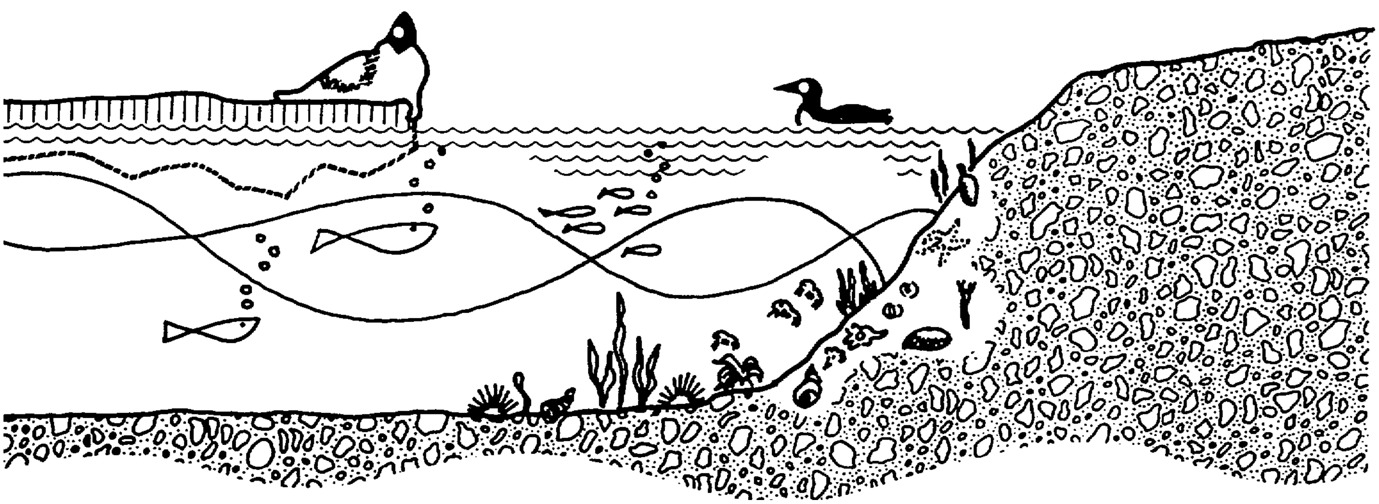
SHORELINE COUNTERMEASURES



Baffin Island Oil Spill Project

WORKING REPORT SERIES

1981 STUDY RESULTS

The Baffin Island Oil Spill Project

OBJECTIVES

The Baffin Island Oil Spill (BIOS) Project is a program of research into arctic marine oil spill countermeasures. It consists of two main experiments or studies. The first of these, referred to as the Nearshore Study, was designed to determine if the use of dispersants in the nearshore environment would decrease or increase the impact of spilled oil. The second of the two experiments in the BIOS Project is referred to as the Shoreline Study. It was designed to determine the relative effectiveness of shoreline cleanup countermeasures on arctic beaches.

The project was designed to be four years in length and commenced in 1980.

FUNDING

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WORKING REPORT SERIES

This report is the result of work performed under the Baffin Island Oil Spill Project. It is undergoing a limited distribution prior to Project completion in order to transfer the information to people working in related research. The report has not undergone rigorous technical review by the BIOS management or technical committees and does not necessarily reflect the views or policies of these groups.

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Final Report

Baffin Island Oil Spill Project -1981 Shoreline Component

Prepared for

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March 15,1982

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1,0 ABSTRACT

Field studies conducted during 1981 on the intertidal and backshore control plots that were laid down 12 months previously indicate that wave action on the exposed coast was effective in removing oil from the plots, but that in the more sheltered environment, oil was still present in observable amounts on both the surface and subsurface of the intertidal plots. Observations conducted in Bay 11, where 15.0 m^3 of aged crude oil was spilled, indicate that, following discharge of oil into the adjacent nearshore waters, the oiling of the shoreline was extremely variable. The volumes of oil stranded on the shoreline were similar to those that were applied to the control and countermeasure test plots. This indicates that the application technique used in the other phases of the shoreline component were realistic and replicated the action of oil becoming stranded from the water surface. Observations in Bay 9, where a dispersant-water-aged crude oil mixture was discharged, indicate that little oil was stranded on the shoreline during or after the spill.

The countermeasure control plots laid down in 1981 were effectively reworked by wave action, so that within 40 days, 80 percent of the oil on these control plots in the intertidal zone had been dispersed naturally. The use of incendiary devices to burn oil on the beach surface was attempted on a series of test plots, but failure of the devices to ignite the oil resulted in cancellation of this component of the countermeasures test. The use of dispersants and of a mixing technique was found to be effective in initially reducing the volume of surface oil on the beach sediments on the plots. However, after 40 days the total hydrocarbon values from the dispersed plots and from the mixing plots were essentially in the same range as those from the control plots. This indicates that natural cleaning is as effective as the countermeasure techniques during the open-water season, when storm-wave action can rework oil that is stranded within the intertidal zone. The solidified tests were successful in that surface oil was encapsulated within the gel compound. The countermeasure experiments effectively replicated shoreline conditions that characterize moderately exposed beaches in an arctic environment.

The results of the studies that have been conducted over 2 years indicate that on high-energy or moderate-energy exposed beaches, wave action is effective in dispersing oil within the intertidal zone at loading levels that are in the order of 2 percent oil in sediment by weight.

2.0 INTRODUCTION

The 1981 Shoreline Component of the Baffin Island Oil Spill (BIOS) experiment involved a continuation of studies that were initiated in 1980 and a series of field experiments on shoreline spill countermeasures. The first phase of this study was conducted at Cape Hatt during the summer of 1980, and the results of this field programme are described in a report by Woodward-Clyde Consultants (1981a). The primary goals of Phase 11 of the Shoreline Component conducted in 1981 were: (1) to continue the monitoring of the 1980 control plots, (2) to test selected spill countermeasures on shoreline test plots, and (3) to monitor the oiling of the shore zone during and subsequent to the Ragged Channel spills. An "Interim Field Report" (dated October 23, 1981) was prepared to document in detail the field activities conducted during 1981. This field report (Woodward-Clyde Consultants, 1981b) should be consulted for further information concerning the field schedule, the test-plot sampling procedures, and the sample locations.

The specific objectives of Phase II of the BIOS Shoreline Component were:

- to monitor experimental test plots that were established in 1980 to evaluate the persistence and weathering characteristics of aged crude oil and of emulsified crude oil on shorelines of differing wave-energy levels,
- to prepare test plots of aged crude oil and emulsified crude oil for a series of microbial experiments that would be conducted by the Norwegian team,
- to conduct a series of experiments using selected countermeasure techniques on shoreline plots oiled with aged crude and emulsified crude oil (the four techniques that were selected were: aerial igniters, chemical dispersants, a solidifying agent, and mechanical mixing), and
- to monitor the distribution and character of oil stranded on the shorelines of Ragged Channel during and subsequent to the nearshore dispersant experiment.

Each of these specific objectives was completed on schedule during the 1981 field season. The objective of this report is to describe and discuss the individual experimental activities and results.

The regional location of the study site is indicated on Figure 2.1, and the specific locations of the study beaches that are described and referred to in this report are identified on Figures 2.2 and 2.3. The 1981 test plots and experimental plots were established at the entrance to Z-Lagoon (a location referred to informally as “Crude Oil Point”), which is identified on Figure 2.4.

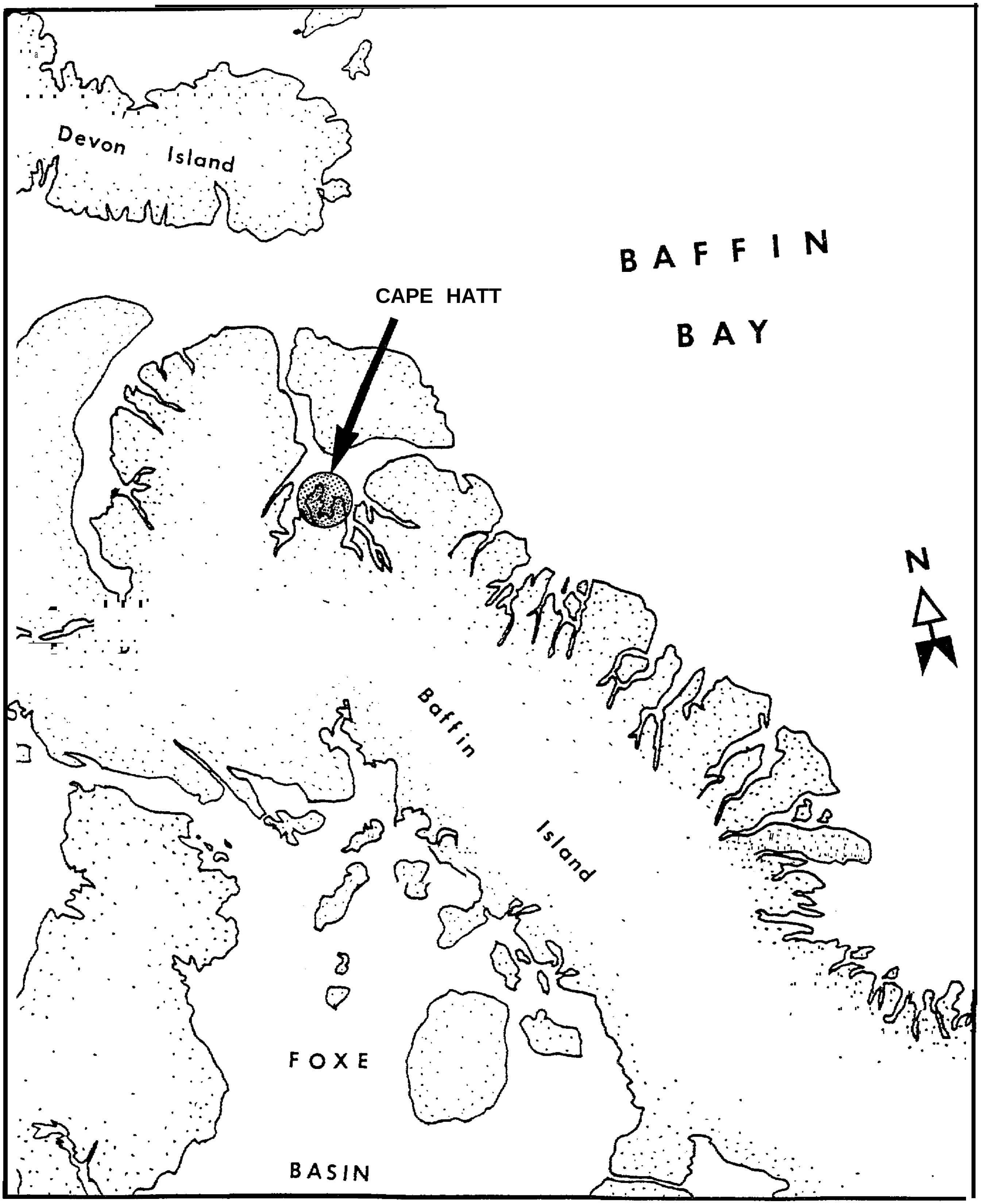
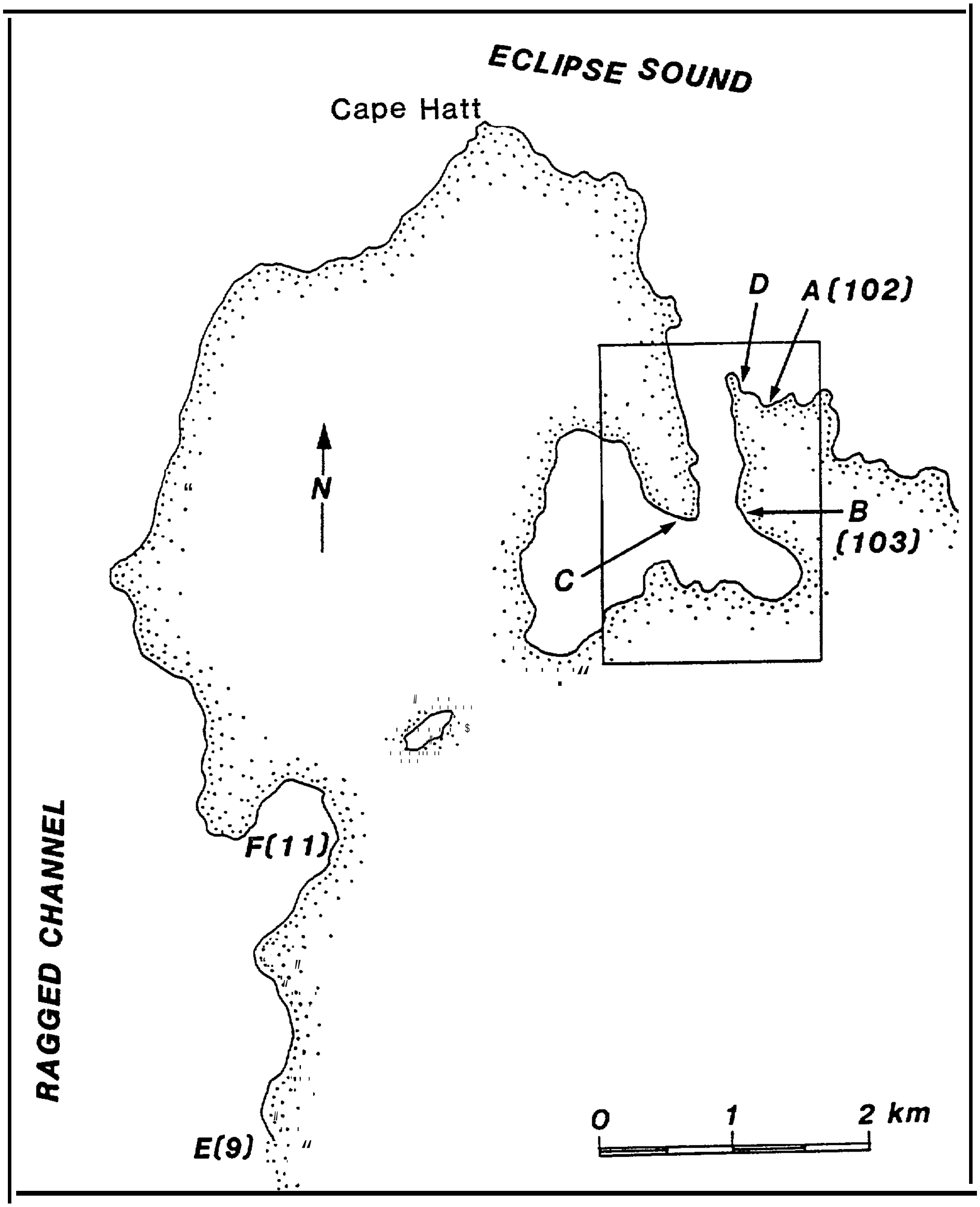


Figure 2.1 Location of Cape Hatt, Baffin Island,



A. 1980 Exposed Beach Control Site: Bay 102 - Plots H1 and H2

B. 1980 Sheltered Beach Control Site: Plots L1 and L2

C. 1980 Backshore Control Site: Plots T1 and T2
1981 Shoreline Countermeasure Experimental and Test Plots

D. 1980 Norwegian Backshore Control Site: Plots TE1 and TE2
1981 Norwegian Backshore Experimental Site

E. Bay 9

F. Bay 11

Figure 2.2 Location of study beaches. Greater detail within the area indicated by the rectangle is provided in Figure 2,3.

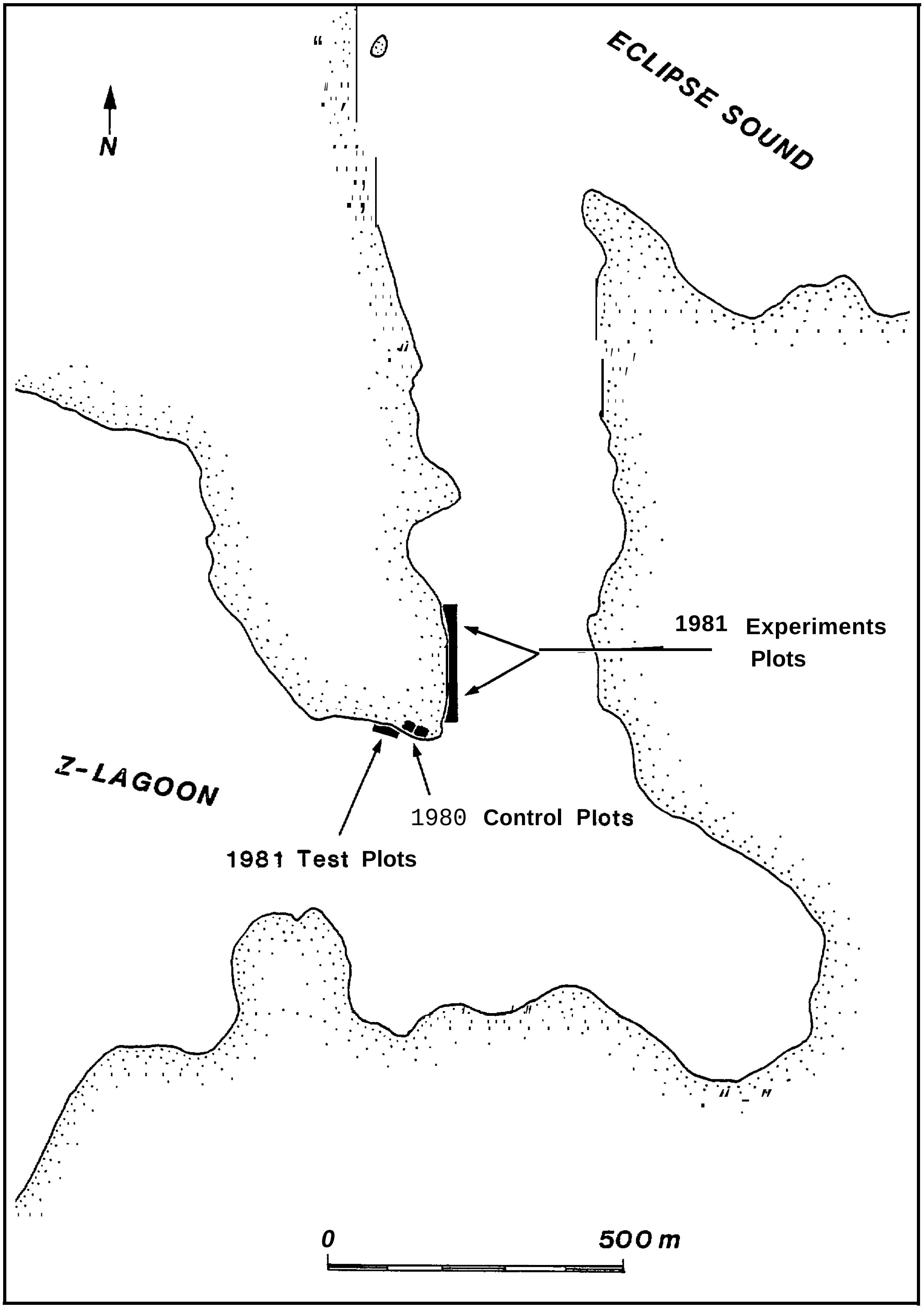


Figure 2.3 Location of 1981 test and experimental plots at Crude Oil Point.

Figure 2.4 View towards the southwest into Z-Lagoon. The exposed beach site (Bay 102) is in the lower right of the photograph, and Crude Oil Point is indicated by the arrow (30 July 1979).

3.0 INTERTIDAL AND BACKSHORE CONTROL PLOTS

This section discusses the second-year results of the long-term control experiments which were initiated during 1980. A brief review of the 1980 results is provided as background to the discussion, and subsequent changes that occurred to both the intertidal and backshore control plots during 1981 are presented.

3.1 SUMMARY OF 1980 RESULTS

A brief review of the 1980 experimental results is presented below; more detailed information is presented in the Final Report on the BIOS Shoreline Component for that year (Woodward-Clyde Consultants, 1981a).

3.1.1 Backshore Control Plots

Four backshore control plots were established in August of 1980 to document the effects of atmospheric and microbial weathering (i.e., non-marine weathering) on oil degradation in the Arctic. The plots were located on substrates similar to those of active beaches. Aged crude oil (Plots T1, TE-1) and a water-in-aged crude oil emulsion (Plots T2, TE-2) were applied to the test plots (locations C and D; Figure 2.2) at a loading rate of 1 cm^3 of oil per cm^2 of plot.

Initial total hydrocarbon contents on the backshore control plots varied between 0.17 and 5.4 percent (by weight), with mean values ranging between 1.4 and 3.8 percent (Table 3.1). Subsequent hydrocarbon analyses performed on samples collected at 2, 4 and 8 days after the spill showed significant variations; however, the variation was apparently the result of the sampling technique, and no detectable oil-concentration changes occurred during 1980 on the backshore control plots.

TABLE 3.1 Total Hydrocarbon Analyses of 1980 Sediment Samples

		HIGH WAVE ACTION				LOW WAVE ACTION				BACKSHORE PLOT (Z LAGOON)				BACKSHORE PLOT (ECLIPSE SOUND)			
		AGED (H-1)		EMULSIFIED (H-2)		AGED (L-1)		EMULSIFIED (L-2)		AGED (T-1)		EMULSIFIED (T-2)		AGED (TE-1)		EMULSIFIED (TE-2)	
		% OIL IN SEDIMENT				% OIL IN SEDIMENT				% OIL IN SEDIMENT				% OIL IN SEDIMENT			
		rface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surface	Surface	Sub-Surfac
MEDIATELY LLOWING .S1	UPPER	2.04	1.04	1.59	2.80	0.67	0.88	0.19	0.05	2.24	1.65	0.94	0.91				
	MIDDLE	1.16	1.49	0.19	0.13	0.87	1.30	0.45	0.22	5.37	1.88	1.27	0.95	4.62	2.94	5.10	0.17
	LOWER	7.74	1.16	2.32	0.22	3.60	2.46	0.37	no sample	4.43	3.43	1.73	2.75				
JAYS 1ER ST	UPPER	0.001	0.0561	0.001	0.002	0.46	0.80	0.021	0.011	5.17	1.68	2.82	1.08				
	MIDDLE	0.019	0.88	0.002	0.001	0.47	0.09	0.032	0.006	3.79	1.70	1.20	2.31	4.96	1.52	10.2	0.46
	LOWER	0.001	0.055	0.001	0.001	0.61	0.69	0.014	0.005	8.53	5.62	1.90	4.74				
DAYS FTER ST	UPPER	0.007	0.18	0.010	0.11	0.45	0.77	0.008	0.00								
	MIDDLE	0.00>	1.62	0.001	0.003	0.25	0.94	0.034	0.001	3.38	3.50	1.27	1.3'	5.02	3.27	2.89	6.15
	LOWER	0.016	0.22	0.001	0.001	0.47	0.47	0.006	0.001								
D A Y S FTER EST	UPPER	0.037	2.74	0.005	no sample	0.57	1.26	0.037	0.00;2								
	MIDDLE	0.32	0.010	0.0003	0.000	0.77	1.83	0.001	0.016	6.58	1.71	6.00	5.8	4.04	4.77	5.80	0.05
	LOWER	0.001	0.26	0.0009	0.000	0.60	1.08	0.001	0.00?								

Differences in oil-retention characteristics were apparent between the two oil types. More aged than emulsified oil was retained on the sediments; initial total hydrocarbon content of the aged oil plots ranged between 3.16 and 3.78 percent, whereas emulsified plots initially retained between 1.42 and 2.64 percent oil by weight.

3.1.2 High-Energy Control Plots

Two intertidal control plots were established on a beach exposed to the relatively high wave-energy levels of Eclipse Sound (Bay 102; Fig. 2.2). The plots were located in the upper half of the intertidal zone. Aged crude oil (Plot H1) and a water-in-aged crude oil emulsion (Plot HZ) were applied separately to the two plots at a loading rate of 1 cm^3/cm^2 of plot surface.

Initial oil contents on the high-energy plots were similar to those of the backshore control plots (Table 3.1) , but oil contents were drastically reduced by marine weathering processes shortly after the spill. Eight days after the spill, surface oil contents had been reduced to less than 5 percent of the initial surface oil contents. Subsurface oil contents varied between 0.4 and 83.0 percent of the initial oil contents after 8 days because of local variations of cut and fill of the beach sediments (Woodward-Clyde Consultants, 1981a, Table 6.3). Between 50 and 90 percent of all the oil that was applied to the plots was removed by wave action shortly after the spill, and the oil that remained in the plots was concentrated in localized buried oil layers.

3.1.3 Low-Energy Control Plots

Two intertidal control plots were established on the beaches of Z-Lagoon (Bay 103; Fig. 2.2), a very protected environment in terms of wave activity. These plots were also located in the upper part of the intertidal zone. Aged crude oil was applied to one plot (Plot Ll) and a water-in-aged crude oil emulsion was applied to the other plot (Plot L2).

Initial oil contents on the aged crude oil plot were slightly lower than those recorded for the backshore control plots (Table 3.1). However, initial oil contents of the water-in-aged crude oil emulsion plot were substantially less than that recorded for other plots, primarily due to the high water content of the sediment at the experimental site (Table 3.1).

Analysis of samples collected eight days after the spill showed that nearly 64 percent of the aged crude oil remained on the plot, whereas only 48 percent of the water-in-aged crude oil emulsion remained on the plot. The primary process that removed the oil was tidal action, because these lagoon shores are protected from wave action.

3.2 BACKSHORE CONTROL PLOTS, 1981 RESULTS

Sediment samples were collected from each of the backshore control plots for total hydrocarbon analysis and GC/MS analysis. Analysis of these samples provides the basis for estimating the effect of weathering on oil degradation.

The sample grid illustrated in Figure 3.1 was used as a guide to sample collection, so that each sample represented several portions of the plot, and so that sampling could be conducted in subsequent years without the risk of sampling from disturbed areas.

On two of the backshore control plots (Tl and T2), one set of composite samples was taken from the surface (upper O-5 cm) and one set of composite samples was collected from the subsurface between 5 and 10 cm, depending upon oil penetration depth. Approximately 2.4 litres of sediment were collected for analysis. Four samples were collected from each of the control plots - two for GC/MS analysis and two for total hydrocarbon analysis.

The two secondary control plots, established adjacent to the microbiology study site (Plots TE-1 and TE-2), were sampled in a manner similar to that described for the primary control plots. However, because of the limited size of the plots, it was possible to collect only one

	81a	81b	83b	82b	83b	81b	81a	82a	
	82a	83a					82b	83a	
	83b	82b					83a	82a	
	81b	82a	81a	83a	83b	81b	82b	81a	

Figure 3.1 Sampling scheme for the two primary backshore control plots, T1 and T2. Each division is 100 cm x 100 cm; late July samples were collected from 81a sites and composite; late August samples were collected from 81b sites and composite.

sample from the 4-m^2 plot (i. e., sample was not a composite). A surface and subsurface sample of approximately 2.4 1 was collected for both GC/MS analysis and total hydrocarbon analysis.

Visual observations of the plot in 1981 indicated that little weathering had occurred. The surface covering was dusted by wind-blown sand material, and some growth of vegetation occurred within the plot (Figs. 3.2 and 3.3).

Total hydrocarbon data from the analysis of sediment samples collected in 1981 on the control plots are presented in Table 3.2. Two sets of total hydrocarbon samples were collected during 1981; however, to date only one of the sample sets has been analyzed. Surface total hydrocarbon contents ranged between 1.6 and 3.4 percent, and the values for all of the plots were similar. Subsurface values ranged between 1.8 and 2.6 percent. On the aged crude oil plots, surface oil contents were higher than subsurface oil contents, whereas on the emulsified oil plots, subsurface oil contents were higher than the surface contents. Further comparison of these 1981 data to the 1980 total hydrocarbon data is included within the discussion section (Section 3.5).

3.3 HIGH-ENERGY INTERTIDAL CONTROL PLOTS, 1981 RESULTS

3.3.1 Beach Morphology Changes

Significant beach morphology changes occurred on the high-energy beach (Bay 102; Fig. 2.2), both between the 1980 and 1981 surveys and during the 1981 survey season. These changes are, no doubt, a significant factor in the dispersal of stranded oil on this particular beach.

The sections of the beach on which the plots were located were the most active, with vertical change in the order of 20 cm between the initial oiling in 1980 and the early August 1981 surveys (see Fig. 3.4). Between the 1980 and 1981 surveys, the beach face underwent a landward migration of 1 to 2 m that was accompanied by the development of a berm, or large swash ridge, landward of the plots (see Fig. 3.4). This change must have occurred in late 1980 as a small pocket of oiled sediments was evident in

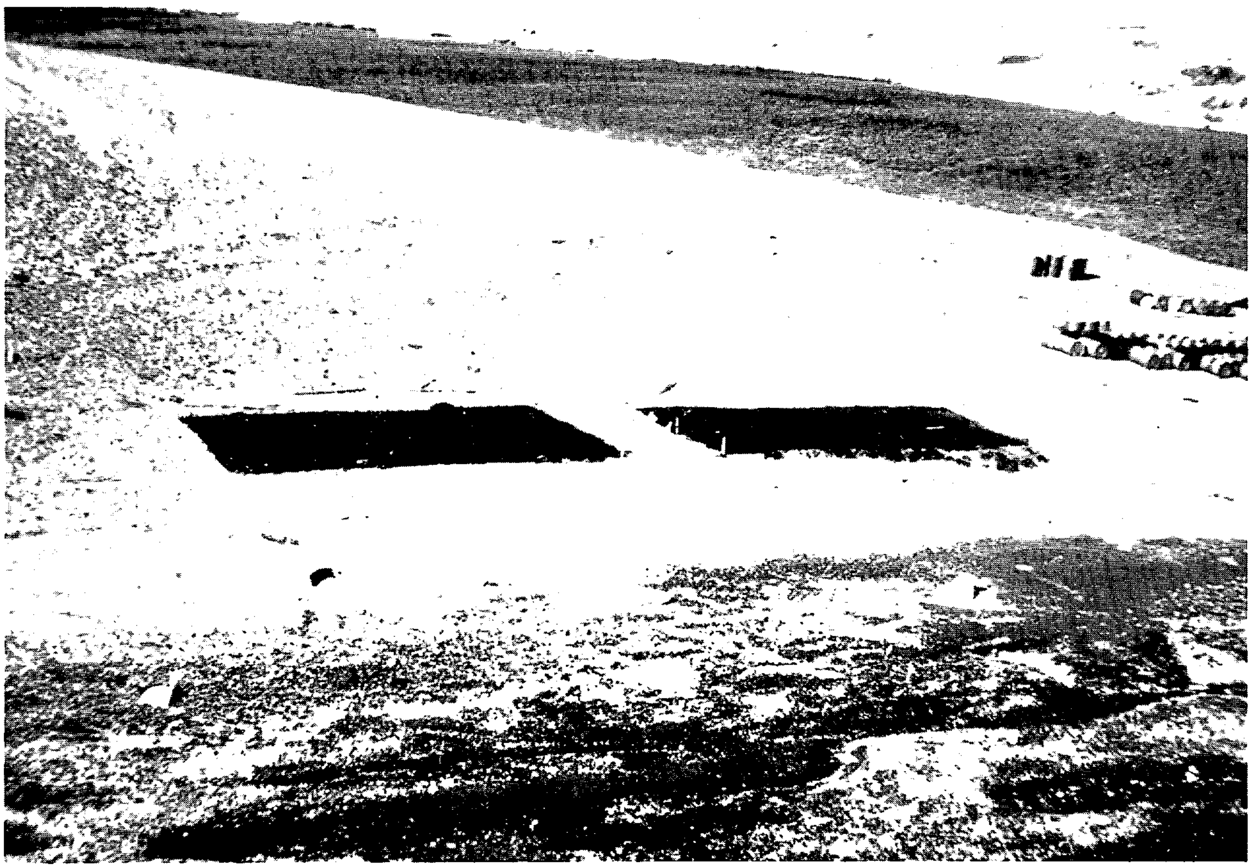


Figure 3,2 Oblique aerial photograph of the two primary control plots, T1 and T2 (29 August 1981).

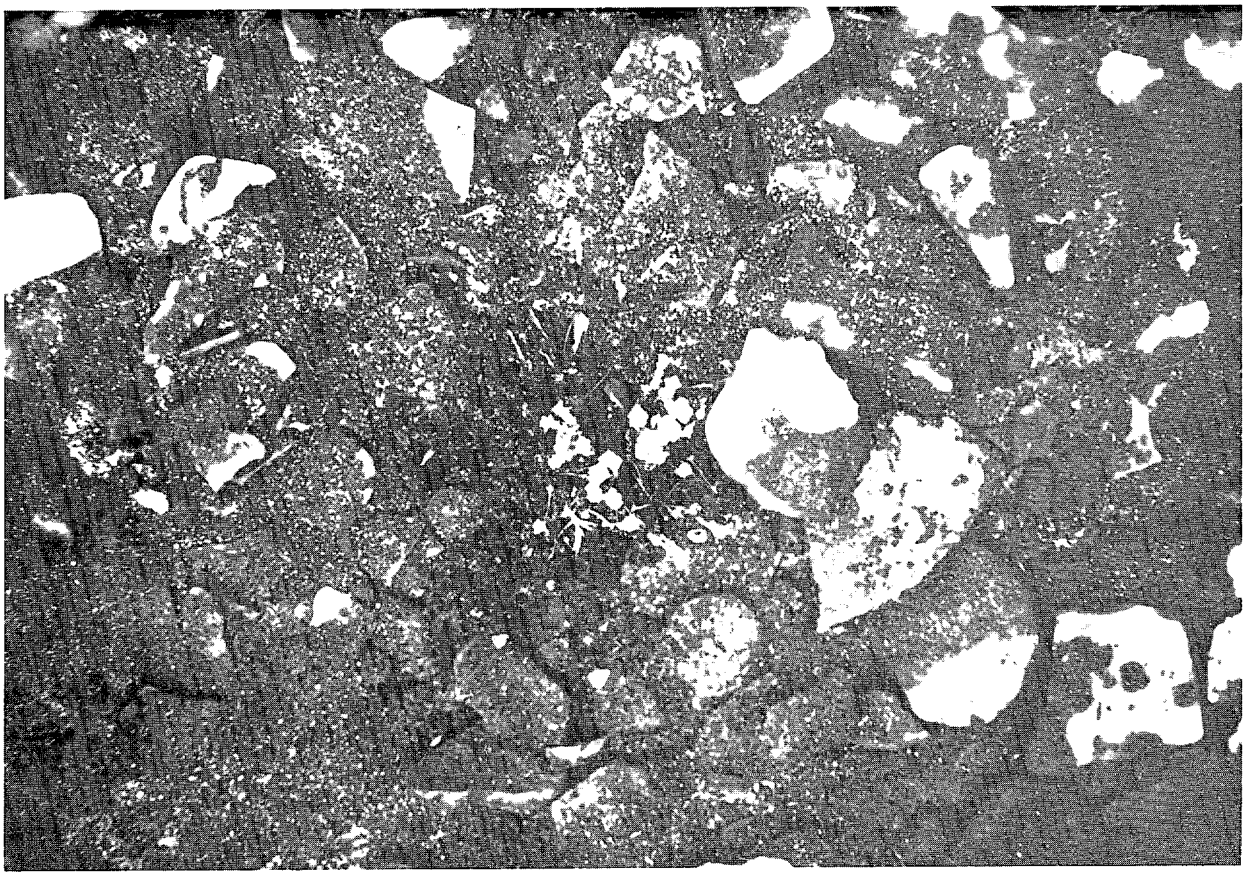


Figure 3.3 Photograph of surface oil on the control plot T2. Note the new growth on the vegetation, as well as the dusting of wind-blown material (4 August 1981).

Table 3.2 Total Hydrocarbon Analyses of Backshore Control Plot Samples

		Total Hydrocarbon Content (% by weight)	
DATE	PLOT	SURFACE	SUBSURFACE
28 July 1981	TE-1	2.9	2.4
19 August 1981	T1	3.4	2.1
29 August 1981	T2	1.6	1.8
29 August 1981	TE-1	2.2	1.9
25 August 1981	TE-2	2.4	2.6

NOTE : Plots T1 and TE-1 are the aged crude oil plots, and Plots T2 and TE-2 are the water-in-aged crude oil emulsion plots.

