Fate and Effects of Drilling Fluid and Cutting Discharges in Shallow, Nearshore Waters

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ABSTRACT

The relationships between selected environmental parameters (sedimentology, trace metals, and hydrocarbons) and macroinfaunal assemblages were studied to determine the fate and effects of drilling fluid and cutting discharges from a multiple wellsite in a shallow, nearshore environment. During the first phase of the program, data were collected during a single survey (October 1986) to evaluate and subsequently select an appropriate study site--"C" Platform in Matagorda Island Area Block 622--and to design the second, intensive phase of the program. During the second phase, two cruises (March/April and August 1987) were conducted; the physical environment and macroinfaunal assemblages were sampled to determine the extent of spatial and temporal differences in the biotic assemblage and the degree of correlation with the environmental factors. Contamination of the sediments from the insoluble, settleable fraction of discharged drilling fluids was wide spread over the study area and greater than at previously studied sites, probably because more materials were used during drilling at this site. Sediment contamination from hydrocarbon sources was limited to within 25 m of the platform, and the sources were thought to be oil-related. Over the entire study area, macroinfaunal assemblages were most affected by season. Differences in habitat structure resulting from materials sloughed from the platform and, perhaps, cuttings were responsible for the occurrence of different macroinfaunal assemblages within 150 m of the platform. Trace metals and hydrocarbons were judged to have little, if any, effect on the macroinfauna.

EXECUTIVE SUMMARY

One of the unresolved issues concerning the discharges of drilling fluids and cuttings into the marine environment is the effect of discharges on the biota from multiple production wells, particularly in shallow, nearshore environments. In an effort to examine this issue, the American Petroleum Institute funded a study to evaluate the effects of discharges at "C" Platform in Matagorda Island Area Block 622--a production platform site located 22 km (12 nmi) off the coast of south Texas where six wells had been drilled from May 1982 to November 1985.

The study approach was to collect samples of macroinfauna (larger organisms living in the sediments) around the platform. The distributions of the macroinfaunal organisms were evaluated in relation to measurements of the surrounding physical environment--sediment grain size, trace metal concentrations, and hydrocarbon concentrations. Benthic macroinfaunal communities provide an important means of measuring changes in marine environments because they tend to integrate the effects of natural alterations as well as perturbations by pollutants, construction, or disposal of sediments and other materials. Infauna are generally immotile; they do not change locations to avoid exposure to water column or sediment contaminants. In addition to effects due to acute toxicity, sublethal effects may be manifested as diminished reproductive success or recruitment and may be detected as changes in species abundance and composition.

Program Overview

The program was conducted in two phases. The objective of Phase I was to select an appropriate site for the study and to collect preliminary information for designing the more intensive Phase II. During the planning stages of the study, there were limited drilling sites available for study because overproduction of oil on a global basis had resulted in an economic downturn in the industry; hence, "C" Platform in Matagorda Island Area Block 622 was determined to be the only appropriate candidate for a study site. During Cruise 1 (October 1986), samples were collected by divers around "C" Platform (Figure ES-1) for analysis of sediment grain size, trace metals, hydrocarbons, and macroinfauna. A single hydrographic profile was also obtained during the cruise. These data were evaluated, and the selection of "C" Platform was finalized as the study site for Phase II of the program.

The Phase II objective was to determine whether or not drilling-related discharges affected the biota in the surrounding environment by evaluating the relationships between trace metal and hydrocarbon distributions and macroinfaunal assemblage distributions. During this phase, Cruises 2 and 3 were conducted in March/April and August 1987, respectively. Nineteen stations were occupied at various distances along three transects radiating from the discharge site (Figure ES-2) during each Phase II cruise. Samples were collected at each station to determine: 1) sediment grain size; 2) total organic carbon and calcium carbonate concentrations; 3) trace metal concentrations; 4) aliphatic and aromatic hydrocarbon concentrations; and 5) macroinfaunal abundances--adults and juveniles (Cruise 2 only). A current meter was deployed near the seafloor during the period between Cruises 2 and 3; and hydrographic profiling was performed during both cruises.

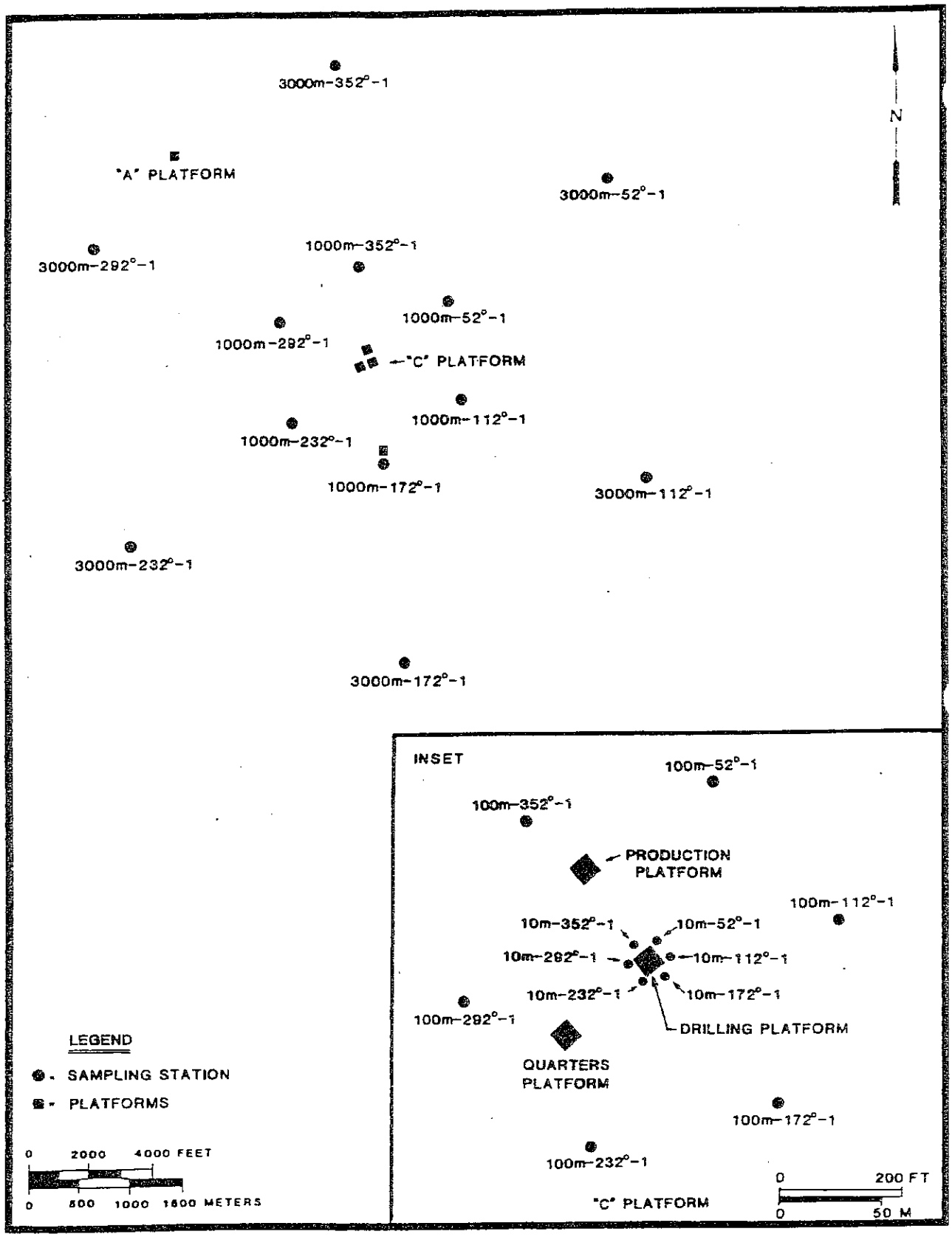

Figure ES-1. Sampling locations occupied during Phase I. Stations are designated "distance from the discharge site" - "direction from the discharge site" - "cruise number".

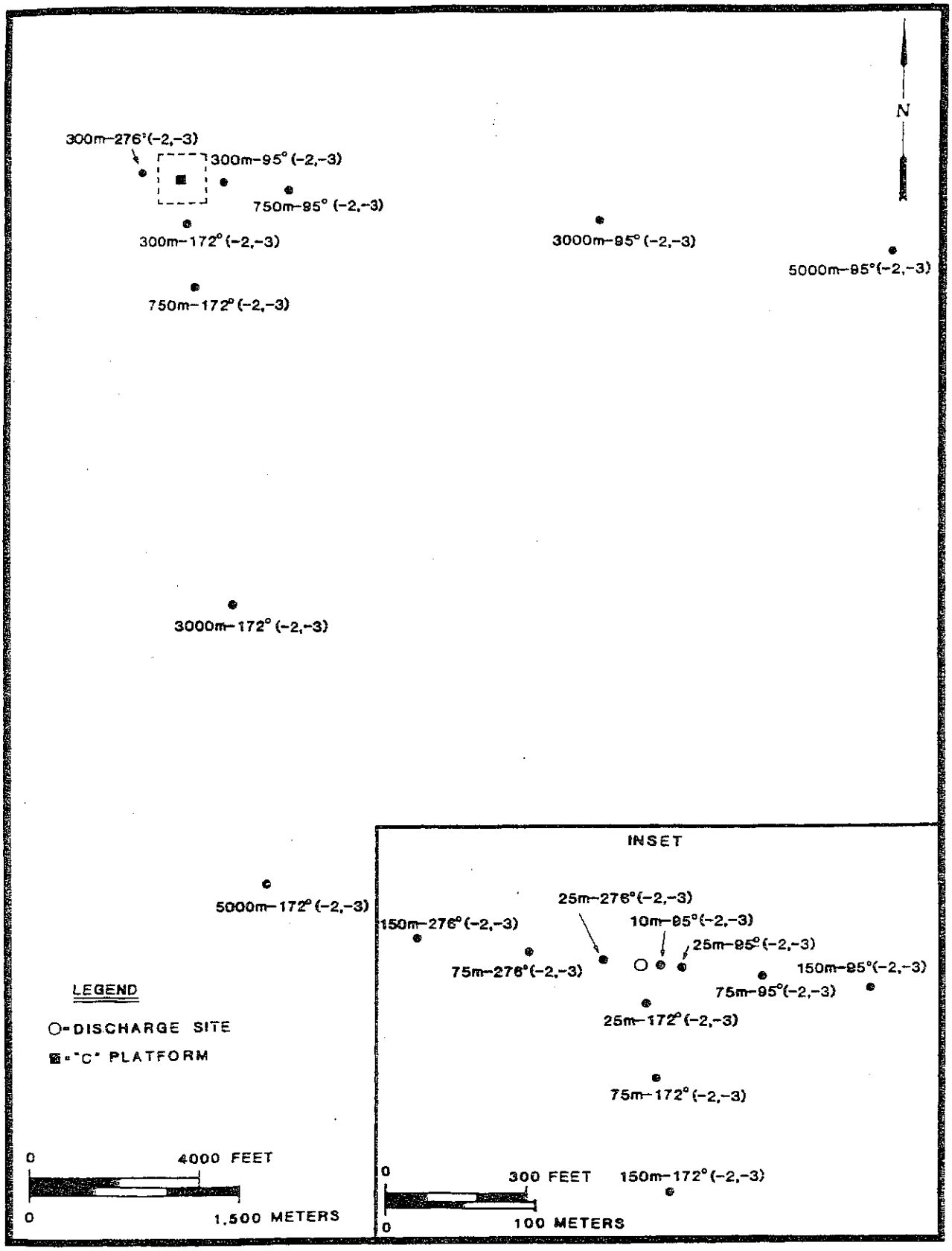

Figure ES-2. Sample locations occupied during Phase II. Stations are designated "distance from the discharge site" - "direction from the discharge site" - "cruise number" (in parentheses).

Physical Oceanographic Results

Longshore flow dominated the near-bottom currents from 27 March to 26 August 1987. The average current speed was 13.6 cm/s (0.3 kn) but currents reached 66 cm/s (1.3 kn). Current speeds tend to be lower later in the study period compared to March through May.

Temperatures were constant from the surface to the seafloor in October 1986 ranging from 25.5 to 25.6°C. They were also relatively constant but somewhat cooler in March 1987 (17.9 to 18.1°C). During the August 1987 cruise, a thermocline was observed between 15 and 20 m, and seasonal warming had increased temperatures compared to the March sampling. During this period, surface temperatures were between 29.3 and 29.5°C; near-bottom temperatures were 25.9 to 26.2°C. Salinities were constant from the surface to the seafloor in October 1986 and August 1987 (35.10 to 35.34 ppt; 36.61 to 36.87 ppt respectively), but reduced near the surface during March 1987 (29.79 to 30.02 ppt). Dissolved oxygen concentrations were near saturation on Cruises 1 and 2.

Sediments

Sediments were predominantly muddy sand or sandy mud on all cruises. Mean Cruise 2 calcium carbonate levels consistently exceeded 5% while mean Cruise 3 levels did not reach this concentration. Organic carbon levels were comparable between Cruises 2 and 3, ranging from approximately 0.2 to 0.7%.

Sediment Trace Metal Results

During Phase I, a gradient of sediment barium concentrations was observed with respect to distance from the discharge site--barium values in the fine-grained sediment fraction were elevated near the platform compared to samples collected farther away. Phase I sediment trace metal samples were sieved in the laboratory and the fine-grained material (<63 μm) was analyzed in an attempt to standardize for differences in grain size among the stations. Barium concentrations in the fine-grained fractions at the 10-m stations exceeded 40,000 ppm at three of the six stations and were greater than 20,000 ppm for the other three. Four of the six 100-m stations had mean barium concentrations between 10,000 and 15,000 ppm, but two had concentrations of 30,000 to 40,000 ppm. At one 3,000-m station, the mean barium concentration was 5,900 ppm, but mean concentrations at the others were less than 2,500 ppm. Barium-to-iron ratios indicated barium enrichment in the Phase I sediment samples, even those from the 3,000-m stations. This ratio was used to normalize the data for variations in quartz and calcium carbonate, which are very low in barium. Similarly, chromium also decreased with distance from the platform, but the enrichments over expected background levels were mostly restricted to the 10-m stations.

The high barium concentrations found in sediments near "C" Platform during Phase I were confirmed during Phase II. The highest Phase II barium concentrations were about 20,000 ppm, whereas several samples from Phase I

had over 40,000 ppm barium. This difference was due to two factors. First, the Phase II sediment samples were not sieved prior to trace metal analysis; hence the difference was partially due to the difference between analyzing whole sediments and fine-grained samples. The second factor was the highly variable distribution of barium in the sediment, both spatially and temporally. Mean barium concentrations were elevated within 75 m of the discharge site, reaching 20,000 ppm, and concentrations remained high at 300 m where 3,000 to 7,000 ppm was observed. At 750 m, a mean concentration of about 2,000 ppm was found at one of the stations on both cruises. At 3,000 and 5,000 m from "C" Platform, barium concentrations were 800 to 1,200 ppm, well above the estimated background level for this area of 500 to 600 ppm. The distributions of chromium, cadmium, mercury, and zinc indicated that high concentrations of these trace metals were restricted almost exclusively to within 25 m of the platform.

Sediment Organic Chemistry

During Phase I, concentrations of total extractable organic matter (EOM), unresolved complex mixture (UCM) and normal alkane hydrocarbons were determined. EOM concentrations exceeded 500 ppm within 10 m of the discharge site; UCM and total alkane concentrations exceeded 100 ppm and 4,600 ppb, respectively, within 10 m of the platform. These concentrations were an order of magnitude higher than at stations located at distances greater than 10 m from the platform.

Average Phase II sediment EOM concentrations at 10 m were 232 and 276 ppm during Cruises 2 and 3, respectively, compared with 535 ppm during Cruise 1. The more closely spaced Phase II sampling revealed that elevated EOM concentrations extended to 25 m east and west of the platform. EOM concentrations were higher at all stations during Cruise 3, possibly as a result of increased biological productivity input from the water column (e.g., phytoplankton bloom) into the sediments during this period. Alkane distributions during Cruises 2 and 3 were primarily due to biogenic hydrocarbons. Cruise 2 UCM concentrations were elevated 10 and 25 m from the platform. Concentrations at these stations were three times higher than observed during Cruise 1 at stations located near the platform; slightly higher concentrations were observed at the background stations compared to Cruise 1. The mean Cruise 3 UCM concentration at 10 m was 852 ppm compared to 280 and 100 ppm during Cruises 2 and 1, respectively. Higher UCM concentrations were observed at most stations during Cruise 3, probably as a result of a large biological lipid input during this period. The UCM concentrations should only be used to provide relative distributions around the platform because the UCM is often higher than the EOM at higher concentrations. Similar patterns were observed for total n-alkanes. Elevated levels were observed at 10 and 25 m during Cruise 2 and at 10, 25, and 75 m during Cruise 3.

In addition to measurements of the EOM and aliphatic hydrocarbon concentrations, polynuclear aromatic hydrocarbon (PAH) concentrations were also determined during Phase II. Elevated concentrations of PAH were restricted to stations located at 10 and 25 m from the platform. The background total PAH concentration at stations located more than 25 m from the platform was 29.4 ppb

compared to an average of 494 and 757 ppb at 10 and 25 m respectively, during Cruises 2 and 3.

Characterization of the Macroinfaunal Assemblages

Three taxonomic groups--Annelida, Crustacea, and Mollusca--dominated the macroinfaunal samples in terms of the numbers of taxa and numbers of individuals. Numbers of taxa did not appear to be related to station locations--numbers of taxa at stations 75 m or closer to the platform were comparable to those observed at more distant stations. Infaunal densities varied widely among stations and among cruises. Stations near the platform (within 75 m) exhibited both the lowest and highest infaunal densities. The seven most abundant taxa accounted for 45.7% of the total individuals collected. In addition, stations located near the discharge site exhibited relatively higher diversities compared to stations located farther away.

Clustering analyses revealed a biological gradient with respect to the platform in terms of taxonomic composition and abundance. Generally, stations located within 75 m of the discharge site were more similar to each other than to stations located farther away. In addition, the clustering analyses indicated temporal differences among stations; however, these differences were within the broader gradient related to distance from the platform. Three macroinfaunal assemblages of taxa were identified. One assemblage, the Shelly Sand Group, was restricted to those stations nearest the platform (i.e., 25 m or less). This assemblage included primarily surface or tube dwellers which were representative of filter-feeding and carnivorous-feeding guilds. The Sand-Silt Clay and Silty-Clayey Sand assemblages were most dominant at stations greater than 150 m from the platform, but were represented in all areas sampled during this study. The Sand-Silt Clay Group included surface or burrowing deposit feeders, while the Silty-Clayey Sand assemblage was dominated by carnivores and surface deposit feeders.

With the exception of the Shelly Sand assemblage, infauna censused during this study were typical of nearshore soft-bottom communities throughout the region. The species in the Shelly Sand assemblage are generally associated with structures and/or coarser sediments. This suggested that the platform influenced the benthos through sloughing of encrustations from platform supports and other hard surfaces. In addition, disposal of cuttings may have provided a coarser substrate and some vertical relief in the vicinity of the discharge site.

Comparisons of the distributions of the measured environmental parameters to the distributions of the macroinfaunal assemblages using canonical discriminant analysis revealed that sediment texture was generally not responsible for differences among the biological groups. In the cases of the individual cruises, correlations with some trace metals and hydrocarbons were observed, which could be interpreted to mean that discharged drilling effluents were directly responsible for the presence of the near-field assemblage. If this were true, the near-field assemblage would probably be numerically dominated by a limited number of opportunistic species and the assemblage would exhibit low diversity and evenness--the classic situation for a polluted outfall. This was not the case because a

relatively balanced assemblage occurred near the platform, probably as a result of the increased habitat structure in the near-field environment. This assemblage was composed of species from the Shelly Sand assemblage and members of the two more ubiquitously distributed assemblages. The addition of the Shelly Sand species was probably a result of the platform acting as a source of materials which increased habitat structure.

The abundances of some of the more ubiquitously distributed species were reduced near the discharge site compared to abundances at the far-field stations. Whether or not these reduced abundances were the result of coincidental distributions of the trace metals/hydrocarbons and the platform-related changes in habitat structure or were more directly related to the drilling effluent tracers cannot be determined from the data collected during this study. However, it is unlikely that the trace metals/hydrocarbons were directly related to the reductions of the more ubiquitously distributed species because these species are especially abundant in fine-grained estuarine sediments known to contain relatively high concentrations of trace metals and hydrocarbons.

Conclusions

The primary conclusions of the study are summarized below.

1) The sediment concentration of the insoluble, settleable fraction of drilling muds around "C" Platform was elevated compared to other previously studied sites such as Matagorda Island Area Block 686 (discussed by Boothe and Presley, 1985). This enrichment was indicated by the widespread distribution of barium in the surface sediments and in the vertical sediment column. A greater quantity of discharges compared to those previously studied sites, as indicated by greater quantities of barite used during drilling at this site, was probably responsible for the observed enrichment.

2) Elevated sediment concentrations of cadmium, mercury, and zinc primarily occurred within 25 m of the platform. The sources of these trace metals were unclear. Poor correlations between the distributions of these metals and barium suggested that drilling discharges may not have been the source, but drilling discharges could not be definitively excluded based on available data.

3) Contamination of the sediments by organic compounds was only observed in the near vicinity of the platform (<25 m). PAH concentrations in this immediate vicinity were from thermogenic (oil-related) sources. It was not possible to determine

whether the elevated hydrocarbon concentrations observed around the platform were from oil-contaminated cuttings or discharges of oil.

4) The species composition, abundance, and diversity of the macroinfauna were similar to the macroinfaunal data reported in the literature for this area.

5) Macroinfauna abundance and diversity changed uniformly throughout the study area over time. This indicated that temporal changes in these parameters were related to season.

6) Similarly, macroinfaunal assemblage structure was most influenced by season. The presence of materials sloughed from the platform and possibly cuttings were responsible for changes in the macroinfaunal assemblage within 150 m of the platform--increased numbers of surface-dwelling macroinfaunal species, including taxa normally associated with shell reefs, rubble bottoms, and hard substrates. Trace metals and hydrocarbons associated with drilling discharges from the platform appeared to have little, if any, effect on the macroinfaunal assemblage structure.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF TABLES
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LIST OF FIGURES

LIST OF FIGURES
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1.0 INTRODUCTION

The potential effects of drilling mud and cuttings discharged in the marine environment have concerned the public for many years. Government agencies and private concerns have conducted numerous studies to examine the fates of discharged drilling muds and cuttings. These studies have included designed field experiments (e.g., Ayers et al., 1980) and field studies associated with monitoring individual drilling efforts (e.g., Continental Shelf Associates, Inc., 1985). Studies of the effects have been conducted as laboratory evaluations of drilling mud toxicities (e.g., Duke and Parrish, 1984) and as field efforts examining biotic changes (e.g., Continental Shelf Associates, Inc.. 1988; EG&G, 1982). Much of the research on the fate and effects of drilling muds has been reviewed and summarized by several authors, such as National Research Council (1983); U.S. Environmental Protection Agency (1985); and Boesch and Rabalais (1985). The overall conclusion has been that effects, if detectible, are generally restricted to the near vicinity of the discharge point, where most of the drilling effluents are deposited (Ayers et al., 1980).

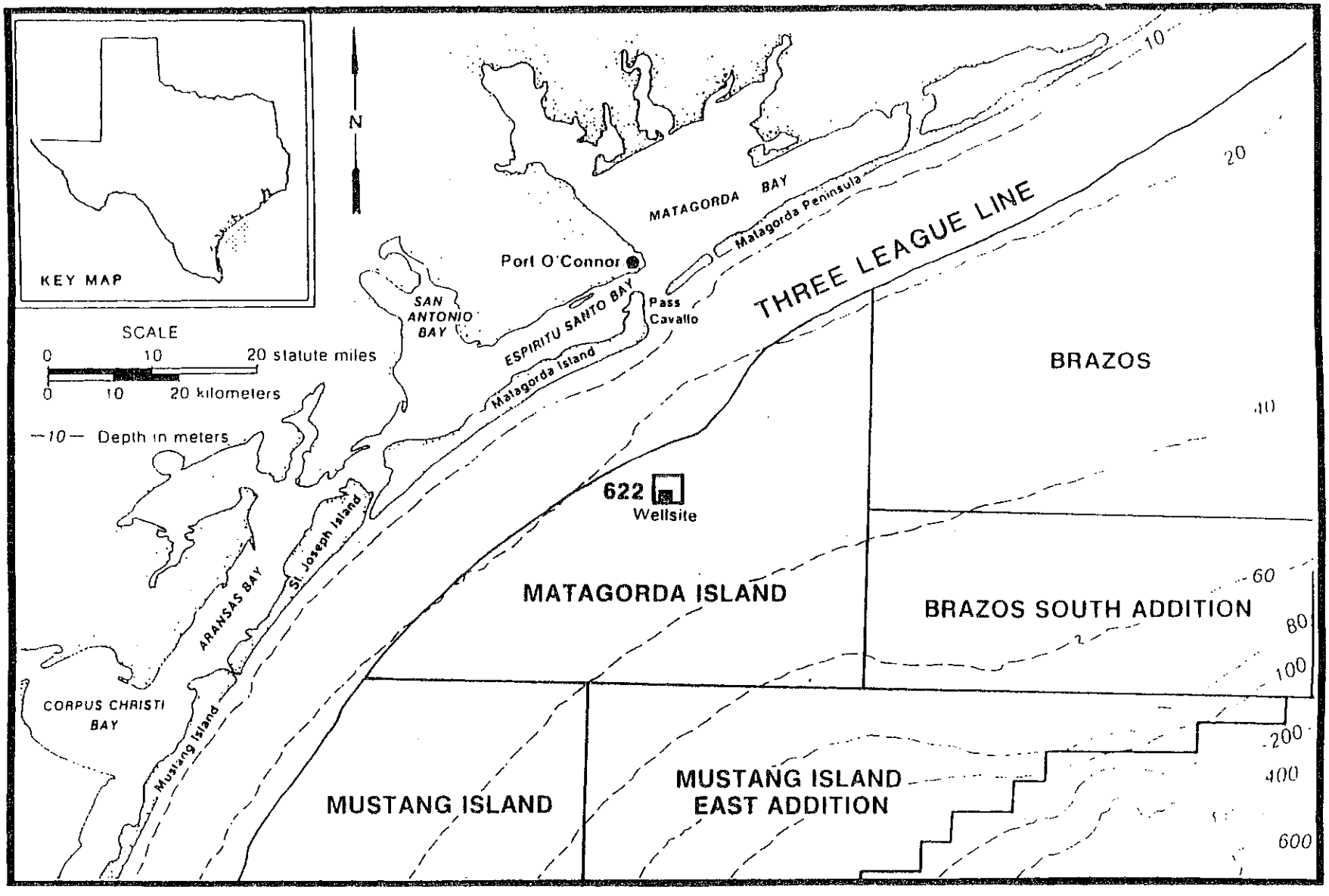
Although much research has been conducted, several issues concerning the effects of discharged drilling effluents remain unresolved. Among these is the effect of discharges from multiple wells from a single site or multiple sites located in close proximity to each other on the biota in the vicinity of the drilling activity. This question has been specifically raised concerning shallow, low energy environments. Much of the previous research has dealt with single exploratory drilling efforts. Development drilling from production platforms differs from exploratory efforts because less material per well is discharged but more total material is discharged. It has been hypothesized that the sheer bulk of material discharged during development drilling may have more serious environmental repercussions than are associated with exploratory efforts, especially where dispersion of the discharged materials is limited.

This program focuses on this environmental question--the environmental effect of discharges from multiple wells in a shallow marine environment.

1.1 ENVIRONMENTAL SETTING

1.1.1 Study Site

The study was conducted from October 1986 to August 1987 in association with the "C" Platform, located in Matagorda Island Area Block 622 at 28°06'07" N, 96°22'52" W. Geographically, it is situated 22 km (12 nmi) off the Texas coast in the Gulf of Mexico (Figure 1). The platform lies in nearshore waters, characterized as having an essentially level bottom--water depths range from 24 to 26 m (80 to 85 ft). The region has a relative broad continental shelf, about 87 km (47 nmi) from the shoreline to the shelf break (Flint and Rabalais, 1981). Surficial sediments in the general area were characterized by Flint and Rabalais (1981) as a variable inner-shelf, sandy mud.


KEY MAP
N
SCALE
0 10 20 statute miles
0 10 20 kilometers
—10— Depth in meters
MATAGORDA BAY
Matagorda Peninsula
Port O'Connor
SAN ANTONIO BAY
ESPIRITU SANTO BAY
Pass Cavallo
Matagorda Island
THREE LEAGUE LINE
BRAZOS
622
Wellsite
MATAGORDA ISLAND
BRAZOS SOUTH ADDITION
ARANSAS BAY
St. Joseph Island
CORPUS CHRISTI BAY
Mustang Island
MUSTANG ISLAND
MUSTANG ISLAND EAST ADDITION
10
20
40
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80
100
200
400
600

1.1.2 Drilling History

Drilling at the platform occurred from May 1982 to November 1985. Within Block 622, four exploratory wells have been drilled in addition to the six wells drilled at "C" Platform (Table 1). Two platforms have been installed in the neighboring Block 623. Drilling activity in the vicinity of the study area is presented in Figure 2.

The depths of the six wells drilled at "C" Platform ranged from 4,324 to 4,953 m (Table 2). Well C-1 was originally drilled during exploration and subsequently completed for production. Maximum drilling mud densities were about 2.2 g/cm^3. Spud muds (saltwater/gel) were used during the initial drilling of each well. At depth (Table 2), the mud system was changed to a lignosulfonate system to complete drilling.

The quantities of materials added to the mud system during drilling of each well are summarized in Table 3. The predominant component used during drilling at "C" Platform was barite, which was used to increase the density of the drilling muds. Other important components were gel (bentonite clay), lignite, chrome lignosulfonate, and caustic soda (sodium hydroxide). Other additives, such as lubricants and lost circulation materials, were added to change the characteristics of the drilling muds to meet downhole conditions.

The estimated quantities of barium used at "C" Platform appeared elevated compared to other similar sites. Assuming barite is 87% barium sulfate and barium sulfate is 58.8% barium (Boothe and Presley, 1985), the total estimated barium discharged from "C" Platform was about 8,583,000 kg. This quantity was over 150% of the largest quantity used at drilling sites reported by Boothe and Presley (1985). In Matagorda Island Area Block 686, located approximately 28 km (15 nmi) southwest of Block 622, Boothe and Presley estimated 2,334,000 kg barium used at a platform, approximately 25% of that used at "C" Platform.

1.2 PROGRAM OVERVIEW

The overall objective of the program was to determine whether or not drilling effluents discharged in a shallow, nearshore environment affected the benthic fauna--macroinfauna (larger organisms living in the sediments) in this case. Briefly, the study approach was to collect samples of the macroinfauna assemblage around a recent multiple well drilling site. The distributions of the macroinfaunal organisms were evaluated in relation to measurements of the physical environment--sediment grain size, trace metal concentrations, and hydrocarbon concentrations.

Benthic macroinfaunal communities provide an important means of measuring changes in marine environments because they tend to integrate the effects of natural alterations as well as perturbations by pollutants, construction, or disposal of sediments and other materials. Infauna are generally immotile, not changing locations to avoid exposure to water column or sediment contaminants. Further, by

Table 1. Drilling activity from and around Platform "C" in Matagorda Island Area Block 622.

Matagorda Island Area Block	Well Number	Spud Date	Original Comp. Date	Well T.D. Final Logging Run
622	002	04-27-83	TA	09-05-83
622	003	10-28-83	Dry Hole	08-01-84
622	004	05-11-84	Dry Hole	07-26-84
622	005	01-13-86	05-23-86	09-04-86
622	C001	05-31-82	11-13-85	10-20-82
622	C002	04-03-83	06-10-84	07-09-83
622	C003	08-02-83	08-28-85	10-30-83
622	C004	11-16-83	11-29-85	04-06-84
622	C005	06-12-84	10-07-85	09-02-84
622	C006	09-29-84	08-02-85	05-24-85
623	003	12-12-81	TA	03-14-82
623	A001	12-30-79	06-10-84	03-24-80
623	A002	09-25-83	06-03-84	12-08-83
623	A003	12-12-83	07-03-84	04-13-84
623	B001	09-13-81	02-24-83	11-23-81
623	B002	03-26-82	Dry Hole	07-09-82
623	B003	10-11-82	04-04-83	12-15-82
623	B005	07-10-82	08-26-83	10-06-82
623	B006	04-02-83	09-21-83	08-02-83
623	B007	09-22-83	Dry Hole	10-21-83

TA = Temporary Abandonment.

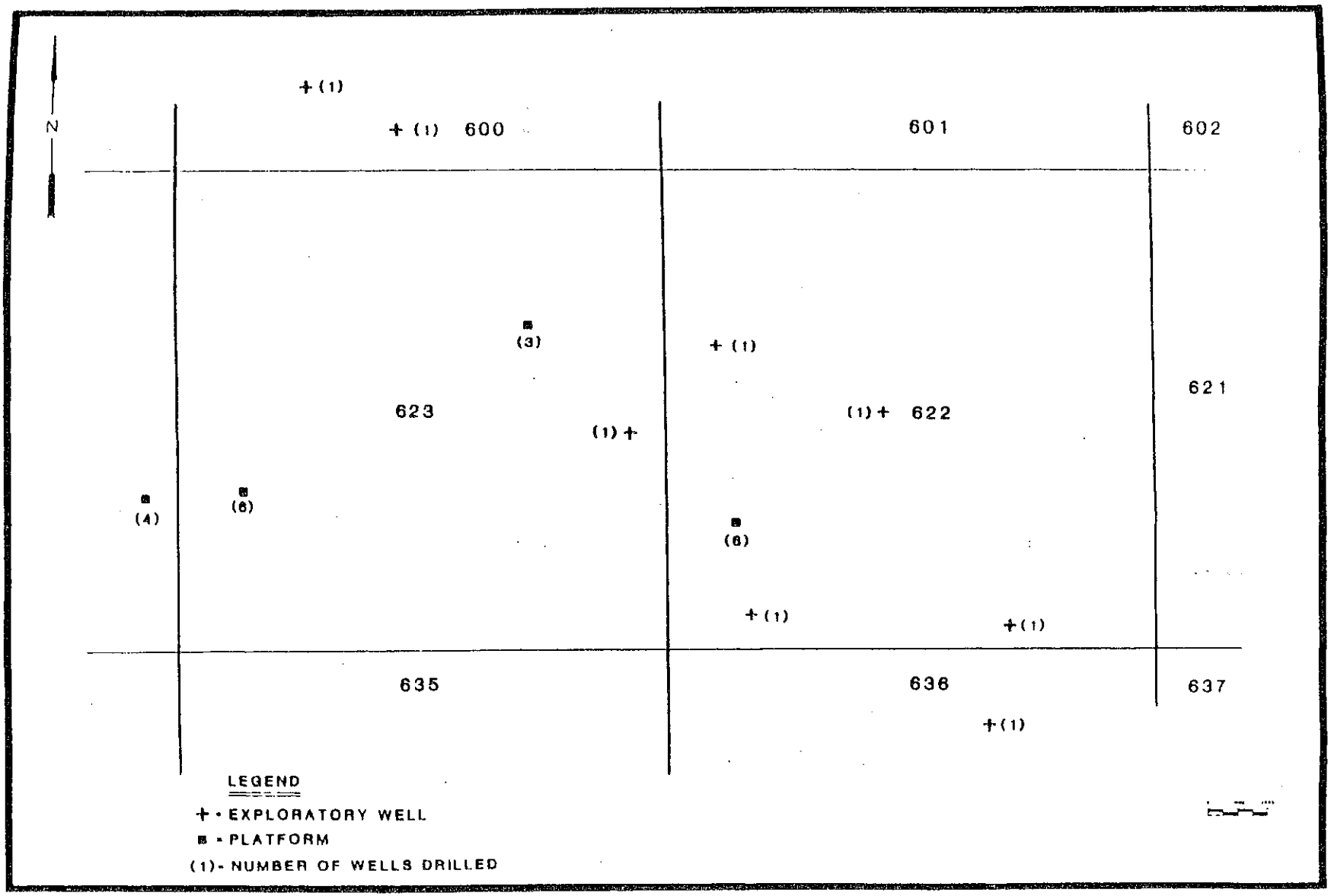


Figure 2. Drilling activity in and around Matagorda Island Area Block 622.

Table 2. Depth of well, maximum drilling mud density, and starting depth of lignosulfonate drilling mud system at "C" Platform.

Well	Depth of Well (m)	Maximum Drilling Mud Density (g/cm^3)	Starting Depth of Lignosulfonate Drilling Mud System* (m)
C-1	4,953	2.22	2,941
C-2	4,324	2.16	2,008
C-3	4,324	2.17	1,999
C-4	4,734	2.17	2,415
C-5	4,343	2.23	2,006
C-6	4,374	2.15	2,844

* A saltwater/gel drilling mud system was used during drilling prior to reaching this depth. A lignosulfonate drilling mud was used during deeper drilling.

Table 3. Materials used during drilling at "C" Platform.

	Well						
	C-1	C-2	C-3	C-4	C-5	C-6	Total
Weighting agent							
Barite (kg)	3,638,008	3,110,335	2,357,495	2,715,340	2,037,480	2,919,869	16,778,528
Viscosifiers							
Bentonite clay (kg)	181,168	308,130	334,530	360,612	334,802	189,832	1,709,074
Bentonite extender (kg)	--	5,851	6,940	446	1,066	--	14,304
Attapulgite clay (kg)	--	--	--	11,340	--	--	11,340
Filtrate reducers							
Lignite (kg)	31,548	74,617	48,807	89,518	44,453	54,183	343,126
Causticized leonardite (kg)	6,668	--	--	--	--	--	6,668
Polymer blend (kg)	4,785	--	--	--	--	--	4,785
Resin additive (kg)	--	--	--	--	3,402	--	3,402
Treated gilsonite (kg)	--	2,041	--	--	--	--	2,041
Sodium polyacrylate (kg)	--	181	--	--	--	295	476
Polyanionic cellulose (kg)	--	--	--	--	68	--	68
Dispersants							
Chrome lignosulfonate (kg)	38,420	56,995	60,261	94,190	76,205	94,031	420,102
Chrome lignite (kg)	--	--	25,969	14,515	13,721	2,313	56,519
Wetting agent (l)	--	--	8,743	3,331	22,483	20,818	55,375
Sulfonated maleic anhydrite co-polymer (kg)	1,089	--	--	--	--	--	1,089
Sodium acid pyrophosphate (kg)	45	454	--	181	45	--	725
Lost circulation materials							
Nut plug (kg)	907	4,717	9,979	20,571	16,897	16,284	69,355
Mica (kg)	930	--	--	--	--	--	930
Granule, flake, and fiber blend (kg)	--	--	--	--	454	--	454
Other lost circulation materials (kg) 113	--	--	--	6,350	--	6,463	
pH control							
Caustic soda (kg)	28,032	51,053	41,640	55,067	48,649	40,393	264,834
Sodium bicarbonate (kg)	1,361	6,713	2,177	1,769	907	1,588	14,515
Lime (kg)	680	--	--	--	--	340	1,021
Lubricants							
Oil-based spotting fluid (l)	--	27,063	--	--	--	52,044	79,107
Solid lubricant (kg)	--	--	--	4,990	2,177	--	7,167
Sulfonated residuum (kg)	4,967	--	--	--	--	--	4,967
Water-dispersable asphaltite (kg)	--	2,268	2,064	--	--	--	4,332
"Sacked fishing tools" (kg)	--	3,402	--	--	--	--	3,402
Glass beads (kg)	--	1,134	--	454	--	--	1,588
Biodegradable oil substitute (l)	--	--	4,164	1,249	416	1,457	7,286
Diesel (l)	4,353	--	--	--	--	--	4,353
Anti-sticking additive (l)	--	833	2,082	1,041	--	--	3,955
Surfactant (l)	--	625	--	--	--	--	625
Drilling mud lubricant (l)	--	--	--	--	568	--	568
Defoamers							
Aluminum stearate (kg)	23	249	249	34	68	136	760
Non-hydrocarbon defoamer (l)	341	--	--	--	--	--	341
Defoamer (l)	--	227	--	--	--	--	227
Flocculant							
Acrylic polymer (kg)	--	102	59	29	73	--	262
Deflocculant							
Deflocculant polymer (kg)	--	454	522	--	--	--	975
Corrosion inhibitor							
Ironite sponge (kg)	--	1,701	794	2,495	--	--	4,990
Surface active agent							
Sodium chromate (l)	1,192	795	757	965	700	1,590	5,999
Shale control inhibitor							
Gilsonite (kg)	--	--	68	--	3,742	4,536	8,346

ingesting sediments and/or surficial detritus, some benthic organisms may assimilat chemicals that accumulate in bottom habitats. Although bioaccumulation o contaminants may not result in acute toxicity to infauna, sub-lethal effects ma diminish reproductive success or affect recruitment, resulting in changes in specie abundance and composition.

Several recent offshore Texas investigations have used benthi community analysis to identify impacts of accidental spills or of permitted discharge of drilling muds and fluids, salt cavern brines, and dredged material. Energ Resources Company, Inc. (1982) investigated the impacts of the Ixtoc and Burma Agate oil spills on benthos and other habitat characteristics along the southern Texa coast (centered near Corpus Christi). Texas A&M University (1983) assessed th effects of brine disposal from the Bryan Mound Strategic Petroleum Reserve facilit near Freeport, Texas (north-central coast). Effects of drilling waste disposal o benthos near Galveston, Texas (Buccaneer Oil Field) were monitored by Harper e al. (1981), while Science Applications International (1984) reported benthi community ecology at several Texas offshore dredged material disposal sites. I addition, the Minerals Management Service-sponsored South Texas Oute Continental Shelf (STOCS) program (Flint and Rabalais, 1981) characterized marin benthic infaunal community structure from Matagorda Bay to Brownsville.

To accomplish the objective of the study, the program was conducte in two phases. Phase I was conducted to select an appropriate site for the stud where multiple wells had been drilled recently in a shallow-water environment, an to collect preliminary information. "C" Platform in Matagorda Island Area Bloc 622 was determined to be the only appropriate candidate for a study site becaus overproduction of oil on a global basis had resulted in a downturn of the industr reducing the number of potential study sites. A preliminary survey of the candidat site, Cruise 1, was conducted in October 1986. The Cruise 1 sampling pattern i presented in Figure 3. One station was located at the discharge site; 24 station were located at four distances (10, 100, 1000, and 3000 m) on six radials centere at the discharge site. Samples were collected for analysis of sediment grain size trace metals, hydrocarbons, and macroinfauna. A single hydrographic profile wa obtained during the cruise.

The data collected during Cruise 1 were evaluated and the selectio of "C" Platform was finalized as the study site for Phase II of the program. Th Phase II objective was to determine whether or not drilling-related discharge affected the biota in the surrounding environment by evaluating the relationship between trace metal and hydrocarbon distributions and macroinfaunal assemblag distributions. To accomplish this objective, two surveys, Cruises 2 and 3, wer conducted during Phase II. Cruise 2 was conducted in the late winter, early sprin (March 1987), and Cruise 3 was conducted during the summer (August 1987).

During each Phase II survey, 19 stations were occupied at variou distances (10, 25, 75, 150, 300, 750, 3,000, and 5,000 m) along three transect radiating from the discharge site (Figure 4). (Station designations are "distance fro

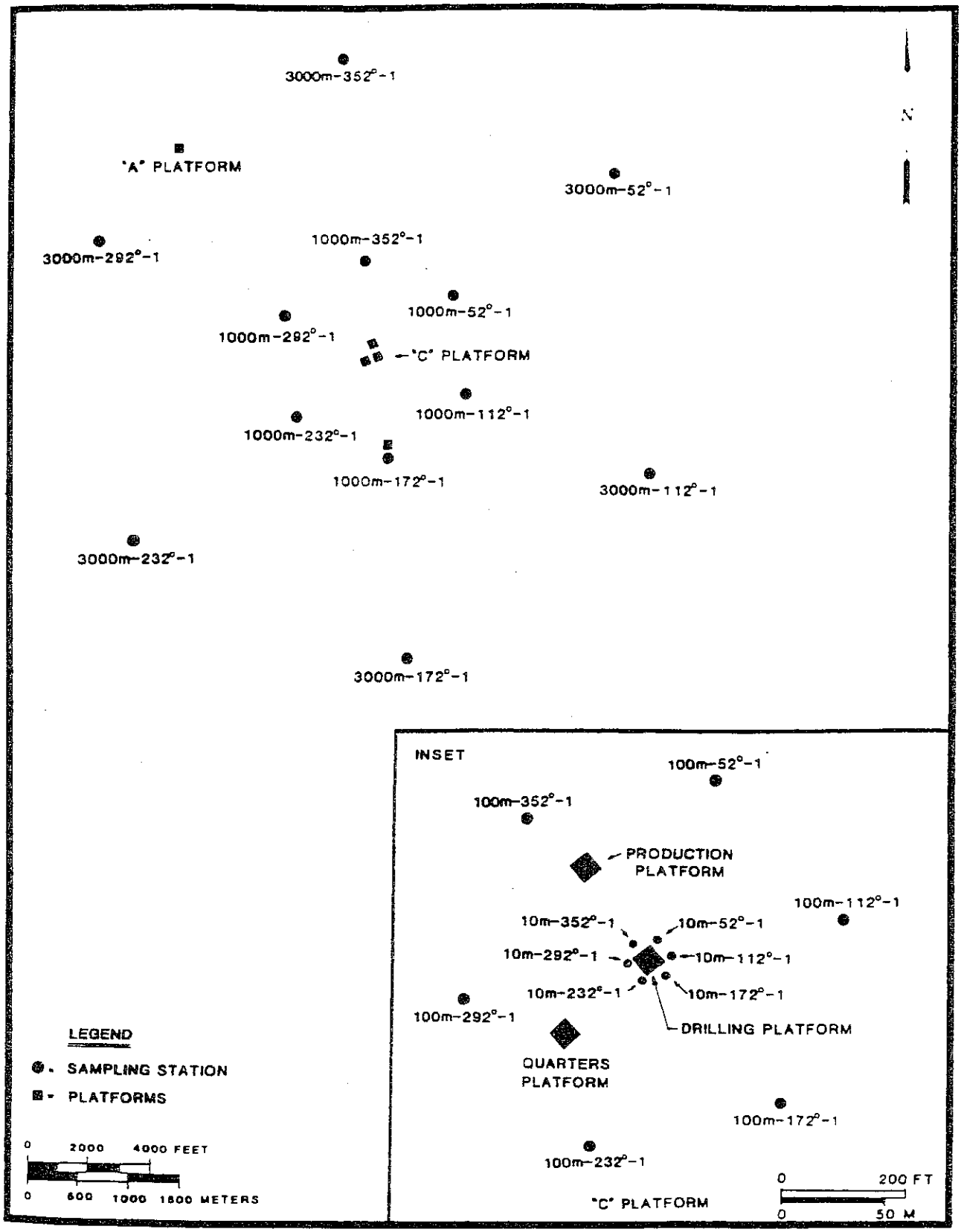


Figure 3. Sampling locations occupied during Phase I. Stations are designated "distance from the discharge site" - "direction from the discharge site" - "cruise number".

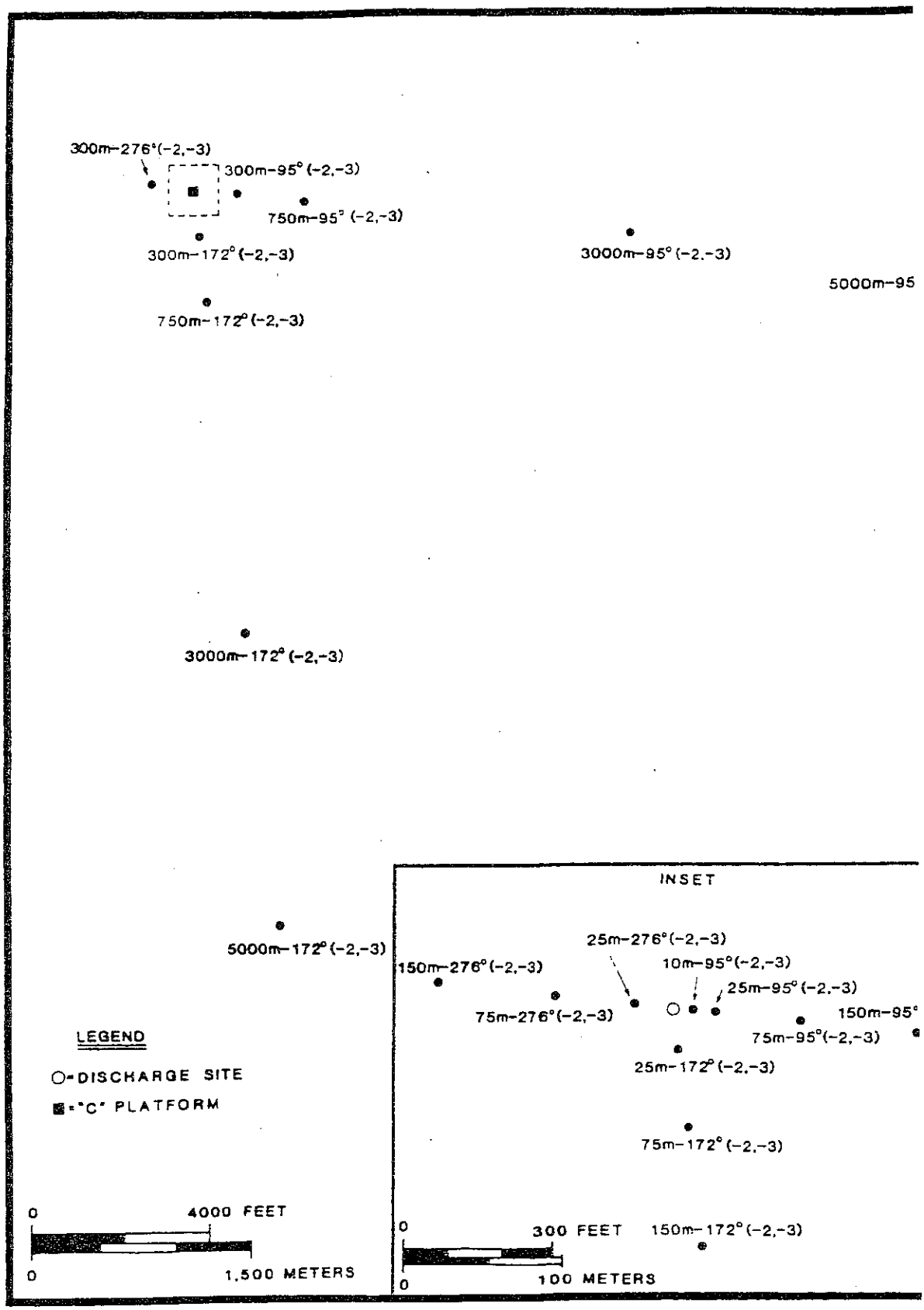


Figure 4. Sampling locations occupied during Phase II. Stations are designated "distance from the discharge site" - "direction from the discharge site" - "cruise number" (in parentheses).

discharge site" - "direction from discharge site" - "cruise number".) Distances and directions of the sampling stations were determined after evaluation of the Cruise 1 data. Stations were oriented along major gradients from the discharge site as well as in the cross-shelf direction. Stations were more closely spaced in the near field but, at the same time, the pattern extended further from the discharge site compared to Cruise 1.

