affected by local erosion. The peaks of disposal mounds commonly are scoured by divergent flow over the mound. This can result in washing away of fines, development of shell or gravel lag deposits, and very thin apparent RPD depths. During storm periods, erosion may completely remove any evidence of the apparent RPD (Fredette et al., 1988).

Depositional events can also affect the thickness of the RPD. A bottom area receiving dredged material in the form of oxidized mud clasts will have an apparent RPD greater than, or equal to, the clast layer. Another important characteristic of the apparent RPD is the contrast in reflectance values at this boundary. This contrast is related to the interactions among the degree of organic loading, bioturbational activity in the sediment, and the levels of bottom-water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand and, subsequently, sulfate reduction rates (and the abundance of sulfide end-products). This results in more highly reduced (lower-reflectance) sediments at depth and higher RPD contrasts. In a region of generally low RPD contrasts, images with high RPD contrasts indicate localized sites of relatively high past inputs of organic-rich material (e.g., organic or phytoplankton detritus, dredged material, sewage sludge, etc.).

2.7 Sedimentary methane

At extreme levels of organic loading, pore water sulfate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernable in REMOTS® images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total areal coverage of all methane bubbles are measured.

2.8 Infaunal successional stage

The mapping of successional stages is possible with REMOTS® technology and is based on the theory that organism-sediment interactions follow a predictable sequence after a major seafloor perturbation. This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest..., our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer, 1982). This theory is formally developed in Rhoads and Germano (1982) and Rhoads and Boyer (1982), with a brief overview presented in the paragraph below.

After an initial disturbance to an area of bottom, the first invertebrate community that appears within days after the disturbance are dense assemblages of tiny, tube-dwelling marine polychaetes that reach population levels of 10^4 - 10^6 individuals m^2. These animals feed at or near the sediment-water interface and have the effect of physically stabilizing the sediment by the production of a mucous "glue" used to build their tubes. We note that some dredged material clast layers contain Stage I tubes still attached to individual clasts. These transported individuals are considered as part of the in-situ fauna in our assignment of successional stages. If there is no repeated disturbances, these initial tube-dwelling, suspension and surface deposit-feeders are followed by burrowing, head-down deposit feeders that rework the sediment deeper and deeper over time and mix oxygen from the overlying water into the sediment. The animals in these later-appearing communities are larger, attain lower overall population densities (10^1 - 10^2 individuals m^2) and can rework the sediments to depths of 3 - 20 cm or more. These animals "loosen" the sedimentary fabric, increase the sediment water content (thereby lowering sediment shear strength), and mix oxygen into the sedimentary column to the depth of the burrowing activity. This phenomenon of mixing the sediment fabric by the reworking activities of burrowing invertebrates is called bioturbation. The continuum of change in animal communities after a disturbance (primary succession) has been divided arbitrarily into three stages: Stage I is the initial community of tiny, dense polychaete communities, Stage II is the start of the transition to head-down, burrowing deposit feeders, and Stage III is the mature equilibrium community of deep-dwelling, head-down deposit feeders.

Infaunal successional stages or seres are recognized in REMOTS® images by the presence of dense assemblages of near-surface polychaetes (Stage I) and/or the presence of subsurface feeding voids produced by head-down deposit feeders (Stage III); both types of assemblages may be present in the same image. Stage II, or transitional sere assemblages, are not yet known for the Hong Kong area. In temperate mid-latitudes, these often tend to be amphipods or shallow-dwelling bivalves. Recognition of Stage II seres for the Hong Kong area will require additional mapping experience over a longer period of time with associated ground-truth verification; however, some initial predictions about assigning local taxa to this soft-bottom successional paradigm can be made. A review of Hong Kong benthic literature has identified candidate species that may be tentatively categorized within this successional paradigm. For example, Thompson and Shin (1983) show that the most severely polluted areas within Victoria Harbor and approach channels have station/species dominance clusters (VH4 and VH3 as labelled in Thompson and Shin, 1983) that may represent a Stage I assemblage (*Thalassodrilides gurwitschi*, *Capitella capitata*, *Minuspio cirrifera*, *Tharyx* sp., and *Aglaophamus* sp., *Hippolytid* sp. and *Alpheus* sp.). Studies in Tolo Harbor also show that fouling communities consisting of barnacles, tunicates, and bryozoans are well developed in stressed environments (Wu, 1982). In profile images where bits of shell or rock are visible, these kinds of epifauna may be recognized.

Clusters VH2 and VH1, as defined for Victoria Harbor (Thompson and Shin, 1983) include species that are candidates for Stage II colonizers such as *Tapes philippinarum*, *Melita* sp., and *Notomastus latericeus*. Benthic studies along a pollution gradient in Tolo Harbor and Mirs Bay show some of the same species found in Victoria Harbor with the addition of the amphipod *Ampelsica* sp. and several bivalve species belonging to the family Tellinidae (Shin, 1983 and 1986). In temperate nearshore benthic environments, *Ampelisca* and tellins are known to be part of a Stage II assemblage.

Stage III candidates are more difficult to identify from the existing literature. Hutchings and Wells (1992) note that two species of polychaete worms belonging to the family Maldanidae are present in Hoi Ha Wan. Another head-down feeding polychaete family Pectinaridae (*Amphictene* sp.) has been reported in grab samples from Lamma Channel and the deep-dwelling sipunculid *Golfingia* is present south of Ninepins (Binnie Consultants, 1994). In temperate latitudes these taxa are important components of Stage III equilibrium assemblages. Other Hong Kong candidates for Stage III species include infaunal ophiuroids (e.g., *Amphiura*; Binnie, 1994) and the holothurian *Protankyra* (Shin, 1986).