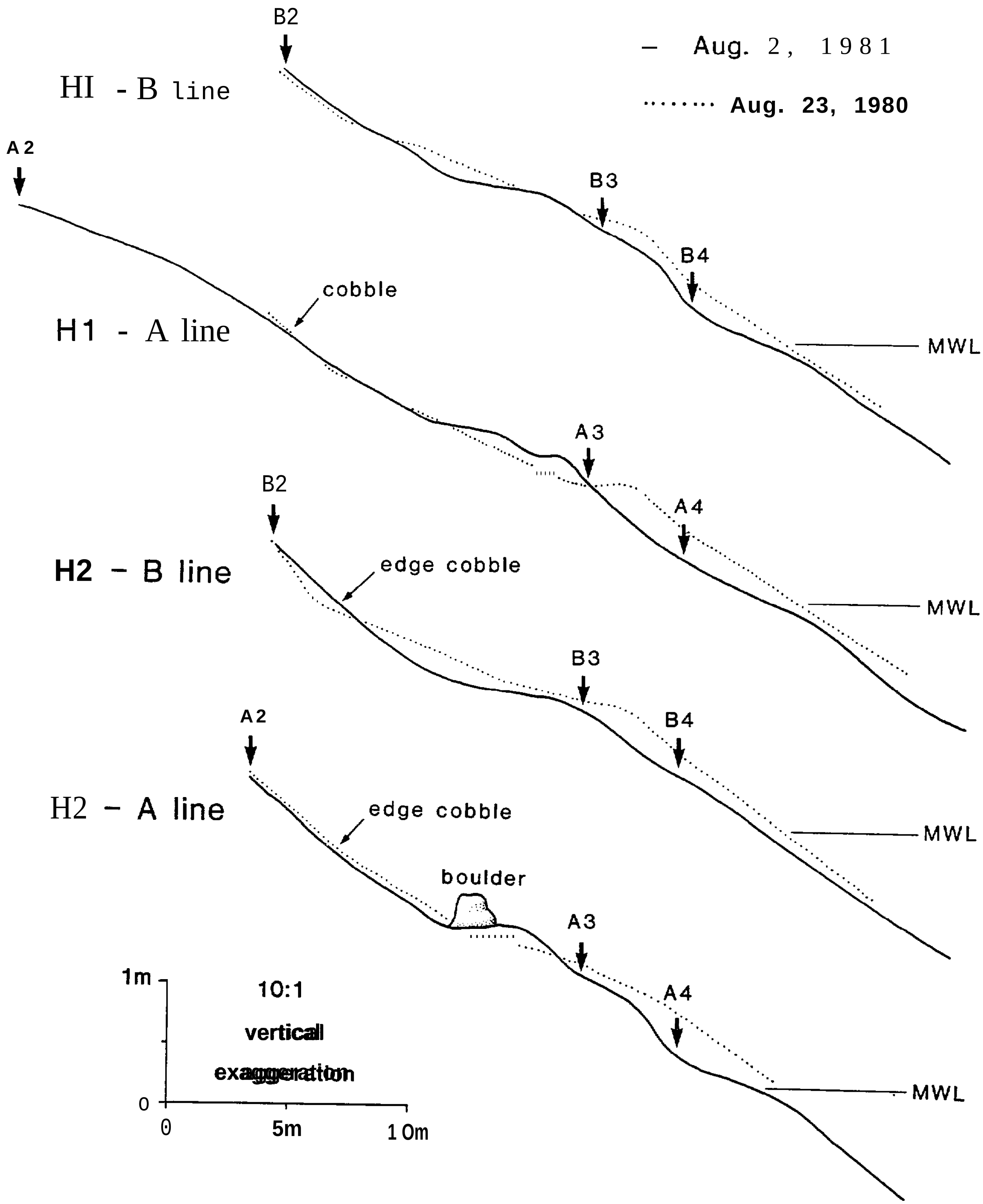


Figure 3.4 Beach profiles from the high-energy plots in Bay 102 showing the beach morphology changes between 1980 and 1981 (see Fig. 3.5 for profile location in relation to the control plots) ,

the southeast corner of Bay 102 at the storm-swash line, indicating that a storm-surge event probably occurred after the surveys were completed during 1980.

During 1981 the beaches underwent a net accretion in the vicinity of the plots, although accretion was not necessarily continuous. Plot H1, the aged crude oil plot, underwent a net accretion of 0.07 m^3, or an average burial covering of 0.2 cm. Plot HZ, the water-in-aged crude oil emulsion plot, underwent a net accretion of 5.4 m^3, or an average cover of 13.4 cm (see Fig. 3.5). From the time of the initial oiling in 1980, Plot H1 underwent a net loss of material of about 4 m^3, whereas Plot H-2 remained stable to slightly accretional. Cut and fill events, as documented by profile changes during 1981 (Fig. 3.5), were generally in the order of 10 cm, and these could have occurred during a single tidal cycle.

3.3.2 Total Hydrocarbon Content of Sediments

Sediment samples were collected from each of the two intertidal control plots for total hydrocarbon and GC/MS analysis. Samples for total hydrocarbon analysis were collected systematically, using the approach employed during the 1980 field experiment. These samples were collected on a fixed pattern, rather than one which was dependent on the observed distribution of oil. Total sample size was in the order of 2.4 litres. Both surface and subsurface samples were collected from each sample location. Samples collected for GC/MS analysis were taken from locations of observed oil on the plots, with the exception of surface samples, which were taken on the beach surface.

Total hydrocarbon contents for the high-energy plot samples are shown in Table 3.3. The data indicate that the small amount of oil that was initially present in the samples during early summer of 1981 was later completely removed from the beach. High wave-energy levels and extensive sediment redistribution appears to be the primary process that accounts for this reduction in overall oil content of the sediments. It is possible that oil was completely buried and actually remained in the beach, but extensive trenching around the plots during late August 1981 indicates that this was not the case. A discussion of the comparison between 1980 and 1981 samples is included in Section 3.5.

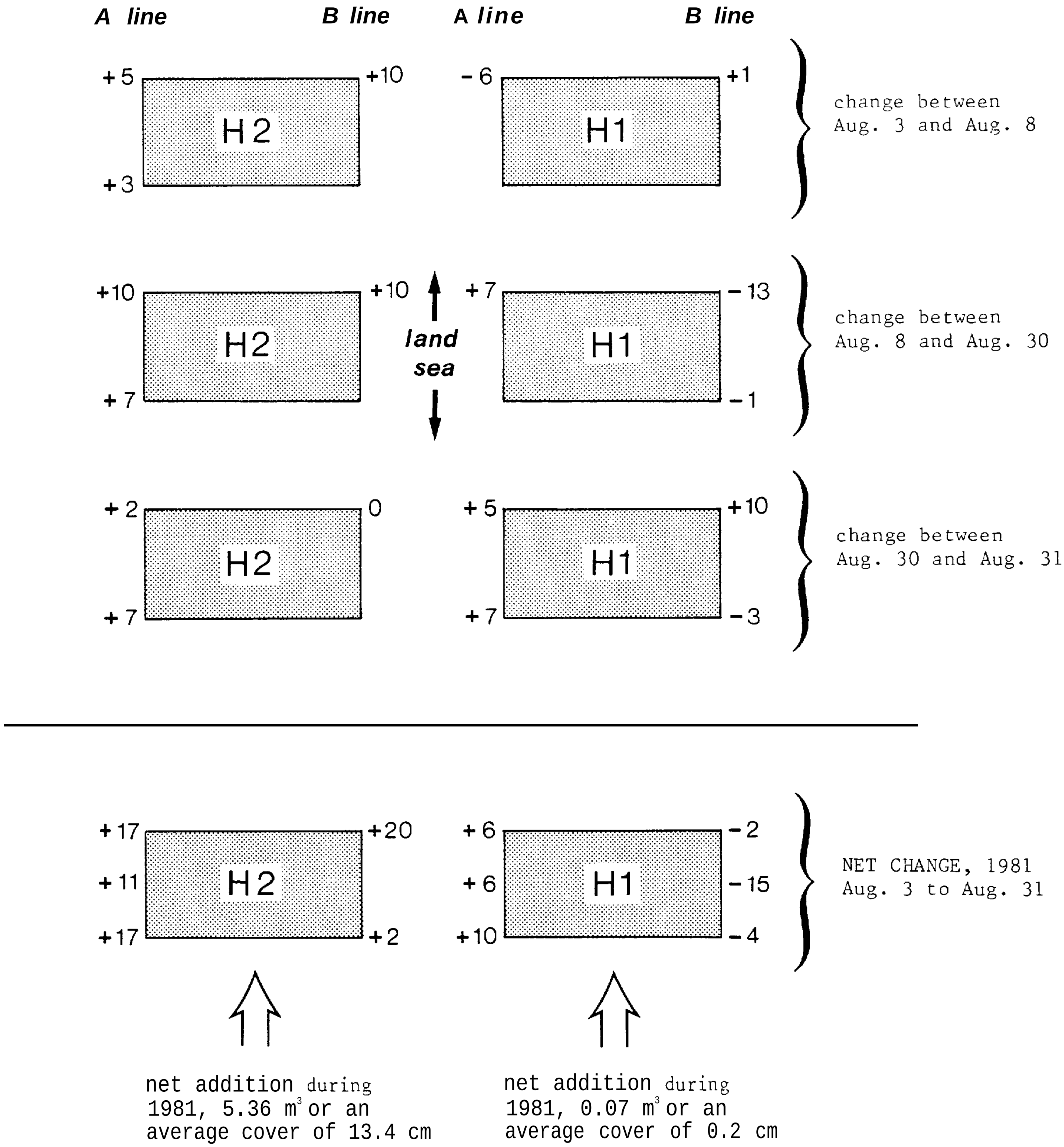


Figure 3,5 Beach elevation changes (in cm) during the 1981 open-water season as measured at stakes around the plots. Plus (+) indicates deposition; minus (-) indicates erosion.

Table 3.3 Total Hydrocarbon Analyses of Intertidal Control Plot Samples

Total Hydrocarbon Content (% by weight)

DATE	PLOT	SURFACE	SUBSURFACE
28 July 1981	H1	0.189	0.073
28 July 1981	H2	0.121	0.026
29 August 1981	H1	0	0
29 August 1981	H2	0	0
28 July 1981	L1	0.472	0.500
28 July 1981	L2	0.014	0.007
29 August 1981	L1	0.16	0.49
29 August 1981	L2	0.015	0.016

3.4 LOW-ENERGY INTERTIDAL CONTROL PLOTS, 1981 RESULTS

3.4.1 Beach Morphology Changes

No significant changes occurred to the beach either after the 1980 survey or during the 1981 survey season. Therefore, redistribution of sediment on these particular beaches is not believed to be a major cause of the weathering of oil. Comparisons of 1980 and 1981 beach profiles are shown in Figure 3.6. Melting of ice mounds, which were present near the mean water level, resulted in elevation changes of 30 to 40 cm on the lower beach; however, these changes did not affect the intertidal plots. Nor was there any indirect evidence of ice gouging or sediment redistribution on these plots.

3.4.2 Total Hydrocarbon Analyses

Sediment samples were collected for total hydrocarbon analysis as well as for GC/MS analysis. Sample collection procedures were the same as those used on the high-energy intertidal plots (see Section 3.3.2 for details). The surface oil content on the crude oil plot (L1) was initially 0.472 percent, but was reduced to 0.16 percent by the latter part of the summer (Table 3.3). Subsurface oil contents on the aged oil plot remained constant throughout the summer at about the 0.5 percent level. Oil contents on the water-in-aged oil emulsification plots were significantly lower than those of the aged oil plots (Table 3.3; Fig. 3.7). Surface oil contents on this plot, L2, did not vary significantly throughout the summer, and remained at the .015 percent level. Subsurface oil contents also showed very little change on this plot (Table 3.3). Comparison between 1980 and 1981 sediment oil contents are discussed below.

3.5 DISCUSSION OF RESULTS

This discussion focusses primarily on comparison between 1980 and 1981 total hydrocarbon data. The GC/MS analyses are incomplete at the present time, and are only discussed briefly. The discussion is subdivided into two sections that focus on (1) comparisons between the backshore control plots, and (2) comparisons between the intertidal control plots.

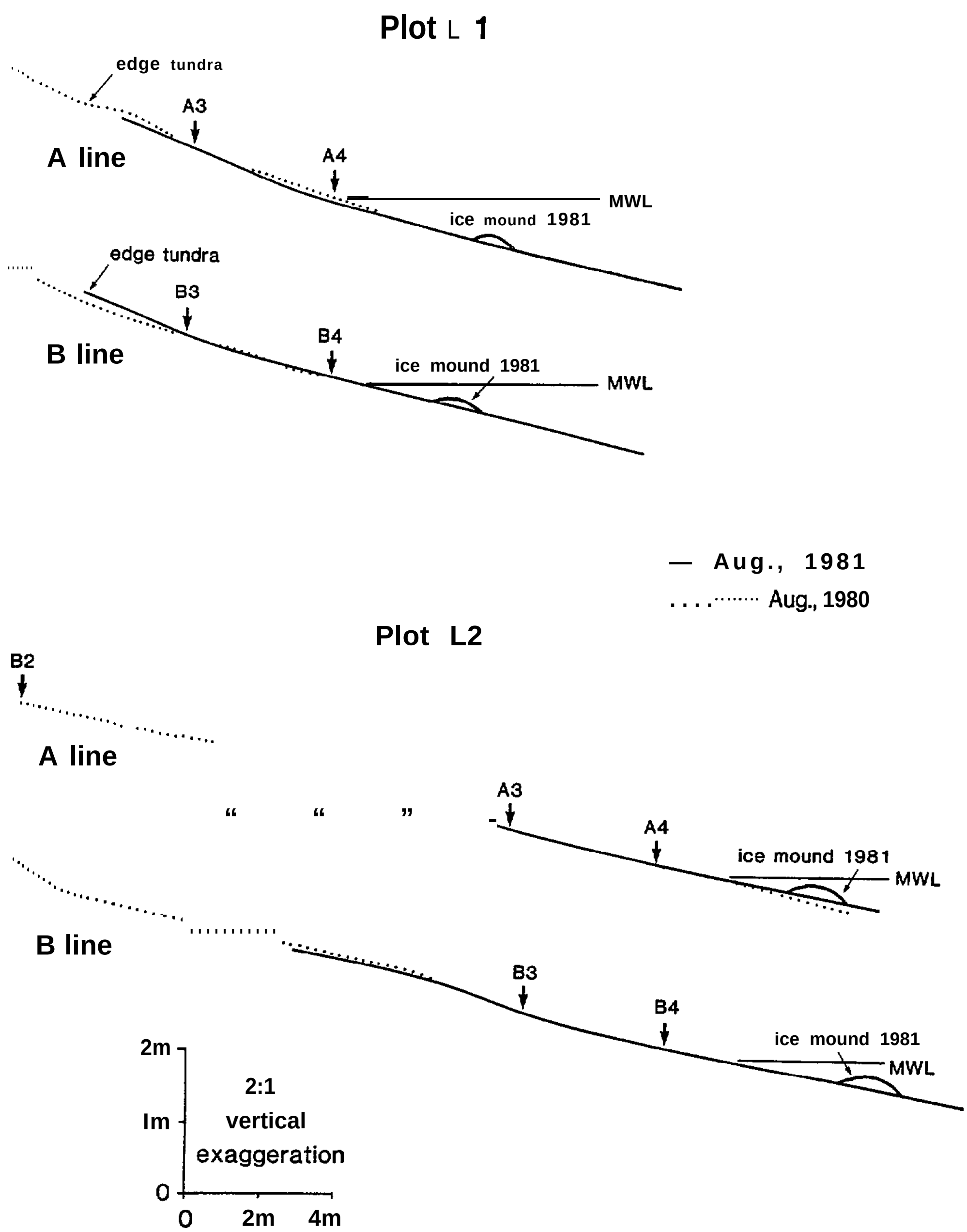


Figure 3.6 Beach profiles from the low-energy plots in Bay 103 showing the lack of change between 1980 and 1981.

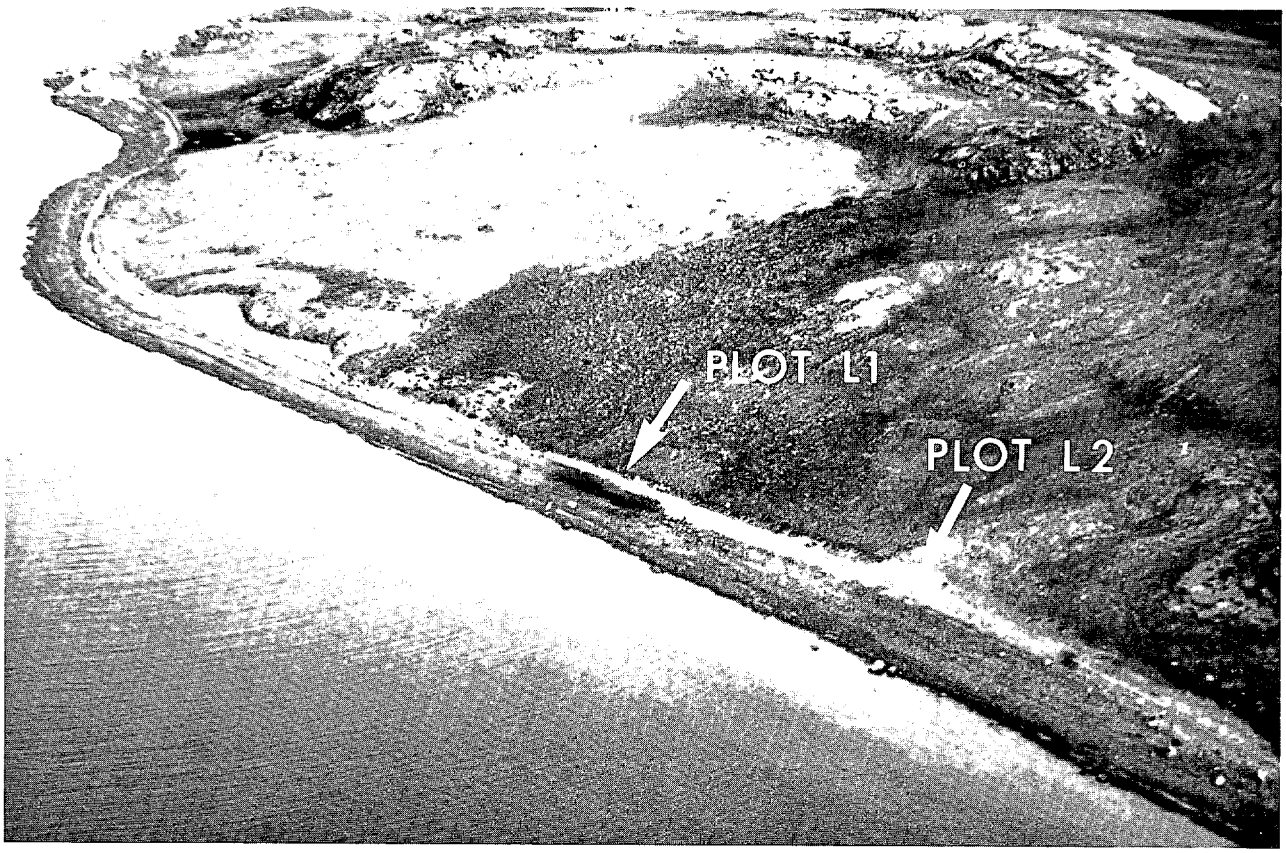


Figure 3.7 Oblique aerial photograph of low-energy plots. Note the relative lack of weathering of crude oil plot, L1. Also compare weathering changes to Figure 3.2 (29 July 1981).

3.5.1 Backshore Control Plots

Although significant variation occurred within the 1980 total hydrocarbon samples, it is nevertheless useful to compare 1980 total hydrocarbon samples to 1981 total hydrocarbon samples. The comparative data are listed in Table 3.4. The 1980 mean values were computed from all of the total hydrocarbon samples that were collected during 1980. Unfortunately, for all but one of the plots, only one 1981 total hydrocarbon sample is available; however, because a more rigorous sampling technique was followed during the collection of the 1981 samples, these are considered to be better representations of the true sediment oil content of the control plots. The 1981 samples are actually a composite of four subsamples, and as such would be comparable to a mean of four subsamples from the 1980 surveys. It should also be noted that the means for the 1980 samples actually represent a considerable scatter of data (e.g., see standard deviation values, Table 3.4).

The scatter of the initial 1980 oil-content data makes meaningful comparisons difficult (see standard deviation values in Table 3.4). However, if one assumes that the means from both years' samples provide an accurate representation of true oil contents, then there is a suggestion that a reduction in the total hydrocarbon content of the surface samples may have occurred between the 1980 and 1981 surveys.

Possible explanations for the apparent reduction in total hydrocarbon contents are that (1) oil percolation into the subsurface sediments may not be adequately represented by the subsurface samples, (2) sediment was added to the plots by wind transport, effectively reducing apparent oil content (see Fig. 3.3), (3) actual weathering by evaporation and microbial decomposition may have occurred, (4) surface runoff during rain and snow melt may have removed some oil prior to 1981 sample collection, and (5) the sampling information does not reflect the true oil concentrations in the plots. It is highly unlikely that significant evaporation and microbial decomposition occurred; however, it is likely that a combination of all these factors may have contributed to the apparent reduction in oil contents between 1980 and 1981 (Table 3.4).

TABLE 3.4 Total Hydrocarbon Contents From Backshore Control Plots

Total Hydrocarbon Content (% by weight)

	1980 Samples			1981 Samples		
	Mean	S.D.	(# Samples)	Mean	S.D.	(# Samples)
T1 Surface	4.9	2.0	8	3.4	0	1
T1 Subsurface	2.6	1.4	8	2.1	0	1
T2 Surface	2.1	1.7	8	1.6	0	1
T2 Subsurface	2.5	1.9	8	1.8	0	1
TE-1 Surface	4.8	0.6	4	2.6	O*5	2
TE-1 Subsurface	3.1	1.3	4	2.1	0.3	2
TE-2 Surface	6.0	3.1	4	2.4	0	1
TE-2 Subsurface	1.7	3.0	4	2.6	0	1
	3,3	2.2	48	2.3	0.54	10

Also of significance is the ratio between surface and subsurface oil contents in 1981. Surface oil contents were apparently reduced more than subsurface oil contents, and this trend was strongest for the emulsified oil plots. There is the suggestion that surface oil weathering was greater on emulsified oil plots than on crude oil plots.

Comparison of weathering ratios, for example, the saturated hydrocarbon weathering ratio (SHWR) and the alkane/isoprenoid (ALK/ISO) weathering ratio, provides indices of evaporative and biologic weathering respectively (Table 3.5). Preliminary analysis of the GC/MS data suggests that the surface oil was weathered more than the subsurface oil (Table 3.5; SHWR for 1981), and that a significant amount of weathering occurred between the last 1980 survey and the 1981 survey. The inconsistency of the ALK/ISO ratio may indicate that biodegradation of the oil was not important, although considerable scatter exists in the data.

Comparison of the 1980 and 1981 total hydrocarbon and GC/MS sample data allows preliminary conclusions to be drawn. First, it is apparent that a significant amount of oil still exists on all of the plots (>1.5 %). Second, some weathering has occurred and this weathering has preferentially

TABLE 3.5 Comparison of Saturated Hydrocarbon Weathering Ratio (SHWR) and Alkane/Isoprenoid Ratio (ALK/ISO) for 1980 and 1981 backshore Control Plots

		SHWR			ALK/ISO		
		1980		1981	1980		1981
		INITIAL	8-DAY		INITIAL	8-DAY	
T1	surface	2.35	2.25	1.6	2.43	2.96	2.1
	subsurface			1.7			2.5
T2	surface	1.93	1.79	1.6	2.58	2.29	2.4
	subsurface			2.0			2.6
TE-1	surface	2.23	2.21	1.5	2.63	2.84	3.1
	subsurface			2.0			3.7
TE-2	surface	2.12	2.07	1.2	2.57	2.64	2.4
	subsurface			1.7			2.7

reduced surface oil concentrations. Third, it is not possible to estimate the exact quantity of oil weathered or removed because of the scatter in the data. Fourth, it is not possible to delineate the mechanisms which may be reducing oil contents, although this is probably a combination of oil percolation, evaporative weathering, surface runoff, and the addition of sediment to the plots (comparison of 1980 and 1981 ALK/ISO ratios suggests that biological weathering has not been significant in reducing oil contents) .

3.5.2 Intertidal Control Plots

Comparisons between 1980 and 1981 total hydrocarbon samples from the intertidal control plots are shown in Table 3.6. For the high-energy plots , H1 and H2, an increase in 1981 oil contents over fall 1980 oil contents indicates that some re-oiling of beach sediment occurred during the late fall of 1980 (Table 3.6). The re-oiling was probably the result of the redistribution of oil previously buried in the beach sediments. The GC/MS sample results (Table 3.7) indicate that the oil on the beach surface in 1981 was fresher than that present in 1980, and this supports the suggestion that the 1981 surface oil was reworked buried oil. Subsequent data samples collected in the fall of 1981 show that oil contents in the plots at that time had been reduced below detectable limits. In terms of the initial oil spilled, 100 percent has been removed, primarily due to wave action.

TABLE 3.6 Total Hydrocarbon Contents From Intertidal Control Plots

Total Hydrocarbon Content (% by weight)

		INITIAL 1980	FALL 1980	JULY 1981	FALL 1981	% REDUCTION 1980 - 1981
H1	Surface	3.6	0.12	0.189	0	100
H1	Subsurface	1.2	0.002	0.073	0	100
HZ	Surface	1.37	0.002	0.121	0	100
HZ	Subsurface	1.05	0.0006	0.026	0	100
L1	Surface	1.71	0.64	0.472	0.16	91
L1	Subsurface	1.55	1.39	0.500	0.49	68
L2	Surface	0.34	0.013	0.014	0.015	96
L2	Subsurface	0.14	0.008	0.007	0.016	89

TABLE 3.7 Comparison of Saturated Hydrocarbon Weathering Ratio (SHWR) and Alkane/Isoprenoid Ratio (ALK/ISO) for 1980 and 1981 Intertidal Control Plots

		SHWR			ALK/ISO		
		1980		1981	1980		1981
		INITIAL	8-DAY		INITIAL	8-DAY	
H1	surface	1.27	1.81	2.0	2.67	2.78	1.6
	subsurface			2.3			2.1
H2	surface	1.04	1.18	2.1	3*73	2.36	2.4
	subsurface			2.2			2.8
L1	surface	2.54	2.52	1.1	2.36	2.55	1.9
	subsurface			2.0			2.4
L2	surface	2.09*	2.00	1.0	2. 70*	2.80	1.1
	subsurface			1.4			1.9

* after 2 days

Changes on the low-energy intertidal control plots were not as large as those which occurred on the high-energy plots. Oil contents on Plot L1, the crude oil plot, were reduced between 1980 and 1981, but the oil contents on L2, the water-in-aged crude oil emulsion, remained unchanged. Some additional reduction of surface oil contents occurred during 1981 on the crude oil plot, L1, but no significant subsurface oil content changes were identified during the 1981 sample period (Table 3.6). Data from the GC/MS analysis indicate that weathering, rather than direct oil removal, may have accounted for the observed changes, and that biological weathering may also have been important (Table 3.7).

Despite the low mechanical wave-energy levels in Z-Lagoon, significant reductions in oil content have occurred since the initial oiling. Greater than 90 percent of the emulsified oil has been removed from L2, and approximately 80 percent of the crude oil has been removed from L1. Oil present on the beach surface can be effectively removed despite low annual wave-energy levels; however, there was insufficient energy to naturally clean the intertidal plots to the degree that was observed on the more exposed intertidal plots. Subsurface oil contents are likely to be greater than surface oil contents, but this oil can also be removed by small waves and tidal action.

4.0 OILING OF NORWEGIAN PLOTS

A series of backshore control plots was established in Bay 102 (Fig. 2.2) for the purpose of monitoring microbial decomposition of oil stranded on arctic shorelines. The actual sampling and monitoring which were conducted by the Norwegian microbiology team are discussed in a separate report. This section describes the physical morphology and textural characteristics of the test sites, as well as the changes that took place on those test sites during the summer observation period.

The five 4m x 5m control plots were located in a level portion of the backshore at Bay 102 (Fig. 4.1), The location of the plots was an area not normally exposed to wave action; however, later during the summer a high-energy storm event did cause submergence of the plots (see below). Sediments in the area of the plots consisted of gravelly sand with pebbles comprising 10 to 20 percent of the coarse fraction.

A 50 percent water-in-oil emulsion was applied to each of the plots using the ATV-mounted oil-application system described in Section 5,3. Approximately 0.2 m^3 (200 l or 43 Imp. gal.) of oil were applied to each plot (i.e., 0.4 m^3 or 400 l or 86 Imp. gal. of emulsion). This represents a loading rate of 2 cm^3 of emulsion per 1 cm^2 of plot surface. In practice, however, some oil ran off the plot and was recovered in trenches. Application, recovery and retention volumes are indicated in Table 4.1. The plots were later treated with fertilizers at various loading rates, rototilled and monitored for microbial decomposition of the oil.

Approximately 1 month after the application of the oil (on 29 August 1981), high water levels caused partial submergence of the plots (Fig. 4.2). Sand and gravel covered the seaward fringes of the plots, and kelp washed approximately midway across the plots. The following day (30 August 1981), an even higher tide, in combination with waves generated in Eclipse Sound, caused complete burial of all the plots (Fig. 4.3). The burial depths of the oiled surfaces are shown schematically in Figure 4.4.

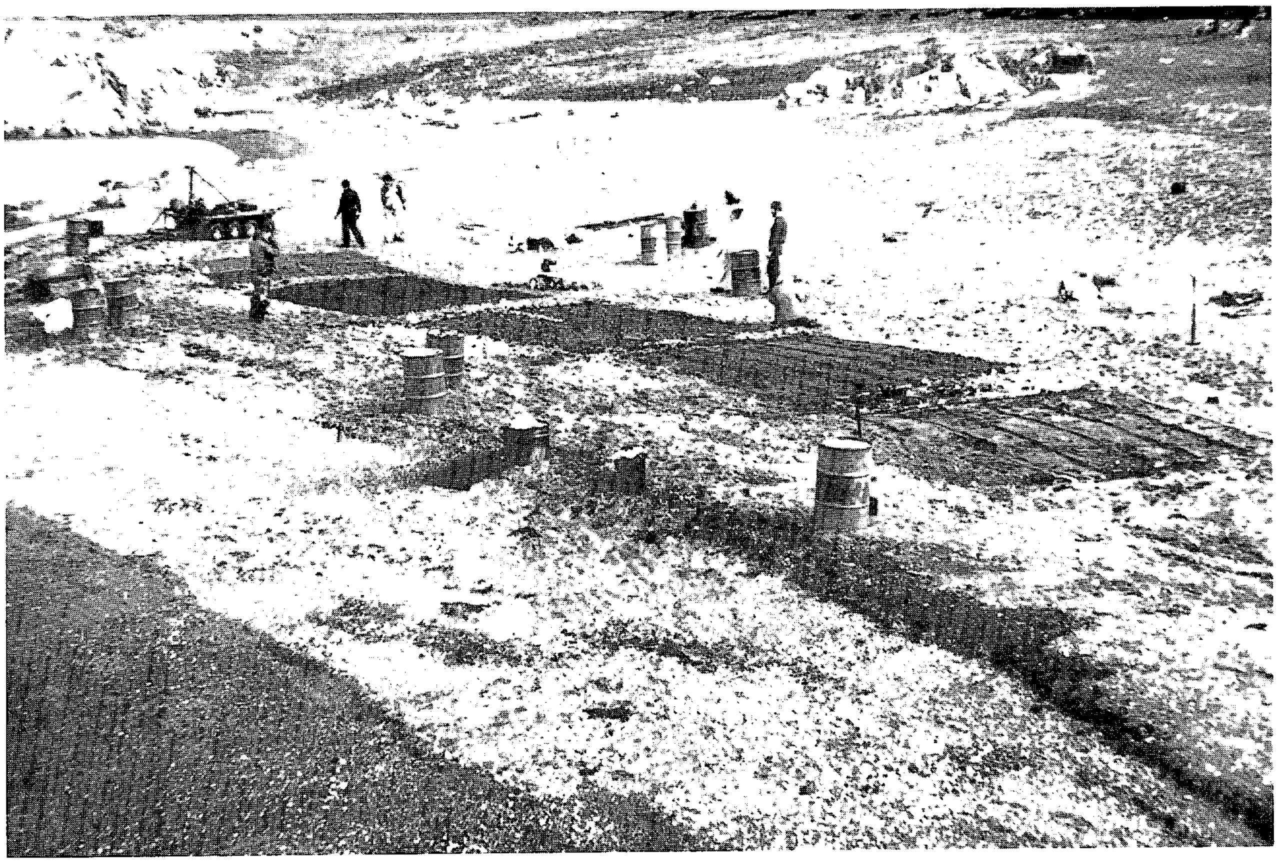


Figure 4.1 Photograph of Norwegian backshore test plots immediately after application of the water-in-oil emulsion. The swash line near the barrels is the 1980 storm-swash level and the lower swash line is the 1981 high-water swash line (1 August 1981).

TABLE 4.1 Oil Application, Recovery and Retention Volumes, Norwegian Test Plots (1 August 1981)

Plot Number	Volume* Applied		Volume Recovered		Volume Retained		Actual Loading
	m^3	Imp. Gal.	m^3	Imp. Gal.	m^3	Imp. Gal.	cm^3/cm^2
102.D	0.2	43	0.034	7*5	0.17	35.5	0.85
102.E	0.2	43	0.043	9.5	0.16	33.5	0.80
102.F	0.2	43	0.061	13.5	0.14	29.5	0.70
102.G	0.2	43	0.057	12.0	0.14	31.0	0.70
102.H	0.2	43	0.089	19.5	0.11	23,5	0.55

* Volume of oil applied, amounts should be doubled to reflect the volume of the emulsion which was applied.

Figure 4.2 Photograph of backshore test plots after partial submergence on 29 August 1981. Note the kelp on the central plots and the partial burial of the most distant plots.

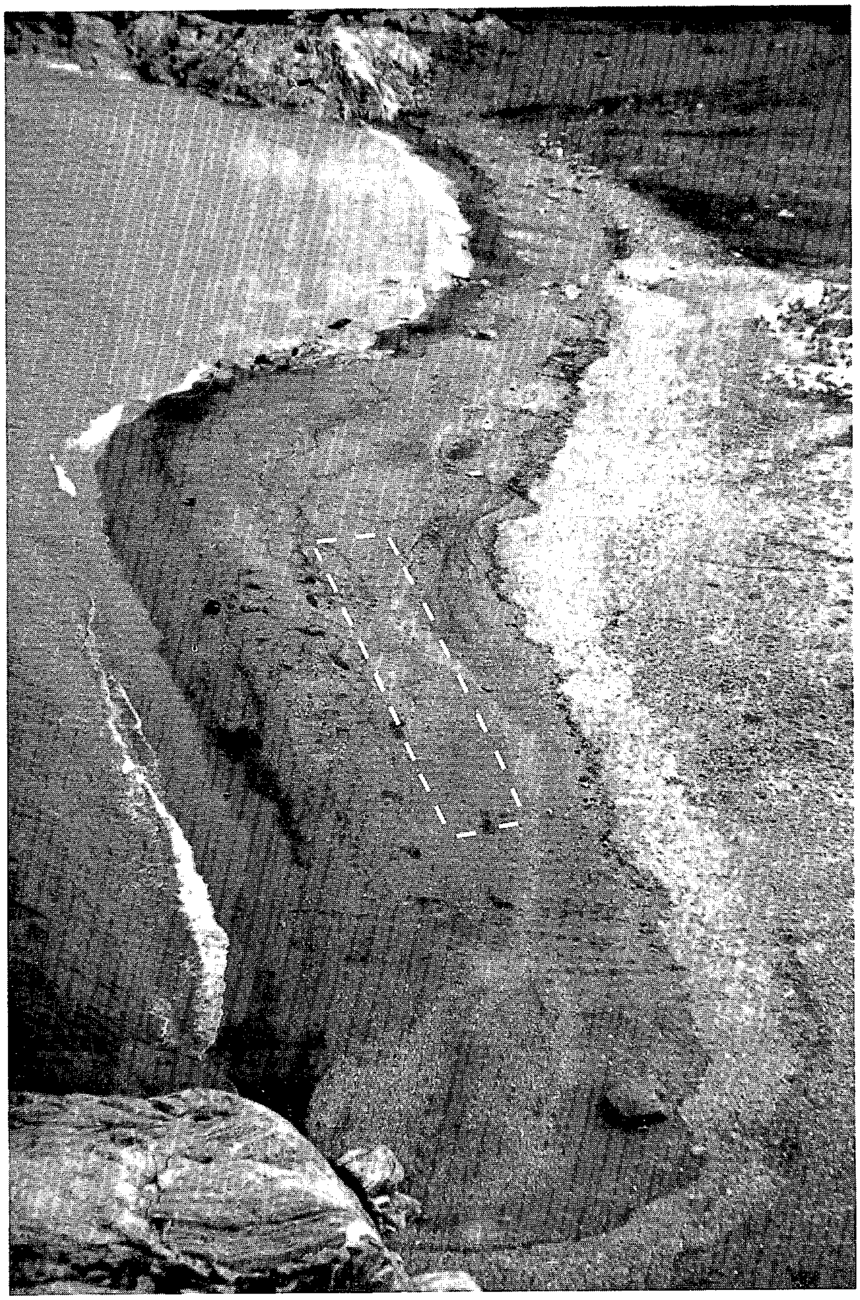


Figure 4.3 Photograph of backshore test plots after burial on 30 August 1981. The approximate position of the plots is shown by the dashed line (cf. position of the swash line with that of Figure 4.1).