Samples were collected at each station to determine: 1) sediment grain size; 2) total organic carbon and calcium carbonate concentrations; 3) trace metal concentrations; 4) aliphatic and aromatic hydrocarbon concentrations; and 5) macroinfaunal abundances--adults and juveniles (Cruise 2 only). A current meter was deployed near the seafloor during the period between Cruises 2 and 3; and hydrographic profiling was performed during both cruises.

2.0 METHODS

2.1 FIELD METHODS

All sediment samples were collected by divers using SCUBA for several reasons. Compared to remote sampling gear, sampling by divers was more efficient because sampling could continue when rough sea conditions could cause premature closing of sampling gear such as a box corer or sediment grab and "washed-out" sediment samples could be a common occurrence. In addition, the "bow wave" associated with using remote devices in fine sediment areas was avoided. Even in rough seas, when remote samplers often strike bottom at an angle, undisturbed samples could be collected. Undisturbed sediment samples could be collected on sand or rubble-covered bottoms where remotely operated corers will not penetrate sufficiently. Divers were able to carefully insert hand-held corers to standard depths in the sediments and obtain replicate samples within a defined area. They were able to collect samples very close to the platform where a surface vessel would not be able to maneuver. In addition, divers could carefully place each of the individual corers to avoid debris in the near vicinity of the platform (pipe, welding rods, steel grating, metal scraps, etc.).

2.1.1 Currents and Hydrography

ENDECO Type 105 recording current meters were deployed at a near-bottom depth (23.8 m) from 27 March to 26 August 1987. Current speed and direction was continuously recorded at 1-h intervals. A single current meter servicing occurred on 23 June 1987.

Water column profiling was performed at Station 3000m-52°-1 during Cruise 1 and at Stations 75m-172° and 300m-276° during Cruises 2 and 3, respectively. Conductivity, salinity, temperature, and dissolved oxygen were measured versus water depth using a Beckman RS5-3 Portable Salinometer and a YSI Model 54 Dissolved Oxygen Meter. Readings were taken from just below the water surface to the seafloor at 3-m (10-ft) intervals.

2.1.2 Hydrocarbon, Trace Metal, and Grain-size Samples

Hydrocarbon (1 sample), trace metal (3), and grain-size (2) samples were collected at 25 sampling stations during Cruise 1 (Phase I). During Cruise 2 and 3 (Phase II), samples were collected for hydrocarbon (3), trace metal (3), grain-size (2), total organic carbon (2), and calcium carbonate (2) analyses at 19 sampling stations. Ten long-core samples were collected for trace metal analysis during Cruise 2.

The hydrocarbon and trace metal samples were collected using 62-mm (internal diameter) polytetrafluoroethylene (PTFE) coring tubes; grain-size, total organic carbon, and calcium carbonate samples in 32-mm acetyl butyrate coring tubes. Long-core samples were obtained using 20-cm long, 47.5-mm acetyl butyrate coring tubes.

Hydrocarbon and trace metal samples were collected within a 1-r area located 2 to 3 m upcurrent of the station marker buoy anchor. Each PTF corer was carefully inserted into the bottom sediments; a PTFE-lined lid was the placed over the top of the corer. Sediment was scooped away from the side of tl corer; a cap was inserted underneath; both lids were secured; and the corer w placed upright in a specially designed sediment core-carrier. Grain-size, tot organic carbon, calcium carbonate, and long-core samples were collected in the san manner except that rubber stoppers or plastic caps were used to cap the ends of tl corers.

At the surface, samples were immediately transferred to pre-clean sample containers. The upper 2.0 cm of sediment from the trace metal core sampl was extruded into plastic bags and frozen. The upper 5.0 cm from a hydrocarb core sample was placed in a glass jar [solvent-rinsed and combusted (400°C)], whi was sealed with a PTFE-lined lid and frozen. Grain-size, total organic carbon, ar calcium carbonate samples (upper 15 cm) were frozen in plastic bags. The end ca of the long-core samples were taped onto the corers and the corers containing tl samples were frozen upright.

2.1.3 Macroinfauna

During Cruise 1, 12 macroinfauna core samples were collected at tv stations--the discharge site (Stations 0m-0°-1) and a 3,000-m station (Station 3000r 172°-1) for sampling adequacy determination. Seven macroinfaunal core sampl were collected at the other 23 sampling stations. During Cruises 2 and 3, seve macroinfaunal samples were collected at each sampling station. The macroinfaun core samples were collected within a 4-m^2 area located 2 to 3 m from the static marker buoy anchor. Stainless steel corers (12.5 x 12.5 x 15 cm high) with 0.5-m mesh covering the upper end were used to collect the samples. The corers we inserted 15 cm into the bottom and one side of the corer was exposed by diggi away the sediment. The diver slipped a hand under the mouth of the corer to cov it, and the corer was lifted out of the sediment, inverted, and placed with tl retained sediment sample into a cotton bag. The bag was securely closed.

At the surface, the bags were placed in a magnesium sulfate ar seawater solution for 20 min to narcotize the infauna. The samples were then gent sieved in a 0.5-mm mesh sieve. All materials retained on the sieve were transferr to labeled containers and preserved in 10% buffered formalin solution stained wi rose bengal.

During Cruise 2, one sample was randomly selected and the materi passing through the 0.5-mm sieve was subsequently sieved through a 0.3-mm me sieve. The sample retained on the 0.3-mm mesh sieve was preserved for juveni macroinfauna analysis in the same manner as the rest of the macroinfaunal sample

2.1.4 Navigation

Cruise 1: An EPSCO Model C-NAV XL Loran-C Receiver and an EPSCO Model C-Plot II 10-in. plotter were used for positioning at the 100-, 1,000-, and 3,000-m stations during Cruise 1. The Loran-C Receiver was calibrated to the actual latitude and longitude of one of the drilling platform legs. The 10-m stations were positioned using a measured line extended out from the drilling platform.

Cruises 2 and 3: Loran-C, a Del Norte Transponder System, and platform ranges and bearings were used for navigation and station positioning during Cruises 2 and 3. Transponders were placed at the top of "A" Platform, "B" Platform, and "C" Platform (Figure 3); a Del Norte Transponder System Receiver was used aboard ship. Initially, the planned direction for the eastward transect was 70°. Due to the low crossing angle between the three transponders along the proposed 70° eastern transect, this transect was repositioned prior to Cruise 2 slightly to the south on a heading of 95° from "C" Platform. This modification aligned the transect with a line extending from "B" Platform through the "C" drilling platform, establishing a visual range to aid in relocating stations along this transect during Cruise 3. The western transect was also positioned along this line on a heading of 276° from the "C" drilling platform. The southern transect was aligned with a line connecting Remote Platform 5 with the "C" drilling platform at a heading of 172°. The combination of these platform ranges and bearings, the Del Norte Transponder System ranges, and the Loran-C system navigation position fixes allowed very accurate repositioning on these station locations during Cruise 3.

2.2 LABORATORY METHODS

2.2.1 Current Meter Data

The film cartridges from the ENDECO current meters were sent to the manufacturer for development and reading. A report of time, current speed, and current direction was generated as hard copy and on magnetic media for data reduction.

2.2.2 Grain Size

Grain-size analysis was performed by the procedure of Folk (1974). Samples were homogenized, treated with an aliquot of 30% hydrogen peroxide to oxidize organic matter, and washed with distilled water to remove soluble salts. Sodium hexametaphosphate was added to deflocculate each sediment sample. The samples were then wet-sieved using a 62.5-μm (4.0-phi) sieve to separate gravel and sand from the silt-clay fraction.

The total gravel and sand fraction was oven dried (40°C), weighed, and sieved at 1/2-phi intervals (-1.5, -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0). The fraction from each sieve was examined for aggregates, desegregated if necessary, and weighed to three significant figures. The silt-clay fraction was analyzed for particle size distribution by the pipette (settling rate) method at 4.5-, 5.0-, 5.5-, 6.0-, 7.0-, 8.0-, 9.0-, and 10.0-phi intervals. Cumulative curves (probability

ordinate) were constructed to estimate statistical parameters of the sedime grain-size distributions.

2.2.3 Inorganic and Organic Carbon

Ancillary sedimentary parameters were determined on a split fro the hydrocarbon sample. Samples were stored frozen (-20°C) between the time collection and analysis. Before analysis, the sediments were freeze dried at -40° and ground with a mortar and pestle. The determinations for inorganic and organi and total carbon content were performed with a Leco Total Carbon System (Mod CR12). Total carbon was determined by placing a weighed sediment subsample in a boat for combustion in the Leco furnace at 1400°C. The sediment was combuste in an oxygen atmosphere and the generated carbon dioxide was analyzed with nondispersive infrared spectrophotometer. For organic carbon determinatior sediment subsamples (0.2 to 0.5 g) were weighed into disposable 5-ml polystyrer beakers. The samples were treated with concentrated 6 normal hydrochloric ac to remove inorganic carbon (principally calcium carbonate). Acid was adde dropwise until no degassing was observed. The treated samples were then dried 50°C in a recirculating oven for 24 to 36 h to remove excess acid and moistur After drying, the sample (now free of inorganic carbon) was analyzed by the metho described above for total carbon. Inorganic carbon was determined as the differen between total and organic carbon values.

2.2.4 Trace Metal Sample Analyses

After the samples were thawed and homogenized by kneading throu the bag, the bags were opened and the sediment was further homogenized by mixi with a plastic spatula. An aliquot of the homogenized material from each samp was freeze-dried and ground for analysis. All samples collected on Cruise 1, a selected samples from Cruises 2 and 3 were also sieved to separate sand and coars material from silt and finer material. About 25 g (wet weight) of sediment w transferred to a 63-μm plastic or stainless steel sieve and washed with a stream distilled water until all material less than 63 μm was washed through the sieve. Th fine-grained material was then allowed to gravity settle in the pyrex beaker in whi it was collected. After 72 h, as much clear water as possible was aspirated off a the remaining wet sediment was frozen, then freeze-dried to a constant dry weigl All freeze-dried material was ground to a fine powder in an aluminum oxi "diamonite" mortar and pestle in preparation for analysis. For some samples bo the unsieved (bulk) fraction and the <63 μm (fine) fraction was analyzed. For oth samples either one or the other fraction was analyzed.

Trace metal analyses were performed using the methodology fro the National Oceanic and Atmospheric Administration's "Status and Tren Program" (Brooks et al., 1987). These methods are briefly described he Detection limits, precision and accuracy are presented in Appendix A. Bariu chromium, and iron were determined on all samples by Instrumental Neutr Activation Analysis. Each finely-ground sample was sealed in a plastic vial a without further pretreatment, was subjected to a neutron flux in order to activate t elements of interest. The Texas A&M nuclear reactor was used, which provides

flux of approximately 10^{13} neutron/cm^2/s. Samples were irradiated for 14 h and were then allowed to "cool" for 10 d before the induced radioactivity was counted. The cooling period allows isotopes of chlorine, sodium, and other background producing elements to decay away thereby improving counting statistics for barium, chromium, and iron. The samples were counted using a Ge(Li) detector coupled to a Nuclear Data Corp. Model 66 pulse height analyzer and computer data acquisition system. Concentrations were obtained by comparing counts for each sample with counts for standard rock powders of accurately known barium, chromium, and iron concentrations.

The three samples collected immediately under the discharge site (Station 0m-0°-1) and the three samples collected 3,000 m from the discharge site (Station 3000m-172°-1) on Cruise 1 were also analyzed for arsenic, cadmium, mercury, lead, and zinc. Of these five metals, cadmium, mercury, and zinc showed the strongest concentration gradients with distance from the platform; therefore, samples collected on Cruises 2 and 3 were analyzed for these three metals. These additional analyses were performed by atomic absorption spectrometry after the finely ground sample was completely dissolved in a mixture of nitric, perchloric, and hydrofluoric acids. The dissolution was accomplished by heating in a sealed all-PTFE "bomb" in order to minimize contamination and to insure that mercury would not be driven off as a vapor. Flame atomic absorption spectometry (Perkin-Elmer Corp. Model 306) was used for the zinc analysis; cold vapor atomic absorption spectometry was used for mercury, whereas graphite furnace atomic absorption spectometry (Perkin-Elmer Corp. Model 3030) was used for the other metals. The reliability of these data was evaluated by a rigorous quality assurance program (Appendix A).

2.2.5 Hydrocarbons

Initial Screening: Hydrocarbon analyses of the samples collected during Cruise 1 utilized methodologies detailed in Brooks et al. (1986). Briefly, samples were freeze-dried (-40°C), ground and Soxhlet extracted for 12 h with methylene chloride. Copper turnings were added during the extraction to remove elemental sulfur. Internal standards (deuterated alkanes) were added to correct for recovery efficiencies. An aliquot of the extract was weighed on a Cahn Electrobalance to determine the extractable organic matter (EOM) content. The sample was then analyzed by gas chromatography (GC) with flame ionization detection (FID).

Component separation was accomplished using 25 m fused silica capillary columns coated with DB-5 (J&W Scientific, Inc.). Interior diameter of the column was 0.25 mm, film thickness 0.32 μm, and flow (He) through the column was 2 to 3 ml/min. Dilutions and injection sizes were appropriately adjusted to be within the detector's linear range. Two Hewlett-Packard (HP) 5880A and two HP 5790A gas chromatographs equipped with HP 7571A autosamplers and flame ionization detectors were used for the analyses. Samples were injected on the capillary column at 60°C, the GC oven was then temperature programmed to 300°C (12°C/min) and held at 300°C for 10 min. Total analysis time was 30 min. Baseline separation on n-C_{17} and pristane, and n-C_{18} and phytane was maintained or the capillary column was replaced.

Detailed Hydrocarbon Analysis: The Phase II (Cruises 2 and hydrocarbon determinations involved a more rigorous analysis than Phase I. T Phase II methods were those used for the National Oceanic and Atmosphe Administration's (NOAA's) Status and Trends (S&T) Project (modified al MacLeod et al., 1985) and for the U.S. Fish and Wildlife Service as part of th organic contaminant analysis program. Phase II analyses determined the concent tions of selected polynuclear aromatic hydrocarbon (PAH) compounds. Most of PAH compounds analyzed were Environmental Protection Agency "Prio Pollutants". The PAH techniques require skill and diligence in sample collecti component isolation, and compound identification/quantification. A comparisor the analytes determined during Phases I and II are listed in Table 4.

Sediment Extraction Procedure: Approximately 25 g of freeze-dr sediment was ground, internal standards added, and Soxhlet extracted for 12 h w 250 ml of methylene chloride. The organic phase was concentrated to ≈10 to 15 in a round bottom flask equipped with a three-ball Snyder condenser. Activa copper was added to the extract during the extraction and concentration steps remove elemental sulfur. The extract was concentrated to ≈1 ml in a 25 Kuderna-Danish (KD) Receiver in a water bath (60°C). Extracts were sto refrigerated (-4°C).

EOM content was determined by weighing an aliquot of the solv extract. Ten microliters of the extract was transferred to a pre-weighed filter p on a Cahn Electrobalance and the solvent was allowed to evaporate. The EO content was determined from the residual weight and reported as a percent of total dry weight of sediment.

Column Chromatography: Aromatic hydrocarbons were separa from other lipids by alumina/silica gel chromatography. Alumina (10 g, 400°C/4 deactivated 1%) was slurry packed in methylene chloride over silica gel (2(170°C/12 h, deactivated 5%). Copper powder was added to the column to remo any residual sulfur. The methylene chloride was replaced with hexane, and extract, in 1 ml of hexane, was transferred to the column. The column was th eluted with 50 ml of pentane (f_1, aliphatics), and 200 ml of 1:1 methyl chloride:pentane (f_2, aromatics). The fractions were concentrated with K concentrators.

Aromatic Hydrocarbon Quantitation GC/MS/SIM: PAHs w quantitatively analyzed by gas chromatography/ mass spectrometry in a selected mode (GC/MS/SIM) utilizing molecular ions (Figure 5). Typical operat conditions are summarized in Table 5. Total analysis time was ≈36 min.

Laboratory Automation/Data Reduction: All GC/FID a GC/MS/SIM analyses were fully automated. The HP 3357 Laboratory Automat System (LAS) acquires, integrates, calibrates, reports, and stores informat generated by chromatographic detectors. The HP 3357 LAS system consists o central processing unit (CPU), memory, disc storage, terminals, and 3357 softwa GC/MS/SIM data was acquired, integrated, calibrated, reported, and stored by

Table 4. Hydrocarbon analytes determined in Phases I and II.

Phase I Aliphatic Compounds	Phase II Aromatic Compounds
$n\text{-}C_{11}$ to $n\text{-}C_{32}$	Naphthalene
Pristane	Methylnaphthalenes
Phytane	Dimethylnaphthalenes
Total Extractable Weight	Trimethylnaphthalenes*
	Biphenyl
	Fluorene
	Fluoranthene
	Acenaphthene
	Acenaphthylene*
	Phenanthrene
	Anthracene
	Methyl phenanthrenes
	Pyrene
	Benz(a)anthracene
	Chrysene
	Benzo(b)fluoranthene*,§
	Benzo(k)fluoranthene*,§
	Benzo(e)pyrene
	Benzo(a)pyrene
	Dibenzanthracene
	Benzo(g,h,i)perylene*
	Indenopyrene*
	Perylene

* These compounds were only quantified during the second, Phase II sampling (Cruise 3).

§ These two isomers are resolved under the GC conditions used but other more complex mixtures of benzofluoranthene isomers may not be fully resolved.

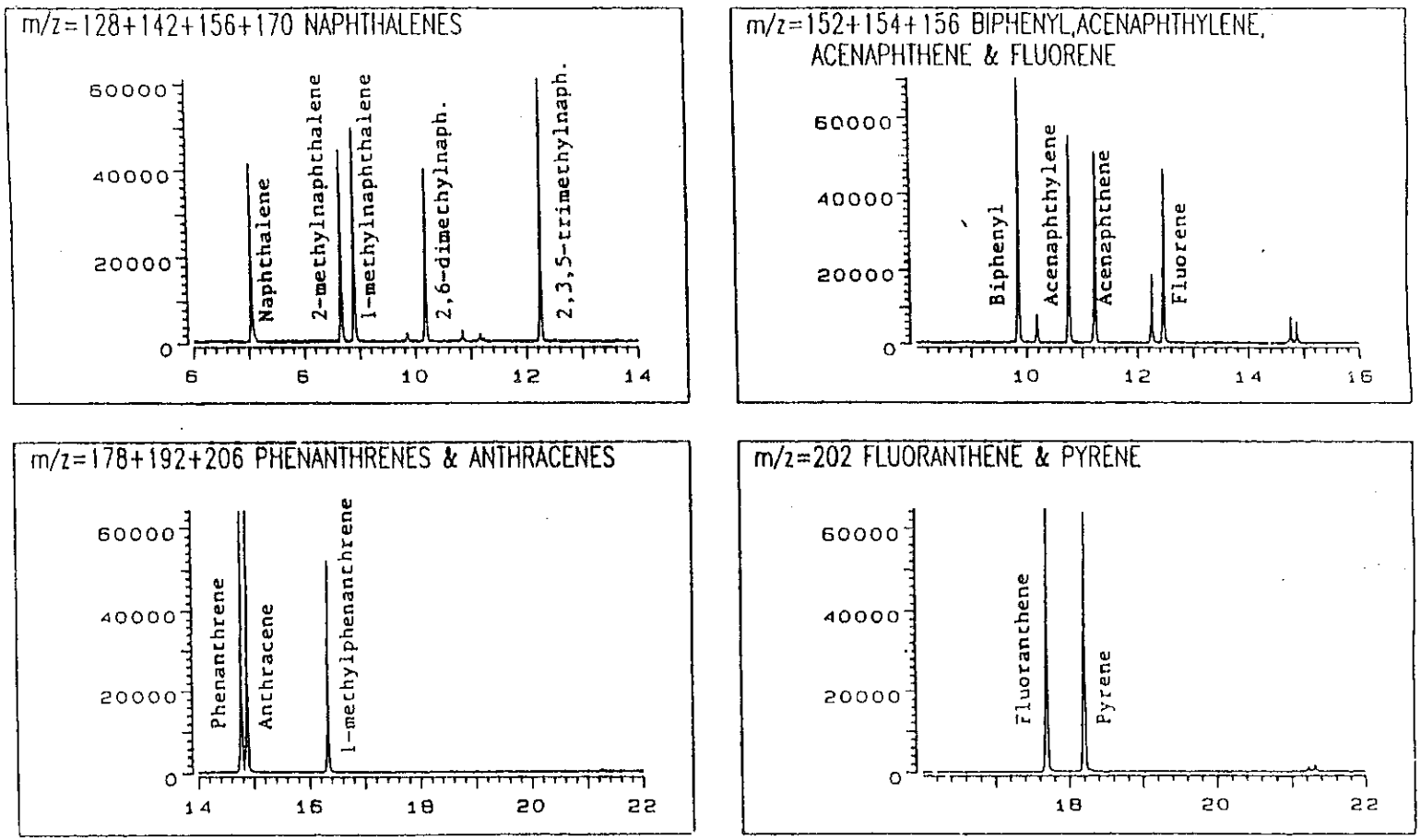


Figure 5. Typical gas chromatography/mass spectrometer selected ion monitoring graphics output for an aromatic standard

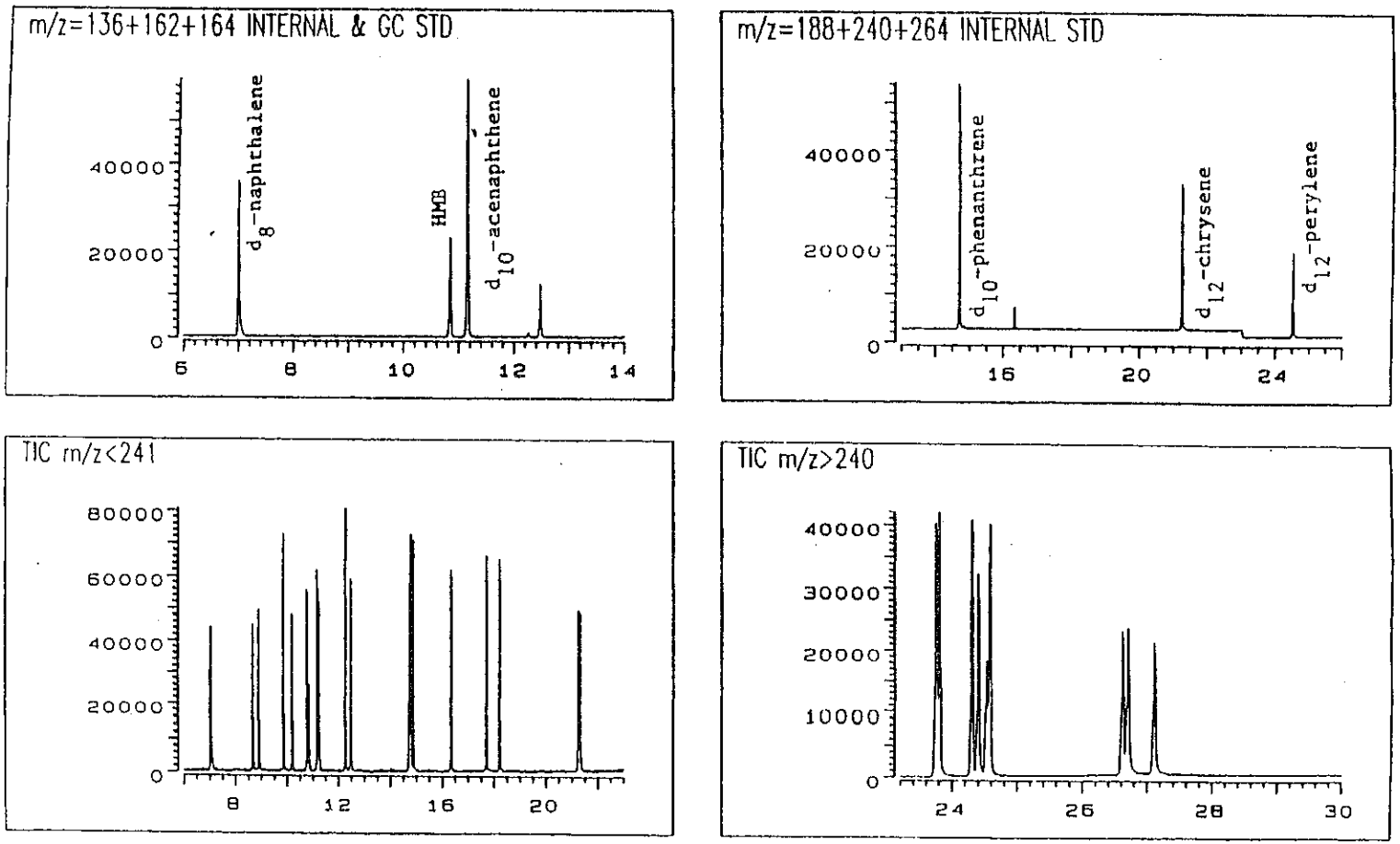
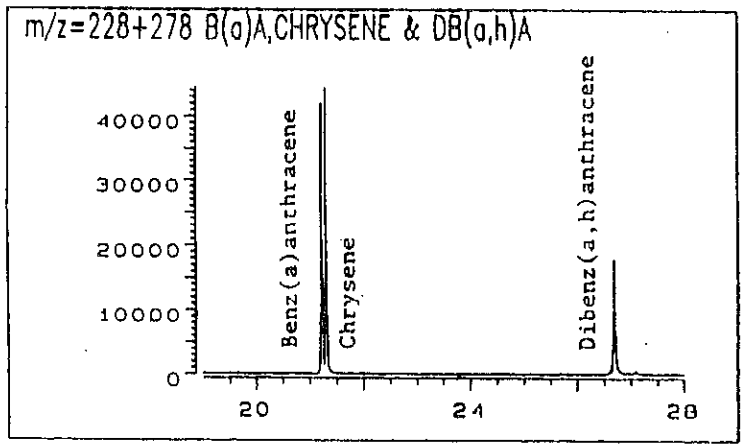


Figure 5. (Continued).



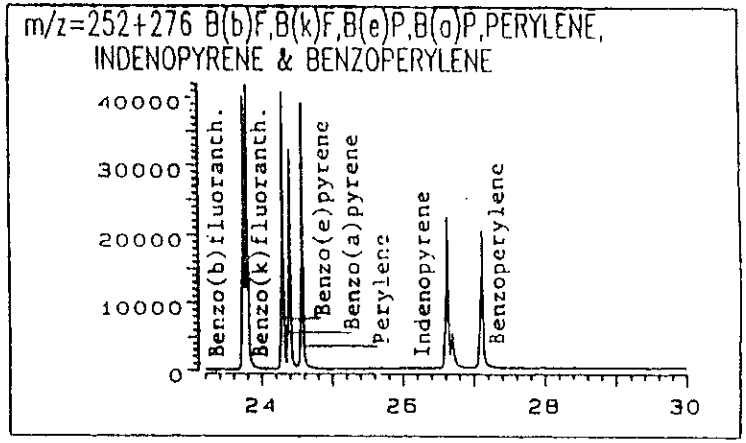


Figure 5. (Continued).

Table 5. Typical GC/MS operating conditions.

Mass Spectrometer: GC/MS HP 5996 linked with an HP 1000 Data System or GC/MSD HP 5970 Mass Selective Detector interfaced to an HP 5890 Gas Chromatograph linked with HP 1000 (RPN) Data System

Ion Source: 250·C	Multiplier Voltage: 2200V
Transfer Line: 280·C	Entrance Lens: 50 mVv/AMU
Analyzer: 250·C	Repeller: 9.8V
Run Time: 30 min	Ion Focus: 16V
Scan Start Time: 5 min	Axis Gain: -63
Electron Energy: 70eV	Axis Offset: -6
X-Ray: 44V	AMU Gain: 149

Selected Ion Monitoring

M/Z	Dwell Time (msec)	Compound Detected
128	30	naphthalene
136	30	*d_8-naphthalene
142	30	C1-naphthalenes
152	30	acenaphthylene
154	30	biphenyl, acenaphthene
156	30	C2-naphthalenes
162	30	*hexamethylbenzene
164	30	*d_{10}-acenaphthene
166	30	fluorene
170	30	C_3-naphthalenes
178	30	phenanthrene/anthracene
188	50	*d_{-10}-phenanthrene
192	50	C_1-3 rings
202	50	fluoranthene, pyrene
228	100	benz(a)anthracene, chrysene
240	100	*d_{12}-chrysene
252	100	benzopyrenes, perylene, and benzofluoranthenes
264	150	*d_{12}-perylene
276	150	indeno(1,2,3-c,d)pyrene and benzo(g,h,i)perylene
278	150	dibenzanthracenes

Gas Chromatography

Injector: 300·C, splitless mode
Total Run Time: 30 min
Column: 30 m, 0.25 μ film, 0.33 mm i.d., 5% phenyl methyl silicone (J&W Scientific, DB-5)

Temp 1	40·C
Time 1	0 min
Rate	10·C/min
Temp 2	300·C
Time 2	4 min

* Internal standards.

HP RPN/Aquarius system. A/D (analog-to-digital) modules, sampler/event co modules, line printing devices, and analytical instruments make up the com system. The HP 1000 processes, stores, and retrieves analytical data. Situ within the loop (cable) were various modules, all of which were interfaced t CPU: i.e., A/D modules convert analog signals from a detector to digital signal transmit them to the CPU and Sampler Control Modules control Auto Samplers. Directly connected to the CPU were various input/output de HP 2623 and HP 2648 terminals allow users to communicate with the syster receive data from the system. Terminals include display screen and/or cartridges. An HP 2631B line printer and HP 9872C (eight pen x-y plotter) sup hard copy reports. The system and the analytical instruments were interfaced communications loop connected to a loop controlled board in the CPU.

2.2.6 Macroinfaunal Sample Analysis

All organisms were separated into major taxonomic groups Annelida, Arthropoda, Mollusca, and other taxa). Organisms not gene considered to be macroinfauna (e.g., nematodes, foraminiferans, copepods) not sorted or processed further. Macroinfauna were identified to species lev most cases. Unidentifiable damaged or immature animals were taken to the lo practical identification level (LPIL). Infaunal species data were recorde standard data entry sheets and compiled in a data management computer fil statistical treatment.

Sample replication requirements were determined during the survey (October 1987) on the basis of analysis of 12 hand cores from the disch point and 12 cores from Station 3000m-172°-1. Thirty-one taxa were collecte Station 0m-0°-1, and 83% of the assemblage was represented by six replicates Station 3000m-172°-1, seven replicates represented 79% of the 47 taxa pre Seven replicate cores were therefore thought adequate to sample the benthic inf in this area during the second phase of the program.

3.0 RESULTS AND DISCUSSION

3.1 CURRENTS AND HYDROGRAPHY

3.1.1 Currents

Near-bottom currents were continuously monitored in the study area from 27 March to 26 August 1987 using a current meter deployed at a depth of 23.8 m, approximately 2 m from the seafloor. Current speed and direction were measured at hourly intervals.

During the early portion of this period (27 March to 30 April 1987), currents were predominantly northeastward with some northwestward and southward flow (Figure 6). Over 66% of the currents had headings between 15 and 75°. Currents generally followed the isobaths and flowed parallel to the coastline, indicating a dominant longshore trend. The resultant vector (vector sum of current vectors over the time period) was 95.5 cm/s (0.2 kn) at 53°. The maximum current speed was 51 cm/s (1.0 kn) and averaged 16.1 cm/s (0.3 kn). About 24% of the current speeds were less than 10 cm/s and 70% were less than 20 cm/s.

Although currents tended to follow the isobaths, the flow pattern in May (Figure 7) was more varied than during the previous period. The dominant directions of flow were east to northeastward (28%) and south to southwestward (48%). The resultant vector during May was 5.6 cm/s (0.1 kn) at 213°. The mean current speed was 12.6 cm/s (0.2 kn), less than that observed during March-April but the maximum current speed (66 cm/s, 1.3 kn) exceeded that observed during the previous period. About 31% of the current speeds were less than 10 cm/s and over 83% were less than 20 cm/s.

Longshore currents dominated the flow pattern observed in June 1987 (Figure 8). After an initial period of variability, southwestward current dominated much of the first part of June. After a reversal in mid-June, northeastward currents predominated, with a short period of southwestward flow, until near the end of the month. In late June, a reversal to the southwest was observed. The resultant vector for June was 1.3 cm/s (<0.1 kn) at 92°, which indicated current vectors were nearly evenly distributed between the two predominant directions. Northeastward flow accounted for 40% of the current vectors and southwestward flow accounted for 32%. The mean current speed was 14.2 cm/s (0.3 kn) and the maximum was 39 cm/s (0.8 kn). About 30% of the current speeds were less than 10 cm/s and 76% were less than 20 cm/s.

In contrast to the previous periods, more cross-shelf flow was observed in July 1987 (Figure 9); approximately 16% of the currents were northwestward, toward the coastline. The resultant current vector was 4.3 cm/s (0.1 kn) at 231°. Over 33% of the current speeds were less than 10 cm/s and 84% were less than 20 cm/s. The maximum current speed was 34 cm/s (0.7 kn) and the mean speed was 13.3 cm/s (0.3 kn).

With the exception of a short period in mid-August, currents late in the study period (Figure 10) were almost exclusively northeastward (88%). These

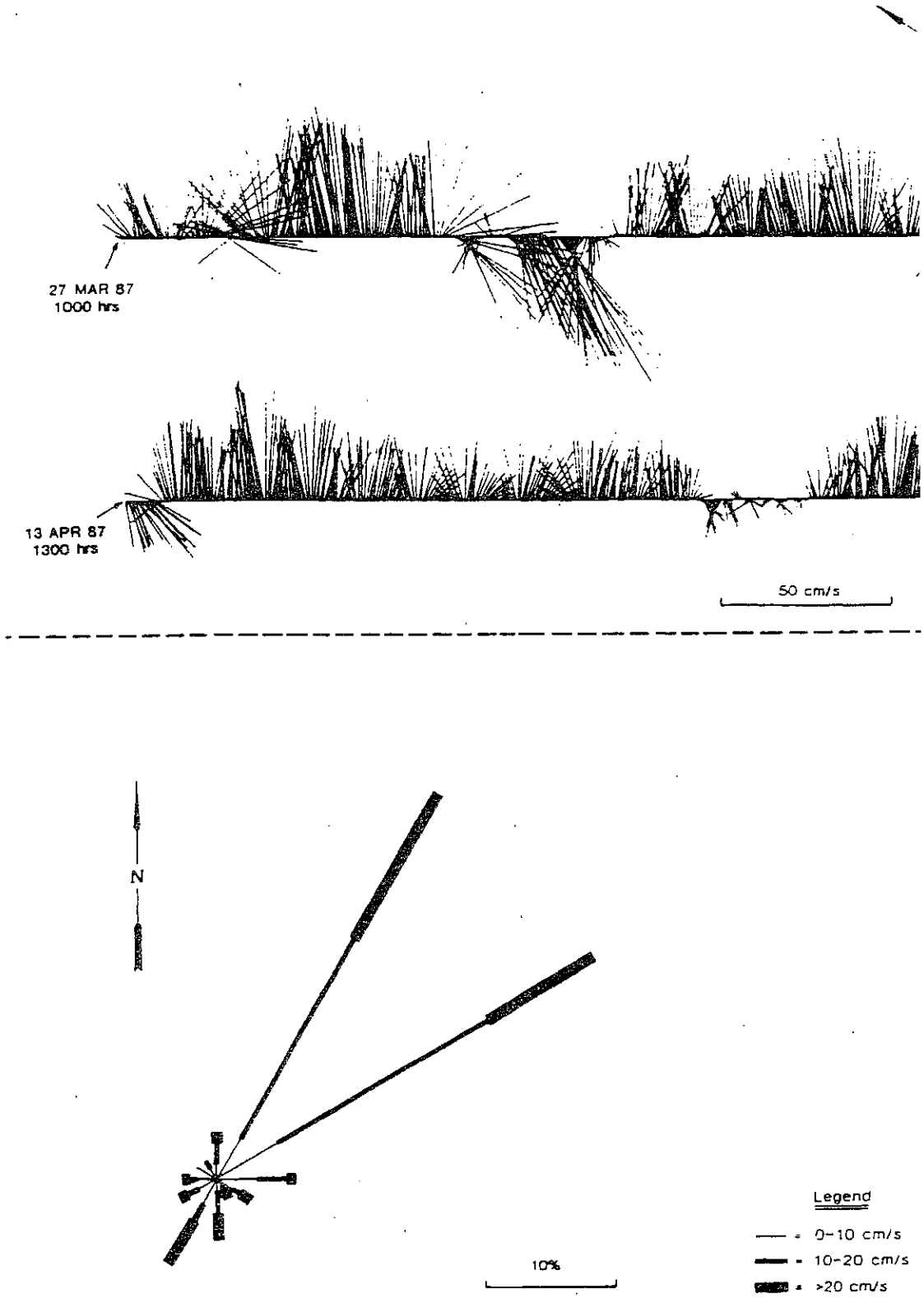


Figure 6. Summary of current data collected between 27 March 1987, 1000 h and 30 A
1987, 2400 h. Data are presented as a stick vector plot and as a current ros

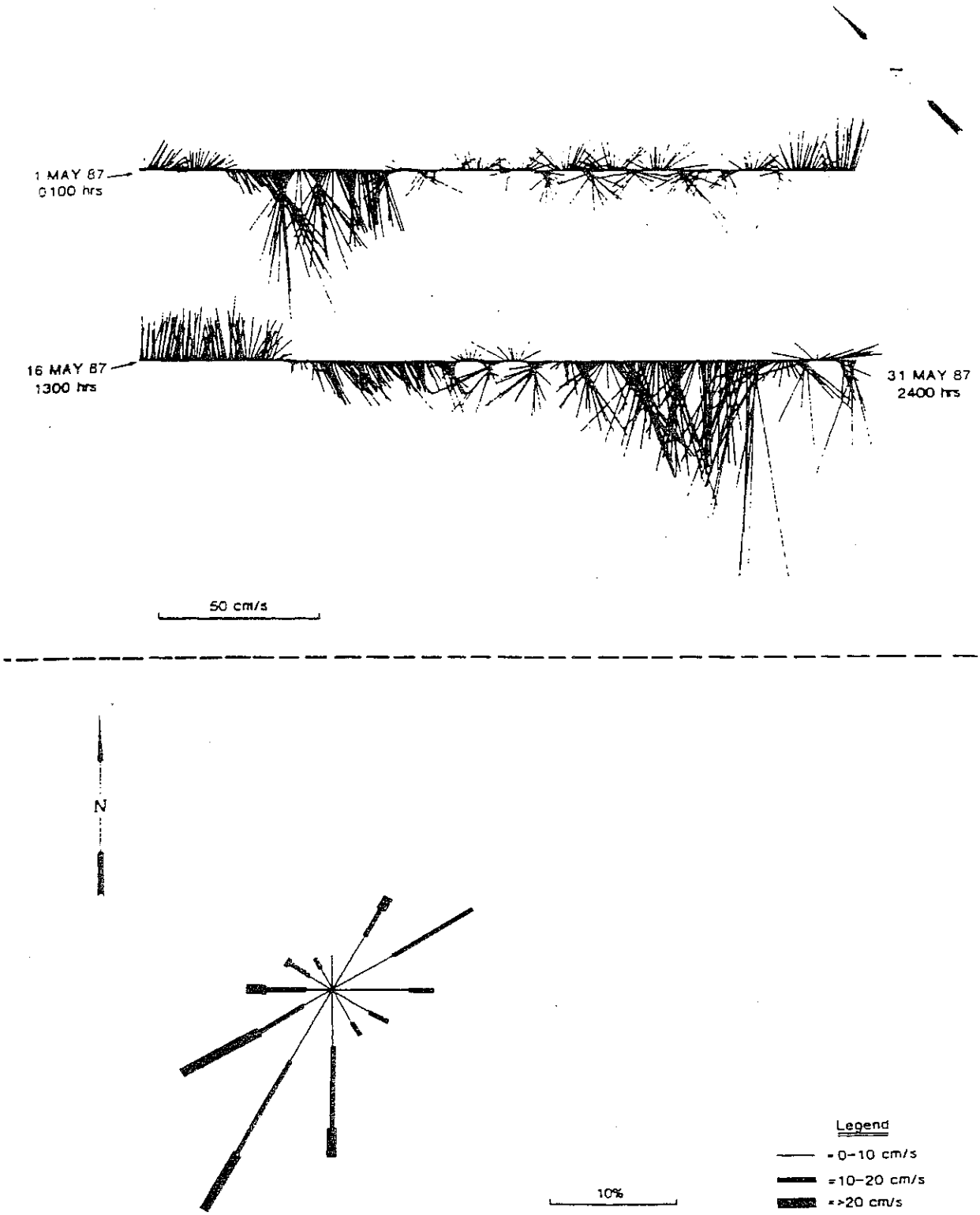


Figure 7. Summary of current data collected between 1 May 1987, 0100 h and 31 May 1987, 2400 h. Data are presented as a stick vector plot and as a current rose.

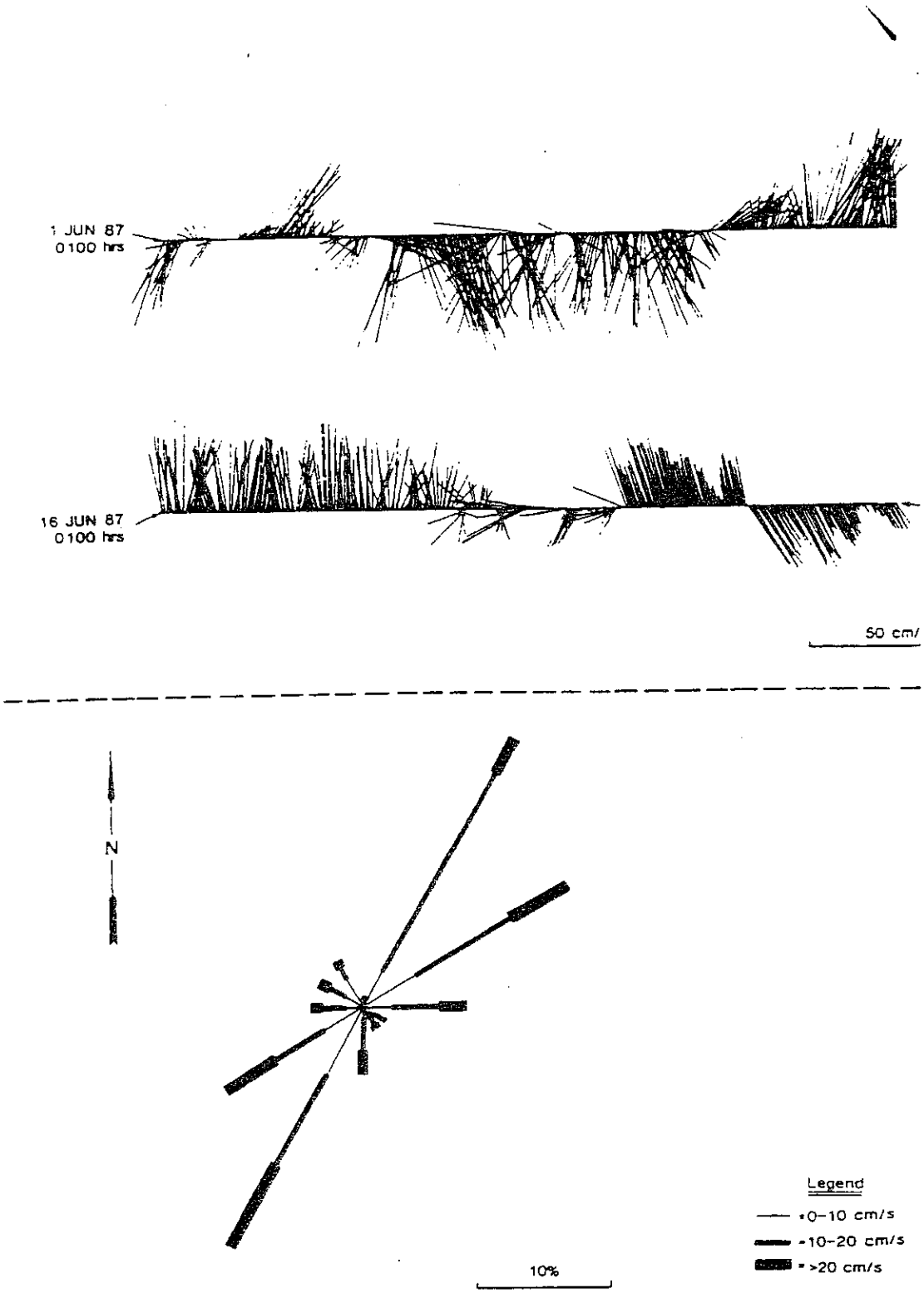


Figure 8. Summary of current data collected between 1 June 1987, 0100 h and 30 Ju
1987, 2400 h. Data are presented as a stick vector plot and as a current ros

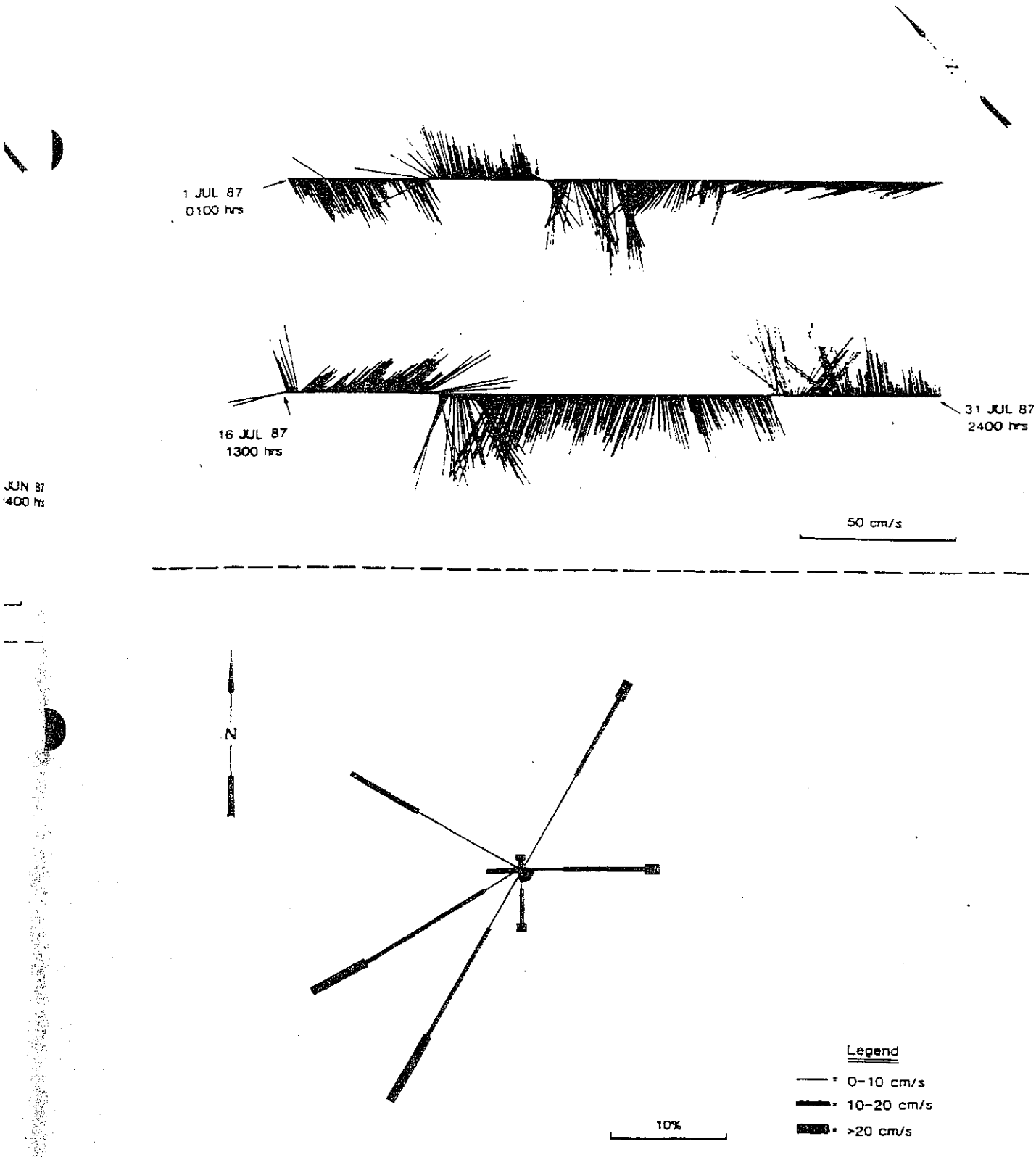


Figure 9. Summary of current data collected between 1 July 1987, 0100 h and 31 July 1987, 2400 h. Data are presented as a stick vector plot and as a current rose.