A major difference noted between the density of infaunal benthos in Hong Kong waters and those of temperate latitudes (particularly Stage I species belonging to the polychaete families Spionidae and Capitellidae) is that the densities of the Hong Kong assemblages appear to be much lower. This may be related to the lower carrying capacity of tropical waters relative to nutrient-rich temperate environments and/or instability of the surface sediments due to frequent physical disturbance, such as that which results from passage of typhoons or strong northeast monsoons. This density factor must be kept in mind while interpreting successional status in Hong Kong sediment-profile images.

2.9 Organism-Sediment Index

The Organism-Sediment Index (OSI) is a summary mapping statistic which is calculated on the basis of four independently measured REMOTS® parameters: mean apparent RPD depth, presence of methane gas, low/no oxygen at the sediment-water interface, and successional status. Table 1 shows how these parameters are summed to derive the OSI.

Table 1. Calculation of the REMOTS® Organism-Sediment Index Value

A. CHOOSE ONE VALUE:

Mean RPD Depth	Index Value
0.00 cm	0
> 0 - 0.75 cm	1
0.76 - 1.50 cm	2
1.51 - 2.25 cm	3
2.26 - 3.00 cm	4
3.01 - 3.75 cm	5
> 3.75 cm	6

B. CHOOSE ONE VALUE:

Successional Stage	Index Value
Azoic	-4
Stage I	1
Stage I → II	2
Stage II	3
Stage II → III	4
Stage III	5
Stage I on III	5
Stage II on III	5

C. CHOOSE ONE OR BOTH IF APPROPRIATE:

Chemical Parameters	Index Value
Methane Present	-2
No/Low Dissolved Oxygen**	-4

The **REMOTS® ORGANISM-SEDIMENT INDEX** is equal to the total of the above subset indices (A+B+C). It has a **RANGE** of -10 to +11.

** Note: This is not based on a Winkler or polarigraphic electrode measurement. It is based on the imaged evidence of reduced, low-reflectance (i.e., high oxygen demand) sediment at the sediment-water interface.

The highest possible OSI value is +11 which reflects a mature benthic community in relatively undisturbed conditions (generally a good yardstick for high benthic habitat quality): deeply oxidized sediment with a low inventory of anaerobic metabolites and low sediment oxygen demand, populated by a climax (Stage III) community. The lowest OSI value is -10 indicating that the sediment has a high inventory of anaerobic metabolites, has a high oxygen demand, and is azoic. In our mapping experience with this parameter over the past 15 years, we have found that OSI values of 6 or less indicate that the benthic habitat has experienced physical disturbance, eutrophication, or excessive, bioavailable contamination in the recent past.

3.0 Mapping and Interpretation of REMOTS® Data

The integration of text files from a computerized navigation system with REMOTS® and GIS software allows the production of maps showing the areal distribution of each of the above REMOTS® parameters. Data from follow-up surveys can then be entered into the GIS system and overlaid and subtracted to look at changes in the system over time.

By comparing the REMOTS® images with Udden-Wentworth sediment standards photographed through the REMOTS® optical system, it is possible to estimate accurately the grain size major mode and range. Also, near-surface stratigraphy such as sand-over-mud or mud-over-sand can be mapped. This information can provide information as to transport directions when mapped on a local scale near facies boundaries. The surface boundary roughness (i.e., sediment surface relief) measured over a horizontal distance of 15 cm can typically range from 0.02 to 3.8 cm and may be related to either physical structures (ripples, rip-up structures, mud clasts), or biogenic features (burrow openings, fecal mounds, foraging depressions). Biogenic roughness typically changes seasonally and is related to the interaction of bottom turbulence and bioturbational activities.

The depth of the camera's penetration into the bottom reflects the bearing capacity and shear strength of local sediments. Over-consolidated or relic sediments and shell-bearing sands resist camera penetration. Highly bioturbated, sulfitic, or methanogenic muds are the least consolidated, and deep penetration is typical. Seasonal changes in camera prism penetration are typically observed at the same station related to the control of sediment geotechnical properties by bioturbation (Rhoads and Boyer, 1982). The effect of water temperature on bioturbation rates appears to be important in controlling both biogenic surface relief and prism penetration depth (Rhoads and Germano, 1982).

The depth of the apparent RPD in the bottom is an important time-integrator of dissolved oxygen conditions within sediment pore waters. The surface layer of most of the aerobic seafloor has high optical reflectance because the grains are coated with ferric hydroxide, and the associated pore waters are relatively free of sulfides. In the absence of bioturbating organisms, this high-reflectance layer (in muds) will typically be 1-3 mm thick (Rhoads, 1974). This depth is related to the rate of supply of molecular oxygen (by diffusion) into the bottom, and the consumption of that oxygen by the sediment and associated microflora. In sediments which have very high sediment oxygen demand (SOD), a high-reflectance layer may be absent even when the overlying water column is aerobic.

The apparent mean RPD depth can be used as an estimate of the depth of pore water exchange, usually through pore water irrigation (bioturbation). In the presence of bioturbating macrofauna, the thickness of the high-reflectance layer may be several centimeters. Biogenic particle mixing depths can be estimated by measuring the maximum and minimum depths of imaged feeding voids in the sediment column. This parameter represents the particle mixing depths of head-down feeders (mainly polychaetes).