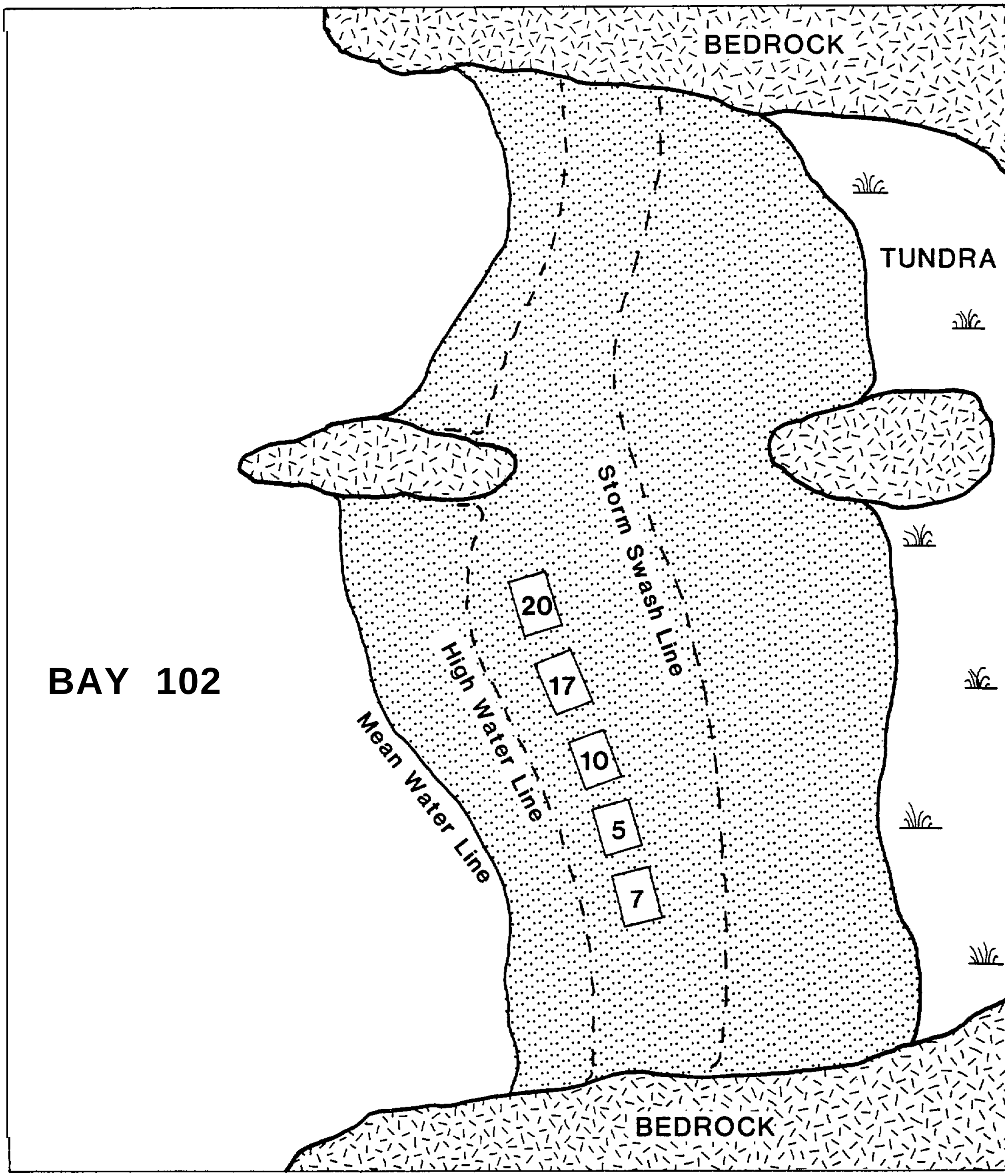


Figure 4.4 Schematic of Norwegian backshore plot locations and the subsequent average burial depth (in cm) of each plot.

The burial of the backshore test plots was unfortunate because it terminated the microbial decomposition studies. Nevertheless, the event is of interest in terms of understanding the effect of natural processes on spill behaviour. The interesting points are: (1) if the area of the test plots had been previously oiled by a spill, then the oiled surface would have been buried to a depth of 15 to 20 cm; (2) if a spill had occurred on the 29th of August, then the oil would have been stranded above the normal high-water level and subsequently buried the following day; (3) if a spill had occurred on the 30th of August, then the oil would have remained on the backshore surface, above the limit of normal high tides; (4) the oil which is now buried within the backshore sediments is unlikely to be reworked by shore-zone processes for several years; and (5) if these sediments are reworked in the future, there will be a recontamination of the lower portions of the intertidal zone.

The event illustrates the complex interaction that can take place between oceanographic processes and sediment redistribution in the shore zone. The unusually high tides that occurred over two days were not predicted, and on one day these high tides happened to coincide with a period of high wave activity and this resulted in an unusually high swash level. The fact that sediment accretion, rather than erosion, occurred in the backshore during a relatively high-energy event was also unusual. Prediction of such events is difficult even with a good environmental data base, and this illustrates the element of uncertainty that accompanies all spill situations.

5.0 COUNTERMEASURE EXPERIMENTAL DESIGN

5.1 INTRODUCTION

The 1981 shoreline countermeasure experiments were conducted on the north shore of Z-Lagoon adjacent to Crude Oil Point (Fig. 2.3). In order that the countermeasure experiments could be conducted efficiently and effectively, a series of initial tests were carried out to ensure that the oil-application system and the countermeasure methods themselves were applicable. The incendiary device, both dispersants, and the solidifying agent, were tested on both crude oil and water-in-oil emulsion test plots. On the basis of this experience, the main countermeasure experiments were carried out on the western shore of the entrance to Z-Lagoon (Fig. 2.3). The experimental sites were sampled prior to application of the oil, following application of the oil, prior to the countermeasure experiment, immediately following the countermeasure experiment, and on two subsequent occasions during the 1981 open-water season.

The purpose of these experiments was to determine the applicability of each of the selected countermeasures for arctic shoreline environments. Each countermeasure was to be evaluated in terms of the potential applicability of the technique and the effectiveness in terms of the persistence of stranded oil. No attempts were made to compare the techniques with each other. All of the selected countermeasures were tested on both crude and water-in-oil emulsion plots. Beach profiles were established on the section of shore which was used for the countermeasure experiments, and these were resurveyed at intervals prior to and following the experiments.

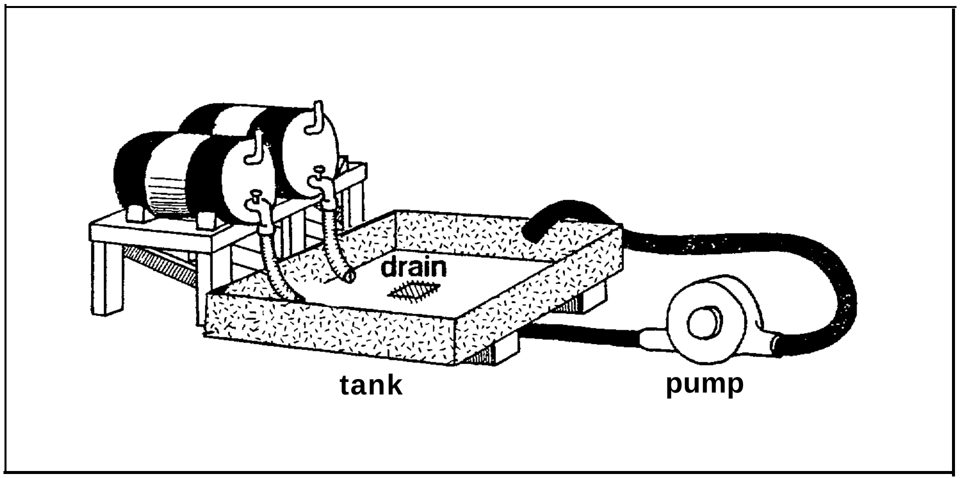
5.2 OIL-WATER EMULSIFICATION SYSTEM

Thirteen drums of weathered Lago Medio crude oil* and thirteen drums of seawater were used to manufacture twenty-six drums of (50% water-50% oil) water-in-aged crude oil emulsion. The system used to make the emulsion is shown in Figure 5.1. Two barrels of crude oil and two barrels of seawater were poured into a 1.8-m (6-foot) square fiberglass mixing tank. The oil/water mixture was then drawn off through a bottom drain and pumped through a 5-cm (2-inch) centrifugal pump back into the mixing tank. The pumping continued until an emulsion was formed (in most cases, this required only five minutes of pumping), The point at which an emulsion was formed was very obvious and was characterized by a shift in colour from black to brownish-black and a sudden increase in the viscosity of the mixture. The entire process, including setting up the system, making twenty-six drums of emulsion, and cleaning up the equipment, was accomplished in eight hours with a four-man crew.

Each 4-drum batch of emulsion was labelled (the lot batch E-7 consisted of only 2 drums) as to batch, and only oil from the same batch was used on any single experimental plot.

An attempt was made to re-emulsify two drums of emulsified oil which had been prepared a year earlier (1980), and which had been left at Crude Oil Point. The emulsion in each drum had broken and the oil and water were separated. The two drums of water and oil were poured into the mixing tank and recirculated through the pump for 1/2 hour. The oil and water would not re-emulsify, which indicates that oil emulsification with water is a one-time process only, and that once a water-in-oil emulsion breaks down, it will not re-emulsify even with a large amount of mixing energy.

*The Lago Medio crude oil was weathered by evaporative loss of 8% by weight of its initial volume.



(a)

(b)

Figure 5.1 Schematic (a) and photograph (b) of the oil-water emulsification system set up at Crude Oil Point in 1981 (30 July).

5.3 OIL-APPLICATION TECHNIQUE

For the tests and experiments, a small, self-contained all-terrain vehicle (ATV) was used to apply the oil onto the test plots. The application system proved to be flexible and performed well despite varying beach slope and sediment conditions.

The basic configuration of the application system is illustrated in Figures 5.2 and 5.3 (see also Fig. 4.2 in Woodward-Clyde Consultants, 1981b). The main components of the system consisted of: (1) an eight-wheeled, ARGO amphibious ATV, (2) a 45-gallon oil drum secured to the back of the ATV, (3) a gasoline-powered, centrifugal pump to transfer the oil from the drum to the distributor pipe (see Fig. 5.3b), which was designed to promote sheeting of the oil and to provide a more uniform oil distribution.

At the test site, a full drum of oil would be rolled up a ramp onto the platform of the ATV and connected by hose to the discharge pump. The ATV was then positioned to pass over the 2 x 10-m test plot.

The slope of the beach varied from plot to plot, so that the distributor bar was adjusted to the horizontal position immediately prior to the oiling of a plot to ensure an even flow of oil. The oil pump was started, and as the oil reached the distributor plate, the ATV transverse the test plot at a predetermined speed (Table 5.1). In practice, a single pass took between 60 and 90 seconds, depending on the viscosity of the oil at the time of application. Because the emulsified oil was comprised of 50 percent water, two passes over the same 2-m swath were required to apply the same amount of oil. The only major difficulty encountered during the application procedure was runoff of some oil from the test plots. In order to minimize cleanup operations, the problem of excessive runoff was countered by digging a trench at the base of the plot, lining it with polyethylene plastic, and removing the oil as it collected (see Fig. 5.4). This procedure also permitted an accurate estimate of runoff, as the amount of oil or emulsion that was removed from the trench was noted.

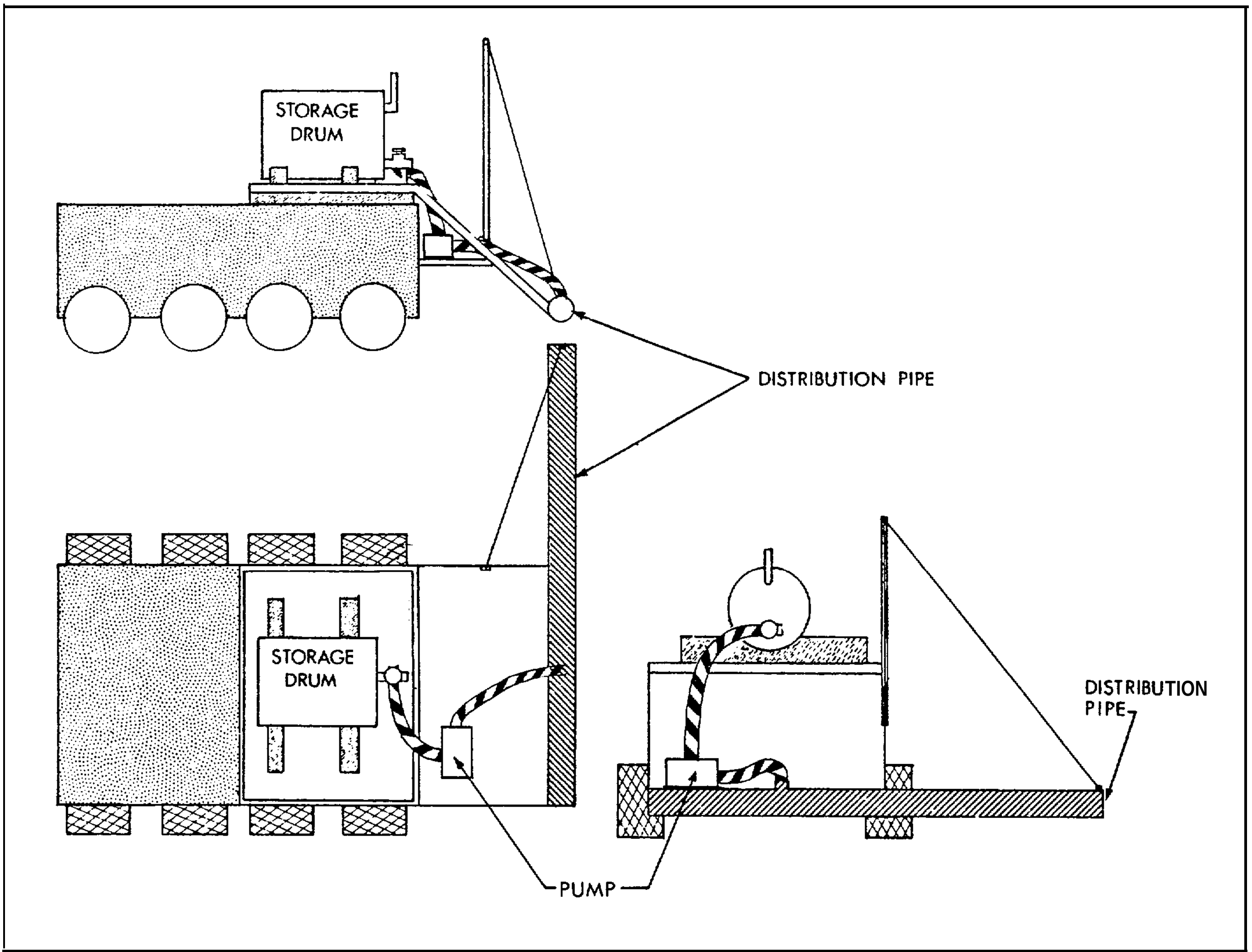


Figure 5.2 Diagram that illustrates the ATV-mounted oil application system used during the 1981 field programme.

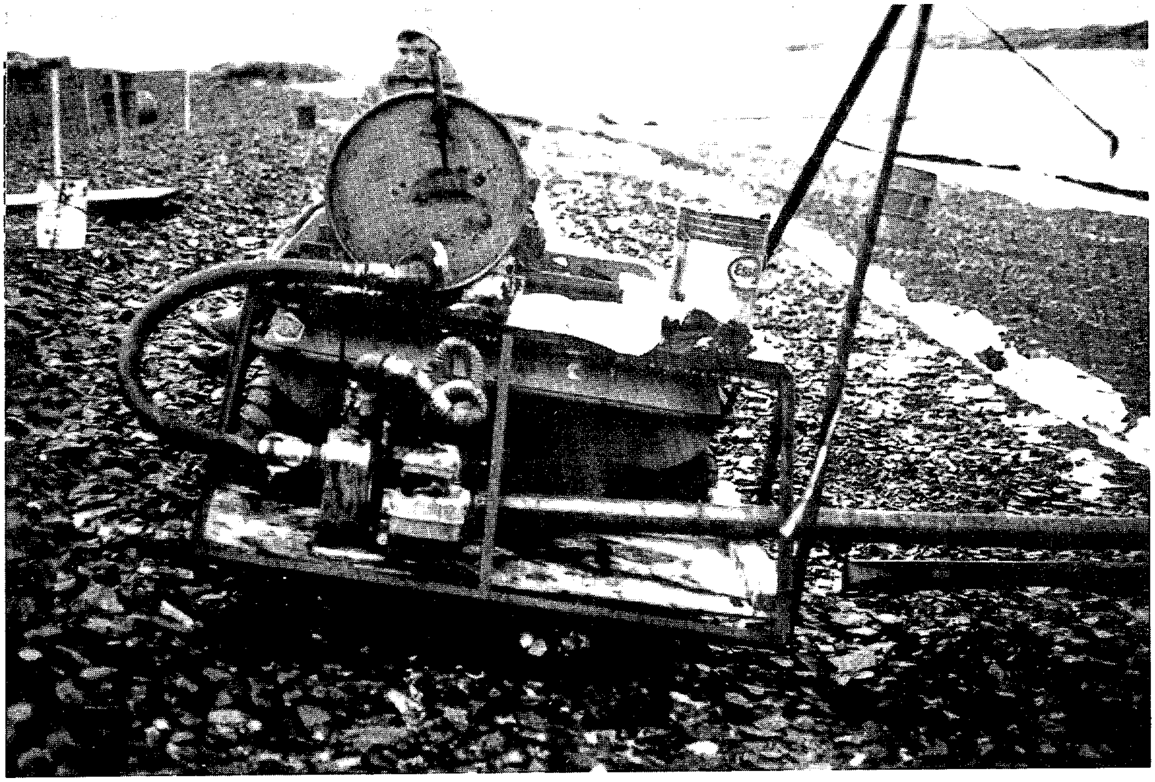


Figure 5.3 Views of the oil application system prior to oiling of (a) the ME and CE countermeasure plots on August 5th, and (b) the Norwegian plots in Bay 102 on August 1, 1981.

TABLE 5.1 Oil Application Parameters

Application System	modified, 8-wheel ATV with self-contained storage drum, pump, and distribution pipe
Capacity	0.208 m^3 or 208 1 (45 Imp. gallons)
Pumping Rate *	2.3-3.1 1/s (30-40 Imp. gal./min.)
Distribution Swath	2 m
Application Rates *	8-10 m/min. or 2.3-3.1 1/s (30-40 Imp. gal/rein)

*partially dependent on oil viscosity at the time of the spill

Figure 5.4 Plastic sheets and lined trench prior to oiling of the test plots on August 4, 1982.

Figure 5.5 View to the north of Crude Oil Point showing boom configuration during an experiment: 15:00 hours, August 6, 1981.

5.4 OIL SPILL CONTINGENCY MEASURES

Control measures were designed to minimize the spread of oil from the spill site that would contaminate adjacent beaches in Z-Lagoon or at Crude Oil Point. The following measures were taken prior to application of the oil to the test plots in order to minimize spillage during distribution of the oil and to collect oil refloated by rising tidal water levels:

- plastic drip sheets were installed at the end of each plot to catch oil dripping from the ATV distributor pipe (Fig. 5.3b),
- a trench was dug at the base of each plot, and the trench was lined with a plastic sheet to collect oil that ran off the test and experimental plots after application of the oil (Fig. 5.4),
- booms were installed adjacent to the test plots to collect oil that was lifted off by rising water levels; oil within the boom was collected using sorbent pads (Fig. 5.5), and
- oil and oiled sorbent pads were burned in barrels adjacent to the experimental plots to minimize the transportation of oil and oiled materials collected after the application procedure.

All the contingency measures were in place prior to application of the oil, and the booms were retained for a minimum of 24 hours following application of the oil onto the plot.

5*5 TEST PLOT LAYOUT

Oil was applied to a series of 2 x 2 m plots at the mean high-water level (Fig. 5.6) in the vicinity of Crude Oil Point (Fig. 2.3). The location of the plots with respect to the 1980 backshore control plots is shown on Figure 5.7. The oil was applied on a single traverse of the applicator system, and plot separation was achieved by a series of plastic sheets that were laid down between the plots (Fig. 5.4), Plot A (Fig. 5.6) was laid down initially to identify the expected retention of crude oil on the beach in the intertidal zone. This plot was laid down one day prior to application of oil to the test plots themselves.

The tests that were carried out were completed on August 4, and these tests involved application of the solidified and of both dispersants to the crude and water-in-oil emulsion plots. Four incendiary devices were used, one on a water-in-oil emulsion plot, two on crude oil test plots, and one which failed to ignite. Field logs for each of the tests are given in the Interim Field Report (Section 4.0).

5.6 EXPERIMENTAL LAYOUT AND SCHEDULE

The experimental beach plots were established on the west shore of the entrance to Z-Lagoon (Fig. 2.3). The actual layout of the plots with respect to the mean high-tide level is shown in Figure 5.8. The countermeasures were applied to the plot approximately 24 hours following application of the oil.

In addition to the countermeasure experimental plots, a single cross plot of oil was applied from the lowest low-water level across the intertidal zone to straddle the beach and to extend above the normal highest high-water level. This cross plot of crude oil was intended to be a reference point from which it would be possible to determine the upper limit of reworking by wave action of oil-contaminated sediments at this location.

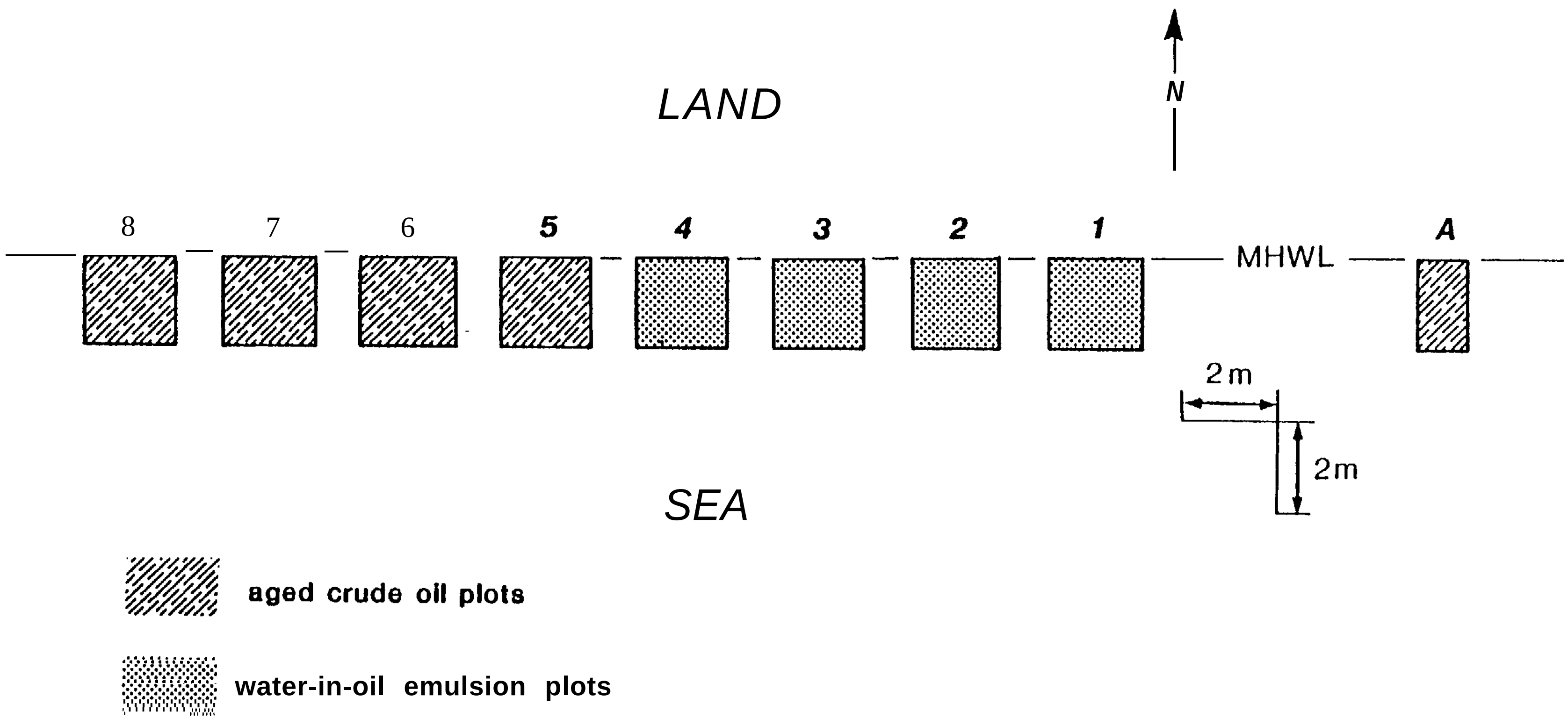


Figure 5.6 Layout of 1981 countermeasure test plots. The plots are located on Figure 2.3 and illustrated on Figure 5.7.

Figure 5.7 Aerial view of the test plots and the two backshore control plots (Tl and T2) at 14:30 hours on 4 August, 1981. Photograph taken at low tide: the mean high-tide level is at the upper limit of the test plots.

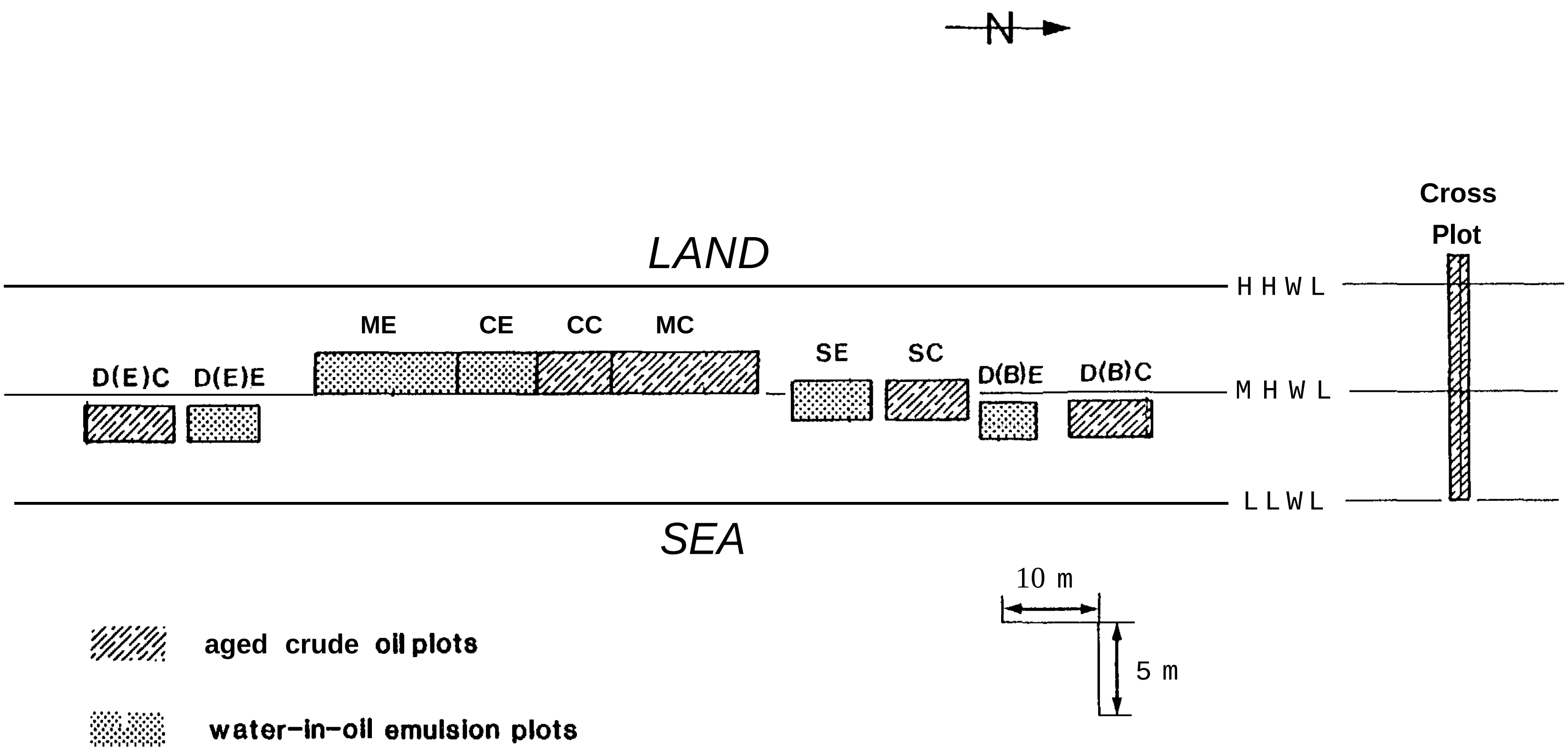


Figure 5.8 Layout of 1981 countermeasure experiment plots. The location of the plots is shown on Figure 2.3, and the plot identification codes are given in Table 5.2.

TABLE 5.2 Plot Identification Codes

D(E)C	Chemical Dispersion (Corexit 7664): Aged Crude
D(E)E	Chemical Dispersion (Corexit 7664): Water-in-oil Emulsion
ME	Mixing: Water-in-oil Emulsion
CE	Control: Water-in-oil Emulsion
CC	Control: Aged Crude
MC	Mixing: Aged Crude
SE	Solidified: Water-in-oil Emulsion
SC	Solidified: Aged Crude
D(B)E	Chemical Dispersion (BP 11OOX): Water-in-oil Emulsion
D(B)C	Chemical Dispersion (BP 11OOX) : Aged Crude
Cross Plot	Aged Crude

The schedule for the countermeasure activities is given in Table 5.3. More specific information on the timing of the experiments is provided on a series of field log sheets which are presented in the Interim Field Report (Section 4.0).

5.7 DATA COLLECTION AND ANALYTICAL TECHNIQUES

Beach profiles were surveyed at an alongshore interval of 20 m across the intertidal zone from the backshore towards the water level, at low tides. Surveys were taken (i) prior to the experiments, (ii) following application of the oil and the test procedure, and (iii) at approximately 22 days following completion of the experiment. The location of the beach profiles is shown on Figure 5.9, and all of the survey profiles are presented in Appendix A in this report.

A log of activities was maintained for each of the tests and experiments conducted at Crude Oil Point. These logs are given in the Interim Field Report (Section 4.0).

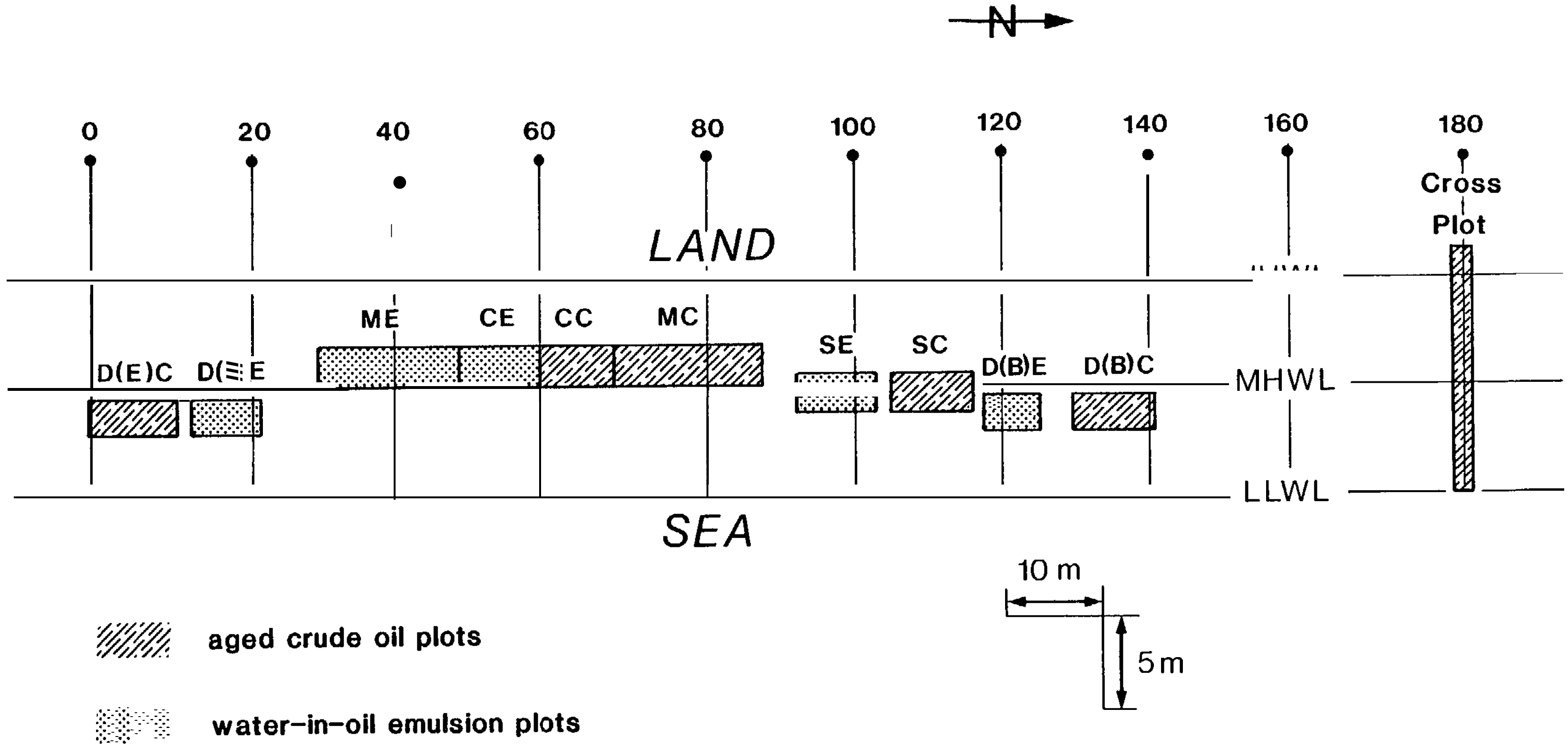


Figure 5.9 Location of beach profiles with reference to the countermeasure experimental plots.

TABLE 5.3 Countermeasure Experiment Activity Schedule

5 August	oil distributed onto plots D(E)C, D(E)E, ME, CE, CC and MC
6 August	mixing experiment on ME and MC chemical dispersion experiment on D(E)C and D(E)E oil distributed onto plots SE, SC, D(B)E and D(B)C
7 August	oil distributed on Cross Plot chemical dispersion experiment on D(B)E and D(B)C solidified experiment conducted on SE and SC

Sediment and oil-sediment samples were collected for analysis of freon-extractable hydrocarbons and for GC/MS analysis, The sample-collection design is described fully in the Interim Field Report (Section 2.0). Essentially, each plot was divided into l-m^2 sections, and each total hydrocarbon sample, from both the surface and subsurface, was a composite of 4 subsamples. For the total hydrocarbon analysis, the entire composite sample was analyzed. For the GC/MS analysis, only one sample was collected.

Total hydrocarbon samples were collected from the surface and subsurface of each plot at the following times:

- prior to application of oil,
- after application of the oil and prior to testing of the countermeasures technique,
- immediately following the countermeasure technique,
- 8 days following the countermeasure experiment, and
- 40 or 41 days following the countermeasure experiment.

In addition, samples of oil were taken from the barrels prior to the application of that oil onto the experimental plots.

Samples for GC/MS analyses were collected on the oiled plots (a) prior to the countermeasures experiment, (b) immediately following the experiment, (c) 8 days following the experiment, and (d) 40 or 41 days following the experiment. The GC/MS analyses are incomplete at the time of writing of this report, and the presentation and a full discussion of this data will be incorporated in future project reports.