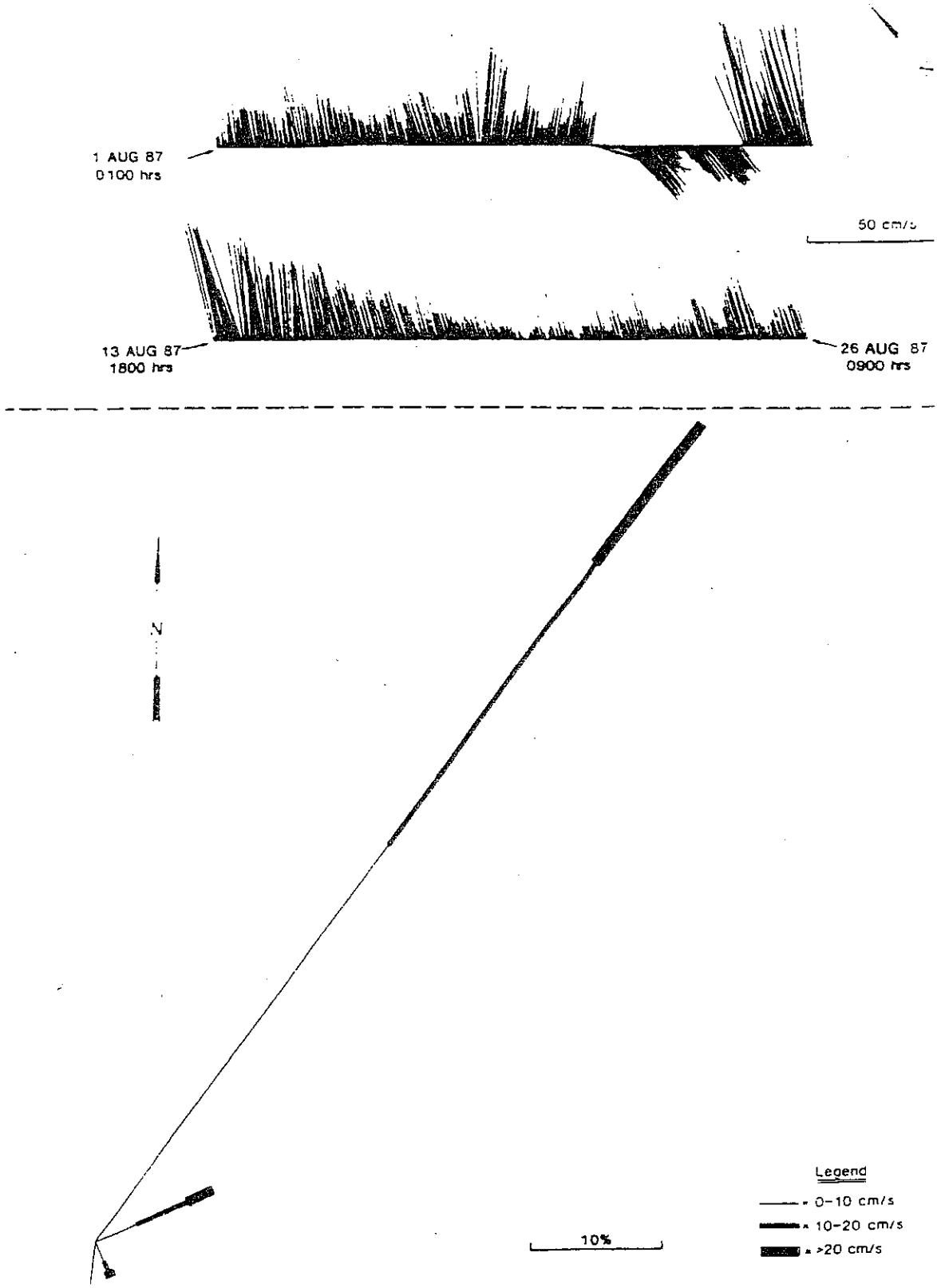


Figure 10. Summary of current data collected between 1 August 1987, 0100 h and 26 August 1987, 0900 h. Data are presented as a stick vector plot and as a current rose.

currents also tended to have lower velocities, averaging 11.8 cm/s (0.2 kn). The maximum velocity was 38 cm/s (0.7 kn). This near uniformity of currents was reflected in the resultant current vector--9.3 cm/s (0.2 kn) at 39°. Over 46% of the currents speeds were less than 10 cm/s and 85% were less than 20 cm/s.

Over the entire study period, longshore flow dominated the near-bottom currents in the study area. Current speeds tended to be lower later in the study period compared to March through May. The average current speed was 13.6 cm/s (0.3 kn), but currents reached 66 cm/s (1.3 kn).

These observations agreed with those collected during the STOCS program. Flow generally followed the isobaths and long-shelf circulation was dominant. Smith (1975, 1978) showed that wind stress was the primary factor in determining flow on the south Texas continental shelf. Tidal and inertial motions played a much lesser role, however, the impact of tides were greater during the summer and the contribution of cross-shelf circulation is greater during this period.

3.1.2 Hydrography

During each cruise, vertical profiles of temperature, salinity, and dissolved oxygen were determined (dissolved oxygen was not measured during Cruise 3 due to an equipment malfunction). In October 1986 (Cruise 1), temperatures were constant from the surface to the seafloor, ranging from 25.5 to 25.6°C (Figure 11). Similarly, salinities varied little through the water column (35.10 to 35.24 ppt). Dissolved oxygen concentrations were near saturation, consistently exceeding 5.0 ppm.

In March 1987, temperature varied little from the surface to the seafloor (Figure 11). Temperatures in the water column ranged from 17.9 to 18.1°C. In contrast, lower salinities (29.79 to 30.02 ppt) were observed in the upper 9 m of the water column, compared to those observed below 18 m (>33.50 ppt). A halocline was observed between 9 and 18 m. Dissolved oxygen levels consistently exceeded 7.5 ppm and were near saturation.

During the summer cruise (August 1987), a thermocline was observed between 15 and 20 m (Figure 11). Above the thermocline, temperatures ranged from 29.3 to 29.5°C, and below the thermocline, they ranged from 25.9 to 26.2°C. A very narrow range of salinities was observed between the surface and seafloor (36.61 to 36.87 ppt).

The results generally agreed with previously observed hydrographic patterns in nearshore areas off the south Texas coast. Shelf waters generally follow an annual cycle related to seasonal meteorological shifts but substantial variability has been observed on shorter time scales (Flint and Rabalais, 1981). In late winter, water temperature can be reduced to approximately 11 to 13°C. In late summer, water temperatures are characteristically 28 to 29°C. The water column is commonly isothermal during winter, fall, and spring. Stratification can occur during the summer. This stratification was observed in August 1987. Salinities can range from open Gulf values exceeding 36 ppt to less than 20 ppt during periods of spring run-off or heavy rains. Reduced surface salinities were observed near the surface

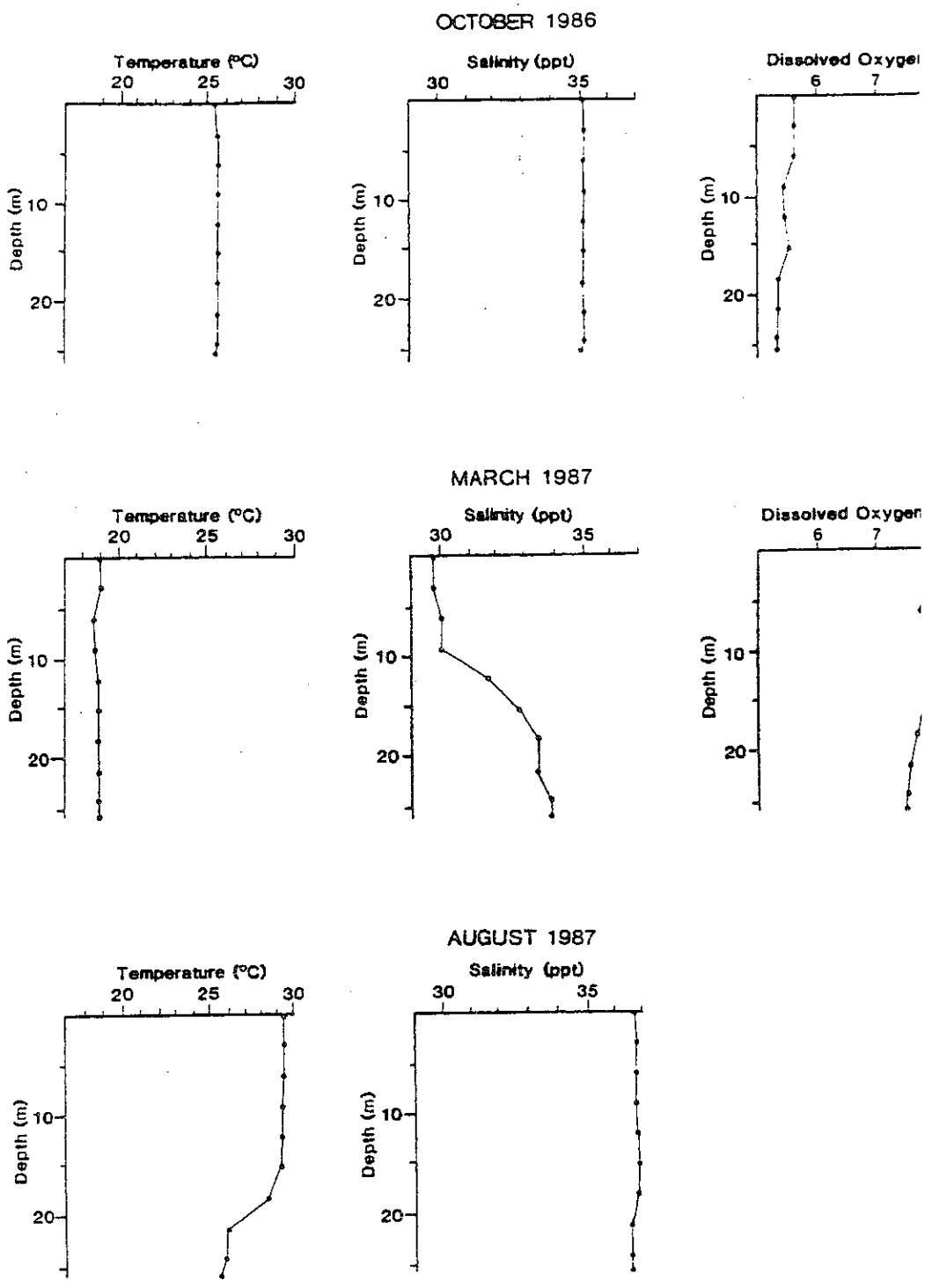


Figure 11. Vertical profiles of temperature, salinity, and dissolved oxygen in Octo
1986, March 1987, and August 1987. Data were collected during Cruise
2, and 3, respectively.

during March 1987, perhaps due to discharges from the Mississippi River moving westward and southwestward during winter and spring (Nowlin, 1972) or to local riverine input and precipitation.

Oxygen concentrations are generally highest in the winter and lowest in the summer. Levels are controlled by physical processes rather than primary productivity. Lower concentrations observed in October 1986, compared to March 1987, were related to the solubility of oxygen in seawater as a function of temperature and salinities (oxygen was less soluble in the warmer, more saline water observed in October 1986).

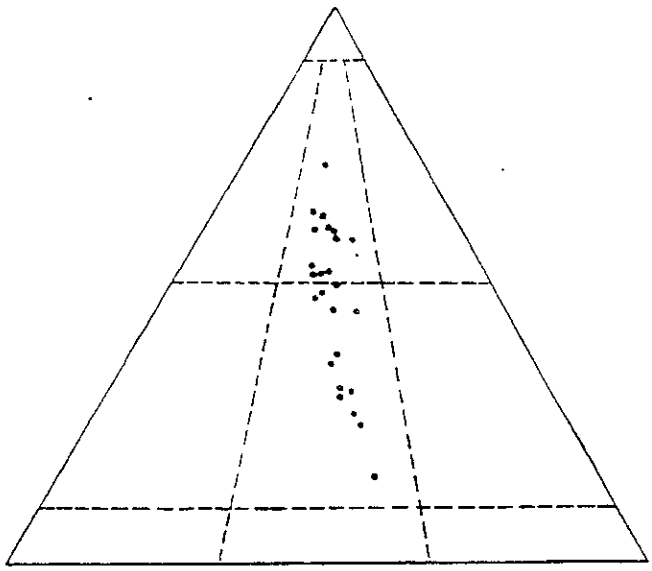
3.2 SEDIMENT GRAIN SIZE, CALCIUM CARBONATE, AND TOTAL ORGANIC CARBON

Muddy sand and sandy mud [following the Folk (1954) sediment classification scheme] predominated in the study area on all cruises (Figure 12). During Cruise 1, sediments at stations located within 10 m of the discharge site were generally muddy sand. All stations located at 1,000 m were finer--sandy mud. The sediments at stations located at 100 and 3,000 m were variable. The range of sediment types observed during Cruise 2 was similar to that observed during Cruise 1 except the sediment type at one 5,000-m station was mud, finer than sediments observed during Cruise 1. Two stations (located 10 and 25 m from the discharge site) had sandy silt sediments during Cruise 3.

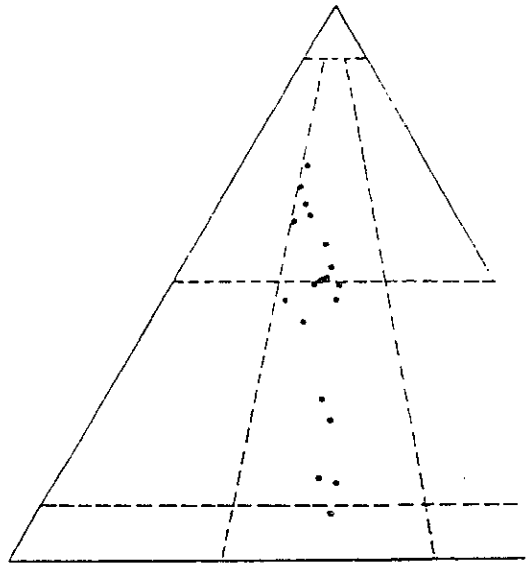
During Cruise 1, mean phi range appeared to increase with increasing distance from the discharge site, indicating coarser sediments occurred near the discharge site (Figure 13). Commensurate with the trend of mean phi, sorting values decreased at distances of 100 m and greater, indicating that the sediment near the discharge site was more poorly sorted. However, sorting values indicated that the sediments in the study area were generally poorly sorted.

Considerable variation in mean phi occurred during Cruise 2, compared to Cruise 3 (Figure 14). During Cruise 3, mean phi values were consistently less than 5.0. In contrast, mean Cruise 2 phi values exceeded 5.0 at stations located 25 m and greater from the discharge site, indicating coarser sediments generally occurred over the study area during Cruise 3 (phi values increase with decreasing particle size). Sediment samples collected during Cruise 3 were generally more poorly sorted compared to those collected during Cruise 2. Mean calcium carbonate levels observed during Cruise 2 consistently exceeded 5% while mean Cruise 3 levels did not reach this concentration (Figure 15). Organic carbon levels were comparable between Cruises 2 and 3.

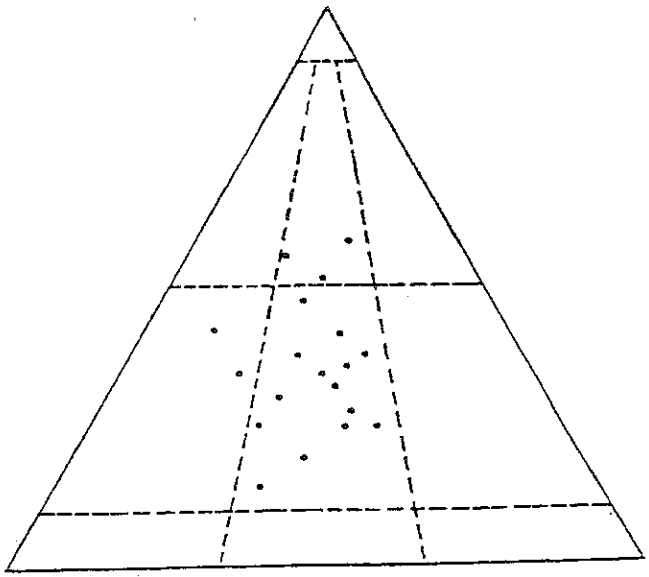
The study area was located in an area of the south Texas continental shelf where variable inner-shelf, sandy muds occur (Flint and Rabalais, 1981). In this area, increases in coarseness (hence, reduction in mean phi size) have been observed--spring coarsening compared to winter sampling. This coarsening observed between March (Cruise 2) and August (Cruise 3) may be related to winnowing of fine sediments.



Cruise 1



Cruise 2



Cruise 3

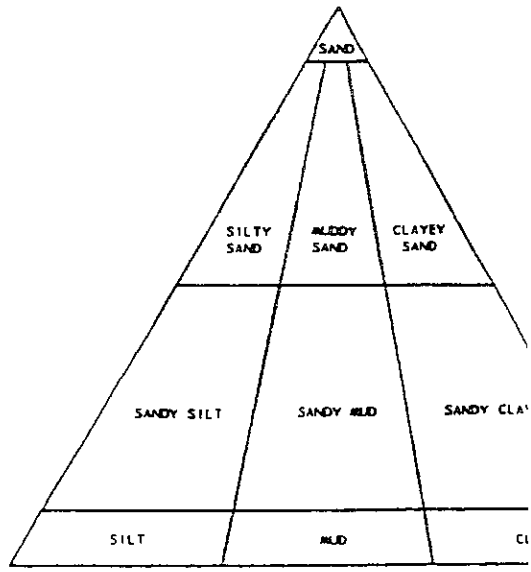


Figure 12. Summary of the sediment grain-size data collected during Cruises 1, and 3. Data are presented as ternary diagrams. Sediment classification fro Folk (1954).

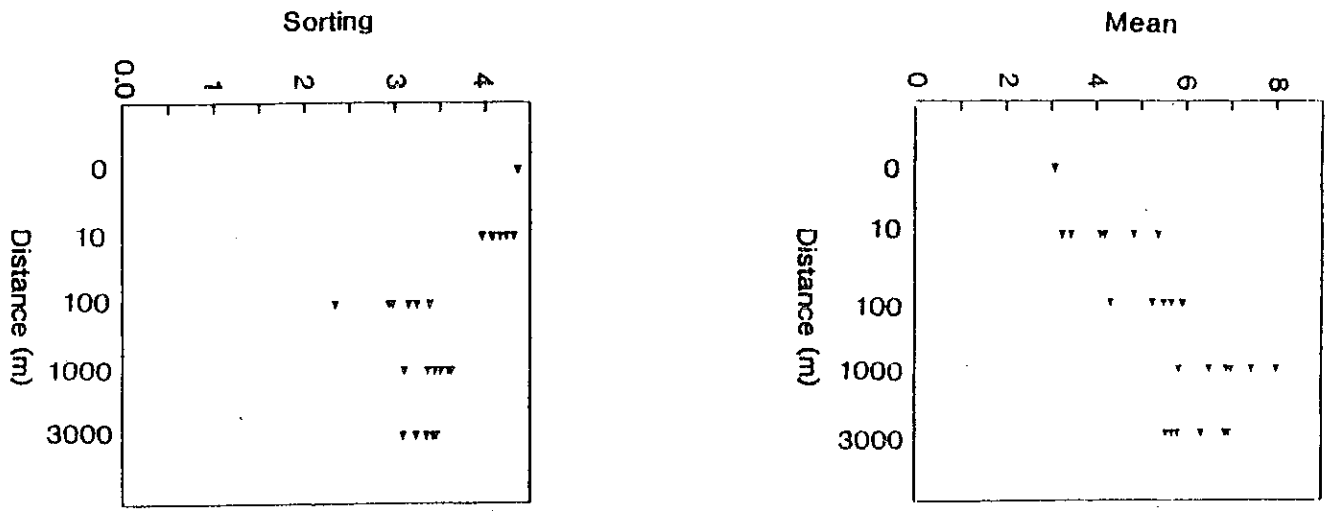


Figure 13. Mean sediment particle sizes and sorting values observed during Cruise 1. Mean particle sizes are presented in phi units.

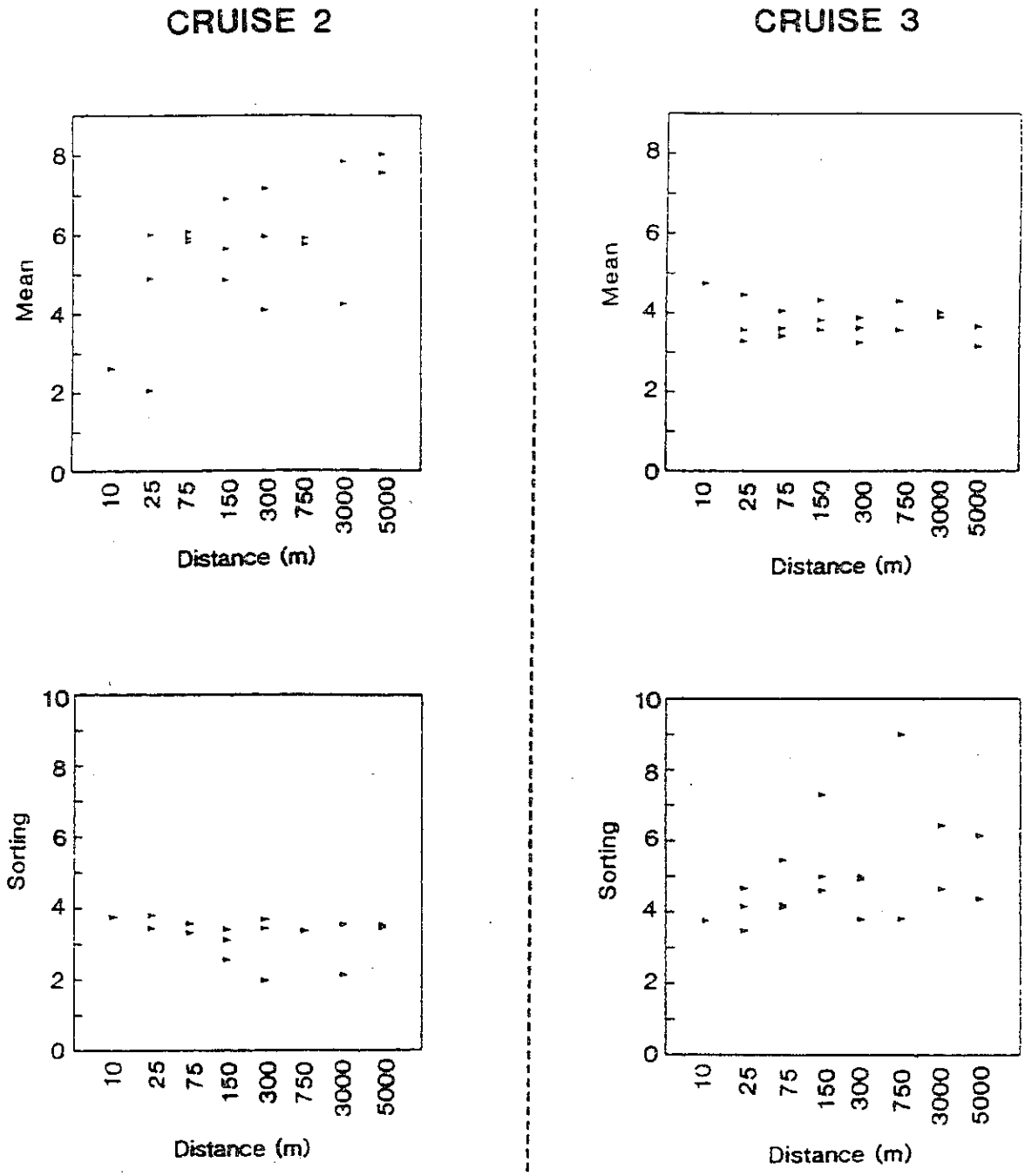


Figure 14. Mean sediment particle sizes and sorting values observed during Cruises 2 and 3. Mean particle sizes are presented in phi units.

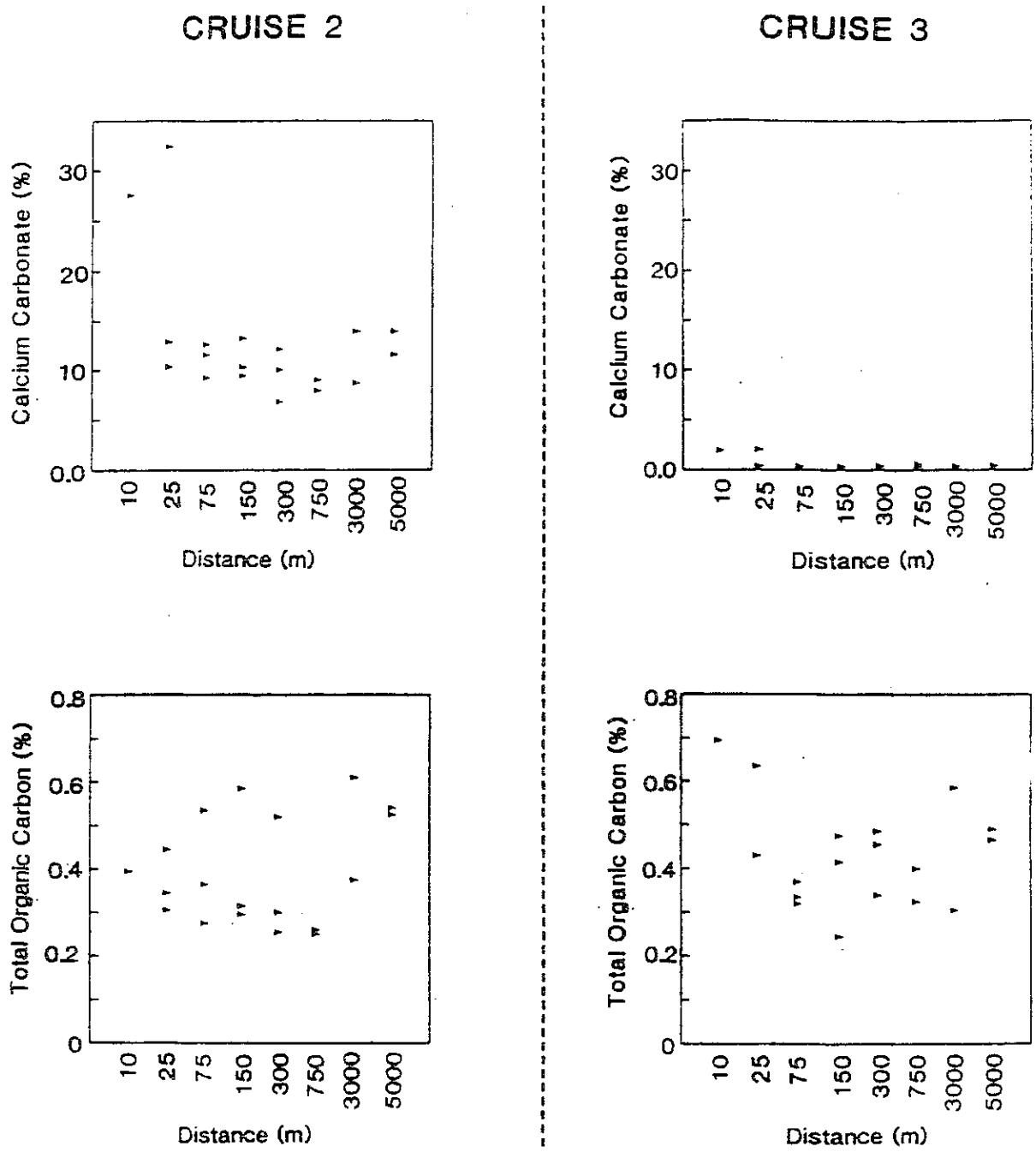


Figure 15. Mean concentrations of calcium carbonate and total organic carbon observed during Cruises 2 and 3.

3.3 TRACE METALS

3.3.1 Phase I (Cruise 1) Data and Comparison to Results From Previ Studies

For Phase I, sediment was analyzed from a station immediately ur the drilling mud discharge point and from 24 stations arranged on four concer rings around the platform at distances of 10, 100, 1,000, and 3,000 m (Figure This arrangement gave a fairly complete picture of the distribution of trace me in the sediment around the platform and established concentration gradients distance from the platform.

Only the fine-grained material (<63 μm) was analyzed during Pha because the sediment from different stations differed greatly in grain size. It felt that analysis of the fine fractions would make between station comparisons n meaningful. As will be discussed below, this proved to be only partially true bec whole-sediment samples were analyzed during Phase II of the study. This proce complicated comparisons of Phase I and II data.

Mean concentrations (average of three replicates) of bari chromium, and iron in the fine-grained sediment fraction at each of the 25 stat are presented in Table 6. Spatial distributions of barium and chromium concer tions are presented in Figures 16 and 17. Several concentrations are surprisi high, especially for barium. High concentrations of barium in sediments aro drilling platforms have been noted in previous studies (e.g., Continental S Associates, Inc., 1985; Boothe and Presley, 1985), but the values observed in study are somewhat higher than values usually observed at shallow water sites. H concentrations also extend farther from the discharge site than is typical for o sites. As an example, Boothe and Presley (1985) collected and analyzed sam near a platform in Matagorda Island Block 686 in 1980. That site is about 24 (15 mi) from the present site, yet barium levels were considerably higher at present site and were elevated at distances farther from the site.

The 18 samples within 10 m of the "C" Platform discharge averaged about 37,000 ppm barium, but showed high variability with one sar having $<20{,}000$ ppm and another with more than 100,000 ppm. High variability also been observed at the site in Matagorda Island Block 686 (closest sampling 30 m from the discharge site). Barium values in the whole-sediment fraction a Block 686 site were generally in the 3,000 to 6,000 ppm range, but one sample 15,000 ppm and another had 28,000 ppm. Barium concentrations decreased ra with increasing distance from the Block 686 discharge site--levels at 250 m beyond were in the 1,000 to 2,000 ppm range. At the "C" Platform site, ba levels at 1,000 m were generally between 2,000 and 3,000 ppm and several sam had levels exceeding 10,000 ppm.

At Matagorda Island Block 686, the mean barium concentra measured at four stations located 3,000 m from the discharge point was 900 At the "C" Platform site, the mean of the six 3,000-m stations was 2,800 Because the expected background level of barium in this area is about 500 pp a sand-free, calcium carbonate-free basis, some enrichment was observed at 3,0 at the Matagorda Island Block 686 site, but enrichment was much more pronou

Table 6. Mean concentrations of barium, chromium, and iron in the fine-grained fraction of sediments collected at the Phase I stations.

Station	Barium Concentration (ppm)	Chromium Concentration (ppm)	Iron Concentration (%)
0m-0°-1	29,400	101	3.34
10m-352°-1	23,700	89.0	3.49
10m-52°-1	28,200	137	3.10
10m-112°-1	29,500	128	3.05
10m-172°-1	59,200	103	3.11
10m-232°-1	43,700	109	3.07
10m-292°-1	40,700	130	3.29
100m-352°-1	10,700	79.7	3.36
100m-52°-1	40,400	86.0	3.29
100m-112°-1	32,200	81.3	3.18
100m-172°-1	10,500	78.7	3.48
100m-232°-1	12,800	82.0	3.53
100m-292°-1	15,800	83.0	3.37
1000m-352°-1	2,230	79.7	3.43
1000m-52°-1	2,400	75.0	3.49
1000m-112°-1	3,280	80.3	3.38
1000m-172°-1	14,800	78.3	3.39
1000m-232°-1	11,100	77.7	3.35
1000m-292°-1	3,060	78.0	3.37
3000m-352°-1	1,300	76.3	3.48
3000m-52°-1	2,250	78.0	3.34
3000m-112°-1	2,300	75.7	3.32
3000m-172°-1	2,220	77.0	3.25
3000m-232°-1	5,910	80.0	3.23
3000m-292°-1	2,420	83.0	3.69

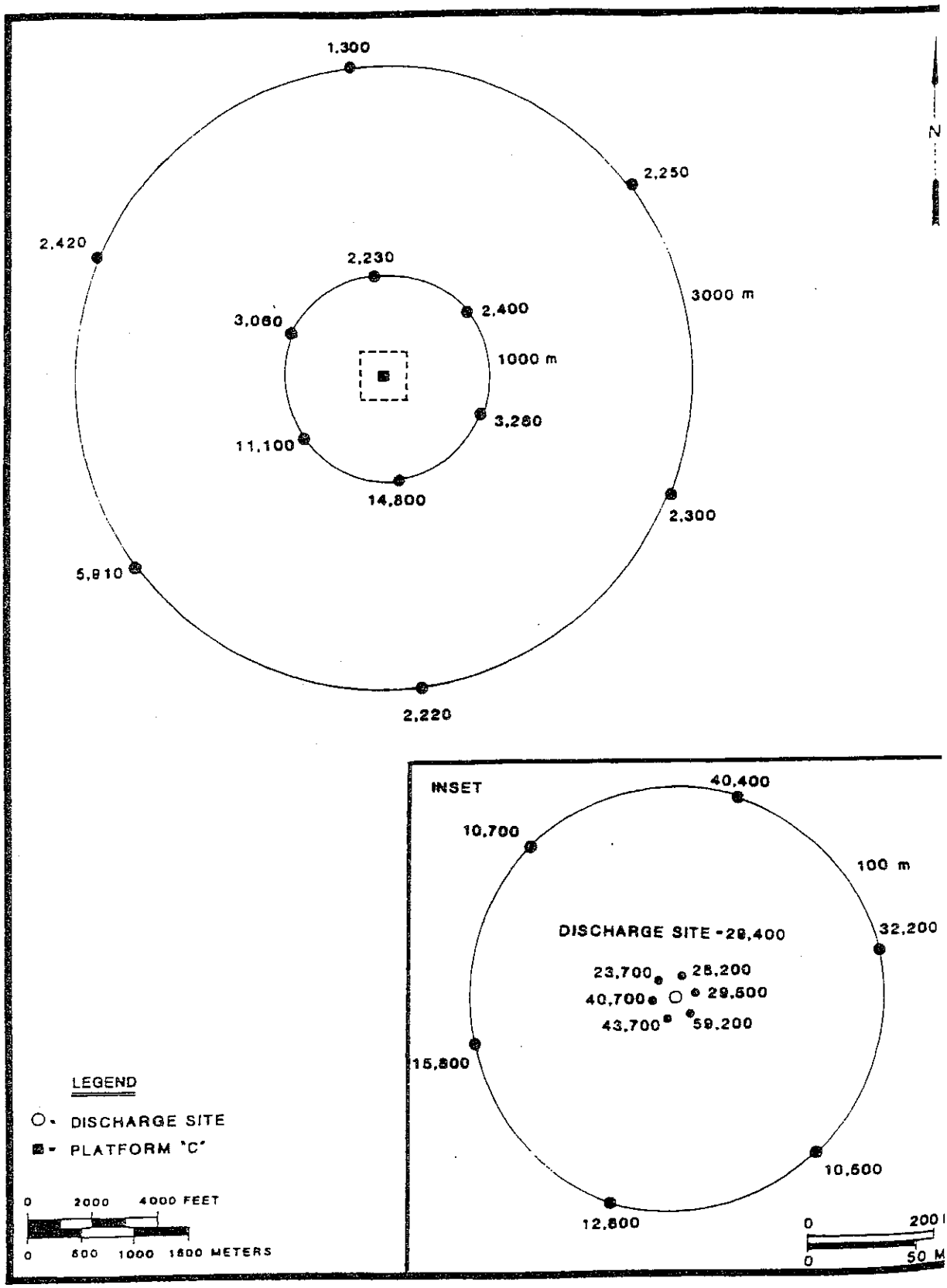


Figure 16. Spatial distribution of mean barium concentrations for samples collected during Cruise 1. Barium concentrations (ppm) are reported for the fine-grained fraction (<63 μm) of the samples. Fine-grained fraction concentrations could not be reliably converted to whole-sediment concentrations (see Section 3.3.4).

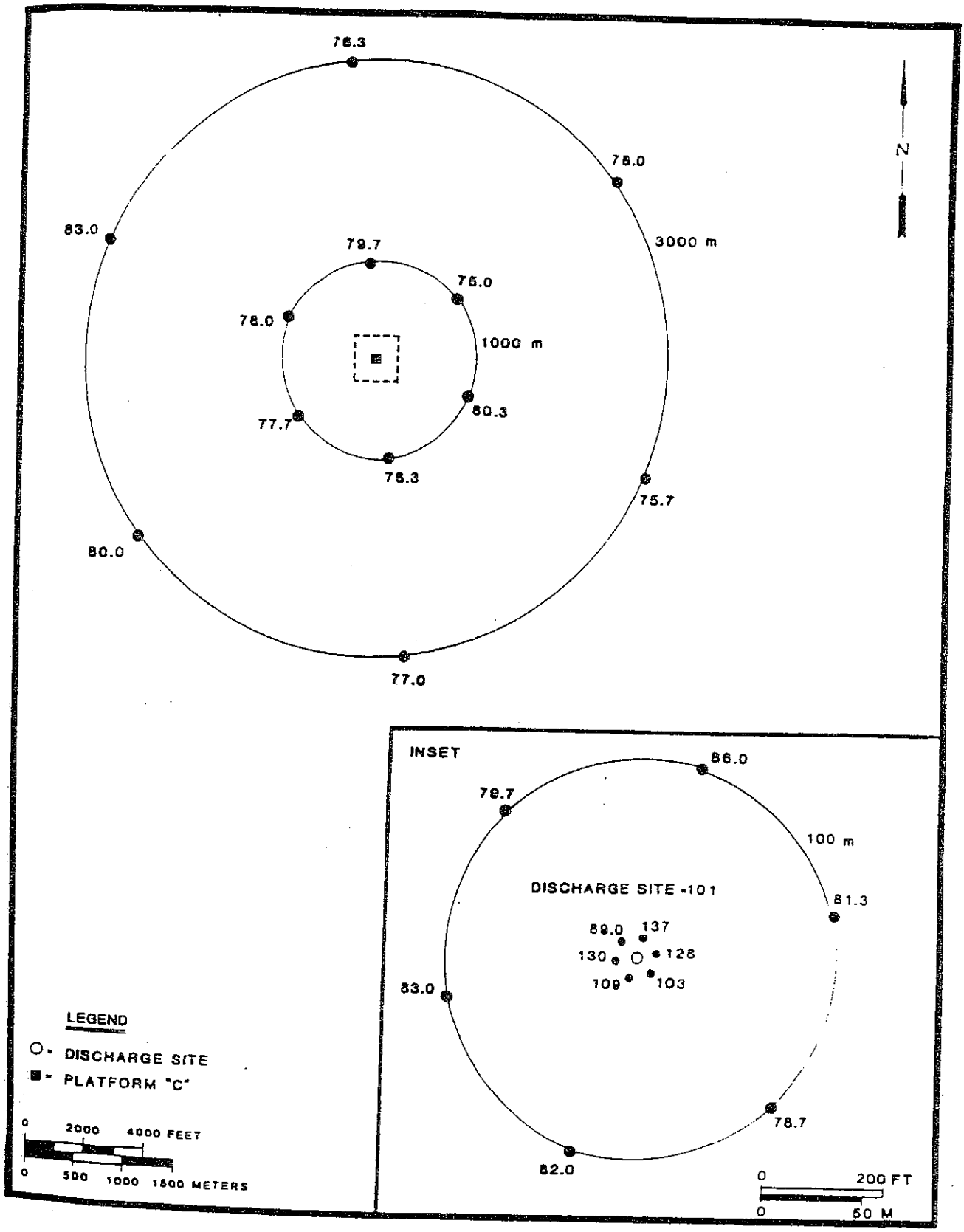


Figure 17. Spatial distribution of mean chromium concentrations for samples collected during Cruise 1. Chromium concentrations (ppm) are reported for the fine-grained fraction (<63 μm) of the samples.

at the "C" Platform site even when consideration is made for analyzing only the f fraction of the sediment.

Mean barium-to-iron and chromium-to-iron ratios for the 25 Platform stations are presented in Figures 18 and 19. These ratios were used normalize the data for variations in quartz and calcium carbonate, which are v low in barium and chromium. Expected background values for these ratios about 0.02 and 0.002, respectively based on analysis of samples free of drilling n influence. Hence, enrichment of barium, and to a lesser extent, chromium observed within 3,000 m of the platform on an iron-ratio basis.

Reasons for the greater enrichment of barium in the sediments aro "C" Platform compared to Matagorda Island Block 686 and other sites which h been previously studied are not clear. Initially, it was thought that analysis of fine-grained fraction (<63 μm) may be responsible. Scrutiny of the data and metal-to-iron ratios revealed that analysis of the fine-grained fraction could acco for only a part of the difference. Sand generally contributed 10% to the sedime at the Matagorda Island Block 686 site except near the platform, where it accoun for about 25% of the sediments. In contrast, the contribution of the sand frac was 50 to 60% near "C" Platform as well as at several stations farther from platform. The grain size of drilling mud barium sulfate particles is normally fi 1 to 50 μm with a mean of about 15 μm; thus, if the particles are not aggrega essentially all should go through the 63-μm sieve and be included in the silt/ fraction. If the coarse (sand-size) material is essentially free of barium sulfat could dilute the fines by 50 to 60% in those samples that are 50 to 60% sand. E this dilution would leave the sediments at "C" Platform richer in barium than th at nearby Matagorda Block 686 and other sites previously studied.

3.3.2 Spatial Distribution of Barium, Chromium, and Iron in the F Fraction of Phase I Sediment

The most obvious spatial pattern in the sediment metal data fi Phase I is the high barium values near the platform and the lower values away fi it (Figure 16). The concentrations at the 10 m stations are very high, greater t 40,000 ppm barium for three of the six stations and greater than 20,000 for the o three. The concentrations drop sharply but erratically with distance, so that at 10 four of the six stations have 10,000 to 15,000 ppm barium, but two have 30,00 40,000. The erratic drop continues with increasing distance, so that at 3,000 m station has 5,900 ppm but all the others have less than 2,500 ppm. The bariu obviously not uniformly distributed around the platform, probably due to both oc current activity and other drilling activity in the area (see Section 1.1.2).

Chromium also decreased with distance from the platform (Figure but the enrichments over expected background levels were mostly restricted to 10-m stations. The contrasting behavior of barium and chromium can be seen be in Figures 18 and 19 as ratios to iron. This ratioing technique compensated for variable quartz sand and calcium carbonate content of the sediment as th components are greatly depleted in barium, chromium, iron, and other trace me Chromium-to-iron ratios remained almost constant beyond the 10-m stati whereas the barium-to-iron ratios were highly variable. Iron is relatively cons

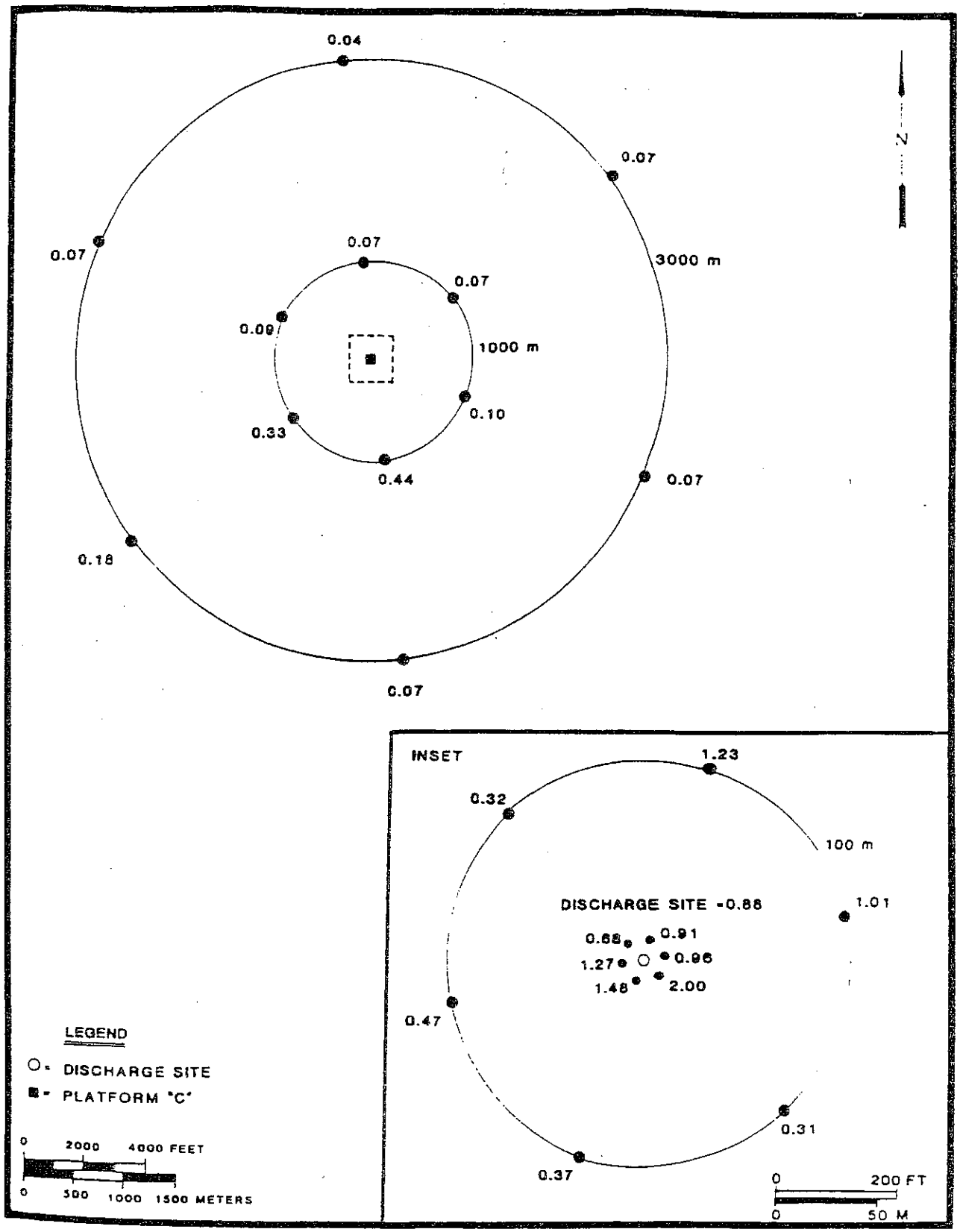


Figure 18. Spatial distribution of mean barium-to-iron ratios for samples collected during Cruise 1. The ratios are reported for the fine-grained fraction (<63 μm) of the samples.

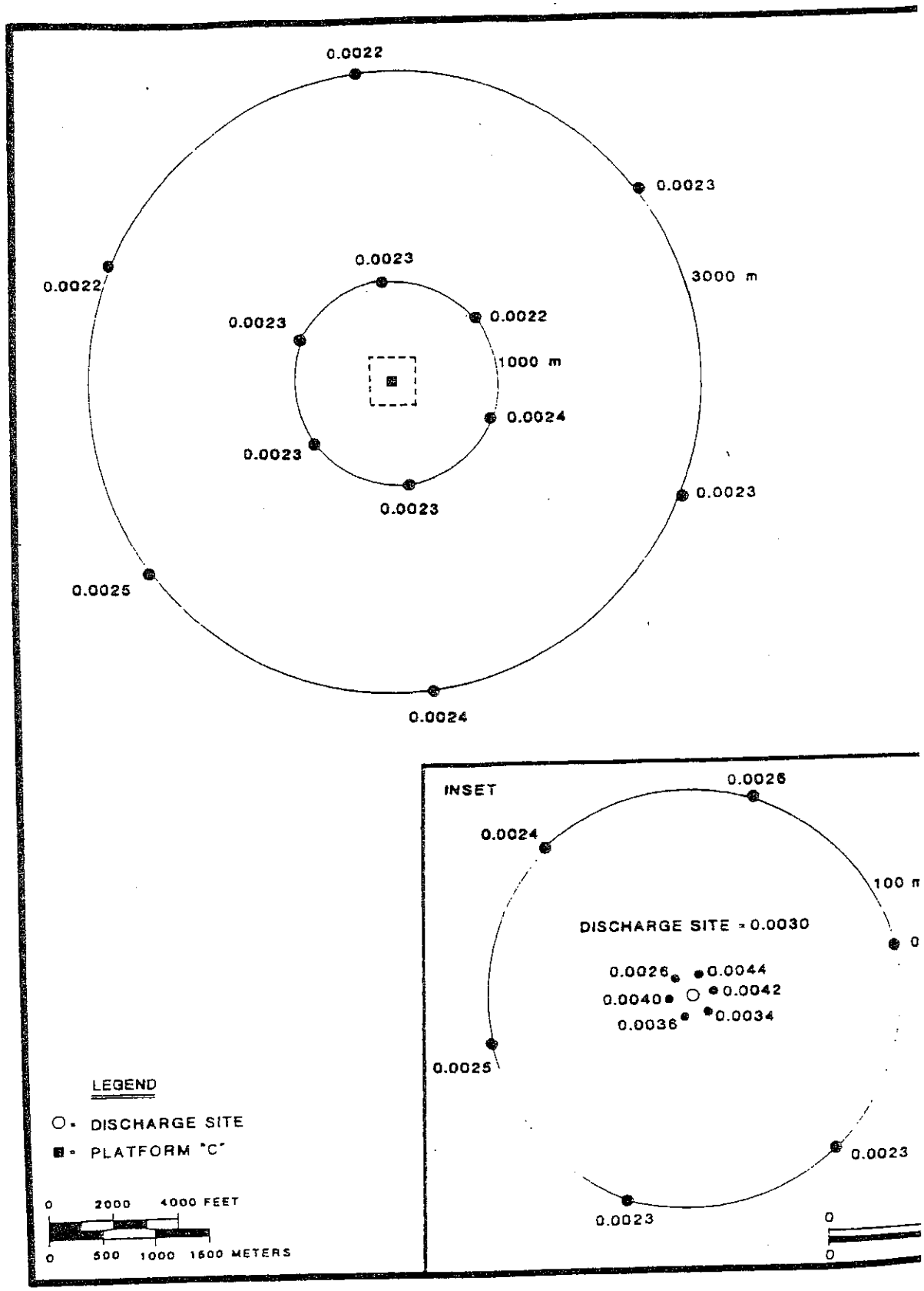


Figure 19. Spatial distribution of mean chromium-to-iron ratios for samples collected during Cruise 1. The ratios are reported for the fine-grained fraction (<63 μm) of the samples.

in these sediments and is unlikely to have been influenced by the drilling. The barium-to-iron ratio implied an enrichment in barium of all the samples from Phase I, even those at the 3,000-m stations.

