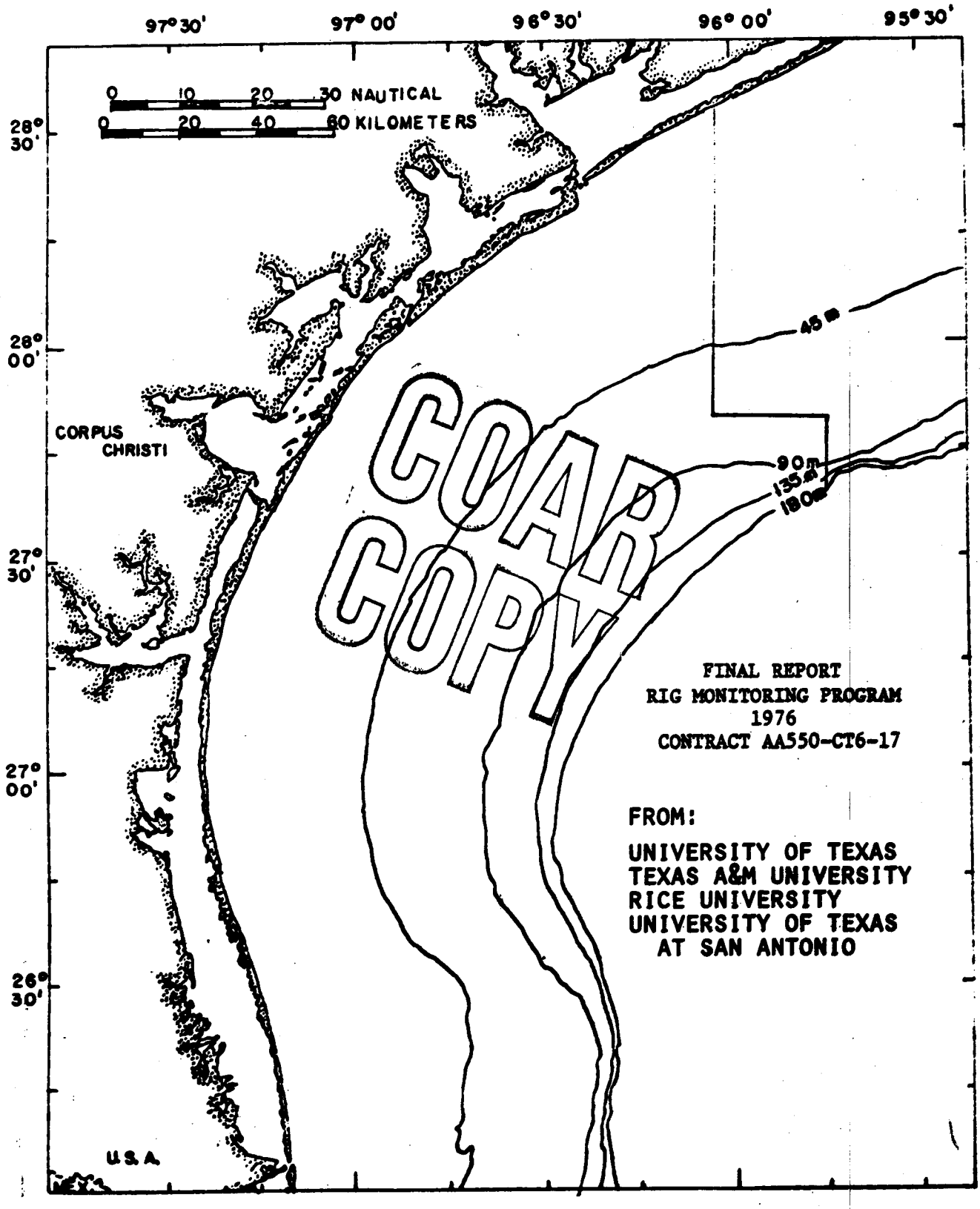
1977 - 16

ENVIRONMENTAL STUDIES, SOUTH TEXAS OUTER CONTINENTAL SHELF, BIOLOGY AND CHEMISTRY



FINAL REPORT
RIG MONITORING PROGRAM
1976
CONTRACT AA550-CT6-17

FROM:

UNIVERSITY OF TEXAS
TEXAS A&M UNIVERSITY
RICE UNIVERSITY
UNIVERSITY OF TEXAS
AT SAN ANTONIO

ENVIRONMENTAL STUDIES,

SOUTH TEXAS OUTER CONTINENTAL SHELF,

RIG MONITORING PROGRAM

Submitted to:

The Bureau of Land Management
Washington, D. C.

by

The University of Texas Marine Science Institute
Port Aransas Marine Laboratory
Port Aransas, Texas 78373

Acting for and on behalf
of a Consortium Program
Conducted by:

Texas A&M University
University of Texas
U.S. Geological Survey

FINAL REPORT
RIG MONITORING PROGRAM
1976
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October 21, 1977

This report has been reviewed by the Bureau of Land Management and approved for publication. Approval does not signify that the contents reflect the views and policies of the Bureau, nor does mention of trade names of commercial products constitute endorsement or recommendation for use.

FOREWORD

This rig monitoring program was a part of the overall study of the South Texas Outer Continental Shelf (STOCS) conducted on behalf of the U.S. Bureau of Land Management. The purpose of this monitoring program was to determine any spatial and temporal impacts on the immediate environment resulting from exploratory drilling activities.

This study was the result of the combined efforts of scientists and support personnel from the University of Texas, Texas A&M University and the U.S. Geological Survey. Cooperation of AMOCO representatives was appreciated.

ENVIRONMENTAL STUDIES,
SOUTH TEXAS OUTER CONTINENTAL SHELF,
RIG MONITORING PROGRAM

List of Contributors

Program Management Staff:

R. D. Groover-Program Manager; Compiler; Editor
G. P. Pfeiffer-Technical Coordinator
C. W. Griffin-Senior Marine Technician; Coordination; Reports
D. A. Kalke-Program Secretary; Compilation; Reports
T. C. Moore-Drafting Technician

Data Management Staff:

N. K. Fowler-Data Manager
J. M. Whitehead-Statistician

University of Texas
Marine Science Institute:

E. W. Behrens
J. S. Holland
P. L. Parker
R. S. Scalan
N. P. Smith
J. K. Winters
D. E. Wohlschlag

Texas A&M University:

C. S. Giam - Project Coordination
P. N. Boothe
J. M. Brooks
H. S. Chan
W. E. Pequegnat
B. J. Presley
R. E. Rezak
W. M. Sackett

United States Geological Survey
Corpus Christi, Texas:

G. Shideler
C. Holmes

Texas A&I University:

S. Barnes (in conjunction with USGS)

CONTRACTING OFFICER'S AUTHORIZED REPRESENTATIVE (COAR):

Dr. R. E. Defenbaugh
Bureau of Land Management
New Orleans OCS Office
Hale Boggs Federal Building
Suite 841
New Orleans, Louisiana 70130

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.'D)

TABLE OF CONTENTS (CONT.'D)

LIST OF TABLES

LIST OF TABLES (CONT.'D)

LIST OF TABLES (CONT.'D)

LIST OF FIGURES

LIST OF FIGURES (CONT.'D)

CHAPTER ONE

INTRODUCTION

Background

In 1974, the Bureau of Land Management (BLM), as manager of the ..er Continental Shelf Leasing Program, was authorized to initiate a National Outer Continental Shelf Environmental Studies Program. The broad objectives of this program, as stated by the BLM, are:

(a) to provide information about the Outer Continental Shelf (OCS) environment to enable the Department of the Interior to make management decisions regarding OCS oil and gas development; and

(b) to fill environmental information needs of management, regulatory and advisory agencies, both Federal and State, for a broad range of OCS activities, including the preparation and review of environmental impact statements under the National Environmental Policy Act (NEPA) of 1969, issuance of regulations and permits, and implementation of certain other laws, such as the OCS Lands Act, Fish and Wildlife Coordination Act, the Coastal Zone Management Act, and counterpart state laws.

The National Outer Continental Shelf Environmental Studies Program consists of three basic elements: (1) baseline studies, which are conducted during the pre-development period; (2) long-term monitoring studies; and, (3) special studies, which may occur during the baseline and monitoring studies phases.

To accomplish the objectives of this program for the South Texas Outer Continental Shelf (STOCS), the BLM developed the Marine Environmental Study Plan for the South Texas Outer Continental Shelf. This plan called for an initial three year period of intensive study. The first year of this study (1975) was dedicated to the development of a biological, chemical,

geological and physical baseline. The objectives for the second year (1976) were to begin assessing the impacts of petroleum exploration and development and to expand the baseline effort to gain additional environmental information beyond that collected in the first year. To begin assessing the impacts of petroleum exploration and development, pre-, during- and post-drilling surveys of a typical exploratory drilling rig were made during the period, September 1976 through March 1977. The results of this rig monitoring program are reported herein.

Purpose and Scope

The purpose of this monitoring program was to determine any spatial and temporal impacts on the immediate environment resulting from exploratory drilling activities. Assessments of biological, physical, chemical, geological and meteorological aspects of the environment in the vicinity of a typical exploratory drilling rig were made. Both descriptive and benchmark data were collected for comparison with the data base being established by the STOCS baseline surveys.

Description of the Study Area

Biological Setting

The Texas coastal area is biologically and chemically a two-part marine system, consisting of coastal estuaries and the broad continental shelf. These two marine systems are separated by barrier islands and connected by inlets or passes. The area is rich in finfish and crustaceans, many of which are commercially and recreationally important. Many of the finfish and decapod crustaceans of the STOCS area exhibit a marine-estuarine dependent life cycle, *i.e.*, spawning offshore, migrating shoreward as larvae and postlarvae, and utilizing the estuaries as nursery grounds (Galtsoff, 1954;

Gunter, 1945). The broad continental shelf supports a valuable shrimp fishery which, as a living resource, contributes significantly to the local economy. An excellent overview of the zoogeography of the northwestern Gulf of Mexico was provided by Hedgepeth (1953).

Location and Bathymetry

The site of the exploratory drilling rig monitored was determined on the basis of inquiry by the BLM through USGS. The site is located within the STOCS baseline study area which covers approximately 19,250 km^2 and is bounded by 96°W longitude in the east, the Texas coastline on the west and the Mexico-United States international border on the south (Figure 1). The continental shelf off south Texas has an average width of about 88.5 km and a relatively gentle seaward gradient that averages 2.3 m/km. The bathymetry of the STOCS area is shown in Figure 2.

Within the STOCS study area, 25 stations on four transects and eight stations on two topographic highs were sampled during the baseline survey. The rig monitoring site (27°44'21.12"N, 96°42'58.86"W in Block 755, Mustang Island Lease Area) was located between Transects I and II, 20 miles East-10° South of Port Aransas, Texas and in close proximity to the main Port Aransas shipping lane (Figures 3 and 4). The water depth at the site was approximately 33 m.

Description of Drilling Activities

The drilling rig was leased by AMOCO and was of the jack-up type. The rig was at the site from December 1, 1976, through January 20, 1977. Drilling began December 3, 1976, and was completed, after reaching a depth of 3352.8 m (11,000 ft), on January 15, 1977. Logging and other tests were conducted between 15 and 20 January. After testing was completed,

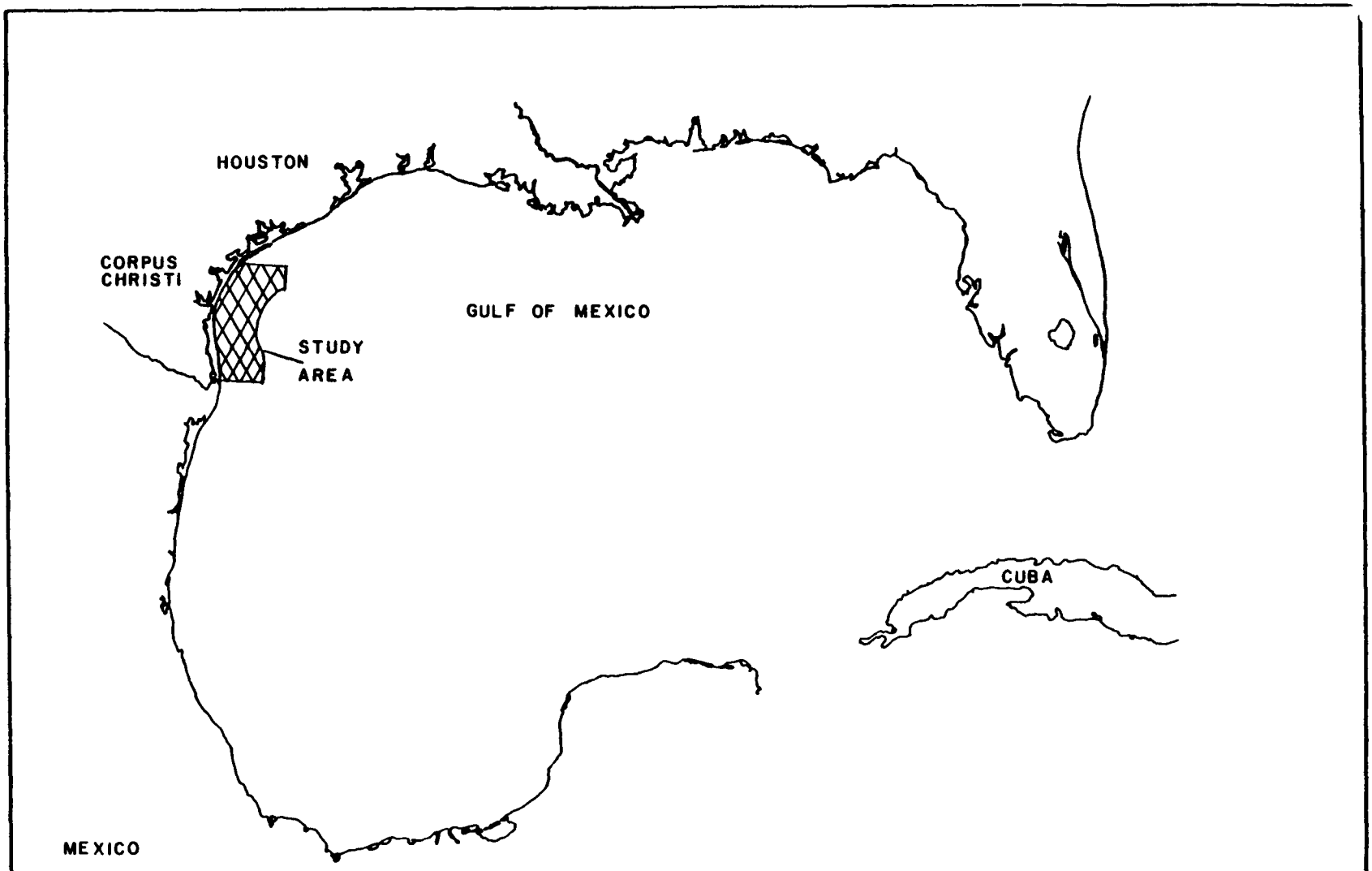


Figure 1. Location of the study area in relation to the Gulf of Mexico.