6,1 INTRODUCTION

The primary objective of the countermeasure experiments was to test the effectiveness and efficiency of selected techniques that would be both applicable and practical in an arctic environment. Two factors were considered paramount in the selection of techniques to be tested. First, if a technique had already proven to be effective and efficient, for example, the use of a grader on a firm sand beach, then there would be little value in retesting the technique. Secondly, methods that are labour intensive, that involve sophisticated or dedicated equipment, or that require elaborate logistic support, were not considered to be practical for large-scale shoreline cleanup operations in remote arctic areas,

Four techniques were selected for testing during the 1981 field season following a consideration of available or potentially innovative methods for shoreline countermeasures:

(1) In-situ combustion using the DREV igniter;
(2) Chemical surfactants designed to disperse oil;
(3) Mechanical mixing of oil-contaminated sediments; and
(4) Application of a surface solidifying agent.

Preliminary discussions on the techniques resulted in the decision to utilize two dispersants (BP 11OOX and Corexit 7664) . It was clearly defined at this initial stage that the intent was to deduce the effectiveness and applicability of dispersants, rather than to compare specific products.

Each of these techniques is described in more detail in this section, and the results of the experiments are presented in Section 7.0.

6.2 INCENDIARY DEVICE

Incendiary devices have been developed by DREV to ignite confined oil slicks. The devices are described in detail by Meikle (1981), and were manufactured with the incendiary disc enclosed by plywood and styrofoam layers. Of the four incendiary devices that were used, one misfired. No attempt was made to ascertain the reason for this misfire. The devices were ignited by removal of a safety pin from the outer styrofoam case, and the igniter itself had a delay, to allow the operator to retire to an appropriate distance (Fig. 6.1).

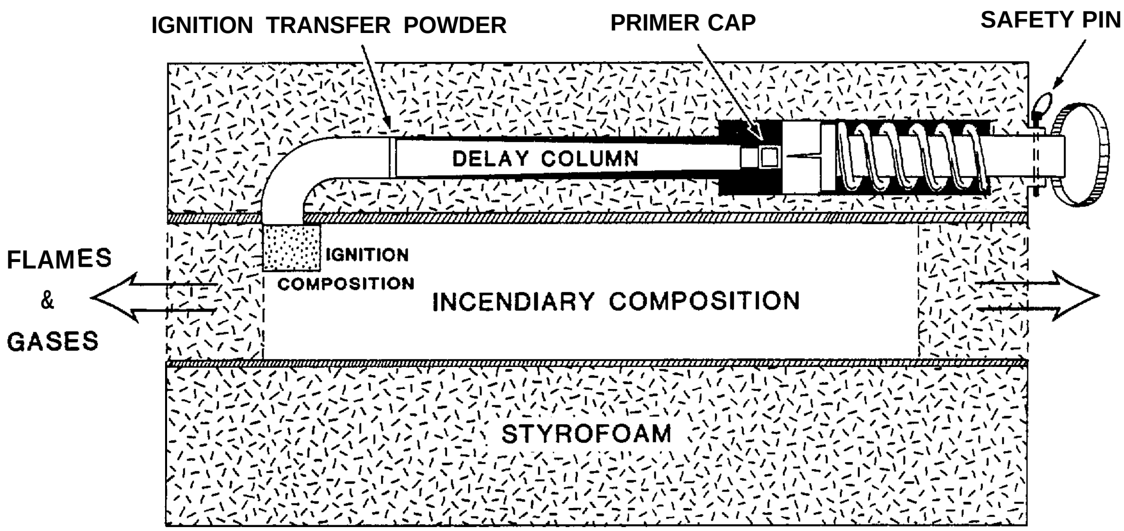


Figure 6.1 Schematic diagram of the DREV incendiary device used on the test plots (see also Figs. 7.6 and 7.7).

6.3 EXXON DISPERSANT

The dispersant Corexit 7664 was applied to both crude and water-in-oil emulsion plots using a 2"-internal diameter fire hose, a Homelite water pump, and an eductor for chemical addition (Fig. 6.2a). Approximately 45 litres of the chemical, diluted with sea water, were sprayed onto each of the two plots prior to an incoming tide. The oil-to-dispersant ratio was in the order of 4 to 1 by volume. Half of each of the chemically treated plots was then flushed with sea water using the fire hose, until little oil was observed in the runoff stream. The actual layout for the chemical dispersion experiments is shown in Figure 6.3.

(a)

(b)

Figure 6.2(a) Water intake hose (at top) connected with dispersant (small diameter hose from bucket) and outflow hose (centre and bottom).

(b) Application of dispersant (Corexit 7664) to crude oil plot D(E)C, August 6, 1981.

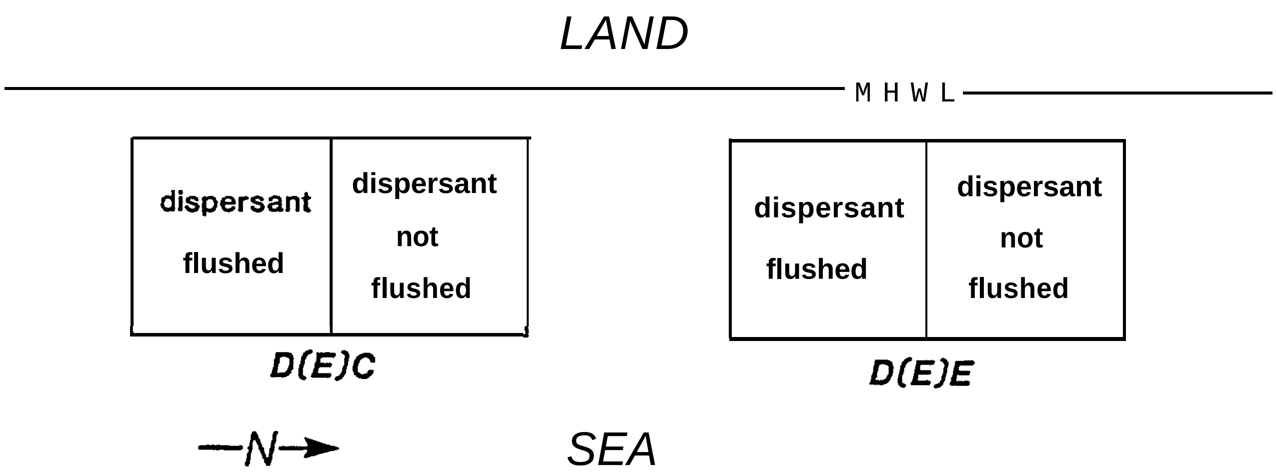


Figure 6.3 Layouts for chemical dispersion experiments on plots D(E)C and D(E)E, using Corexit 7664.

Corexit 7664 is composed of non-ionic surfactants in a water-based system, and was designed for use in the dispersal of oil on shorelines or for distribution onto shorelines threatened by floating oil, The dispersant stream (chemical plus water) was sprayed onto the beach using a fire-hose nozzle (Fig. 6.2b) so that the high velocity would force penetration of the chemical into the sediments and would provide mixing energy for the chemical-oil interaction. This was undertaken because Corexit 7664 does not have a "self-mix" composition.

Two test plots, each 10 m long and 2 m wide, were established as described earlier (Section 5.6). Approximately 25 hours following application of oil onto the plots, the dispersant was applied.

6.4 BP DISPERSANT

The dispersant BP 1100X consists of a solution of non-ionic surface-active agents in a hydrocarbon solvent. This dispersant is composed of oil-soluble emulsifiers designed to rapidly disperse oil into small particles without additional mixing procedures, such as flushing. A 5-litre Cooper-Pegler backpack hand sprayer was used to apply approximately 10 litres of dispersant to each of the test plots (Fig. 6.4), The

Figure 6.4 Application of BP dispersant to plot D(B)C using the backpack spray; August 7, 1981.

dispersant was applied neat (i.e., not diluted) to each plot approximately 45 minutes to 1 hour prior to the incoming high tide, 26 hours after the oil was laid down on the plots. The dispersant was then left to be flushed naturally by mechanical wave action.

6.5 MIXING

The two plots were mixed using a gasoline-powered rotovator that was deployed manually (Fig. 6.5). The rotovator was used to simulate the action of heavier equipment that could be deployed on a shoreline to disturb the surface sediments: for example, a bulldozer, a front-end loader, or tractor. Each of the two plots was thoroughly mixed to a depth in the order of 20 to 30 cm. Mixing took place on a rising tide, prior to water covering the plots, approximately 26 hours after the application of oil onto the experimental sections.

Figure 6.5 Rototilling plot ME, August 6, 1981.

6.6 BP SOLIDIFIED

A solidifying agent, developed by BP, was applied to crude and oil-emulsion plots to encapsulate the stranded oil. The agent consisted of a polymer and a cross-linking agent that solidified to form three-dimensional lattices that absorbed and contained the oil. Essentially, the solidifying compound produced a liquid rubber that hard-ens to form a rubber-like material.

Two cross-linking agents were used, a slow and fast cross link, and were raked, with the polymer, into the oil-contaminated sediments. The exact techniques and their distribution on the experimental plots are shown in Figure 6.6. The plot upon which the polymer was mixed with a slow cross-link and not raked involved application of 20 litres of the polymer with 6 litres of the slow cross link. The central sections of the plot were treated with 40 litres of the polymer and 10 litres of the slow cross 1 ink. These agents were premixed and raked into the oil-contaminated sediments (Fig. 6.7). On the third section of each plot, 20 litres of the polymer were raked into the oil-contaminated sediments, followed by 5 litres of the fast cross-link agent, which were also raked into the sediments.

The active ingredients of the solidifying compound account for approximately only 5 percent by volume. The remaining volume consists of odourless kerosene.

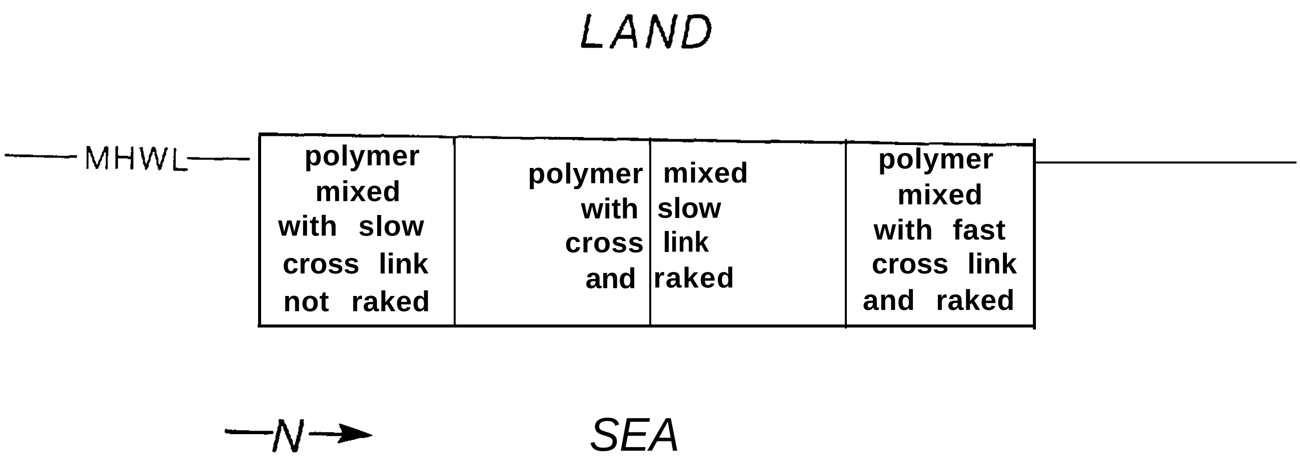


Figure 6.6 Layout used for both gel experiments on plots SE and SC (see also Fig. 5.8, page 5-13).

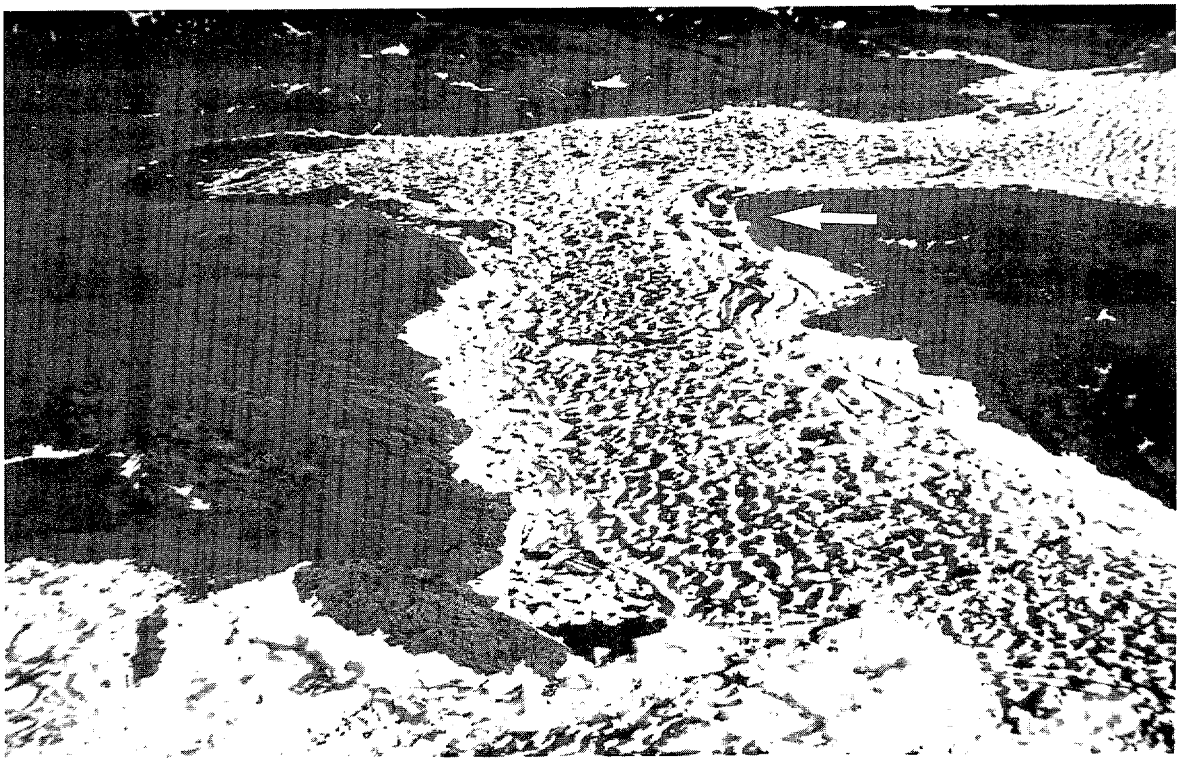
Figure 6.7 Distribution of polymer to one of the test plots, August 4, 1981. The scale indicates 5 cm squares.

7.0 COUNTERMEASURE EXPERIMENT RESULTS

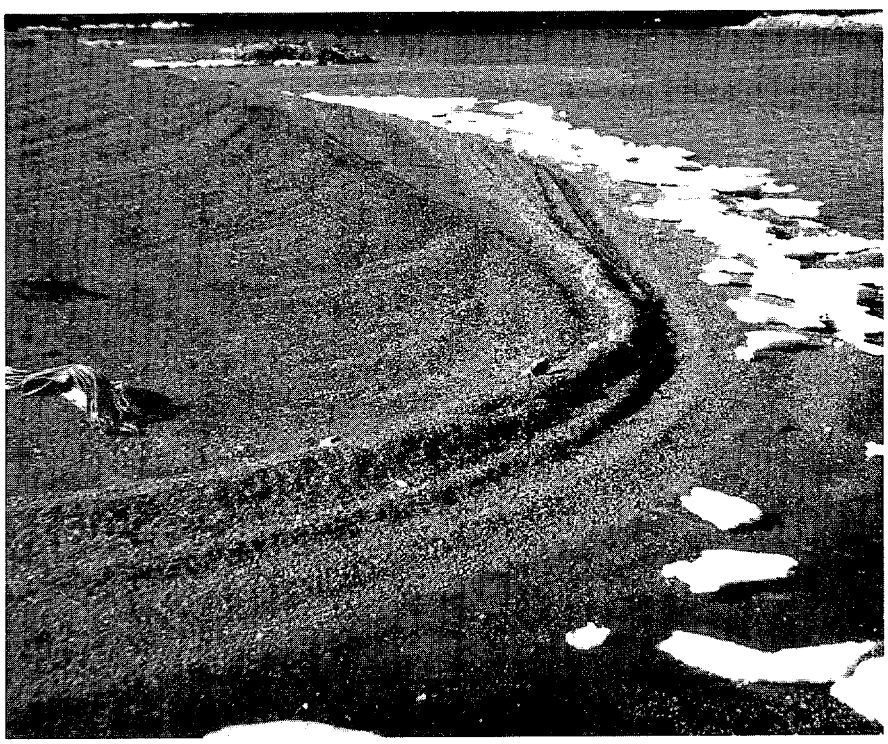
7.1 INTRODUCTION

The 1981 countermeasure experiments were conducted at Crude Oil Point at the entrance to Z-Lagoon (Figs. 2.3 and 7.1a). Crude Oil Point is a modified recurved spit (Fig. 7.1b) that has been formed by the longshore transport of sediments that are predominantly in the sandy-gravel size range. Recent changes in relative sea-level elevations have resulted in the abandonment of a series of active beaches to produce a set of backshore raised gravel beaches (Fig, 7.1b).

The spit has grow-n towards the south into Z-Lagoon as a result of waves out of the north and northeast. Relatively deep water depths in the channel allow moderate-sized waves (>0.75 m) to rework the beach sediments. The maximum fetch distances for this area on the south coast of Eclipse Sound are in the order of 30 - 100 km towards the north and northeast. Waves from this quadrant would dissipate their energy directly on the exposed beaches (e.g. , the “High-Energy Plots” on Bay 102; Fig. 2.2), but these waves would be partially refracted and modified before reaching the countermeasure beach site, due to the partial protection afforded by the channel entrance. By contrast, the “Low-Energy Plots” in Bay 103 in Z-Lagoon are sheltered from waves generated in Eclipse Sound, and these plots have a maximum fetch distance of only 2 km. The countermeasure experiments were conducted on a beach that could be considered as characterized by “moderate” energy levels for arctic coasts.



(a)



(b)

Figure 7.1 Aerial views of Crude Oil Point: (a) looking towards the south from Eclipse Sound into Z-Lagoon, 30 July 1979, and (b) detail of the Point looking north on 29 July 1981. The lower photo is located by the arrow on (a).

It is important to note that following the countermeasures experiments on Crude Oil Point the beaches were subject to storm-wave activity during a period of high water levels (a storm surge) that resulted in reworking of all of the beach sediments to elevations above the normal limit of wave activity. The high tidal water levels reached 1.2 m above the mean water-level datum used for this study. Wave heights in the order of 0.5 m resulted in reworking of sediments at elevations up to 1.75 m above the mean water level.

A Cross Plot was established at the northern end of this experimental beach to provide a long-term control for the upper limit of active sediment or oil reworking on this shoreline. The Cross Plot extended well above the highest limit of wave activity that was evidenced by sediment reworking or debris deposition on this section of coast. As a result of the storm, the entire cross plot was eroded (see discussion below, Section 7.2). The storm was not considered particularly unusual, as a similar event occurred during the 1980 open-water season. The only potentially unusual aspect of this storm during 1981 was the high water levels induced by strong onshore winds that coincided with a high tide.

7.2 CONTROL PLOTS

Following application of the aged crude oil it was determined that the runoff from the plot was minimal, and that the approximate loading of oil to the plot was 0.91 cm^3/cm^2 (Table 7,1) . The mean value of loading for all of the aged crude oil plots was 0.876 cm^3/cm^2. By contrast with the water-in–aged crude oil emulsion there was a significant runoff of oil into the lined trench at the base of the plot, and approximately 40 percent of the emulsion was retrieved. The approximate loading of this plot was 0.52 cm^3/cm^2, with a mean value for all of the water-in-oil emulsion plots of 0.632 cm^3/cm^2 (Table 7.1). In general, more oil was retained on the aged crude oil plots than on the water-in-oil emulsion plots.

Total hydrocarbon samples were collected on the mixing and control plots prior to the mixing experiment. These data indicate that the total hydrocarbon content of the composite surface sample (4 subsamples that were

TABLE 7.1 Volumes of Oil. Applied to Countermeasure Plots

PLOT	VOLUME OF* OIL APPLIED		VOLUME OF* OIL RECOVERED		TOTAL LOADING* OF OIL		APPROX.* LOADING
	m^3	Imp. Gal.	m^3	Imp. Gal.	m^3	Imp. Gal.	cm^3 / cm^2
Control:Crude (CC)	0.19	42	0.01	2	0.18	40	0.91
Control:Emulsion (CE)	0.18	40	0.08	17	0.10	23	0.52
Exxon Disp:Crude D(E)C	0.19	42	0.01	2	0.18	40	0.91
Exxon Disp:Emulsion D(E)E	0.18	40	0.05	10	0.14	30	0.68
BP Disp:Crude D(B)C	0.18	40	0.02	5	0.16	35	0.79
BP Disp:Emulsion D(B)E	0.18	40	0.05	10	0.14	30	0.70
Mixing:Crude (MC)	0.39	85	0.02	4	0.37	81	0.91
Mixing:Emulsion (ME)	0.36	80	0.15	33	0.21	47	0.53
Solidify:Crude (SC)	0.18	40	0.02	5	0.16	35	0.79
Solidify:Emulsion (SE)	0.19	41	0.04	9	0.15	32	0.73

*Volumes and loading rates refer to amount of aged oil only - volumes of water-in-aged oil emulsification would be double those indicated.

mixed together for analysis) was 2.1 percent (by weight) on the aged crude oil control plot, and 1.2 percent on the water-in-aged crude oil plot (Table 7.2 and Fig. 7.2). On both plots there was significant penetration of the oil, and composite samples indicate that total hydrocarbon values in the order of 0.3 percent and 0.1 percent characterize the subsurface sediments of the aged crude and water-in–oil emulsion plots respectively.

It is interesting to note that samples collected from Bay 11 show total hydrocarbon values in the range of 0.019 to 3.6 percent immediately following stranding of the spilled oil. Seventeen of the 33 sample values fell within the range of 0.5 to 2.0 percent, with 14 of the remainder having values less than 0.5 percent. This indicates that the volume of oil contained in the surface sediments on the plots to which oil was applied artificially is in the same range as those plots where the oil was allowed to drift onshore "naturally." Thus the oiling procedures used during this experiment replicate accurately situations where oil is washed ashore on the water surface.

Eight days after the oil had been laid down on the two control plots, the total hydrocarbon values remained within the range of values of those samples collected immediately following application of the oil (Table 7.2) . However, by day 41 following application of the oil to the control plots the values had lowered to less than 0.3 percent by weight of oil in sediment for surface samples, and less than 0.01 percent for the subsurface values (Fig. 7.3). This reduction in the total hydrocarbons resulted primarily from reworking of the sediments by wave activity, although it is possible that dispersant washed from nearby test plots could have had a small effect in reducing oil contents on the control plots. The changes in the beach profiles between August 2 and August 30 (Profile line 60, Fig. 5.9) indicate that the beach surface had been lowered by approximately 10 cm, as a result of strong wave activity reworking the beach sediments. In particular, storm waves on August 29 and 30 resulted in significant reworking of all of the countermeasure experiment plots.

TABLE 7.2 Total Hydrocarbons in Composite Samples (in Weight Percent)

PLOT	PRE-OIL	POST-OIL/ PRE-TEST	POST TEST	+8 DAYS	+40/41 DAYS
Control:Crude (CC)					
Surface sample		2.1		1.7	0.311
Subsurface sample		0.302		0.15	0.015
Control:Emulsion (CE)					
Surface sample		1.2		2.17	0.093
Subsurface sample		0.106		0.038	0.011
Exxon Disp:Crude (D(E)C					
Surface sample	0	2.5	0.61	0.044	0.036
Subsurface sample		0.03	0.59	0.24	0.017
Exxon Disp:Emulsion D(E)E					
Surface sample		2.4	2.0	0.24	0.033
Subsurface sample		0.014	0.051	0.029	trace
BP Disp:Crude D(B)C					
Surface sample		0.431	1.05	trace	trace
Subsurface sample			0.31	0.32	trace
BP Disp:Emulsion D(B)E					
Surface sample		0.737	0.27	0.007	trace
Subsurface sample		0.007	0.44	0.008	trace
Mixing:Crude (MC)					
Surface sample	trace	2.1	2.8	0.498	1.9
Subsurface sample		0.302	1,0	1.6	0.188
Mixing:Emulsion (ME)					
Surface sample	trace	1.2	2.1	1.9	0.188
Subsurface sample		0.106	0.029	0.031	0.019
Solidify:Crude (SC)					
Surface sample		1.4	2.3	0.176	1.87
Subsurface sample		0.37	4.0	0.449	0.29
Solidify:Emulsion (SE)					
Surface sample		1*9			
Subsurface sample		0.026	0.023		

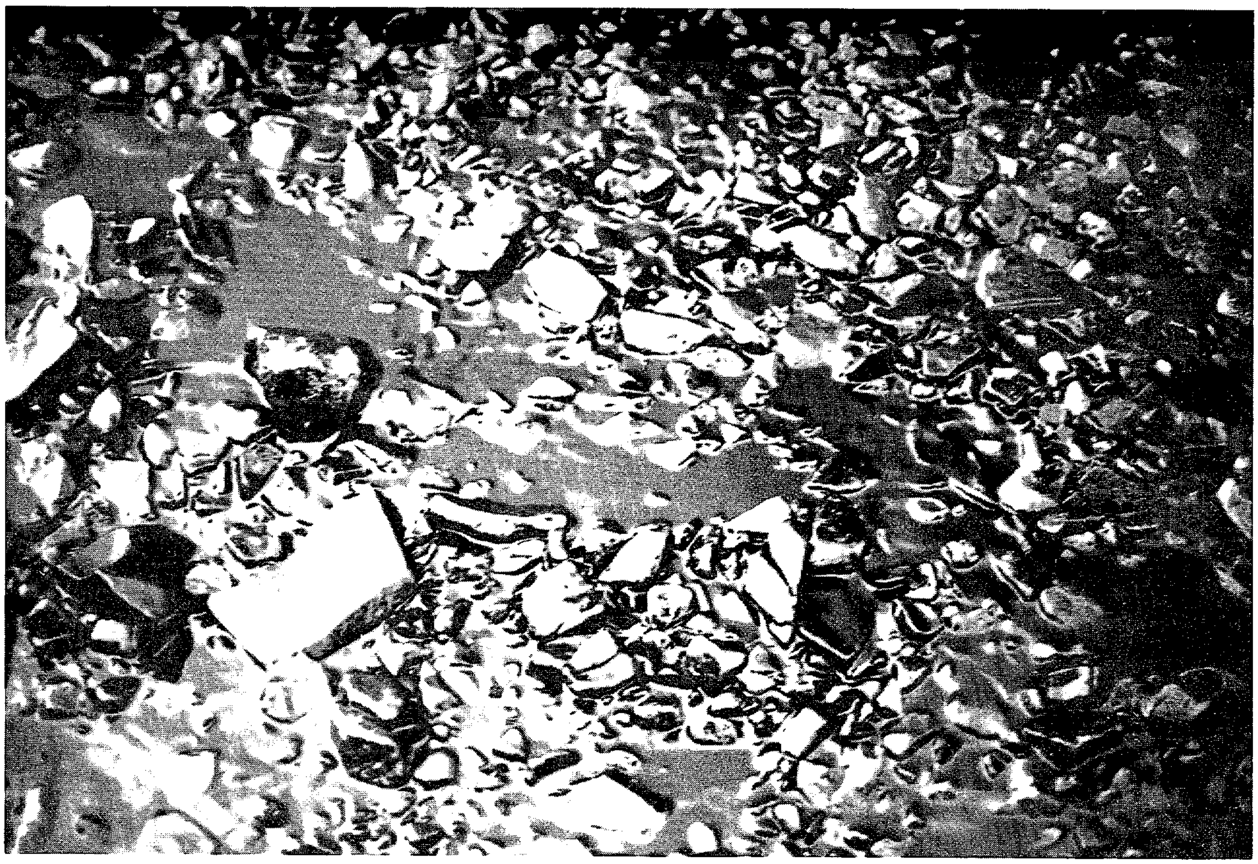


Figure 7.2 Closeup of water-in-oil emulsion on the surface of an intertidal plot.

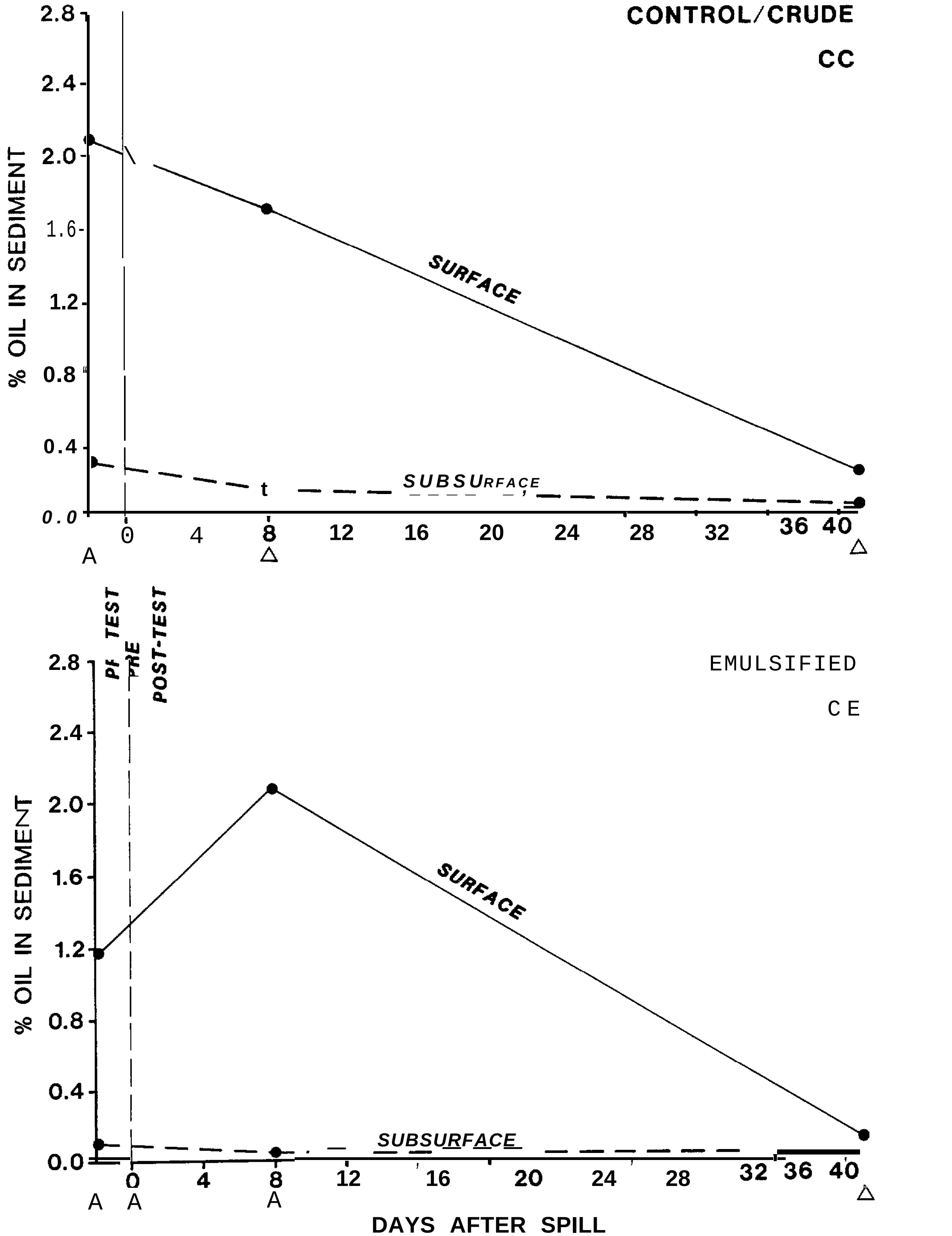


Figure 7.3 Total hydrocarbon values expressed as a percentage by weight of oil in sediment. Day 0 is August 6 and Day 41 is September 16, 1981.

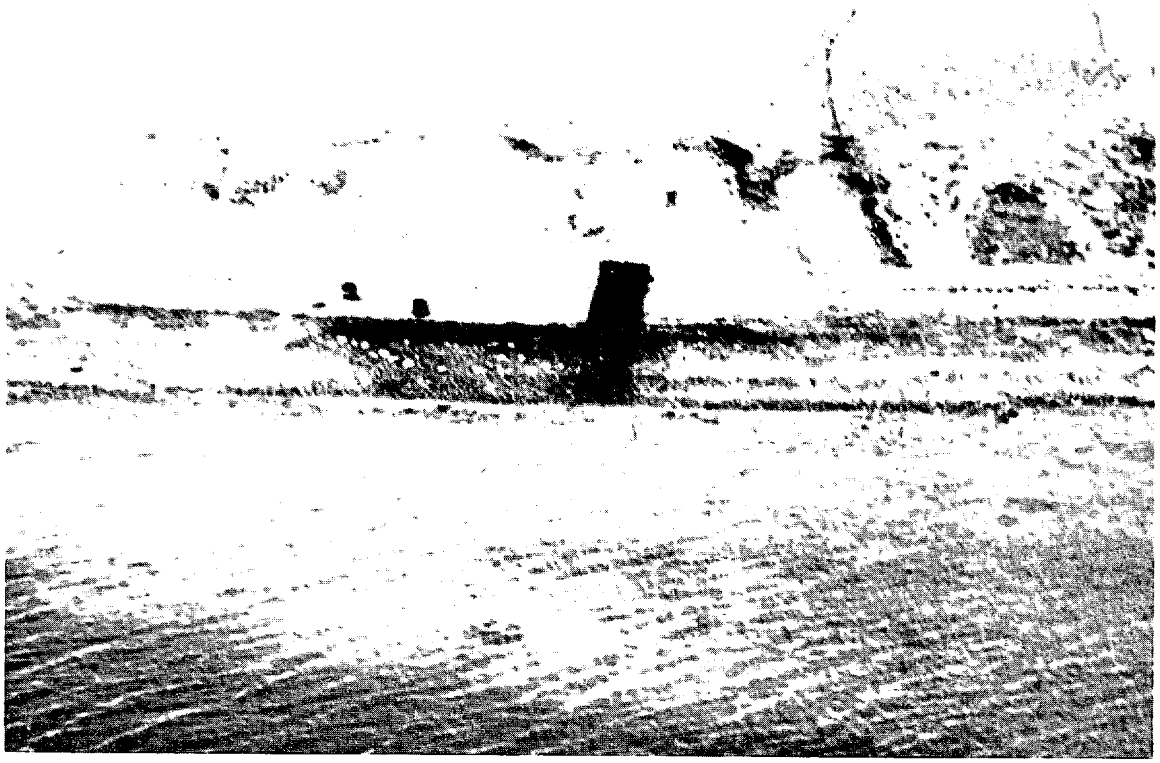
Over the 40-day period covered by the sample collection programme, the volume of oil in the surface and immediate subsurface sediments was reduced from approximately 2.0 percent to less than 0.3 percent. Natural cleaning of the oiled plots was therefore a relatively effective process during this short period. Similar natural cleaning of oiled plots in the intertidal zone occurred on the high-energy test plots in Bay 102 (see Section 3.0). It can be concluded, therefore, that oil stranded within the intertidal zone on the exposed or moderately exposed beaches in this region would likely be cleaned by normal and/or storm-wave processes during one or two open-water seasons, depending upon the length of the open-water season and wave generation during that period.

An initial analysis of the GC/MS data shows that evaporative weathering can be clearly identified on both the aged crude and water-in-oil emulsion plots (Table 7.3). Over the sample period, the SHRW values were reduced from 3.0 to 1.6 and 3.0 to 1.4 respectively for the crude and emulsion plots. Biodegradation was less apparent on either of the plots, and the Alkane/Isoprenoid ratio is initially inconsistent on the crude plot, but by the end of the sample period, was reduced to 1.6. Biodegradation data from the water-in-oil emulsion plots show no significant biodegradation at the end of the sample period when compared to the initial sample.