In addition, the barium and barium-to-iron ratios indicated that the distribution of the settleable fraction of the discharged drilling effluents was not entirely symmetrical around the discharge site. These values are reported for the fine-grained fraction of the sample and could not be reliably compared to those from analysis of whole-sediment samples (bulk samples) for the reasons discussed below (see Section 3.3.4 for problems associated with predicting whole-sediment sample concentrations from the reported fine-grained fraction concentrations). At distances greater than 10 m, higher concentrations were observed in the alongshore (northeast to southwest) direction compared to the cross-shelf (northwest to southeast) direction. The observation agreed with the reports of the prevailing currents for this portion of the Texas shelf, although drilling at other sites in the area (see Section 1.1.2) may have also influenced the observed distribution patterns.

3.3.3 Determination of Additional Metals

In addition to barium, chromium, and iron, concentrations of five metals--arsenic, cadmium, lead, mercury, and zinc--were determined in sediment samples collected at the discharge site and at one 3,000-m station, Station 3000m-172°-1. The purpose of these analyses was to select a suite of three metals to be analyzed along with barium, chromium, and iron in the sediment samples to be collected during Phase II of the program. The results of these analyses are presented in Table 7.

To determine which three metals should be chosen, the null hypothesis that there was no difference between the two stations with respect to mean concentrations of each metal was tested. The three metals which exhibited the greatest differences between the two sites, based on t-tests, were to be included in Phase II. Results of the t-tests were as follows:

Metal	t-value
arsenic	1.83
cadmium	34.2
lead	2.12
mercury	5.07
zinc	5.12

Based on these analyses, significant differences ($p < 0.05$) between the two stations were observed for cadmium, mercury, and zinc. These three metals were, therefore, selected to be analyzed during Phase II of the program.

Table 7. Results of analyses of fine-grained sediment fraction from the discharge site and Station 3000m-172°-1 for arsenic, cadmium, lead, mercury, and zinc.

Station	Replicate	Arsenic (ppm)	Cadmium (ppb)	Lead (ppm)	Mercury (ppb)	Zinc (ppm)
0m-0°-1	a	2.9	670	19	89	910
(Discharge Site)	b	3.6	700	26	96	1,280
	c	4.9	640	24.5	84	1,540
3000m-172°-1	a	2.8	65	16	35	100
	b	1.8	60	18.5	32	95
	c	3.0	50	18.0	64	95

3.3.4 Phase II Sediment Metal Concentrations

The Phase II (Cruises 2 and 3) sampling pattern is presented in Figure 4. Unsieved samples collected during this phase were analyzed, and cadmium, mercury, and zinc were determined on all samples in addition to barium, chromium, and iron.

Eight Phase II samples were sieved and both fine and bulk fractions were analyzed. Thirteen Phase I samples were analyzed in bulk form to compare Phase I and Phase II data. These data are presented in Tables 8 and 9. Fine fractions were generally enriched in barium and chromium compared to the bulk fractions, but in a few cases the opposite was true. The barium and chromium concentrations that would be expected in the bulk fraction if these elements are depleted in the bulk fraction compared to the fines in the same proportion as iron are also presented. This simple calculation accurately predicted the barium and chromium concentration in the bulk fraction from concentrations in the fine fraction in many samples, but in some samples the prediction was much too high or too low for barium. The hazard of trying to predict bulk concentrations of chromium, and especially barium, from analysis of sieved samples was evident. Some of the drilling mud barium was associated with material >63 μm in size, perhaps with cuttings. The situation was much more serious for cadmium and zinc than it was for barium as was shown by Phase II samples (Table 9). Some samples which were greatly enriched in these elements had the excess concentrated in particles caught on the 63-μm sieve and thus the bulk sample had much higher concentrations than the corresponding fine fraction. The zinc and cadmium rich particles are almost certainly not part of drilling mud, but rather metal slivers or welding slag from the platform. Clearly, differences in the fractions analyzed between the two phases must be considered in comparisons between Phase I and Phase II trace metal concentrations.

3.3.5 Distribution of Metals in Phase II Sediments

Mean trace metal concentrations for sediments collected on Cruises 2 and 3 are presented in Table 10. The high barium concentrations found in sediments near "C" Platform during Phase I were confirmed by these data. However, the highest Phase II barium concentrations were about 20,000 ppm, whereas several samples from Phase I had over 40,000 ppm barium. This difference was partially due to the difference between analyzing bulk and fine samples and partially due to the highly variable distribution of barium in the sediment, both spatially and temporally. Spatial variability was indicated by the difference in barium concentrations among replicates taken at each station. At many stations, the replicates differed by approximately 10%, but at others, differences were more than a factor of two. Differences among closely spaced stations also indicated small-scale spatial variability. For example, barium concentration was about 10,000 ppm at the 10-m station sampled on Cruises 2 and 3. At a station only 15 m away (25 m-95°, Figure 4), barium concentrations ranged from 11,000 to 25,800 ppm in replicate samples collected during Cruise 3. Barium concentrations in the replicate Cruise 2 samples from this station ranged from 6,200 to 8,700 ppm.

Table 8. Barium, chromium, and iron concentrations measured in fine (<63 μm) and bulk sediments from Phase I and barium and chromium concentrations calculated to be in the bulk by multiplying fine barium and chromium by the bulk/fine iron values.

Station	Replicate	Sediment Fraction	Observed			Calculated	
			Barium (ppm)	Chromium (ppm)	Iron (%)	Barium (ppm)	Chromium (ppm)
10m-352°-1	a	fine	23,200	83	3.41	--	--
	a	bulk	19,500	57	2.05	13,950	50
10m-112°-1	a	fine	40,600	145	3.15	--	--
	a	bulk	23,000	110	2.90	37,370	133
10m-232°-1	a	fine	20,000	93	3.35	--	--
	a	bulk	23,000	110	2.85	19,570	94
100m-352°-1	a	fine	8,100	77	3.45	--	--
	a	bulk	9,500	36	1.25	2,930	28
100m-112°-1	c	fine	34,500	81	3.10	--	--
	c	bulk	25,000	37	1.50	16,690	39
100m-292°-1	a	fine	19,600	84	3.34	--	--
	a	bulk	12,000	37	1.35	7,920	34
1000m-172°-1	b	fine	7,350	76	3.48	--	--
	b	bulk	6,000	60	2.75	5,810	60
1000m-232°-1	b	fine	11,200	79	3.37	--	--
	b	bulk	10,500	55	2.35	7,810	55
1000m-292°-1	a	fine	3,110	79	3.38	--	--
	a	bulk	1,750	45	2.00	1,840	47
3000m-352°-1	a	fine	1,190	75	3.50	--	--
	a	bulk	750	45	1.95	660	42
3000-52°-1	b	fine	2,250	78	3.29	--	--
	b	bulk	1,500	55	2.25	1,540	53
3000m-172°-1	b	fine	1,960	78	3.29	--	--
	b	bulk	1,400	50	2.20	1,310	52
3000m-232°-1	a	fine	6,280	76	3.02	--	--
	a	bulk	4,300	55	2.25	4,680	57

Table 9. Metal concentrations measured in fine (<63 μm) and bulk sediments from Phase II and concentrations calculated to be in the bulk by multiplying fine values by the bulk/fine iron values.

Station	Sediment Fraction	Observed					Calculated			
		Barium (ppm)	Chromium (ppm)	Iron (%)	Cadmium (ppm)	Zinc (ppm)	Barium (ppm)	Chromium (ppm)	Cadmium (ppm)	Zinc (ppm)
25m-95°-1	fine	18,100	129	3.17	0.56	1,275	--	--	--	--
	bulk	8,700	128	3.31	0.31	4,990	18,900	135	0.58	1,330
25m-172°-1	fine	36,000	79	3.19	0.23	395	--	--	--	--
	bulk	21,800	34	1.59	1.10	5,420	17,950	39	0.12	195
75m-95°-1	fine	49,000	82	3.12	0.13	135	--	--	--	--
	bulk	23,200	33	1.41	0.075	115	22,150	37	0.058	61
75m-172°-1	fine	9,000	76	3.33	0.090	105	--	--	--	--
	bulk	12,100	37	1.71	0.10	88	4,620	39	0.046	54
150m-95°-1	fine	9,100	74	3.18	0.085	115	--	--	--	--
	bulk	10,600	51	2.12	0.075	97	6,070	49	0.057	77
300m-95°-1	fine	6,700	73	3.12	0.155	110	--	--	--	--
	bulk	10,700	47	2.01	0.051	82	4,320	47	0.100	71
750m-95°-1	fine	4,200	82	3.44	0.070	105	--	--	--	--
	coarse	950	27	0.85	0.029	36	1,040	20	0.017	26
3000m-95°-1	fine	1,080	71	3.15	0.060	100	--	--	--	--
	coarse	560	24	1.07	0.023	38	370	24	0.020	34
5000m-95°-1	fine	1,220	78	3.20	0.070	95	--	--	--	--
	coarse	630	34	1.64	0.036	55	625	40	0.036	49

Table 10. Mean concentrations of metals at stations occupied during Cruises 2 and 3 (Phase II). Whole (bulk) samples were analyzed.

Station	Cruise	Barium (ppm)	Cadmium (ppb)	Chromium (ppm)	Iron (%)	Mercury (ppb)	Zinc (ppm)
10m-95°	2	10,870	333	88	3.19	81	2,950
	3	10,480	2,300	126	3.32	53	5,030
25m-95°	2	7,330	613	129	3.24	42	4,640
	3	17,780	700	154	3.12	70	2,900
25m-172°	2	20,100	453	33	1.56	51	1,942
	3	9,800	130	51	2.23	145	465
25m-276°	2	15,770	855	126	2.77	50	836
	3	7,300	335	53	2.36	112	1,065
75m-95°	2	20,330	80	31	1.28	39	128
	3	14,500	88	44	1.72	52	88
75m-172°	2	13,000	85	35	1.62	30	114
	3	10,700	88	38	1.72	53	118
75m-276°	2	10,200	217	30	1.86	21	383
	3	6,650	227	49	1.86	62	407
50m-95°	2	10,270	21	49	2.02	47	97
	3	6,230	91	51	2.21	41	97
50m-172°	2	11,670	43	36	1.53	19	69
	3	9,000	63	50	2.06	41	87
50m-276°	2	10,200	72	39	1.66	23	104
	3	6,350	61	48	2.08	23	87
300m-95°	2	6,170	52	51	2.25	37	77
	3	3,700	70	57	2.53	24	60
300m-172°	2	2,730	40	52	2.12	22	66
	3	3,330	48	49	2.04	40	63
300m-276°	2	7,430	60	51	2.14	37	80
	3	3,630	56	53	2.47	31	63
750m-95°	2	1,970	23	56	2.40	29	77
	3	1,870	46	55	2.23	43	65
750m-172°	2	17,330	37	45	1.88	24	76
	3	12,330	132	53	2.23	17	400
3000m-95°	2	1,090	44	54	2.27	29	74
	3	970	37	51	2.49	60	67
3000m-172°	2	1,200	60	57	2.45	39	64
	3	1,050	43	53	2.32	39	72
5000m-95°	2	775	46	59	2.50	33	78
	3	770	44	52	2.54	50	57
5000m-172°	2	810	42	59	2.54	36	83
	3	800	51	55	2.42	39	71

The temporal variability observed at Station 25m-95° was also found at many other stations. For example, at 25m-172° the Cruise 2 samples ranged from 12,100 to 26,400 ppm barium, averaging 20,100 ppm, whereas Cruise 3 samples ranged from 5,700 to 15,100 ppm barium and averaged 9,800 ppm. Thus, an increase in barium of more than twofold was observed at one of these two stations between Cruises 2 and 3 while at the other (nearby) station, a decrease between Cruises 2 and 3 of more than twofold was observed. Obviously the drilling mud barium sulfate was either distributed very patchily, moving around on the seafloor with ocean currents, or both. Redistribution of sediment on the seafloor by ocean currents was supported by variations in other elements, including iron, between Cruises 2 and 3.

As was the case during Phase I, erratic decreases in barium concentration with distance from the platform were observed during Phase II (Figures 20 to 23). Many of the 25- and 75-m samples have higher concentrations than any of the 10-m samples and some of the 150-m samples are about as high as the 10-m samples. Perhaps cuttings diluted the drilling mud deposited at 10 m, or perhaps much of the drilling mud was carried by currents 25 to 75 m during discharges prior to deposition.

In any case, barium concentrations remained high at 300 m where 3,000 to 7,000 ppm was observed and at 750 m where about 2,000 ppm was found at one of the stations on both cruises. At 3,000 and 5,000 m from "C" Platform, barium concentrations were 800 to 1,200 ppm, well above the estimated background level for this area of 500 to 600 ppm and somewhat higher than the approximately 700 ppm barium Boothe and Presley (1985) found in sediments 3,000 m from a platform in Matagorda Block 686. It should be noted, however, that only four 3,000-m samples were analyzed from Matagorda Block 686 and while barium concentrations in three of these were about 700 ppm, one had a concentration of 1,600 ppm. This re-emphasizes the patchy nature of barium sulfate distributions on the seafloor and the hazards involved in making generalizations based on a few samples collected at one particular time.

In describing the distribution of barium around "C" Platform, special note must be made of samples from Station 750m-172°. Although 750 m from "C" Platform, this station is only about 250 m from a single satellite well which was drilled in 1986, just before samples for this study were taken. The influence of this well can be seen very clearly in Figures 24 and 25 as barium concentration in the sediment are 10,000 to 20,000 ppm versus about 2,000 ppm for the other station sampled at 750 m from "C" Platform. Obviously the satellite well greatly complicated barium distributions around the platform.

Sediment concentrations of metals other than barium show the influence of "C" Platform and nearby wells. The other metal-enriched samples are distributed even more erratically than was the case for barium-enriched ones, except that other metals were enriched only very near the drillsite. Zinc, for example, was found at 3,000 to 5,000 ppm in a number of samples from within 25 m of the platform, but was at a background 75 to 200 ppm level in most samples beyond 150 m. The 750-m samples which gave high barium concentrations were enriched in zinc (400 ppm) on Cruise 3 but not on Cruise 2 (75 ppm).

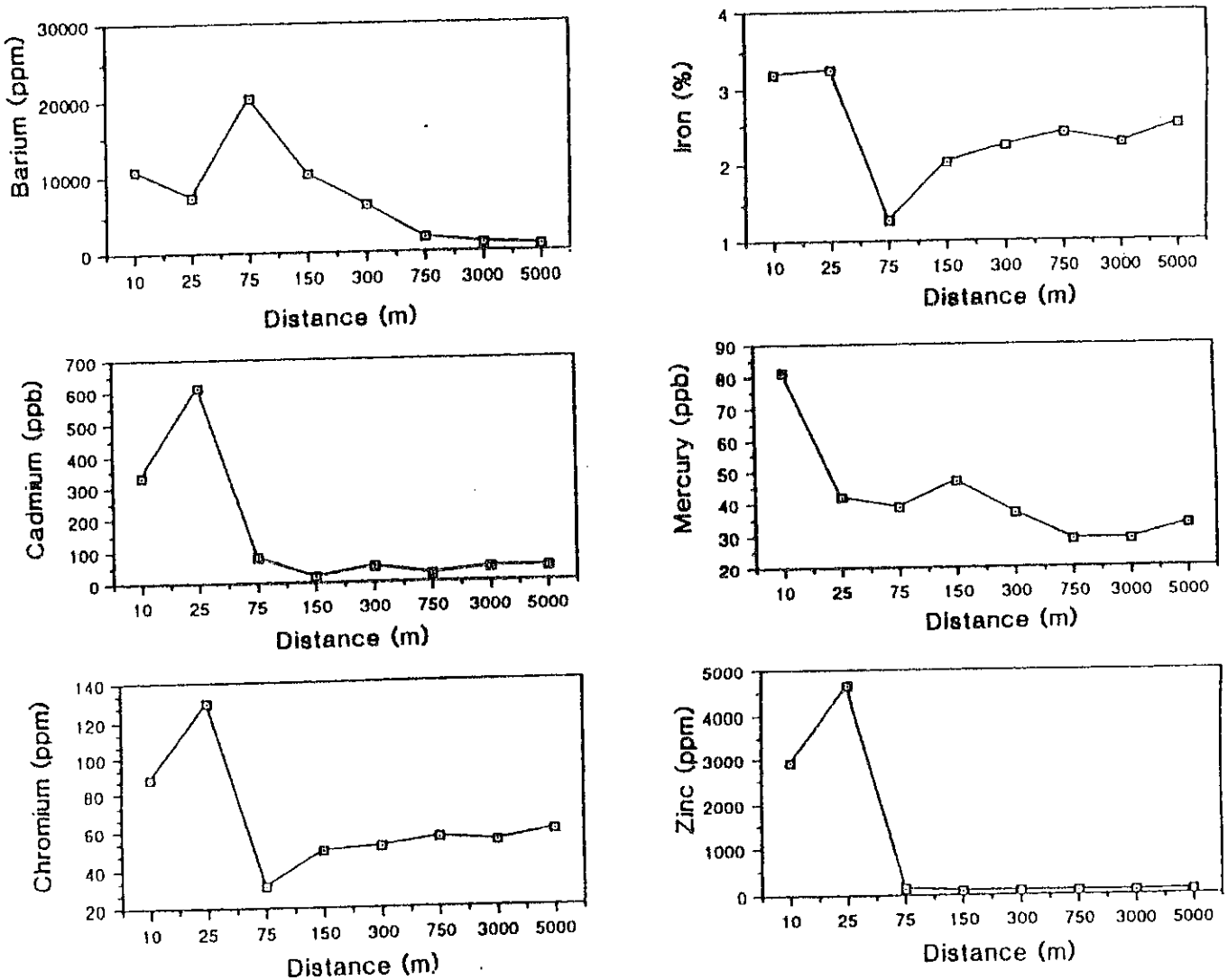


Figure 20. Mean Cruise 2 concentrations of barium, cadmium, chromium, iron, mercury, and zinc on the 95° radian (see

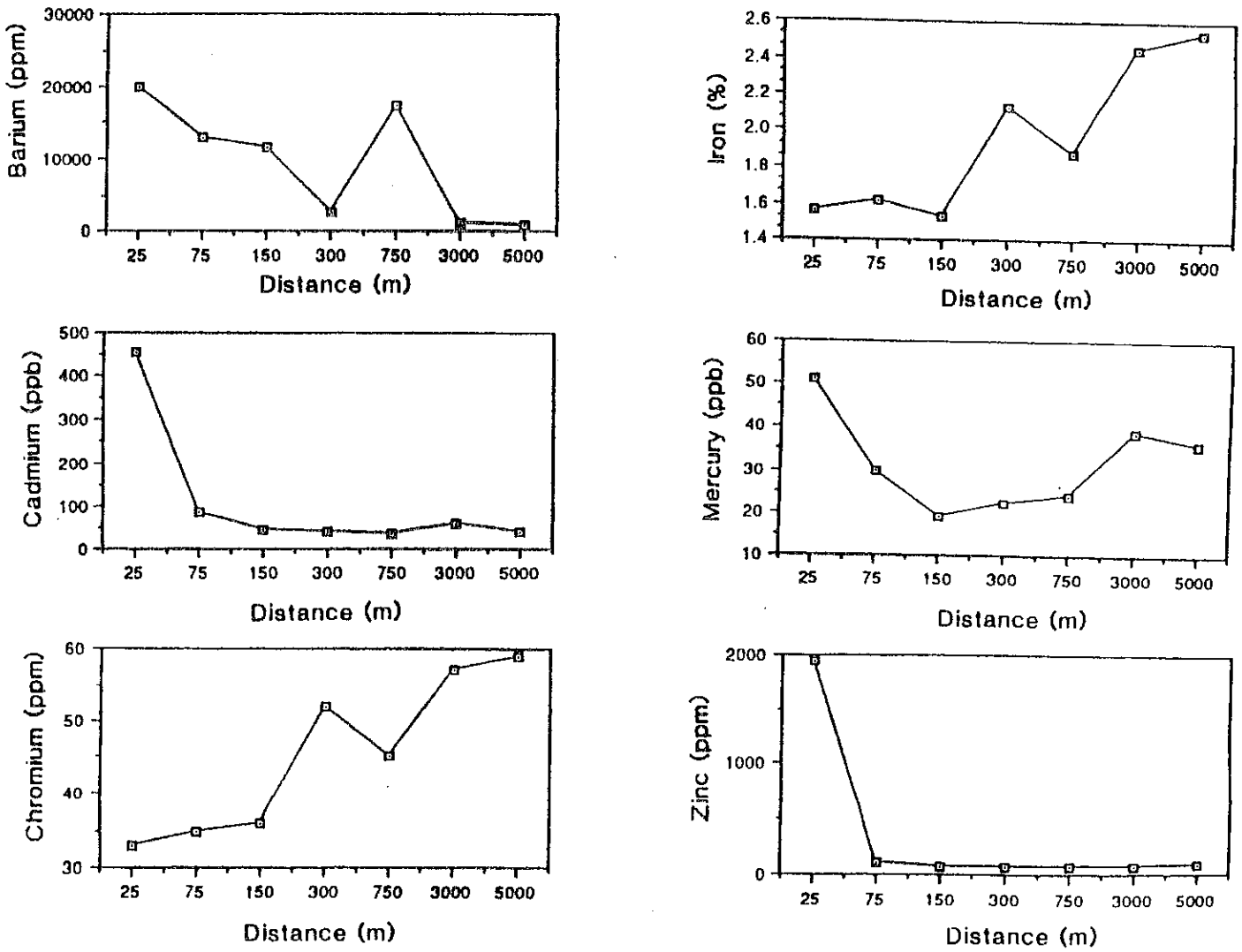


Figure 21. Mean Cruise 2 concentrations of barium, cadmium, chromium, iron, mercury, and zinc on the 172° radian (see Figure 4). Concentrations are reported for the whole sediments.

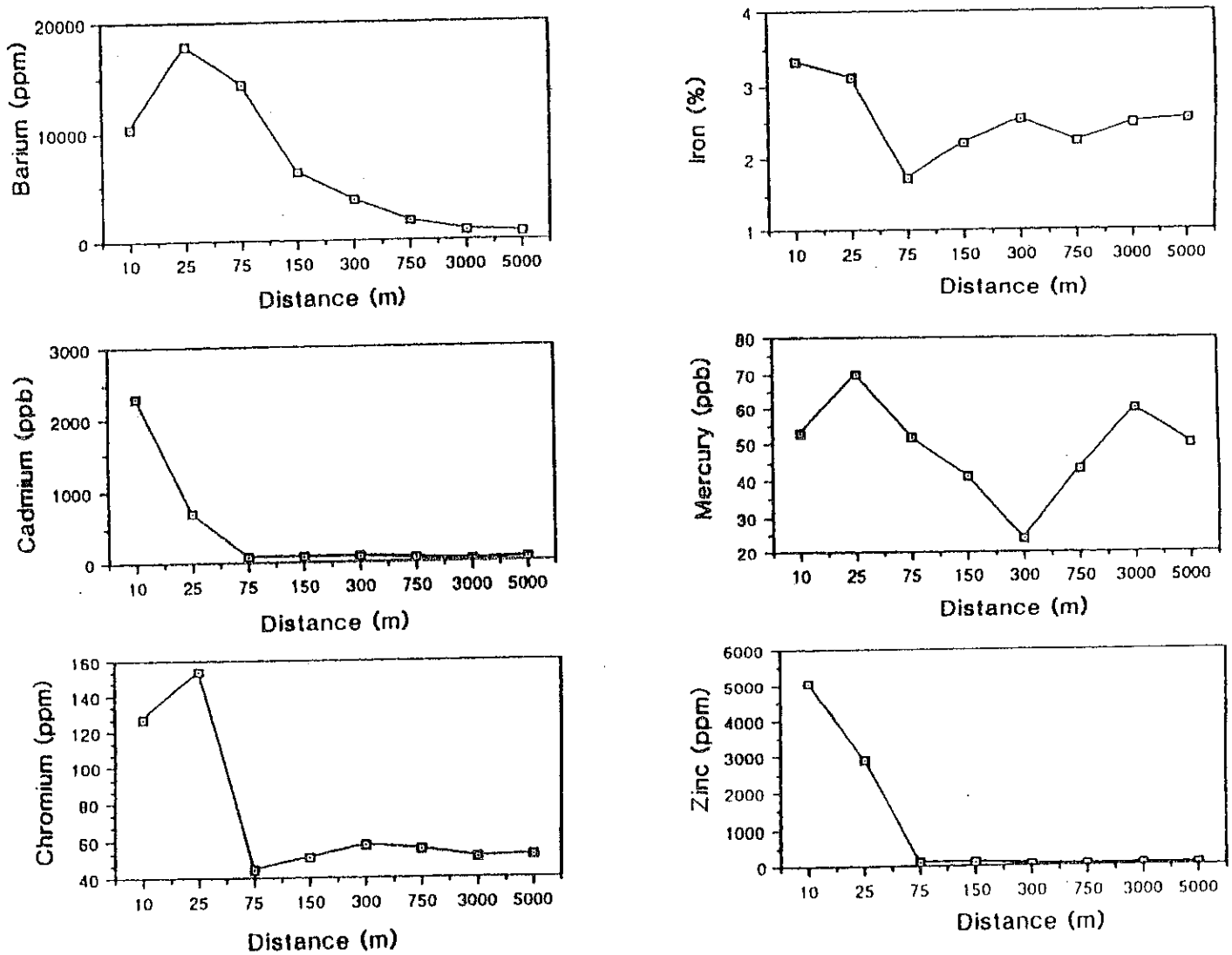


Figure 22. Mean Cruise 3 concentrations of barium, cadmium, chromium, iron, mercury, and zinc on the 95° radian (see Figure 4). Concentrations are reported for the whole sediments.

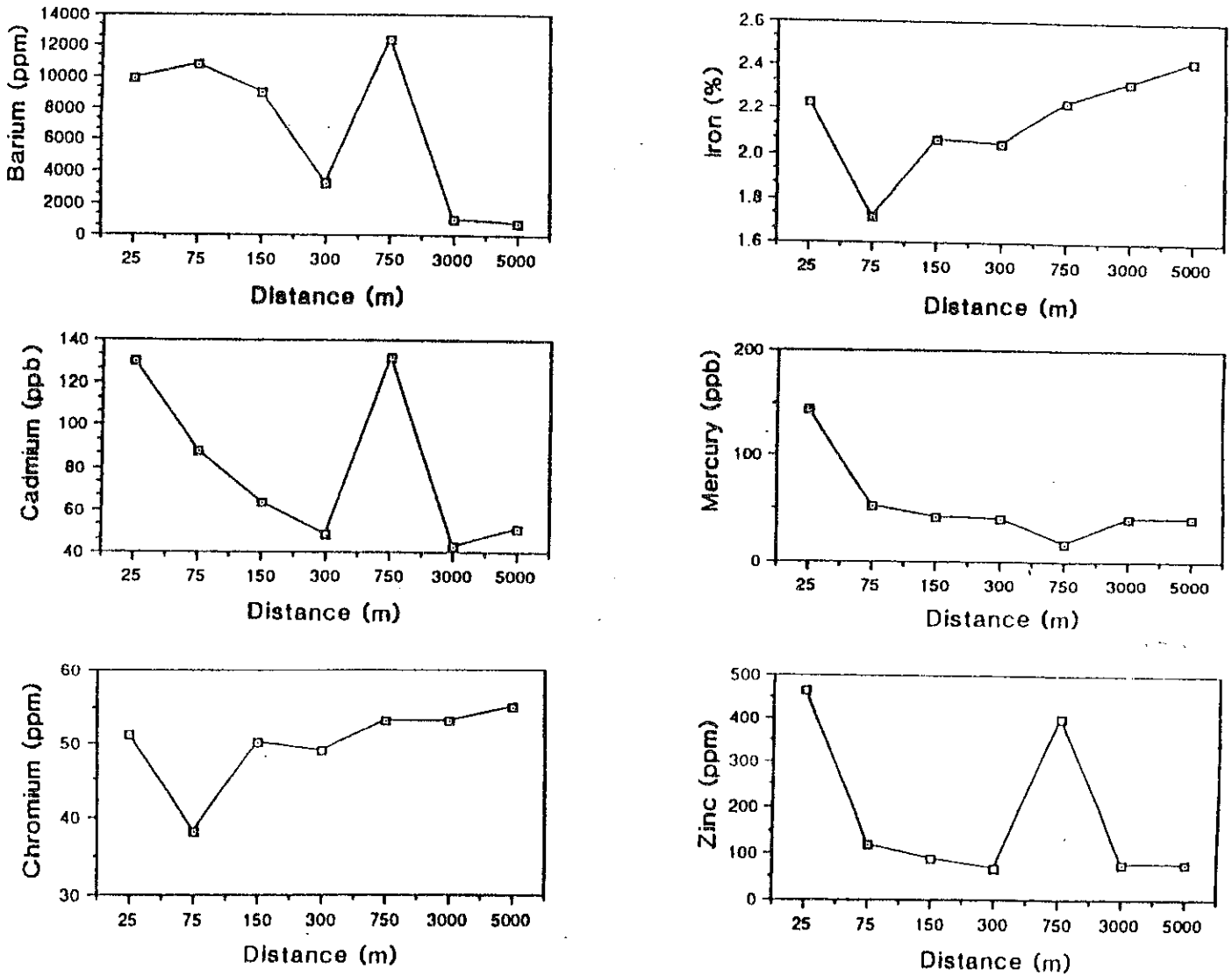


Figure 23. Mean Cruise 3 concentrations of barium, cadmium, chromium, iron, mercury, and zinc on the 172° radian (see Figure 4). Concentrations are reported for the whole sediments.

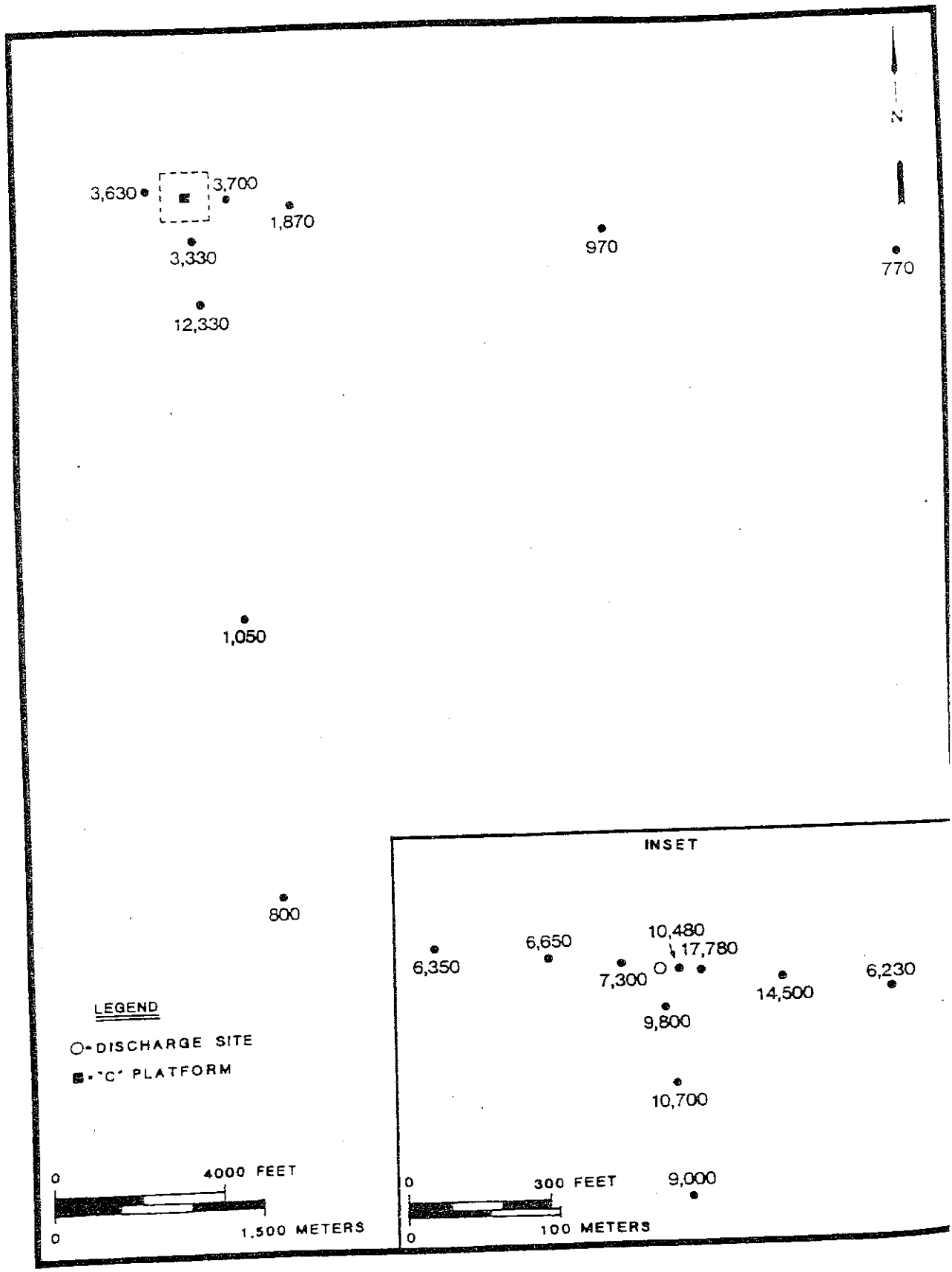


Figure 24. Spatial distribution of mean barium concentrations for samples collected during Cruise 2. Barium concentrations are reported in ppm of the whole sediment.

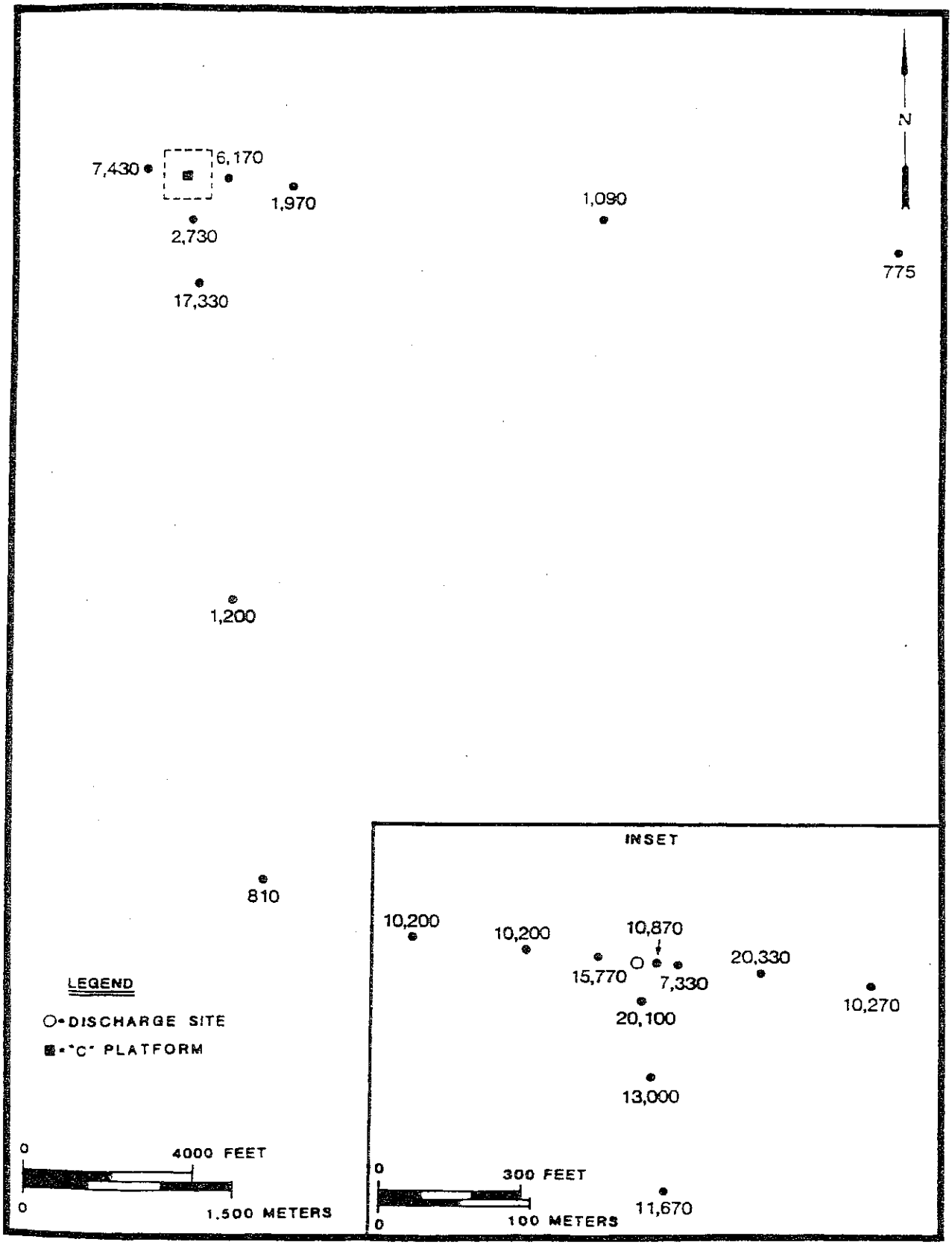


Figure 25. Spatial distribution of mean barium concentrations for samples collected during Cruise 3. Barium concentrations are reported in ppm of the whole sediment.

There was good agreement among replicates at some of the zinc-enriched stations, but very poor agreement at others. An extreme was Station 25m-172° which on Cruise 2 produced samples having 185 ppm and 5,420 ppm zinc. Sediment from that station had zinc concentrations ranging from 330 to 550 ppm on Cruise 3. The sieved (fine) fraction of the sample that gave 5,420 ppm zinc had only 395 ppm and one other zinc-enriched sample also had higher zinc in the bulk than in the fines. It seems likely that the highly zinc-enriched samples contained flakes of galvanized metal, slag from metal welding on the platform or some other particles that are caught on a 63-μm sieve. More subtle enrichment of the sediment with zinc might come from drilling mud, for example the 400 ppm zinc found in the 750m-172° samples on Cruise 3. However, several samples which were highly enriched in drilling mud barium, for example the 750m-172° samples on Cruise 2, show little or no zinc enrichment. The relationship between zinc and drilling mud is thus not clear and some other activity associated with drilling must be suspected of adding zinc to the sediment.

Cadmium concentrations in the sediments followed zinc rather closely, with elevated (twofold) concentrations near the platform and background levels beyond 75 m. The 750m-172° samples which showed the influence of a satellite well in barium and zinc also had high cadmium concentrations. Furthermore, on Cruise 2, where barium showed enrichment at this station but zinc did not, cadmium was at background. It seems likely that something other than drilling mud was responsible for zinc and cadmium in the sediment at some stations near "C" Platform.

Mercury concentrations were generally low through the area although enrichment factors of two to three were noted in a few samples. There was a poor correlation between mercury and barium; if drilling mud was the source of the mercury, the drilling muds must have varied in mercury content during drilling. The cadmium, mercury, and zinc distributions are thus more similar to chromium distribution than barium, with high values restricted almost exclusively to within 25 m of the platform. The high enrichments near the platform may have been due to metal pieces from the platform and most fine-grained trace metal-rich particles were widely dispersed and diluted to background levels.

During Cruise 2, a series of deep cores were collected to evaluate concentrations of barium, chromium, and iron in the sediment column at several distances (10, 150, 750, and 5,000 m) from the discharge site. Vertical profiles of the trace metal concentrations (whole sediment) provided temporal records of trace metal fluctuations at individual stations which could be evaluated for relationships to drilling activities. The results of these analyses are presented in Table 11. Chromium and iron were relatively constant through the sediment column, indicating little enrichment of these trace metals as a result of drilling activities.

Background whole sediment barium concentrations in this area are 0.04 to 0.06%. The barium profile at the 10-m station indicated large enrichments to the deepest interval analyzed (10 cm). Such enrichment probably extended deeper into the sediment column at this station. The profile suggested that a mound (at least

Table II. Summary of barium, chromium, and iron concentrations (whole sediment) in the sediment column at four distances from the discharge site.

Depth Interval (cm)	Barium Concentration (%) at Distance From Discharge Site (m)				Chromium Concentration (ppm) at Distance From Discharge Site (m)				Iron Concentration (%) at Distance From Discharge Site (m)			
	10	150	750	5,000	10	150	750	5,000	10	150	750	5,000
0-1	2.9	0.9	0.2	0.065	88	40	53	60	2.58	1.80	2.05	2.90
1-2	2.2	0.85	0.23	0.08	80	35	56	58	2.40	1.50	2.10	2.50
5-6	0.9	1.08	0.21	0.078	70	45	54	54	3.00	1.98	2.05	2.30
6-7				0.75				56				2.52
9-10	1.83				72				2.52			
10-11		0.75	0.065			51	70			2.40	3.30	
11-12				0.048				56				2.45
12-13			0.062				40				1.38	
16-17		0.095				57				2.65		

10 cm high) of barium-rich drilling muds and cuttings had accumulated near the discharge site.

The level of enrichment was less at the 150-m station compared to the 10-m station, but excess (discharged) barium was detectable to at least 11 cm (some elevation above background concentrations was evident at 16 to 17 cm). The profile at the 750-m station was similar to that at 150 m but the enrichment level was less. The 150 and 750-m profiles suggested that a great deal of drilling had occurred in the area. In addition, considerable sediment resuspension and mixing had occurred which worked the deposited barium deeper into the sediment column. For comparison, at the Matagorda Island Area Block 686 site studied by Boothe and Presley (1985), the depth of excess barium was only 5 cm at similar distances from the discharge site.

The profile at the 5,000-m station was essentially identical to that collected at the 3,000-m station at the Matagorda Island Area Block 686 site. This suggested that accumulations of discharged barium in the sediment column was minimal at these distances.

3.4 HYDROCARBONS

There are two important sources of hydrocarbons to the marine environment--biogenic and thermogenic. In any study examining anthropogenic inputs, one must be able to differentiate hydrocarbons introduced by man from those that are from biological sources. A number of parameters have been used to identify petroleum hydrocarbons in the environment including:

1. The presence of an unresolved complex mixture (UCM) of hydrocarbons (i.e., petroleum has a much broader and tremendously more complex collection of compounds);

2. A homologous series of compounds in which the sequential members are of approximately equal abundance (i.e., compounds with consecutive even and odd numbers of carbon atoms);

3. The absence of olefinic (unsaturated) compounds (except in refined products);

4. The presence of abundant cycloalkanes and aromatic compounds; and

5. Ratios of pristane/phytane, pristane/C_{17}, and phytane/C_{18} (e.g., incorporation of oil within a sample increases the ratio due to increased isoprenoid concentrations).

When analyzing trace quantities of hydrocarbons, it is often difficult to differentiate between compounds of petrogenic (oil-related) and biogenic

(produced by biological processes) origin. The differentiation is complicated by weathering, degradation, and the wide hydrocarbon compositions from various sources. Pyrolytic compounds (combustion-related) can also be found in coastal sediments.

3.4.1 Phase I

Only the aliphatic hydrocarbon components and the total EOM were measured in samples collected during Cruise 1. The measured parameters included the UCM, selected isoprenoids (pristane and phytane) and the normal (straight-chain) alkanes with 15 to 32 carbon atoms.

Extractable Organic Matter

The EOM is that portion of the sediment (on a dry-weight basis) that is extractable in organic solvent (in this case methylene chloride). EOM is composed of hydrocarbons and various other soluble organic compounds (lipids). A low level background of biogenic lipids exist in all marine sediments. Background concentrations are determined primarily by biological organic matter input to the sediment and the sediment redox potential. High level petroleum contamination can be differentiated from this background biogenic EOM near point sources of contamination.

The sediment EOM distributions during Cruise 1 are shown in Table 12 and Figures 26 and 27. Significantly higher EOM concentrations are observed beneath and 10 m from "C" Platform. EOM directly beneath the platform was 500 ppm and the average of the six sites at 10 m was 535 ppm. Concentrations as high as 890 ppm were observed at 10 m, and concentrations were generally higher to the south and southwest. At sites located 100 m and greater from the discharge site, EOM concentrations were an order of magnitude lower (approximately 50 to 70 ppm), and the spatial distribution was homogeneous.

Aliphatic Hydrocarbons

The UCM is composed of those compounds that cannot be resolved under the given chromatographic conditions. Because biological processes generally produce only a limited number of compounds, an UCM is often utilized as an indicator of petroleum-derived hydrocarbons. Total UCM was nearly an order of magnitude higher directly beneath (100 ppm) and 10 m distant (mean 127 ppm) from the platform compared to stations located 100 m or greater from the discharge site (approximately 15 ppm) (Figure 27, Table 12). This same relative increase was also observed in the EOM distribution. As with EOM, the six station total UCM average concentration at 10 m was slightly higher (127 ppm) than directly beneath the platform (100 ppm). UCM concentrations were most elevated at the 10 m distance to the south and southwest of the platform (Figures 28 and 29). Little spatial variation in UCM was observed beyond the 10 m sampling sites. The UCM at both the contaminated inner stations (≤10 m) and background outer stations

Table 12. Mean concentrations of extractable organic matter, unresolved complex mixture, and total alkanes with distance from the discharge site as observed during Cruise 1.

Distance (m)	EOM* (ppm)	UCM§ <n-C_{23} (ppm)	UCM >n-C_{23} (ppm)	Total UCM (ppm)	Total Alkanes (ppb)
0	500	29	71	100	4,947
10	535	38	89	127	4,648
100	55	4	12	16	360
1,000	67	3	12	15	393
3,000	55	3	10	13	456

* Extractable organic matter.
§ Unresolved complex mixture.

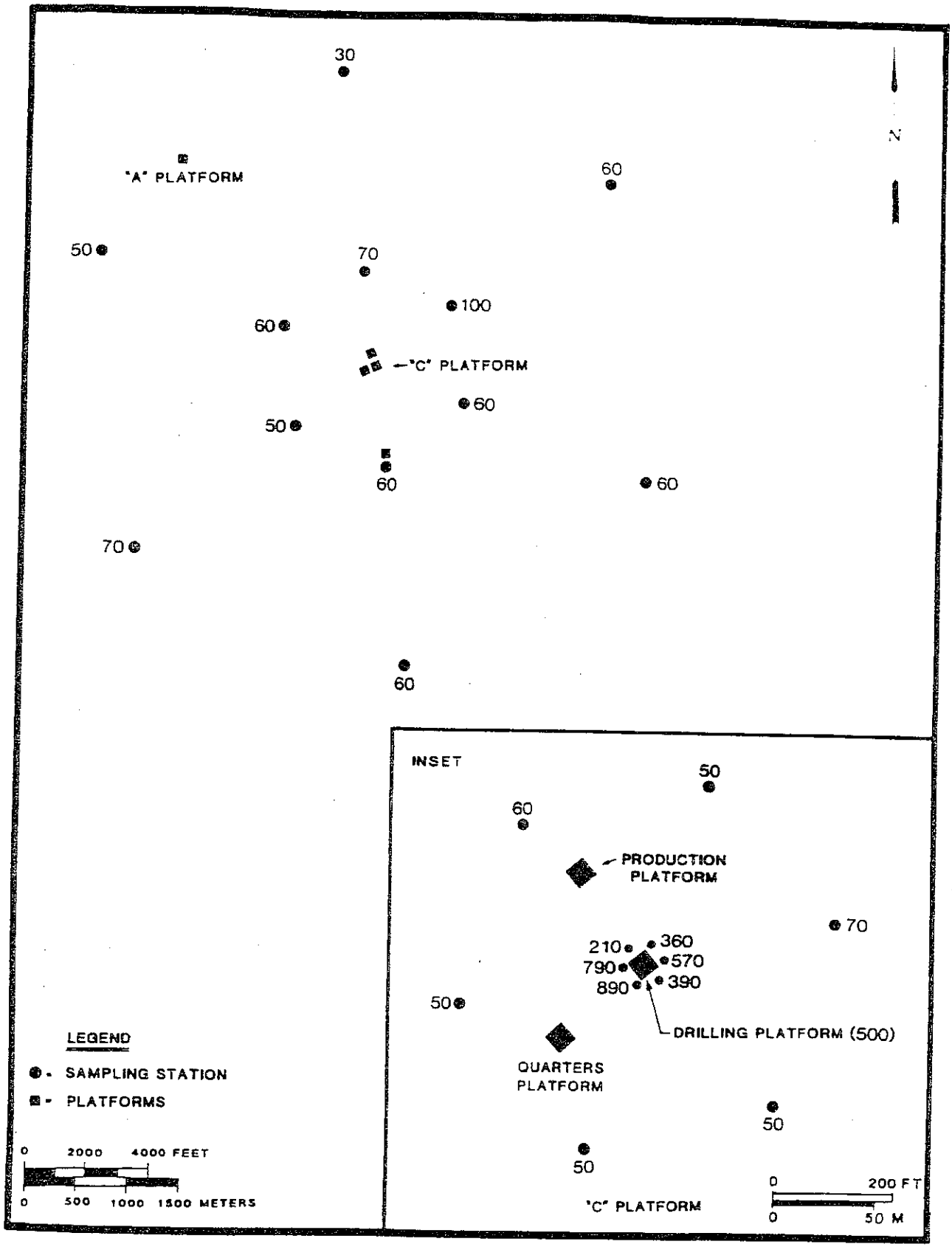


Figure 26. Spatial distribution of extractable organic matter (ppm) observed during Cruise 1.