The depression of the apparent RPD within the sediment is relatively slow in organic-rich muds (on the order of 200 to 300 micrometers per day); therefore this parameter has a long time constant (Germano and Rhoads, 1984). The rebound in the apparent RPD is also slow (Germano, 1983). Measurable changes in the apparent RPD depth using the REMOTS® optical technique can be detected over periods of one or two months. This parameter is best used to document changes (or gradients) which develop over a seasonal or annual cycle related to water temperature effects on bioturbation rates, seasonal hypoxia, sediment oxygen demand, and infaunal recruitment.

By combining these measured REMOTS® parameters with, for example, precision bathymetric survey results and comparing successive surveys, it is possible not only to detect the thickness and areal extent of dredged material deposits along with assessing the effectiveness of capping operations, but also to identify near-bottom kinetic gradients, areas of erosion or deposition, and disturbance gradients in the biological communities. In addition, the rate of benthic recolonization, ecosystem recovery, and depth of bioturbation can be assessed.

4.0 Using REMOTS® Data to Assess Benthic Health

While various measurements of water quality are often used to assess regional ecological health (e.g., dissolved oxygen, various contaminant or nutrient levels), interpretation is difficult because of the transient nature of water column phenomena. Measurement of a particular level of any water column variable represents an instantaneous "snapshot" that will change within minutes after the measurement is taken. Very often by the time an adverse signal in the water column is persistent (e.g., low dissolved oxygen levels), the system has degraded to the point where resource managers can do little but map the areal extent of the phenomenon while gaining a minimal understanding of factors contributing to the overall degradation.

The seafloor, on the other hand, is a long-term time integrator of sediment and overlying water quality; levels of any variable measured are the result of physical, chemical, or biological interactions on time scales much longer than those present in a rapidly moving fluid. The seafloor, therefore, is an excellent predictor of environmental health, both in terms of historical impacts and as an indicator of future trends for any particular variable. Physical measurements made with the REMOTS® system from profile images provide background information about gradients in physical disturbance (e.g., dredging, disposal, or storm erosion) from maps of sediment grain size, boundary roughness, fabrics, and structures. The level of organic matter in the sediment (an important indicator of the relative value of the sediment as a carbon source for both bacteria and infaunal deposit feeders) and sediment oxygen demand can be inferred from the optical reflectance of the sediment column and the depth of the apparent RPD. Sediment oxygen demand is an important measure of ecological health; oxygen can be depleted quickly in sediment by the accumulation of organic matter and bacterial respiration, both of which place an oxygen demand on the interstitial water, thereby competing with animals for a potentially limiting oxygen resource (Kennish, 1986).

The distribution of successional stages in the context of the mapped disturbance gradients described above is one of the most sensitive indicators of the ecological health of the seafloor (Rhoads and Germano, 1986). The presence of equilibrium Stage III equilibrium taxa (mapped from subsurface feeding voids as observed in profile images) can be a good indication of high benthic habitat stability and relative "health". A Stage III assemblage indicates that the sediment surrounding these organisms has not been disturbed severely in the recent past and that the inventory of bioavailable contaminants is relatively low. These inferences are based on past work primarily in temperate latitudes showing that Stage III species are relatively intolerant to sediment disturbance, organic enrichment, and sediment contamination. Stage III species expend metabolic energy on sediment bioturbation (both particle advection and pore water irrigation) to control sediment properties including pore water profiles of sulfate, nitrate, and the redox potential discontinuity in the sedimentary matrix near their burrows or tubes (Aller, in press; Rice and Rhoads, 1989). This bioturbation results in an enhanced rate of decomposition of polymerized organic matter by stimulating microbial decomposition ("microbial gardening"). Because of their stability, benthic assemblages of this structure are also called climax or equilibrium seres.

The metabolic energy expended in bioturbation is rewarded by creating a sedimentary environment where refractory organic matter is converted to usable food. Stage III bioturbation has been likened to processes used in tertiary sewage treatment plants to accelerate organic decomposition, such as stirring and aeration (these can be interpreted as a form of human bioturbation). Physical disturbance, contaminant loading, and/or overenrichment result in habitat destruction leading to local extinction of the climax sere. Loss of Stage III species results in the loss of sediment stirring and aeration (tertiary treatment analogy) and may be followed by a build-up of organic matter (eutrophication) of the sediment. A classic example of this process in the Hong Kong region can be seen at some stations of the Fairway Channel transect (see SAIC, 1994a). Because Stage III species tend to have relatively conservative rates of recruitment and intrinsic population increase as well as slow ontogenetic growth rates, they may not reappear for several years once they are excluded from an area.

The October 1993 survey (SAIC, 1994a) showed evidence of widespread reworking of bottom sediments by typhoon generated waves on the shelf surrounding Hong Kong. These same sediments showed evidence of Stage III seres. This appears to be an anomaly relative to the preceding discussion linking physical habitat stability and Stage III equilibrium seres. In a shelf environment experiencing wave reworking of the bottom on a time-scale $\leq$ 1 year, it is possible that a non-equilibrium suite of very mobile head-down feeding species may occupy this deep infaunal niche, for example, the ophiuroid genus *Amphiura* and the infaunal holothurian *Protankyra bidentata*. Both *Amphiura* and *Protankyra* are part of a Stage III assemblage described from the East China Sea shelf off the Changjiang delta platform (Rhoads et al., 1985).