A further indication of the degree of reworking by wave action is given by examination of the oil swath that was laid down to the north of the countermeasure experimental area as a Cross Plot. The oil on this plot was laid down at a low tide from the lowest low-water mark to an elevation approximately 1 m above the highest high-water mark on August 8 (see Profile 180 in Appendix A). Comparison of an aerial photograph taken on the 9th of August, approximately 50 hours after the oil had been applied to the Cross Plot, with a ground view on the 29th of August (Fig. 7.4) indicates that much of the oil laid down in the intertidal zone had been reworked and redistributed from the Cross Plot prior to the 29th of August. The beach profile indicates that erosion to a depth of 10-15 cm had taken place up to an elevation of 1.0 m above the mean water level, an elevation which would correspond to the large boulder indicated by the arrow on Figure 7.4b. Following a period of storm-wave activity on the 29th and

TABLE 7.3 Initial GC/MS Results: Aging Ratios

	EVAPORATIVE WEATHERING			BIODEGRADATION		
	Saturated Hydrocarbon Ratio Weathering			Alkane to Isoprenoid Ratio		
Days Following Test	0	+8	+40/41	0	+8	+40/41
Control:Crude (CC)	3.0	2.6	1.6	2.1	2.6	1.6
Control:Emulsion (CE)	3.0	2.3	1.4	2.7	2.6	2.7
Exxon Disp:Crude D(E)C	2.3	1.8	1.9	3.2	4.1	2.6
Exxon Disp:Emulsion D(E)E	1.9	1.9	-	3.2	2.8	-
BP Disp:Crude D(B)C	7.0	1.4	2.6	3.8	2.9	2.7
BP Disp:Emulsion D(B)E	20.9	3.3	1.2	5.3	4.5	1.2
Mixing:Crude (MC)	3.0	1.8	2.0	2.1	2.1	2.5
Mixing:Emulsion (ME)	3.0	2.1	2.0	2.7	4.0	2.1
Solidify:Crude (SC)		6.6	-		4.2	-
Solidify:Emulsion (SE)	105.0	5.2	-	5.0	8.1	-



(a)

(b)

Figure 7.4 Cross Plot (a) 2 days following the oiling (14:30 on 9 August) and (b) on 29 August.

30th of August, the entire beach was further eroded and no traces of the Cross Plot remained on the profile. Comparison of Figure 7.5 with Profile 180 (in Appendix A) indicates that erosion had taken place to form a notch at approximately 1.75 m above mean water level, which corresponded to the upper limit of the Cross Plot, so that the entire Cross Plot had been eroded during this storm.

7.3 INCENDIARY DEVICE TESTS

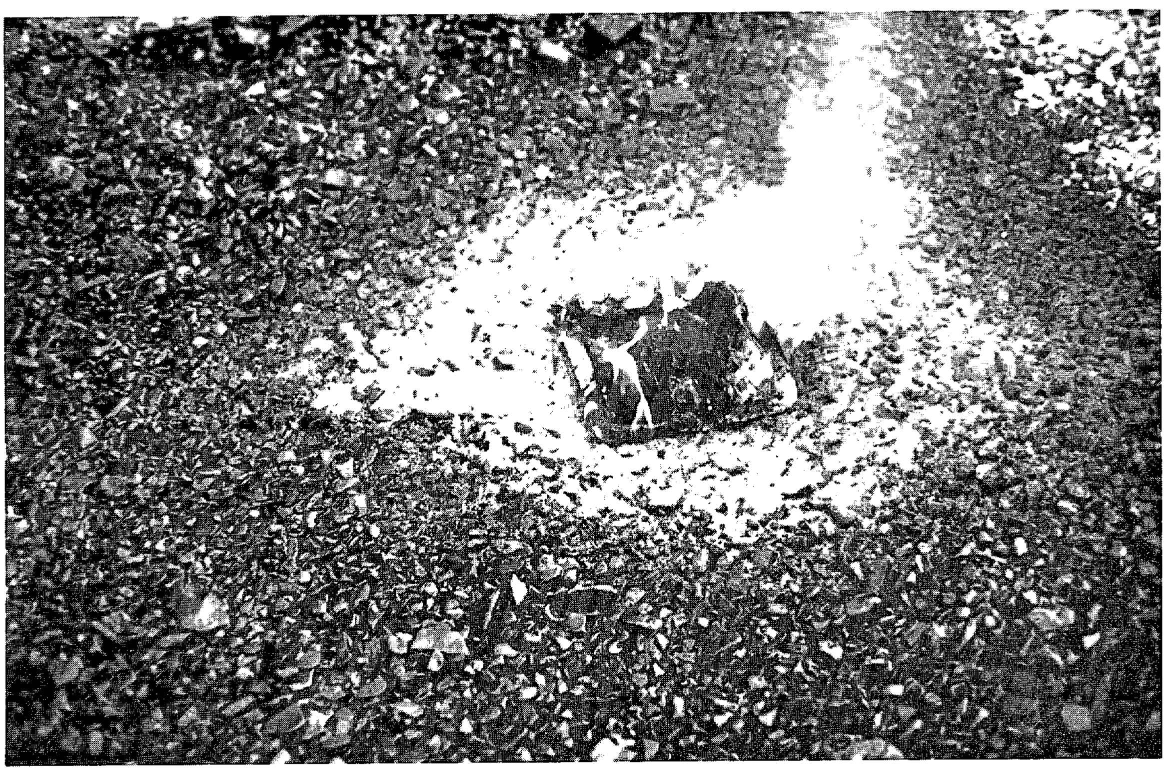
A series of precountermeasure tests were conducted on the south-facing shore of Crude Oil Point on 4 August. The first test was conducted on the water-in-oil emulsion Plot No. 8. The first device that was activated did not ignite, for unknown reasons. A second device was placed on the plot, and this burned for approximately 5 min. (Fig. 7.6a). The oil on the surface of the plot was not ignited except within a very short distance of the incendiary device (approximately 20 cm). A gray-coloured residue was left on the surface of the plot in the vicinity of the incendiary device, and this was probably some of the incendiary composition material released during burning of the device (Fig. 7.6b).

A second test, on Plot No. 1 using the incendiary device On a water-in-oil emulsion surface, similarly failed to ignite the oil (Fig. 7.7). On this test burn, two small pools of oil immediately adjacent to the incendiary device were not ignited even though the surface of the oil was heated and bubbled. Hot splashes of the incendiary composition landed in the small oil pools, but these also produced no flame.

An additional incendiary devices was ignited on an aged crude test plot (No. 7), and again the oil was not ignited. On the basis of these tests, it was decided not to conduct a countermeasure experiment at Crude Oil Point. The conclusion was drawn that the incendiary device would not be a practical countermeasure technique for stranded oil that had been deposited on the shore. The ignition tests took place on plots that had been oiled only a matter of hours previously, before those plots were submerged by a high tide.

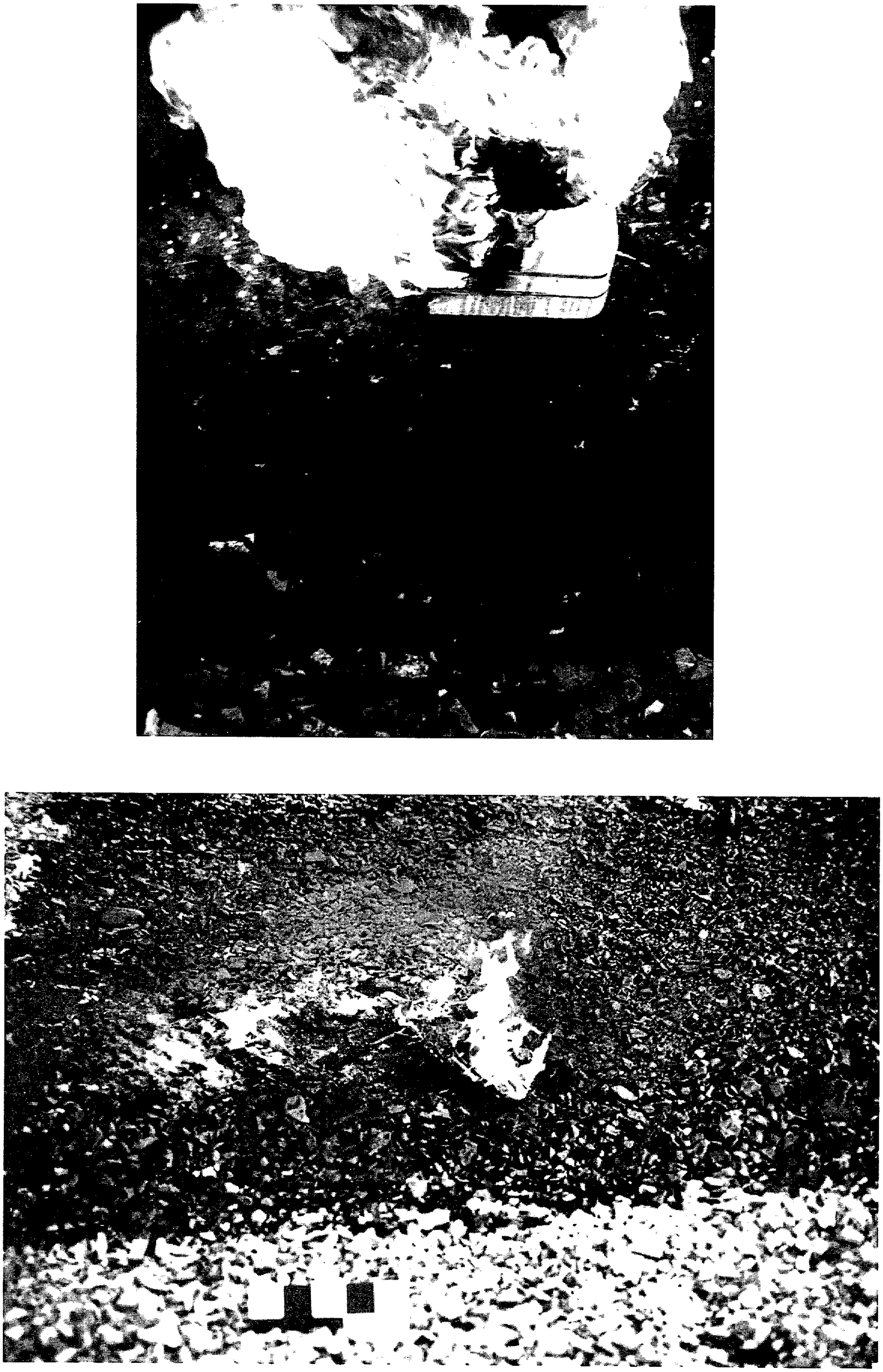
Figure 7.5 Cross Plot on 30 August 1981. The boulder indicated by the arrow is the same as that shown on Figure 7,4b.

(a)



(b)

Figure 7.6 Burn test on Plot No. 8 (4 August 1981): (a) general view 2 minutes after ignition, and (b) closeup of the burned-out device illustrating the grey residue and the unburned oil.



(a)

(b)

Figure 7.7 Closeup view on Plot No. 1: (a) during the initial ignition phase, and (b) closeup view on Plot No. 1 following the burn test (scale indicates 5 cm^2) (4 August, 1981).

7.4 EXXON DISPERSANT

The dispersant Corexit 7664 was applied to the crude oil and water-in-oil emulsion plots (D{E}C) and (D{E}E) approximately 26 hours after the oil had been laid down on those plots. The volumes of oil or emulsion that were applied and retrieved are indicated in Table 7.1. The two plots were divided in half, so that the southern half of each could be flushed following application of the dispersant (see Fig. 5.11).

Samples were collected from the two halves of each plot for total hydrocarbon analysis, but unfortunately these were composite, so that the total hydrocarbon data reflects a total analysis of four samples from the entire area of each of the crude, aged oil and the emulsified oil plots. The results of the total hydrocarbon analysis indicate that the initial oil loading on the surface of the plots was approximately 2.5 percent. The oil did not readily penetrate into the sediments, and subsurface sample values are low, less than 0.3 percent (Fig. 7.8 and Table 7.2).

Samples collected following the countermeasure experiment, on the same day before the plots were covered by the high tide, indicate that on the crude plot the surface and subsurface values were almost identical, but that on the emulsified plot, relatively little change had taken place as a result of the dispersant. More significant are the data from eight days following the experiment, by which time the surface values had been reduced from the post-test values by an order of magnitude. At this time the subsurface samples had also been considerably reduced, by approximately 50 percent from the post-test values. At day plus 40, the sample values were in all cases low; surface sample values were below 0.036 percent and subsurface values less than 0.017 percent.

The initial results from the GC/MS analysis of samples collected on both the aged crude oil and the water-in-oil emulsion plots show no significant differences that can be attributed to evaporative weathering or to biodegradation (Table 7.3). The high value of 4.1 on day 8 for the biodegradation is probably a result of an increase in the lighter fractions due to the presence of these fractions in the dispersant that was applied to the plot.

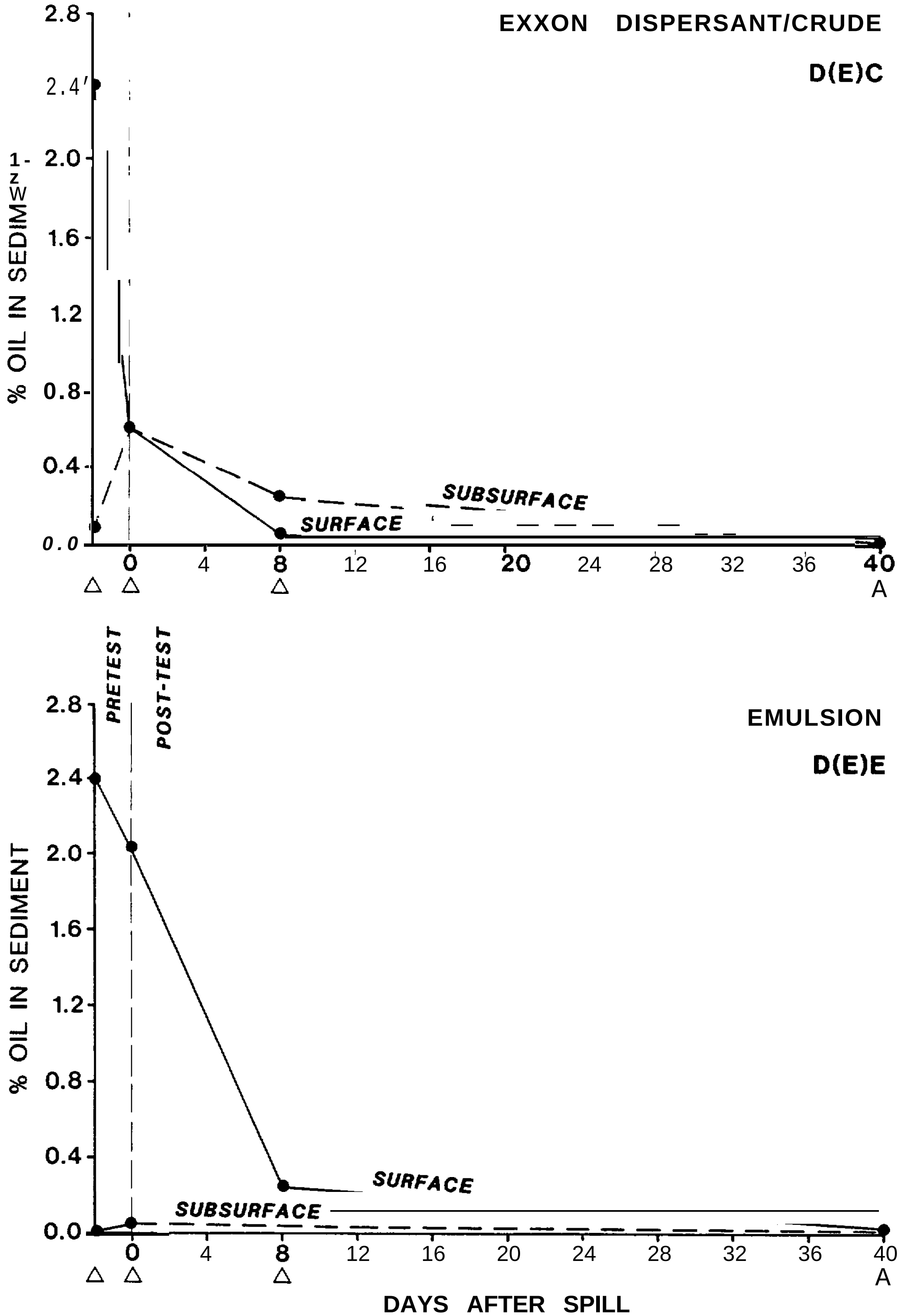


Figure 7.8 Total hydrocarbon values expressed as a percentage by weight of oil in sediment. Day 0 is August 7 and Day 40 is September 16, 1981.

On the basis of relatively few data points, it can be said that the dispersant was effective in reducing the total oil loading on the crude oil plot, although oil was driven deeper into the sediments. The dispersant appeared to have been less effective on the emulsified oil plot, both in dispersing the surface oil and in driving the oil deeper into the sediments.

7.5 BP DISPERSANT

The dispersant BP 11OOX was applied to the aged crude oil and the water-in-oil emulsion plots approximately 26 hours after the oil had been applied. The total volume of oil that was loaded onto these plots is similar to that which was loaded onto the Exxon dispersant plots (Table 7.1), although the total hydrocarbon samples taken of the oiled plots prior to testing indicate that less oil survived on the sediments following two tidal submergence periods (Table 7.2).

The total hydrocarbon analyses results prior to application of the dispersant indicate that the surface oil and sediment values are in the order of 0.4 - 0.7 percent (Table 7.2). Following application of the dispersant, the total hydrocarbon value increased on the crude plot but decreased on the emulsion plot. This difference may be in part due to the sampling procedures, even though each sample was a subset of four that were composite. Of greater significance than this apparent disparity on the crude oil plot is that the subsurface sample values increased significantly, and it may be inferred that one effect of dispersant application was to increase the penetration of the oil-dispersant mixture into the sediments. This inference cannot be treated as a conclusion because the post-test subsurface total hydrocarbon value from the aged in crude oil plot (0.313 percent) is in the same range as the subsurface value for the control aged crude oil plot (0.302 percent) (Table 7.2).

The sample analysis results from day 8 show that most of the oil on the plots had been removed, primarily as a result of wave action reworking the oiled sediments. An exception is the subsurface sample from the aged crude oil plot, which indicates a value almost identical to that measured from the immediate post-test sample (Fig. 7.9). This may reflect the

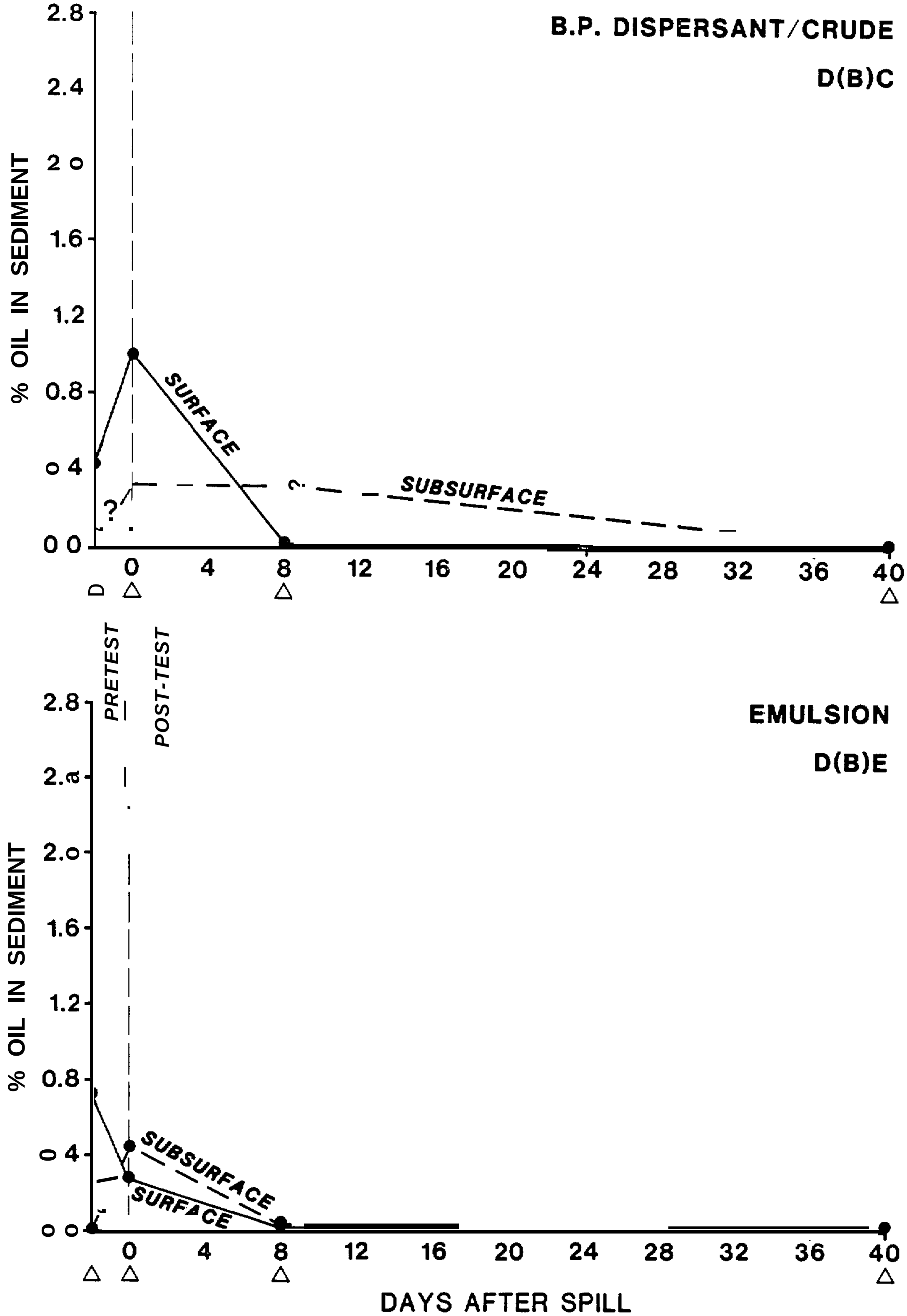


Figure 7.9 Total hydrocarbon values expressed as a percentage by weight of oil in sediment. Day 0 is August 7 and Day 40 is September 16, 1981.

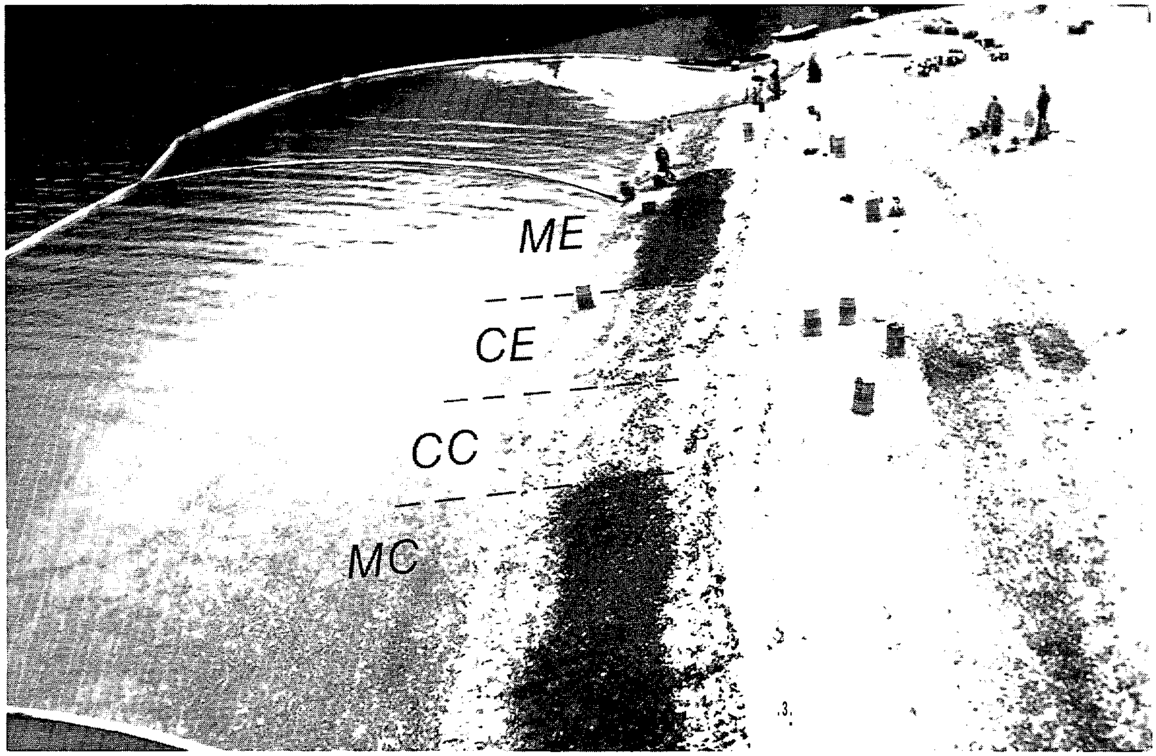
inhomogenous character of wave processes in reworking beach sediments, as it is rare that all of a beach is uniformly reworked in an alongshore or across-shore direction. Therefore, it is possible that one section of a plot may be thoroughly reworked by physical wave processes to a depth of 15 or even 30 cm, whereas an adjacent section only a metre or a few metres away may be subject only to surface reworking by wave action. It is significant that by day 40 only traces of hydrocarbons could be found in the samples collected from the surface and subsurface of both plots.

The evaporative weathering data (Table 7,3) indicate the initial high values that are due to the presence of aromatic fractions in the dispersant that was applied to the plots. The presence of these hydrocarbon fractions in the dispersant clearly makes the data of limited value. The alkane to isoprenoid ratio is of more value, and indicates that no degradation was evident on both the aged crude and the water-in-oil emulsion plots.

The data indicate that, on the water-in-oil emulsion plot, oil was driven more deeply into the sediments following application of the dispersant. The subsurface total hydrocarbon values from the crude plot are not significantly greater than those from the control plot, so that on this test, no definitive comments can really be made concerning the increased penetration of oil into the sediments on the aged crude oil plot. The significant parameter is that by day 40, all of the total hydrocarbon values were reduced to trace values.

7.6 MIXING

The mixing experiments were carried out on plots that were 20 m in length each, adjacent to the control plots (Fig. 7,10a). The mixing operations took approximately 1 hour for each plot, and were conducted 26 hours following application of the oil to the plots. The loading values of the oil (0.91 and 0,53 cm^3/cm^2 for the crude and emulsion plots respectively) are virtually identical to those values for the two control plots (Table 7.1),



(a)

(b)

Figure 7.10 (a) Aerial view (15:00, 6 August) of the mixing and control plots, and (b) ground view (6 August) of the ME (mixing of emulsified oil) plot and the CE (emulsified oil control) plot.

The total hydrocarbon values from composite samples collected immediately after the mixing of the sediments indicate a marked increase when compared to the pre-test samples (Table 7.2 and Fig. 7.11). This probably reflects the fact that oil was spread more evenly on the surface of the sediments, so that the total weight of oil with respect to sediment would be greater because on the pre-test sediments, many of the lower underside surfaces of pebbles and cobbles would probably be oil free. On the crude oil plot, there was a significant mixing process, so that the subsurface sample from this site had a total hydrocarbon value of 1.0 percent, a threefold increase from the pre-test value. On the water-in-oil emulsion plot, the total hydrocarbon value remained low following mixing (Table 7.2), and this probably reflects the fact that the sample was taken below the actual depth of mixing. The hydrocarbon values from day 8 show that on the crude plot the subsurface value remained high, whereas the surface value was reduced to 1/5 of the post-test value. These data reflect that the mixing action probably promoted the mechanical dispersal of surface oil, but that the subsurface oil was unaffected by the mechanical (wave) reworking of the beach' sediments. On the water-in-oil emulsion plot, little change was evident from the post-test samples at day 8, and this section of the beach underwent relatively little or no sediment reworking between August 2 and August 8 (see Profile 40, Appendix A).

Sediment reworking on the emulsified plot by day 41 (September 16) resulted in a marked reduction of the total hydrocarbon value of the surface sediments from 1.9 to 0.2 percent (Fig. 7.11). The hydrocarbon values from the aged crude oil plot appear to indicate that the surface hydrocarbon volume increased from 0.5 to 1.9 percent, and that the subsurface values decreased from 1.6 to 0.2 percent (Table 7.2 and Fig. 7.11). It is difficult to explain this apparent reversal in terms of observed oil. The surface value from the aged crude oil plot of 1.9 percent is in the same order of magnitude as the initial oil loading on this and on the control plots. Some visible oil was present on the mixing plots, as well as up to 8 cm below the surface (Blair Humphrey, pers. comm.).

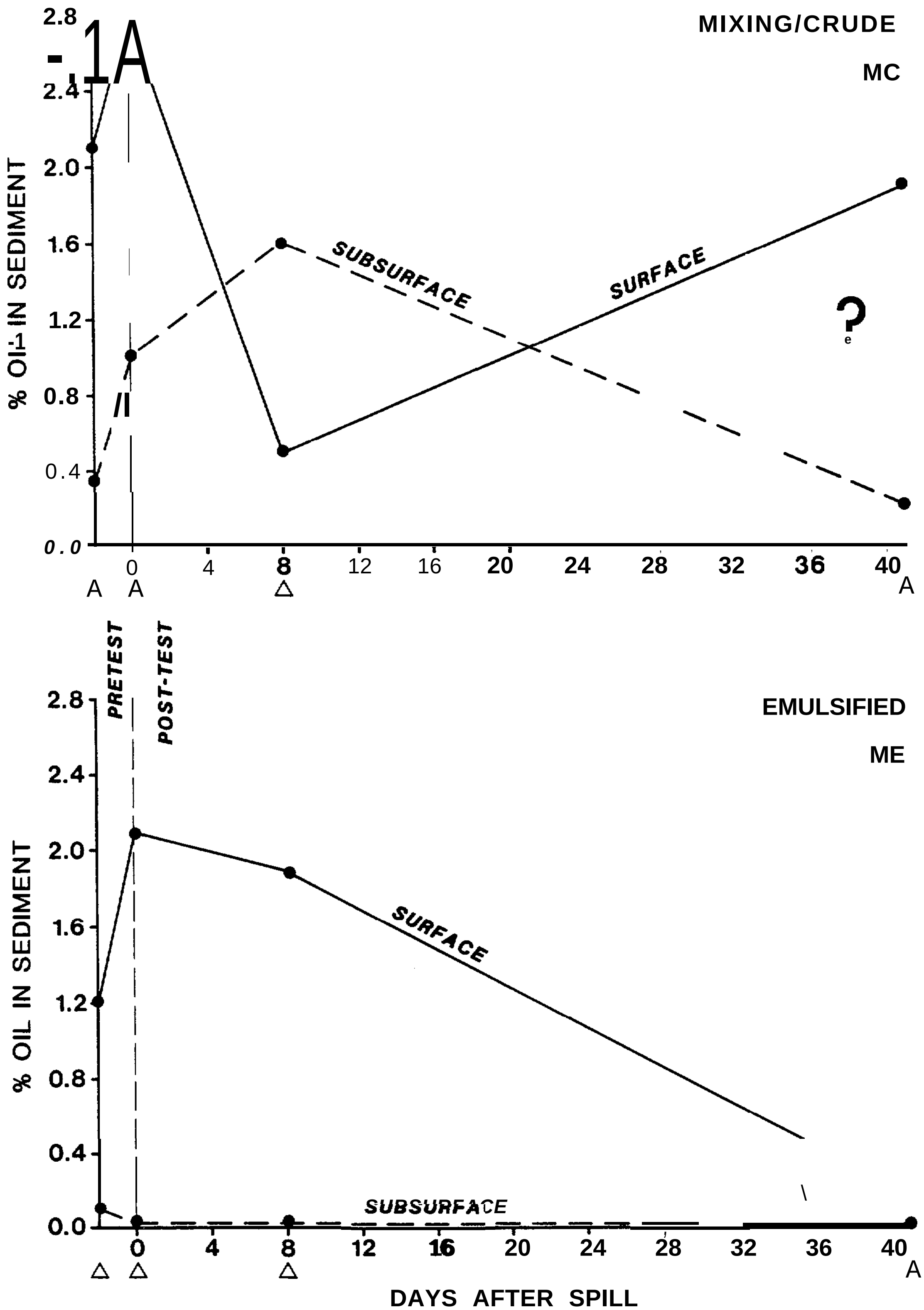


Figure 7.11 Total hydrocarbon values expressed as a percentage by weight of oil in sediment. Day 0 is August 6 and Day 41 is September 16, 1981.

Two potential explanations may be offered for these data points: (a) the oiled plot was buried by sediment on day 8 and exhumed by day 41, or (b) that inadvertently, samples were mislabeled, and the surface sample is in fact the subsurface one and vice versa. The first explanation, sediment reworking and burial followed by exhumation, is unlikely, as the beach profile surveyed at the site (Profile 80, Appendix A) indicates that following a period of erosion on August 2, the profiles of both August 8 and August 30 show no significant change. Therefore, the level of the beach on these latter two dates was virtually identical, and erosion or burial would not have produced a sampling error. It is unlikely that the total hydrocarbon content of the surface sample could have increased by a factor of 4, in that the sample was a composite of 4 widely spaced subsamples, and it is also unlikely that the total hydrocarbon content of the subsurface sample could have been increased by an order of magnitude on a beach where no major morphological change occured; therefore, the explanation of the data discrepancy apparently lies elsewhere. If the surface and subsurface data points are reversed, it is possible to explain the results logically. The subsurface sample would have a high value (1.9 percent) that is in the same range as the subsurface sample from day 8. The surface sample would have decreased in value from the day 8 sample, and would be in the same range as that from the surface of the mixed emulsion plot. It is difficult to provide a rational explanation for the data points on day 41 without invoking mechanisms that did not apply to adjacent plots, or without suggesting that the samples may have been inadvertently labelled or misplaced with respect to each other. It may be possible to verify the data by extracting total hydrocarbons from the GC/MS sample, but this has not been done to date.

The evaporative weathering data (Table 7.3) indicate that there was a significant decrease in the SHRW ratio from post-test samples to the day 8 samples, but that from day 8 to day 41 no significant change took place. The biodegradation data provide less information, and it is apparent that on the emulsified oil plot at day 8, the surface had become contaminated by lighter fractions from outside the plot to give an excessively high value for that sample.

With the exception of the inexplicable data points from day 41 of the mixed crude plot, the general trend indicated by the data is that mixing reduces surface concentrations of stranded oil, but increases subsurface concentrations. This conclusion supports the hypothesis upon which selection of the mixing procedure for shoreline countermeasures was initially based.

7.7 BP SOLIDIFIED

The application of the solidifying agent varied within each plot (see Fig. 6.6, p. 6-7). Each plot was divided into three sections, and polymer was mixed with slow or fast cross-link agents (Fig. 6.6). In all six tests, the compound gelled quickly and encapsulated the surface oil. Only total hydrocarbon data for the aged crude oil plot are available, and this indicates that at the end of the sampling period, as much oil remained on the surface as was initially present (Fig. 7.12). This would be consistent with the experimental design, as the solidifying agent does not disperse or remove any of the stranded oil, but rather bonds it within the compound (Table 7.2). A GC/MS sample collected from the water-in-oil emulsion plot produces a saturated hydrocarbon ratio of 105, due to the presence of odourless kerosene, which constitutes 95 percent of the solidifying compound.

The samples that were collected and analyzed on these plots provided little useful data, as the sampling programme was not designed specifically for this countermeasure experiment. Field observations indicated that the solidifying agent acted to retard sediment reworking in the intertidal zone. This phenomenon does not show clearly on slides or black-and-white photographs, but field notes show that on several occasions the surface of the intertidal sediments was lowered between 5 and 10 cm adjacent to the solidified oil, which protruded above the lowered level of the beach.