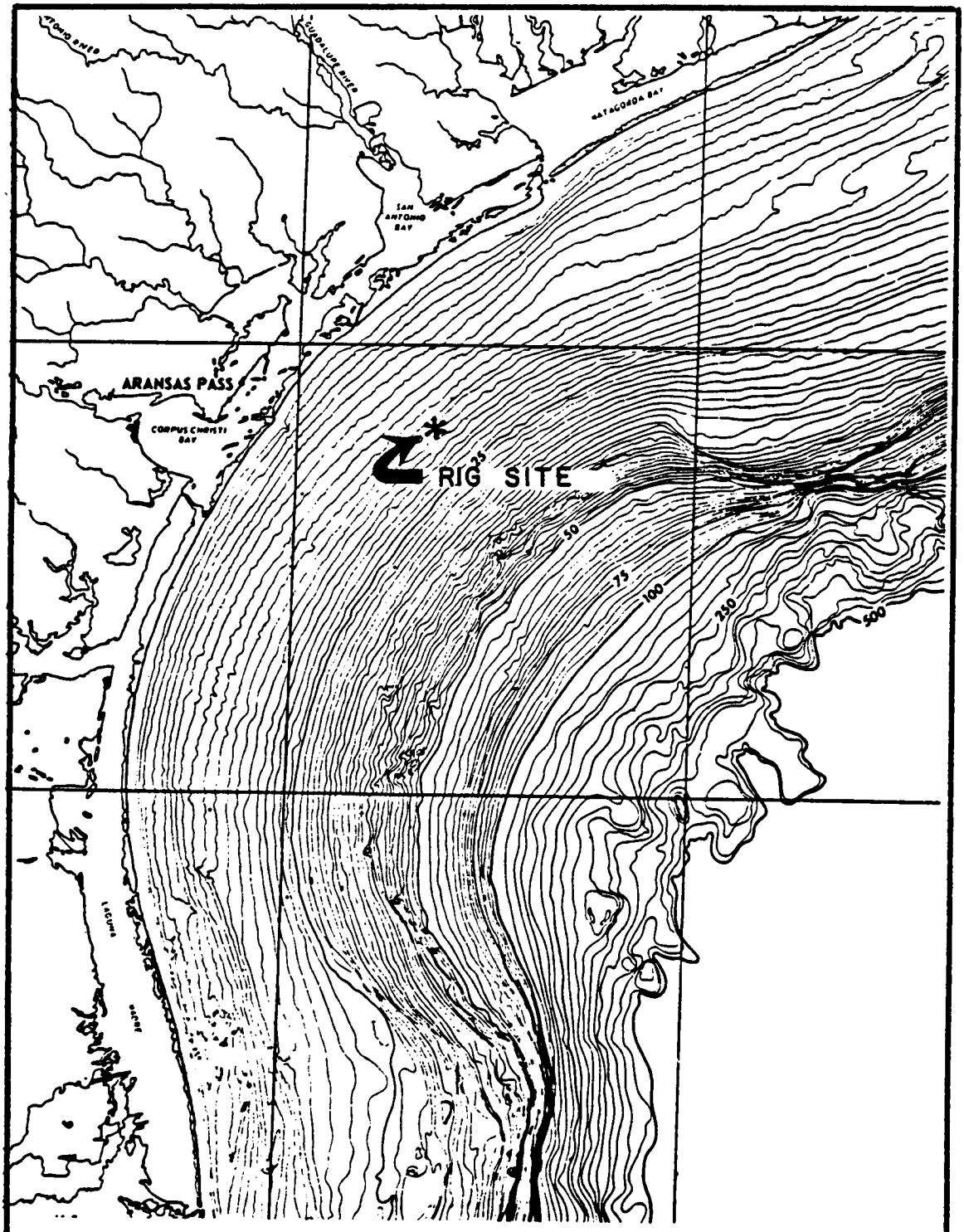


Figure 2. Bathymetry of the South Texas Outer Continental Shelf (Depth in Fathoms) From Berryhill *et al.*, 1976, Part I, Figure 3.

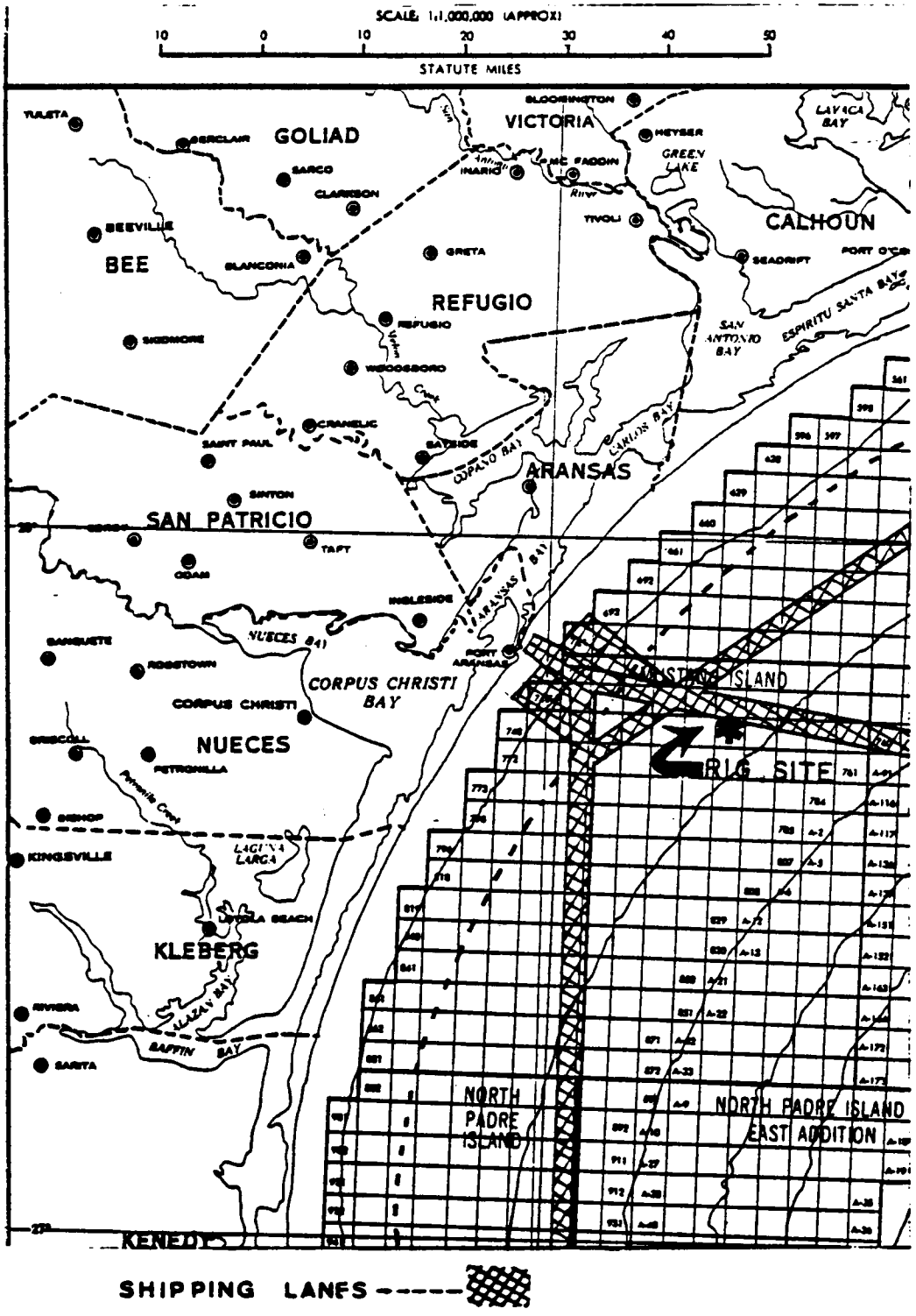


Figure 3. Rig Monitoring Drill Site-Mustang Island Lease Area-Block 755.

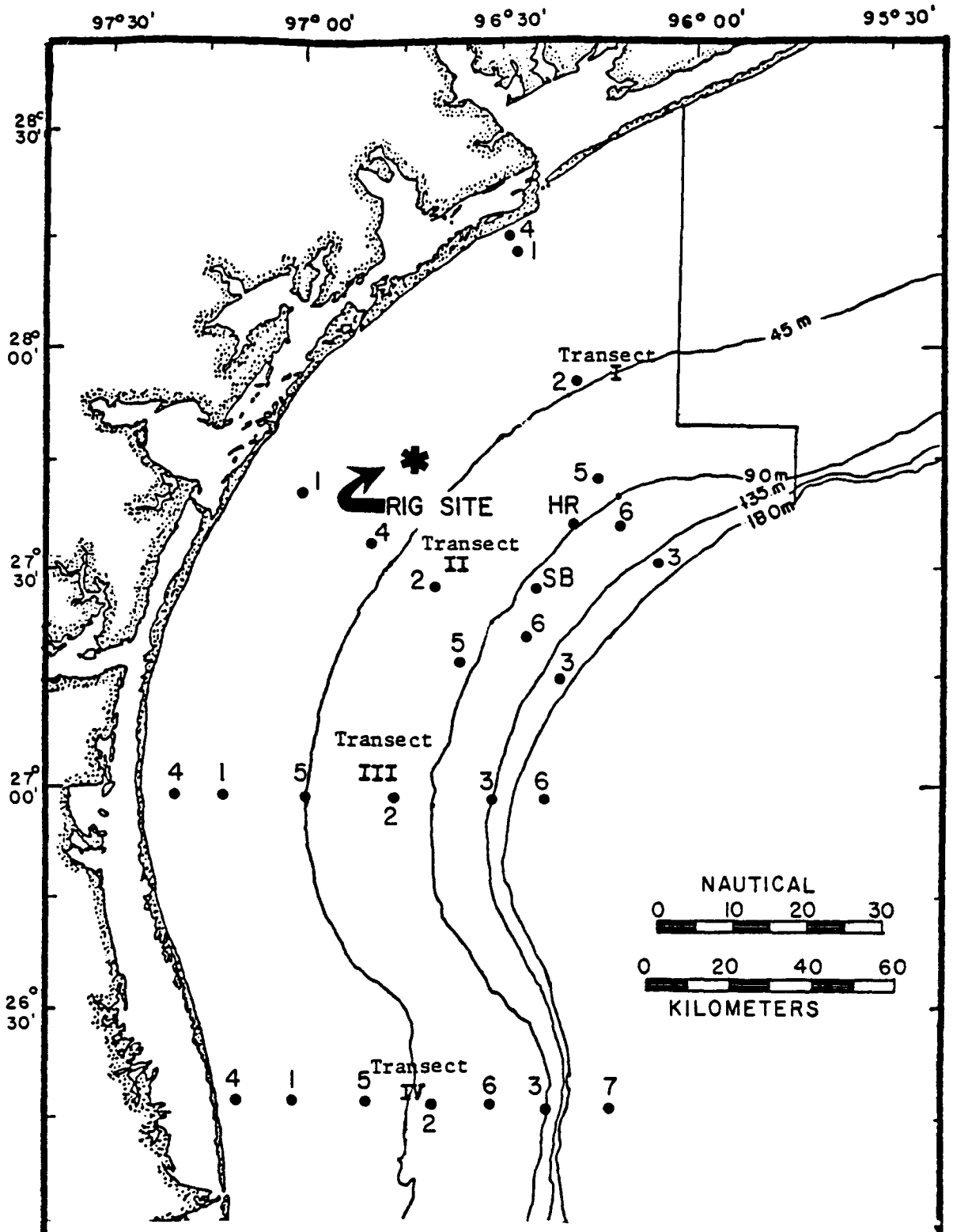


Figure 4. Station Locations for the 1976 South Texas Outer Continental Shelf Study. Depths in Meters.

a 76.2 cm (30 in) diameter pipe extending 4.57 m (15 ft) above the mud line was capped and left at the site.

Several drilling muds and additives were used in the drilling process. These included bentonite (montmorillonite), barite (Barium sulfate), lignosulfonate, caustic-sodium hydroxide, soda ash, aluminum stearate, sodium acid pyrophosphate, diatomaceous earth, walnut hulls, and ground-up polyethylene sheeting. These muds and additives were washed from the cuttings with fresh water and reused. The cuttings were then washed overboard with salt water. At the end of drilling operations approximately 500 barrels of drilling mud were dumped. The discharge from the drilling rig was approximately 50 ft above the sea surface.

Work Plan

Time Frame

The pre-drilling survey was accomplished September 25, 26 and 27, 1976 as the rig was expected to be on location by October 1, 1976. The during-drilling survey was conducted January 7 and 14, and post-drilling sampling was accomplished February 28, March 1 and 2, 1977. Laboratory analysis of all samples were complete by June 6, 1977.

Survey Vessels

Most sampling and measurements were taken aboard the University of Texas research vessel the R/V LONGHORN. The LONGHORN, designed and constructed as a coastal research vessel in 1971, is a 24.38 m (80 ft) long, 7.42 m (24 ft) wide, 2.13 m (7 ft) draft, steel-hulled ship. She carries a crew of five and can accomodate a scientific party of ten. The R/V LONGHORN is equipped with a stern-mounted crane, a trawling winch, scan sonar, radar, LORAN-A and LORAC navigational systems, and dry and wet laboratory space.

Low-molecular-weight hydrocarbon samples and transmissometry profiles for the pre-drilling survey were taken from Texas A&M University's vessel the R/V GYRE. Current meter placement and recovery were done from the Southwest Research Institute vessel, the R/V SOUTHWEST RESEARCHER.

Sampling Stations

Sampling stations, as specified in Contract AA550-CT6-17, were established at the intersections of transects emanating from the drill site and concentric circles 100, 500, 1000 and 2000 m from the drill site (Figure 5). Two additional stations, 100 m from the rig in the sediment plume and 100 m from the rig opposite the sediment plume, were added for the during-drilling survey.

Sampling Effort

Table 1 lists the types of samples taken and the sampling gear utilized. Figures 6-8 show the sampling frequency and location for the different sample types.

Navigation for station location was by the LORAC navigational system. LORAC readings were taken upon the successful collection of each sample. LORAC readings were also taken when the trawl started to the bottom, when it was on the bottom, when it started coming up, and again when the trawl reached surface. The total distance the trawl sampled and the distance sampled along the bottom can be obtained from these readings.