The presence of Stage I seres (in the absence of Stage III seres) can indicate that the bottom is in an advanced state of organic enrichment or has received high contaminant loading. Unlike Stage III communities, Stage I seres have a relatively high tolerance for organic enrichment and contaminants. These opportunistic species have high rates or recruitment, high ontogenetic growth rates, and live and feed near the sediment-water interface, typically in high densities. Often, Stage I seres co-occur with Stage III seres in marginally enriched areas. In this case, Stage I seres feed on labile organic detritus settling onto the sediment surface while the subsurface Stage III seres tend to specialize on the more refractory buried organic reservoir of detritus.

The presence of Stage II seres is a transitional stage indicating a community "in recovery" following a disturbance. It provides a preliminary indication of the time constant for the frequency of disturbance once the successional sequence for a particular region is documented. At the present time, the makeup and dynamics of Stage II communities for Hong Kong regional waters are unknown; these can be determined after either seasonal mapping occurs over a longer period of time or a time series of REMOTS® monitoring is planned after an initial disturbance has taken place in a known area in order to monitor the full successional sequence from start to finish.

A review of tropical and subtropical benthic literature indicates that in high depositional areas off of major river mouths and in lagoonal soft sediments frequently scoured by waves and currents, the full range of Stage I, II, and III seres may not be realized. In these situations, the benthic assemblage may not progress beyond a pioneering sere (Alongi and Christoffersen, 1992; Alongi, et al., 1992; Aller, in press). These chronic disturbance assemblages tend to be dominated by pioneering species and large organisms are conspicuously absent. Periodic anoxia can also retrograde succession, resulting in a narrow range of succession (e.g. Wu, 1982; Hutchings and Wells, 1992).

The end-member successional seres (Stage I and Stage III) also have dramatically different effects on sediment geotechnical properties (Rhoads and Boyer, 1982). With their high population densities and feeding efforts limited at or near the sediment-water interface, Stage I communities tend to physically bind fine-grained sediments, making them less susceptible to resuspension and transport. Just as a thick cover of grass will prevent erosion on a terrestrial hillside, so too will these dense assemblages of tiny polychaetes serve to stabilize the sediment surface. Conversely, Stage III taxa increase the sediment water-content and lower its shear strength through their deep burrowing and pumping activities, rendering the bottom more susceptible to erosion and resuspension. In shallow areas of fine-grained sediments that are susceptible to storm-induced or wave orbital energy, it is quite possible for Stage III taxa to be carried along in the water column in suspension with fluid muds. When redeposition occurs, these Stage III taxa can become quickly re-established in an otherwise physically disturbed surface sedimentary fabric.

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APPENDIX B

BENTHIC GRAB DATA

Appendix B1

Phylum-level abundance at all MBDS stations (Control= S1-S45; Disposal= S48-S90)

	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23
GP	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
POLYCHAETES	69	89	71	109	144	66	48	36	50	55	117	87	134	69	73	55	44	57	121	66	79	72	45
CRUSTACEANS	3	10	3	11	5	3	7	1	3	8	13	6	1	5	3	7	7	1	8	5	6	7	6
MOLLUSCS	14	9	6	6	20	3	12	14	14	0	20	9	1	15	10	6	0	8	9	0	6	4	7
ECHINODERMS	29	16	16	14	17	13	16	7	12	2	28	4	26	13	8	8	10	7	9	1	17	6	6
OTHERS	1	6	7	7	7	0	2	5	2	4	5	3	1	1	4	5	6	5	11	4	9	3	5
NEMERTEANS	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1

	S24	S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40	S41	S42	S43	S44	S45	S48
GP	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	D
POLYCHAETES	65	107	72	88	54	61	81	65	61	95	43	45	131	118	40	46	67	88	57	73	53	77	221
CRUSTACEANS	5	3	10	10	9	9	10	11	13	5	11	5	15	12	2	1	6	13	6	12	9	5	41
MOLLUSCS	13	8	7	11	4	13	24	10	17	5	4	14	25	12	17	6	6	6	12	22	12	10	30
ECHINODERMS	14	19	10	4	11	23	8	19	21	21	16	8	40	52	20	16	13	27	24	34	11	20	22
OTHERS	7	7	9	12	8	7	4	7	5	8	4	3	4	9	15	4	5	5	11	9	4	8	15
NEMERTEANS	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	0	1

	S49	S50	S51	S52	S53	S54	S55	S56	S57	S58	S59	S60	S61	S62	S63	S64	S65	S66	S67	S68	S69	S70	S71
GP	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
POLYCHAETES	309	95	204	93	434	343	291	359	267	85	260	74	100	252	161	164	247	231	207	199	183	114	229
CRUSTACEANS	11	34	45	16	116	45	77	82	80	27	48	22	152	134	75	40	99	50	88	218	93	40	44
MOLLUSCS	11	2	9	4	93	8	3	15	13	13	25	19	23	35	5	6	27	20	21	36	33	2	6
ECHINODERMS	50	5	10	21	12	17	6	26	16	2	7	23	11	8	8	31	8	21	8	5	38	21	23
OTHERS	20	8	8	2	7	16	11	11	10	7	20	7	6	8	6	6	9	16	3	3	1	3	10
NEMERTEANS	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1

Phylum-level abundance at all MBDS stations (Control= S1-S45; Disposal= S48-S90)