7.8 DISCUSSION

All field studies that are designed to improve the knowledge and understanding of shoreline processes and spills are an attempt to replicate real-world conditions that may exist at the time of a real spill incident. Thus, any experimental results must be qualified by an assessment of the environmental conditions at the time of that experiment to determine if, in

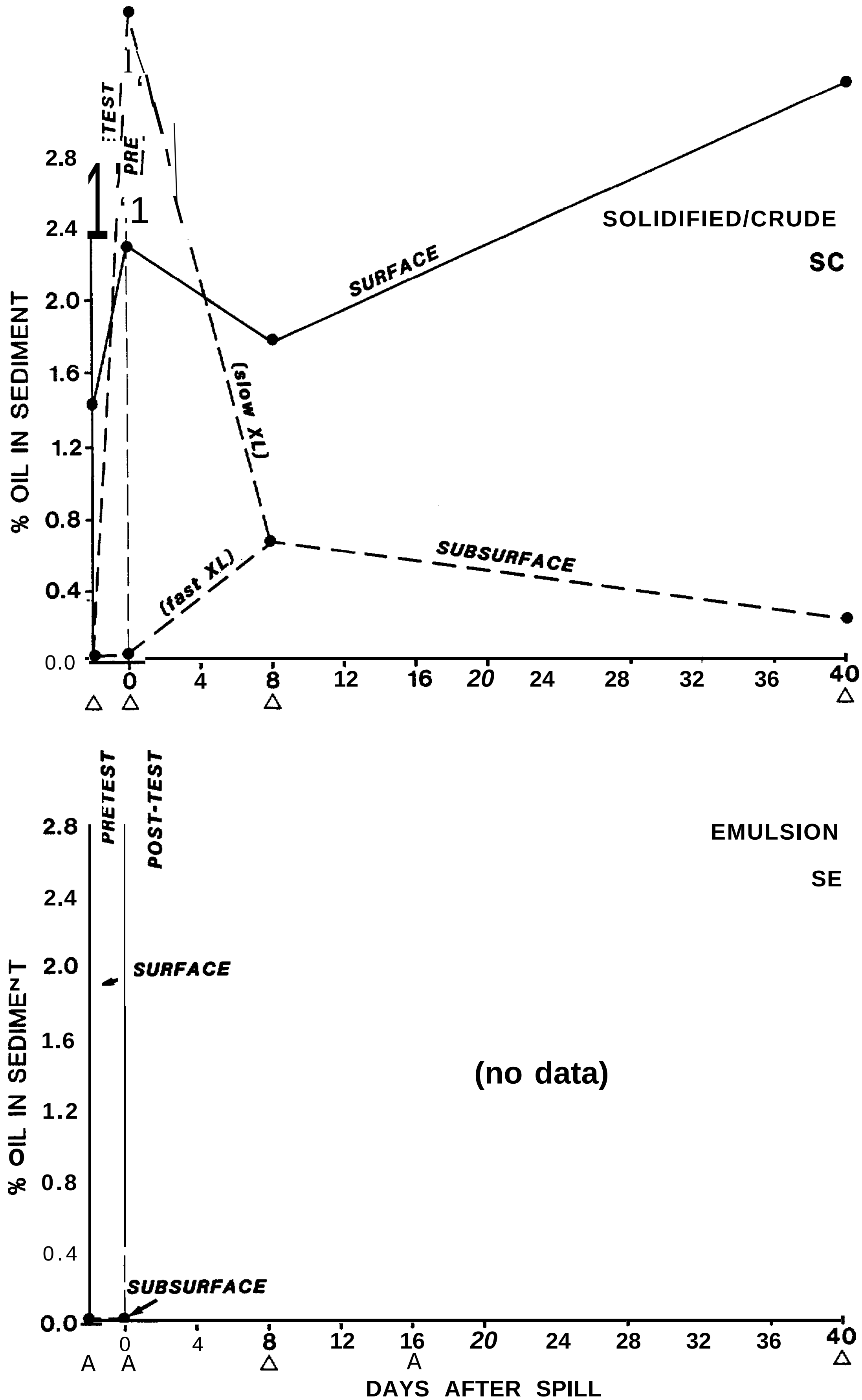


Figure 7.12 Total hydrocarbon values expressed as a percentage by weight of oil in sediment. Day 0 is August 7 and Day 40 is September 16, 1981.

fact, they are realistic or abnormal. Two years of studies on the control and countermeasure plots have indicated that storms are a significant element of coastal processes during the open-water season. Both the high-energy intertidal control plot (Bay 102) and the Crude Oil Point countermeasure test plots are exposed to waves generated in Eclipse Sound. Both beaches underwent significant wave reworking during the study periods. The countermeasures experiments are, therefore, not an isolated test of the techniques themselves, but are a test of the techniques in real-world conditions.

A primary conclusion drawn from the experiments is that during the study period, the removal of oil from the control intertidal plots, set up in 1981, was of the same order as oil removal from the countermeasure plots, even though the latter were also subject to a variety of cleanup techniques. Between August 2 and 8, data from all of the profiles surveyed on the countermeasures beach indicate that erosion predominated, with sections of accretion on the lower part of Profile 40 and the upper parts of Profiles 100 and 140 (Appendix A). Between August 8 and 30, accretion characterized most of the net shore-zone change in the intertidal zone, although this pattern is less uniform, with sections of erosion on Profile O, 80, 100, 120 and 160. The results of the countermeasure experiments therefore show not only the effects of the countermeasure technique but also the influence of normal processes redistributing sediments and reworking contaminated material.

The initial loading of the oil was in the order of 2 percent by weight oil in sediment. Within 40 days on the control plots, 80 percent of this oil had dispersed naturally. The effects of dispersant application and of mixing contaminated materials produced significant changes in the character of the contamination during the period initially following application of the particular technique. However, by day 41 there was little significant difference between any of the plots and the control plot data. This indicates that the techniques are really no more efficient than natural degradation processes on exposed beaches during the open-water season.

The application of countermeasure techniques significantly reduced oil loadings during the period immediately following application of the oil to the beach surface. Therefore, these techniques may be of some value in the mitigation of potential adverse impacts immediately following stranding of the oil, but over the longer time periods, natural reworking of intertidal sediments is as effective as man-induced countermeasures. The solidified proved to be an effective agent in the encapsulation of stranded oil, but the incendiary devices did not prove effective for the ignition and burning of oil on the test plots.

8.1 INTRODUCTION

During the summer of **1981**, two moderate-scale spill experiments were conducted to the west of the Cape Hatt camp in Ragged Channel (Fig. 2.2). One spill involved the discharge of weathered crude oil into a control bay (Bay 11) which was boomed off from the main channel. The second spill involved the discharge of a water, dispersant and oil mixture into a separate control bay (Bay 9; Fig. 2.2). An observation programme was conducted during and after these experiments to monitor the impact of oil on the nearby shorelines.

8.2 CRUDE OIL SPILL, BAY 11

The characteristics of the Bay 11 spill are noted in Table 8.1, as are the oceanographic conditions at the time of the spill and the general shore-zone character features. The spill involved the discharge of 15,0 m^3 of crude oil onto the water surface; the spill was confined by means of a curtain boom. Subsequent skimming of the water surface recovered 5.5 m^3 of oil (actually 11.9 m^3 of oil-in-water emulsion with 47% oil content were recovered). It is estimated that as much as 1.9 to 2.4 m^3 may have evaporated after the spill (Peter Blackall, pers. comm. , 1981) .

8.2.1 Spill Setting

Oceanographic conditions during and immediately after the spill were calm. Wave heights were very low (<10 cm) until 24 August, when significant wave action (probably >30-cm wave heights) caused the containment boom to break. Tidal range at the time of the spill was 1.9 m, with a decreasing range (see tidal curves, Appendix B) . Currents at the time of the spill are unknown, but the concentration of oil at the east end of the bay suggests that they were to the northeast.

TABLE 8.1 Bay 11 Spill Characteristics

DATE : 19 August 1981 (15:45 - 18:45 EDT)

SPILL CHARACTER	AMOUNT OF OIL SPILLED	∿15.0 m^3 or 3,330 Imp. Gal.
	AMOUNT OF OIL RECOVERED	∿5.5 m^3 or 1,215 Imp. Gal.
	AMOUNT OF OIL ON SHORE	∿7.1 - 7.6 m^3 or 1232 - 1562 Imp. Gal.
	DISCHARGE CHARACTERISTICS	Single point discharge on water surface
	TYPE OF OIL	Lago Medio crude oil, artificially weathered
ENVIRONMENTAL CONDITIONS	TIDAL CONDITIONS	1.9-m range (decreasing)
	WAVE CONDITIONS	very low (<10 cm) until 24 August
	CURRENT CONDITIONS	unknown, probably low
SHORE CHARACTER	SHORE-ZONE CHARACTER	sandy gravel sediments with 5° slopes; some rock outcrops
	LENGTH OF SHORELINE OILED	360 m
	WIDTH OF SHORELINE OILED	6 - 45 m
	AREA OF INTERTIDAL ZONE OILED	9,144 m^2

There are two distinct units of shore-zone character within the bay (Figs. 8.1 and 8.2). The primary unit consists of a sandy gravel intertidal zone of moderate width, whereas the secondary unit consists of well-jointed bedrock outcrops. Across-beach profiles from the beach segment of the shoreline are shown in Figure 8.3. Intertidal zone width varies throughout the bay, with the central part of the bay having the greatest widths (approximately 50 m). Slopes are low for intertidal zones, 5° or less, although local breaks in the topography are present at the high- and low-water lines. A small ridge at the high-water line indicates the presence of a poorly developed berm. A small ridge or mound feature is also present near the low-water line. This low-water mound was present throughout the summer, and is not believed to be one of the ice mound features discussed in Appendix C.

Sediment texture varied significantly across the intertidal beach zone. The surficial backshore sediments were very poorly sorted and ranged from mud material to cobble-sized material; these sediments were extensively reworked by surface runoff processes and cryoturbation. Sediments near the high-water line, in the poorly developed berm, were better sorted than other intertidal-zone sediments, and consisted primarily of pebble-sized material with some cobbles. Sediments within the mid- and lower intertidal zones were very poorly sorted, and ranged from silty sand-sized material to boulder material (Fig. 8.2). The ridge along the low-water line consisted primarily of cobble and boulder- sized gravel over sand material. Small streams discharging across the beach produced alongshore variation in sediment-size characteristics. For example, a broad band of fine, silty-sand material is present near the central part of the bay (Fig. 8.2),

8.2.2 Oiling Observations

As a result of the spill conditions (high discharge rates, low wave-energy levels, confining booms and a wide intertidal zone), a large amount of oil was stranded in the intertidal zone

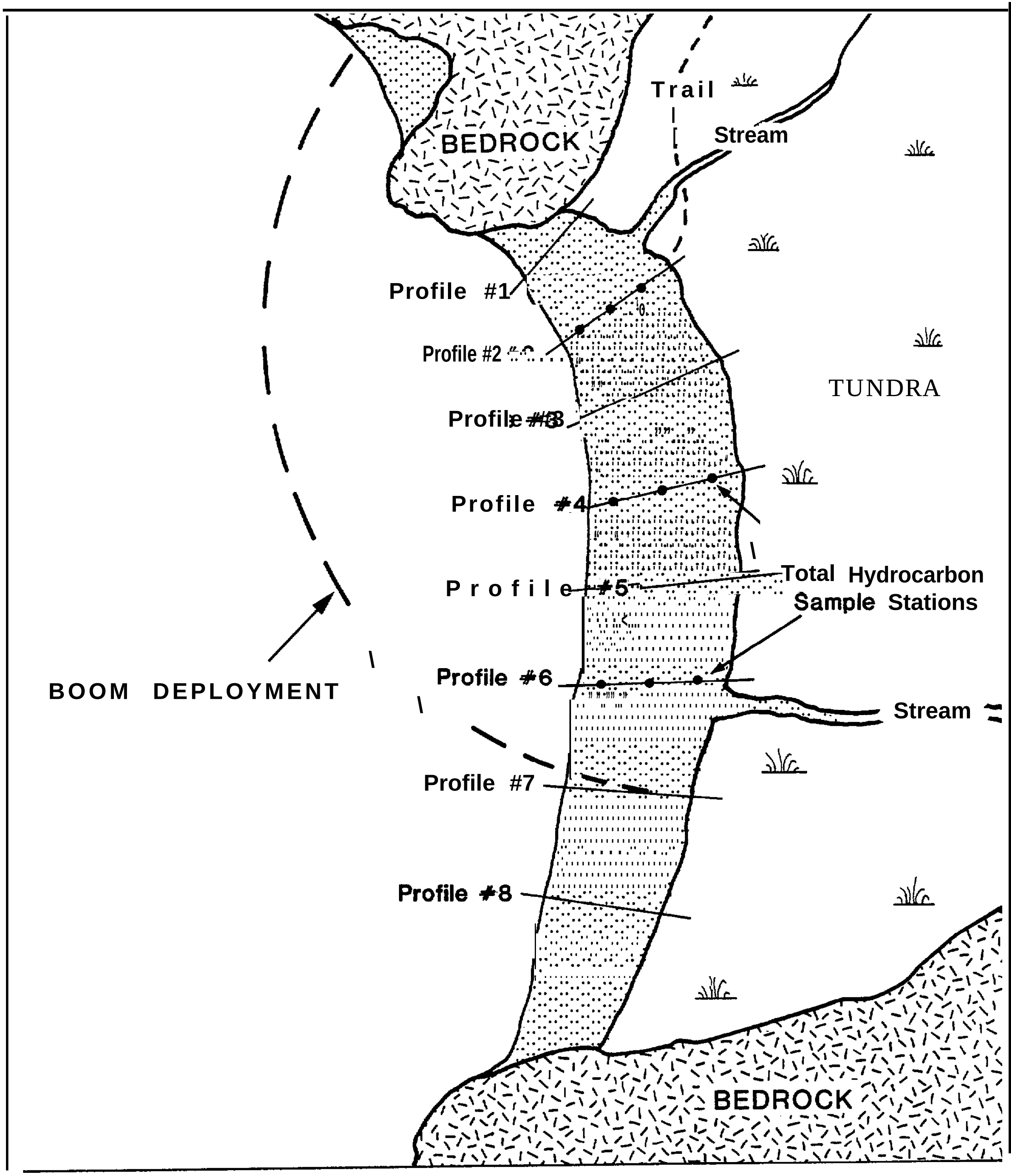


Figure 8.1 Schematic diagram of major geomorphic features in Bay 11, the position of the containment boom during the spill, surveyed beach profile locations and total hydrocarbon sample locations.

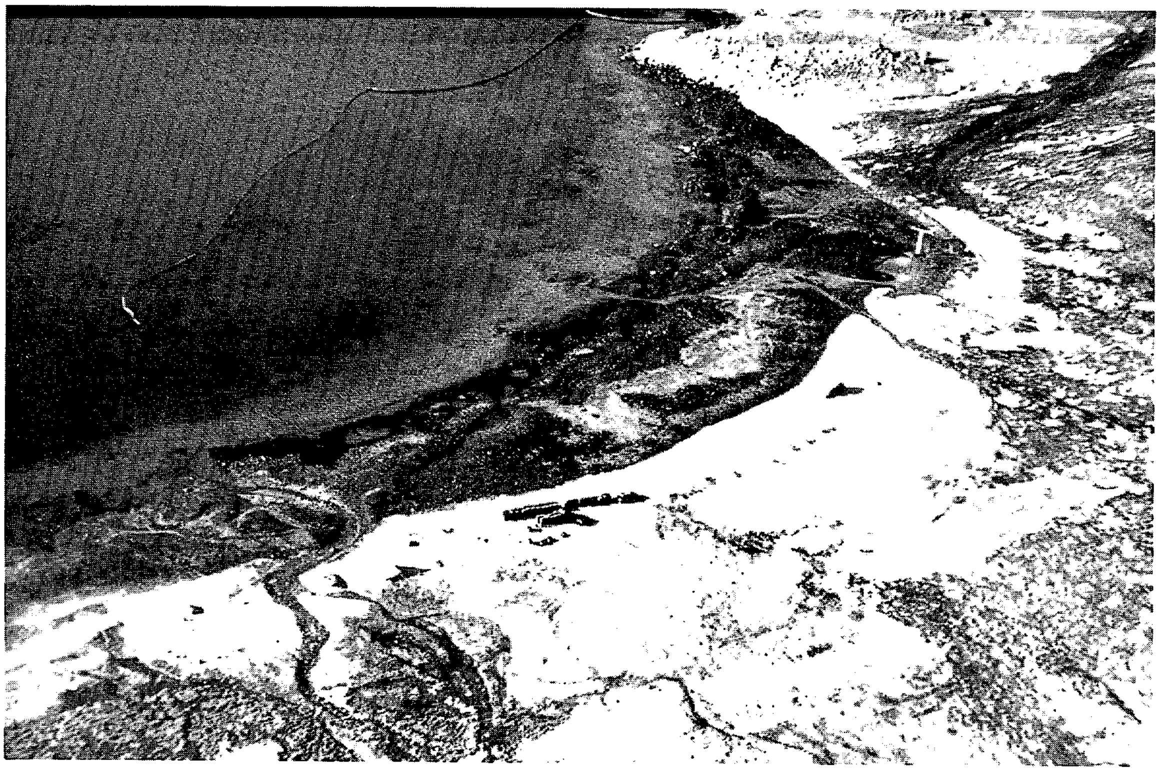


Figure 8.2 Oblique aerial photograph of Bay 11 on 27 August (eight days after the spill), Note the effect of streams in flushing oil from the intertidal zone and also the absence of oil on the sandy area in the central part of the bay.

BEACH PROFILES -BAY II

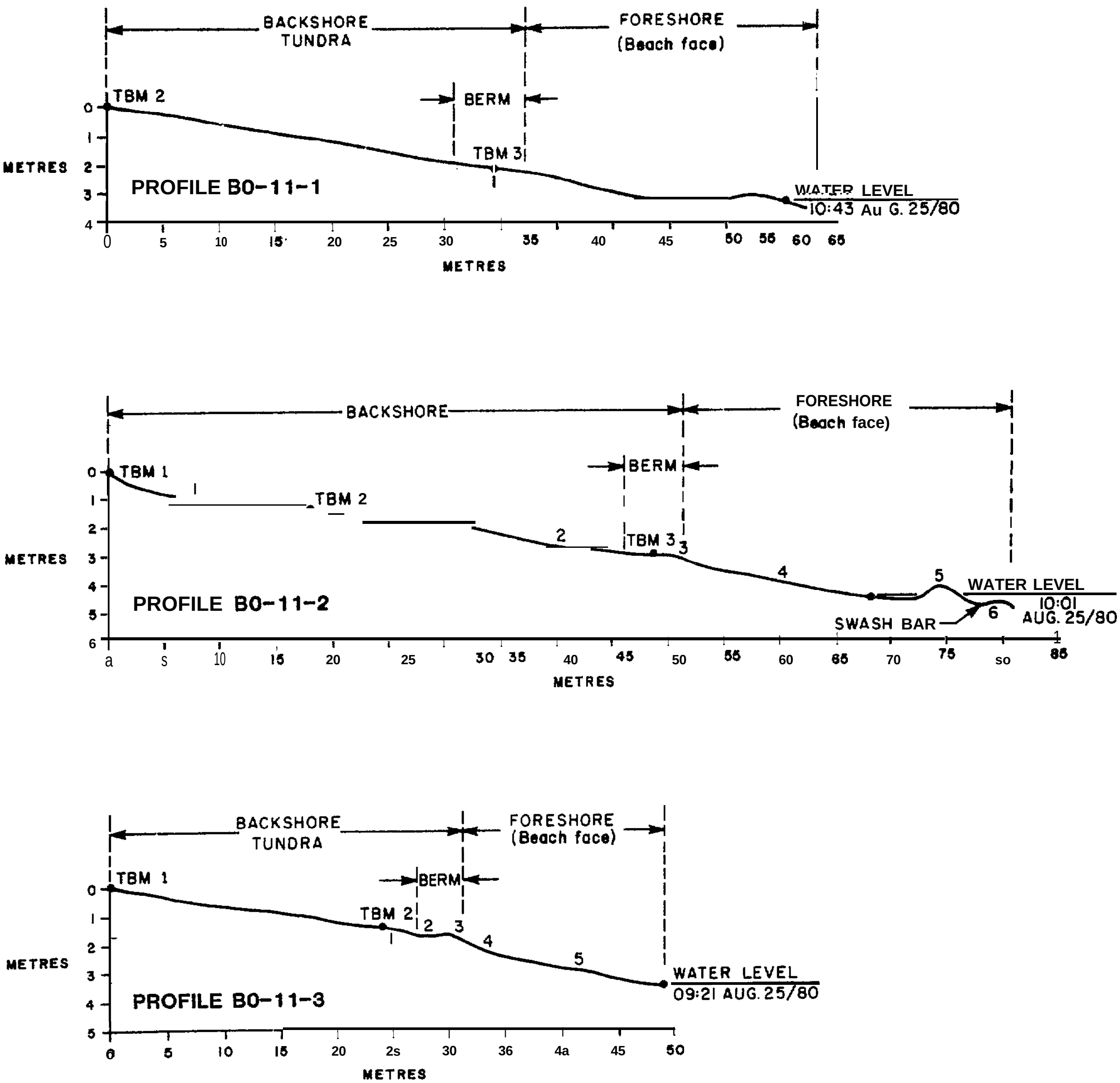


Figure 8.3 Beach profiles from Bay 11 taken during 1980 (from Barrie ~~et al.~~, 1981). The profiles correspond to profiles 2, 4 and 8 of the 1981 survey (see Fig. 8.1).

The distribution of oil on the surface of the beach was mapped seven days after the spill. The surface covering of oil was visually estimated along a series of transects in Bay 11 (Fig. 8.4). The estimates are uncalibrated in terms of an absolute scale, but they do provide excellent background information on the relative oil distribution within the bay. The distribution map indicates that the surface concentrations ranged from 5 percent surface covering to 100 percent surface covering. Zones of low oil concentrations were associated with the silty-sand areas that had high water contents; the high water content prevented the oil from adhering to the sediments. Areas of highest concentration were near the eastern end of the bay (Fig. 8.5) and also along the ridge at the lower water line. Surface coverings seaward of the low-tide ridge dropped off rapidly.

Integration of the surface covering estimates (Fig. 8.4) indicates that 6,037 m^2 of the total oiled area of 9,144 m^2 was covered with oil (i.e., surface covering of the oil was on the average 66 percent of the total surface area). Knowing that approximately 7.1 to 7.6 m^3 (Table 8.1) was stranded in the intertidal zone, then a mean surface covering thickness of 1.2 mm is estimated. The thickness of the surface covering on cobbles and pebbles appeared thinner than this estimate ($\leq$0.5 mm); however, the oil thickness in sand and granular-sized material is likely somewhat greater.

8.2.3 Total Hydrocarbon Analyses

Surficial sediment samples were collected for analysis of total hydrocarbon content. Samples were collected from upper, mid- and lower intertidal segments on three profiles in the bay (Figs. 8.1 and 8.4); on the first low tide following the spill and thereafter at 8 and 25 days. The sample locations in relation to the estimated surface oil covering are shown in Figure 8.4. It should be noted that these sample locations provide an index of some of the oiled area, but are not necessarily representative of the entire bay.

The results of the total hydrocarbon analyses are tabulated in Table 8.2 and illustrated in Figures 8.6, 8.7 and 8.8. The data indicate that there was considerable spatial and temporal variation in the content of oil

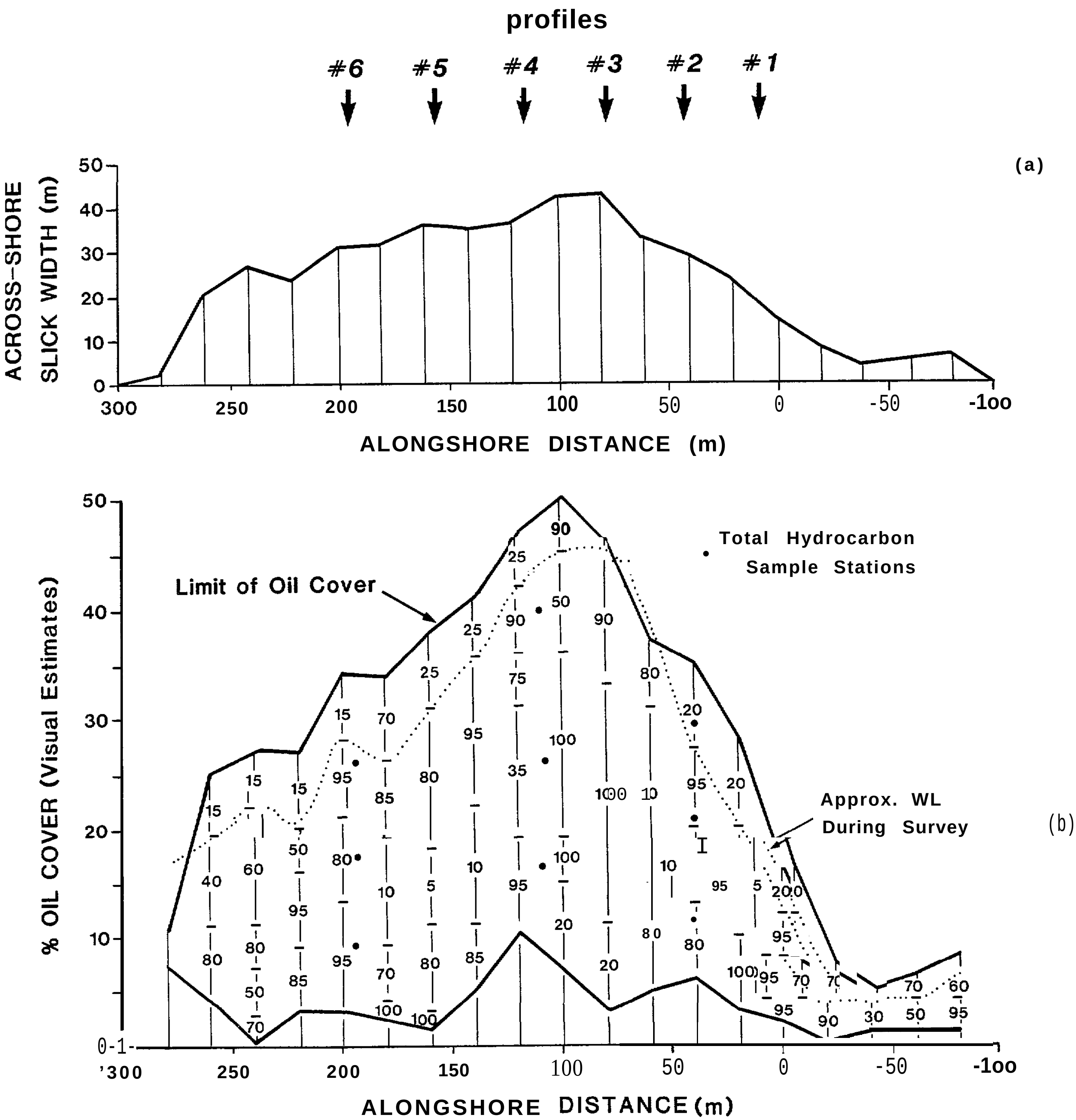


Figure 8.4(a) Slick width as measured along transects perpendicular to the shoreline (refer to Fig. 8.1 for locations).

Figure 8.4(b) Visual estimates of surface oil covering on Bay 11, 26 August 1981. Numbers indicate average surface oil covering, in percent, along transect segments.

Figure 8.5 Photograph of oiled intertidal-zone surface, Bay 11 (25 August 1981, 6 days after spill). Note the very sharp contrast between the oiled and non-oiled sediments.

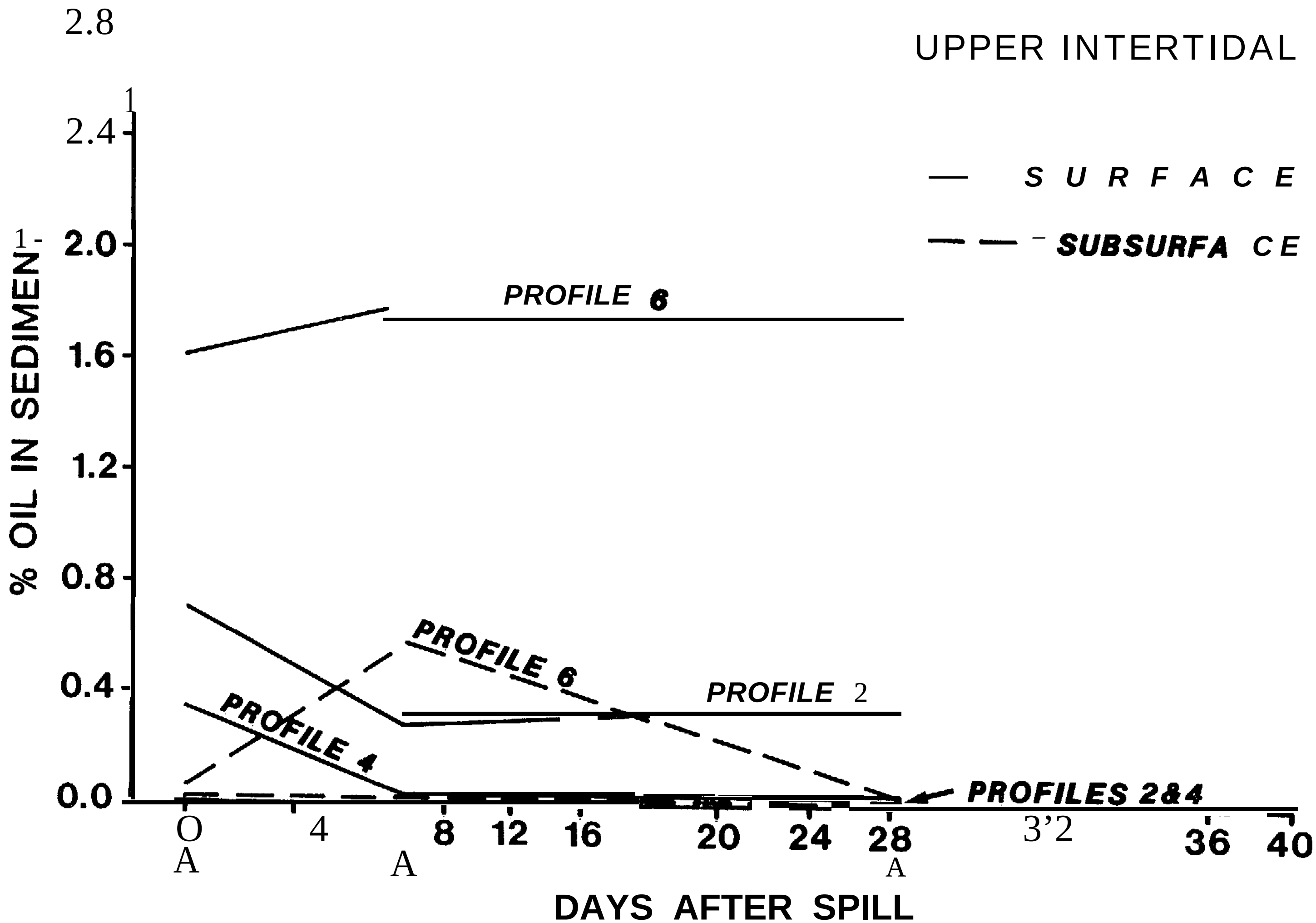


Figure 8.6 Total hydrocarbon contents of sediment samples from the upper intertidal zone of Bay 11. Subsurface samples were collected from depths of 5 to 10 cm.

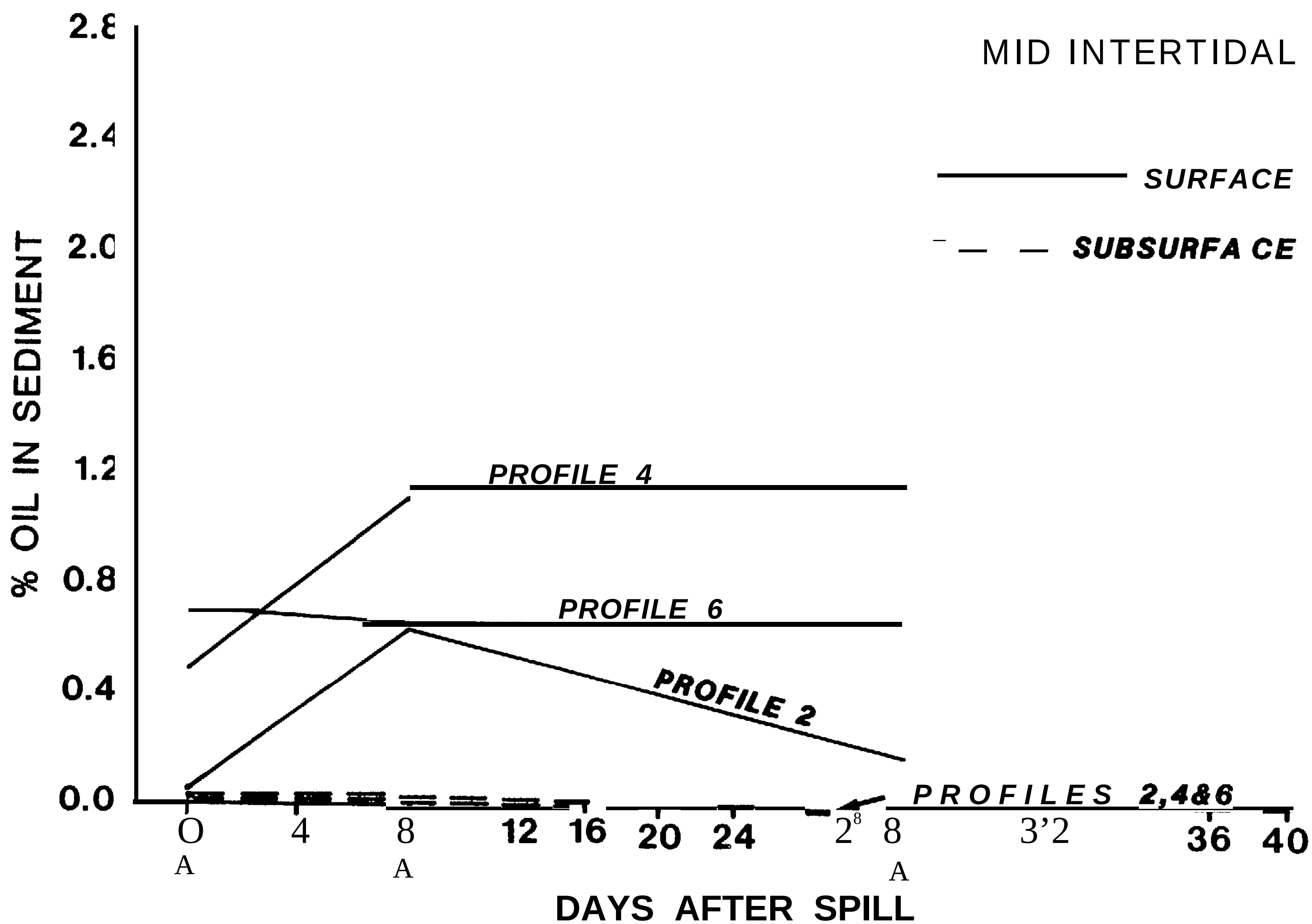


Figure 8.7 Total hydrocarbon contents of sediment samples from the mid-intertidal zone of Bay 11. Subsurface samples were collected from depths of 5 to 10 cm.

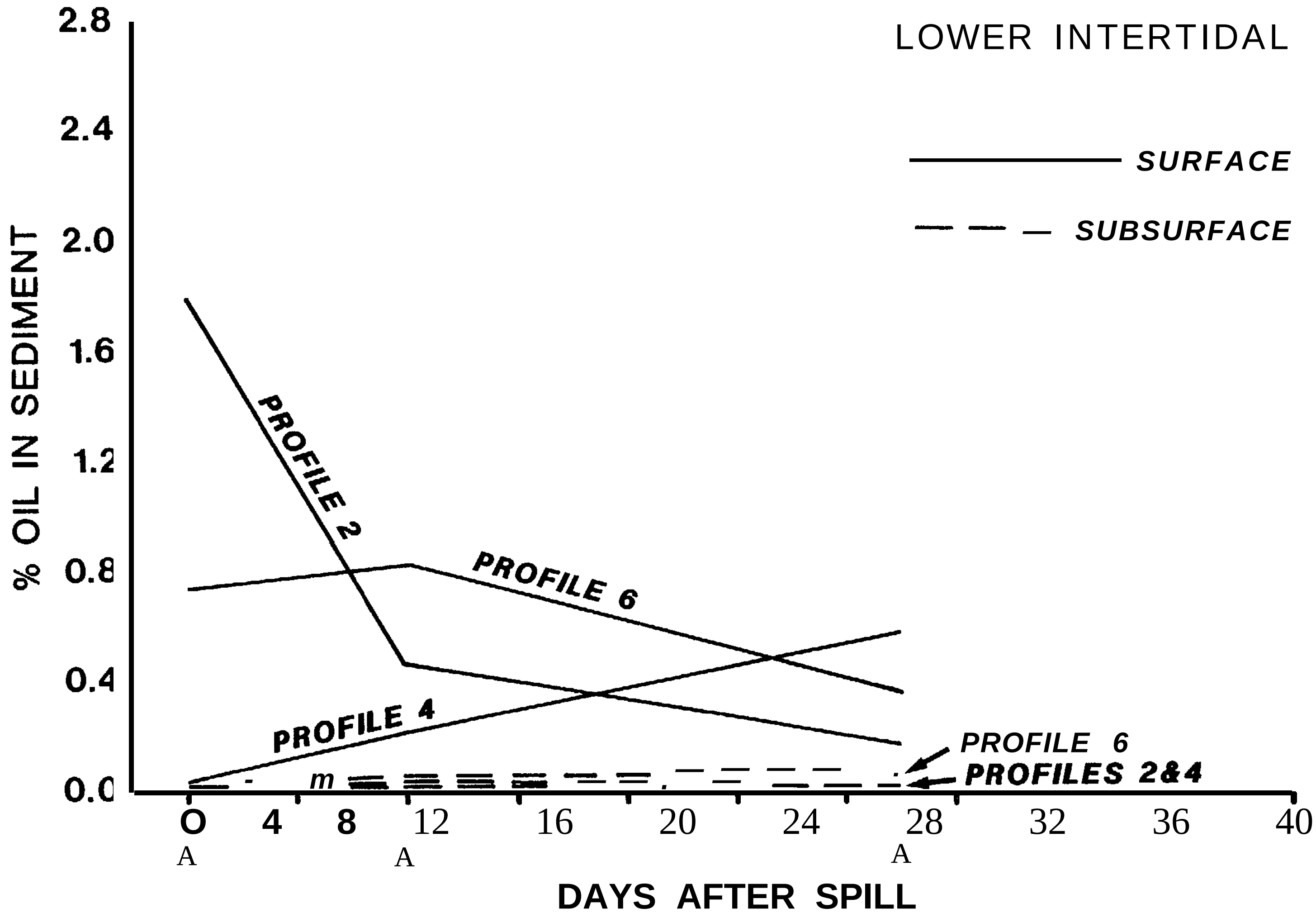


Figure 8.8 Total hydrocarbon contents of sediment samples from the lower intertidal zone of Bay 11. Subsurface samples were collected from depths of 5 to 10 cm.

in the surface sediments. As with other total hydrocarbon analyses, there remains the question of whether this variation is due to the sampling technique or to true variations in total hydrocarbon content (Woodward-Clyde Consultants, 1981a, 1981c).