Table 2 summarizes the samples collected during the rig monitoring study. A summary of high-molecular-weight hydrocarbons and trace metal quality control samples collected is given in Table 3. Hydrocarbon quality control samples have been delivered to the University of New Orleans for analysis. Trace metal quality control samples are in storage

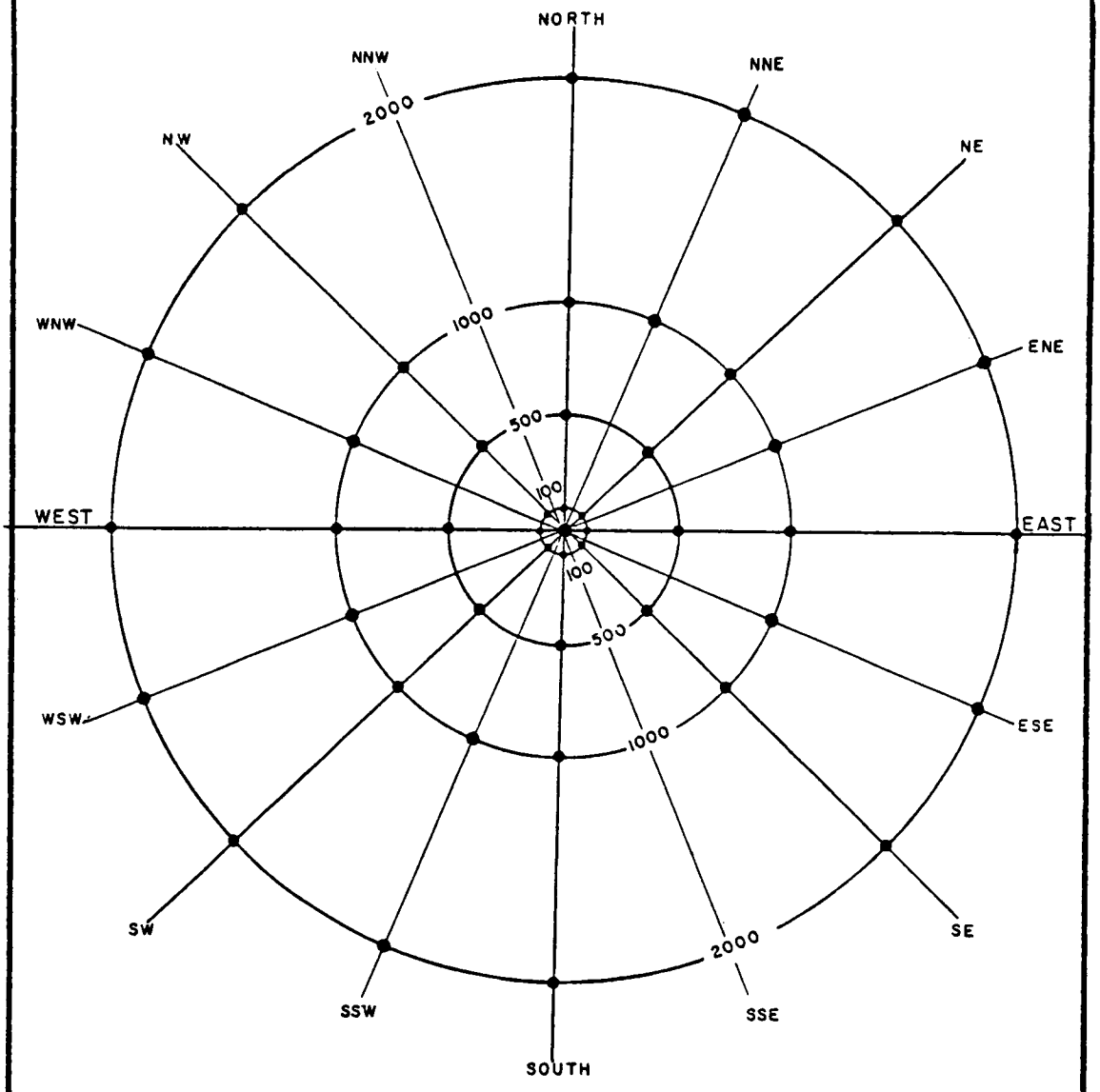
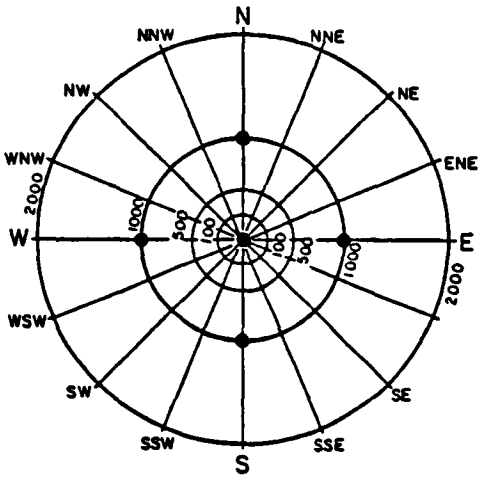
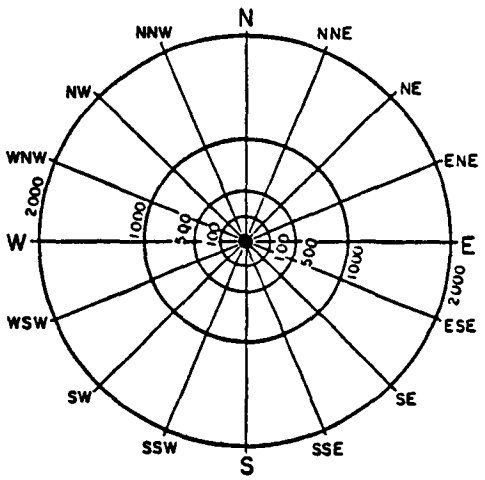


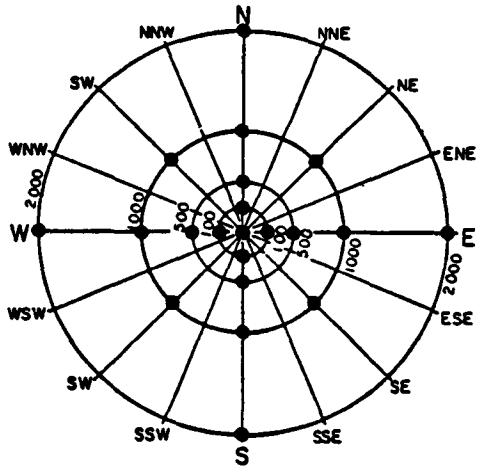
Figure 5. Sampling Stations for the Rig Monitoring Project. (Rings are 100, 500, 1000 and 2000 m from center of drill site)



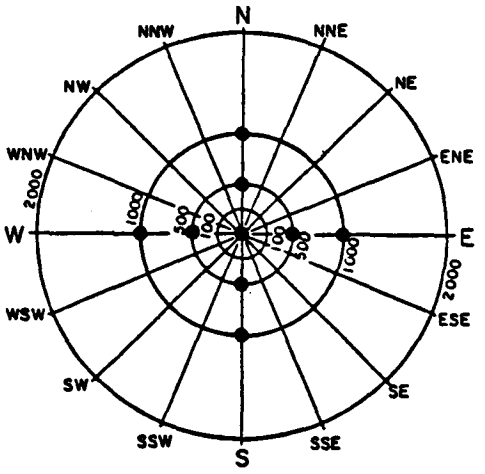
STD, Transmissometry, Sediment Trace Metal and Hydrocarbons, Sediment-Deposition and Low-Molecular-Weight Hydrocarbons



Particulate Trace Metals, Suspended Sediment Mineralogy, Macro-epifauna and Demersal Fishes Taxonomy, Hydrocarbon & Trace Metal

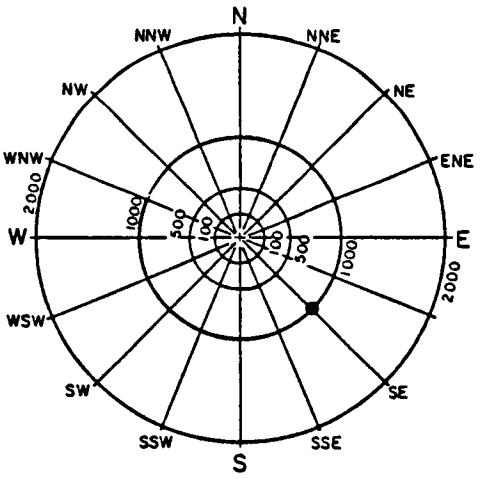


Macroinfauna, Sediment Texture

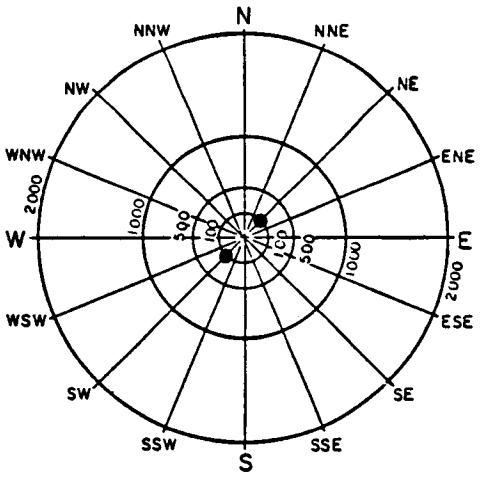


Meiofauna

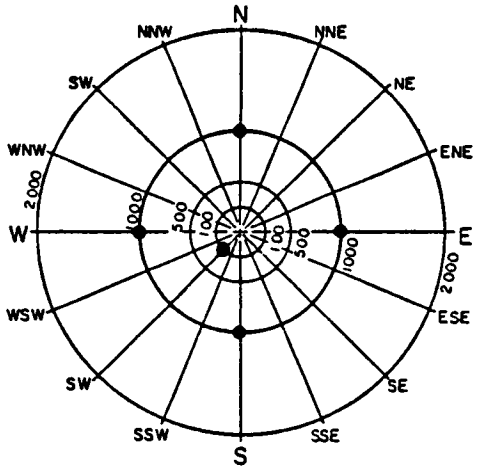
Figure 6. Pre-Drill Sampling Locations by Study Element.



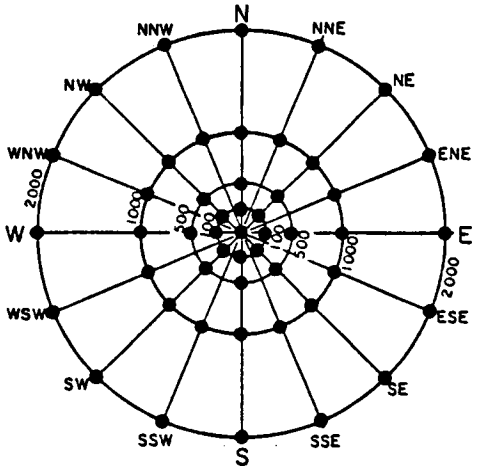
Currents



Suspended Sediment Mineralogy & Particulate-Trace Metals (In and Out of Sediment Plume)

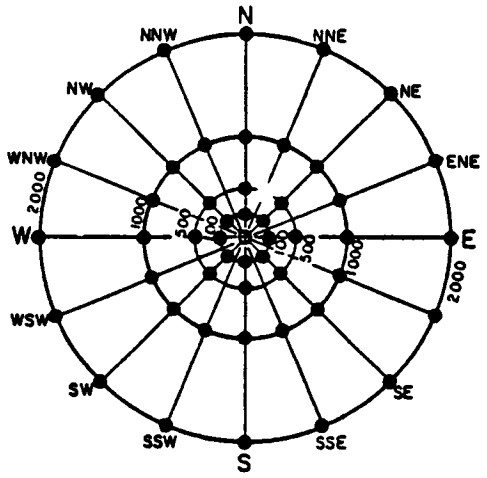


STD & Transmissometry

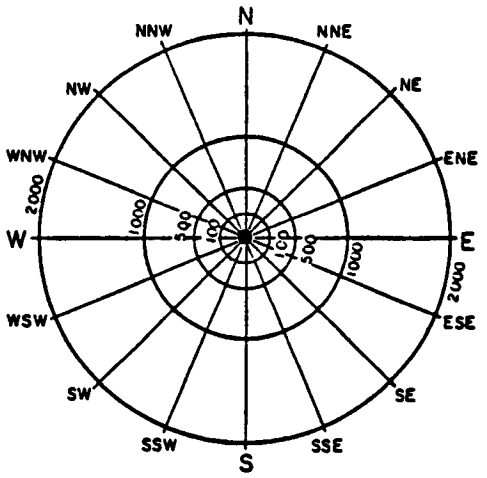


Low-Molecular-Weight Hydrocarbons

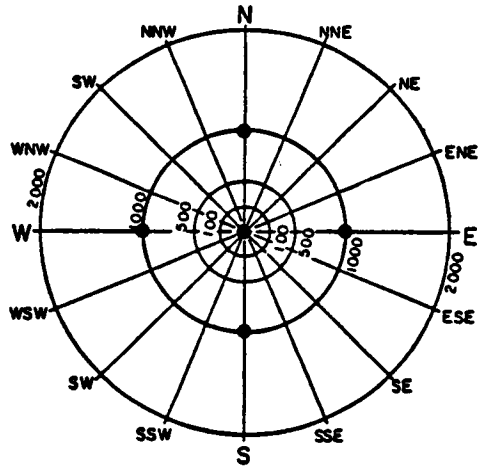
Figure 7. During-Drill Sampling Locations by Study Element.



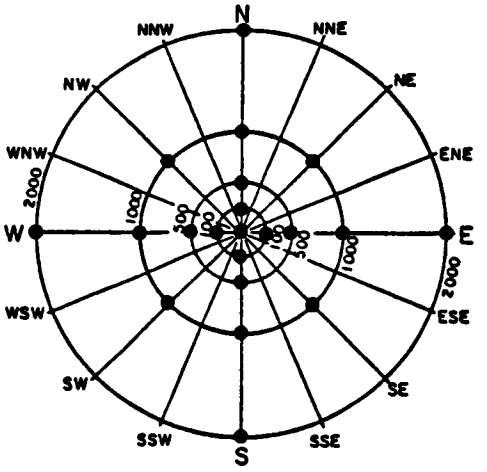
Low-Molecular-Weight Hydrocarbons



Particulate Trace Metals and Suspended Sediment Mineralogy

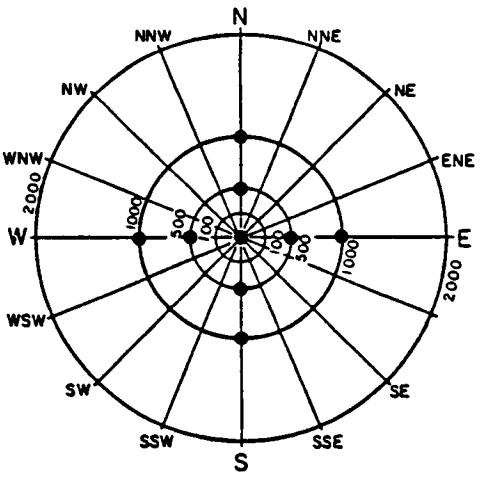


STD, Transmissometry and Sediment Hydrocarbon and Trace Metals

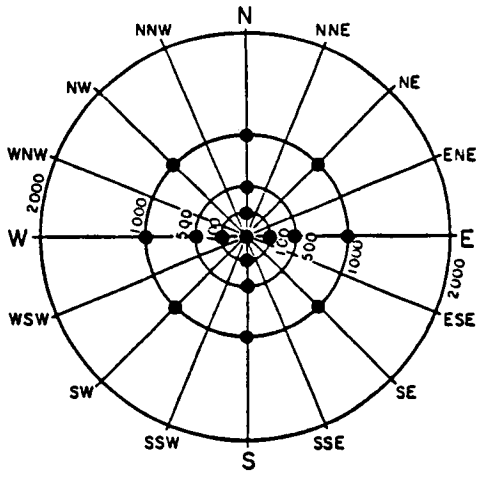


Macroinfauna and Sediment Texture

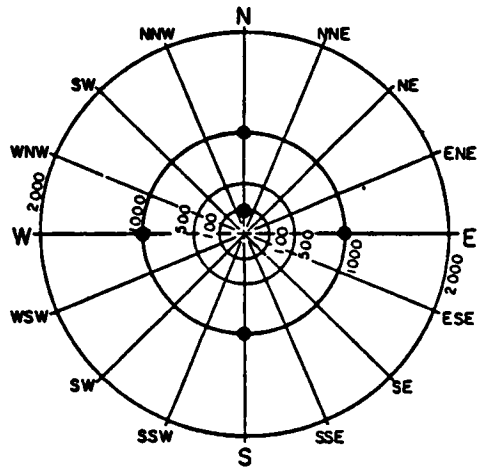
Figure 8. Post-Drill Sampling Locations by Study Element.