	S72	S73	S74	S75	S76	S77	S78	S79	S81	S82	S83	S84	S85	S86	S87	S88	S89	S90
GP	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
POLYCHAETES	145	127	70	230	140	196	330	54	388	238	204	144	43	218	137	102	43	73
CRUSTACEANS	16	37	10	108	98	118	60	7	37	98	119	129	18	33	30	49	9	11
MOLLUSCS	4	6	1	42	12	10	33	5	28	46	28	10	6	1	1	10	5	8
ECHINODERMS	18	18	2	22	2	4	38	2	13	14	6	2	5	2	8	19	11	9
OTHERS	14	3	6	8	1	19	8	1	17	22	6	3	2	4	10	4	1	6
NEMERTEANS	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1

Key : C: Control Site
D: Disposal Site

Remark :
1) Station S46 & S47 are empty grabs
2) Station S80 is half-grab
3) Since all Annelids were polychaetes, we have used the designation "POLYCHAETES"
4) Since all Arthropods were crustaceans, we have used the designation "CRUSTACEANS"

Appendix B2
Family-level abundance at Control (S1-45) and Disposal (S48-90) sites

Mirs Bay December 1995 Recolonization Study: Control Sites

Phylum	Order	Family	S1	S4	S6	S7	S10	S12	S14	S18	S20	S22	S25	S26	S28	S30	S31	S33	S34	S37	S41	S44	S45
POLYCHAETA	Spionida	*Spionidae*	8	21	3	6	10	17	8	7	9	4	14	13	7	15	6	11	4	4	10	6	5
POLYCHAETA	Spionida	*Cirratulidae*	15	22	9	8	18	21	13	17	24	28	26	13	12	15	2	29	3	4	5	5	9
POLYCHAETA	Spionida	*Poecilochaetidae*	0	0	0	0	1	0	2	1	0	0	1	0	0	1	3	0	1	0	1	0	0
POLYCHAETA	Spionida	*Magelonidae*	0	0	1	2	0	0	0	0	0	1	0	0	1	1	1	0	2	1	1	0	1
POLYCHAETA	Capitellida	*Capitellidae*	21	21	6	7	7	9	4	8	7	3	9	18	4	11	5	10	6	2	8	3	9
POLYCHAETA	Capitellida	*Maldanidae*	2	0	2	2	0	0	0	0	0	1	1	0	1	2	6	0	0	6	5	1	7
POLYCHAETA	Phyllodocida	*Pilargiidae*	9	12	9	6	11	14	9	9	5	5	18	6	8	8	8	8	13	6	0	7	7
POLYCHAETA	Phyllodocida	*Nephtyidae*	3	11	12	5	6	10	14	13	10	11	13	9	3	11	4	7	8	12	5	6	13
POLYCHAETA	Phyllodocida	*Polynoidae*	2	2	5	4	0	1	1	3	0	0	2	0	0	1	10	6	2	26	13	9	6
POLYCHAETA	Phyllodocida	*Glyceridae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3	0	0
POLYCHAETA	Phyllodocida	*Hesionidae*	0	6	2	3	0	1	4	0	2	2	3	2	2	2	2	9	3	5	2	4	8
POLYCHAETA	Phyllodocida	*Phyllodocidae*	0	1	0	3	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1
POLYCHAETA	Phyllodocida	*Nereidae*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
POLYCHAETA	Phyllodocida	*Sigalionidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
POLYCHAETA	Phyllodocida	*Syllidae*	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0
POLYCHAETA	Phyllodocida	*Goniadidae*	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	1
POLYCHAETA	Phyllodocida	*Lacydoniidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
POLYCHAETA	Phyllodocida	*Gonadidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
POLYCHAETA	Phyllodocida	*Eulepethidae*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
POLYCHAETA	Phyllodocida	*Aphroditidae*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
POLYCHAETA	Phyllodocida	*Alciopidae*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA	Orbiniida	*Paraonidae*	3	6	4	0	1	4	4	4	3	3	3	4	7	4	8	6	4	12	9	5	5
POLYCHAETA	Orbiniida	*Orbiniidae*	0	1	0	0	0	1	4	1	2	0	2	0	0	1	1	0	1	2	3	1	0
POLYCHAETA	Terebellida	*Terebellidae*	0	1	5	0	2	2	0	1	1	0	4	2	4	3	1	1	1	3	6	0	0
POLYCHAETA	Terebellida	*Ampharetidae*	1	0	1	15	0	0	0	0	0	1	0	0	0	1	2	1	0	0	1	1	0
POLYCHAETA	Terebellida	*Trichobranchidae*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
POLYCHAETA	Eunicida	*Eunicidae*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
POLYCHAETA	Eunicida	*Lumbrineridae*	0	1	0	0	1	0	1	0	0	0	0	1	0	0	1	2	0	2	2	1	1
POLYCHAETA	Eunicida	*Dorvellidae*	2	0	1	0	2	0	0	1	1	0	0	0	2	1	0	0	1	0	0	0	0
POLYCHAETA		*Polychaeta*	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA		*MBDS84-3*	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mirs Bay December 1995 Recolonization Study: Control Sites