The initial surface total hydrocarbon contents varied between 0.011 and 1.8 percent by weight (Table 8.2), with a mean of all surface samples of 0.71 percent total hydrocarbon content (Table 8.3). It is interesting to note that this initial oil content lies within the range of initial loadings of oil on the artificially oiled test plots in Z-Lagoon. Subsurface oil concentrations, as determined from samples collected between -5 to -10 cm, were significantly lower, ranging between trace to 0.056 percent, with a mean of 0.017 percent total hydrocarbon content. High water contents of the subsurface sediments apparently prevented penetration of the oil into the subsurface sediments. The low initial subsurface oil content is also low in comparison to previously documented subsurface oil content values (Woodward-Clyde Consultants, 1981a; Table 6,3).

It is clear that significant spatial variation in initial oil contents existed shortly after the spill (Fig. 8.4). It must be emphasized that the total hydrocarbon analyses are based on only nine sample locations, and that these sample locations are not necessarily representative of the overall distribution of oil within Bay 11. Spatial trends in initial oiling concentrations are weak; the mid-intertidal zone has slightly lower oil concentrations (Table 8.3), as does Profile 4 (Fig. 8.6 to 8.8). This may reflect the lower concentrations which occurred near the centre of the bay (Fig. 8.4).

Concentrations of oil in time also varied significantly, but again, evidence for overall trends is not strong due to the variability of the data. At some locations an increase in oil content occurred in time, whereas at other stations a decrease occurred. The overall trend was a reduction of surface oil concentrations (Table 8.3) and an increase of subsurface oil concentrations. The upper intertidal zone showed the greatest reduction (Table 8.3). An opposite trend occurred in subsurface oil contents, although this trend is only weakly supported by the data.

TABLE 8.2 Total Hydrocarbon Contents (in Weight Percent), Bay 11 Sediment Samples Collected During 1981

LOCATION UNKNOWN (pre-spill)	
SAMPLE NUMBER	18 August
1	0
2	0
3	trace
4	0
5	trace
6	0

	PROFILE 2*		
	20 August	28 August	15 September
upper surface	0.705	0.284	0.392
upper subsurface	0.009	0.022	trace
mid surface	0.048	0.64	0.192
mid subsurface	0.005	0.032	0.033
lower surface	1.8	0.454	0.186
lower subsurface	0.006	0.019	0.024
	PROFILE 4*		
upper surface	0.344	0.019	0.026
upper subsurface	0.014	0.014	trace
mid surface	0.480	1.100	1.2
mid subsurface	0.006	0.011	0.024
lower surface	0.047	0.205	0.582
lower subsurface	0.020	0.038	trace
	PROFILE 6*		
upper surface	1.6	1.8	1.7
upper subsurface	0.056	0.58	0.022
mid surface	0.609	0.654	0.65
mid subsurface	0.017	0.045	0.036
lower surface	0.734	0.827	0.364
lower subsurface	0.018	0.05	0.054

*see Figure 8.4 for sample locations.

TABLE 8.3 Summary of Total Sediment Hydrocarbon Content by Weight Percent

	SURFACE				SUBSURFACE			
	HIGH	MID	LOW	MEAN	HIGH	MID	LOW	MEAN
DAY +0	0.88	0.38	0.86	0.71	0.026	0.009	0.015	0.017
DAY +8	0.70	0.79	0.50	0.66	0.205	0.029	0.036	0.090
DAY +25	0.71	0.68	0.38	0.59	0.007	0.031	0.026	0.021

Some apparent changes in the spatial concentrations of oil in the alongshore direction also occurred in time (Figs. 8,6 to 8.8). At Profile 2, at the eastern end of the bay, a significant reduction in surficial oil concentrations occurred, whereas an increase apparently occurred on Profile 4; no significant change took place on Profile 6.

8.2.4 Discussion

The oiling of the shoreline in Bay 11 provides an interesting data point between the very small, controlled spills which took place in Z-Lagoon and large offshore oil spills. Significant observations of the Bay 11 spill are:

(1) Initial sediment oil contents were highly variable over short distances (Fig. 8.4), thus a large number of samples were required to determine "mean" oil concentrations.

(2) Despite the large quantities of spilled oil in the bay, sediment samples showed a maximum concentration of 1.8 percent, suggesting that a beach surface has a maximum retention potential despite the loading volume.

(3) Initial oil retention is related to sediment characteristics, and to a lesser extent, local topography. Highest oil concentrations occurred at locations of coarse sediments and topographic highs (e.g., ridge crests or upper part of intertidal zone), Lowest oil concentrations occurred in areas of fine sediments, which also coincide with areas of high water tables, and in topographic lows.

(4) Approximately 9,150 m^2 of the intertidal zone were oiled, with surface oil covering ranging from <10 percent to 100 percent; mean surface covering was 66 percent. Estimated mean oil thickness was approximately 1.2 mm for areas oiled.

8.3 OIL-WATER-DISPERSANT SPILL, BAY 9

The characteristics of the Bay 9 spill are noted in Table 8.4, as are the oceanographic conditions at the time of the spill and general shore-zone character. The spill involved a discharge of 15 m^3 of crude oil which was mixed with approximately 75 m^3 of seawater and 1.5 m^3 of dispersant. The oil-dispersant-water mixture was discharged (Fig. 2.2) through a discharge pipe located perpendicular to the shoreline in the central part of the bay (Fig. 8.9); the mixture was discharged through numerous orifices in the pipe. The spill mixture was not contained by a surface boom, and was allowed to circulate within the bay. None of the oil-dispersant-water mixture was recovered and it eventually diffused into Ragged Channel.

8.3.1 Spill Setting

Oceanographic conditions at the time of the spill were more energetic than those which occurred during the Bay 11 spill. Wave heights between 20 and 30 cm and wave periods in the order of 3 to 3.5 s were observed during the early part of the spill; the wave-approach direction was from the north. The general circulation within the bay was that of a clockwise gyre which caused currents toward the south along the shore and currents toward the north immediately offshore (Fig. 8.9). The gyre caused the recirculation of oil within the bay before being diffused into the channel. At the time of the spill, the tidal range was 1.7 m, and this increased over the following days.

As in Bay 11, two distinct units of shore-zone character exist within the bay. The primary unit consists of a well-sorted pebble beach backed by an eroding, unconsolidated cliff, whereas the secondary unit consists of resistant bedrock outcrops. The total length of shoreline within the bay is 670 m, and the intertidal zone is generally narrow (<20 m).

TABLE 8.4 Bay 9 Spill Characteristics

DATE : 27 August 1981 (13:00 - 19:00 EDT)

SPILL CHARACTER	AMOUNT OF OIL SPILLED	15.0 m^3 or 3,330 Imp. Gal.
	AMOUNT OF OIL RECOVERED	none - open system
	AMOUNT OF OIL ON SHORE	trace (<0.1 m^3 or 22.5 Imp. Gal.)
	DISCHARGE CHARACTERISTICS	through 30 m perforated pipe
	TYPE OF OIL	Lago Medio crude oil mixed with seawater and dispersant
ENVIRONMENTAL CONDITIONS	TIDAL CONDITIONS	1.7-m range (increasing)
	WAVE CONDITIONS	height 20-30 cm; 3.0 to 3.5-s period; approach from north
	CURRENT CONDITIONS	to south along the shore; to the north offshore
SHORE CHARACTER	SHORE-ZONE CHARACTER	well sorted pebble material; some outcrops
	LENGTH OF SHORELINE OILED	300 m
	WIDTH OF SHORELINE OILED	0.5 - 1.0 m
	AREA OF INTERTIDAL ZONE OILED	<250 m^2

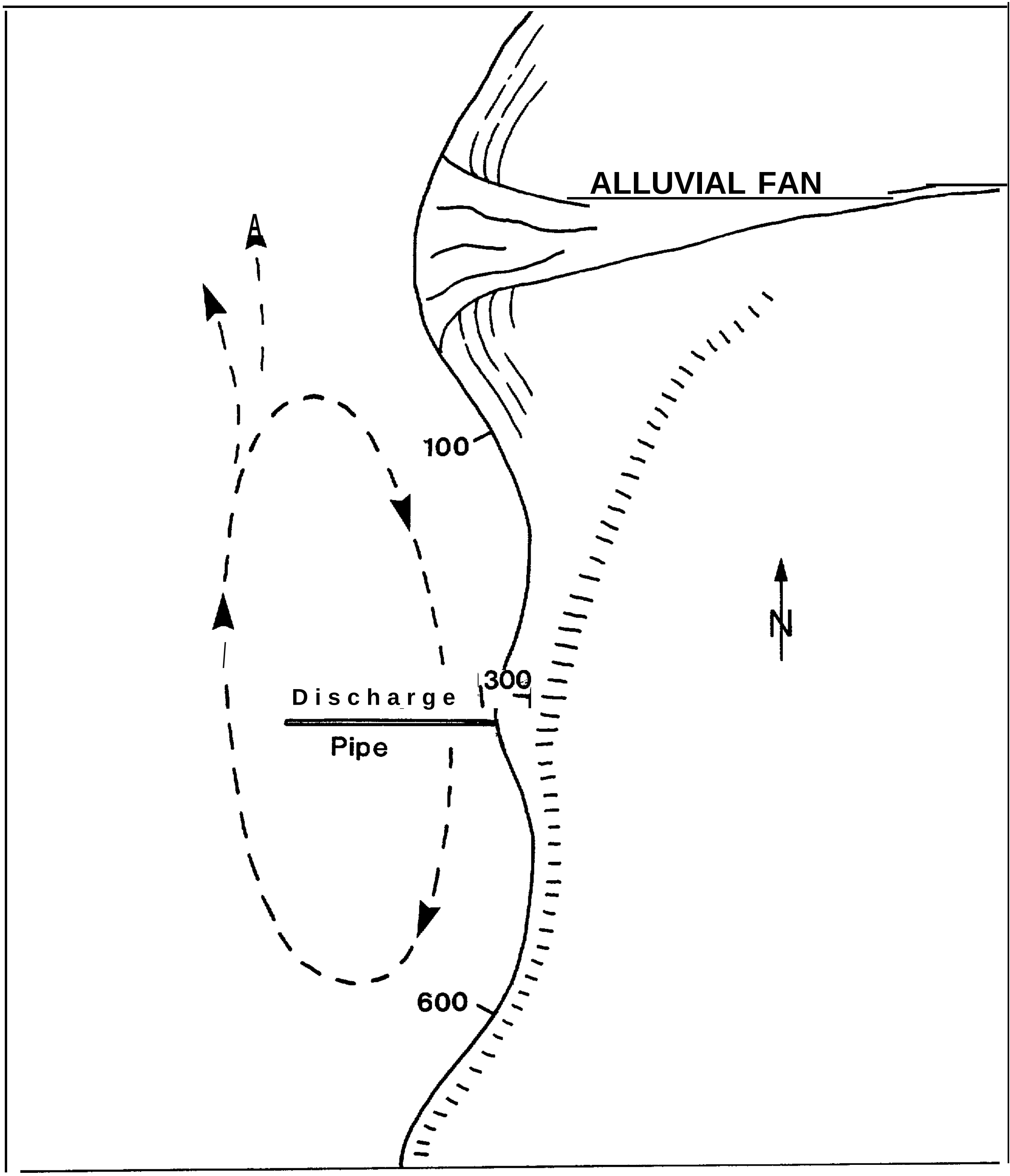


Figure 8.9 Schematic of Bay 9 showing major geomorphic features of the bay, the configurations of the discharge pipe, and the general circulation pattern (dashed line) during the discharge operation. Numbers indicate total hydrocarbon sample locations.

Some alongshore variation exists in both beach morphology and sediment texture. In the northern part of the bay, the lower beaches are sandy or gravelly with a pebbly upper portion, commonly in the form of a small swash ridge. In the southern part of the bay, beaches are mostly composed of flat, pebble-sized material (shingle) and are very steep; the beach width in the southern part of the bay is generally less than 10 m.

8.3.2 Oiling Observations

No oil was observed on the shore during the spill operations; however, during the high tide of the night following the spill, a small amount of oil was deposited in a thin band at the high-water line. The band was narrow ($\leq$1 m) and was absent in the southern half of the bay. The sediment samples generally did not have visible oil droplets, but rather were covered by a sheen of oil; the bottom side of pebbles occasionally contained small oil droplets. The mid- and lower portions of the intertidal zone showed no visible oil covering.

8.3,3 Total Hydrocarbon Analyses

Samples were collected for total hydrocarbon analysis from the middle and upper portions of the beach at three locations. The total hydrocarbon analyses are listed in Table 8.5, and support the visual observations of oil covering the sediments. Only the upper part of the intertidal zone in the northern end of the bay contained any measurable hydrocarbons.

8.3.4 Discussion

The oiling of the shoreline of Bay 9 provides an interesting comparison to the Bay 11 crude oil spill. The implication from the experimental results is that the use of dispersants on offshore oil slicks significantly reduces the potential for oil becoming stranded in the intertidal zone. It is estimated that less than 1 percent of the total amount of oil spilled was stranded in the shore zone.

TABLE 8.5 Total Hydrocarbon Contents in Weight Percent of Sediment Samples from Bay 9 (Collected 28 August 1981)*

	TOTAL HYDROCARBON CONTENT (% BY WEIGHT)	
PROFILE	UPPER INTERTIDAL	MID INTERTIDAL
100	0.126	0
300	0	0
600	0	0

* refer to Figure 8.8 for sample locations

The shoreline component of BIOS conducted in 1981 involved three major components:

- continued monitoring of the 1980 control plots;
- monitoring of the shores of Ragged Channel adjacent to the nearshore spills; and
- countermeasure experiments on shoreline test plots.

These studies were completed successfully, and this report presents the preliminary analysis of data obtained during the Field Programme. An initial analysis of geochemical data that was available at the time of writing is included in the interpretation of results. Further analytical results are expected, and these will be considered in future reports,

9.1 1980 BACKSHORE AND INTERTIDAL CONTROL PLOT MONITORING

Samples collected from the exposed, high-energy beach that was oiled during 1980 indicated that oil was present on 28 July 1981 in similar quantities to those which existed in late August 1980. However, by late August 1981, all of the sediment samples collected from these plots showed no traces of oil. On these intertidal control plots, wave action was therefore effective in causing the redistribution of sediments and the natural cleaning of the oiled test plots.

The test plots that were laid down in a sheltered location on the east shore of Z-Lagoon were characterized in 1981 by observable quantities of surface and subsurface oil. Comparison with sample data obtained immediately following application of oil to the plots with the samples collected during the 1981 season indicates that by August 1981, 5 to 10 percent (by weight) of the original oil remained on the surface of the plots, and that 10 to 30 percent remained in the subsurface of the sediments (10-15 cm) below the surface. A difference between the water-in-aged crude oil plot and the aged crude oil plot was observed visually and indicated by the total hydrocarbon samples, with lower total hydrocarbon values on the emulsified oil plot.

Sample data from the backshore control plots indicate that all of the 1981 sample results are within the range of values from the 1980 suite of samples, Comparison of the overall mean of 1980 oil-in-sediment values with those from 1981 samples indicates a reduction from 3.3 percent to 2.3 percent. It is not possible at this time to determine the significance of this reduction in total hydrocarbon content. Preliminary geochemical analyses indicate that biological weathering was not a significant factor of oil degradation on these backshore plots, but that a significant amount of evaporative weathering occurred between the 1980 and the 1981 surveys.

9.2 1981 RAGGED CHANNEL EXPERIMENTS

The distribution of oil on the shoreline of Bay 11, where an aged crude oil was spilled on the water surface, was extremely variable, with highest oil concentrations observed on topographic highs or in areas of coarse sediments. The total hydrocarbon content of sediment samples collected from the surface of the beaches shortly after oiling indicated oil-in-sediment values in the range of 0.01 to 1.8 percent by weight. These values are in the same range as those of samples collected immediately after application of the oil to the control plots and countermeasure plots, where oil was “artificially” applied to the shore zone. This indicates that the oiling procedure used during the other components of the shoreline study replicates accurately situations where oil is washed ashore from the water surface.

On the Bay 9 spill, where a dispersant-water-aged crude oil mixture was discharged into the water, visual observations and analysis of total hydrocarbon content of beach samples indicate that very little oiling of the Bay 9 beaches occurred.

9.3 1981 COUNTERMEASURE EXPERIMENTS

Control plots of aged crude oil and water-in-aged crude oil were laid down on one section of the beach where the countermeasure experiments were to be conducted. The initial oil loading was up to 2 percent by weight. Within 40 days, 80 percent of the oil which had been laid down on the control plot had been dispersed naturally.

A series of tests were conducted prior to initiation of the countermeasures experiments in the vicinity of Crude Oil Point. The techniques to be tested included:

- in-situ combustion using an incendiary device,
- mechanical mixing of contaminated sediments,
- chemical surfactants to disperse oil, and
- application of solidifying agents to oiled surface.

Preliminary tests indicated that the incendiary device could not ignite oiled sediments, and this technique was therefore not tested further. The plots that were subject to mechanical mixing showed initially a reduction in surface concentration of oils and an increase in the subsurface concentration of oil in the sediments. Within 40 days following the countermeasures experiments, the values from the mixing plots were in the same range as those from the control oiled plots. The application of two different commercially available brands of dispersants resulted in a significant reduction of surface and subsurface oil volumes immediately following the tests. The total hydrocarbon samples indicated that the dispersants reduced the oil-in-sediment volume by approximately one order of magnitude. However, after 40 days the total hydrocarbon values from the dispersant plots were in the same range as those from the control plots. The application of solidifying agents to the oiled test plots was successful in terms of the objectives of these tests, as oil was effectively encapsulated within the gel.

The results indicate that, with the exception of the solidified tests, the countermeasure techniques which were applied initially reduced the volumes of oil on the test beaches, but that after a period of 40 days the levels of contamination were similar on the control plots to the countermeasure plots. The techniques could significantly reduce oil loadings during the period immediately following stranding of oil at the shoreline, but in the long run it appears that these techniques are really no more efficient than natural degradation in terms of reducing the volume of oil that resides in the intertidal zone.

9.4 IMPLICATIONS OF 1981 STUDY RESULTS

The primary conclusions that result from the 1981 studies are that there are significant differences between the exposed and sheltered control plots that were set up in 1980, in terms of the volume of oil that was naturally dispersed. Oil was still present on the sheltered beach (low-energy plot), whereas plots of the same oil applied in 1980 to the same relative location in the intertidal zone at a more exposed site (high-energy plot) were cleaned, with no detectable trace of oil present in the sediment samples by the end of August 1981. Comparison of total hydrocarbon samples from the control and countermeasure plots falls within the same range as samples that were collected from Bay 11; this indicates that the application system used for the control and experimental plots is realistic in terms of oil loadings. The countermeasures that were tested were effective in reducing the volume of oil initially, with the exception of the incendiary device and the solidified, but by the end of the survey period (41 days) there was no significant difference in the total hydrocarbon volumes between the control plots or the dispersant and mixing countermeasure plots.

APPENDIX A - BEACH PROFILES

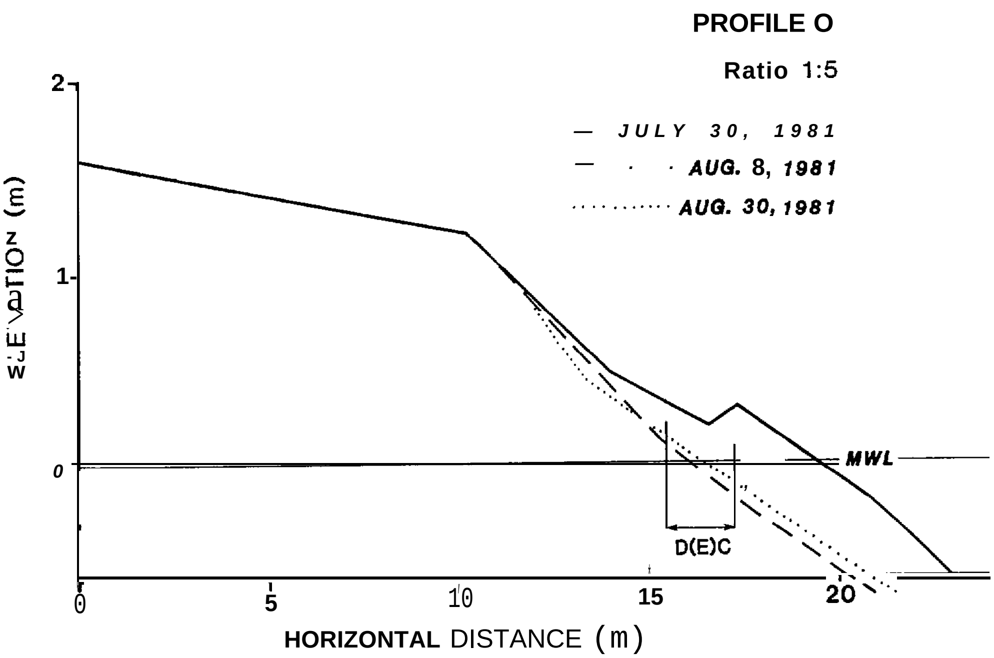
A series of beach profiles were surveyed across the intertidal zone on the countermeasure experiment shoreline. The profiles were surveyed at low tide, using a self-levelling level and survey staff. All profiles were tied into a common line that ran parallel to the shore zone above the present-day beach, so that all elevations on the plotted profiles are related to the same datum.

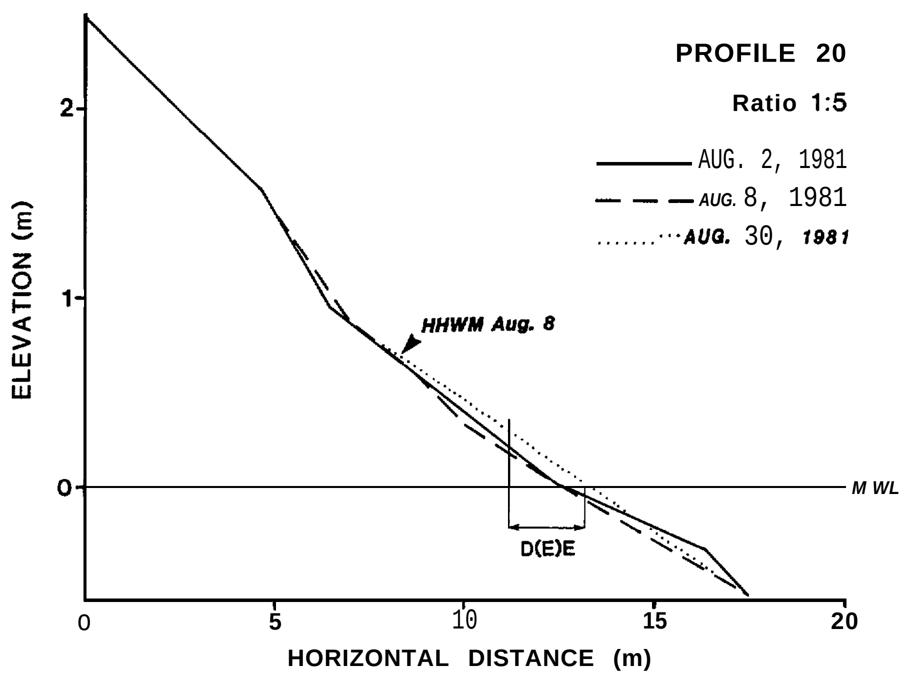
The exact location of the mean high-water and mean low-water marks are not known on this beach. For comparative purposes, all of the profile data have been reduced to a common level, the mean water level (MWL), that has been approximated from both the profile data and from available tidal water-level data.

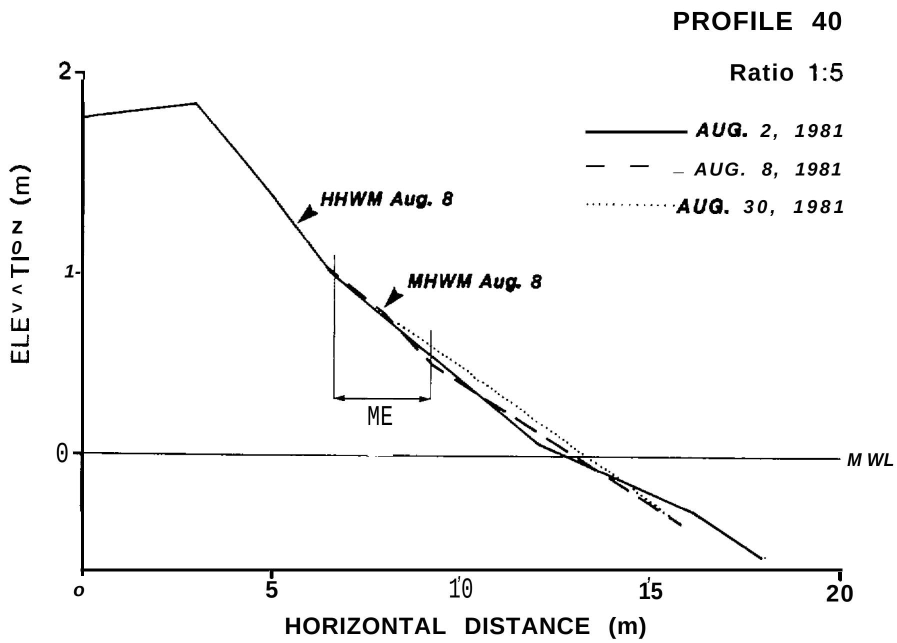
The tides of this area are characterized by unequal, semi-diurnal tidal levels. Thus, on a single day the height of the two high tides may vary by as much as 0.25 m. Where sufficient evidence was visible during the survey on August 8, the heights of these two high tides for that day are indicated on each profile (HHWM = Highest High-Water Mark: MHWM = Mean High-Water Mark).

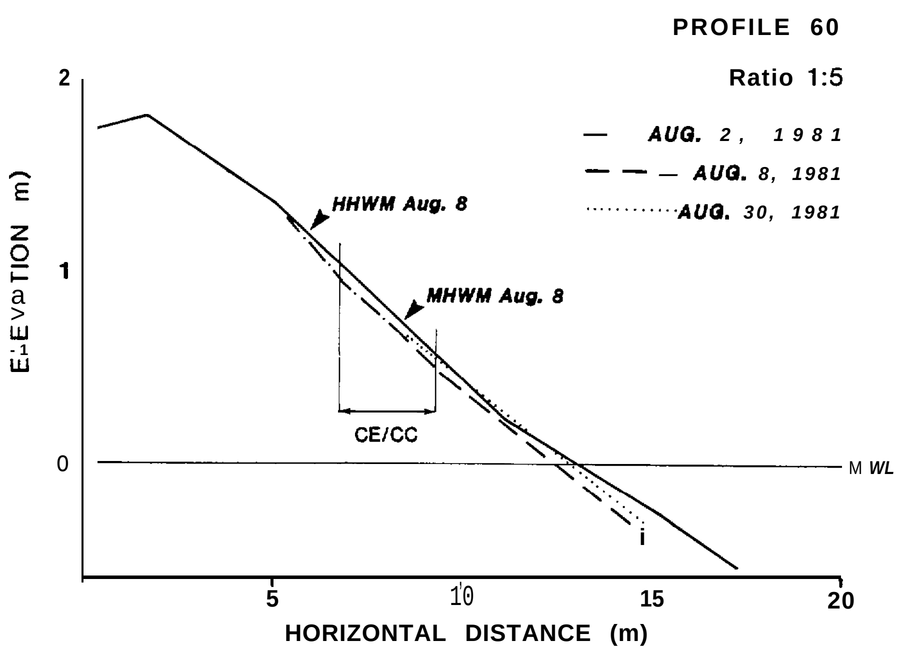
The location of the experimental plots with respect to the beach profile is indicated where appropriate.

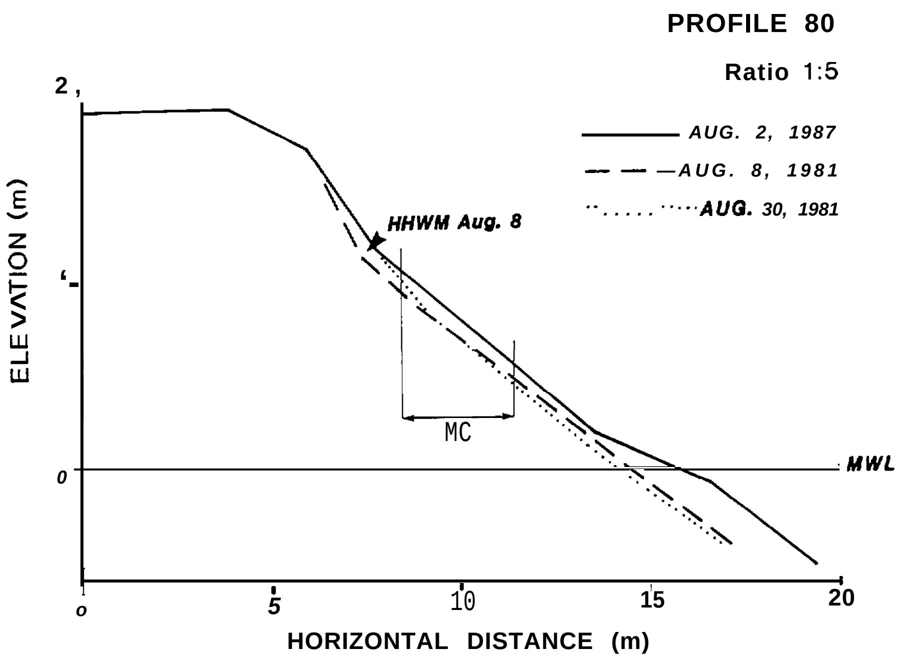
The location of the profiles is given in Figure 5.9 (Page 5-15).

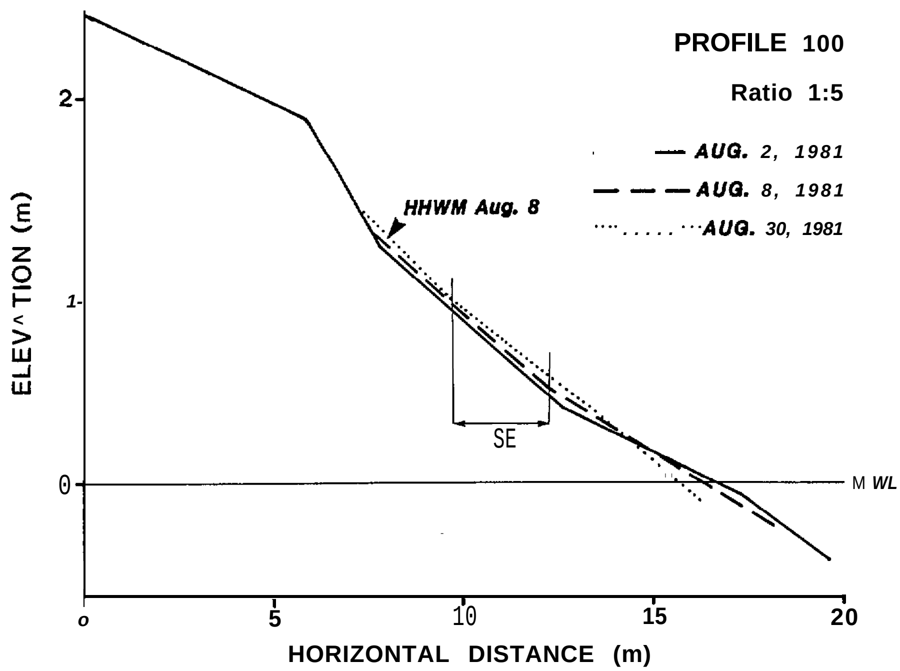

PROFILE O
Ratio 1:5
JULY 30, 1981
AUG. 8, 1981
AUG. 30, 1981
MWL
D(E)C
ELEVATION (m)
HORIZONTAL DISTANCE (m)

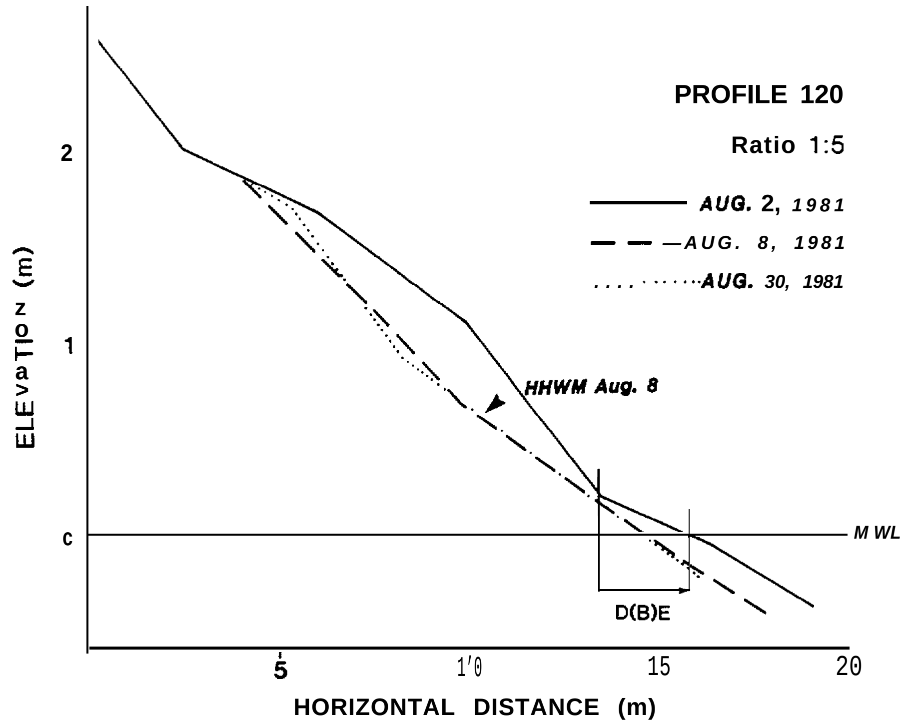

PROFILE 20
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
M WL
D(E)E
ELEVATION (m)
HORIZONTAL DISTANCE (m)

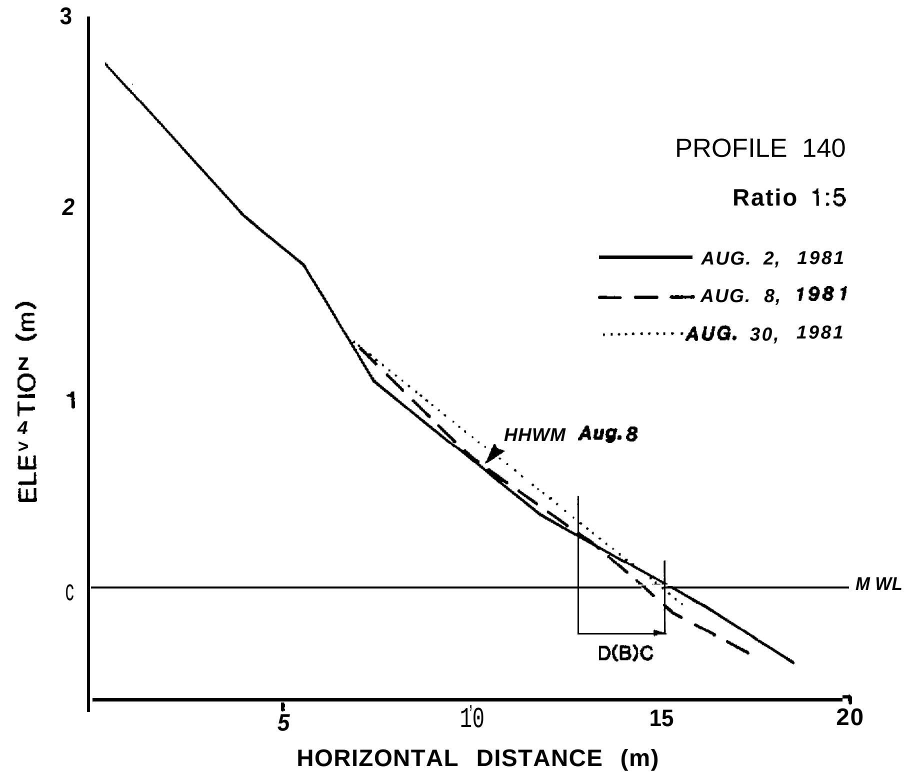

PROFILE 40
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
MHWM Aug. 8
ME
M WL
ELEVATION (m)
2
1
0
0
5
10
15
20
HORIZONTAL DISTANCE (m)