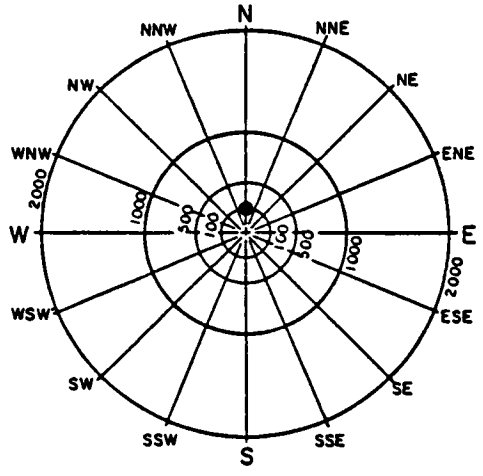
Meiofauna



Sediment Deposition



Macroepifauna and Demersal Fishes Taxonomy



Macroepifauna and Demersal Fishes Hydrocarbon & Trace Metal

Figure 8. Cont.'d

TABLE 1

SAMPLING GEAR USED DURING THE RIG MONITORING STOCS STUDY
1976

Element	Sampling Gear
Hydrography	Plessey Salinity/Temperature/Depth Profiling System and Nansen Bottles Equipped with Reversing Thermometers
Currents	ENDECO (Environmental Devices Corporation Type 105 Film Recording Current Meters)
Transmissometry	Modified MARTEK Transmissometer
Low-Molecular-Weight Hydrocarbons in Water	1-ℓ Nansen Bottles Equipped with Reversing Thermometers
Particulate Trace Metals	30-ℓ Niskin Bottles
Suspended Sediment Mineralogy	30-ℓ Niskin Bottles
Macroinfauna	Smith-McIntyre Grab Sampler (.0125 m^3)
Meiofauna	Smith-McIntyre Grab Sampler (.0125 m^3)
Sediment Hydrocarbons	Smith-McIntyre Grab Sampler (.0125 m^3)
Sediment Trace Metals	Smith-McIntyre Grab Sampler (.0125 m^3)
Sediment Texture	Smith-McIntyre Grab Sampler (.0125 m^3)
Macroepifauna	35-ft. (10.7 m) otter trawl
Demersal Fishes	35-ft. (10.7 m) otter trawl
High-Molecular-Weight Hydrocarbons and Trace Metals in Macroepifauna and Demersal Fishes	35-ft. (10.7 m) otter trawl

TABLE 2

SUMMARY OF SAMPLES COLLECTED BY TYPE
AND NUMBER DURING THE RIG MONITORING STUDY

Sample Type	No. of Samples Collected
STD	15
Transmissometry	5
Suspended Sediment	15
Dissolved LMW-Hydrocarbons	102
Particulate-Trace Metals	25*
Currents	5
Sediment Deposition	44*
Sediment Texture	284
Sediment Trace Metals	14*
Sediment Hydrocarbons	14*
Meiofauna	72
Macroinfauna	252
Macroepifauna	6
Demersal Fishes	6
Macroinfauna and Demersal Fish Trace Metals	6
Macroinfauna and Demersal Fish Hydrocarbons	6

* Replicates taken

TABLE 3

SUMMARY OF QUALITY CONTROL SAMPLES COLLECTED
DURING THE RIG MONITORING STUDY

Sample Type	No. of Samples Collected
Sediment Trace Metals	3
Sediment Hydrocarbons	3
Macroepifauna and Demersal Fish	
Trace Metals	2
Hydrocarbons	2

TMSI/PAML pending selection of a trace metal quality control laboratory.

Participants

The University of Texas Marine Science Institute, Port Aransas Marine Laboratory, was contracted by the BLM to provide overall project management, logistics, ship time, data management, and certain scientific efforts. Additional scientific effort was provided by a subcontract between the University of Texas and Texas A&M University. The balance of the scientific effort was provided by the United States Geological Survey's Corpus Christi, Texas Office of Marine Geology.

A total of 17 Principal Investigators participated in the project. Table 4 lists these P.I.'s by institution represented and scientific responsibility.

Sampling Problems

The only sampling problems encountered during the rig monitoring study occurred in the during-drilling phase. On January 7, 1977, the during-drilling sampling was initiated, but had to be postponed when it was noticed that the LORAC preplots for the drill site were not those for the actual location of the drilling rig. This discrepancy was explained when it was discovered that the LORAC navigational system was off by six lanes (553.85 m, 1800 ft). Also, the pre-drilling station locations were calculated from a drill site location supplied by AMOCO but the rig was actually set 21.18 m (69.5 ft) SW (223.5°) of this location. During- and post-drilling station locations were calculated using actual location of the rig. Therefore, all during- and post-drillirg station preplots were 21.18 m SW of the pre-drill station preplots (Figure 9).

TABLE 4

RIG MONITORING STOCS BIOLOGICAL AND CHEMICAL COMPONENT PARTICIPANTS BY WORK ELEMENT AND INSTITUTION

University of Texas Marine Science Institute-Port Aransas Marine Laboratory

Hydrography and Currents	Ned P. Smith
High-Molecular-Weight Hydrocarbons in Sediment	Patrick L. Parker, Richard S. Scalan, J. K. Winters
Sediment Texture and Deposition	E. William Behrens
Macroinfauna and Macroepifauna	J. Selmon Holland
Demersal Fishes	Donald E. Wohlschlag

Texas A&M University

High-Molecular-Weight Hydrocarbons in Macroepifauna and Demersal Fishes	C. S. Giam, H. S. Chan
Trace Metals in Macroepifauna and Demersal Fishes	B. J. Presley, Paul N. Boothe
Low-Molecular-Weight Hydrocarbons	William M. Sackett, James M. Brooks
Meiofauna	Willis E. Pequegnat
Transmissometry	Richard Rezak

U. S. Geological Survey, Corpus Christi, Texas, Office

Particulate-Trace Metals	Chuck Holmes
Suspended Sediment Mineralogy	Chuck Holmes
Trace Metals in Sediment	Chuck Holmes
Sediment Texture (Chemical Samples)	Gerald L. Shideler

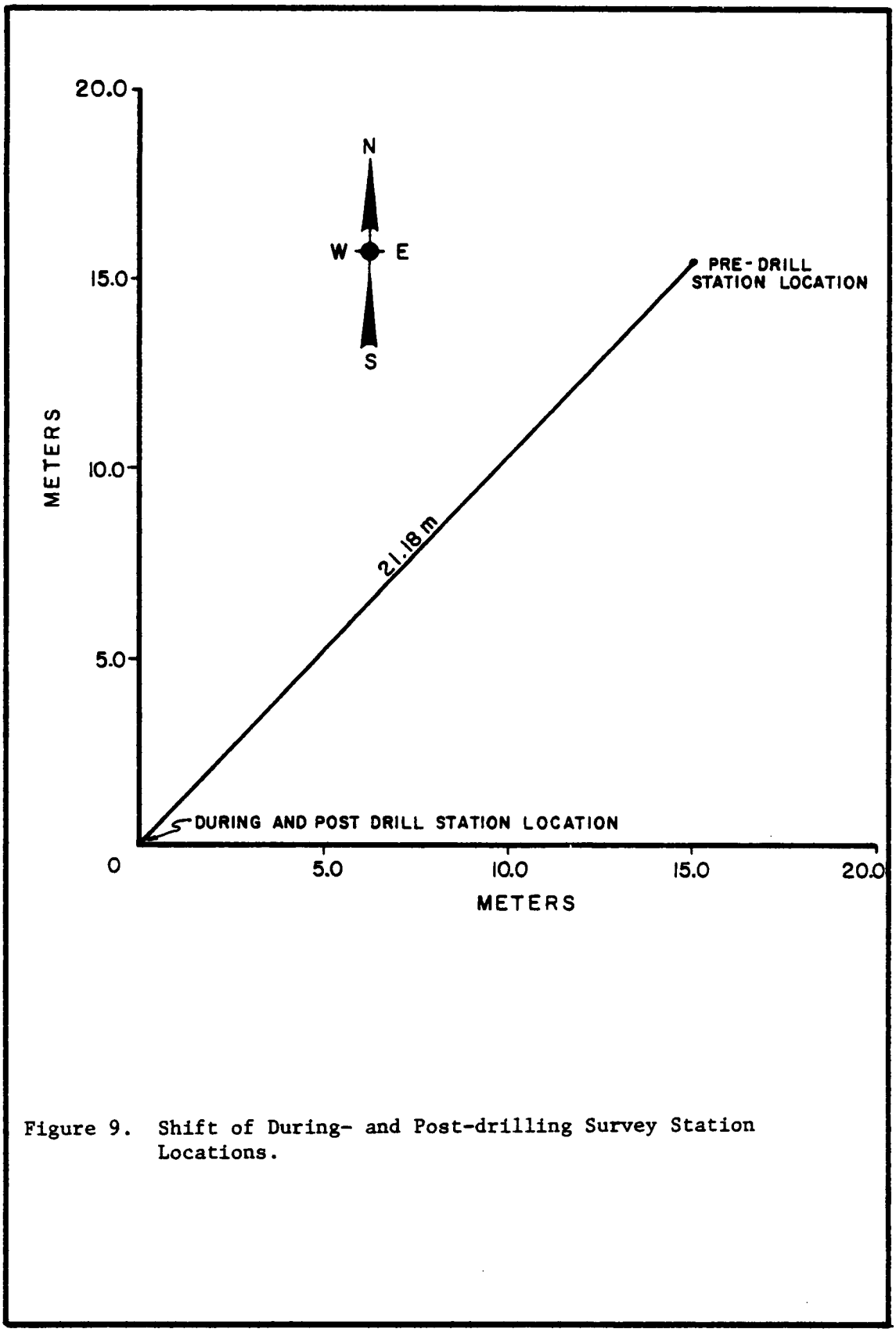


Figure 9. Shift of During- and Post-drilling Survey Station Locations.

The LORAC navigational system was calibrated, the new reading for the drill site used to compute the station locations, and on January 14, 1977, the during-drill sampling was completed. Those samples taken in the sediment plume and opposite the sediment plume 100 m from the rig were taken on January 7, 1977, as preplots were not needed for these samples.

Another problem encountered was the loss of the surface buoy marking the location of the current meters. Three unsuccessful attempts were made to locate the current meters with side scan sonar and grapling hooks. On the fourth attempt a concrete block anchor was lowered with a line attached to a buoy at the surface. Another line was run from the anchor line to a ZODIAC. The ZODIAC then ran in a circular pattern around the buoy. On the first pass the current meters were hung and divers were able to recover the current meters, the sub-surface buoy, and the anchoring set up.

Finally, no transmissometry profiles were taken for the during- and post-drilling surveys due to a malfunction of the transmissometer.

CHAPTER TWO

SIGNIFICANT FINDINGS AND RECOMMENDATIONS

Summary of Significant Findings

Reports by the Principal Investigators responsible for the various work elements are included in Chapters 3 through 14. The significant findings reported by each Principal Investigator are summarized below:

Hydrographic and Current Meter Study (Dr. Smith, UTMSI/PAML)

Thirty-nine days of current data were obtained from recording current meters at four levels. The current data at all water levels indicated longshore motion predominantly to the south, but with three distinct current reversals during the study period. Spectral analysis indicated a concentration of sub-surface motion at periodicities in excess of one day. The coherence of longshore motion through the water column was statistically significant only at the very longest periodicities; cross-shelf motions were not coherent between near-bottom and near-surface levels. Harmonic analysis of current component time series indicated that the tidal component of the current was an insignificant fraction of the total observed motion. Supporting hydrographic data is reported on for the pre-, during- and post-drilling surveys.

Transmissometry (Dr. Rezak, TAMU)

Transmissometry profiles were scheduled to be taken for the pre-, during- and post-drilling surveys. However, due to equipment failure, profiles for the during and post-drilling surveys were not obtained. A very thin layer (2-2.5 m) of turbid water, the nepheloid layer, was observed on the bottom in the drill site area during the pre-drilling survey.

Low-Molecular-Weight Hydrocarbons (Drs. Sackett and Brooks, TAMU)

No anomalies in low-molecular-weight hydrocarbon concentrations were observed at the rig monitoring site during the pre-, during- and post-drilling surveys. Since the drilling at the rig monitoring site was only an exploratory well, no additions of light hydrocarbons were expected and none were observed.

Trace Metal and Mineralogical Analysis of Suspended and Bottom Sediment (Dr. Holmes, USGS; Dr. Barnes, Texas A&I)

The trace metal content of suspended sediments fell within the range established during the environmental phase of the South Texas Outer Continental Shelf study with the exception of cadmium and zinc. It is suspected that the high and variable values obtained for these metals were a result of sampling or procedural contamination. Three clay minerals were detected in these samples: montmorillonite; illite; and, kaolinite. The presence of montmorillonite in the samples from the during-drilling phase may have resulted from the drill fluid sinking to the sea floor as previous work has shown that early spring waters in the region are almost devoid of montmorillonite.

Chromium, copper, manganese, and nickel levels in the sediment, showed no apparent change as a result of drilling activity. Levels of iron and vanadium, co-variant elements, were somewhat lower, while lead showed a two-fold increase after the drilling activity. Zinc, barium and cadmium were directly tied to drilling activity as these elements showed a marked increase at the drill site following drilling operations. These variations in trace metal levels were observed only at the drill site.

High-Molecular-Weight Hydrocarbons in Sediment (Drs. Parker, Scalan and Winters, UTMSI/PAML)

Saturated and non-saturated high-molecular-weight hydrocarbons were measured in samples from five pre- and five post-drilling stations. The pre-drill samples indicated no evidence of oil pollution. One of the seven post-drilling samples was apparently contaminated with petroleum hydrocarbons. This sample was one of three samples taken at the drill site. Whether this contamination resulted directly from drilling operations, oil from another source, or just drill cuttings from ancient shales could not be determined.

Benthic Sediment Textural Analysis (Dr. Shideler, USGS)

Comparisons of textural variability between composite pre-drilling and post-drilling sample suites were made. The results suggested that statistically significant differences occurred between the two suites for the following textural parameters: skewness, silt percentage, clay percentage, silt/clay ratio, and mean diameter. No meaningful inferences could be formulated regarding causative factors as the observed sea-floor textural changes could potentially have resulted from a combination of modified sampling procedures, analytical variability, natural seasonal variability, and drilling rig operations.

Sediment Deposition and Texture (Dr. Behrens, UTMSI/GGL)

Two cores and one grab sample at the drill site station contained obvious foreign material deposited in connection with drilling operations. Other sediment textural changes generally had low statistical significance, but an addition of coarse (sandy) materials was strongly indicated 100 m south and west of the drill site and was suggested over 1000 m from the drill site in the sector extending from Station S-1000 clockwise to Station NW-1000. Farther from the drill site (1000 m or more) and in the opposite directions (to the northeast and southeast) there was a suggestion of clay transport and deposition.

Meiofauna (Dr. Pequegnat, TAMU)

Two stations that could have been affected by drilling operations when the characteristic longshore current underwent reversals produced lower than expected meiofaunal populations and markedly higher harpacticoid/nematode ratios.

Invertebrate Epifauna and Macroinfauna (Dr. Holland, UTMSI/PAML)

Analyses of benthic populations showed a high degree of similarity among pre-drill samples. Post-drill samples, although slightly separated along a north-east to south-west line through the study area, also showed a high degree of similarity.

Differences between pre-drill and post-drill samples were attributed to drilling operations and seasonality. Benthic populations were definitely diminished at the drill site, presumably due to direct impact from drilling operations. All other post-drill stations were fairly distinct from pre-drill stations due to several groups of organisms that appeared to have some members that are seasonal.

Analysis of individual species distribution patterns indicated that many species were apparently distributed on a small scale relative to the size of the study area.