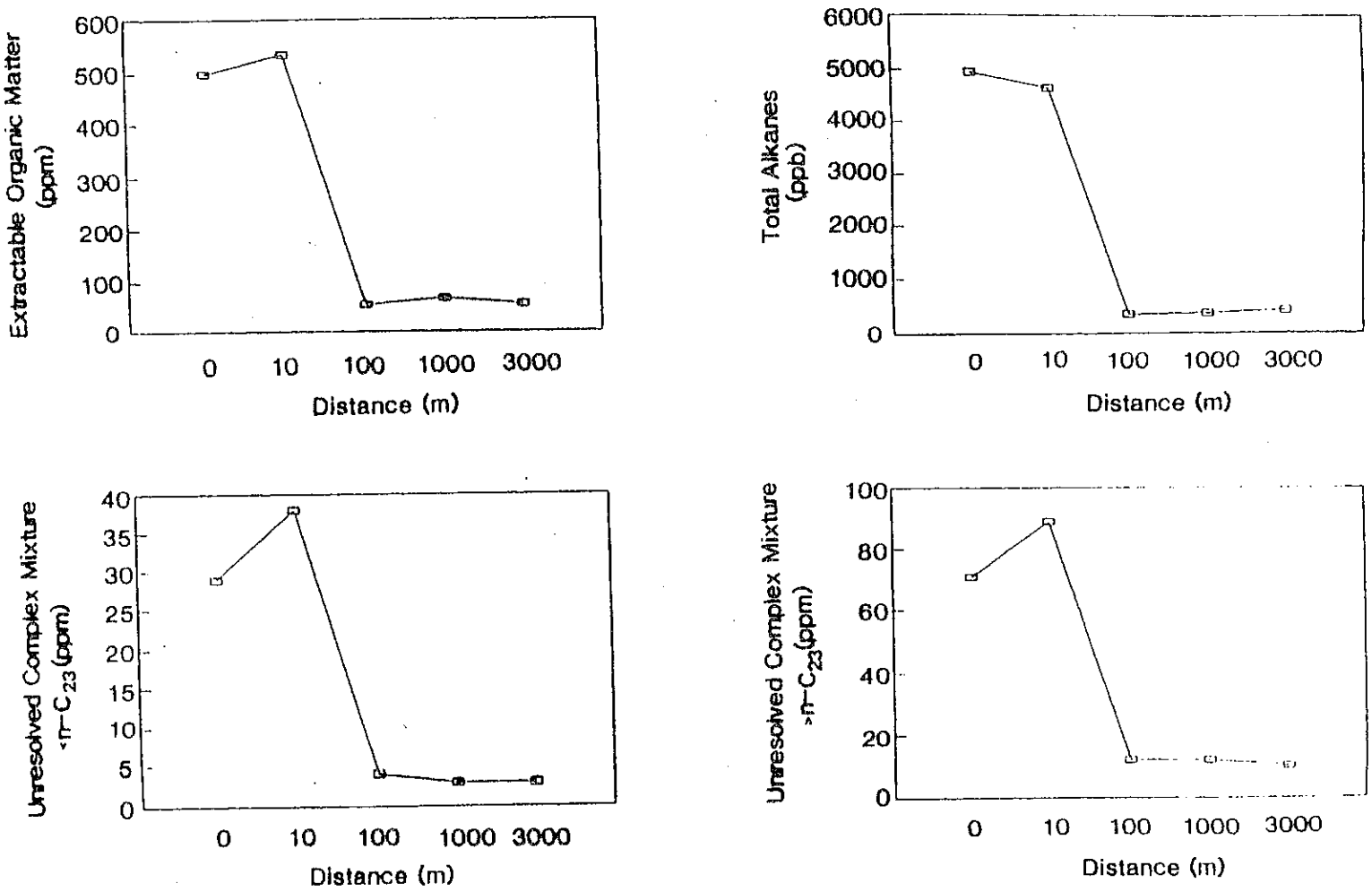


Figure 27. Mean concentrations of extractable organic matter, total alkanes, and unresolved complex mixture with distance from the discharge site as observed during Cruise 1.

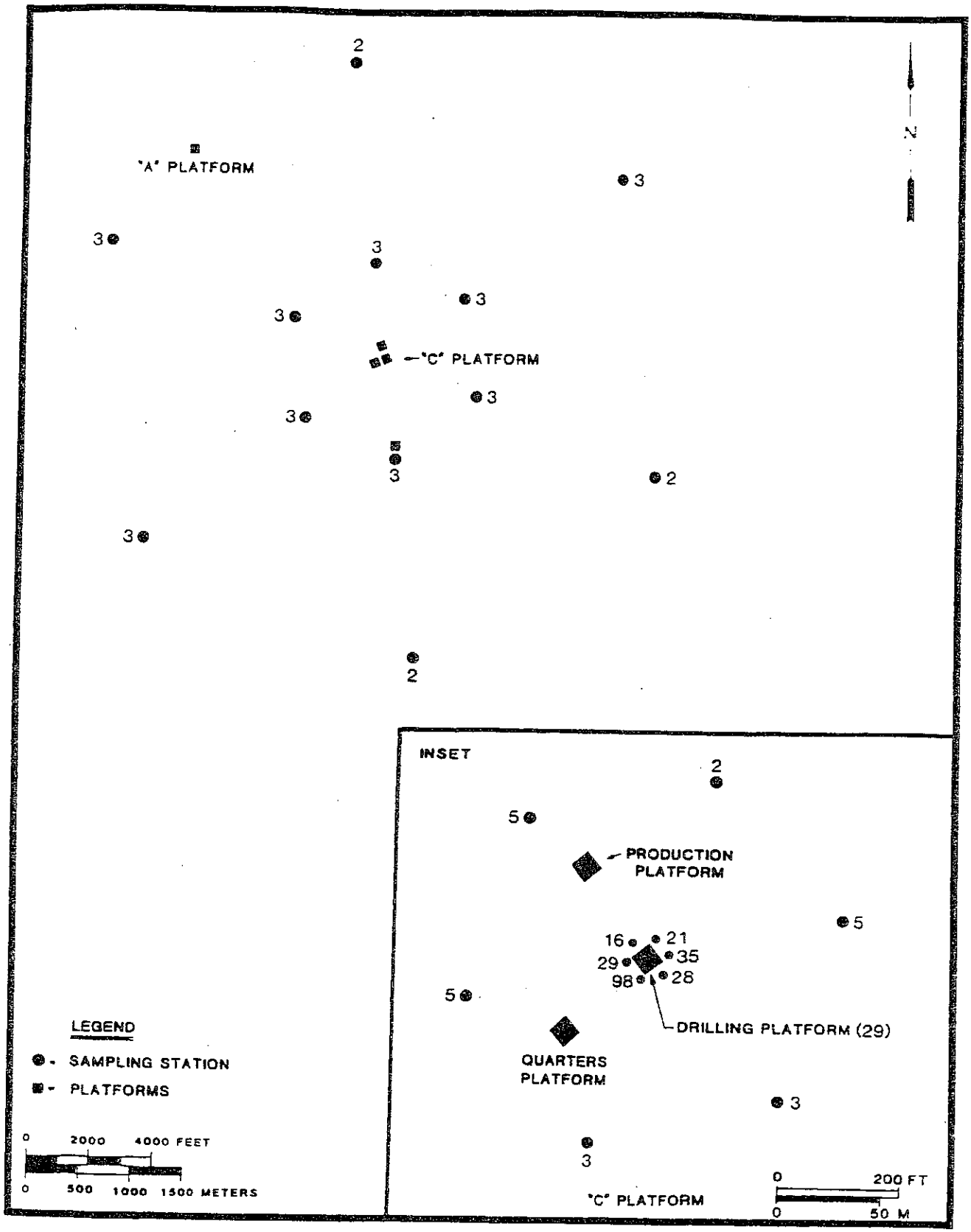


Figure 28. Spatial distribution of mean unresolved complex mixture $<n\text{-}C_{23}$ concentrations (ppm) observed during Cruise 1.

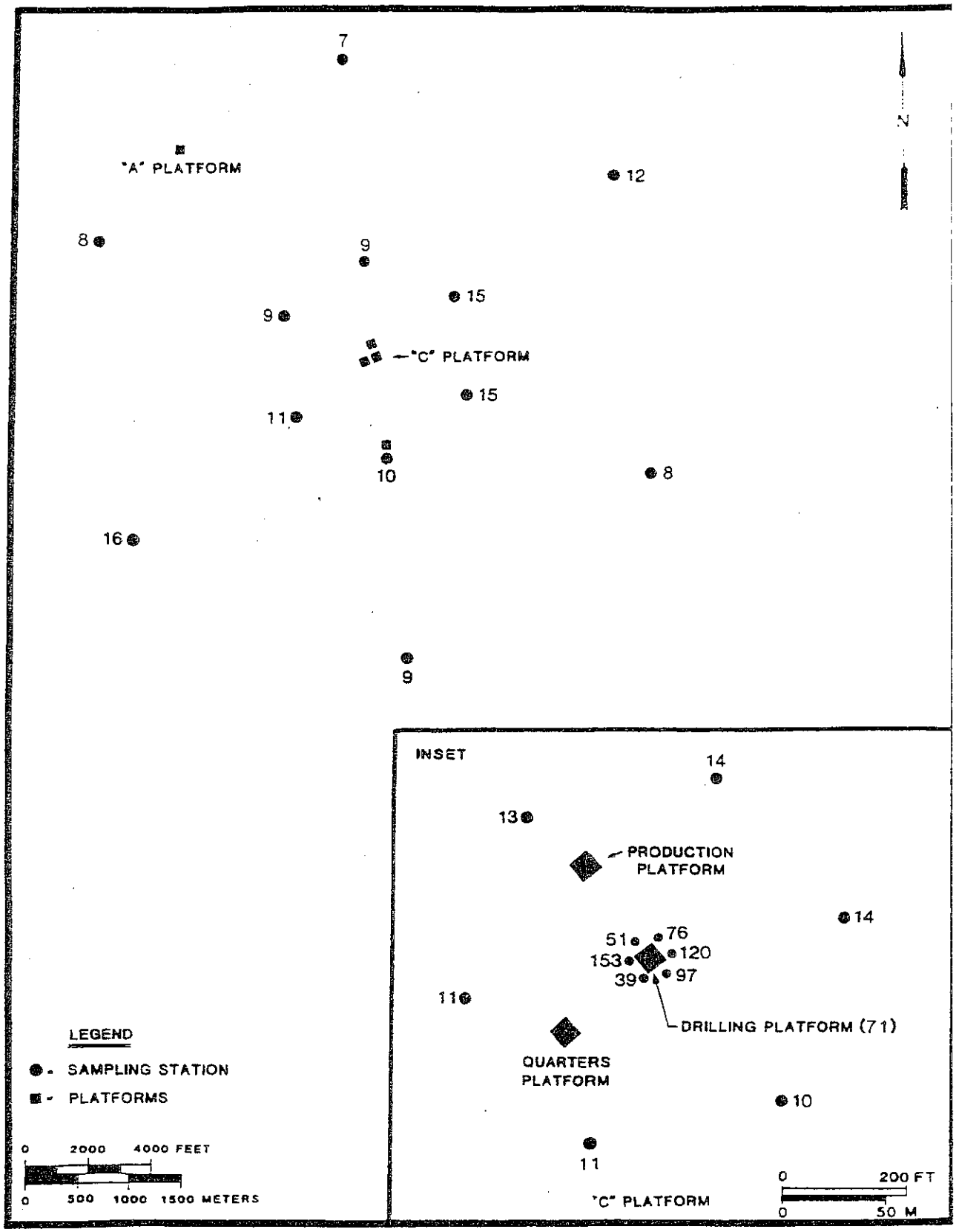


Figure 29. Spatial distribution of mean unresolved complex mixture >n-C_{23} concentrations (ppm) observed during Cruise 1.

(> 10 m) were predominantly composed of compounds more volatile than n-C_{23} (Table 12).

The total n-alkane distribution was very similar to EOM and UCM distributions. Again, concentrations were an order of magnitude higher at stations located at the discharge site and 10 m away (Figure 27), and higher concentrations were observed to the south and southwest of the platform (Figure 30). Similar distributions were also seen in most of the individual n-alkane measurements (Table 13).

3.4.2 Phase II

During Phase II, three replicate samples were collected at 19 stations for hydrocarbon analysis (Figure 4). Compared to Phase I, the analytical protocol was more complex in Phase II, i.e., not only were the EOM and aliphatic hydrocarbon concentrations measured in Phase II, but PAH concentrations were also determined. The PAH have little or no biogenic source and are derived either from thermogenic (oil-related) or pyrogenic (combusted-related, e.g., automobile exhaust, fires, etc.) sources.

Extractable Organic Matter

Average sediment EOM concentrations at 10 m were 232 and 276 ppm during Cruises 2 and 3, respectively, compared with 535 ppm during Cruise 1 (Table 14). The more closely spaced sampling clearly showed that elevated EOM concentrations extended to the 25-m distance from the platform in the east and west directions, but not the south (Figures 31 and 32). The same pattern at 25 m was observed during both samplings, no doubt reflecting the east or west transport of the drilling effluent constituents. There was more variation in the background levels (≥75 m distant) during Cruises 2 and 3, but the concentrations at these stations were generally similar to those concentrations observed during Cruise 1. EOM concentrations were higher at all stations during Cruise 3, possibly a result of increased water column biological productivity input to the sediments during this period.

Aliphatic Hydrocarbons

Alkane distributions during Cruises 2 and 3 were primarily due to biogenic hydrocarbons. Examination of the Cruise 2 UCM distributions revealed: 1) an UCM dominated by compounds > n-C_{23} (Table 14); 2) elevated UCM levels at 10- and 25-m distances from the platform; 3) concentrations three times higher than observed during Cruise 1 at the contaminated stations at ≤25 m; 4) slightly higher concentrations at the background stations compared to Cruise 1; and 5) a pattern of contamination at the 25-m distance restricted to the stations directly east and west of the platform. There was considerably more variability in the UCM distributions during Cruise 3 than during the previous two samplings. The average total UCM at 10 m was 852 ppm compared to 280 and 100 ppm during Cruises 2

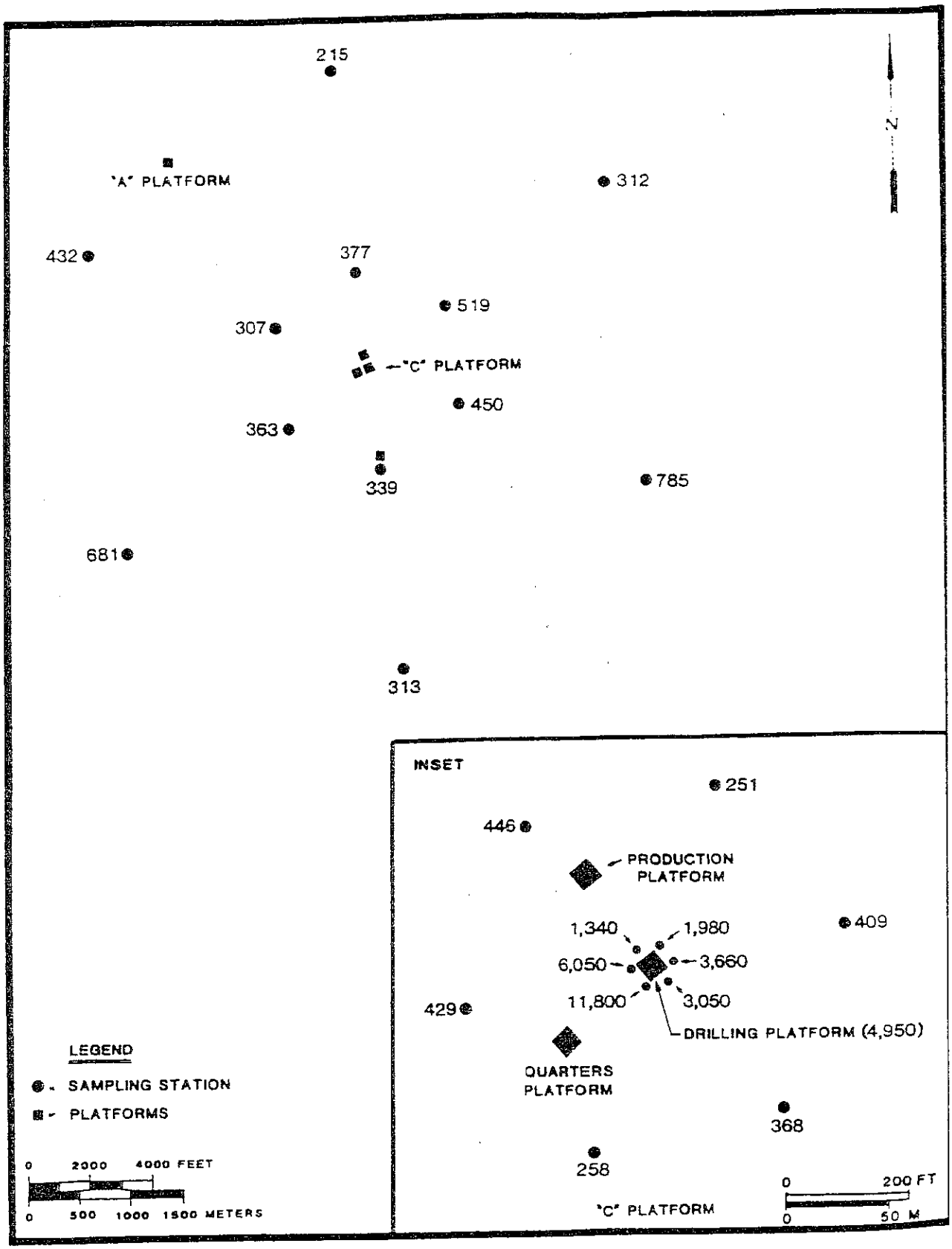


Figure 30. Spatial distribution of mean total alkane concentrations (ppb) observed during Cruise 1.

Table 13. Mean Cruise 1 concentrations of normal alkanes (ppb) with distance from the platform.

Normal Alkane	Distance (m)				
	0	10	100	1,000	3,000
$n\text{-}C_{15}$	302	490	6	2	2
$n\text{-}C_{16}$	385	504	9	11	9
$n\text{-}C_{17}$	614	611	25	15	15
Pristane	468	518	15	10	8
$n\text{-}C_{18}$	526	579	25	16	13
Phytane	263	309	10	6	5
$n\text{-}C_{19}$	498	437	21	11	10
$n\text{-}C_{20}$	334	231	19	13	14
$n\text{-}C_{21}$	226	161	24	50	47
$n\text{-}C_{22}$	159	106	10	5	3
$n\text{-}C_{23}$	110	81	11	7	8
$n\text{-}C_{24}$	66	45	7	7	5
$n\text{-}C_{25}$	63	63	8	13	9
$n\text{-}C_{26}$	34	28	7	11	8
$n\text{-}C_{27}$	29	45	12	21	17
$n\text{-}C_{28}$	65	81	7	11	8
$n\text{-}C_{29}$	15	44	14	35	26
$n\text{-}C_{30}$	33	48	4	9	7
$n\text{-}C_{31}$	748	244	123	134	241
$n\text{-}C_{32}$	9	25	4	5	3

Table 14. Mean concentrations of extractable organic matter, unresolved complex mixture, and total alkanes with distance from the discharge site as observed during Cruises 2 and 3.

Distance (m)	Cruise	EOM* (ppm)	UCM§ $<n\text{-}C_{23}$ (ppm)	UCM $>n\text{-}C_{23}$ (ppm)	Total UCM (ppm)	Total Alkanes (ppb)
10	2	232	84	196	280	7,420
	3	276	229	623	852	20,720
25	2	148	53	107	160	5,025
	3	164	83	314	396	8,599
75	2	41	13	34	46	2,566
	3	48	77	252	329	5,916
150	2	48	12	37	50	1,348
	3	66	29	73	102	1,694
300	2	54	7	30	38	1,314
	3	78	16	48	64	1,185
750	2	43	7	29	36	595
	3	94	145	311	456	11,975
3,000	2	58	4	22	25	822
	3	85	19	58	77	1,196
5,000	2	70	19	61	80	5,071
	3	83	9	23	32	750

* Extractable organic matter.
§ Unresolved complex mixture.

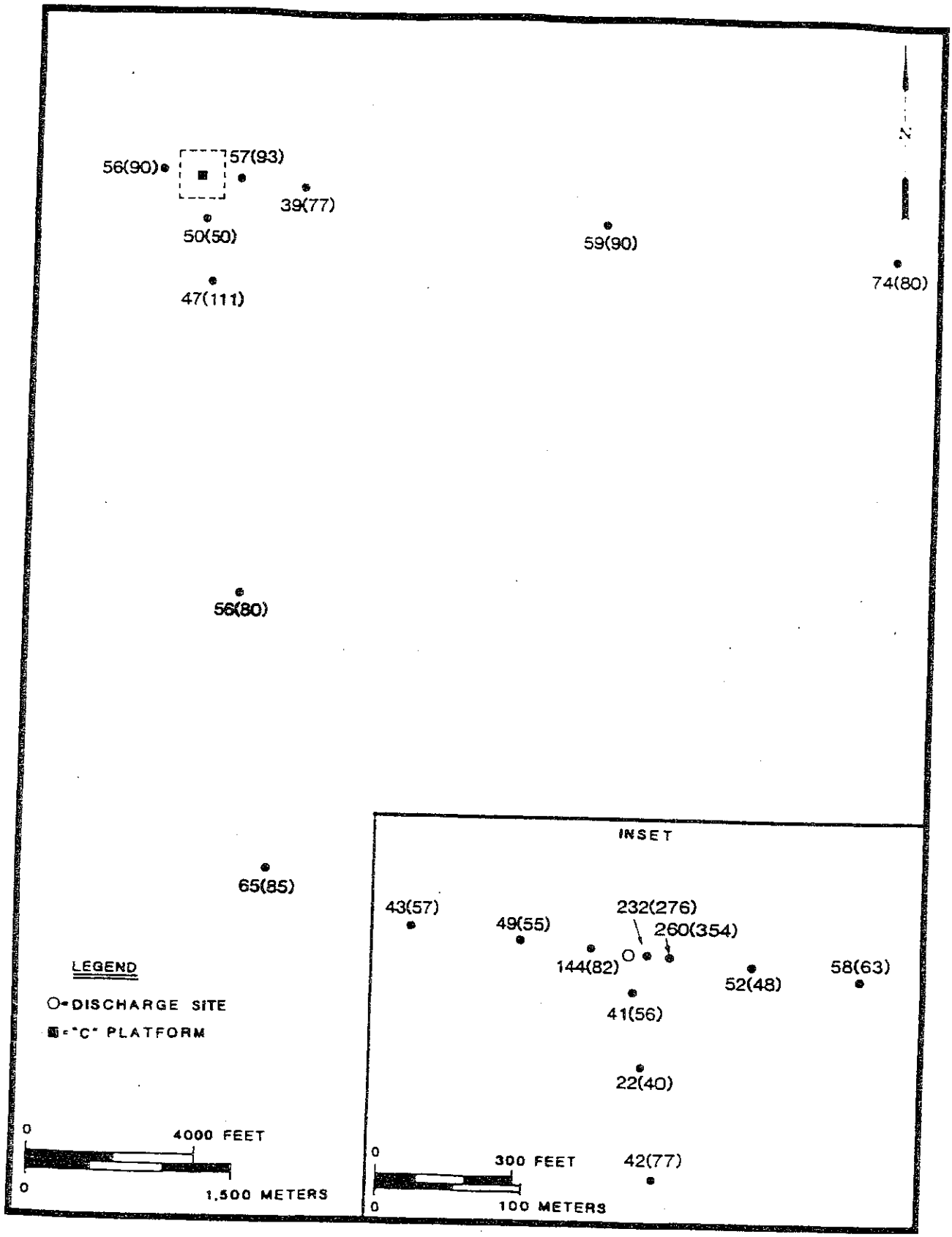


Figure 31. Spatial distribution of mean extractable organic matter concentrations (ppm) observed during Cruises 2 and 3. Cruise 3 concentrations are in parentheses.

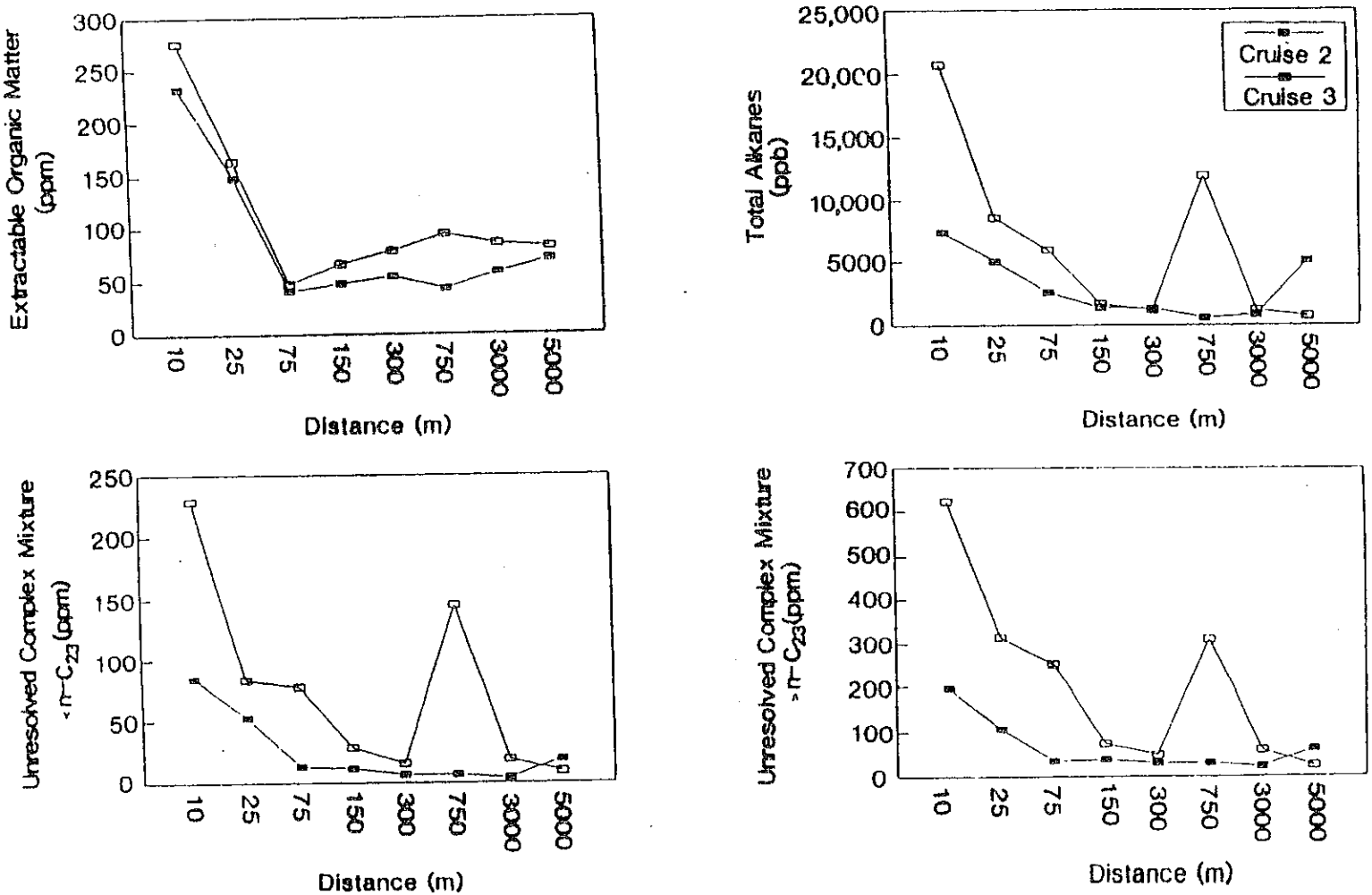


Figure 32. Mean concentrations of extractable organic matter, total alkanes, and unresolved complex mixture with distance from the discharge site as observed during Cruises 2 and 3.

and 1, respectively. However, higher UCM concentrations were observed during Cruise 3 at most stations, no doubt reflecting other contamination or a large biological lipid input during this period (e.g., phytoplankton bloom). Because the UCM is only semiquantitative, the UCM concentrations are often higher than the EOM (especially at higher concentrations). Thus, the UCM only provides relative distributions of this complex hydrocarbon component. During Cruise 3, elevated UCM concentrations were observed at 25 m to the south of the platform in addition to the elevated levels to the east and west as observed during the other samplings. In general, the UCM was significantly greater at all stations during Cruise 3 with a large anomaly observed at 750 m south of the platform (Table 14; Figures 32 to 34).

Patterns similar to the UCM were observed for total n-alkanes (Figures 32 and 35). Elevated levels were observed at 10 and 25 m during Cruise 2 and at 10, 25, and 75 m during Cruise 3. There was considerable biological interferences in n-alkane concentrations during Cruises 2 and 3.

Aromatic Hydrocarbons

Aromatic hydrocarbon distributions are derived almost exclusively from thermogenic or pyrogenic hydrocarbons. Thus, there is less potential for biological hydrocarbon interferences when attempting to trace the distribution of anthropogenic hydrocarbon contamination in the sediments. Distributions of aromatic hydrocarbons determined during Cruises 2 and 3 are presented in Tables 15 and 16. These are aromatic compounds composed of 2-, 3-, 4-, and 5-ring compounds.

As indicated by most parameters [total PAH (Figures 36 and 37); 2-, 3-, and 4-ring PAH (Figure 38); naphthalene, phenanthrene, biphenyl, and anthracene (Figure 39)], elevated PAH concentrations were restricted to ≤25 m of the platform. The background total PAH concentration at >25 m from the platform was 29.4 ± 27.8 ppb (mean ± standard deviation) compared to an average 494 ± 251 and 757 ± 1,818 ppb at 10 and 25 m, respectively, during Cruises 2 and 3 (Table 15). There was some evidence of PAH contamination at the southern and eastern 75-m stations during Cruise 3 (especially the 2- and 3-ring aromatics). PAH concentrations measured during Cruises 2 and 3 showed general agreement. This reflected the smaller influence of the biological activity in the area than was observed for the aliphatic hydrocarbons.

The contaminated sediment PAH concentrations (≤25 m) were clearly dominated by the 2-ring aromatics (Figure 38, Table 15), whereas sediments at distances >25 m were dominated by the 4- and 5-ring aromatic hydrocarbons. This reflected: 1) the high concentrations of 2- to 4-ring aromatics and low concentrations of 5-ring aromatics in the petroleum or drill cutting contamination from the platform; and 2) the domination of background PAH distributions by the less biodegradable 4- and 5-ring aromatics. No influence of the platform on the 5-ring aromatic hydrocarbon distributions was evident, specifically, in the vicinity of the platform (Figure 38).

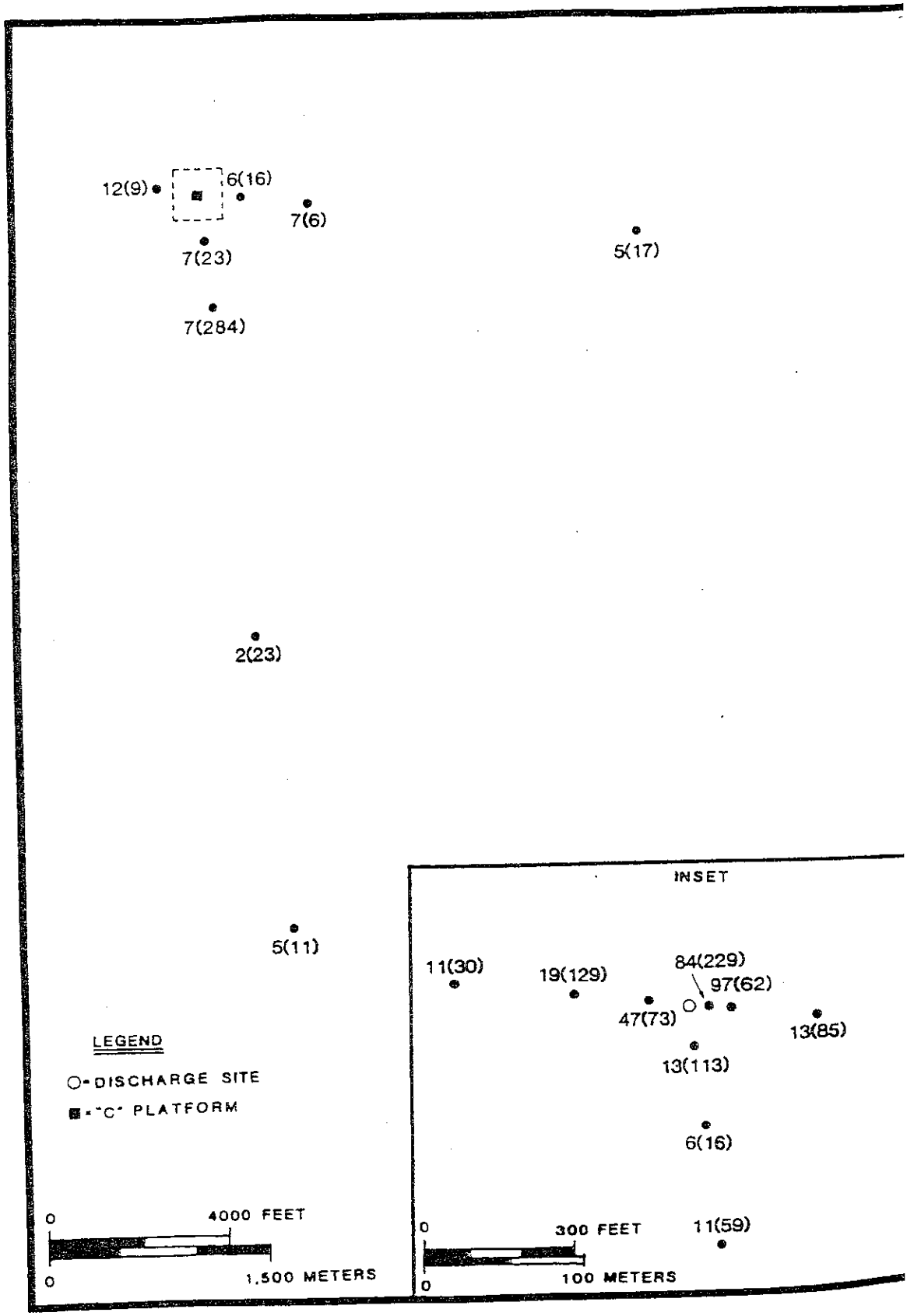


Figure 33. Spatial distribution of mean unresolved complex mixture $<n\text{-}C_{23}$ concentrations (ppm) observed during Cruises 2 and 3. Cruise 3 concentrations are in parentheses.

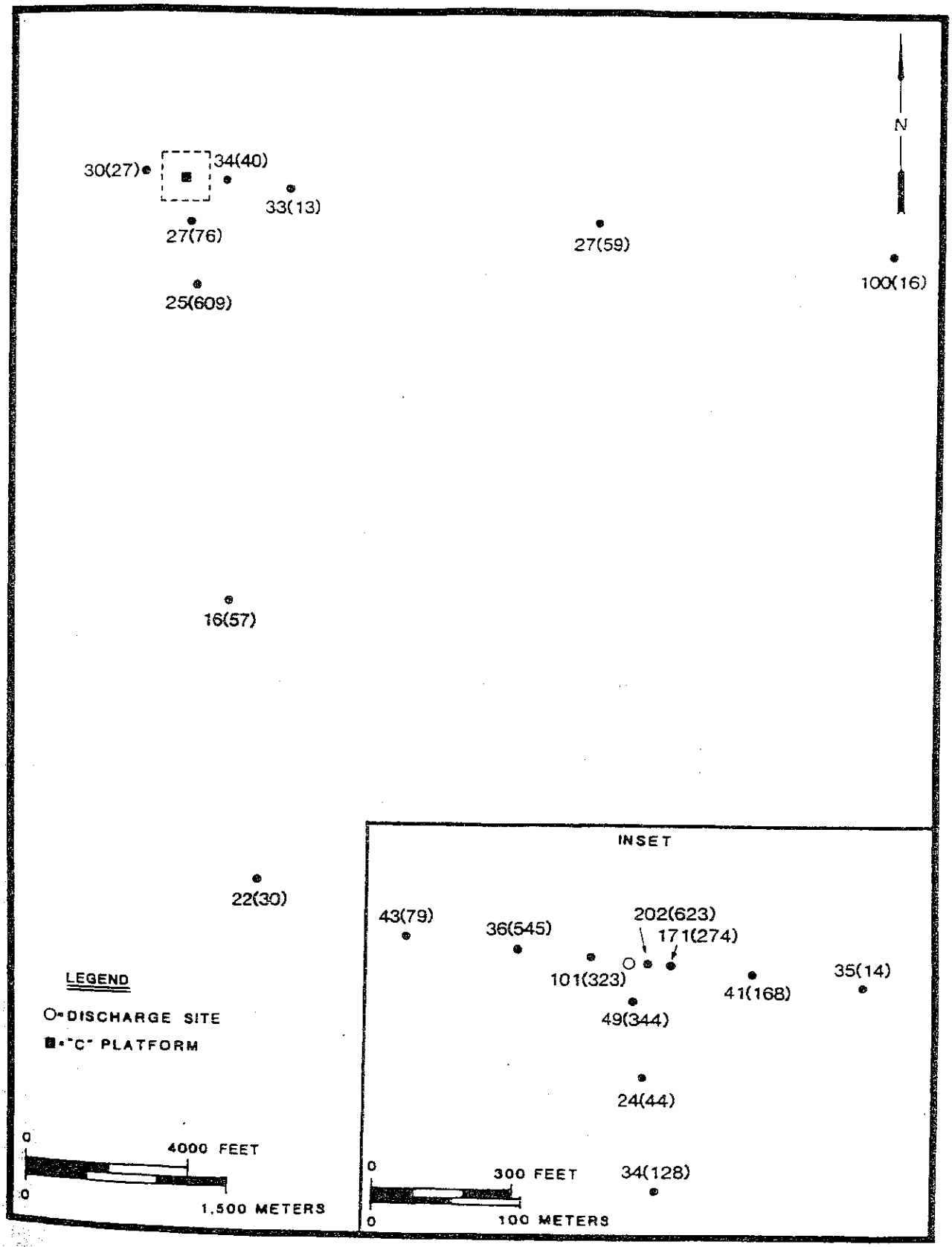


Figure 34. Spatial distribution of mean unresolved complex mixture >n-C_{23} concentrations (ppm) observed during Cruises 2 and 3. Cruise 3 concentrations are in parentheses.

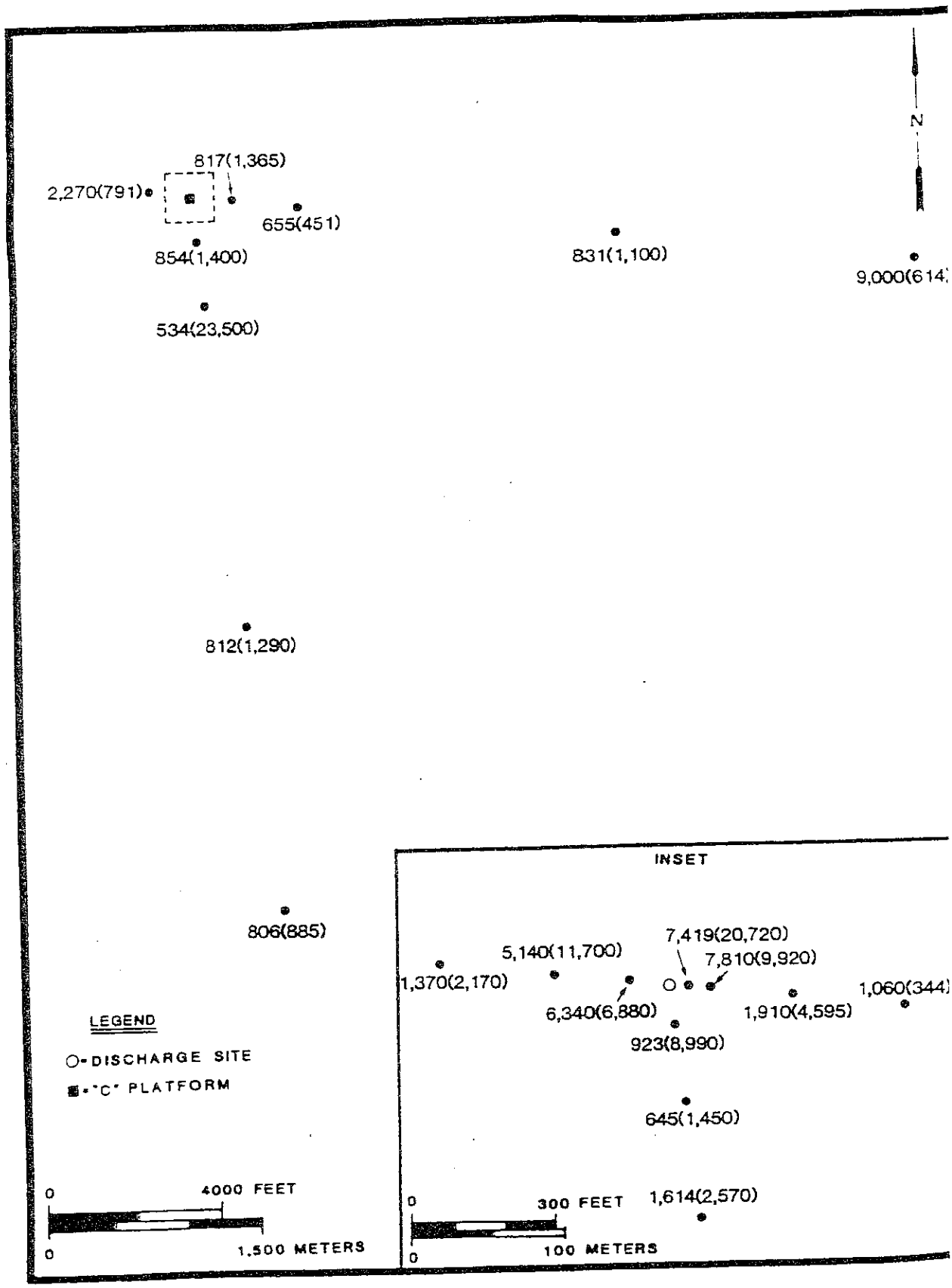


Figure 35. Spatial distribution of mean total alkane concentrations (ppb) observed during Cruises 2 and 3. Cruise 3 concentrations are in parentheses.

Table 15. Polynuclear aromatic hydrocarbon concentrations (ppb) observed during Phase II.

Aromatic Compounds	Cruises 2 and 3 10 m from Platform*	Cruises 2 and 3 25 m from Platform§	Cruises 2 and 3 >25 m from Platform¶
Naphthalene	54.7 ± 28.6	61.9 ± 96.6	3.2 ± 7.1
Methylnaphthalenes	50.4 ± 18.3	55.3 ± 73.8	2.0 ± 4.3
Dimethylnaphthalenes	112 ± 133	70.5 ± 94.3	0.6 ± 3.7
Trimethylnaphthalenes	66.6 ± 112	41.1 ± 95.5	0.5 ± 3.5
Biphenyl	43.5 ± 29.6	46.9 ± 71.3	0.3 ± 1.8
Fluorene	9.9 ± 6.5	21.6 ± 59.9	0.0 ± 0.0
Fluoranthene	12.1 ± 11.2	45.7 ± 175	1.8 ± 4.6
Acenaphthene	1.4 ± 3.5	32.1 ± 122	0.0 ± 0.0
Acenaphthylene	0.0 ± 0.0	1.1 ± 2.5	0.0 ± 0.0
Phenanthrene	60.8 ± 27.6	116 ± 345	1.5 ± 6.0
Anthracene	0.0 ± 0.0	19.5 ± 81.4	0.1 ± 0.6
Methyl phenanthrenes	21.9 ± 15.8	21.8 ± 31.4	0.4 ± 2.5
Pyrene	22.5 ± 10.7	41.0 ± 140	2.8 ± 4.5
Benz(a)anthracene	8.7 ± 7.0	54.8 ± 213	1.4 ± 2.7
Chrysene	13.8 ± 7.2	26.8 ± 87.6	2.7 ± 3.8
Benzofluoranthene	7.5 ± 12.6	57.0 ± 236	1.6 ± 3.4
Benzo(e)pyrene	0.0 ± 0.0	29.7 ± 119	3.1 ± 6.5
Benzo(a)pyrene	5.4 ± 13.3	22.1 ± 90.8	0.7 ± 2.1
Dibenzanthracene	0.0 ± 0.0	3.4 ± 14.2	0.3 ± 1.3
Benzo(g,h,i)perylene	5.1 ± 8.8	20.4 ± 82.5	0.9 ± 2.2
Indenopyrene	0.0 ± 0.0	23.5 ± 97.8	2.4 ± 7.8
Perylene	4.8 ± 8.7	9.6 ± 26.7	5.2 ± 7.7
Total 2-ring	332 ± 207	313 ± 427	7.2 ± 16.3
Total 3-ring	72.2 ± 34.8	189 ± 607	1.6 ± 6.1
Total 4-ring	79.0 ± 32.7	190 ± 630	9.1 ± 11.7
Total 5-ring	10.2 ± 16.8	64.8 ± 250	9.3 ± 12.3
Total PAH	494 ± 251	757 ± 1818	29.4 ± 27.8

* Averages represent one station x two samplings x three replicates, six analyses.

§ Averages represent three stations x two samplings x three replicates, 18 analyses.

¶ Averages represent 15 stations x 2 samplings x 3 replicates, 90 analyses.

Table 16. Mean concentrations of aromatic compounds with distance from the discharge site.