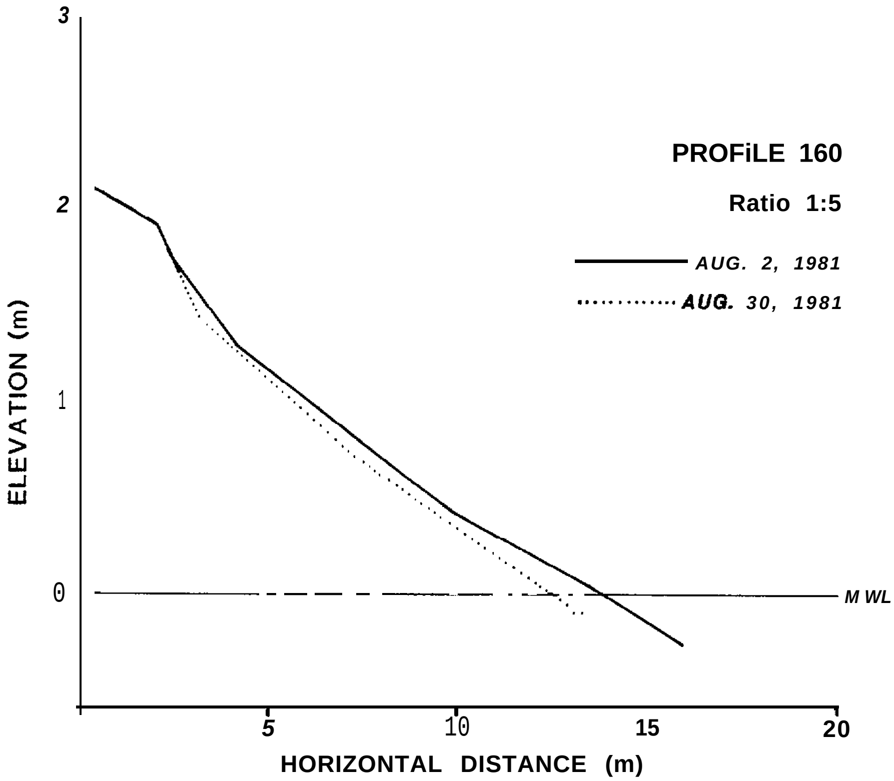

PROFILE 60
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
MHWM Aug. 8
CE/CC
M WL
ELEVATION (m)
2
1
0
5
10
15
20
HORIZONTAL DISTANCE (m)

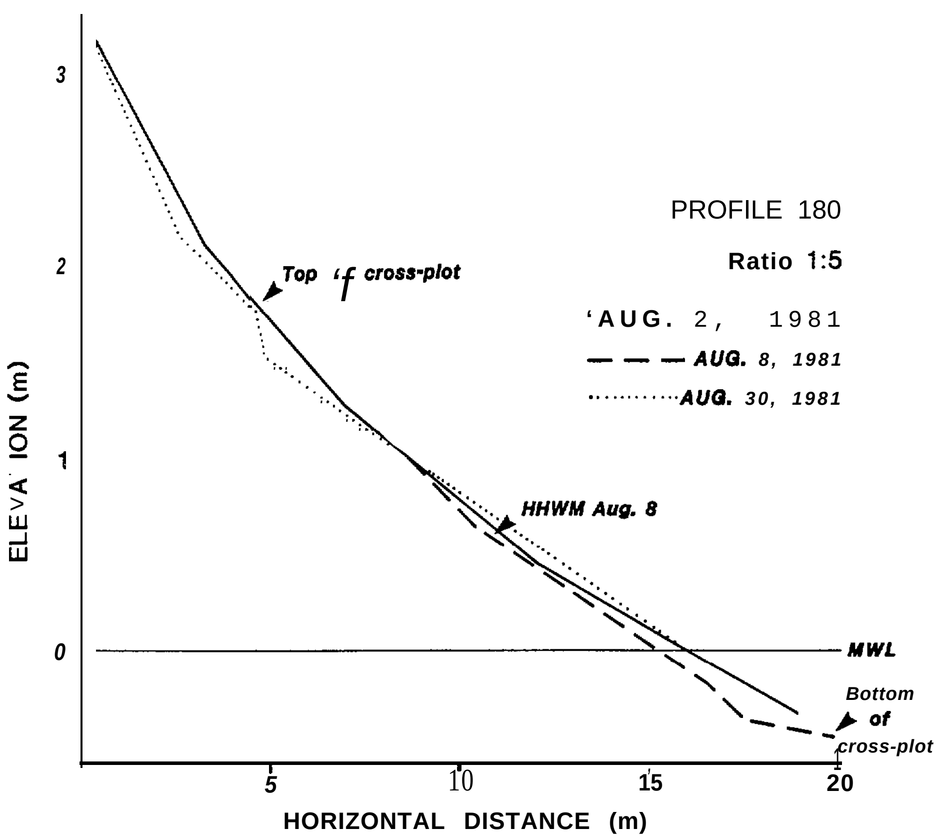

PROFILE 80
Ratio 1:5
AUG. 2, 1987
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
MC
MWL
ELEVATION (m)
2
0
0
5
10
15
20
HORIZONTAL DISTANCE (m)

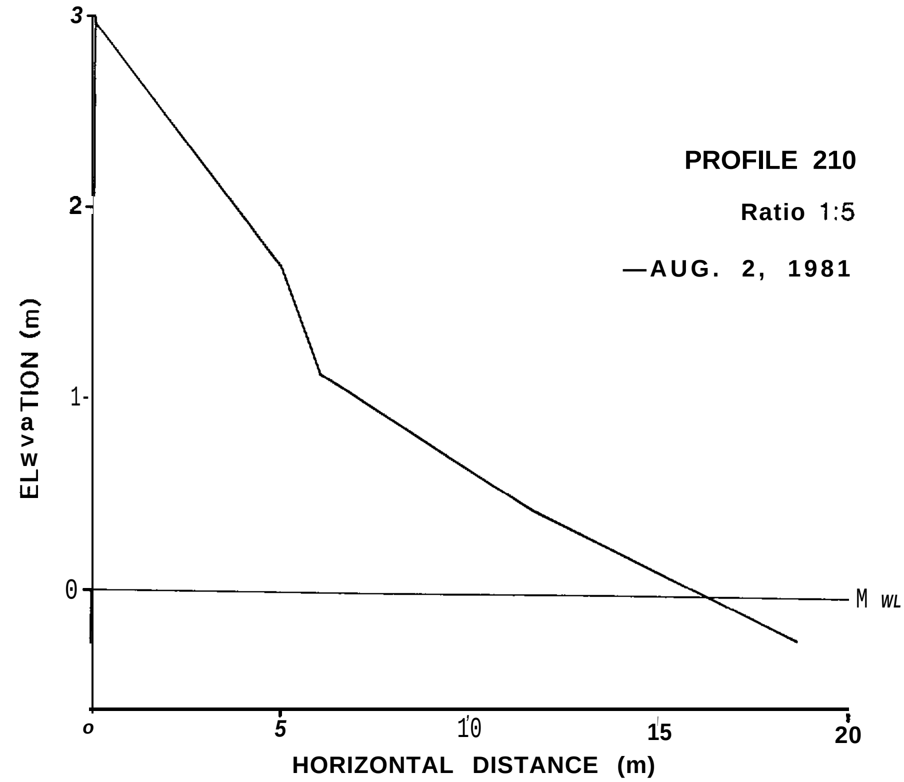

PROFILE 100
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
SE
MWL
ELEVATION (m)
2
1
0
0
5
10
15
20
HORIZONTAL DISTANCE (m)

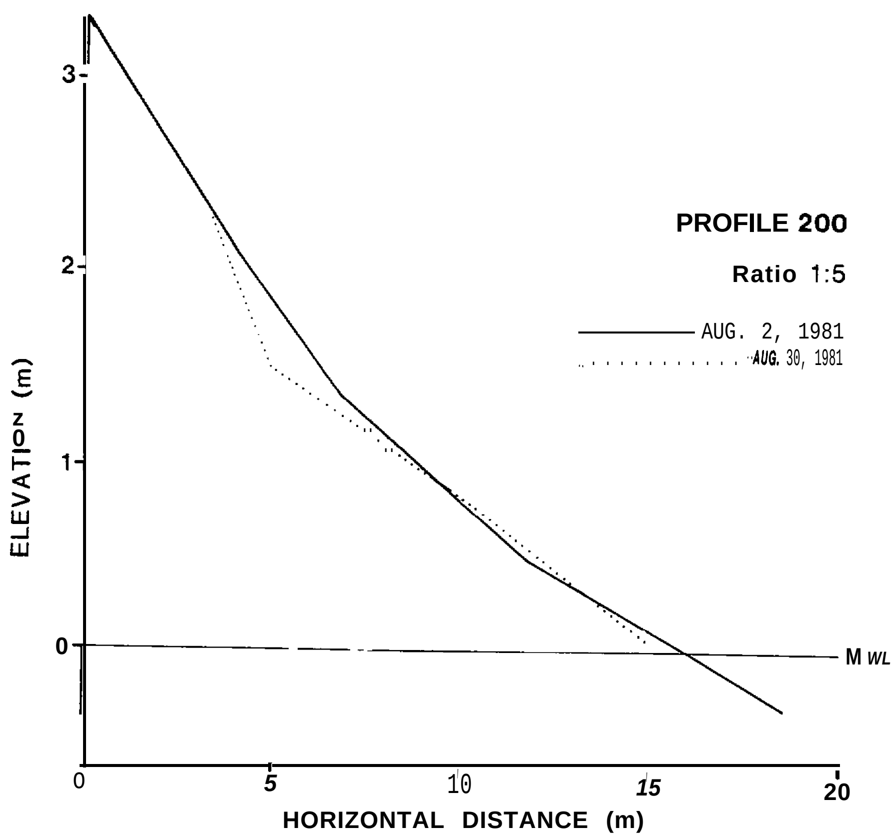

PROFILE 120
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
M WL
D(B)E
ELEVATION (m)
2
1
C
5
10
15
20
HORIZONTAL DISTANCE (m)


PROFILE 140
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
HHWM Aug. 8
M WL
D(B)C
ELEVATION (m)
3
2
1
C
5
10
15
20
HORIZONTAL DISTANCE (m)


PROFiLE 160
Ratio 1:5
AUG. 2, 1981
AUG. 30, 1981
M WL
ELEVATION (m)
HORIZONTAL DISTANCE (m)
3
2
1
0
5
10
15
20


PROFILE 180
Ratio 1:5
AUG. 2, 1981
AUG. 8, 1981
AUG. 30, 1981
Top of cross-plot
HHWM Aug. 8
MWL
Bottom of cross-plot
ELEVATION (m)
HORIZONTAL DISTANCE (m)
3
2
1
0
5
10
15
20


PROFILE 210
Ratio 1:5
—AUG. 2, 1981
ELEVATION (m)
3
2
1
0
M WL
0
5
10
15
20
HORIZONTAL DISTANCE (m)


PROFILE 200
Ratio 1:5
AUG. 2, 1981
AUG. 30, 1981
ELEVATION (m)
3
2
1
0
M WL
0
5
10
15
20
HORIZONTAL DISTANCE (m)

APPENDIX B - TIDE DATA

Uncorrected tidal data for both the Z-Lagoon side of Cape Hatt and the Ragged Channel side of Cape Hatt (Fig. B.1) is included as background information to the oil spill countermeasure experiments and the Ragged Channel spill experiments. The tidal data are not corrected for atmospheric pressure variations, which could cause errors of up to 10 cm in the curves shown. However, the curves are useful for illustrating the periods of spring and neap tides in relation to the spill dates, as well as for illustrating the relative magnitudes of the tidal changes.

The tide data was collected as part of the physical oceanographic studies around Cape Hatt (conducted by Petro-Canada and Seakem Oceanography Ltd.), and was reduced by personnel from the Institute of Ocean Sciences in Sidney, B.C.

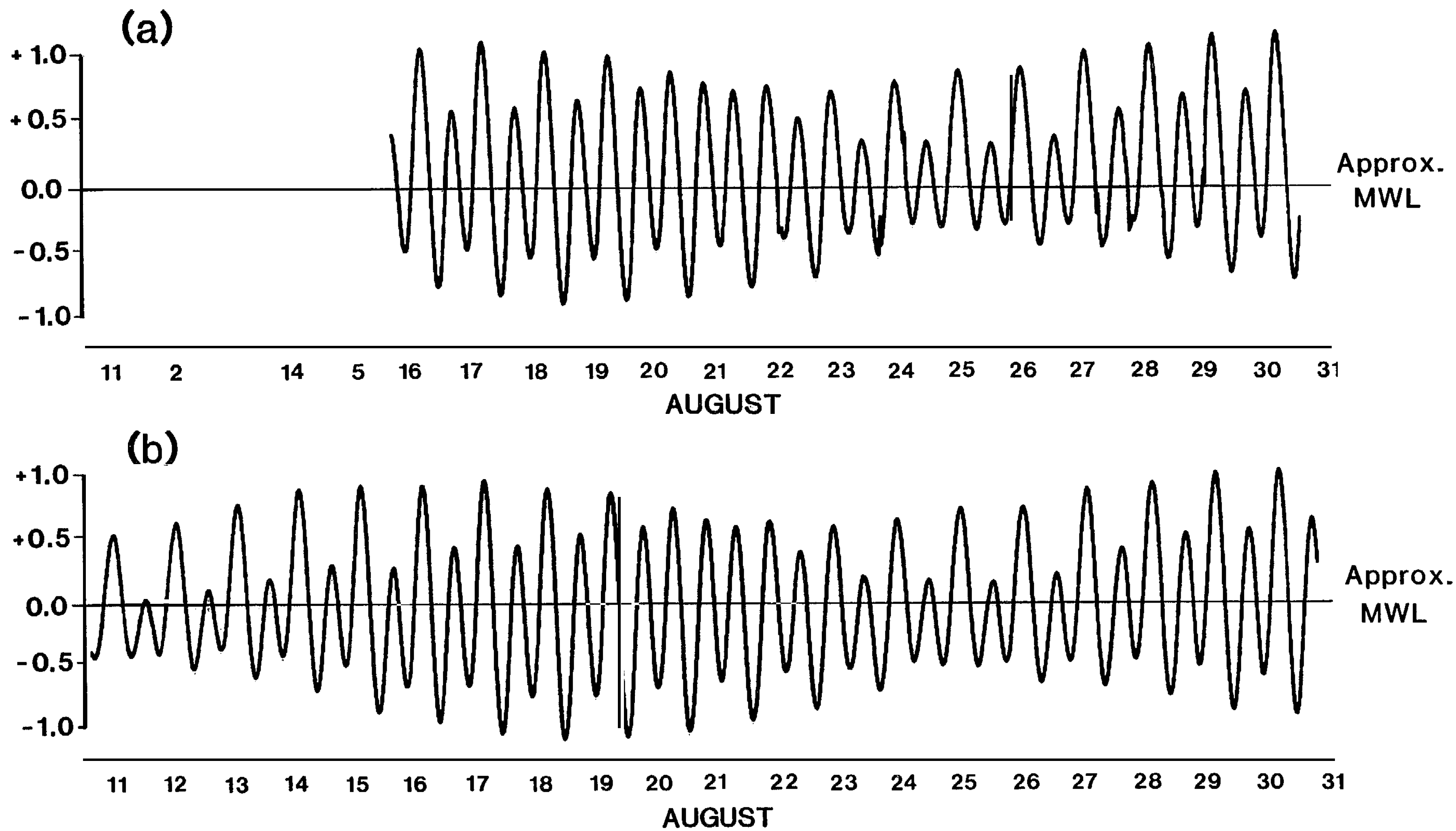


Figure B.1(a) Uncorrected tidal data from Bay 102, western Eclipse Sound, during August of 981. Atmospheric pressure variations have not been removed from the tidal record.

(b) Uncorrected tidal data for Bay 11, Ragged Channel. The tidal data has not been corrected for atmospheric pressure variations.

APPENDIX C - ICE MOUND OBSERVATIONS

During the early part of the 1981 summer, low gravelly sand ridges cored by ice were a common feature of the Cape Hatt beaches (Fig. C.1). These features, tentatively referred to as "ice mounds," were noted during the 1980 studies (Dickens, 1981; Barrie et al., 1981; Woodward-Clyde Consultants, 1981a) and were the subject of a separate investigation during late spring of 1981 (Semples, pers. comm.). The morphology of the "ice mounds," investigated during the early 1981 summer, is discussed briefly below in conjunction with possible modes of origin.

The "ice mound" features typically consisted of a linear ridge parallel to the shore and located in the lower intertidal zone, usually just above the mean low-water line. Relief of the ridges was less than 1 m, although some melting of the ice core may have occurred prior to our observations. The width of the "ice mounds" averaged about 2 m. A gravelly sand veneer of about 10 cm in thickness typically covered the ice-cored mound. Cobble- to boulder-sized material occurred on some of these ridges (Fig. C.2).

In some cases, the sand-gravel veneer was absent and the ice core was exposed in the intertidal zone (Fig. C.3). The presence of the ridge created a barrier to the surface runoff, and water was frequently ponded on the landward side of the ridges (Fig. C.4).

A narrow trench excavated through an ice core showed that some sediment (up to pebble size) was incorporated within the ice material, but the sediment did not appear to form any distinct layers within the ice (Fig. C.5). The maximum thickness of the ice core at this site was 35 to 40 cm (Fig. C.6).

The origin of the "ice mounds" around Cape Hatt is uncertain, but appears to be related to groundwater extrusion during freeze-up. Sadler and Serson (1981) have suggested that anchor ice noted along the shores of Cornwallis Island may have formed due to groundwater extrusion.

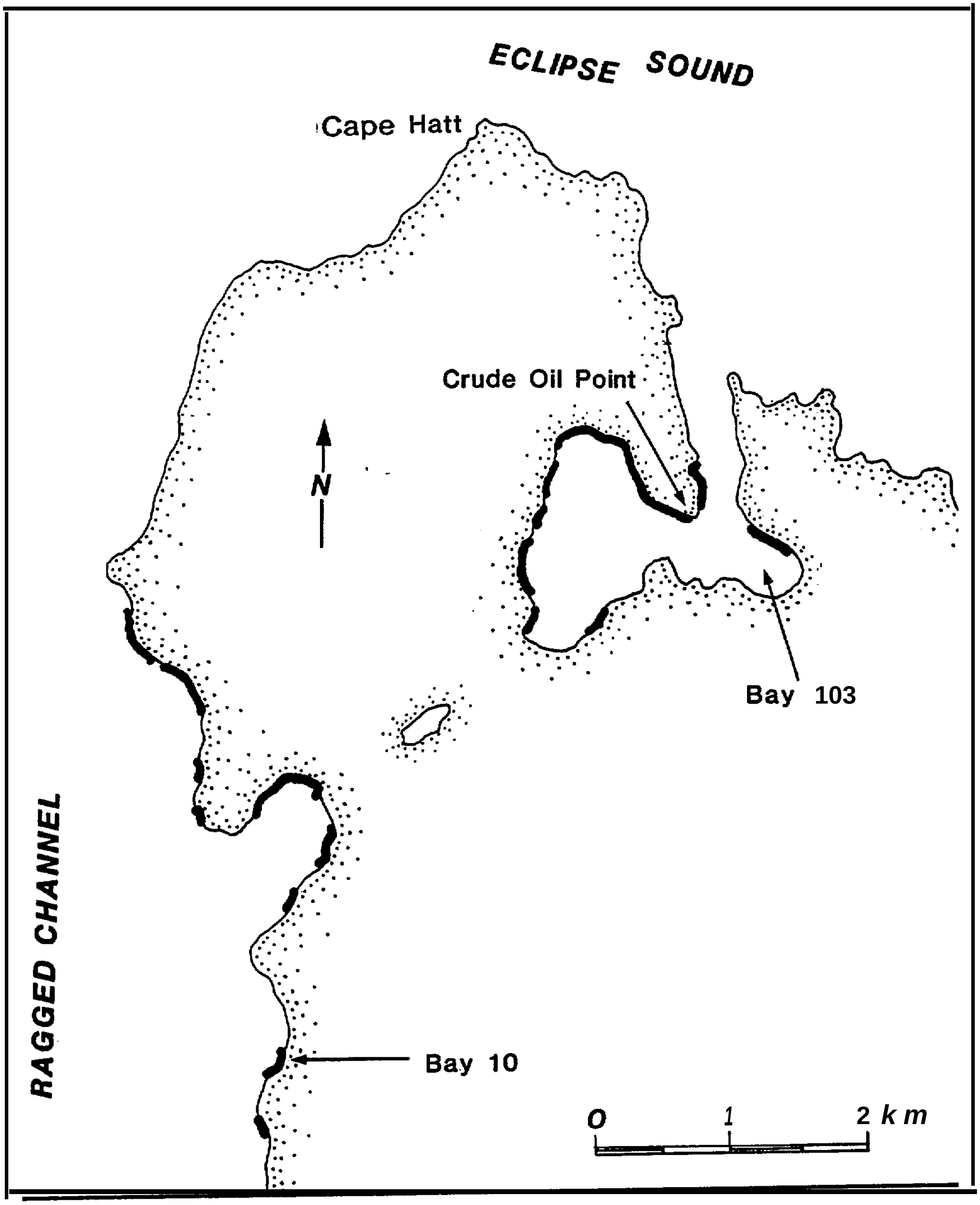


Figure C. 1 The distribution of "ice mounds" in the Cape Hatt vicinity (shown by heavy lines), as observed during a helicopter survey on 29 July 1981.

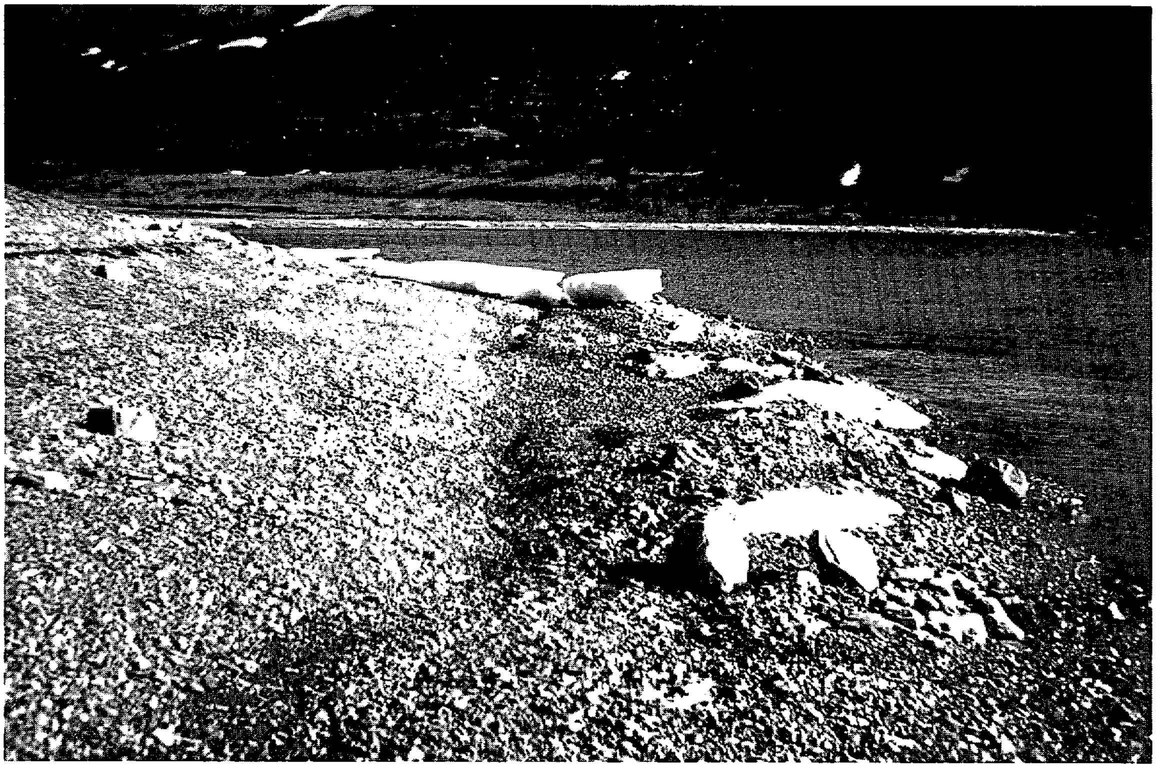


Figure C.2 Photograph of an "ice mound" near Bay 103 (see Fig. Cl) in Z-Lagoon. Note that relief is less than 1 m, and cobble-size material is present on the mound feature. Ice in the immediate foreground is part of the ice core, but other ice was floated in place (29 July 1981),

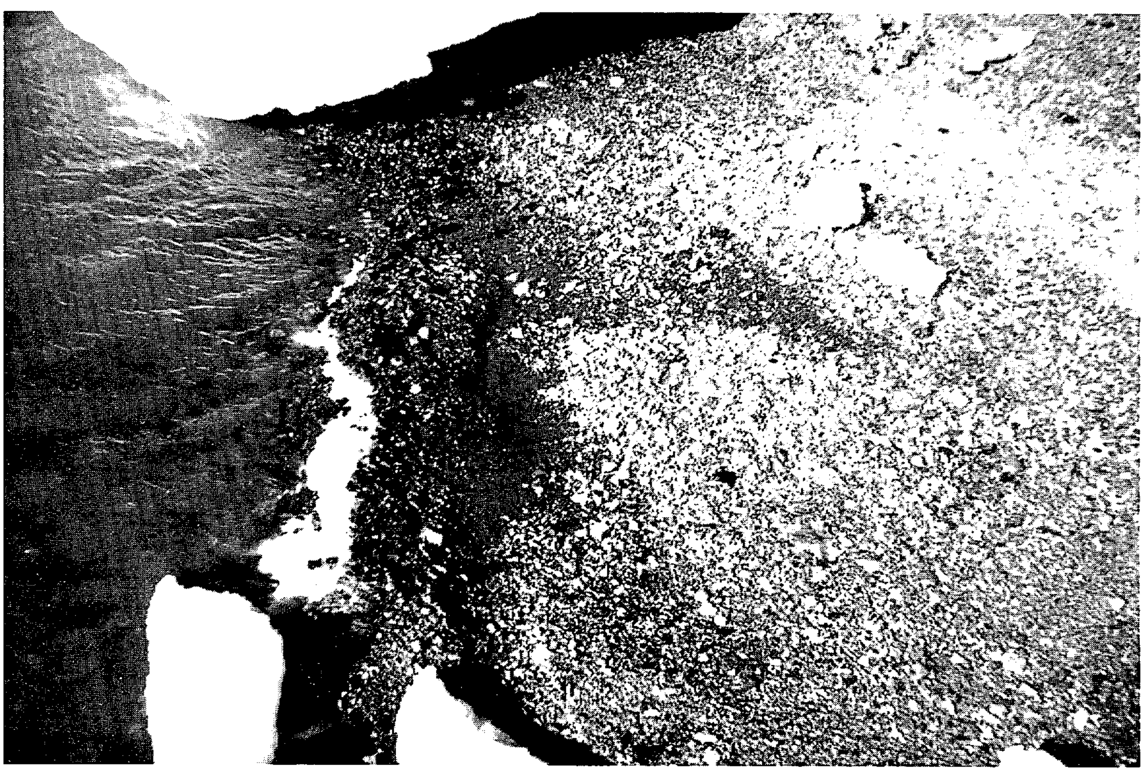


Figure C.3 Photograph of an "ice mound" in Bay 10 showing an exposed ice core (see Fig. C.1 for location; 29 July 1981).

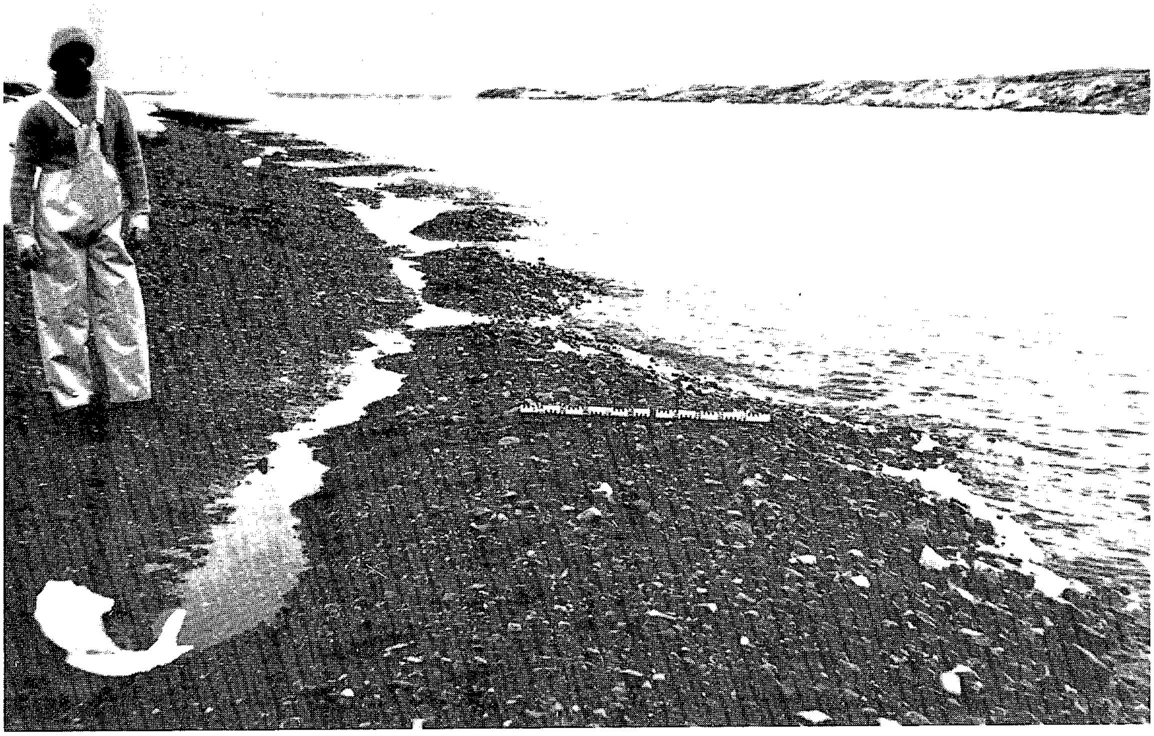


Figure C.4 Photograph of an "ice mound" on Crude Oil Point near the entrance to Z-Lagoon (see Fig. Cl) showing the pending of water on the landward side of the ridge. The trench shown in Figure C.5 was cut at the location of the survey staff (30 July 1981).

Figure C.5 Photograph of a cross section through an ice mound (see Fig. C.4). It is apparent that some sediment, up to pebble-size material, was incorporated in the ice; however, no distinct layering was present.

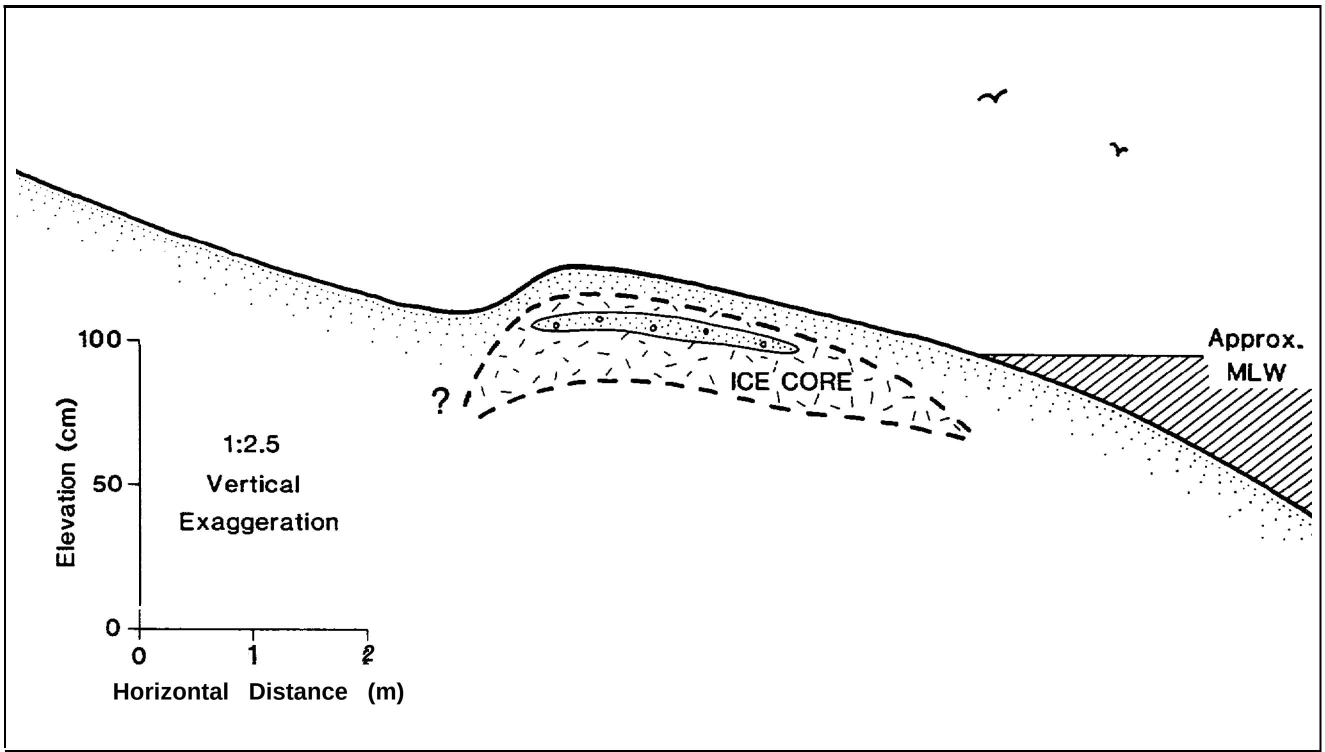


Figure C.6 Cross section of trench shown in Figure C.5.

Other origins which have been suggested include that of ice-foot formation (Wiseman _et al_., 1981) or kaimoo formation (Moore, 1966). Ice-cored mounds in the intertidal zone have been observed at numerous locations in this region during breakup. In 1968, Owens observed non-linear ice-cored mounds up to 1.5 m in height on the north coast of Lancaster Sound. These mounds were similarly masked by a 5-10 cm thick layer of pebble-cobble sediments. The fact that the ice mounds occur extensively in low wave-energy environments such as Z-Lagoon, and that the ice mounds are veneered by sediments up to the cobble or boulder size, would appear to preclude mound formation solely due to hydraulic reworking of material. The spatial extent of the "ice mounds" noted in this survey also precludes ice push as a viable explanation of origin.

Other features noted in the Cape Hatt area lend support to the groundwater extrusion hypothesis. First, anchor ice was also noted below the mean water level in Z-Lagoon, suggesting that Sadler and Serson's (1981) explanation of anchor ice formations may be related to the ice mound formation. Secondly, many of the Cape Hatt beaches are comprised of a thin sandy gravel veneer over finer "solifluction-like" deposits; in some areas these finer sediments had been squeezed through the sandy gravel onto the beach surface, suggesting that some hydroplastic deformation of the underlying sediments had occurred. A similar process of groundwater extrusion and freezing during active layer freeze-back is not uncommon in terrestrial environments, and considerable quantities of water can be extruded (Taber, 1943). Although groundwater extrusion appears to be a plausible hypothesis for the "ice mounds" at Cape Hatt, as with all ice-related shore-zone features it is rarely possible to provide an accurate interpretation of the formative processes without actual field observations of these processes. Positive explanation of the processes that form the "ice mounds" would require a field programme to determine shore-zone morphology prior to and immediately following ice-foot formation, as well as data that groundwater extrusion can take place simultaneously with sea-ice formation.

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__________, 1981c. Baffin Island Oil Spill Project - 1981 shoreline component (technical proposal). Woodward-Clyde Consultants, Victoria, B.C., Unpub. Report to Environmental Protection Service, Edmonton, Alberta.

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