Demersal Fishes (Dr. Wohlschlag, UTMSI/PAML)

Analysis of pre- and post-drilling trawl data revealed numerical and biomass declines, up to a radius of 1 km about the drill site, in relation to the general trends in the STOCS study area in 1975 and 1976. The data, however, were not statistically definitive. There were also post-drilling declines in diversity, equitability and probability in interspecific encounter.

Heavy Molecular Weight Hydrocarbons in Epifauna (Drs. Giam and Chan, TAMU)

The three pre-drilling specimens, squid, rough scad and Atlantic croaker, contained no evidence of petroleum hydrocarbons. The n-alkane distributions in three post-drilling samples, butterfish, shoal flounder and shrimp, were petroleum-like, most notably in the shrimp. Also, the shrimp sample had a hydrocarbon content 150% higher than the range for this species in the surrounding areas. In all these samples no aromatic compounds were detected. Thus, there may be an indication of a low level petroleum contamination of post-drilling samples but more analyses are needed to verify this observation and the sources of contamination.

Trace Metals in Epifauna (Drs. Presley and Boothe, TAMU)

The trace metals data set did not permit a realistic assessment of the possible impact of drilling operations on the levels of trace metals in organisms inhabiting the immediate vicinity. Not enough samples were collected and only one species occurred in both pre- and post-drilling sample groups. The species collected were all very mobile and their period of exposure to the ambient environment of the rig was probably variable and very limited.

General Conclusions

The following conclusions can be made regarding the effects of the exploratory drilling rig monitored:

1) Obvious foreign material was seen in sediments taken from the drill site, as discussed in Chapter 9.

2) Zinc, barium, and cadmium levels in the sediment increased markedly at the drill site. Lead levels in the sediment increased two-fold, probably as a result of the drilling activity via the fuel used by the rig and supply vessels.

3) Petroleum contamination was measured in one of the three sediment samples collected at the drill site.

4) Macroinfauna populations were definitely diminished at the drill site.

5) Montmorillonite was detected in the suspended sediment samples. This was thought to be a result of the drilling activity in that spring waters in the area are usually devoid of montmorillonite and one of the drilling muds used (bentonite) contained montmorillonite.

Although other changes in benthic populations and chemistry were detected following exploratory drilling activity, it is not possible to determine the exact source of these changes. The individual reports by the Principal Investigators discuss possible sources.

As would be expected for an exploratory drilling operation, there were biological, chemical, and physical effects within the immediate area of the drill site. The spatial extent of these effects cannot be precisely determined. However, from the data collected from the 100 m stations, it appears that it was somewhat less than 100 m from the drill site. The temporal extent of these effects cannot be determined as there was only one post-drilling sampling made shortly after drilling operations were completed.

Recommendations

As can be seen in the summary of significant findings, several problems were encountered when trying to draw meaningful conclusions about the effects of the exploratory drilling from the data collected. Most of these problems apparently resulted from poor study design. In the interest of improving future monitoring studies of this nature, the following recommendations are made:

1) The number of samples taken during the pre-drilling survey should be large enough to accurately characterize the area. For example, only two 15-minute trawls at one station were scheduled for demersal fish and macroepifauna taxonomy. While the exact number of trawls needed to confidently characterize the area is not known, it is felt that two was not sufficient.

2) The number of samples and sampling stations should be the same for the pre- as for the post-drilling survey to allow meaningful comparisons to be made. Only one station was sampled for demersal fish and macroepifauna taxonomy during the pre-drilling survey, while five stations were sampled during the post-drilling survey.

3) Control stations should be established in an area similar to that being monitored. A possibility would be to have stations on a concentric ring 5000 m from the drill site. Samples of every type collected from the monitoring stations should be collected from the control stations. While seasonal variability is somewhat known for the area from the baseline survey, samples from control stations would give a better idea of seasonal variability and other changes not directly induced by the exploratory drilling.

4) The rig monitoring site should not be located within an area subject to the effects of other offshore activity. The site monitored in this study was close to the very active Port Aransas shipping lane. The influence of the shipping lane is not known, but it is suspected ship traffic could cause (a) a constant reworking of the bottom sediments, (b) serve as a means of transport of organisms into the area, and (c) be a source of pollutants to the environment.

5) Transient and highly mobile species should not be used as indicators of pollution. Hydrocarbon and trace metal content of macroepifauna and demersal fish were used to monitor the effects of the exploratory drilling in this project. It is recommended that less mobile species be used for these analyses.

6) Samples of drilling muds and additives and drill casings should ideally be made available for analysis by the investigators. Samples should be taken before and after the muds and additives have been used as it is suspected that the intense temperatures and pressures to which they are subjected during the drilling process alters their chemical composition and toxicity.

7) A second post-drilling sampling should be made six to twelve months after drilling operations are complete to adequately assess the temporal extent of the effects of the exploratory drilling.

As is indicated by these recommendations and the general conclusions, the effects of exploratory drilling are probably very limited both spatially and temporally and as such, an adequate sampling regime to monitor these effects is difficult to design.

CHAPTER THREE

HYDROGRAPHIC AND CURRENT METER PROJECT

University of Texas
Marine Science Institute
Port Aransas Marine Laboratory

Principal Investigator:
Ned P. Smith

Associate Investigators:
James Evans
William MacNaughton

ABSTRACT

Recording current meter data from four levels in 33-m of water are presented and discussed for a 39-day period in December 1976 and January 1977. Supporting hydrographic data are presented from before, during and after the current meter study.

The current data at all water levels indicated longshore motion predominantly to the south, but with three distinct current reversals during the study period. Spectral analysis indicated a concentration of subsurface motion at periodicities in excess of one day. The coherence of longshore motion through the water column was statistically significant only at the very longest periodicities; cross-shelf motions were not coherent between near-bottom and near-surface levels. Harmonic analysis of current component time series indicated that the tidal component of the current was an insignificant fraction of the total observed motion.

INTRODUCTION

Purpose

Previous circulation studies in the northwestern Gulf of Mexico have, for the most part, utilized the drift bottle approach along the inner shelf, or involved the compilation and interpretation of accumulated ship drift calculations. A general pattern has emerged, defining, among other features, the Loop Current and cyclonic gyres in the Gulf of Campeche and the Florida Middle Ground. Still, the departure from the multi-annual mean patterns that can be expected in any given year are poorly understood, and the data base for characterizing sub-surface motion are nearly non-existent.

The purpose of measuring currents as part of the Rig Monitoring Study was three-fold: (1) Direct measurements of sub-surface currents would relate directly to the spatial distributions and trajectories of materials introduced throughout the water column at the drilling site. (2) Long time series of relatively closely spaced observations would indicate clearly the relative importance of motions occurring over shorter time scales, which would be averaged out of the seasonal patterns defined by the drift bottle and ship drift data. The characteristics of inertial and tidal rotary motions are unreported for this area, even though they would play an important role in dispersing point-source pollutant discharges. (3) Measurements of sub-surface currents would significantly extend what is presently known of the circulation of the northwestern Gulf of Mexico by indicating vertical variations in current speed and/or direction through the water column.

Literature Survey of Previous Work

Much of the work over the past 20 years to investigate the circulation

of the Texas Outer Continental Shelf area was aimed at defining temporal and spatial characteristics of a postulated surface convergence along the south-central Texas coast near latitude 27°N. This pattern was first suggested by Leipper (1954) who explained it in terms of seasonal winds intersecting a concave coastline. Though Leipper cast some doubt on his own interpretation, most of the current studies conducted since that time have explicitly either supported or rejected the concept of a surface convergence.

Geological evidence in the form of heavy mineral distributions (Bullard, 1942; Van Andel and Poole, 1960), sand size modes (Hayes, 1965), and the longshore distribution of shell material (Watson, 1968) all support the idea of a convergence in the littoral drift along central Padre Island, Texas. Drift bottle studies over the inner shelf during the past 10 years are in general agreement; however, the considerable scatter in drift bottle recovery sites suggests that the convergent pattern may not occur at any instant of time, but may exist only as an annual or multi-annual net motion. Leipper (1954) noted that a surface convergence such as that appearing in the ship drift data could exist only if there were sub-surface return flow. Recent drift bottle and bottom drifter studies by the USGS, Corpus Christi (Hunter *et al.*, 1974) have indeed suggested that when surface motion has an onshore component, bottom flow tends to be directed offshore, and vice versa. Furthermore, Hunter *et al.*, postulated the existence of a convergence of bottom water from bottom drifter returns. Such a pattern may be displaced in a longshore direction some distance from the surface convergence.

While the existence or characteristics of a convergent pattern along the Texas continental shelf have not been satisfactorily resolved, previous work has established the presence of considerable seasonal variability in

the net direction of the longshore current. Watson and Behrens (1970) used drift bottles to document a net northerly drift in summer and an alternating drift in winter months, due, in part, to frontal passage. Hydrographic Office charts, on the other hand, reflecting longer time averages and ship drift data from further offshore, indicate currents to the southwest and west-northwest in December and January, respectively, and to the north in July.

Few studies have been conducted in the northwestern Gulf to investigate current variations occurring over shorter time scales. The characteristics of tidal and inertial motions are poorly known for the Texas shelf. Kimsey and Temple (1962) used a direct readout current meter in 27 m of water to obtain short time series, lasting on the order of one day. While it is impossible to identify the patterns as reflecting the steady current or as an anomalous perturbation on the steady flow, the considerable variation in speed and direction from one observation to the next suggests that the instantaneous current may be poorly represented by the time-integrated data provided by the ship drift or drift bottle techniques.

Recording current meters have been used increasingly in the northwestern Gulf of Mexico, as elsewhere, in studies designed to investigate shorter-period variations, as well as the sub-surface motion not revealed by drift bottle studies. A pilot study was initiated in 1973 along the inner shelf off the central Texas coast to investigate temporal variability in shelf circulation. Current meters were placed approximately 10 km offshore for two periods of just over one month each in the winter and summer of 1973 (Smith, 1975). Results showed a quasi-steady flow to the south-southwest during the winter period. The same general sampling period was repeated the following year to determine the extent to which the seasonal

patterns recorded the first year were repeated. Results of the second year's study [Smith, 1977 (in press)] showed an alternating longshore current in both summer and winter seasons. High coherences between longshore components of both coastal winds and sub-surface currents suggested that the different winter current patterns noted in the two studies may be explained in terms of differences in coastal wind patterns. In view of the statistically significant coherences between wind and sub-surface current readings, the absence of statistically significant tidal and inertial period motion, and the lack of a quasi-permanent coastal current system in the northwestern Gulf of Mexico, one must tentatively conclude on the basis of previous studies that the shelf circulation along the Texas coast is primarily wind-driven. At the same time, however, the rather poor correlation found in parts of the records indicates that the response to wind forcing is not necessarily a local one, even along the inner shelf. An understanding of the meso-scale response to windstress over the continental shelf awaits a study in which both circulation and wind forcing are monitored over a substantially broader geographical area.

METHODS AND MATERIALS

Data Collection

Hydrographic Data

Vertical profiles of temperature and salinity, from surface to bottom, were obtained on three surveys, *i.e.*, before, during and following drilling at the rig monitoring site. The pre-drilling study was conducted on 25 September 1976, well in advance of the arrival of the drilling platform. Hydrographic profiles were obtained at the drill site and at four points 1000 m from the drill site along each of the four points of the compass. Horizontal homogeneity was great enough such that spatial variations were

minimal at any given level. The primary purpose of the hydrographic data was to provide direct support to other water column sampling, rather than to identify horizontal gradients.

The during-drilling survey was conducted on 7 and 14 January 1977. Vertical profiles were obtained at the five sites surrounding the drill site.

The final survey was conducted on 28 February 1977, shortly after the drilling rig had been removed. Vertical profiles were obtained at the five sites sampled on the pre-drilling cruise.

A total of 15 temperature-salinity (T-S) profiles were obtained, along with top and bottom T-S data, which were used to calibrate the vertical profiles. Additional hydrographic variables were computed using a computer program developed at the NOAA Pacific Oceanographic and Meteorological Laboratories. Tables of the calibrated and computed hydrographic data and plots of temperature, salinity and sigma-t profiles from the 14 stations on the three cruises are given in Appendix A.

Current Meter Data

Recording current meters were installed at five levels along a taut-line mooring, approximately 0.5 km southeast of the drilling platform on 16 December 1976. The water depth at the study site was approximately 33 m and there was no significant bathymetric relief.

The current meters sampled hourly (half-hourly at the lowest level) over a 39-day period until they were recovered on 25 January 1977. The current meters were the Environmental Devices Corporation Type 105 Film Recording Current Meters. These instruments provide time-integrated current speeds and directions over the half-hourly or hourly sampling periods. Data are recorded on 16 mm film cartridges, and initial digitization is done by the manufacturer. According to the manufacturer, the speed accur-

acy is ±2.7 cm/sec; the direction accuracy is ±7°.

When the initially digitized current records were returned from the manufacturer, it was learned that the top-most instrument had not operated properly during the study period. Thus, current records are available from depths of 10, 17, 26 and 31 m. The lowest current meter was approximately 2 m above the bottom.

Wind Data

Though not required in the contract, coastal wind readings at approximately hourly intervals were obtained from a 100-ft high anemometer tower located at the Port Aransas Marine Laboratory. The anemometer tower was installed by the University of Texas Atmospheric Science Group, Austin. An analog trace of the north-south and east-west components of the wind velocity was recorded. The availability and analysis of wind records provided an opportunity to investigate shelf circulation as a response to wind forcing. Wind data are digitized from 15 December 1976, through 6 January 1977.

Data Analysis

Hydrographic Data

When the Martek TDC Metering System was used to obtain hydrographic profiles, conductivities were converted to salinities, correcting for temperature effects, using the formulae suggested by Bennett (1976). Temperature and salinity profiles were corrected for systematic instrumentation errors by utilizing calibration data obtained at the top and bottom of the water column. TDC data were obtained at approximately 3-m inter-
ls, depending on water depth and observed vertical variations of temperature and conductivity. When the Plessey Model 9060 Self-contained STD Profiling System was used to obtain hydrographic profiles, data were

digitized at 3-m intervals.

From the vertical profiles of temperature and salinity, a series of hydrographic variables were computed, using a computer program developed at the NOAA Pacific Oceanographic and Meteorological Laboratories. These hydrographic variables included sigma-t, the specific volume anomaly, the dynamic height anomaly, the potential energy anomaly, the Brünt-Vaisala frequency and the speed of sound. Together, these provided a much better picture of the hydrographic climate of the study site than did vertical profiles of temperature and salinity alone.

Current Meter Data

Progressive Vector Diagrams

A good overview of current data is provided by plotting sequentially in head-to-tail manner the hourly or half-hourly current observations from a given level. The resulting pattern indicates how water moves past the current meter, rather than providing the water parcel trajectory, but one may get a quick impression of characteristic current speeds and directions and the occurrence of events. Examples of the latter might include reversals in the longshore motion, periods of well-developed tidal or inertial rotary motion, or periods of predominatly cross-shelf motion.

Histograms

Another way to survey a large amount of current data is to treat current speeds and directions separately and construct histograms at suitable intervals of speed and direction. The patterns indicate immediately the most common current speeds during the study period, and the direction histogram shows the extent to which the motion was restricted to a longshore direction and whether the longshore current alternated in direction.