Phylum	Order	Family	S1	S4	S6	S7	S10	S12	S14	S18	S20	S22	S25	S26	S28	S30	S31	S33	S34	S37	S41	S44	S45
POLYCHAETA		*MBDS44-4*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
POLYCHAETA	Sternaspida	*Sternaspidae*	2	1	3	3	0	5	4	0	2	1	1	1	2	2	0	1	0	2	3	0	1
POLYCHAETA	Cossurida	*Cossuridae*	0	0	1	0	0	1	1	0	0	1	0	2	1	0	0	2	0	1	4	1	3
POLYCHAETA	Amphinomida	*Amphinomidae*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0
POLYCHAETA	Flabelligerida	*Flabellligeridae*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
CRUSTACEA	Amphipoda	*Corophiidae*	2	0	1	0	0	0	0	0	0	0	0	0	2	0	1	1	1	1	5	0	0
CRUSTACEA	Amphipoda	*Ampelisciidae*	0	3	0	0	0	0	1	0	0	0	0	3	2	0	3	0	1	1	2	1	0
CRUSTACEA	Amphipoda	*Liljeborgiidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	2	0
CRUSTACEA	Amphipoda	*Melitidae*	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
CRUSTACEA	Amphipoda	*Oedicerotidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
CRUSTACEA	Decapoda	*Callianassidae*	0	2	0	2	3	2	0	0	0	0	0	3	0	2	0	0	0	0	1	1	0
CRUSTACEA	Decapoda	*Goneplacidae*	0	0	1	1	0	1	1	0	1	1	0	0	1	2	2	1	0	3.	0	0	1
CRUSTACEA	Decapoda	*Pinnotheridae*	0	6	0	1	0	2	0	0	0	0	2	1	0	2	0	1	0	0	2	3	3
CRUSTACEA	Decapoda	*Porcellanidae*	0	0	0	0	1	0	0	0	0	2	0	0	1	0	0	0	3	3	0	0	0
CRUSTACEA	Decapoda	*Alpheidae*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
CRUSTACEA	Decapoda	*Decapoda*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Decapoda	*Shrimp*	0	0	1	0	0	0	1	0	4	1	0	2	0	0	4	0	0	0	1	0	0
CRUSTACEA	Decapoda	*MBDS44-2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
CRUSTACEA	Mysidacea	*Mysidacea*	0	0	0	0	0	0	2	0	0	2	0	0	3	0	0	0	5	3	0	0	0
CRUSTACEA	Cumacea	*Cumacea*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0
CRUSTACEA	Stomatopoda	*Stomatopoda*	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
ECHINODERMATA	Amphiuridae	*Amphiuridae*	29	14	13	0	2	4	12	6	1	5	18	10	11	8	19	20	13	36	26	11	20
ECHINODERMATA	Amphiuridae	*Echinodermata*	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
MOLLUSCA	Bivalvia	*Corbulidae*	3	2	0	3	0	3	0	2	0	1	2	4	0	6	0	0	0	1	1	0	0
MOLLUSCA	Bivalvia	*Semelidae*	3	2	0	0	0	2	0	0	0	0	4	0	0	10	0	0	0	0	1	7	1
MOLLUSCA	Bivalvia	*Montacutidae*	0	0	0	0	0	1	11	1	0	0	0	0	3	4	1	0	0	1	1	0	0
MOLLUSCA	Bivalvia	*Tellinidae*	5	0	0	0	0	1	2	1	0	2	0	1	1	1	5	0	2	6	0	0	0
MOLLUSCA	Bivalvia	*Bivalvia*	0	0	3	2	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
MOLLUSCA	Bivalvia	*Thracidae*	0	1	0	1	0	0	1	1	0	0	2	1	0	0	1	3	0	0	0	0	1
MOLLUSCA	Bivalvia	*Nuculanidae*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
MOLLUSCA	Bivalvia	*Veneridae*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0
MOLLUSCA	Bivalvia	*Mactridae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
MOLLUSCA	Bivalvia	*Carditidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
MOLLUSCA	Bivalvia	*Arcidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
MOLLUSCA	Bivalvia	*MBDS44-1*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Mirs Bay December 1995 Recolonization Study: Control Sites

Phylum	Order	Family	S1	S4	S6	S7	S10	S12	S14	S18	S20	S22	S25	S26	S28	S30	S31	S33	S34	S37	S41	S44	S45
MOLLUSCA	Bivalvia	*Solenidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
MOLLUSCA	Gastropoda	*Atyidae*	1	1	0	1	0	0	0	0	0	0	0	1	0	2	2	1	0	1	0	1	1
MOLLUSCA	Gastropoda	*Nassariidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
MOLLUSCA	*Gastropoda*		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	*Scaphopoda*		1	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
MOLLUSCA		UNID	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SIPUNCULA			1	4	0	0	2	3	0	0	3	3	5	7	7	3	6	6	3	5	5	4	5
PHORONIDA			0	2	0	2	2	0	0	1	1	1	1	2	1	1	0	2	0	0	1	0	0
NEMERTEA			1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0
ECHIURA			0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
UNID		*MBDS44-3*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
PIECES			0	0	0	1	1	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1
PIECES		*Polynemidae*	1	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
PIECES		*Trypauchenidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
CNIDARIA		*Cnidaria*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Mirs Bay December 1995 Recolonization Study: Disposal site