Compound (ppb)	Cruise	Distance (m)							
		10	25	75	150	300	750	3,000	5,000
Naphthalene	2	36	47	5	4	2	3	1	0
	3	43	53	16	8	1	4	2	0
2-methyl naphthalene	2	55	68	7	2	0	0	0	0
	3	62	75	4	0	0	4	2	0
1-methyl naphthalene	2	37	49	6	3	2	5	2	0
	3	45	55	3	0	0	3	1	0
Biphenyl	2	28	32	3	0	0	0	0	0
	3	26	56	3	0	0	2	1	0
2,6 dimethyl naphthalene	2	49	60	5	1	0	0	0	0
	3	50	99	5	0	0	4	2	0
Acenaphthylene	2	0	0	0	0	0	0	0	0
	3	0	2	0	0	0	0	0	0
Acenaphthene	2	0	4	0	0	0	0	0	0
	3	0	4	0	0	0	0	0	0
2,3,4 trimethyl naphthalene	2	0	0	0	0	0	0	0	0
	3	38	65	3	0	0	4	2	0
Fluorene	2	11	10	0	0	0	0	0	0
	3	5	9	0	0	0	0	0	0
Phenanthrene	2	49	47	4	1	3	2	0	0
	3	48	41	2	0	3	8	4	1
Anthracene	2	0	0	0	0	0	0	0	0
	3	0	1	0	0	1	0	0	0
1-methyl phenanthrene	2	17	17	1	0	0	0	0	0
	3	11	27	2	0	0	2	1	3
Fluoranthrene	2	13	6	1	0	4	3	0	1
	3	3	2	0	2	5	1	2	4
Pyrene	2	25	12	1	0	4	2	1	5
	3	15	7	1	2	6	4	5	4
Benz(a)anthracene	2	9	6	3	2	2	4	1	0
	3	2	4	0	0	0	0	0	0
Chrysene	2	10	6	1	0	2	1	0	1
	3	7	8	4	6	6	5	5	6
Benzofluoranthrene	2	0	0	0	0	0	0	0	0
	3	5	4	0	3	2	2	4	4
Benzo(e) pyrene	2	0	1	2	5	4	8	11	15
	3	2	4	0	0	0	0	1	1
Benzo(a) pyrene	2	0	0	3	3	2	0	1	1
	3	1	1	0	0	0	0	0	0
Perylene	2	11	6	3	12	6	6	8	6
	3	3	4	1	3	0	6	5	2
Indenopyrene	2	0	0	0	0	0	0	0	0
	3	0	1	3	8	1	0	16	4
Dibenzo anthracene	2	0	0	0	0	1	1	1	0
	3	0	0	0	0	0	0	0	0
Benzo(ghi) perylene	2	0	0	0	0	0	0	0	0
	3	10	4	0	3	0	2	2	2
Total PAH	2	347	372	44	52	36	35	31	39
	3	327	451	41	22	22	41	30	21
2-ring PAH	2	205	255	27	9	4	8	2	0
	3	225	338	30	8	1	16	7	1
3-ring PAH	2	59	61	4	1	3	2	0	0
	3	52	55	3	0	4	8	4	1
4-ring PAH	2	73	48	6	2	11	10	3	7
	3	38	48	7	10	17	11	13	15
5-ring PAH	2	11	8	7	19	13	15	21	22
	3	6	9	1	3	0	6	6	3

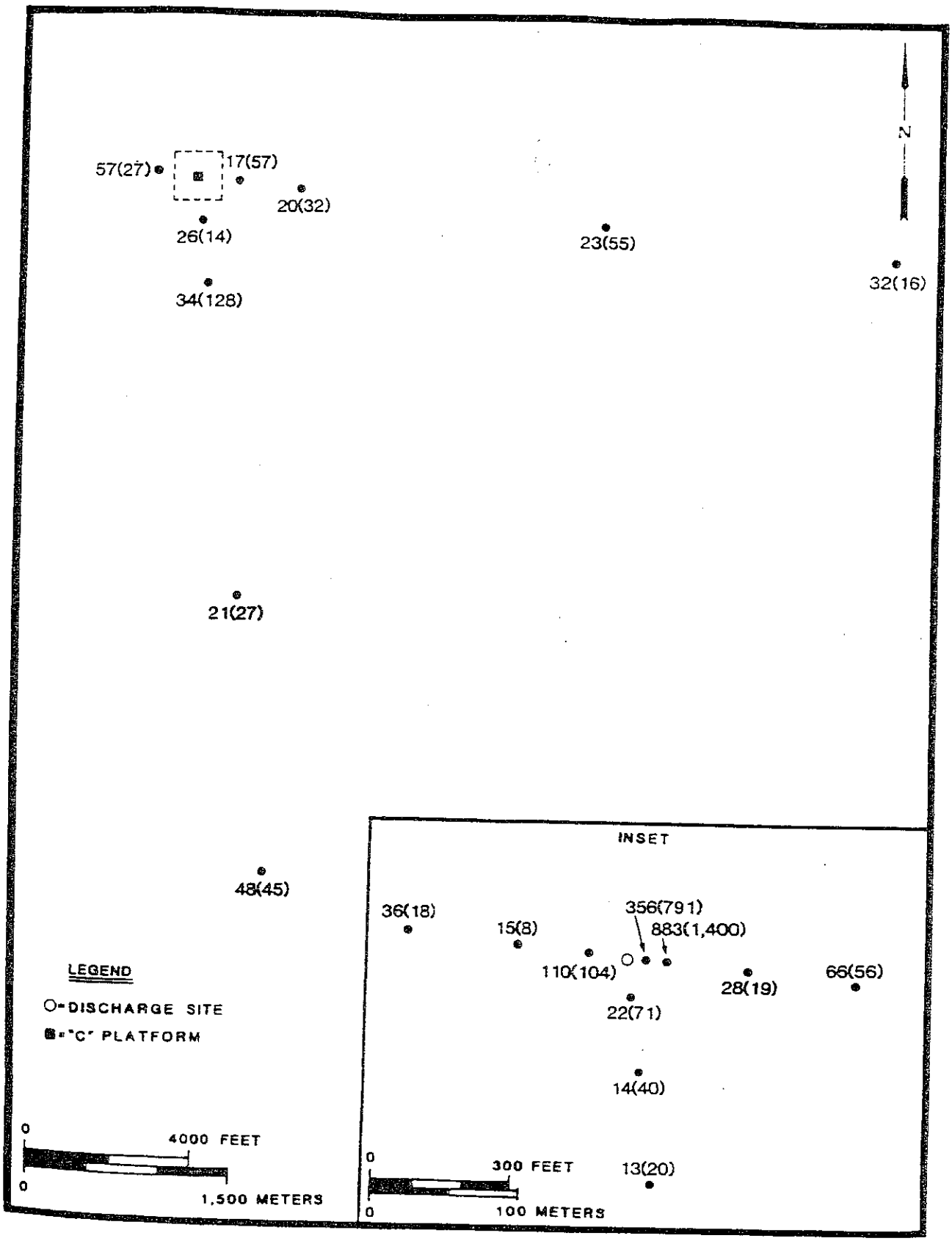


Figure 36. Spatial distribution of mean total polynuclear aromatic hydrocarbon concentrations (ppb) observed during Cruises 2 and 3. Cruise 3 concentrations are in parentheses.

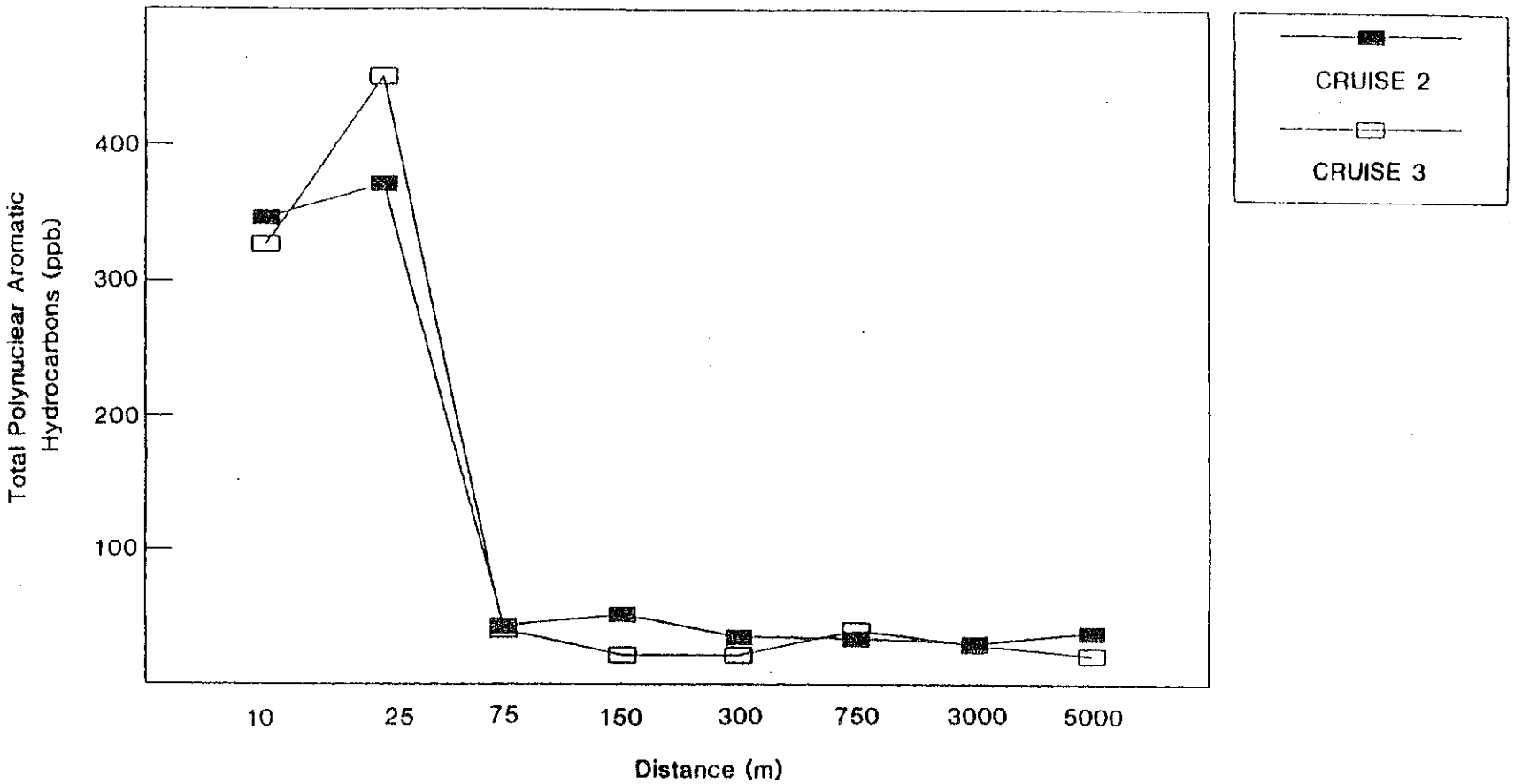


Figure 37. Mean total polynuclear aromatic hydrocarbon concentrations observed during Cruises 2 and 3 with distance from the discharge site.

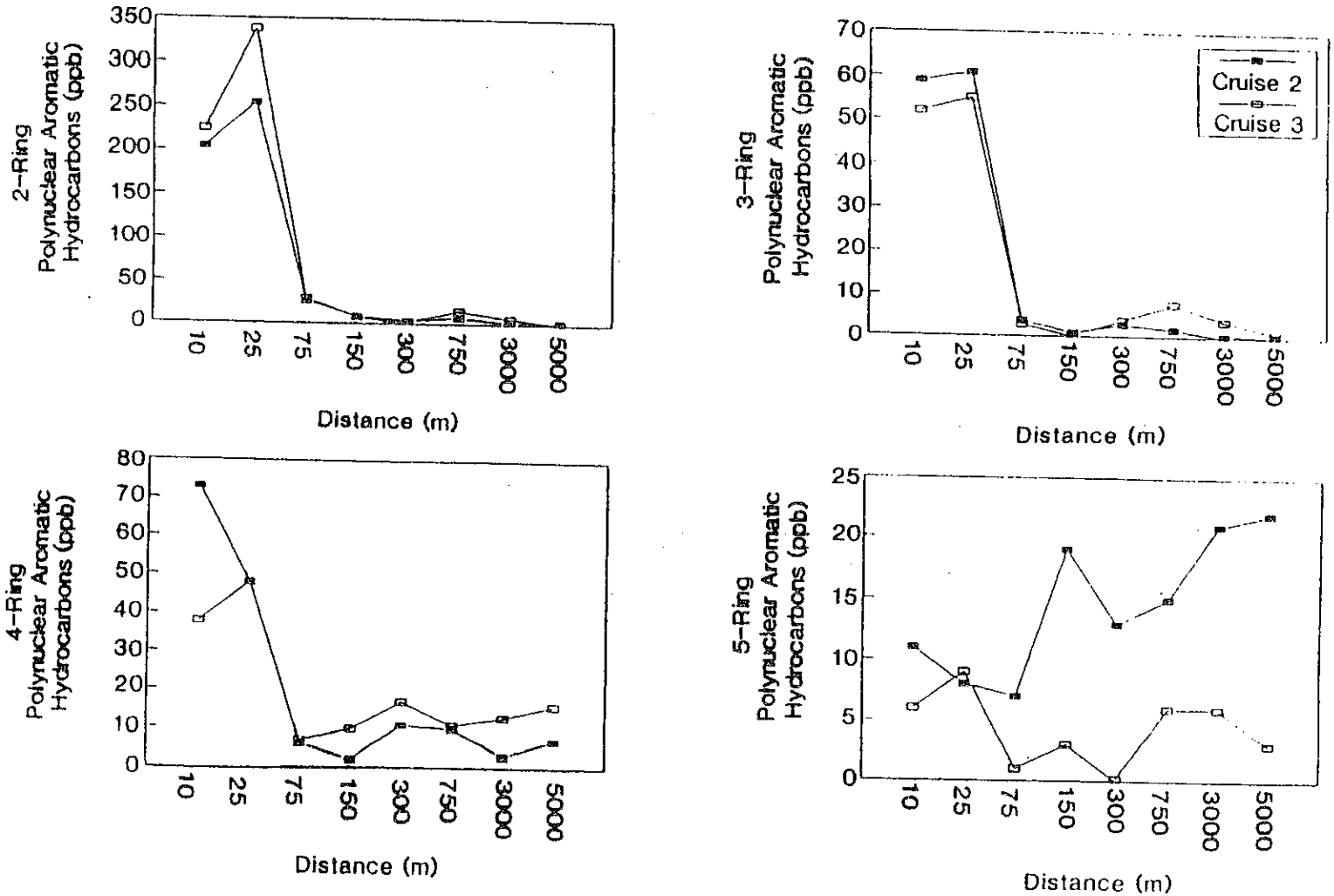


Figure 38. Mean concentrations of 2-, 3-, 4-, and 5-ring polynuclear aromatic hydrocarbons observed during Cruises 2 and 3 with distance from the discharge site.

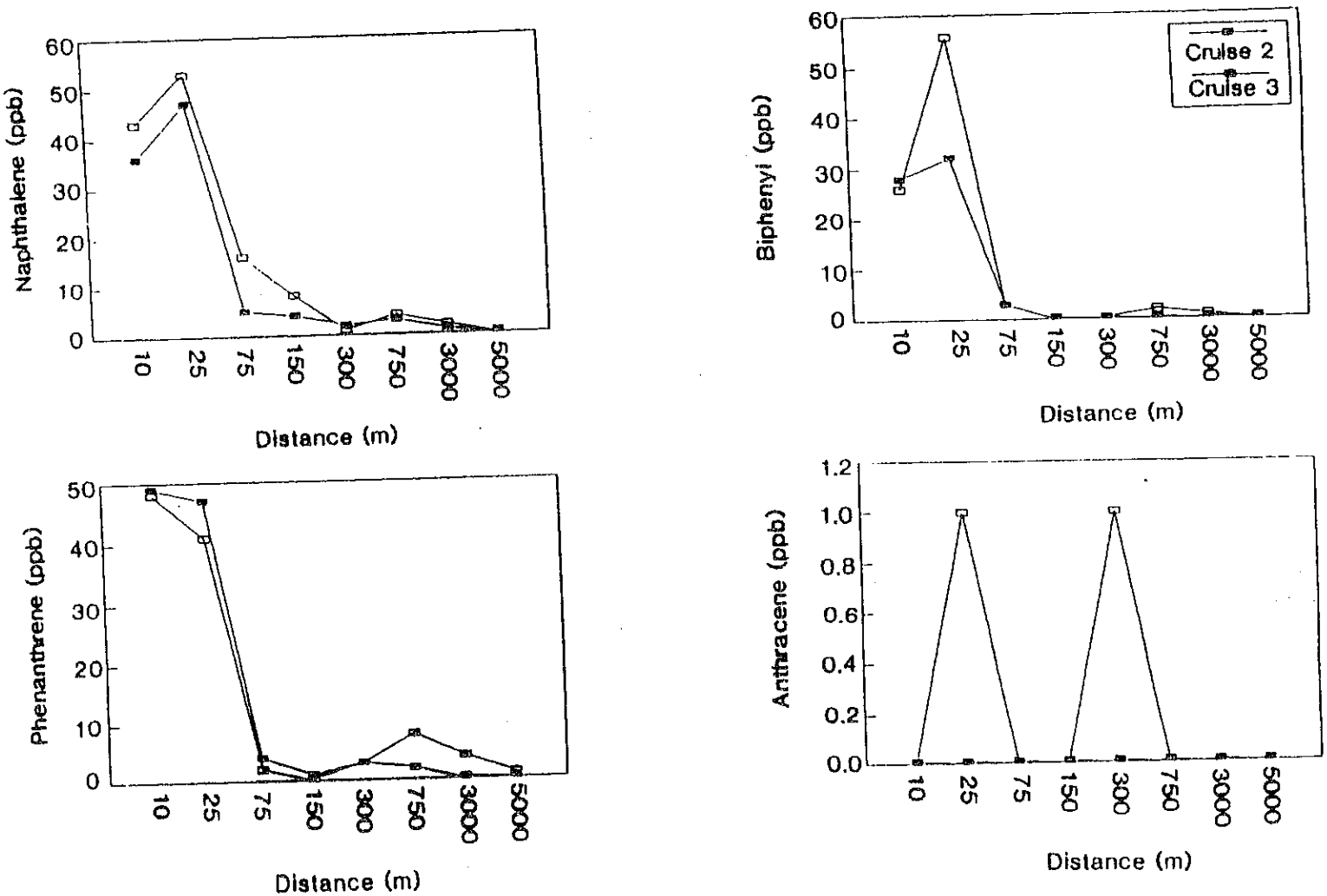


Figure 39. Mean concentrations of naphthalene, phenanthrene, biphenyl, and anthracene observed during Cruises 2 and 3 with distance from the discharge site.

3.4.3 Comparison with Estuarine Status and Trends Mussel Watch Stations

One way to assess the significance of hydrocarbon contamination from this platform is to compare the PAH concentrations with the NOAA S&T Mussel Watch stations in the estuaries and bays adjacent to the offshore platform site. The S&T Mussel Watch program was established to determine the long-term temporal and spatial trends of selected environmental contaminant concentrations in bays and estuaries. Sampling sites for the S&T program were specifically chosen to avoid known point sources of contaminant input and generally represent fine-grained sediments. The S&T program represents the most extensive and highest quality data base for contaminant concentrations yet produced for Gulf of Mexico coastal areas.

The PAH contaminant levels detected in Gulf of Mexico estuaries are generally lower than those on the east and west coasts, probably because the Gulf of Mexico samples are generally far removed from point sources of inputs which is harder to achieve on the other coasts. Eleven S&T Mussel Watch sites that were selected for comparison of PAH contamination are shown in Figure 40. Analyses of three oyster and three sediment samples at each of the stations were conducted during the S&T Mussel Watch program. The sediment data from the S&T program is compared below with the sediments from the present study. Similar methodologies were employed for the S&T program and this study.

Average total PAH concentrations for the 1986 and 1987 Mussel Watch sediment sites were 510 and 590 ppb with ranges of <5 to 36,700 and <5 to 10,692 ppb, respectively. The average total PAH concentration for the 11 sites nearest to the site of this study averaged 96.4 ± 112 ppb (Table 17, Figure 41). The sediment PAH distributions in the S&T study, based on ring size of the aromatic compounds, were dominated by the 4-ring PAH accounting for 42 to 60% of the total PAH (Figure 42, Table 17). The 5-ring aromatics also accounted for a substantial percentage of the sediment PAH. Very few 2- and 3-ring PAH were found in typical S&T Mussel Watch stations. The average 4- and 5-rings to the 2- and 3-rings PAH for Gulf of Mexico sites was 3.8, indicating a predominance of higher molecular weight compounds in the sediments. This is reflected in the PAH ring number distribution for the 11 Texas stations shown in Figure 42. The 4- and 5-ring predominance was attributed to the loss of the more water soluble lower molecular weight PAH from the sediments by dissolution and/or preferential biodegradation.

Only the sites at 10 and 25 m are as contaminated as the Texas coastal sites (Table 17). The background PAH levels in the offshore coastal area (>25 m from the platform) are considerably less than the estuarine and bay PAH concentrations. The background sites (>25 m) in this area of the Gulf are about three times less contaminated with respect to total PAH concentrations than the S&T estuarine sites. Average sediment total PAH concentrations were 96.4 ± 112, 494 ± 251, and 757 ± 1,818 ppb at the 11 S&T sites and at the 10 and 25 m platform sites, respectively.

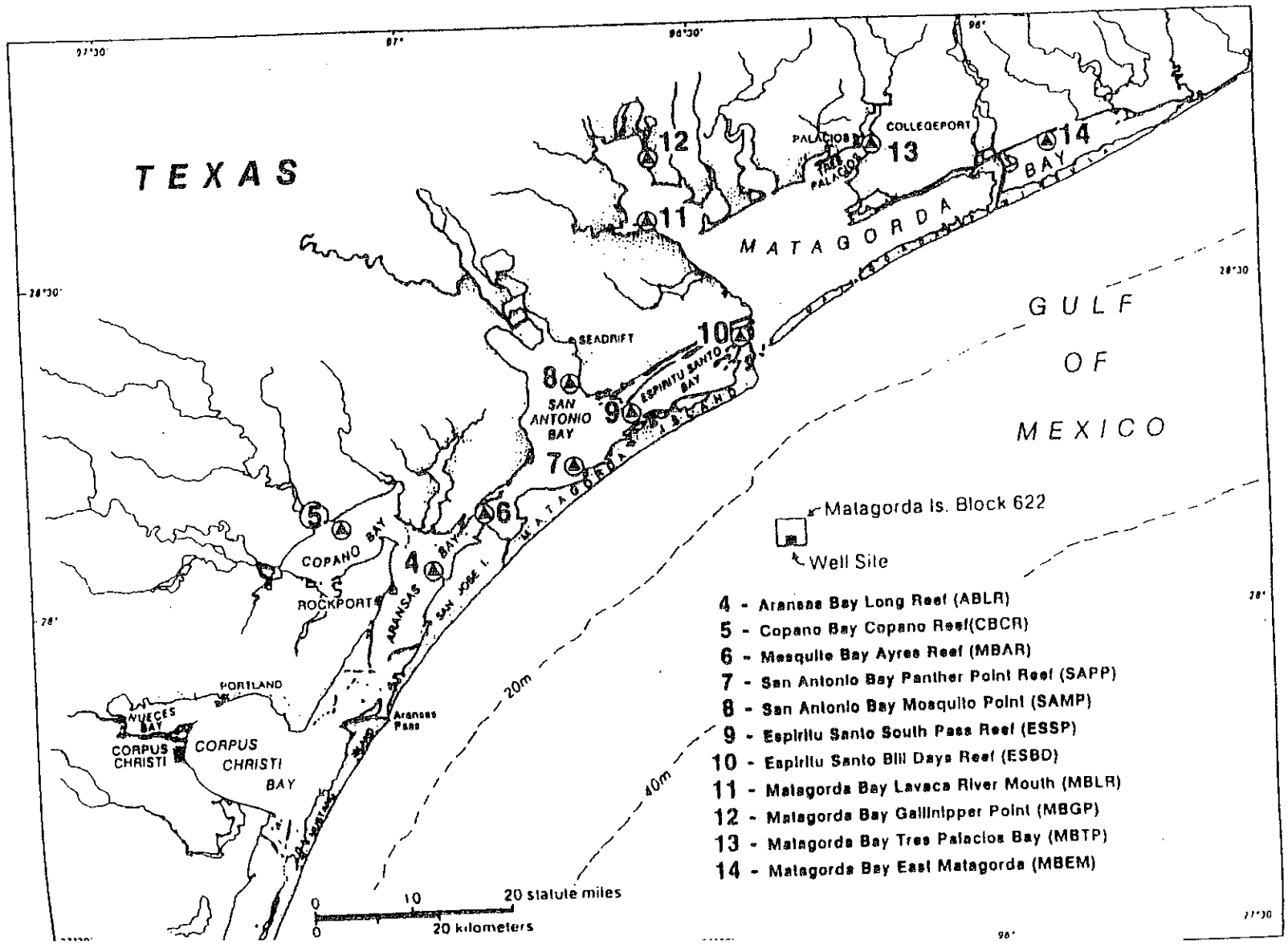

TEXAS
GULF
OF
MEXICO
MATAGORDA
BAY
MATAGORDA
ISLAND
SEADRIFT
SAN
ANTONIO
BAY
ESPIRITU SANTO
BAY
COPANO BAY
ROCKPORT
ARANSAS
BAY
SAN JOSE I.
PORTLAND
NUECES
BAY
CORPUS
CHRISTI
CORPUS
CHRISTI
BAY
Aransas
Pass
PALACIOS
TRES
PALACIOS
COLLEGEPORT
20m
40m
Malagorda Is. Block 622
Well Site
4 - Aransas Bay Long Reef (ABLR)
5 - Copano Bay Copano Reef(CBCR)
6 - Mesquite Bay Ayres Reef (MBAR)
7 - San Antonio Bay Panther Point Reef (SAPP)
8 - San Antonio Bay Mosquito Point (SAMP)
9 - Espiritu Santo South Pass Reef (ESSP)
10 - Espiritu Santo Bill Days Reef (ESBD)
11 - Matagorda Bay Lavaca River Mouth (MBLR)
12 - Matagorda Bay Gallinipper Point (MBGP)
13 - Matagorda Bay Tres Palacios Bay (MBTP)
14 - Matagorda Bay East Matagorda (MBEM)
0 10 20 statute miles
0 20 kilometers

Table 17. Polynuclear aromatic hydrocarbon concentrations (ppb) near "C" Platform and in adjacent estuarines and bays.

Aromatic Compounds	Coastal Estuarine Sites*	Cruises 2 and 3 10 m from Platform§	Cruises 2 and 3 25 m from Platform¶	Cruises 2 and 3 >25 m from Platform†
Naphthalene	2.1 ± 5.8	54.7 ± 28.6	61.9 ± 96.6	3.2 ± 7.1
Methylnaphthalenes	1.0 ± 5.3	50.4 ± 18.3	55.3 ± 73.8	2.0 ± 4.3
Dimethylnaphthalenes	0.3 ± 1.4	112 ± 133	70.5 ± 94.3	0.6 ± 3.7
Trimethylnaphthalenes	0.2 ± 1.0	66.6 ± 112	41.1 ± 95.5	0.5 ± 3.5
Biphenyl	0.0 ± 0.0	43.5 ± 29.6	46.9 ± 71.3	0.3 ± 1.8
Fluorene	0.1 ± 1.1	9.9 ± 6.5	21.6 ± 59.9	0.0 ± 0.0
Fluoranthene	12.8 ± 18.6	12.1 ± 11.2	45.7 ± 175	1.8 ± 4.6
Acenaphthene	0.2 ± 0.9	1.4 ± 3.5	32.1 ± 122	0.0 ± 0.0
Acenaphthylene	0.0 ± 2.5	0.0 ± 0.0	1.1 ± 2.5	0.0 ± 0.0
Phenanthrene	4.2 ± 6.2	60.8 ± 27.6	116 ± 345	1.5 ± 6.0
Anthracene	1.2 ± 3.7	0.0 ± 0.0	19.5 ± 81.4	0.1 ± 0.6
Methyl phenanthrenes	0.0 ± 0.0	21.9 ± 15.8	21.8 ± 31.4	0.4 ± 2.5
Pyrene	13.1 ± 19.5	22.5 ± 10.7	41.0 ± 140	2.8 ± 4.5
Benz(a)anthracene	4.6 ± 8.9	8.7 ± 7.0	54.8 ± 213	1.4 ± 2.7
Chrysene	6.1 ± 9.7	13.8 ± 7.2	26.8 ± 87.6	2.7 ± 3.8
Benzofluoranthene	17.3 ± 20.7	7.5 ± 12.6	57.0 ± 236	1.6 ± 3.4
Benzo(e)pyrene	5.7 ± 9.1	0.0 ± 0.0	29.7 ± 119	3.1 ± 6.5
Benzo(a)pyrene	5.3 ± 9.8	5.4 ± 13.3	22.1 ± 90.8	0.7 ± 2.1
Dibenzanthracene	2.5 ± 5.2	0.0 ± 0.0	3.4 ± 14.2	0.3 ± 1.3
Benzo(g,h,i)perylene	4.9 ± 7.2	5.1 ± 8.8	20.4 ± 82.5	0.9 ± 2.2
Indenopyrene	4.5 ± 6.8	0.0 ± 0.0	23.5 ± 97.8	2.4 ± 7.8
Perylene	34.6 ± 31.8	4.8 ± 8.7	9.6 ± 26.7	5.2 ± 7.7
Total 2-ring	5.9 ± 15.4	332 ± 207	313 ± 427	7.2 ± 16.3
Total 3-ring	5.7 ± 9.5	72.2 ± 34.8	189 ± 607	1.6 ± 6.1
Total 4-ring	36.7 ± 54.2	79.0 ± 32.7	190 ± 630	9.1 ± 11.7
Total 5-ring	48.1 ± 50.3	10.2 ± 16.8	64.8 ± 250	9.3 ± 12.3
Total PAH	96.4 ± 112	494 ± 251	757 ± 1818	29.4 ± 27.8

* Average of PAH concentrations in 11 Texas estuaries adjacent to the offshore, shallow water platform site. Averages represent triplicate analyses at each of the 11 stations.

§ Averages represent one station x two samplings x three replicates, six analyses.

¶ Averages represent three stations x two samplings x three replicates, 18 analyses.

† Averages represent 15 stations x two sampling x three replicates, 90 analyses.

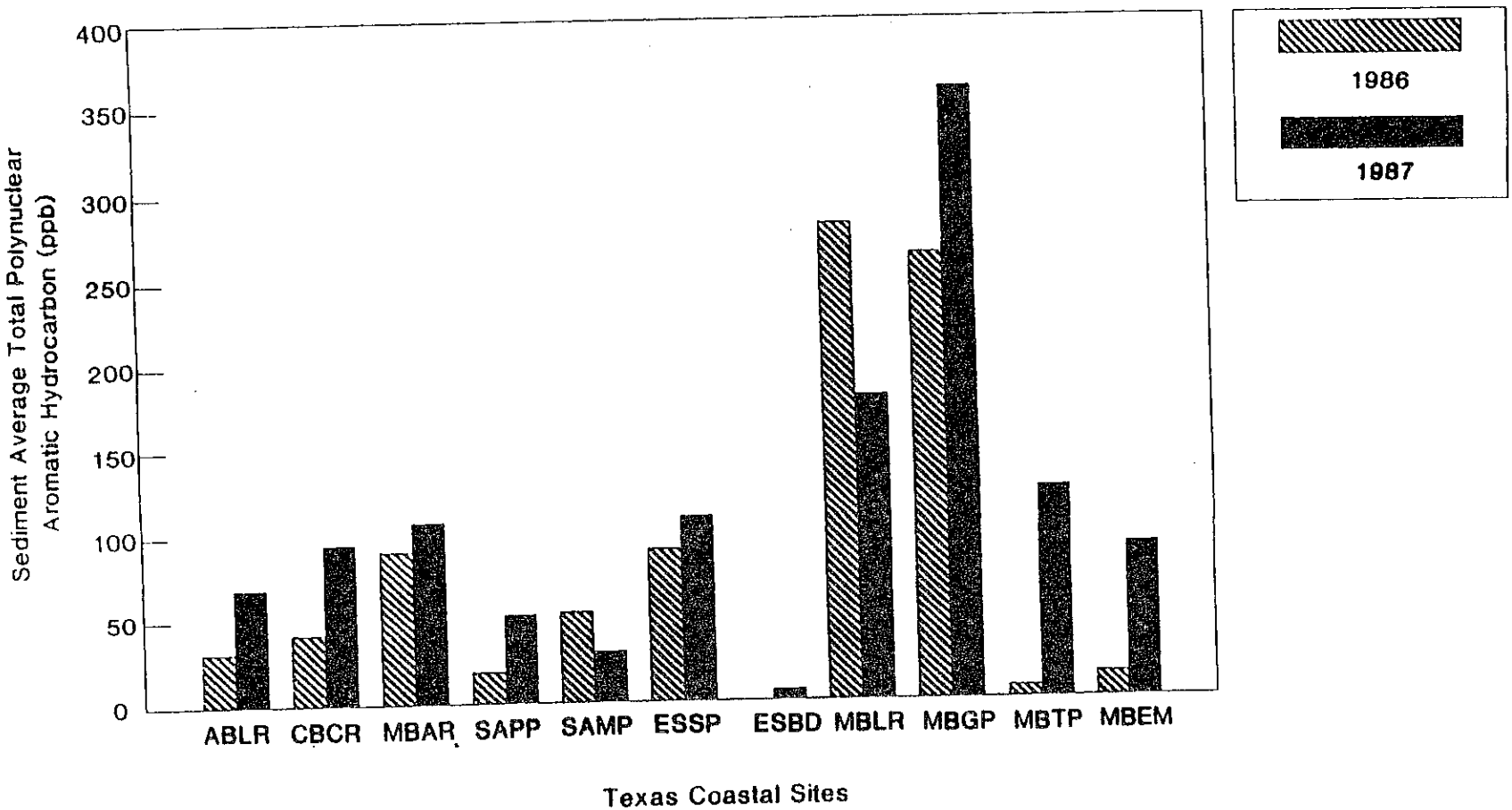


Figure 41. Mean total polynuclear aromatic hydrocarbon concentrations in sediments at the NOAA Status and Trends Mussel Watch stations in coastal Texas. The key to station locations and designations is presented in Figure 40.

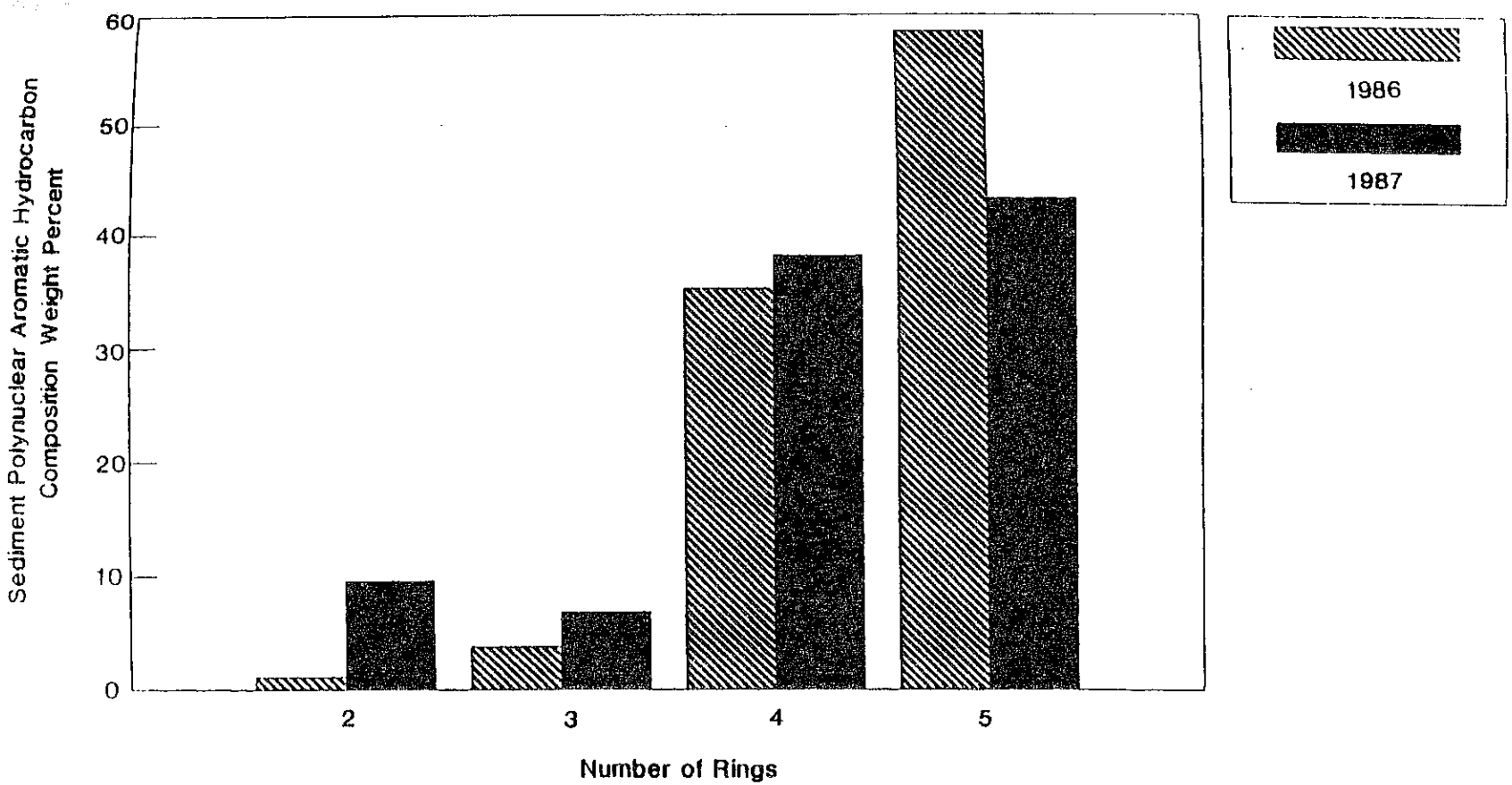


Figure 42. Distribution of aromatic ring numbers in sediments at the NOAA Status and Trends Mussel Watch stations in coastal Texas.

The mean phenanthrene to phenanthrene plus anthracene ratios fo the S&T Mussel Watch sites are plotted in Figure 43. There is little, if an anthracene in most petroleums (i.e., ratio of phenanthrene/anthracene is 50). Th ratios reported for the Gulf S&T Mussel Watch sites range from <1 to a high 6.7. This indicated that fresh petroleum was not the major source of PAH reported. The source of the PAH was more likely due to pyrolysis products various processes including incomplete fossil fuel burning, carbonization of coal a forest fires. Phenanthrene and anthracene are produced by these processe Phenanthrene seems to be lost from sediments more rapidly than anthracen perhaps due to its slightly higher water solubility and/or its higher microb degradation rate.

The ratio of phenanthracene to phenanthracene plus anthracene w distance from the discharge site is presented in Figure 44. Unlike the S&T Mus Watch sites, sediments at all offshore stations were dominated by phenanthre anthracene was detected at only two stations during Cruise 3 (Figure 39). T indicated that nearly all the PAH at the platform are derived from petroleum a not pyrolytic hydrocarbons.

3.5 MACROINFAUNA

3.5.1 Composition, Abundance, and Diversity

The macroinfauna sampling revealed that 305 benthic macroinfa taxa representing 12 phyla were present during the three surveys of this stu Three taxonomic groups--Annelida, Crustacea, and Mollusca--were dominant terms of the numbers of taxa and numbers of individuals. Other important ma taxonomic groups included Echinodermata and Rhynchocoela. Annelids (princi ly, polychaetes) contributed 36.4% of the species present; crustaceans and mollu contributed 34.4% and 21.3% respectively (Table 18). Of the 15,084 individ enumerated, 65.4% were polychaetes, 17.4% were mollusks, and 10.0% w crustaceans. The most abundant species was the polychaete *Paraprionospio pinn* (2,753 individuals; 18.2%); other numerically important taxa were the polycha *Nereis micromma* (919 individuals; 6.1%), *Mediomastus* spp. (770 individuals; 5.1 and *Armandia maculata* (763 individuals; 5.1%). Rhynchocoela (576 individ 3.8%) and the bivalves *Nuculana acuta* (557 individuals; 3.7%) and *Tellina versic* (550 individuals; 3.6%) were also numerically important. Collectively, these s taxa accounted for 45.7% of the total individuals collected.

During Cruise 1, numbers of taxa at individual stations did not ap related to distance from the discharge site (Table 19). For example, 31 taxa sampled at the discharge site during October 1986 while from 24 to 47 taxa present at stations 3,000 m from the discharge site. The mean number of sampled during this cruise was 26, ranging from 7 to 47. The average Cru density was 1,838 individuals m^{-2}, ranging from 281 individuals m^{-2} at Station 52°-1 to 2,725 individuals m^{-2} at Station 3000m-52°-1. Mean densities depressed at three stations located 10 m from the discharge during Cru (Table 19).

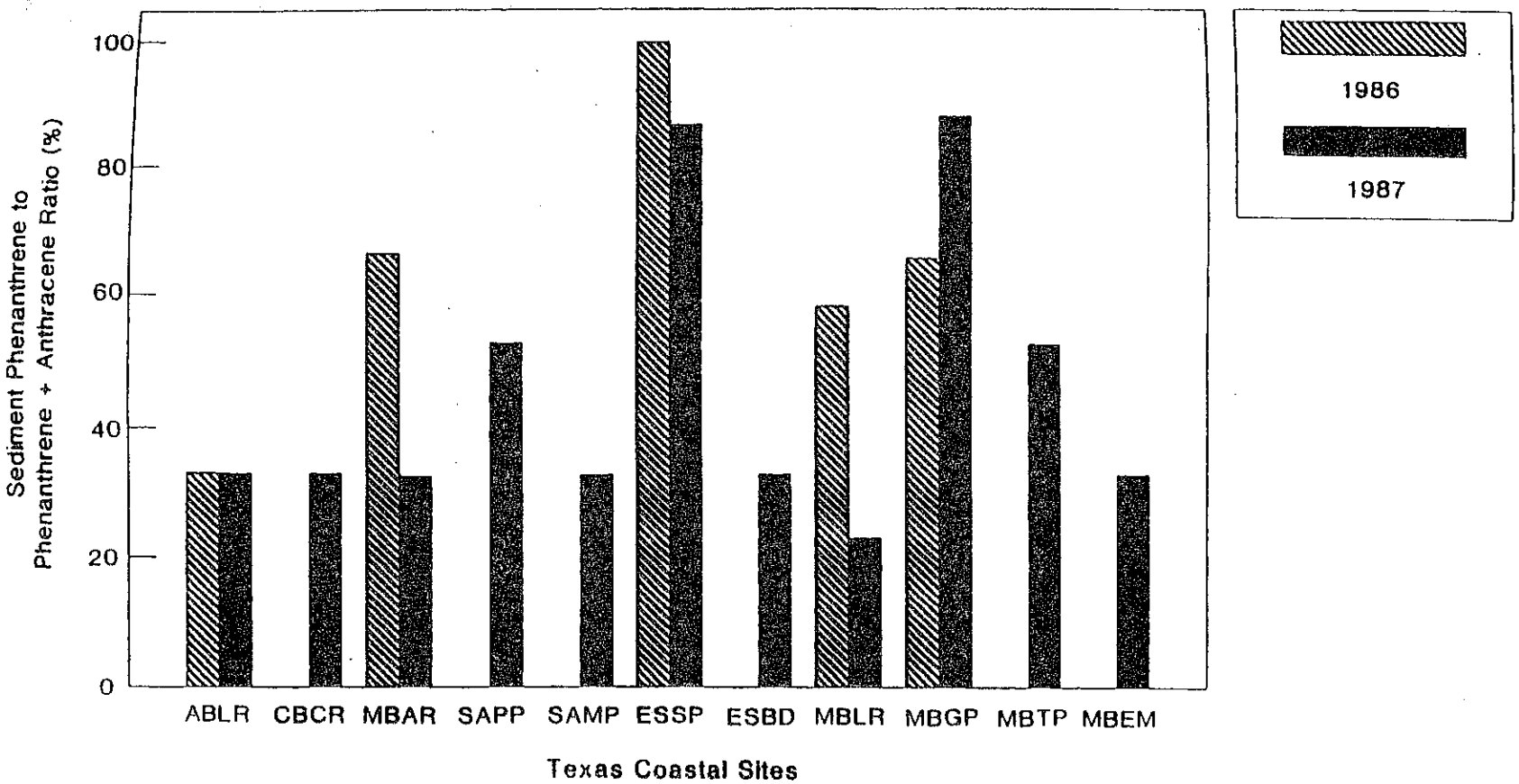


Figure 43. Ratios of phenanthrene to phenanthrene plus anthracene in sediments at the NOAA Status and Trends Mussel Watch stations in coastal Texas. The key to station locations and designations is presented in Figure 40.

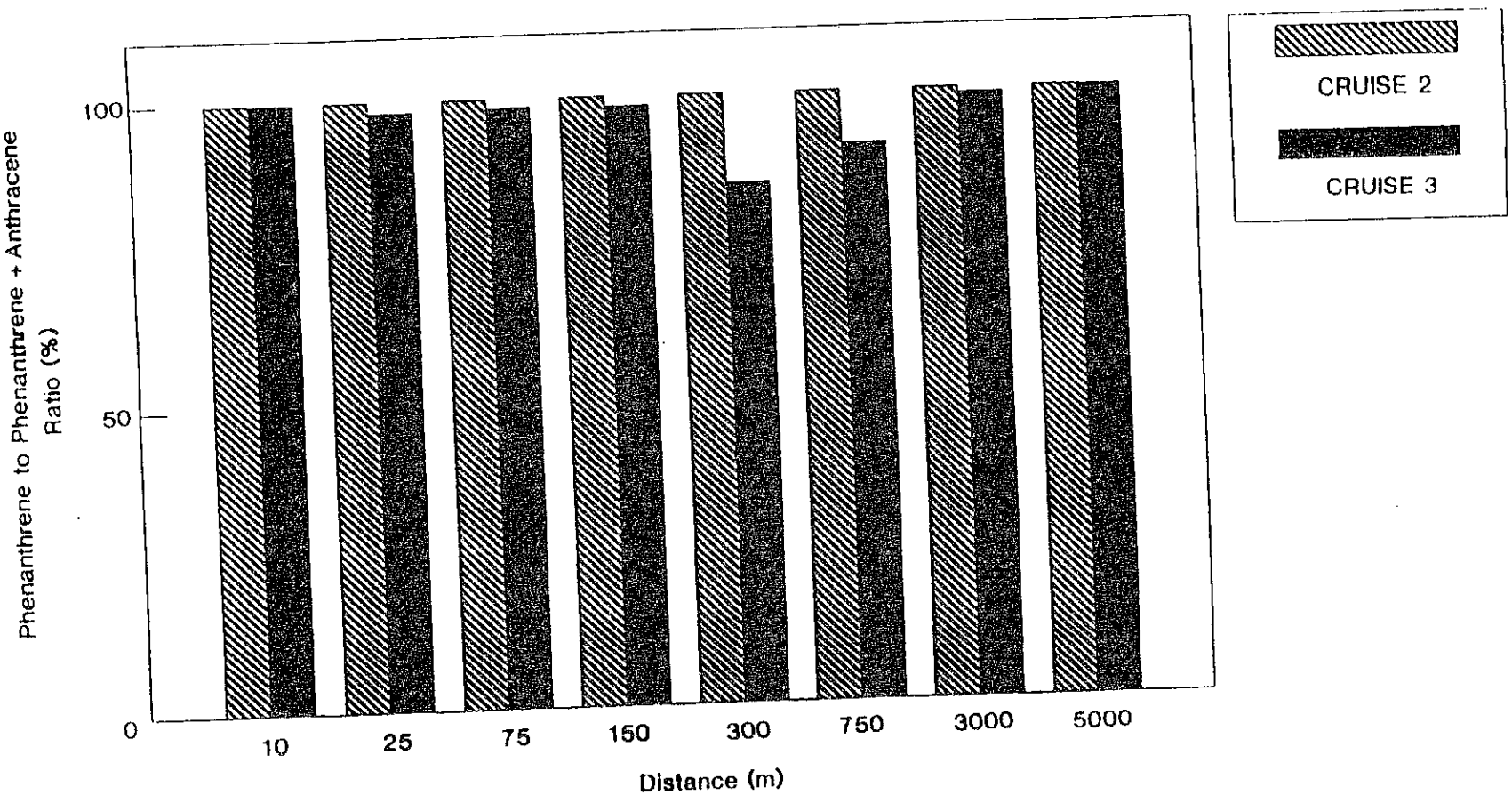


Figure 44. Mean ratios of phenanthrene to phenanthrene plus anthracene in sediment samples collected during Cruises 2 and 3 with distance from the discharge site.

Table 18. Summary of representation of taxonomic groups in the API benthic studies, October 1986 through August 1987.

Phylum	Number Taxa	Percent of Total	Number of Individuals	Percent of Total
Cnidaria	2	0.7	39	0.3
Platyhelminthes	1	0.3	3	0.0
Rhynchocoela	1	0.3	576	3.8
Mollusca	65	21.3	2,626	17.4
Brachiopoda	1	0.3	12	0.1
Annelida	111	36.4	9,869	65.4
Phoronida	1	0.3	12	0.1
Echiura	2	0.7	4	0.0
Sipuncula	3	1.0	7	0.0
Arthropoda	105	34.4	1,501	10.0
Echinodermata	9	3.0	409	2.7
Cephalochordata	4	1.3	26	0.2
TOTAL	305	100.0	15,084	100.0

Table 19. Cruise 1 macroinfaunal assemblage parameters.

Station	Total Taxa	Mean Density (individuals/m^2)	Species Diversity*	Evenness§	Sp Ric
0m-0°-1	31	1,619	2.55	0.74	5
10m-352°-1	28	900	3.03	0.91	6
10m-52°-1	7	281	1.89	0.97	2
10m-112°-1	13	300	2.46	0.96	3
10m-172°-1	24	587	2.97	0.93	5
10m-232°-1	27	2,100	2.56	0.78	5
10m-292°-1	42	2,137	3.13	0.84	7
100m-352°-1	20	912	2.28	0.76	4
100m-52°-1	27	1,400	2.56	0.78	5
100m-112°-1	22	1,787	1.85	0.60	4
100m-172°-1	25	1,800	2.12	0.66	4
100m-232°-1	27	1,325	2.65	0.80	5
100m-292°-1	30	2,112	2.48	0.73	5
1000m-352°-1	19	1,900	1.14	0.39	3
1000m-52°-1	15	2,162	0.87	0.32	2
1000m-112°-1	33	2,125	2.35	0.67	6
1000m-172°-1	29	1,762	2.11	0.63	5
1000m-232°-1	22	1,225	1.67	0.54	4
1000m-292°-1	23	1,775	1.47	0.47	3
3000m-352°-1	25	2,337	1.67	0.52	
3000m-52°-1	30	2,725	2.05	0.60	
3000m-112°-1	32	1,775	2.06	0.59	
3000m-172°-1	47	1,796	2.29	0.59	
3000m-232°-1	24	2,012	1.80	0.57	
3000m-292°-1	25	2,425	1.63	0.51	

* Shannon-Weaver Index (Pielou, 1975).
§ Pielou Index (Pielou, 1975).
¶ Margalef Index (Margalef, 1958).

The mean number of taxa collected during Cruise 2 was 32; numbers of taxa ranged from 19 to 54 (Table 20). The largest number of taxa during April 1987 (54) occurred at Station 25m-276°-2. The Cruise 2 mean density was 1,532 individuals m^{-2} and densities ranged from 580 individuals m^{-2} at Station 25m-172°-2 to 2,669 individuals m^{-2} at Station 25m-276°-2.