Energy Density and Coherence Spectra

The relative importance of periodic or quasi-periodic variations over a broad range of time scales is given by computing energy density spectra from current components. Current velocity vectors at each level were decomposed into longshore and cross-shelf components and used to obtain spectra using a computer program developed by Fee (1969). This program uses a fast-Fourier transform technique, after the linear trend has been removed from the time series. The 90% confidence interval was determined using the method described by Panofsky and Brier (1958).

Coherence spectra are obtained from the same computer program when two time series are read in. Coherence spectra involving the longshore and cross-shelf components at a given level are useful in describing organized rotary motions at tidal and inertial periods. Coherence spectra of longshore and cross-shelf components from two levels along the taut-line are useful in determining vertical uniformity and/or vertical variations in longshore or cross-shelf motions.

Tidal Computations

The contribution of tidal forces to the observed motion may be determined from a harmonic analysis of a 29-day time series of the longshore or cross-shelf current components from a given level. The computer program used in this analysis was developed by the National Ocean Survey (Dennis and Long, 1971). The rotary motions superimposed onto the quasi-steady wind drift are an important factor in estimating the dispersion of a point-source pollutant introduced into the water column at the surface or at some sub-surface level.

Numerical Filtration of Current Data

To remove tidal and local inertial period (25.78 hours) variations

in the current data, a numerical filtering technique was used. The filter used was the "D39" Doodson-Warburg type filter described by Groves (1955). A measure of the relative importance of tidal/inertial motions and long-period motions is provided by computing the variance of the time series both before and after it has been filtered. The ratio of the variance of the filtered series divided by that of the unfiltered series is used in the expression: 1 - [var(filt)/var(unfilt)]. The difference between unity and the ratio defined in this way provides an estimate of the relative importance of tidal and inertial period components in the total current.

Windstress Computations

Hourly wind observations recorded at Port Aransas during the 39-day study period were used to compute a time series of windstress vectors. This was, in turn, decomposed into the longshore and cross-shelf components of sub-surface currents.

The anemometer was located atop a 100-ft anemometer tower, approximately 0.5 km from the coast and 30 km from the study site. Data were recorded in analog form and digitized following the study.

Recorded wind speeds were first reduced to an equivalent 10-m level wind speeds, assuming a log-linear wind profile. Windstress values were computed using the expression $\tau = \rho c_D |V| V$, where ρ is the air density (assumed constant at 1.19 kg/m^3), c_D the drag coefficient, and V the 10-m level wind velocity. No directional shear was assumed between the 10-m level and the anemometer level. The drag coefficient was calculated as a non-linear function of wind speed with the expression $c_D = 0.5\ V^{\frac{1}{2}} \times 10^{-3}$, as recommended by Wu (1969).

RESULTS

Hydrographic Data

Pre-Drilling Survey (25 September 1976)

The pre-drilling hydrographic survey was conducted at or just after the time of highest annual temperatures. On the September seasonal cruise, conducted in the middle of September, surface temperatures were generally between 28.5° and 29.0°C. Surface temperatures at the drilling site ranged between 28.0 and 28.8°C.

Thermal stratification in the water column varied from one location to the next. For example, at Station S-1000, a 2.2°C difference in temperature was observed between surface and bottom levels. The temperature variation was distributed nearly uniformly through the water column. A similar pattern was observed at Stations W-1000 and E-1000.

At the drilling site, and again at Station N-1000, a somewhat different pattern was observed. In the lowest 5 m, there appeared to be a distinct decrease in salinity and thus in the computed sigma-t. In both cases, however, the decrease in salinity with increasing depth was a result of a suspiciously high value at the next-to-last level. For example, at the 27-m level at Station N-1000, a salinity of 36.60 parts per thousand (ppt) was computed from TDC data. This was believed to be about 0.2 ppt too high, judging from what is normally characteristic of mid-shelf waters off Texas.

At all stations, the temperature profiles were characterized by a gradual decrease with increasing depth; salinity increased by about 2.2 ppt to 2.8 ppt. No strong pycnocline was detected in the study area. The horizontal variability at any given level should be interpreted with caution, however, as mid-shelf waters are characterized by some degree of

inhomogeneity. It is noteworthy that T-S variations of 0.2 - 0.3° and 0.3 - 0.4 ppt occurred within the restricted study area. Thus, the T-S values obtained from the much more widely spaced transect stations should perhaps not be read to the nearest 0.01° and 0.01 ppt. This precision may well limit the spatial representativeness of the measurement to a very small area, both horizontally and vertically.

During-Drilling Survey (7 and 14 January 1977)

The mid-winter sampling during drilling provided hydrographic data distinctly different from that obtained during the pre-drilling survey. Water temperatures had decreased on the order of 12-14°C, and there was no appreciable increase in salinity with depth. The four profiles taken 1 km from the platform along the principle compass directions indicated considerable horizontal inhomogeneity over the short distance surveyed. Temperature differences of as much as 0.5°C were noted at any given level and salinity variations were as much as 0.4 ppt. Temperatures increased approximately 1.5°C from top to bottom.

The sediment plume station was monitored in 7 January and distinct differences were noted in both temperature and salinity profiles. The temperature profile was shifted toward warmer temperatures from 1.7 to 2.9°C. Also, salinities were approximately 1.0 - 1.4 ppt higher in the sediment plume. Substantial T-S variations over the one-week interval underline the importance of advective processes in determining the hydrographic climate of mid-shelf waters.

Post-Drilling Survey (28 February 1977)

The post-drilling hydrographic survey suggested an essentially two-layered water column, with nearly isothermal and isohaline water above and again below a transition layer at about the 20-m level. The upper

15-20 m had temperatures of about 15.0 - 15.5°C, while the lower part of the water column had temperatures generally between 16.0 and 16.5°C. Salinities increased from about 33.0 - 33.5 ppt in the surface layer to just over 36 ppt near the bottom.

Recording Current Meter Data

Progressive Vector Diagrams

Figure 1 shows the progressive vector diagram computed from currents measured 2 m above the bottom at the study site between 16 December 1976, and 25 January 1977. The pattern was characterized by a distinct net flow in a longshore direction toward 213°. A slight net onshore deflection was superimposed onto the longshore motion. The longshore current was reversed on three occasions during the approximately 40-day study period. A longshore current toward 033° began on 27 December and continued for just over 4 days before reversing again. Starting on 7 January, longshore flow to the south-southwest again halted for approximately four days. The final reversal in the longshore motion occurred at the end of the record, when the progressive vectors trace out a large anticyclonic ellipse over an approximately 9-day period.

The net displacement, and thus the average current, may be determined from the progressive vector diagram. By dividing the end points of the progressive vectors by the total time interval of the study period, an average current of 7.7 cm/sec is obtained for the current meter 2 m above the bottom. It is important to note, however, that this underestimates the instantaneous current due to the canceling effect of current reversals. The instantaneous current, which may be important in the erosion and transport of bottom sediments, can better be estimated from the histogram presented later in this section.

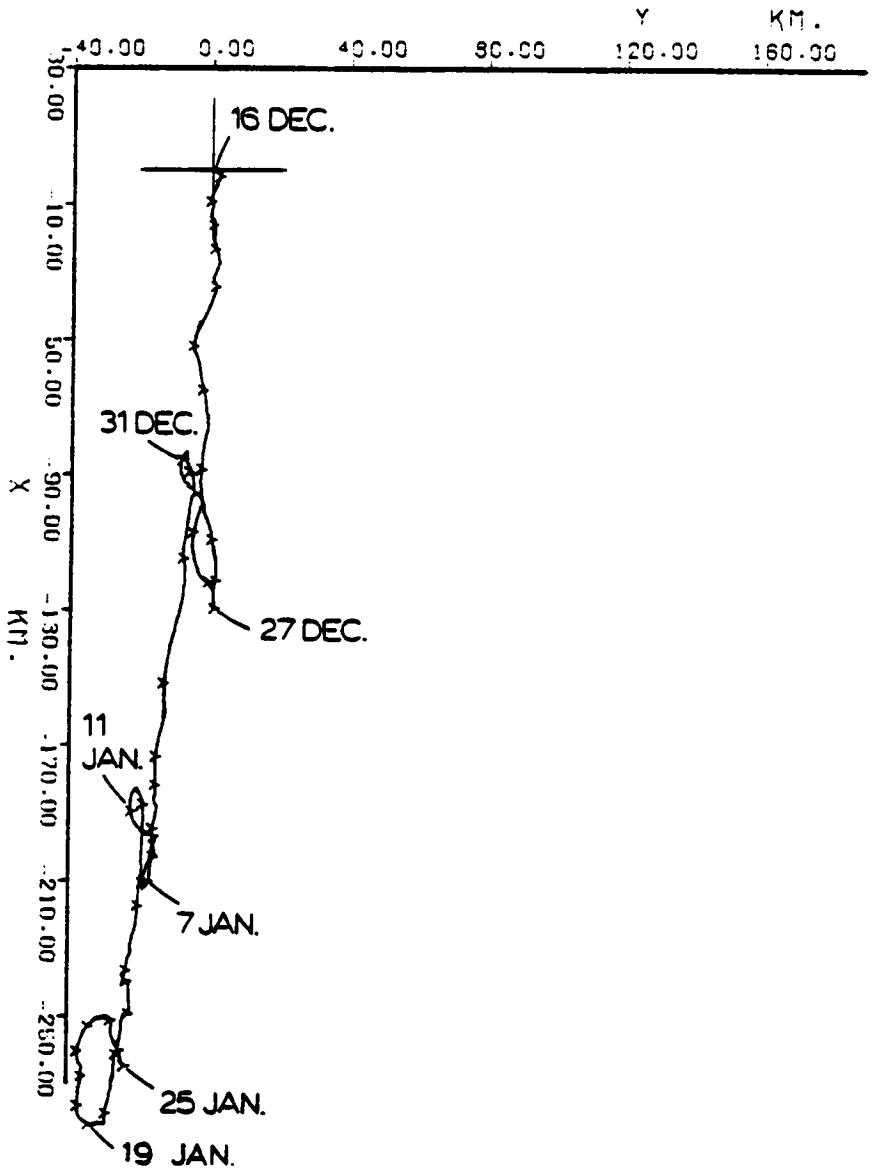


Figure 1. Progressive Vector Diagram from Current Measurements at the Study Site 2 m Above the Bottom, 15 December 1976 to 26 January 1977. Positive X-Axis is Toward 213°; Positive Y-Axis is Offshore.

The cumulative longshore and cross-shelf motion, computed from these two components of the recorded current vectors, may be used to determine trigonometrically the net cross-shelf deflection of the near-bottom current. For this time interval, there was little indicated cross-shelf motion. The data indicate that over the 40-day period the net deflection of the longshore current was just over 5° in an onshore direction.

There were both similarities and marked differences in the progressive vector diagram (PVD) computed from the currents recorded 7 m above the bottom (Figure 2). The pattern was basically similar, with three periods in which the longshore motion had reversed. The return flow during the first such period was almost exactly in a longshore direction. This, coupled with the distinct onshore deflection when the longshore current moved into the southwest, tended to widen the PVD into a zig-zag pattern during this time interval. During the second period when the longshore current reversed, the progressive vectors nearly doubled back. The third period again resulted in an elliptical shape, though it was somewhat more flattened.

The average current speed during the study period was 10.2 cm/sec but this may substantially underestimate the average current speed without regard to direction. The net deflection in the longshore motion was substantially greater. Over this time interval, the net motion was 24° to the right (onshore) of the local longshore direction.

The third current meter was 16 m above the bottom at approximately mid-depth. Both the average current speed and the net cross-shelf deflection were greater (Figure 3). Over this time interval, the average speed was 12.6 cm/sec and the net motion was just under 36° to the right (onshore) of the local longshore direction. The three periods of reversed longshore motion, together with continued onshore deflection, were the most

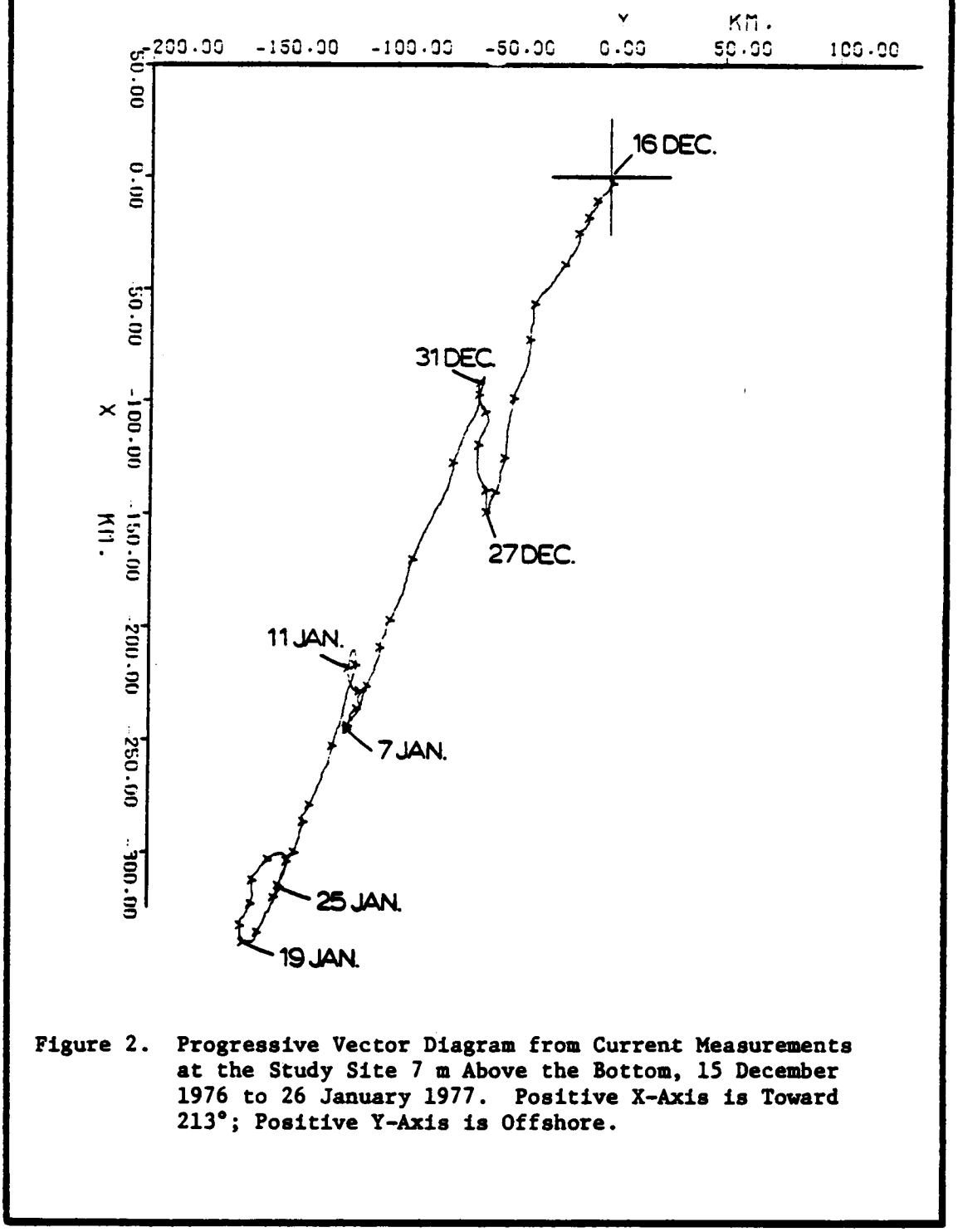


Figure 2. Progressive Vector Diagram from Current Measurements at the Study Site 7 m Above the Bottom, 15 December 1976 to 26 January 1977. Positive X-Axis is Toward 213°; Positive Y-Axis is Offshore.