Phylum	Order	Family	S51	S53	S55	S56	S57	S63	S64	S67	S70	S71	S72	S73	S74	S75	S78	S80	S84	S86	S87	S88	S89
POLYCHAETA	Spionida	*Spionidae*	20	66	66	62	48	15	20	60	12	22	6	14	6	11	23	11	15	73	11	15	0
POLYCHAETA	Spionida	*Cirratulidae*	21	41	30	16	15	13	14	10	9	21	7	8	3	42	58	1	18	11	10	8	2
POLYCHAETA	Spionida	*Poecilochaetidae*	1	2	5	6	3	1	1	3	1	1	0	1	1	6	8	3	2	3	2	1	0
POLYCHAETA	Spionida	*Magelonidae*	1	2	3	5	0	0	1	7	2	5	0	2	5	4	4	0	1	1	0	1	0
POLYCHAETA	Capitellida	*Capitellidae*	73	151	77	94	77	35	40	56	38	67	28	32	11	59	111	8	43	32	30	17	3
POLYCHAETA	Capitellida	*Maldanidae*	1	7	3	28	7	5	6	1	3	22	11	4	1	4	8	0	1	2	7	0	3
POLYCHAETA	Phyllodocida	*Pilargiidae*	11	18	11	20	11	3	10	7	10	11	9	10	7	3	13	0	3	3	7	0	6
POLYCHAETA	Phyllodocida	*Nephtyidae*	2	2	2	5	1	2	5	0	0	2	1	1	2	1	3	0	0	1	0	1	3
POLYCHAETA	Phyllodocida	*Polynoidae*	3	2	0	5	3	1	5	3	2	4	5	6	0	7	0	1	0	1	7	0	3
POLYCHAETA	Phyllodocida	*Glyceridae*	5	12	26	12	10	6	1	10	1	7	2	3	1	9	8	2	7	13	2	1	1
POLYCHAETA	Phyllodocida	*Hesionidae*	0	6	2	3	7	2	5	2	5	8	2	3	1	3	5	4	7	4	2	1	1
POLYCHAETA	Phyllodocida	*Phyllodocidae*	5	5	1	8	7	3	1	2	4	1	1	2	0	1	7	0	7	4	1	5	0
POLYCHAETA	Phyllodocida	*Nereidae*	1	3	5	0	1	1	0	0	1	1	1	1	0	2	4	1	2	2	0	6	3
POLYCHAETA	Phyllodocida	*Sigalionidae*	0	1	1	1	1	0	5	0	1	1	0	0	0	0	12	2	0	0	1	2	0
POLYCHAETA	Phyllodocida	*Syllidae*	1	0	0	0	0	0	1	0	0	2	2	0	0	2	1	1	0	0	0	0	1
POLYCHAETA	Phyllodocida	*Goniadidae*	0	2	0	1	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0
POLYCHAETA	Phyllodocida	*Lacydoniidae*	0	3	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0
POLYCHAETA	Phyllodocida	*Gonadidae*	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0
POLYCHAETA	Phyllodocida	*Eulepethidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
POLYCHAETA	Phyllodocida	*Aphroditidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
POLYCHAETA	Phyllodocida	*Alciopidae*	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA	Orbiniida	*Paraonidae*	42	49	44	42	35	18	34	7	15	33	28	24	19	23	32	4	8	21	29	7	6
POLYCHAETA	Orbiniida	*Orbiniidae*	3	2	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	2
POLYCHAETA	Terebellida	*Terebellidae*	1	6	4	12	4	2	4	2	3	5	3	1	3	9	12	1	9	1	1	2	0
POLYCHAETA	Terebellida	*Ampharetidae*	0	16	2	7	0	2	2	5	2	2	0	7	2	4	5	0	2	4	1	2	2
POLYCHAETA	Terebellida	*Trichobranchidae*	0	0	0	1	2	0	0	0	0	2	0	0	0	1	1	3	1	0	0	0	0
POLYCHAETA	Eunicida	*Eunicidae*	3	20	0	11	1	7	3	14	0	1	2	1	1	9	3	0	1	1	1	3	2
POLYCHAETA	Eunicida	*Lumbrineridae*	3	16	5	8	7	2	1	5	0	1	1	2	1	13	0	0	1	1	1	3	0
POLYCHAETA	Eunicida	*Onuphidae*	0	3	4	5	4	1	0	1	1	0	0	0	1	0	1	0	4	2	2	0	0
POLYCHAETA	Eunicida	*Dorvellidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	0
POLYCHAETA		*Polychaeta*	0	0	0	0	0	1	0	3	0	0	2	3	4	0	0	0	0	0	2	2	0
POLYCHAETA		*Chrysopetalidae*	0	2	0	1	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	0
POLYCHAETA		*Palmyridae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0