During Cruise 3, the mean number of taxa was 58 and numbers of taxa ranged from 44 to 76. The mean Cruise 3 density was 3,839 individuals m^{-2}, ranging from 2,294 individuals m^{-2} at Station 750m-172°-3 to 5,678 individuals m^{-2} at the 10-m station. This increase of mean density compared to Cruise 2 was unexpected because infaunal abundance generally decreases in northern Gulf of Mexico nearshore waters during late summer (Vittor et al., 1987).

In August 1987 (Cruise 3), diversity and species richness were uniformly higher than during previous cruises (Tables 19 to 21). Highest diversity (3.58) and richness (13.18) occurred at Station 25m-276°-3. Generally increased species diversity during August 1987 was attributed to a reduction in the numerical dominance of the most common species, especially *Paraprionospio pinnata* and *Nereis micromma*, in combination with additions of a large number of taxa not previously censused.

Examination of the data collected during the three cruises indicated that numbers of taxa showed no relationship to station locations. Numbers of taxa at stations 75 m or closer to the platform were comparable to those observed at more distant stations. The maximum number of taxa (76) observed during the study occurred at Station 25m-276°-3 during August 1987 (Table 21). Infaunal densities varied widely among stations and among cruises. Stations near the platform (within 75 m) exhibited both the lowest and highest infaunal densities: 281 individuals m^{-2} at Station 10m-52° during Cruise 1 and 5,678 individuals m^{-2} at Station 10m-95° during Cruise 3. Species diversity, evenness, and richness corresponded well with trends in numbers of taxa and infaunal densities. At stations located on the 172° radian, diversity was moderate because individual abundances were low but there were a moderate number of taxa. For example, Station 25m-172° had the lowest infaunal abundance during April 1987 but had a diversity of 2.64 compared to an average diversity of 2.53 and a range of 1.71 and 3.49. At Station 75m-172° during Cruise 2 the diversity was 2.23 but the density was second lowest. The relatively high diversity at stations located near the discharge site were the result of rather low numbers of numerically dominant taxa, as reflected in moderate to high evenness values during all three surveys.

Comparison of these data with those from previous studies suggested that the study area was representative of the habitats that occur on this part of the Texas shelf. Flint and Rabalais (1981) reported similar results in the STOCS program, where five of the numerically dominant taxa collected during this study were among their list of the 10 numerically dominant infaunal taxa. Numbers of taxa corresponded well with those reported by Holland (1977) for Transect II in the STOCS study area, but not to Transect I, which included some sample stations in the general vicinity of "C" Platform. However, in consideration of the relatively limited duration and geographical extent of the present study, it is believed that the

Table 20. Cruise 2 macroinfaunal assemblage parameters.

Station	Total Taxa	Mean Density (individuals/m^2)	Species Diversity*	Evenness§	Species Richness¶
10m-95°-2	51	1,133	3.49	0.89	10.32
25m-95°-2	35	857	3.25	0.91	7.45
25m-172°-2	24	580	2.64	0.83	5.51
25m-276°-2	54	2,669	3.16	0.79	9.30
75m-95°-2	28	1,285	2.43	0.73	5.43
75m-172°-2	19	705	2.23	0.76	4.12
75m-276°-2	38	973	3.02	0.83	7.89
150m-95°-2	26	1,330	1.91	0.59	5.00
150m-172°-2	30	1,357	2.51	0.74	5.77
150m-276°-2	28	1,589	2.39	0.72	5.21
300m-95°-2	26	2,276	2.12	0.65	4.51
300m-172°-2	30	2,321	1.90	0.56	5.22
300m-276°-2	27	2,125	1.71	0.52	4.75
750m-95°-2	35	2,410	2.52	0.71	6.07
750m-172°-2	36	1,178	2.99	0.83	7.17
3000m-95°-2	21	1,383	1.89	0.62	3.97
3000m-172°-2	30	1,464	2.87	0.84	5.69
5000m-95°-2	30	1,839	2.21	0.65	5.44
5000m-172°-2	37	1,625	2.85	0.79	6.92

* Shannon-Weaver Index (Pielou, 1975).
§ Pielou Index (Pielou, 1975).
¶ Margalef Index (Margalef, 1958).

Table 21. Cruise 3 macroinfaunal assemblage parameters.

Station	Total Taxa	Mean Density (individuals/m^2)	Species Diversity*	Evenness§	Species Richness¶
10m-95°-3	63	5,678	3.14	0.76	9.60
25m-95°-3	67	5,232	2.97	0.71	10.36
25m-172°-3	56	2,312	3.41	0.85	9.90
25m-276°-3	76	2,642	3.58	0.83	13.18
75m-95°-3	51	5,598	2.82	0.72	7.76
75m-172°-3	44	2,642	2.87	0.76	7.56
75m-276°-3	64	2,812	3.28	0.79	10.95
150m-95°-3	64	4,705	3.15	0.76	10.05
150m-172°-3	55	4,366	3.09	0.77	8.72
150m-276°-3	60	4,633	3.24	0.79	9.44
300m-95°-3	65	3,839	3.43	0.82	10.55
300m-172°-3	59	3,767	3.23	0.79	9.59
300m-276°-3	53	3,964	3.10	0.78	8.53
750m-95°-3	45	2,812	3.04	0.80	7.65
750m-172°-3	63	2,294	3.54	0.85	11.17
3000m-95°-3	53	4,500	2.94	0.74	8.36
3000m-172°-3	46	3,366	2.98	0.78	7.59
5000m-95°-3	66	4,517	3.38	0.81	10.44
5000m-172°-3	51	3,250	2.93	0.75	8.48

* Shannon-Weaver Index (Pielou, 1975).
§ Pielou Index (Pielou, 1975).
¶ Margalef Index (Margalef, 1958).

numbers of taxa censused were representative of macroinfaunal communities in this region. Science Applications, Inc. (1984) reported a total of only 182 taxa from the Matagorda Offshore Dredged Material Disposal Site. This lower number of species may have been related to the comparatively homogeneous habitat types sampled during that survey. Overall, average macroinfaunal density (2,113 individuals m^{-2}) was similar to that estimated during this study. As in the present study, polychaetes comprised the numerically dominant macroinfaunal group in the Science Applications, Inc. survey. Harper et al. (1981) reported strong seasonal changes in macroinfaunal communities sampled in connection with benthic investigations at the Buccaneer Oil Field (Texas). In contrast to the present study, Harper et al. found that infaunal abundance and diversity were relatively low during Fall-Winter, then increased through Spring (April).

3.5.2 Macroinfaunal Assemblages

The relationships among the stations and among the taxa collected during the three cruises were examined using cluster analysis. Cluster analysis is a numerical technique for classifying entities into groups based on similarities or measured characteristics. For clustering stations (commonly called normal analysis) the taxa collected at each station were used as the characteristics. Similarities between stations were therefore based on their taxonomic composition. The Bray-Curtis index (Clifford and Stephenson, 1975) was used to determine similarities between pairs of stations. Only taxa identified to the species level (except *Mediomastus* spp.) were included. Rare and infrequent taxa were also excluded. Abundances were transformed using common logarithms to avoid overemphasizing numerically dominant taxa. Clustering species (inverse analysis) required using abundances at the stations as characteristics. Species which had similar distribution in the study area clustered together. Clustering analysis was performed for Cruise 1, 2, 3, and Cruises 2 and 3 combined.

Cluster analysis of macroinfaunal data demonstrated consistent groupings of stations and of species over the four data sets. During October 1986 (Cruise 1), stations were classified into four groups on the basis of species affinities (Table 22, Figure 45). Station Groups 1 and 2 included stations located within 10 m of the discharge site, Group 3 contained only stations located 100 m from the platform, and Group 4 consisted of the 1,000-m, 3,000-m stations and one 100-m station. As seen in Table 22 and Figure 46, these stations groupings were corroborated by generally strong species groupings. For example, Species Group C occurred almost exclusively among Group 4 stations, and Species Group D were nearly restricted to station Group 1, nearest the platform. Although Species Group A was ubiquitous, it was best represented at distances of 100 m or greater.

Although species groupings were not as well-defined, April 1986 (Cruise 2) clusters were similar to those observed in October 1986. Station Groups 1 and 2 included habitats within 75 m of the discharge site, while Groups 3 and 4 were comprised of stations further from the platform (Table 23, Figure 47). Species Group C was most representative of near-platform stations (especially station Group 1), but was more widely distributed than during Cruise 1 (when it clustered as Group D) (Figure 48). Species Group A was again comprised of

Table 22. Two-way coincidence table for Cruise 1 stations and species.

	0-0-1	10-232-1	10-252-1	10-172-1	10-292-1	10-52-1	10-112-1	100-352-1	100-52-1	100-292-1	100-112-1	100-232-1	100-172-1	3000-292-1	1000-172-1	1000-112-1	3000-352-1	3000-52-1	3000-172-1	1000-352-1	1000-52-1	1000-232-1	1000-292-1	3000-112-1	3000-232-1
Paraprionospio pinnata			*					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mediomastus (LPIL)	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nereis micromma	*	*			*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Magelona sp. H					*			*	*	*	*	*	*	*		*	*	*				*			*
Lumbrineris verrilli		*	*	*	*				*	*		*	*	*	*	*	*	*	*	*		*	*		
Sigambra tentaculata	*		*		*				*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	
Magelona sp. I			*					*	*	*	*	*				*	*		*	*	*	*	*		
Cossura soyeri					*								*	*		*	*	*		*	*	*	*	*	*
Tharyx cf. annulosus										*		*		*			*	*	*	*	*			*	
Levinsenia sp. K										*			*			*	*	*		*				*	
Ampelisca sp. C								*			*		*		*	*	*	*	*		*	*	*	*	*
Nephtys incisa														*	*		*	*	*			*	*	*	*
Leptochela serratorbita	*		*	*	*		*	*	*	*	*														
Tellina texana			*				*	*	*	*	*		*		*										
Ampelisca abdita								*	*	*					*										
Processa hemphilli								*					*											*	
Diopatra neotridens				*					*			*			*										
Vitrinella helicoidea											*	*				*				*					
Aricidea sp. U					*			*			*					*	*	*	*				*		
Prionospio cirrifera																	*	*	*						
Prionospio cristata													*			*		*	*						
Ninoe sp. B																*			*					*	
Ampelisca sp. A																	*		*					*	*
Ancistrosyllis jonesi																	*		*					*	
Ampelisca agassizi														*	*	*			*		*		*	*	
Synchelidium americanum															*	*			*						
Asychis elongatus														*	*	*	*	*	*					*	*
Alpheus floridanus					*								*	*	*	*		*			*		*		
Volvulella texasiana													*	*	*	*		*							
Nuculana acuta													*	*	*										
Syllis gracilis	*	*		*	*															*					
Nanoplax xanthiformis	*	*		*	*																				
Bhawania heteroseta		*	*	*	*	*																			
Chione grus	*	*	*	*	*	*	*		*																
Armandia maculata	*	*														*									
Upogebia sp. C	*	*			*																				
Lumbrineris ernesti		*		*	*				*																
Paramphinome sp. B				*	*				*																
Aonides mayaguezensis		*	*	*	*																				
Owenia sp. A			*		*							*													

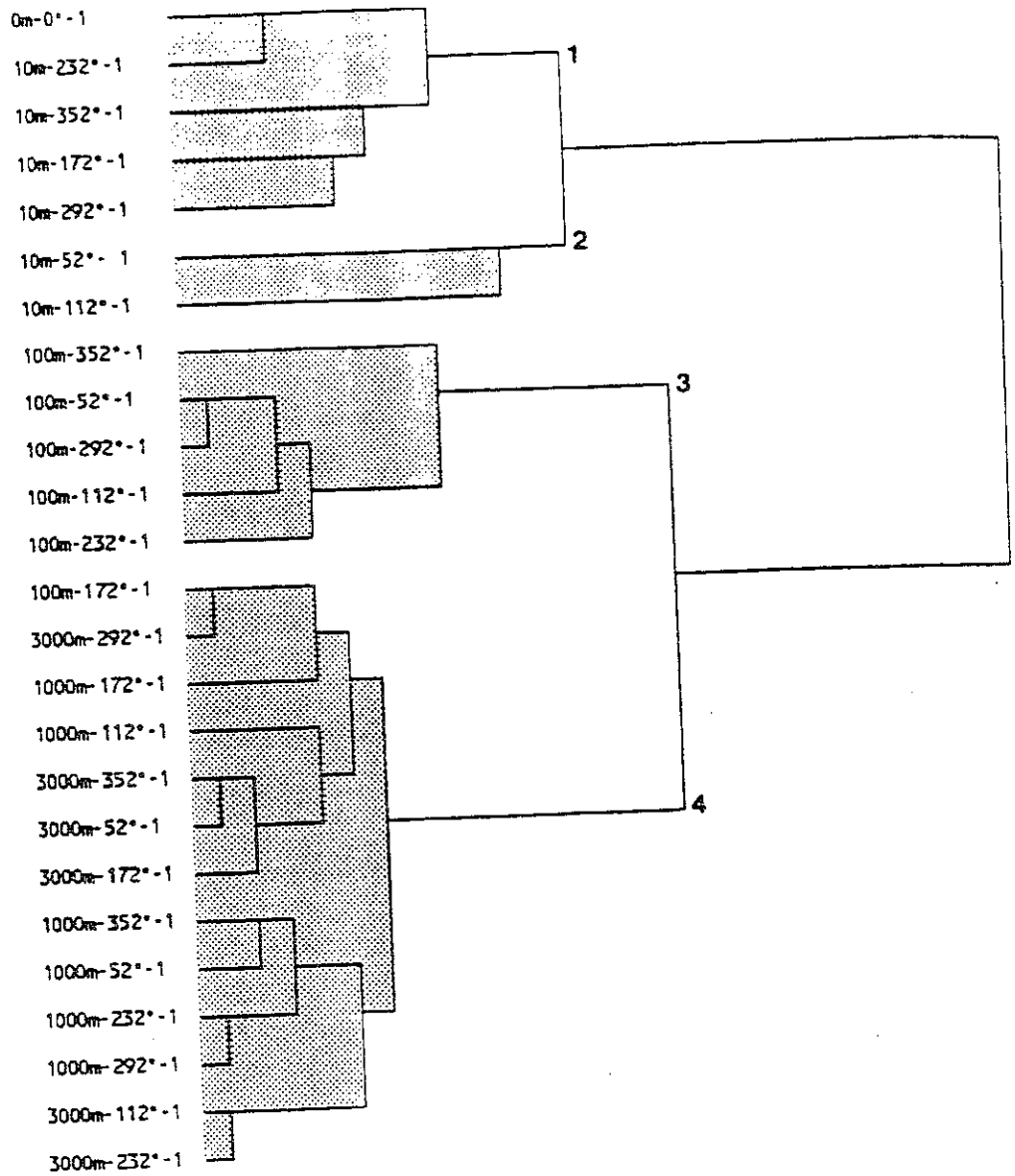


Figure 45. Dendrogram depicting the similarities among the Cruise 1 stations based on the macroinfaunal compositions. Abundances of the macroinfauna were transformed using common logarithms. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of stations with similar taxonomic compositions are indicated by shading; these station groups are numbered 1 through 4.

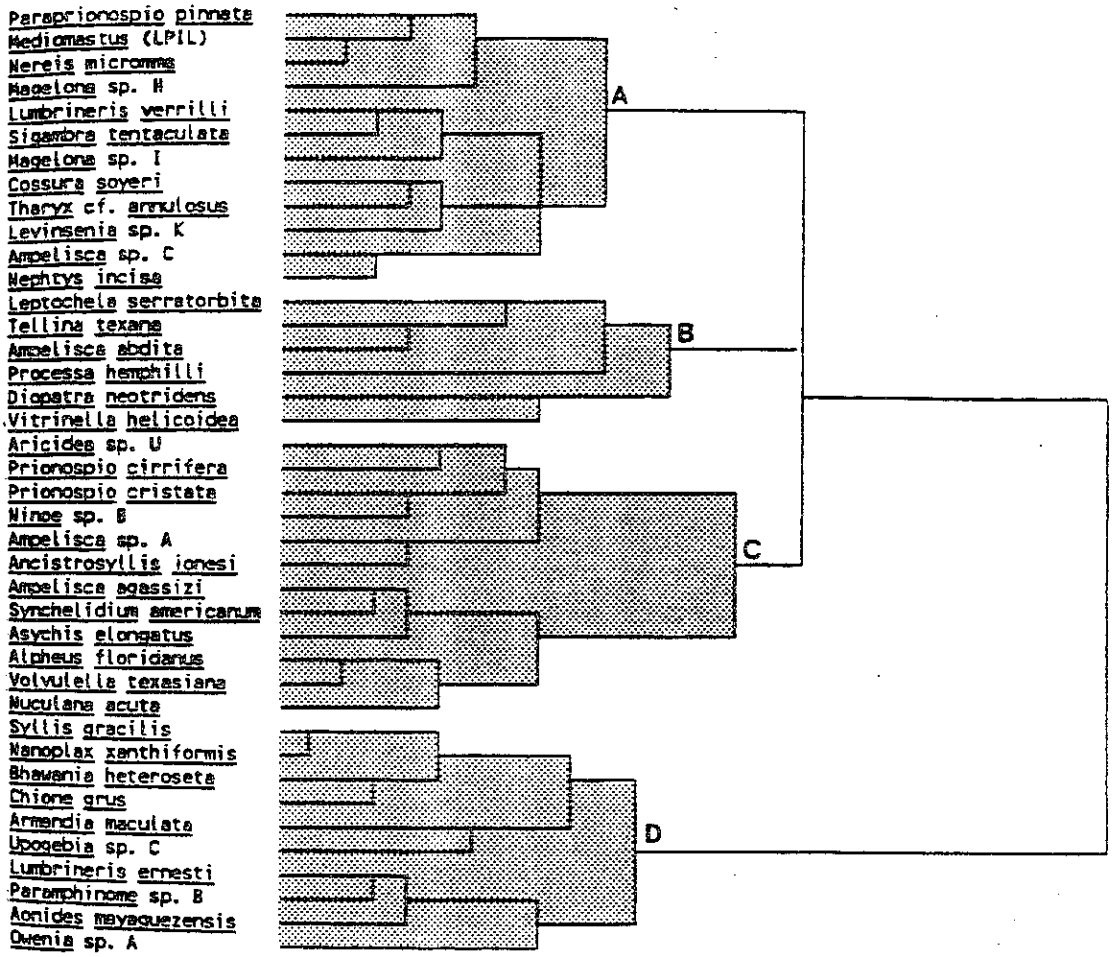


Figure 46. Dendrogram depicting the similarities among the macroinfaunal species collected at the Cruise 1 stations. Similarities were based on abundances (common logarithmic transformation) at the Cruise 1 stations. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of species with similar distributions among the stations are indicated by shading; these species groups are lettered A through D.

Table 23. Two-way coincidence table for Cruise 2 stations and species.

	10-95-2	25-95-2	25-276-2	25-172-2	75-95-2	75-172-2	75-276-2	150-95-2	150-172-2	150-276-2	5000-95-2	300-95-2	750-95-2	300-172-2	750-172-2	300-276-2	3000-172-2	3000-95-2	5000-172-2
Paraprionospio pinnata	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Aricidea sp. U	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Lumbrineris verrilli	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nereis micromma	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mediomastus (LPIL)	*	*	*		*			*	*	*	*	*	*	*	*	*	*	*	*
Magelona sp. H	*		*	*	*	*	*	*	*	*	*		*	*	*	*	*		
Ampelisca sp. C				*						*	*	*	*	*	*	*	*	*	*
Nephtys incisa											*	*	*	*	*	*	*	*	*
Ampelisca agassizi								*	*		*	*	*	*	*	*	*	*	
Armandia maculata	*							*	*		*	*	*	*	*	*	*		*
Sigambra tentaculata	*		*					*	*	*	*	*	*	*	*		*	*	*
Cossura soyeri						*		*	*	*	*	*	*	*	*		*	*	*
Syncnelidium americanum			*				*	*		*	*	*		*	*		*	*	*
Ampharete sp. A		*		*			*			*	*	*	*			*		*	*
Tharyx cf. *annulosus*	*		*	*								*	*	*	*		*	*	
Spiochaetopterus oculatus	*							*			*	*	*			*	*		
Ampelisca sp. A										*			*		*	*	*	*	*
Levinsenia sp. K													*		*		*		*
Sabellaria sp. A			*																
Lumbrineris ernesti	*	*	*	*	*	*	*	*									*		
Bhawania heteroseta	*	*	*																
Nanoplax xanthiformis	*	*	*																
Paramphinome sp. B	*		*				*												
Owenia sp. A			*				*								*				
Glycera americana	*	*	*	*	*						*		*	*	*				*
Diopatra cuprea	*	*		*	*		*				*								*
Prionospio cristata	*										*				*				*
Nuculana acuta					*									*	*				
Spiophanes cf. *missionensis*	*	*					*		*			*		*					
Euceramus sp. A	*	*		*															
Podarkeopsis levifuscina	*	*	*																
Photis macromanus								*	*						*				
Alpheus floridanus							*	*	*				*	*	*				*
Volvulella texasiana									*			*	*	*	*				
Automate evermanni								*			*		*	*					
Speocarcinus lobatus								*					*		*				
Magelona sp. I			*		*	*			*	*	*	*	*						*
Polydora socialis			*					*	*		*								
Magelona sp. L				*					*									*	
Trachypenaeus similis						*	*	*											
Processa hemphilli					*	*		*											

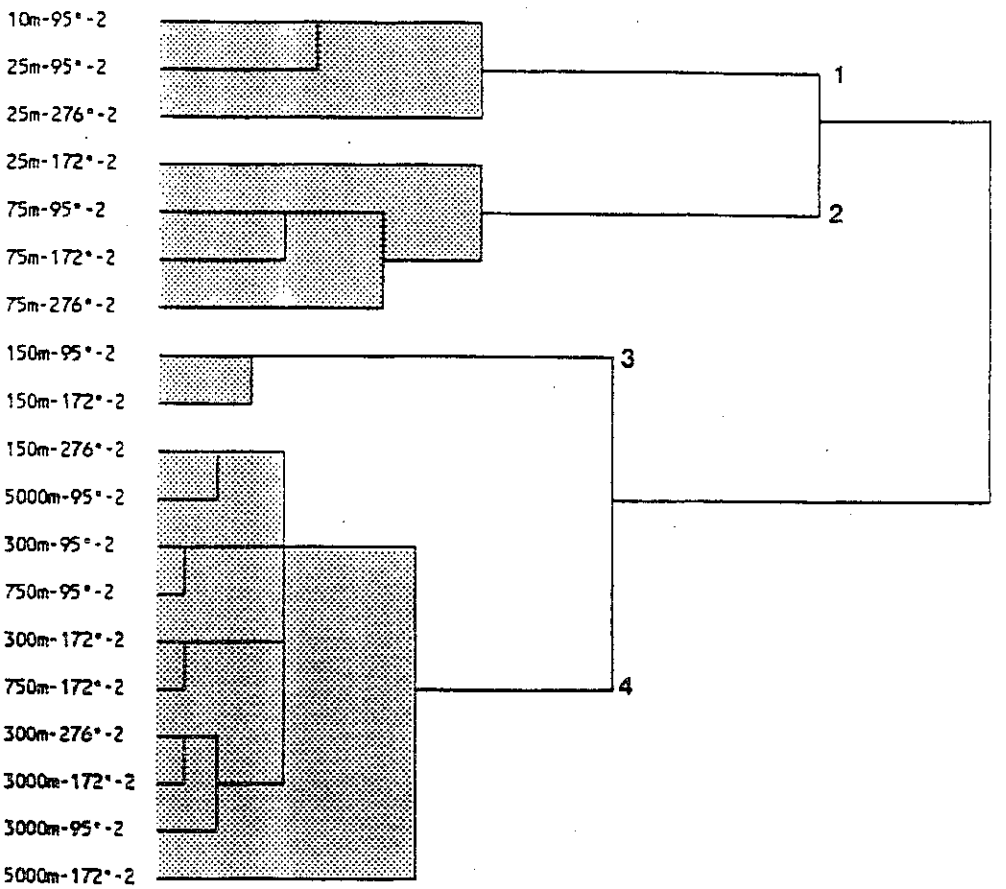


Figure 47. Dendrogram depicting the similarities among the Cruise 2 stations based on the macroinfaunal compositions. Abundances of the macroinfauna were transformed using common logarithms. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of stations with similar taxonomic compositions are indicated by shading; these station groups are numbered 1 through 4.

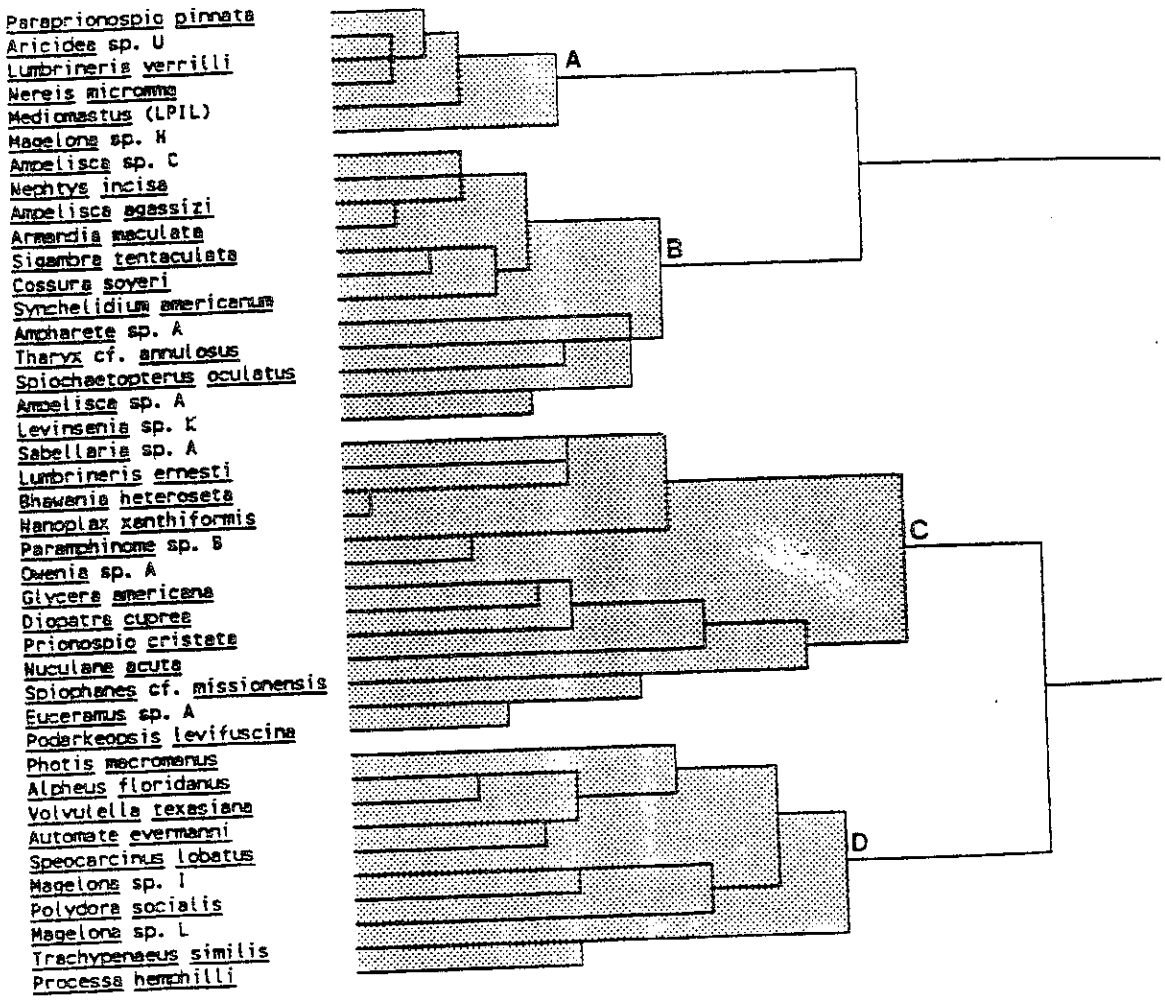


Figure 48. Dendrogram depicting the similarities among the macroinfaunal species collected at the Cruise 2 stations. Similarities were based on abundances (common logarithmic transformation) at the Cruise 2 stations. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of species with similar distributions among the stations are indicated by shading; these species groups are lettered A through D.

ubiquitous and numerically dominant species, while Group B contained those taxa found primarily at Group 4 stations.

In August 1987 (Cruise 3), stations were again grouped according to distance from the discharge site. Station Groups 1, 2, and 3 were comprised of sites within 75 m of the discharge site, with the exception of Station 750m-172°-3 (Table 24, Figure 49), which was distinguished from other outer stations by containing measurable amounts of gravel or shell hash. Group 4 was comprised of stations more than 150 m from the platform. Opportunistic and ubiquitous species were generally clustered in Species Group A, which was most prevalent at Groups 3 and 4 stations--stations located 75 m or more from the platform (Table 24, Figure 50). Group B species were less well-represented near the platform (i.e., within 75 m), while species Group C was essentially absent from near-platform Group 1 stations and only poorly represented at Groups 2 and 3 stations. The converse was observed for species Group D, which was comprised of low-abundance taxa associated with near-platform habitats.

When data from Cruises 2 and 3 (which involved the same station locations) were analyzed together, five stations and four species groups were evident (Table 25, Figures 51 and 52). Despite a strong seasonal separation, Groups 1, 2, and 3 included most of the near-platform stations. All stations 150 m or further from the platform occurred in Groups 4 (Cruise 2) or 5 (Cruise 3). Species clustering was also affected by season: Group B was prevalent during Cruise 3 but was also represented during Cruise 2 at most stations. Group D was associated primarily with stations more than 150 m from the discharge site, while Species Group C was comprised of taxa found especially at near-platform stations during both April and August 1987. These station and species groupings indicated the presence of a gradient of macroinfaunal assemblages from 25 to 150 m from the discharge point. The similarity of near-platform assemblages to reference station assemblages increased with increasing distance from the platform to a distance of 150 m. At that distance, assemblages exhibited only minor differences from those at reference distances.

Using the results of the clustering analysis, three benthic assemblages in the study area were defined--a Sand-Silt Clay Group; a Silty-Clayey Sand Group; and a Shelly Sand Group (Table 26). These benthic assemblages were dominated by polychaetes. Taxa characteristic of this general area--the Sand-Silt Clay and Silty-Clayey Sand Groups--included primarily burrowing or surface deposit feeders and corresponded well to species sampled by Harper et al. (1981) and Baker et al. (1981). Such species are opportunistic and are ubiquitous in silt-clay sediments in the Gulf of Mexico. Species in the Shelly Sand Group are typically found in sediments containing shell hash and rubble throughout the northern Gulf of Mexico (Holland, 1977; Dames and Moore, 1979).

The Shelly Sand Group was restricted to those stations nearest the platform (i.e., 25 m or less). This assemblage included primarily surface or tube dwellers, such as *Sabellaria* sp. A, *Bhawania heteroseta*, and *Nanoplax xanthiformis*; these species are representative of filter-feeding and carnivorous feeding guilds. Some unusual taxa occurred among the Shelly-Sand assemblage during each survey.

Table 24. Two-way coincidence table for Cruise 3 stations and species.

	10	25	27	55	75	75	75	70	15	30	50	10	30	50	10	30	50	70	50	00	30
	95	95	17	27	77	95	72	72	95	05	05	07	05	02	07	06	06	07	05	07	02
	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Armandia maculata	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nereis micromma	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Tellina versicolor				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nuculana acuta						•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nephtys incisa			•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Paraprionospio pinnata		•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Mediomastus (LPIL)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Owenia sp. A	•	•	•	•	•		•			•	•		•	•	•	•	•	•	•	•	•
Lumbrineris verrilli	•			•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Asychis elongatus						•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
Sthenelais sp. A				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ampelisca agassizi			•						•	•	•	•	•	•	•	•	•	•	•	•	•
Ampelisca sp. C						•	•		•	•	•	•			•	•	•	•	•	•	•
Ampelisca sp. L		•				•		•	•	•	•	•	•	•				•		•	
Diopatra cuprea				•	•	•	•	•	•	•	•	•			•	•	•				
Synchelidium americanum			•	•	•	•	•		•	•	•	•			•	•	•			•	•
Automate evermanni				•		•		•	•	•	•	•	•	•	•	•	•	•			
Prionospio cristata	•	•	•		•	•	•	•	•				•	•	•	•	•			•	•
Ariciosa sp. U		•							•		•	•	•	•	•	•	•	•	•	•	•
Tharyx cf. annulosus		•		•	•	•	•				•	•	•	•	•	•	•		•	•	•
Cossura soyeri													•	•	•	•	•		•	•	•
Levinsenia sp. K							•				•	•		•	•	•	•			•	•
Volvulella texasiana							•				•	•	•	•	•	•	•			•	•
Sigambra tentaculata	•	•	•		•		•	•			•	•	•	•	•	•	•			•	
Magelona sp. I			•		•	•	•				•	•			•		•		•	•	
Vericorbula operculata		•	•		•	•		•			•	•	•		•	•		•			
Magelona sp. H					•	•	•	•			•	•		•	•	•			•		
Abra aequalis	•	•			•	•	•	•			•	•	•	•	•	•					
Corbula barrattiana	•	•	•		•	•		•			•			•	•				•		
Prionospio sp. K	•	•			•		•				•	•	•			•	•		•		•
Gouldia cerina	•	•	•			•		•			•	•	•								
Axiothella sp. A							•	•			•			•	•	•	•	•	•	•	
Spiophanes cf. missionensis	•		•		•									•	•	•	•	•	•		
Magelona sp. L					•			•					•	•	•	•	•	•	•		
Chione latilirata						•		•						•	•		•				
Automate sp. C					•									•	•						
Acteocina bidentata														•	•						
Macoma tenta					•	•					•	•							•		•
Chaetozone sp. D											•	•	•								•
Alpheus floridanus											•		•	•			•	•	•		•
Speocarcinus lobatus					•		•				•		•	•							•
Pinnixa sp. A					•								•			•			•		•
Astropecten duplicatus													•		•			•	•		
Ceratocephale oculata											•		•							•	
Eudorella monodon												•								•	•
Munna hayesi											•									•	•
Photis macromanus						•						•	•				•				
Drilonereis longa												•	•		•		•				
Pectinaria gouldii						•						•					•				
Lima sp. A											•	•			•		•		•		
Paresterope zeta						•					•				•						
Acteocina candei								•				•					•				
Monoculodes nyei						•						•					•				•
Processa hemphilli					•						•	•					•				
Chione grus	•	•	•		•	•															
Syllis gracilis	•	•	•		•	•															
Lumbrineris ernesti	•	•	•		•	•	•	•					•							•	
Chloeia viridis		•	•		•	•		•					•		•						
Hepatus epheliticus		•			•	•		•													
Glycera americana					•	•	•	•													
Amphiodia pulchella	•						•	•					•	•							
Vitrinella floridana						•												•			
Laevicardium mortoni						•	•	•													
Prionospio sp. L								•								•	•				
Spiochaetopterus oculatus		•			•												•				
Amaitides groenlandica		•	•			•															
Pinnotheres ostreum		•				•											•				
Ampharete sp. A			•		•		•	•									•				
Nanoplax xanthiformis	•	•	•		•						•										
Bhawania heteroseta	•	•	•																		
Anadara transversa	•	•	•		•																
Parampninome sp. B	•	•	•		•		•														
Schistomeringos cf. rudolphi	•	•	•																		
Podarkeopsis levifuscina	•	•	•																		
Glyptoplax smithii	•	•					•														
Litocorsa antennata	•	•												•							
Nassarius albus	•	•			•	•															
Sabellaria sp. A	•	•			•																
Anachis semiplicata	•		•			•															
Ebalia stimpsonii	•		•			•															

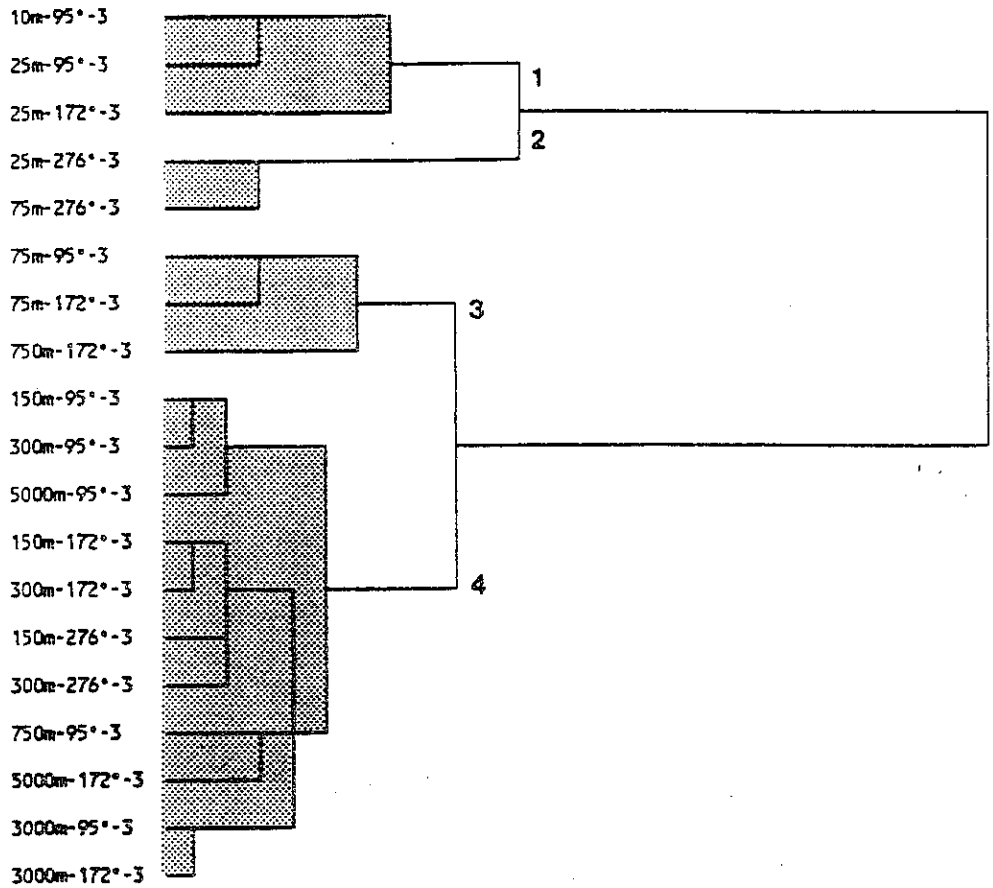


Figure 49. Dendrogram depicting the similarities among the Cruise 3 stations based on the macroinfaunal compositions. Abundances of the macroinfauna were transformed using common logarithms. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of stations with similar taxonomic compositions are indicated by shading; these station groups are numbered 1 through 4.

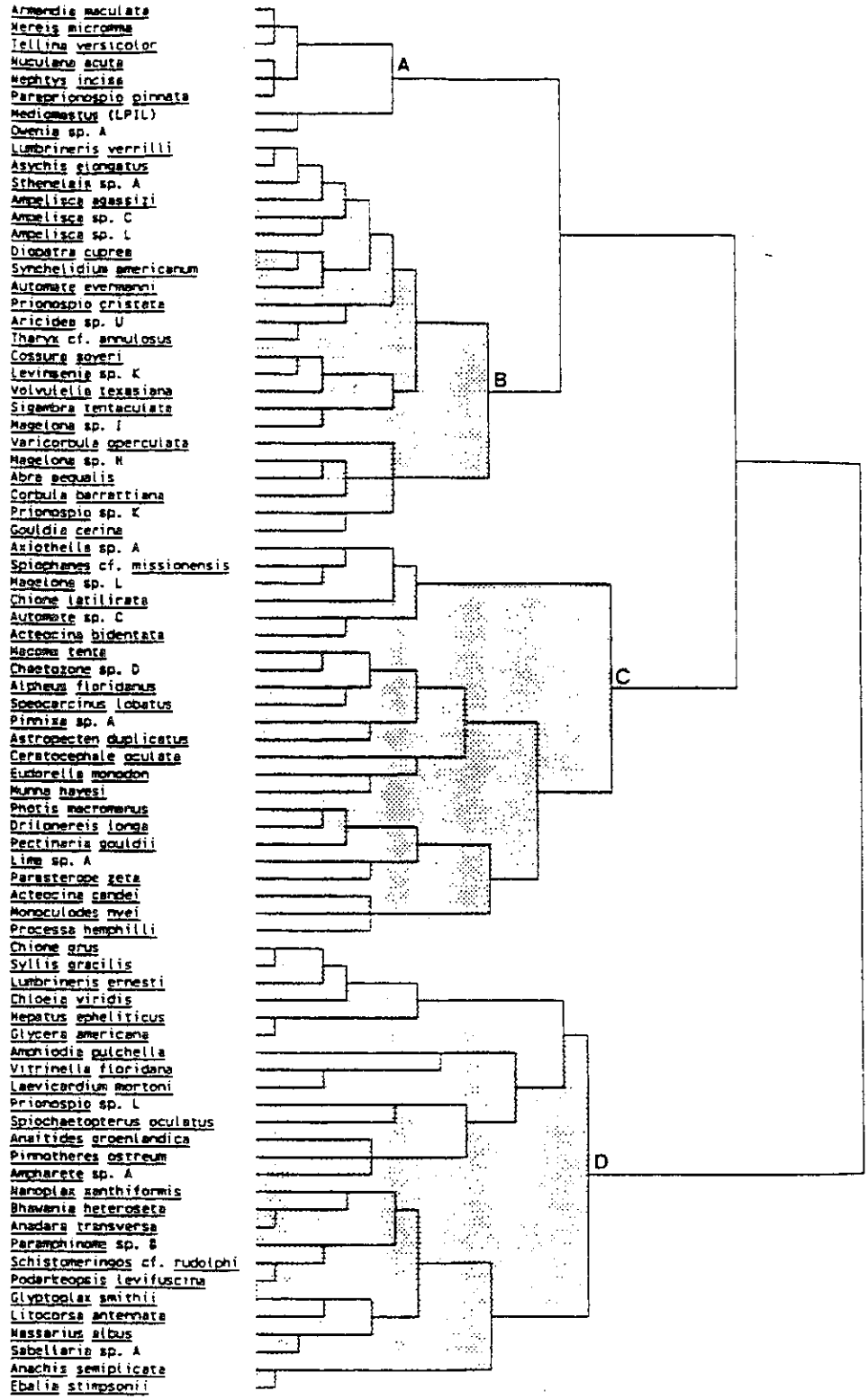


Figure 50. Dendrogram depicting the similarities among the macroinfaunal species collected at the Cruise 3 stations. Similarities were based on abundances (common logarithmic transformation) at the Cruise 3 stations. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of species with similar distributions among the stations are indicated by shading; these species groups are lettered A through D.

Table 25. Two-way coincidence table for combined Cruises 2 and 3 stations and species.

Species	10-095-2	25-095-2	25-276-2	10-095-3	25-095-3	25-172-3	25-276-3	75-276-3	25-172-2	75-095-2	75-172-2	75-276-2	150-095-2	150-172-2	150-276-2	300-095-2	300-172-2	750-095-2	5000-095-2	300-276-2	3000-095-2	750-172-2	3000-172-2	5000-172-2	75-095-3	75-172-3	750-172-3	150-095-3	150-172-3	150-276-3	300-172-3	750-095-3	300-095-3	5000-095-3	300-276-3	3000-095-3	3000-172-3	5000-172-3
Paraprionospio pinnata	•	•	•		•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nereis micromma	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Lumbrineris verrilli	•	•	•	•				•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Mediomastus (LPIL)	•	•	•	•	•	•	•	•		•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Aricidea sp. U	•		•		•				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•				•	•	•	•	•		•	•	•	•	•
Magelona sp. H	•		•				•	•	•	•	•	•	•	•	•		•	•	•	•		•	•		•	•	•	•	•	•	•		•					•
Ampelisca agassizi						•							•	•		•	•	•	•	•	•	•	•					•	•	•	•	•	•	•	•	•	•	•
Ampelisca sp. C									•						•	•	•	•	•	•	•	•	•	•	•	•		•	•		•	•	•	•	•	•	•	•
Cossura soyeri											•		•	•	•	•	•	•	•		•	•	•	•				•	•	•	•		•		•	•	•	•
Synchelidium americanum			•			•	•	•				•	•		•	•	•		•		•	•	•	•	•	•		•	•	•		•	•	•	•	•	•	
Sigambra tentaculata	•		•	•	•	•		•					•	•	•	•	•	•	•		•	•	•	•		•	•		•	•	•		•	•	•	•		
Tharyx cf. annulosus	•		•		•		•	•	•							•	•	•			•	•	•		•	•			•	•	•		•	•	•	•	•	•
Armandia maculata	•			•	•	•	•	•					•	•		•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Tellina versicolor							•	•																	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nuculana acuta										•							•					•			•	•	•	•	•	•	•	•	•	•	•	•	•	•
Nephtys incisa						•										•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Owenia sp. A			•	•	•	•	•	•				•										•					•			•	•	•	•	•	•	•	•	•
Lumbrineris ernesti	•	•	•	•	•	•	•	•	•	•	•	•	•										•		•	•	•							•		•		
Prionospio cristata	•			•	•	•		•											•			•		•	•	•	•	•	•	•	•	•				•	•	•
Amphiodia pulchella				•																						•	•		•					•				
Sthenelais sp. A							•	•																	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Asychis elongatus												•							•						•		•	•	•	•	•	•	•	•	•	•	•	•
Ampelisca sp. L					•																				•		•	•	•	•		•	•				•	•
Diopatra cuprea	•	•					•	•	•	•		•							•					•	•	•	•	•	•	•		•	•	•	•			
Automate evermanni								•					•				•	•	•						•		•	•	•	•	•	•	•	•	•			•
Varicorbula operculata		•	•		•	•	•	•																	•			•		•	•	•	•	•				
Abra aequalis				•	•		•	•																	•	•	•	•	•	•	•		•	•				
Corbula barrattiana	•			•	•	•	•	•				•													•		•	•	•	•				•				•
Gouldia cerina	•		•	•	•	•		•																	•			•					•	•				
Prionospio sp. K				•	•		•																			•		•		•			•	•	•		•	•
Spiophanes cf. missionensis	•	•		•		•	•					•		•		•	•												•	•	•	•			•			•
Axiothella sp. A																										•	•	•	•	•	•	•			•	•		•
Magelona sp. L							•		•					•							•						•		•	•	•			•	•			•
Chione latilirata										•															•		•		•		•				•			
Levinsenia sp. K																		•				•	•	•			•	•	•	•			•		•	•	•	
Volvulella texasiana														•		•	•	•				•					•	•	•	•	•		•	•	•	•	•	
Alpheus floridanus												•	•	•			•	•				•		•				•	•			•		•	•		•	•
Speocarcinus lobatus							•						•					•				•					•	•	•					•			•	
Chione grus	•			•	•	•	•	•																														
Anadara transversa				•	•	•	•					•																										
Nanoplax xanthiformis	•	•	•	•	•	•	•																					•										
Syllis gracilis			•	•	•	•	•	•																														
Bhawania heteroseta	•	•	•	•	•	•																																
Paramphinome sp. B	•		•	•	•	•	•					•													•													
Podarkeopsis levifuscina	•	•	•	•	•	•																																
Sabellaria sp. A			•	•	•		•																															
Nassarius albus				•	•		•	•																														
Capitella capitata	•	•		•			•																															
Chloeia viridis					•	•	•	•																			•				•			•				
Hepatus epheliticus					•		•	•																			•											
Glycera americana	•	•	•				•	•	•	•							•	•	•			•		•	•		•											
Aneitides groenlandica					•	•		•																		•												
Ampharete sp. A		•				•	•		•			•			•	•		•	•	•	•			•		•	•			•								
Magelona sp. I			•			•	•	•		•	•			•	•	•		•	•					•		•	•	•	•				•		•	•		•
Ampelisca sp. A															•			•		•	•	•	•	•														
Spiochaetopterus oculatus	•				•		•						•			•		•	•	•			•												•			
Photis macromanus													•	•								•			•								•	•	•			
Polydora socialis			•										•	•					•																			
Lima sp. A			•												•													•			•		•		•			•
Pectinaria gouldii															•										•								•		•			
Macoma tenta							•	•																				•					•	•			•	•
Chaetozone sp. D																												•					•	•			•	
Pinnixa sp. A								•		•						•														•				•			•	•
Processa hemphilli								•		•	•		•															•		•			•					
Monoculodes nyei											•														•					•			•				•	
Eudorella monodon																							•	•									•			•	•	•
Polydora cornuta						•															•			•														•
Drilonereis longa																							•	•							•		•	•	•			
Listriella carinata																•							•								•			•				
Astropecten duplicatus																							•	•							•	•		•				•

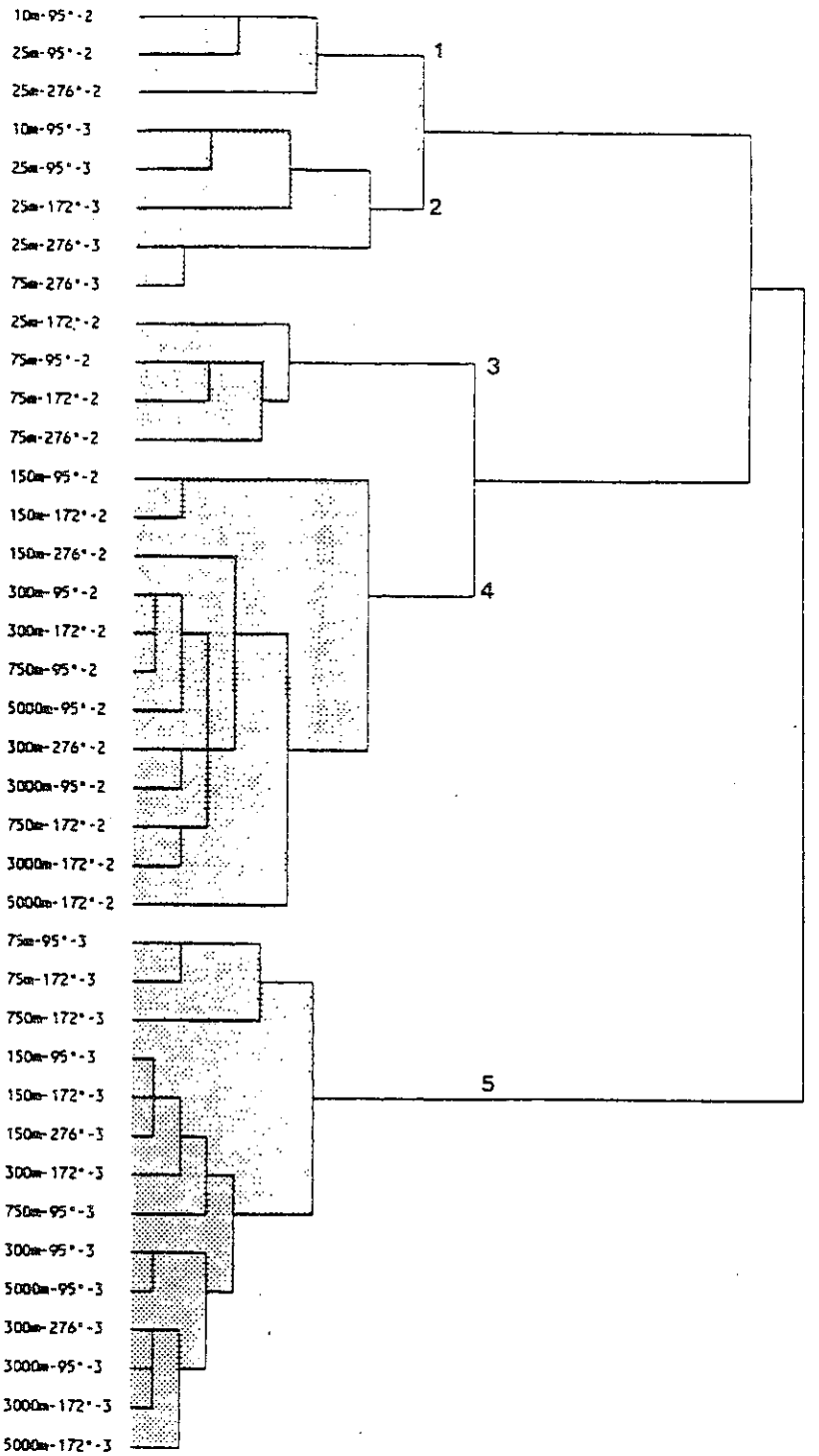


Figure 51. Dendrogram depicting the similarities among the Phase II stations (Cruises 2 and 3) based on the macroinfaunal compositions. Abundances of the macroinfauna were transformed using common logarithms. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of stations with similar taxonomic compositions are indicated by shading; these station groups are numbered 1 through 5.