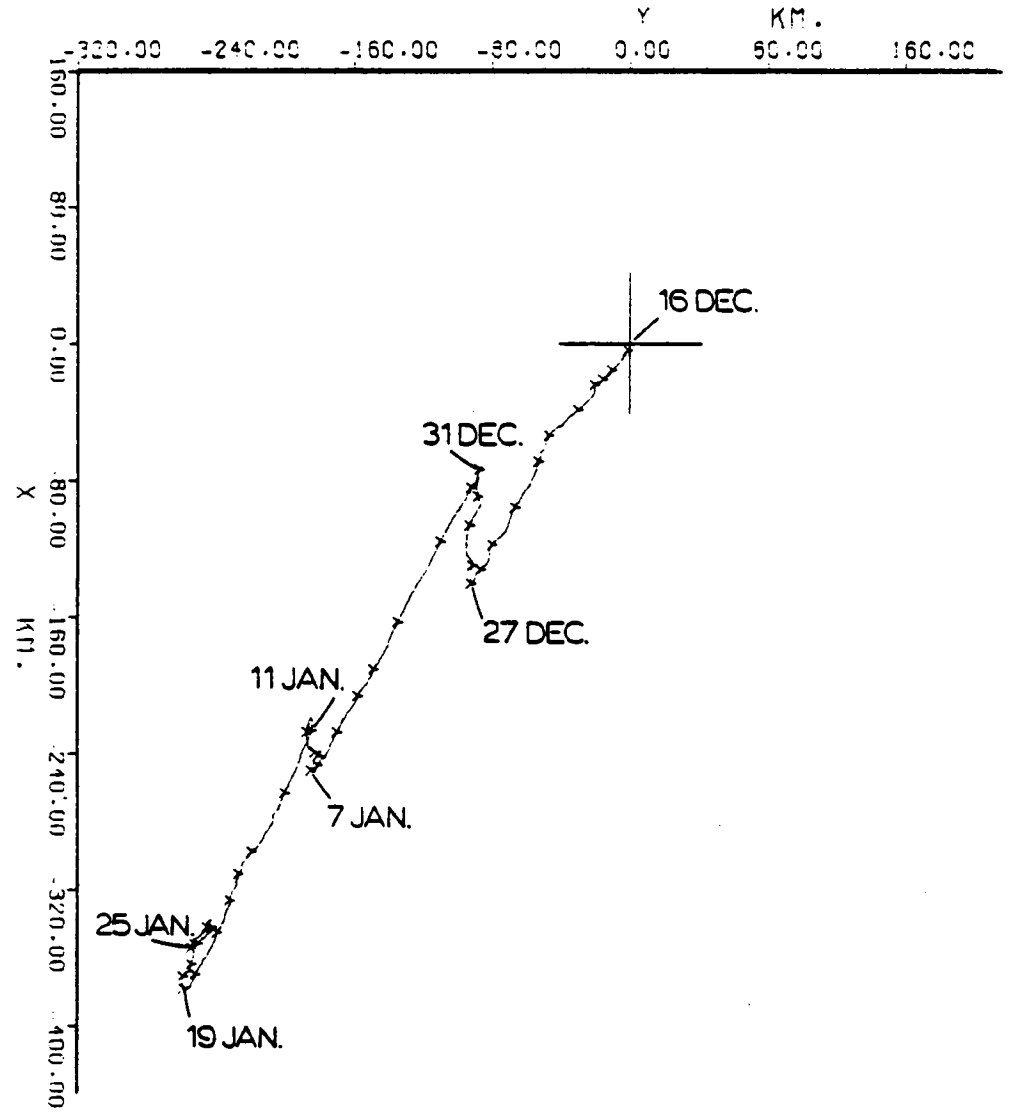


Figure 3. Progressive Vector Diagram from Current Measurements at the Study Site 16 m Above the Bottom, 15 December 1976 to 26 January 1977. Positive X-Axis is Toward 213°; Positive Y-Axis is Offshore.

noteworthy features of the PVD.

The fourth current meter was 23 m above the bottom and approximately 10 m below the surface. The pattern established by the lower three records continued at the fourth level (Figure 4). The average current speed at this level was 14.5 cm/sec, or just over a third of a knot. The cross-shelf deflection was just under 39° to the right (onshore).

The first of the three longshore current reversals was well-defined in the PVD, however, during the second and third the current slows and becomes more variable in direction. The second period actually involves two short reversals, and there is little net motion to the north-northeast.

Histograms of Current Speeds and Directions

Histograms were constructed by dividing current speeds and directions into intervals of 3 cm/sec and 10°, respectively. Results from the lowest current meter (2 m above bottom) are shown in Figure 5. The histogram of current speeds shows a pattern that is distinctly skewed toward slower speeds. The greatest frequency of speeds occurs in the interval between 9 and 12 cm/sec, though over 10% of the observations fall in each of the speed intervals between 6 and 15 cm/sec. The right side of the histogram indicates current speeds trailing off only gradually. Highest current speeds recorded at this level and over this time interval were just under 60 cm/sec. Speeds of over a knot this close to the bottom could be expected to move substantial amounts of bottom sediments.

The direction histogram shows the effects of an alternating longshore current. The pattern is bimodal, but there is a distinct concentration of recorded directions between south and southwest in the longshore direction. The direction histogram is clearly consistent with the progressive vector diagram, showing a net near-bottom transport to the south-southwest.

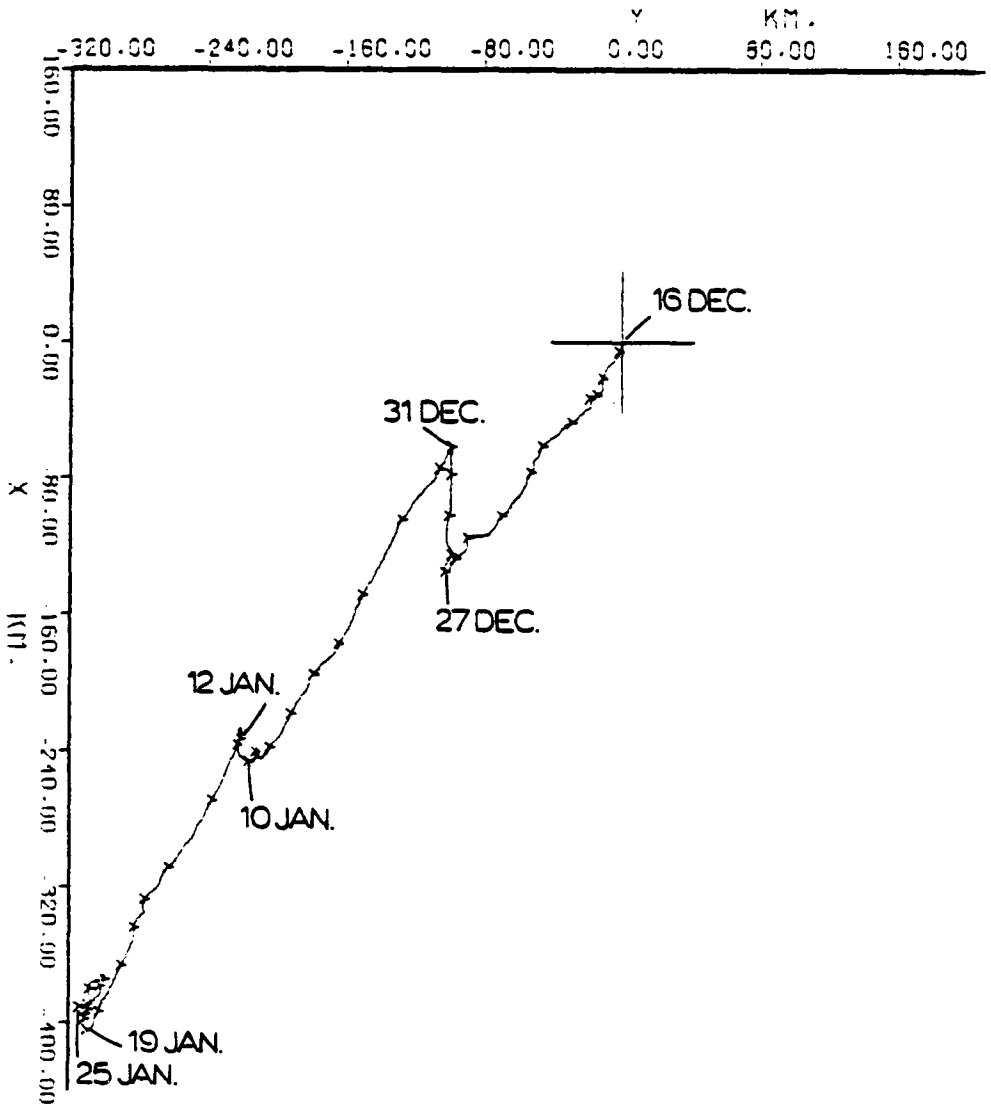


Figure 4. Progressive Vector Diagram from Current Measurements at the Study Site 23 m Above the Bottom, 15 December 1976 to 26 January 1977. Positive X-Axis is Toward 213°; Positive Y-Axis is Offshore.

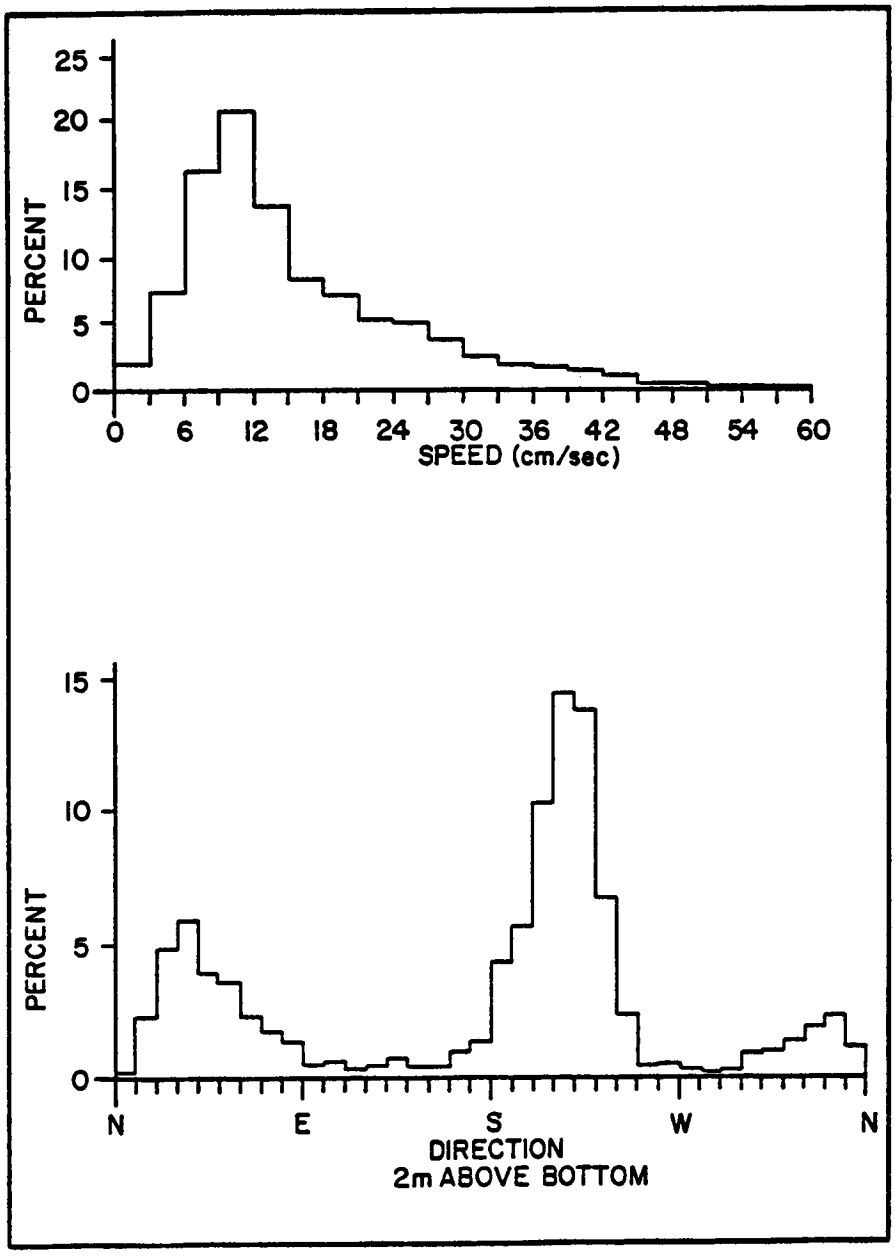


Figure 5. Histograms of Current Speeds and Directions, 16 December 1976 to 25 January 1977.

The current meter positioned 7 m above the bottom provided a similar pattern in the speed histogram (Figure 6) though the peak is somewhat broader and shifted slightly toward higher speeds. The three speed intervals with over 10% of the current observations include the range of 9 to 10 cm/sec. Highest speeds were just under 66 cm/sec.

The direction histogram from the 7-m level is again bimodal, with the primary peak in the longshore motion shifted slightly to the right. There was no appreciable concentration of onshore-deflected motion in an otherwise longshore motion to the north-northeast as shown in Figure 5.

At the mid-depth level of 16 m above bottom (Figure 7), the speed histogram indicates an almost complete absence of calm water, and a still more broadly distributed peak. The speed interval with over 10% of the observations extends between 9 and 21 cm/sec. Percent values decrease ·ly with increasing speed. Analysis of the current data from this level indicated four observations in excess of the 66 cm/sec shown in the histogram.

The direction histogram (Figure 7) is almost completely separated into two parts. No current directions toward 130-160° (just to the right of directly offshore) were recorded during this time. This reflects the absence of a quasi-steady wind-drift motion in this direction, but also indicates the absence of tidal or inertial period rotary motions. The peak attributed to longshore motion to the south-southwest is again shifted slightly to the right and includes the range of 230-260°. Longshore motion in the opposite direction is centered at a direction of 40-50°.