Mirs Bay December 1995 Recolonization Study: Disposal site

Phylum	Order	Family	S51	S53	S55	S56	S57	S63	S64	S67	S70	S71	S72	S73	S74	S75	S78	S80	S84	S86	S87	S88	S89
POLYCHAETA		*Sabellidae*	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA		*Pisonidae*	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
POLYCHAETA		*Isopisidae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
POLYCHAETA	Sternaspida	*Sternaspidae*	2	0	0	0	0	1	3	0	0	2	0	0	0	1	1	0	1	0	0	0	1
POLYCHAETA	Cossurida	*Cossuridae*	3	0	0	0	0	0	0	0	0	1	1	1	0	2	4	0	1	0	0	0	1
POLYCHAETA	Amphinomida	*Amphinomidae*	0	0	0	0	0	0	0	1	0	0	0	1	0	8	0	0	0	4	0	0	1
POLYCHAETA	Flabelligerida	*Flabellligeridae*	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
POLYCHAETA	Opheliida	*Opheliidae*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Corophiidae*	19	49	47	0	33	21	3	60	5	8	2	14	4	68	35	17	118	18	20	10	2
CRUSTACEA	Amphipoda	*Ampelisciidae*	13	35	8	69	30	39	11	19	8	5	2	8	1	18	15	0	1	2	2	7	4
CRUSTACEA	Amphipoda	*Liljeborgiidae*	0	8	0	0	2	0	0	0	2	8	0	0	0	1	0	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Melitidae*	1	0	7	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
CRUSTACEA	Amphipoda	*Oedicerotidae*	0	0	2	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Caprella sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Tonaidacae*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Caprella sp*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
CRUSTACEA	Amphipoda	*Ingolfiellidae*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Decapoda	*Callianassidae*	4	6	6	4	3	0	6	0	15	11	0	0	0	1	2	1	0	0	0	0	0
CRUSTACEA	Decapoda	*Goneplacidae*	0	4	1	2	2	4	3	5	0	2	0	2	0	8	1	0	2	1	1	7	1
CRUSTACEA	Decapoda	*Pinnotheridae*	1	3	1	2	1	0	1	0	3	3	0	0	0	1	1	0	1	0	0	0	0
CRUSTACEA	Decapoda	*Porcellanidae*	0	0	0	0	0	0	0	1	2	0	1	2	1	3	0	0	0	1	0	1	0
CRUSTACEA	Decapoda	*Alpheidae*	0	0	1	4	3	0	4	0	0	0	0	0	0	1	0	0	1	0	0	0	0
CRUSTACEA	Decapoda	*Decapoda*	0	0	0	0	0	1	3	0	2	0	0	0	0	2	0	0	0	0	0	2	0
CRUSTACEA	Decapoda	*Shrimp*	0	1	2	0	1	0	0	0	0	0	1	0	4	0	0	0	0	1	1	0	2
CRUSTACEA	Decapoda	*Hermit crab*	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Decapoda	*Portunidae*	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Decapoda	*Euphausiidae*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Decapoda	*MBDS84-5*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
CRUSTACEA	Decapoda	*Sergestidae*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Mysidacea	*Mysidacea*	0	1	0	0	1	0	0	1	0	0	7	9	0	1	0	0	0	1	3	5	0
CRUSTACEA	Cumacea	*Cumacea*	7	5	1	0	1	3	7	1	0	0	0	2	0	2	2	0	0	0	1	0	0
CRUSTACEA	Stomatopoda	*Stomatopoda*	0	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
CRUSTACEA	Amphipoda	*Tanaidacae*	0	0	0	0	1	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0

Mirs Bay December 1995 Recolonization Study: Disposal site

Phylum	Order	Family	S51	S53	S55	S56	S57	S63	S64	S67	S70	S71	S72	S73	S74	S75	S78	S80	S84	S86	S87	S88	S89
ECHINODERMATA	Amphiuridae	*Amphiuridae*	8	10	4	26	14	7	31	5	21	22	17	17	2	20	36	2	2	2	11	17	11
ECHINODERMATA	Amphiuridae	*Echinodermata*	2	2	2	0	0	0	0	0	0	1	0	1	0	1	2	2	0	0	0	0	0
ECHINODERMATA	Amphiuridae	*Echinoidea*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
ECHINODERMATA	Holothroidea	*Holothroidea*	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Bivalvia	*Corbulidae*	2	17	0	6	6	0	1	0	0	3	0	0	1	5	11	1	3	0	0	0	1
MOLLUSCA	Bivalvia	*Semelidae*	0	17	0	0	0	0	1	0	0	2	0	0	0	0	13	0	0	0	0	0	0
MOLLUSCA	Bivalvia	*Montacutidae*	3	0	0	0	0	0	0	1	1	0	0	1	0	17	4	10	1	0	0	0	0
MOLLUSCA	Bivalvia	*Tellinidae*	1	2	2	0	3	3	2	3	0	0	0	2	0	2	3	0	2	0	0	0	3
MOLLUSCA	Bivalvia	*Bivalvia*	0	8	0	4	0	1	0	9	1	0	1	0	0	0	0	0	1	0	1	6	0
MOLLUSCA	Bivalvia	*Thracidae*	0	6	1	5	1	1	0	3	0	0	1	1	0	2	1	0	1	0	0	0	1
MOLLUSCA	Bivalvia	*Nuculanidae*	0	10	0	0	0	0	0	1	0	0	0	0	0	10	1	0	0	0	0	0	0
MOLLUSCA	Bivalvia	*Veneridae*	0	3	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Bivalvia	*Mactridae*	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0
MOLLUSCA	Bivalvia	*Mytilidae*	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Atyidae*	0	1	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Liotimara sp.*	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Buccinidae*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Cancellariidae*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*MBDS84-2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
MOLLUSCA	Gastropoda	*Potamididae*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Terebridae*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Gastropoda*	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
MOLLUSCA	Gastropoda	*Polyplacophora*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SIPUNCULA			5	2	7	4	9	3	5	2	2	7	8	2	6	8	5	0	0	2	5	4	1
PHORONIDA			1	0	3	6	0	0	0	0	0	3	1	0	0	0	2	3	3	0	3	0	0
NEMERTEA			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ECHIURA			2	2	1	1	0	0	1	4	1	0	3	1	0	0	1	0	0	0	2	0	0
CNIDARIA		*Cnidaria*	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0
CNIDARIA		*Hydras*	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
CNIDARIA		*Sea anemone*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
OLIGOCHAETA		*Oligochaeta*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0