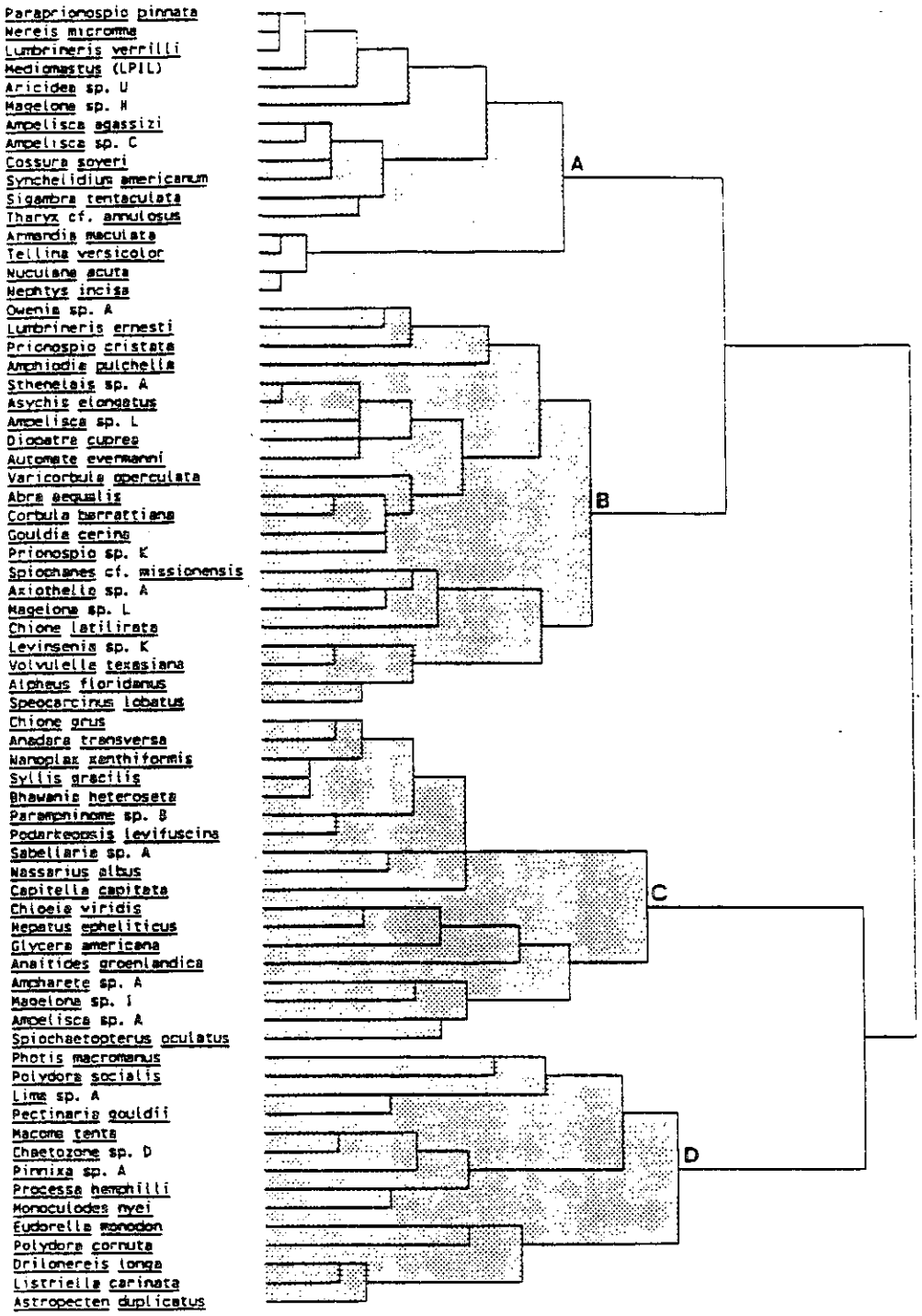


Figure 52. Dendrogram depicting the similarities among the macroinfaunal species collected at the Phase II (Cruises 2 and 3) stations. Similarities were based on abundances (common logarithmic transformation) at the Phase II stations. Clustering analysis used flexible sorting and Bray-Curtis similarity index. Groups of species with similar distributions among the stations are indicated by shading; these species groups are lettered A through D.

Table 26. Representative macroinfauna taxa in the study area.

Sand-Silt Clay Group
Paraprionospio pinnata (P)*
Nereis micromma (P)
Mediomastus spp. (P)
Cossura soyeri (P)
Prionospio crustata (P)
Varicorbula operculata (M)
Nuculana acuta (M)
Telina versicolor (M)
Ampelisca agassizi (C)
Silty-Clayey Sand Group
Nephtys incisa (P)
Owenia sp. A (P)
Paramphinoma sp. B (P)
Lumbrineris ernesti (P)
Podarkeopis levifuscina (P)
Armandia maculata (P)
Processa hemphilli (C)
Shelly Sand Group
Sabellaria sp. A (P)
Bhawania heteroseta (P)
Syllis gracilis (P)
Chloeia viridis (P)
Litocorsa antennata (P)
Chione grus (M)
Nanoplax xanthiformis (C)

* P = polychaete.
M = mollusk.
C = crustacean.

These included the serpulid polychaete genus *Hydroides*, which is an encrusting genus associated with structures such as drilling platforms, and the spionid polychaetes *Polydora cornuta* and *P. socialis*, which are associated with shell hash or rubble bottoms.

The Sand-Silt Clay and Silty-Clayey Sand assemblages were most dominant at stations greater than 150 m from the platform but were represented in all areas sampled during this study. At the same time, some of these taxa (e.g., *Varicorbula operculata*, *Tellina versicolor*) appeared in significant numbers only during Cruise 3 (August 1987). The Sand-Silt Clay Group included surface or burrowing deposit feeders, while the Silty-Clayey Sand assemblage was dominated by carnivores and surface deposit feeders.

With the exception of the Shelly Sand assemblage, infauna censused during this study were typical of nearshore soft-bottom communities throughout the region. The presence of species in the Shelly Sand assemblage that are typically associated with structures and/or coarser sediments suggested that this platform influenced the infauna through sloughing of encrustations from platform supports and other hard surfaces, as well as by disposal of cuttings, which provided a coarser substrate and some vertical relief in the vicinity of the discharge site.

3.5.3 Factors in Distribution of Macroinfaunal Assemblages

To determine which environmental factors were related to the distributions of the macroinfaunal assemblages, the data collected during Cruises 2 and 3 were analyzed using canonical discriminant analysis (SAS Institute Inc., 1985). The objective of these analyses was to find the combination of environmental factors which best explained differences among groups of biologically similar stations. To this end, the data collected during Cruises 2 and 3 were analyzed independently and combined in three separate analyses.

The first step in the canonical discriminant analysis was to define the station groups. The results of the clustering analyses presented above were used for this purpose.

As is clear from the preceding discussion, a large number of environmental variables were available for the analysis. It was therefore necessary to limit the set of variables to a manageable number. Hence, the second step was to select the more appropriate environmental parameters to be included in each canonical discriminant analysis to differentiate the station groups. For each analysis case (Cruise 2, Cruise 3, and combined Cruises 2 and 3) the data were divided into five suites of environmental parameters--sedimentological, trace metals, aliphatic hydrocarbons, unresolved complex mixture, and aromatic hydrocarbons. The sedimentological suite included grain-size fractions (gravel, sand, silt, and clay as weight percent), total organic carbon and calcium carbonate concentrations, and sediment grain-size distribution statistics (mean, sorting, skewness, and kurtosis). The other environmental suites included the appropriate parameters (mean values) determined from chemical analyses of the sediment samples. Principal component analysis (Morrison, 1976) was then applied to each set of variables to determine the

number of principal components which accounted for more than 80% of the variability among the stations. In the cases of the sedimentological and trace metal data sets, the variables which were best correlated with the principal components were used in the canonical discriminant analysis. For the UCM, aliphatic hydrocarbon, and aromatic hydrocarbon data sets, the first principal components were sufficient to satisfy the 80% variability criterion; and most parameters were relatively equally correlated with their respective principal components. Total UCM, total aliphatic hydrocarbon, and total aromatic hydrocarbon concentrations were, therefore, used in the canonical discriminant analyses.

The third step was to perform the canonical discriminant analyses for Cruise 2, Cruise 3, and Cruises 2 and 3 combined. In the latter case, the Julian date of collection was also included to determine the importance of seasonality. The results of the canonical discriminant analyses are presented below.

The results of the three canonical discriminant analyses are summarized in Table 27. Correlations between the first canonical discriminant variate derived in each analysis and the original variables are presented because this accounted for most of the variability among the station groups in all three cases--99%, 92%, and 87% for the Cruise 2, Cruise 3 and combined cruises analyses, respectively.

In the separate Cruise 2 and 3 analyses, sediment texture did not correlate well with the canonical discriminant variates (Table 27). Stronger correlations were observed with UCM, n-alkanes, mercury, and zinc. These results might suggest that station groupings were less related to sediment texture than to some other factors such as petroleum hydrocarbons and some heavy metals. In addition, variables that could be attributed to drilling disposal (e.g., aromatics, barium) did not correlate well with percent clay, which is normally elevated due to drilling mud disposal (Tables 28 and 29).

During Cruise 3, gravel and calcium carbonate correlated moderately with station groupings. Examination of the taxonomy of the benthic communities censused (and the species groups described earlier) suggested that the delineation of station groups could be explained in part by the addition to the community of a number of taxa associated with shell hash or rubble substrates. This community response to drilling fluid disposal was unusual in that species were added rather than eliminated at the discharge, resulting in moderate to high diversity and evenness near the platform. Other assemblages were also complemented by introductions of new species, such as *Sthenelais* sp. A at silty-clayey sand stations, and *Ampelisca* sp. L at sand-silt clay stations. In all, during Cruise 3, 61 new species appeared, while 15 species were absent. The widespread occurrence of these added species reflected uniformly good benthic habitat quality, despite correlations between station groupings and variables such as mercury and UCM.

Discriminant analysis of Cruises 2 and 3 combined highlighted seasonal effects on community structure (Tables 27 and 30). Station groups were also correlated with calcium carbonate, which was assumed to represent shell and encrusting material that was most abundant nearest the discharge site. Other

Table 27. Correlations between habitat variables and first canonical discriminant axis.

Variable	Cruise 2	Cruise 3	Cruises 2 and 3 Combined
Julian	--	--	1.00
Gravel	--	0.58	--
Sand	0.40	-0.27	-0.36
Silt	-0.26	0.09	0.31
Clay	-0.45	-0.07	0.23
TOC	--	0.30	0.14
Calcium Carbonate	0.79	0.53	-0.81
Barium	0.46	0.55	-0.24
Chromium	0.75	0.50	0.13
Iron	0.70	0.33	0.13
Mercury	--	0.71	0.24
Cadmium	0.84	0.55	0.10
Zinc	0.80	0.64	-0.01
Total UCM	0.94	0.71	0.40
Total n-Alkanes	0.90	0.64	0.29
Total Aromatics	0.76	0.44	0.15

Table 28. Correlations among the environmental parameters used in the Cruise 2 canonical discriminant analysis.

	Silt	Clay	Calcium Carbonate	Barium	Chromium	Iron	Cadmium	Zinc	Total Unresolved Complex Mixture	Total n-Alkanes	Total Aromatics
Sand	-0.96	-0.95	0.21	0.17	0.22	0.00	0.29	0.44	0.48	0.35	0.40
Silt		0.85	-0.17	-0.08	-0.15	0.10	-0.18	-0.41	-0.38	-0.23	-0.35
Clay			-0.22	-0.28	-0.21	-0.00	-0.32	-0.42	-0.51	-0.40	-0.39
Calcium Carbonate				-0.01	0.88	0.68	0.53	0.88	0.89	0.77	0.91
Barium					-0.15	-0.16	0.69	0.14	0.28	0.36	0.01
Chromium						0.87	0.48	0.81	0.80	0.66	0.91
Iron							0.41	0.54	0.65	0.61	0.63
Cadmium								0.70	0.72	0.77	0.57
Zinc									0.90	0.77	0.92
Total Unresolved Complex Mixture										0.90	0.85
Total n-Alkanes											0.75

Table 29. Correlations among the environmental parameters used in the Cruise 3 canonical discriminant analysis.

	Sand	Silt	Clay	Total Organic Carbon	Calcium Carbonate	Barium	Chromium	Iron	Mercury	Cadmium	Zinc	Total Unresolved Complex Mixture	Total n-Alkanes	Total Aromatics
Gravel	-0.37	0.42	-0.54	0.72	0.99	0.52	0.97	0.76	0.15	0.87	0.96	0.47	0.54	0.79
Sand		-0.79	-0.33	-0.70	-0.43	-0.21	-0.38	-0.63	-0.24	-0.27	-0.34	-0.17	-0.22	-0.35
Silt			-0.21	0.69	0.49	0.05	0.46	0.71	-0.06	0.35	0.38	0.08	0.14	0.35
Clay				-0.19	-0.52	-0.07	-0.54	-0.34	0.31	-0.52	-0.51	-0.14	-0.17	-0.36
Total Organic Carbon					0.74	0.14	0.71	0.74	0.15	0.64	0.69	0.17	0.23	0.53
Calcium Carbonate						0.55	0.98	0.78	0.11	0.83	0.93	0.48	0.57	0.81
Barium							0.48	0.13	0.25	0.35	0.46	0.55	0.58	0.57
Chromium								0.77	0.10	0.74	0.87	0.36	0.46	0.89
Iron									0.08	0.68	0.74	0.29	0.37	0.57
Mercury										0.12	0.20	0.24	0.14	0.15
Cadmium											0.97	0.60	0.63	0.38
Zinc												0.59	0.64	0.59
Total Unresolved Complex Mixture													0.98	0.18
Total n-Alkanes														0.27

Table 30. Correlations among the environmental parameters used in the combined Cruises 2 and 3 canonical discriminant analysis.

	Sand	Silt	Clay	Total Organic Carbon	Calcium Carbonate	Barium	Cadmium	Chromium	Iron	Mercury	Zinc	Total Unresolved Complex Mixture	Total n-Alkanes	Total Aromatics
Julian Day	-0.36	0.31	0.24	0.15	-0.81	-0.24	0.09	0.13	0.12	0.24	-0.02	0.39	0.28	0.15
Sand		0.87	-0.74	-0.68	0.37	0.15	-0.07	-0.10	-0.25	-0.24	0.11	-0.13	-0.12	-0.17
Silt			0.37	0.67	-0.29	-0.10	0.21	0.24	0.41	0.10	0.02	0.12	0.13	0.25
Clay				0.32	-0.30	-0.26	-0.37	-0.33	-0.10	0.23	-0.45	-0.07	-0.12	-0.24
Total Organic Carbon					0.05	-0.17	0.38	0.50	0.50	0.24	0.34	0.16	0.18	0.39
Calcium Carbonate						0.20	0.08	0.25	0.23	-0.06	0.40	-0.18	-0.06	0.03
Barium							0.36	0.05	-0.10	0.04	0.23	0.17	0.26	0.20
Cadmium								0.65	0.53	0.17	0.82	0.59	0.64	0.40
Chromium									0.81	0.23	0.83	0.42	0.49	0.80
Iron										0.27	0.62	0.33	0.40	0.46
Mercury											0.25	0.32	0.23	0.18
Zinc												0.52	0.58	0.54
Total Unresolved Complex Mixture													0.96	0.26
Total n-Alkanes														0.33

variables did not appear to be strongly related to the station groupings in the analysis of the combined cruises, despite moderate correlations noted above for the Cruise 2 and 3 analyses. The importance of season and calcium carbonate, rather than sediment texture or heavy metal/hydrocarbon levels, corroborated species assemblage distributions described previously. It also indicated that habitat modifications that could be related to drilling operations affected infauna assemblages less than changes caused by normal seasonal variation.

In summary, sediment texture was not related to the station groupings. In the cases of the individual cruises, correlations with some trace metals and hydrocarbons were observed, which could be interpreted to mean that discharged drilling effluents were directly responsible for the presence of the near-field assemblage. However, the composition of the near-field assemblage does not support this argument. Rather than a classical polluted outfall situation with the numerical dominance of a limited number of opportunistic species and associated low diversity and evenness, a relatively balanced assemblage occurred near the platform as a result of the habitat structure in the near-field environment. The grain-size data collected did not adequately indicate the change in habitat structure. The platform probably increased the habitat structure through sloughing of encrustations from platform supports and other hard surfaces. Cuttings, which provided a coarser substrate and some vertical relief in the vicinity of the discharge site may have also played a role.

In addition, reductions of some of the more ubiquitously distributed species occurred near the discharge site compared to abundances at the far-field stations. It is not possible to determine whether these reduced abundances were the result of coincidental distributions of the trace metals/hydrocarbons and the platform-related changes in habitat structure or were more directly related to the drilling effluent tracers. However, it is unlikely that the trace metals/hydrocarbons were directly related to the reductions of the more ubiquitously distributed species because these species are especially abundant in fine-grained estuarine sediments known to contain relatively high concentrations of trace metals and hydrocarbons.

3.5.4 Macroinfaunal Recruitment

Juvenile and larval life stages of macroinfauna were censused at each of the 19 benthic stations during Cruise 2. The numbers of taxa and mean densities were variable among the stations (Table 31). The significance of these observations cannot be evaluated based on a single sample at each station during a single cruise. Further sampling would be necessary for complete evaluation.

In terms of composition, polychaetes dominated the juvenile infauna, especially capitellids and paraonids. These polychaete families contained generally small species, which would be expected to be well-represented among organisms that pass through a 0.5-mm screen but retained on a 0.3-mm screen. In the fraction retained on the 0.3-mm screen, a fairly homogeneous mixture of macroinfaunal life stages--small adults and subadults--was present and the composition of the juvenile fractions was generally represented in the adult community. Therefore reproductive populations of infauna were probably present at all stations, including those proximal to the drilling disposal site. This indicated that normal recruitment of various taxa was occurring rather than immigration of older, larger adult individuals.

Table 31. Total taxa and mean densities for larval and juvenile macroinfauna.

Station	Total Taxa	Mean Density (individuals m^{-2})
10m-95°-2	1	125
25m-95°-2	1	63
25m-172°-2	8	1,500
25m-276°-2	4	500
75m-95°-2	6	2,250
75m-172°-2	4	1,875
75m-276°-2	3	625
150m-95°-2	10	3,438
150m-172°-2	14	4,000
150m-276°-2	6	1,688
300m-95°-2	5	1,750
300m-172°-2	7	3,688
300m-276°-2	8	1,750
750m-95°-2	8	3,438
750m-172°-2	12	2,563
3000m-95°-2	4	563
3000m-172°-2	13	4,250
5000m-95°-2	5	1,375
5000m-172°-2	15	4,125

4.0 SUMMARY

This program was conducted under the auspices of the American Petroleum Institute to examine the fate and effect of drilling fluid and cutting discharges from a multiple wellsite in a shallow, nearshore environment. The program was conducted in two phases. During the first phase, one cruise (Cruise 1) was conducted at a candidate site located on the south Texas continental shelf--"C" Platform in Matagorda Island Area Block 622--in October 1986. Preliminary sampling was conducted at the candidate site to determine: 1) whether or not the site was appropriate for the more intensive part of the program and 2) to determine the sampling program for the second phase. Samples for analysis of sediment grain size, trace metals, hydrocarbons, and macroinfauna were collected by divers at one station located at the discharge site and at 24 stations located at four distances (10, 100, 1,000, and 3,000 m) on six radials which were centered at the discharge site. Based on evaluation of the data collected during Cruise 1, this candidate site was selected as the Phase II study site.

During the second, intensive phase, two surveys of the selected study site were conducted in March/April and August 1987 (Cruises 2 and 3, respectively). During each cruise, 19 stations were occupied at eight distances (10, 25, 75, 150, 300, 750, 3,000, and 5,000 m) along three transects radiating from the discharge site. Transects were oriented from the discharge site along major gradients of trace metals and hydrocarbons (east and west) as well as in the cross-shelf direction (south).

Biological and physical sampling was conducted to determine whether or not drilling-related discharges affected the biotic assemblage in the surrounding environment. Samples were collected at each station to determine: 1) sediment grain size; 2) total organic carbon and calcium carbonate concentrations; 3) trace metal concentrations; 4) aliphatic and aromatic hydrocarbon concentrations; and 5) macroinfaunal abundances--adults and juveniles (Cruise 2 only). A current meter was deployed near the seafloor during the period between Cruises 2 and 3, and hydrographic profiling was performed during both cruises.

Longshore flow dominated the near-bottom currents from 27 March to 26 August 1987. The average current speed was 13.6 cm/s (0.3 kn) but currents reached 66 cm/s (1.3 kn). Current speeds tended to be lower later in the study period compared to March through May.

Temperatures were constant from the surface to the seafloor in October 1986 ranging from 25.5 to 25.6°C. They were also relatively constant but somewhat cooler in March 1987 (17.9 to 18.1°C). During the August 1987 cruise, a thermocline was observed between 15 and 20 m, and seasonal warming had increased temperatures compared to the March sampling. During this period, surface temperatures were between 29.3 and 29.5°C; near-bottom temperatures were 25.9 to 26.2°C. Salinities were constant from the surface to the seafloor in October 1986 and August 1987 (35.10 to 35.34 ppt; 36.61 to 36.87 ppt respectively), but

reduced near the surface during March 1987 (29.79 to 30.02 ppt). Dissolved oxygen concentrations were near saturation on Cruises 1 and 2.

Sediments were predominantly muddy sand or sandy mud on all cruises. Mean Cruise 2 calcium carbonate levels consistently exceeded 5% while mean Cruise 3 levels did not reach this concentration. Organic carbon levels were comparable between Cruises 2 and 3, ranging from approximately 0.2 to 0.7%.

During Phase I, a gradient of sediment barium concentrations was observed with respect to distance from the discharge site--barium values in the fine-grained sediment fraction were elevated near the platform compared to samples collected farther away. Phase I sediment trace metal samples were sieved in the laboratory and the fine-grained material (<63 μm) was analyzed in an attempt to standardize for differences in grain size among the stations. Barium concentrations in the fine-grained fraction at the 10-m stations exceeded 40,000 ppm at three of the six stations and were greater than 20,000 ppm for the other three. Four of the six 100-m stations had mean barium concentrations between 10,000 and 15,000 ppm, but two had concentrations of 30,000 to 40,000 ppm. At one 3,000-m station, the mean barium concentration was 5,900 ppm, but mean concentrations at the others were less than 2,500 ppm. Barium-to-iron ratios indicated barium enrichment in the Phase I sediment samples, even those from the 3,000 m stations. This ratio was used to normalize the data for variations in quartz and calcium carbonate, which are very low in barium. Similarly, chromium also decreased with distance from the platform, but the enrichments over expected background levels were mostly restricted to the 10-m stations.

The high barium concentrations found in sediments near "C" Platform during Phase I were confirmed during Phase II. The highest Phase II barium concentrations were about 20,000 ppm, whereas several samples from Phase I had over 40,000 ppm barium. This difference was due to two factors. First, the Phase II sediment samples were not sieved prior to trace metal analysis; hence the difference was partially due to the difference between analyzing whole sediments and fine-grained samples. The second factor was the highly variable distribution of barium in the sediment, both spatially and temporally. Mean barium concentrations were elevated within 75 m of the discharge site, reaching 20,000 ppm, and concentrations remained high at 300 m where 3,000 to 7,000 ppm was observed. At 750 m, a mean concentration of about 2,000 ppm was found at one of the stations on both cruises. At 3,000 and 5,000 m from "C" Platform, barium concentrations were 800 to 1,200 ppm, well above the estimated background level for this area of 500 to 600 ppm. In addition to barium, chromium, and iron, Phase II trace metal samples were analyzed for cadmium, mercury, and zinc. The distributions of chromium, cadmium, mercury, and zinc indicated that high concentrations of these trace metals were restricted almost exclusively to within 25 m of the platform.

During Phase I, concentrations of EOM, UCM, and normal alkane hydrocarbons were determined. EOM concentrations exceeded 500 ppm within 10 m of the discharge site; UCM and total alkane concentrations exceeded 100 ppm and 4,600 ppb, respectively, within 10 m of the platform. These concentrations were an

order of magnitude higher than at stations located at distances greater than 10 m from the platform.

Average Phase II sediment EOM concentrations at 10 m were 232 and 276 ppm during Cruises 2 and 3, respectively, compared with 535 ppm during Cruise 1. The more closely spaced Phase II sampling revealed that elevated EOM concentrations extend to 25 m east and west of the platform. EOM concentrations were higher at all stations during Cruise 3, possibly as a result of increased biological productivity input from the water column into the sediments during this period. Alkane distributions during Cruises 2 and 3 were primarily due to biogenic hydrocarbons. Cruise 2 UCM concentrations were elevated 10 and 25 m from the platform. Concentrations at these stations were three times higher than observed during Cruise 1 at stations located near the platform; slightly higher concentrations were observed at the background stations compared to Cruise 1. The mean Cruise 3 UCM concentration at 10 m was 852 ppm compared to 280 and 100 ppm during Cruises 2 and 1 respectively. Higher UCM concentrations were observed at most stations during Cruise 3, probably as a result of other contamination or a large biological lipid input during this period. Similar patterns were observed for total n-alkanes. Elevated levels were observed at 10 and 25 m during Cruise 2 and at 10, 25, and 75 m during Cruise 3. There was considerable biological interferences in n-alkane concentrations during Cruises 2 and 3.

In addition to measurements of the EOM and aliphatic hydrocarbon concentrations, PAH concentrations were also determined during Phase II. Elevated concentrations of PAH were restricted to stations located at 10 and 25 m from the platform. The background total PAH concentration at stations located more than 25 m from the platform was 29.4 ppm compared to an average 494 and 757 ppm at 10 and 25 m respectively, during Cruises 2 and 3.

Three taxonomic groups--Annelida, Crustacea, and Mollusca--dominated the macroinfaunal samples in terms of the numbers of taxa and numbers of individuals. Annelids (principally, polychaetes) contributed 36.4% of the taxa present; crustaceans and mollusks contributed 34.4% and 21.3%, respectively. Numbers of taxa did not appear to be related to station locations. Numbers of taxa at stations 75 m or closer to the platform were comparable to those observed at more distant stations. In terms of numbers of individuals, 65.4% were polychaetes, 17.4% were mollusks, and 10.0% were crustaceans. The seven most abundant taxa accounted for 45.7% of the total individuals collected. Infaunal densities varied widely among stations and among cruises. Stations near the platform (within 75 m) exhibited both the lowest and highest infaunal densities. Relatively higher diversities were observed at stations located near the discharge site.

Clustering analyses revealed a biological gradient with respect to the platform in terms of taxonomic composition and abundance. Generally, stations located within 75 m of the discharge site were more similar to each other than to stations located farther away. In addition, the clustering analyses indicated temporal differences among stations; however, these differences were within the broader gradient related to distance from the platform. Three macroinfaunal assemblages of taxa were identified. One assemblage, the Shelly Sand Group, was restricted to

those stations nearest the platform (i.e., 25 m or less). This assemblage included primarily surface or tube dwellers which were representative of filter feeding and carnivorous feeding guilds. The Sand-Silt Clay and Silty-Clay Sand assemblages were most dominant at stations greater than 150 m from the platform but were represented in all areas sampled during this study. The Sand-Silt Clay Group included surface or burrowing deposit feeders, while the Silty-Clayey Sand assemblage was dominated by carnivores and surface deposit feeders.

With the exception of the Shelly Sand assemblage, infauna censused during this study were typical of nearshore soft-bottom communities throughout the region. The species in the Shelly Sand assemblage are associated with structures and/or coarser sediments. This suggested that the platform influenced the benthos through sloughing of encrustations from platform supports, anchors/chains, or other hard surfaces. In addition, disposal of cuttings may have provided a coarser substrate and some vertical relief in the vicinity of the discharge site.

Comparisons of the distributions of the environmental parameters to the distributions of the macroinfaunal assemblages using canonical discriminant analysis revealed that sediment texture was generally not responsible for differences among the biological groups. In the cases of the individual cruises, correlations with some trace metals and hydrocarbons were observed, which could be interpreted to mean that discharged drilling effluents were directly responsible for the presence of the near-field assemblage. If this were true, the near-field assemblage would be numerically dominated by a limited number of opportunistic species and the assemblage would exhibit low diversity and evenness--the classic situation for a polluted outfall. This was not the case because a relatively balanced assemblage occurred near the platform, probably as a result of the increased habitat structure in the near-field environment. This assemblage was composed of species from the Shelly Sand assemblage and members of the two more ubiquitously distributed assemblages. The addition of the Shelly Sand species was probably a result of the platform acting as a source of material (sloughing of encrustations and perhaps drill cuttings) which increased habitat structure.

The abundances of some of the more ubiquitously distributed species were reduced near the discharge site compared to abundances at the far-field stations, and trace metal and hydrocarbon distributions may have been related to these reduced abundances. Whether or not these reduced abundances were the result of coincidental distributions of the trace metals/hydrocarbons and the platform-related changes in habitat structure, or were more directly related to the drilling effluent tracers, cannot be determined from the data collected during this study. However, it is unlikely that the trace metals/hydrocarbons were directly related to the reductions of the more ubiquitously distributed species because these species are especially abundant in fine-grained estuarine sediments known to contain relatively high concentrations of trace metals and hydrocarbons.

5.0 CONCLUSIONS

The primary conclusions of the study are summarized below.

1) The sediment concentration of the insoluble, settleable fraction of drilling muds around "C" Platform was elevated compared to other previously studied sites such as Matagorda Island Area Block 686 (discussed by Boothe and Presley, 1985). This enrichment was indicated by the widespread distribution of barium in the surface sediments and in the vertical sediment column. A greater quantity of discharges compared to those previously studied sites, as indicated by greater quantities of barite used during drilling at this site, was probably responsible for the observed enrichment.

2) Elevated sediment concentrations of cadmium, mercury, and zinc primarily occurred within 25 m of the platform. The sources of these trace metals were unclear. Poor correlations between the distributions of these metals and barium suggested that drilling discharges may not have been the source, but drilling discharges could not be definitively excluded based on available data.

3) Contamination of the sediments by organic compounds was only observed in the near vicinity of the platform (<25 m). PAH concentrations in this immediate vicinity were from thermogenic (oil-related) sources. It was not possible to determine whether the elevated hydrocarbon concentrations observed around the platform were from oil-contaminated cuttings or discharges of oil.

4) The species composition, abundance, and diversity of the macroinfauna were similar to the macroinfaunal data reported in the literature for this area.

5) Macroinfauna abundance and diversity changed uniformly throughout the study area over time. This indicated that temporal changes in these parameters were related to season.

6) Similarly, macroinfaunal assemblage structure was most influenced by season. The presence of materials sloughed from the platform and possibly cuttings were responsible for changes in the macroinfaunal assemblage within 150 m of the platform--increased numbers of surface-dwelling macroinfaunal species, including taxa normally associated with shell reefs, rubble bottoms, and hard substrates. Trace metals and hydrocarbons associated with drilling discharges from the platform appeared to have little, if any, effect on the macroinfaunal assemblage structure.

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APPENDIX A

QUALITY ASSURANCE

QUALITY ASSURANCE

Organic And Inorganic Carbon

Blanks and standards were run on a daily basis. Leco steel carbon rings were analyzed as calibration standards. Precision at typical marine sediment concentrations is 5%.

Trace Metals

The procedure used to collect the trace metal samples was described in the Sampling section of this report and in cruise reports submitted to API previously. This procedure was designed to insure that an undisturbed sample of the seafloor was collected, that it included the surface-most sediment layer, and that the sediment was not contaminated during sampling or storage.

Every precaution was taken to avoid contamination of the sample during preparation and analysis in the laboratory. Only low trace metal content containers and implements were used and the samples were kept covered to avoid dust from laboratory air. All reagents used were selected for their low trace metal content and blanks were analyzed with every set of samples.

The analytical procedures used for this study were identical to those used for the National Oceanic and Atmospheric Administration National Status and Trends (S&T) Program. This laboratory has participated in the S&T Program for three years and in the course of that participation has been involved in several intercalibration exercises. These exercises consisted of analyzing sediment samples for 17 different trace metals and comparing results with other participating laboratories, including the National Bureau of Standards. Our results have consistently been within 10% of the accepted values in these exercises.

In addition to analyzing samples of previously unknown composition as part of intercalibration exercises, standard reference sediments of known composition obtained from the U.S. National Bureau of Standards and other sources were analyzed with every set of samples analyzed in this study. These materials were chosen because of their similarity to the sediment samples collected during this study. Trace metal analysis accuracies, precisions, and detection limits for Phase I samples are presented in Table QA-1. Data obtained during Phase II of the project are given in Tables QA-2 and QA-3 for instrumental neutron activation analysis and atomic absorption spectrometry, respectively.

Hydrocarbons

Alkanes

A quantitative alkane standard (including pristane and phytane) from n-C_{11} to n-C_{34} containing all of the internal standards is prepared twice yearly

Table QA-1. Trace metal analysis accuracy, precision, and detection limits.

Element	Material*	Method§	N¶	Concentration†		Relative Error**	Coefficient of Variation§§	Detection Limit¶¶
				This Study	Accepted			
Arsenic	MESS-1	FLAA	7	10.7	10.6	0.9	6.2	0.2
Barium	NBS 1646	INAA	5	435	425‡‡	2.4	5.5	25
Cadmium	MESS-1	FLAA	5	0.63	0.59	6.8	4.7	0.01
Chromium	NBS 1646	INAA	5	77	76	1.3	2	1.0
Iron	NBS 1646	INAA	5	3.30	3.35	1.5	2.5	70
Lead	MESS-1	FLAA	5	32	34	-5.9	6.0	0.1
Mercury	NBS 1646	CVAA	10	0.068	0.063	7.9	10.0	0.010
Zinc	MESS-1	FAA	5	185	191	-2.9	5.2	2

* NBS 1646 = National Bureau of Standards Estuarine Sediment.
MESS-1 = National Research Council of Canada Marine Sediment.

§ FAA = Flame atomic absorption spectrophotometry.
FLAA = Flameless atomic absorption spectrophotometry.
INAA = Instrumental neutron activation analysis.
CVAA = Cold vapor atomic absorption.

¶ N = Number of replicates analyzed to determine accuracy and precision.

† All concentrations are in µg/g dry weight except iron which is in weight percent.

** Relative Error = {[(concentration this study) - (concentration accepted)]/(concentration accepted)} x 100.

§§ Coefficient of Variation = standard deviation/mean x 100.

¶¶ Detection Limit in ppm = concentration equal to twice the blank signal.

‡‡ Calibrated by primary element standards, n = 10.

Table QA-2. Accuracy and precision of neutron activation analysis.

Element	Reference Material*	Type of Material	N§	Concentration¶ This Study	Concentration¶ Accepted	RE†	Precision** P.C.V.	Precision** Difference
Barium	GXR-5	Soil	6(5)	2024 ± 36	2000	1.2	2.0	2.3
Chromium	GXR-5	Somerset Co.	6(5)	103 ± 2.3	101	2.0	2.5	2.8
Iron	GXR-5	Maine, USA	6(5)	3.60 ± 0.06	3.49	2.3	1.8	1.8
Barium	TAMU-1	Mississippi	13(6)	745 ± 14	740	0.6	-	-
Chromium	TAMU-1	River Delta	13(6)	65 ± 1.2	66	-1.7	-	-
Iron	TAMU-1	Sediment	13(6)	3.05 ± 0.06	3.07	-0.7	-	-
Barium	TAMU-2	Mississippi	25(7)	701 ± 16	705	-0.5	-	-
Chromium	TAMU-2	River Delta	25(7)	86.8 ± 3.0	88	-1.4	-	-
Iron	TAMU-2	Sediment	25(7)	3.71 ± 0.07	3.76	-1.2	-	-

* GXR-5: USGS geochemical exploration standard; TAMU-1 and TAMU-2: Locally prepared sediment standards.

§ Number of replicate analyses (separate irradiations) performed to produce the accuracy data presented.

¶ All concentrations are in μg/g dry weight except Fe which is in percent dry weight. Accepted concentrations are based on calibration against primary element standards.

† RE = Relative Error = $\frac{\text{(conc. this study) - (conc. accepted)}}{\text{(conc. accepted)}} \times 100$

** P.C.V.: Mean percent coefficient of variation [(S.D./Mean) x 100] based on the analysis of a total of 44 replicate aliquots among the three reference materials.
Diff.: Mean percent difference among 18 samples (three separate irradiations) analyzed in duplicate.

Table QA-3. Accuracy and precision of atomic absorption analyses.

Element	Reference Material*	N§	Concentration¶ This Study	Concentration¶ Accepted	RE†	P.C.V.**
Cadmium	MESS-1	9	606	590 ± 10	2.7	7.5
Mercury	MESS-1	4	180	171 ± 14	-5.3	10.7
Zinc	MESS-1	9	191	191 ± 17	0.0	5.8
Cadmium	NBS-1646	9	359	360	0.3	9.2
Mercury	NBS-1646	4	80	63	27	11.0
Zinc	NBS-1646	9	132	138	4.3	4.3
Cadmium	TAMU-2	3	464	435	6.7	5.3
Mercury	TAMU-2	-	-	-	-	-
Zinc	TAMU-2	2	139	138 ± 6	0.7	4.6

* MESS-1: National Research Council of Canada marine sediment; NBS-1646: U.S. National Bureau of Standards estuarine sediment; TAMU-2: locally prepared Mississippi River Delta sediment standard.

§ Number of replicate analyses performed to determine accuracy and precision of data given.

¶ All concentrations are in ng/g dry weight except Zn which is in μg/g dry weight.

† RE = Relative Error as defined in Table QA-2.

** P.C.V. = Percent Coefficient of Variation as defined in Table QA-2.

(Alltech Assoc. and MSD Isotopes). The new standard is calibrated against the previous standard.

Initial calibration and determination of linearity of the gas chromatographic flame ionization detector (GC/FID) was accomplished with the injection of quantitative standards at three concentrations. The instrument was in calibration when the R (correlation coefficient) of the calibration points exceeded 0.99 for a first degree fit of the data. Concentrations of identified compounds were calculated from the average response factor for the three quantitative standard injections. An unresolved complex mixture (UCM) concentration was calculated using a computer-based method. An electronic baseline generated from the daily solvent blank injection was subtracted from each sample analysis and an UCM was calculated exclusive of any resolved peaks. An average response factor for n-alkanes over the retention time range of the UCM was used to calculate a pseudo-concentration.

A calibration check was run twice daily (per ≈10 sample analyses) and calculated values must have predicted the known value within ±20% on average for all analytes and ±30% for any single analyte or remedial action was taken. No further samples were analyzed until the instrument was in calibration. A "blank" and "spiked blank" were included in each set (≈10) of samples. "Spiked blanks" and/or standard reference materials (SRMs) had to calculate within ±30% of the known concentration on average for all analytes and within ±35% for individual analytes or analyses were halted. Duplicate samples were analyzed at a frequency of 5%.

Aromatics

All glassware was pre-cleaned by washing in Micro cleaning solution, rinsing with distilled water and combusting at 400°C for 4 h. All solvents were glass-distilled, nanograde purity (e.g., Burdick and Jackson). Solvent purity was checked by concentration of each solvent 10-fold greater than the concentration factor required in the analytical methodology. The concentrated solvent was tested by the same analytical and detection systems as samples and all analytes of interest in the blank analysis had to be lower than the limit of quantitation (LOQ) for the solvents to be acceptable for sample processing.

Each set of samples (10 to 20) was accompanied by a "system blank" and a "spiked blank" which were carried through the entire analytical scheme in a manner identical to samples. "System blanks" and "spiked blanks" were evaluated by GC with appropriate detectors. "System blanks" included all reagents, solvents, and internal standards. "System blanks" were acceptable if all of the analytes of interest were below the LOQ, otherwise corrective action was taken. No samples were processed until an acceptable "system blank" was obtained. "Spiked blanks" were "system blanks" plus known amount of all analytes. Standard reference materials (in the appropriate matrix) were analyzed as additional quality assurance checks.

Internal standards (IS's) were added to all samples immediately before extraction. The aromatic IS contained d_4-1, 4-dichlorobenzene, d_8-naphthalene, d_{10}-acenaphthene, d_{10}-phenanthrene, d_{10}-chrysene, and d_{10}-perylene. IS's were added at

a concentration similar to that expected for the analytes of interest. It has be verified that all IS's are fully resolved from, and do not interfere with, natura occurring substances under the described analytical conditions. All data w corrected for IS recoveries.

The mass spectrometry (MS) was calibrated daily to the stand Hewlett Packard autotune parameters using perfluorotributylamine. The chromatography/mass spectrometry (GC/MS) was initially calibrated and detec linearity was determined by duplicate injection of standards (including all inter standards) at three concentrations (usually 0.5 ng/μl, 2.5 ng/μl, and 5.0 ng/μl). T GC/MS was in calibration when a R of better than 0.99 for a first degree fit of data is obtained. Sample components were quantified from the average response the standard injections. Peak identity was confirmed by their molecular ion, ratio of the primary (base) ion to the secondary ion, and retention time. A minimum, calibration checks were analyzed daily. "Spiked blanks" and "syst blanks" were analyzed with each set of samples. Calibration checks were routin analyzed twice daily (per ≈10 samples analyses). The GC/MS was considered to in calibration if the average percent difference between the calculated value and known value for the calibration check was on average less than ±20% for all analy and less than ±30% for individual analytes. Typical calibration parameters GC/MS selective ion monitoring for quantification of aromatic hydrocarbons presented in Table QA-4. Duplicate samples were run at a frequency of 5%. T "spiked blank" and/or SRM was considered acceptable if the percent differe between the calculated and the known value was less than ±30% on average for analytes and individual analytes were less than ±35%. A gas chromatograp internal standard (GC-IS) (haxamethylbenzene) was added just prior to the chromatography/mass spectrometry/selected ion mode (GC/MS/ SIM) analy The sample analyte concentrations were calculated using the appropriate inter standard area and the average response factor from the six standard injections. T GC-IS recoveries were used to estimate absolute recoveries in order to evalu analyte losses during the analytical procedure. Data were not corrected for GC recoveries.

Due to the potential for artifacts created by the high degree automation in today's analytical systems, visual and manual calculation checks essential. Every GC and GC/MS/SIM pattern was visually inspected to ve proper selection of peaks for quantitative calculations based on retention tin Analyte retention times were verified versus the standard run most closely in ti After establishment of calibration curves all standards were recalculated to verify calibration file. Calculations were checked every third day manually. Tabulati of the daily response factor were maintained in order to assure stability with t and to highlight any unusual shifts in sensitivity or possible misidentificatior peaks.

LOQ for sediment polynuclear aromatic hydrocarbon compounds w 5 ng/g (ppb). These limits were determined by serial dilution of authentic stand and set at the level where the error in replicate injections of a standard was gre than ±30%.

Table QA-4. Typical calibration parameters for GC/MS selected ion monitoring for the quantification of aromatic hydrocarbons.

Enter list format Short (S) or Full (F): S
Quant ID File: INBS: L1
Title: MUSSEL WATCH YEAR II ID FILE (NBS STDS-USE WITH GC/MS)
Last EDIT Date: 870519 10:27 Last Calib Date: 870519 09:07

RT Window (+/- min):	.35
Max Hits/Compound:	5
Minimum Area:	100
Peak/Base Peak Ratio:	20.00%
Slope Sensitivity:	.750
Subtraction Method:	2
Auto Qdel Method:	1
Units of Conc:	ppb

Number of Compounds: 30

Comp No.	Compound Name	Retention Time Min. (Rel)	R.F.	Conc.
1)	*Hexamethylbenzene	14.43 (1.000)	0.00000	7.94
2)	*d8-Naphthalene	10.27 (1.000)	0.00000	4.00
3)	Naphthalene	10.31 (1.004)	1st DEGREE	5.50
4)	2-Methylnaphthalene	12.08 (1.176)	1st DEGREE	6.50
5)	1-Methylnaphthalene	12.31 (1.199)	1st DEGREE	6.27
6)	*d10-Acenaphthene	14.67 (1.000)	0.00000	4.00
7)	Biphenyl	13.25 (.903)	1st DEGREE	5.57
8)	2,6-Dimethylnaphthalene	13.70 (.934)	1st DEGREE	5.78
9)	Acenaphthylene	14.26 (.772)	1st DEGREE	5.78
10)	Acenaphthene	17.74 (1.005)	1st DEGREE	5.59
11)	2,3,5-trimethylnaphthalene	15.85 (1.080)	1st DEGREE	5.32
12)	Fluorene	16.04 (1.093)	1st DEGREE	5.84
13)	*d10-Phenanthrene	18.33 (1.000)	0.00000	4.00
14)	Phenanthrene	18.39 (1.003)	1st DEGREE	5.60
15)	Anthracene	18.51 (1.010)	1st DEGREE	6.23
16)	1-methylphenanthrene	19.99 (1.090)	1st DEGREE	5.58
17)	Fluoranthene	21.40 (1.167)	1st DEGREE	4.73
18)	Pyrene	21.93 (1.196)	1st DEGREE	4.73
19)	*d12-Chrysene	25.00 (1.000)	0.00000	4.00
20)	Benz(a)anthracene	24.99 (.999)	1st DEGREE	2.86
21)	Chrysene	25.07 (1.003)	1st DEGREE	5.59
22)	*d12-Perylene	28.81 (1.000)	0.00000	4.00
23)	Benzo(b)fluoranthene	27.78 (.964)	1st DEGREE	4.18
24)	Benzo(k)fluoranthene	27.81 (.965)	1st DEGREE	4.49
25)	Benzo(e)pyrene	28.52 (.990)	1st DEGREE	4.48
26)	Benzo(a)pyrene	28.66 (.995)	1st DEGREE	5.44
27)	Perylene	28.89 (1.003)	1st DEGREE	5.67
28)	Indeno(1,2,3-c,d)pyrene	32.78 (1.138)	1st DEGREE	5.05
29)	Dibenz(a,h)anthracene	32.81 (1.138)	1st DEGREE	4.21
30)	Benzo(g,h.i)perylene	33.84 (1.174)	1st DEGREE	4.21

* Internal standard.

Macroinfauna

Approximately 5% of the samples were resorted for quality control purposes; all contained fewer than 5% of the total individuals present, and passed the quality check. Taxonomic identifications were verified by in-house quality control checks and by comparison with in-house reference collections. Several representatives of each species were placed in a project voucher collection.

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