The uppermost current meter at 23 m above bottom and 10 m below the surface has the most broadly distributed speed histogram (Figure 8). Only one interval (15-18 cm/sec) contains over 10% of the observations, yet over 5% of the observations are contained in each of the inter-

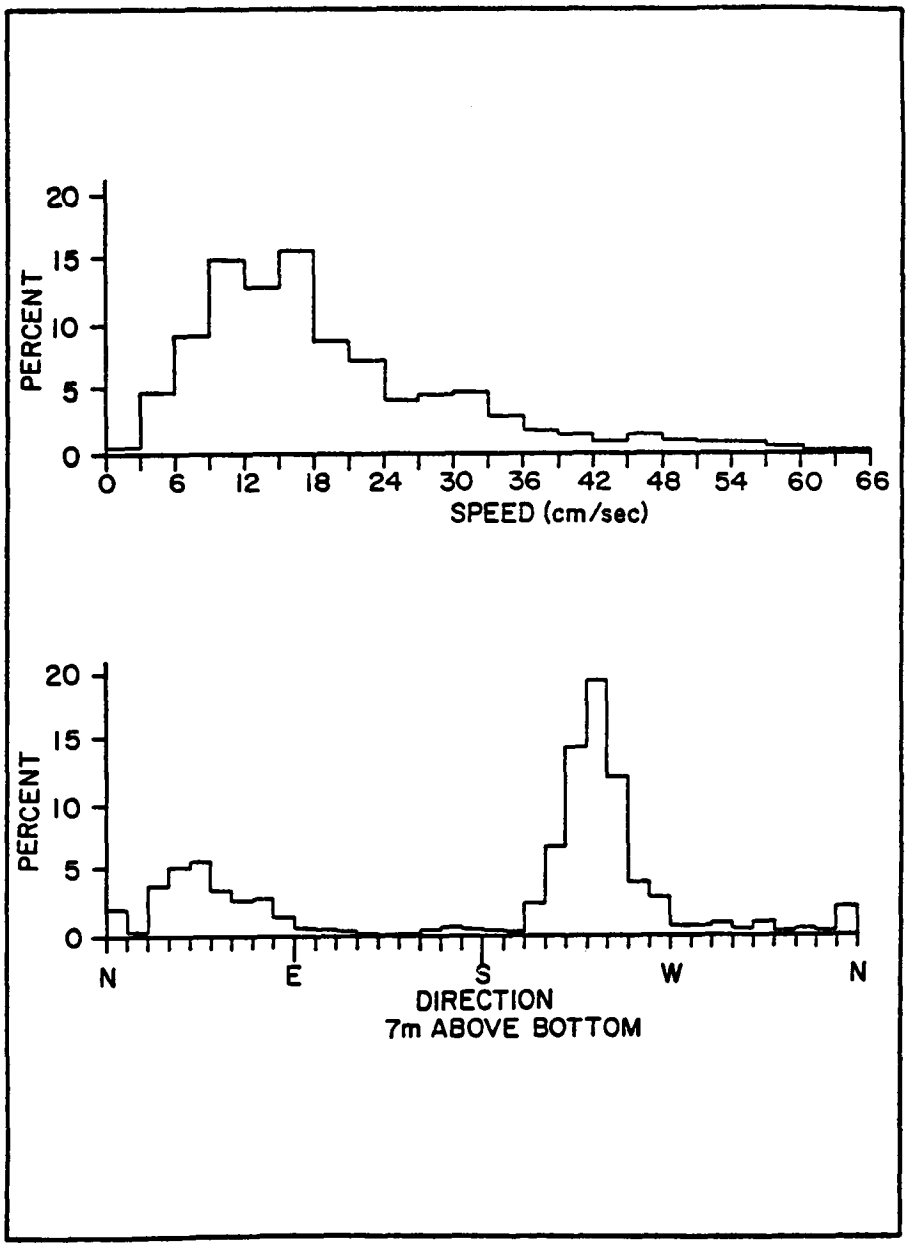


Figure 6. Histograms of Current Speeds and Directions, 16 December 1976 to 25 January 1977.

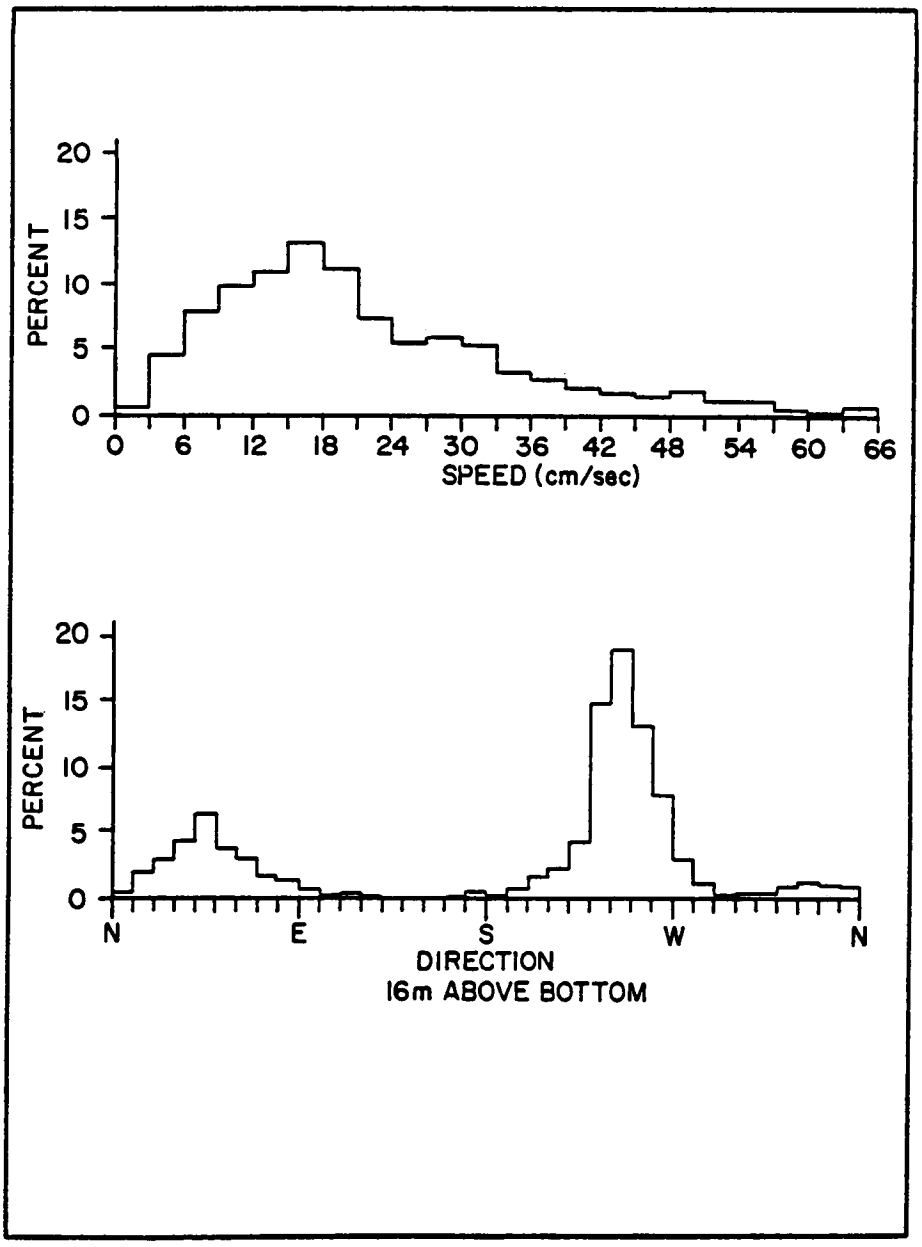


Figure 7. Histograms of Current Speeds and Directions, 16 December 1975 to 25 January 1977.

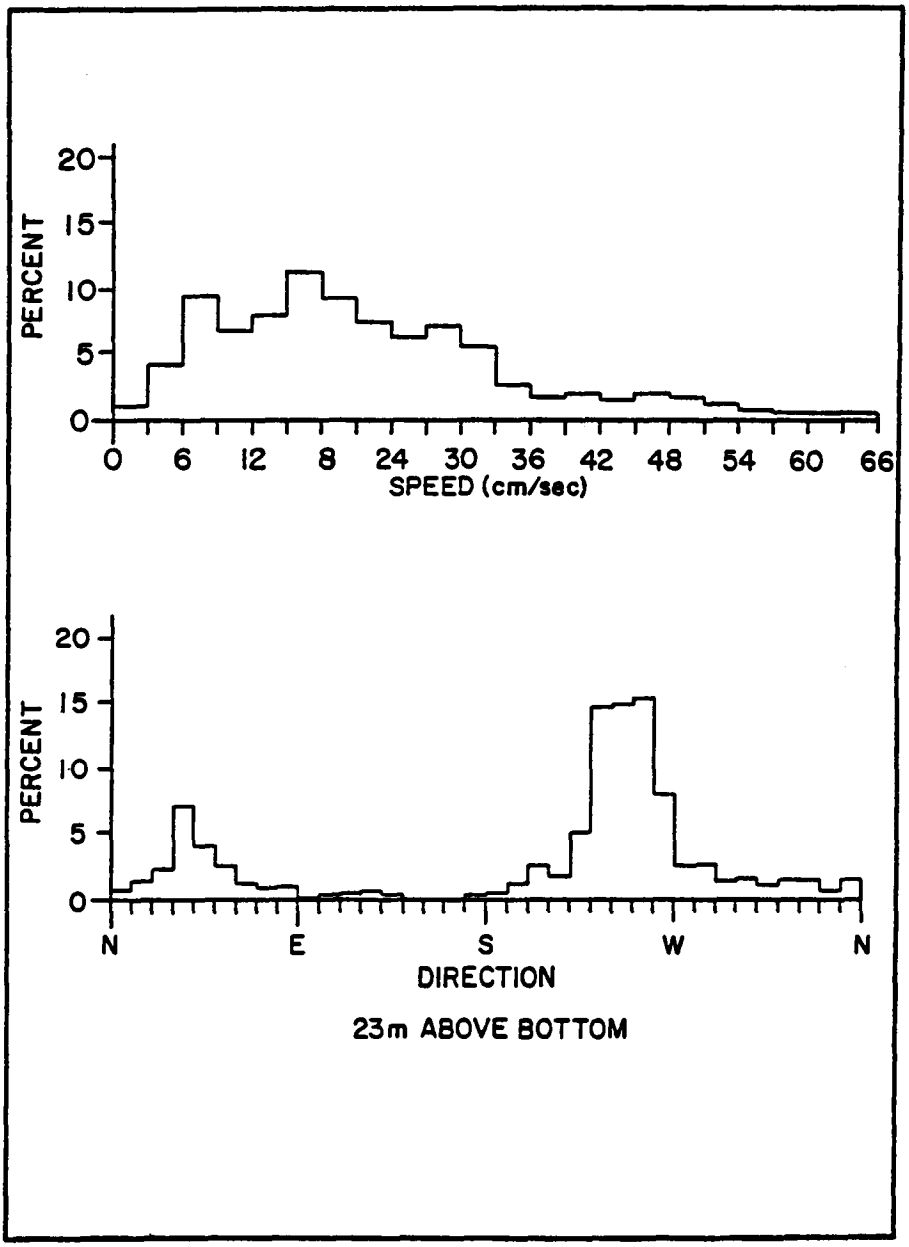


Figure 8. Histograms of Current Speeds and Directions, 16 December 1976 to 25 January 1977.

vals between 6 and 33 cm/sec. Again, four observations recorded speeds in excess of 66 cm/sec.

The direction histogram (Figure 8) is similarly decoupled, though between 140-170° at this level. The peak in the direction histogram between 230 and 260° is nearly flat-topped, with all intervals recording approximately 15% of the total number of observations. The peak in the longshore motion in the opposite direction exactly parallels the orientation of the coastline with a maximum between 30-40°.

Energy Density and Coherence Spectra

The computation and interpretation of energy density spectra are useful for investigating the dominant time scales of sub-surface shelf motion. Time series of hourly current measurements have been decomposed into longshore and cross-shelf components for analysis. Results from the lowest level, 2 m above the bottom are shown in Figure 9. For the longshore component of the current, energy density levels decrease rapidly through five orders of magnitude from the longest periods down to the semi-diurnal tidal period. At this level in the water column, neither diurnal nor semi-diurnal tidal motions appear to contribute significantly to the total circulation.

The spectrum of cross-shelf current components shows distinct differences, especially at the longest periodicities. An identifiable peak occurs at a period of between 2 and 3 days, and a small peak is present at the diurnal tidal/inertial period. At shorter periods, the spectrum becomes somewhat ragged, and the computed spectral peaks below 8 hours probably do not reflect real physical processes.

The spectra computed from the time series obtained 7 m above the bottom (Figure 10) is essentially similar to that from the 2-m level. At

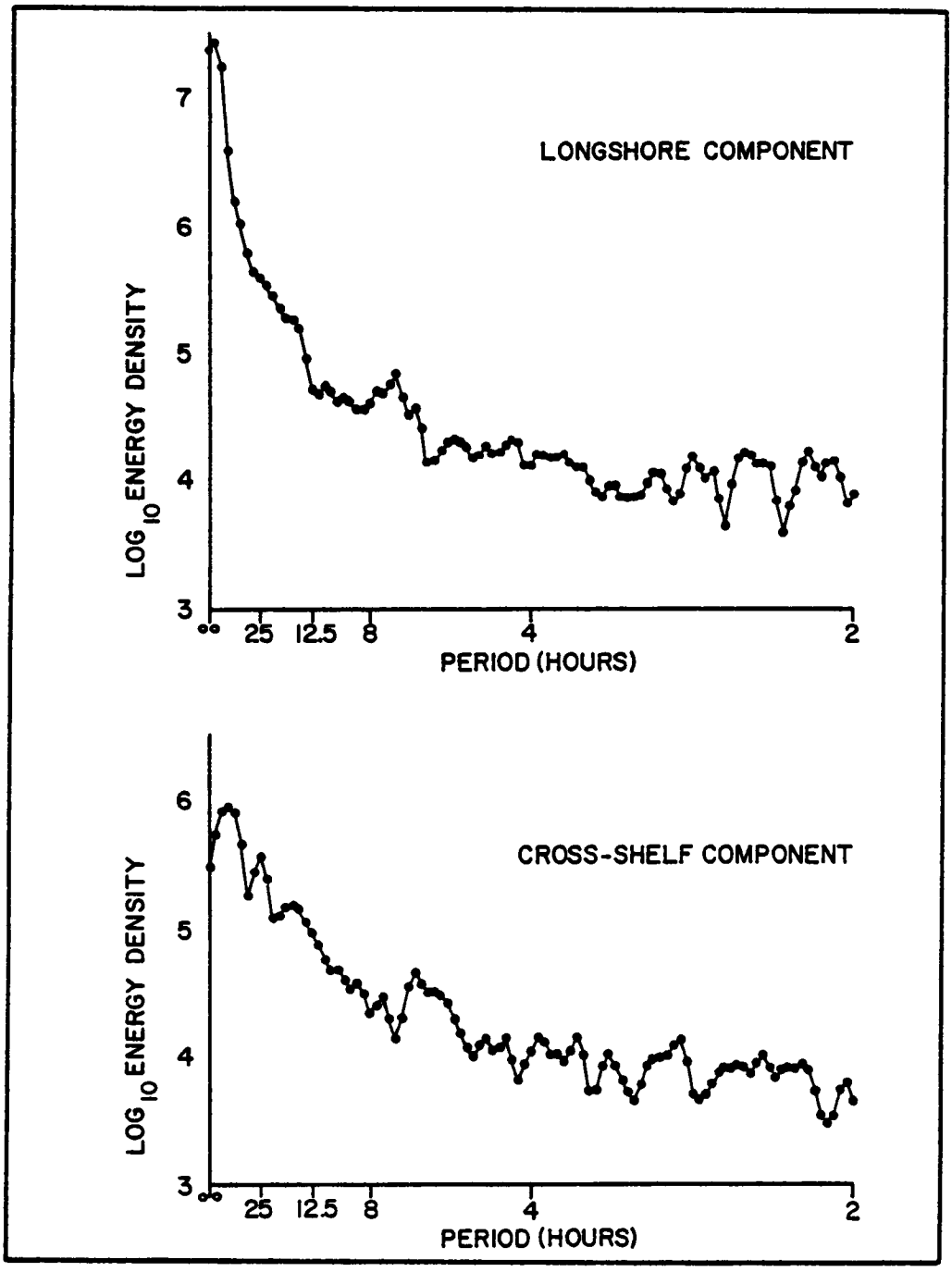


Figure 9. Energy Density Spectra of Longshore and Cross-shelf Current Components Measured 2 m above the Bottom, 16 December 1976 to 25 January 1977. Vertical axis in $(cm/sec)^2$/cycles per hour (cph). Spectral Resolution is 0.003 cph.

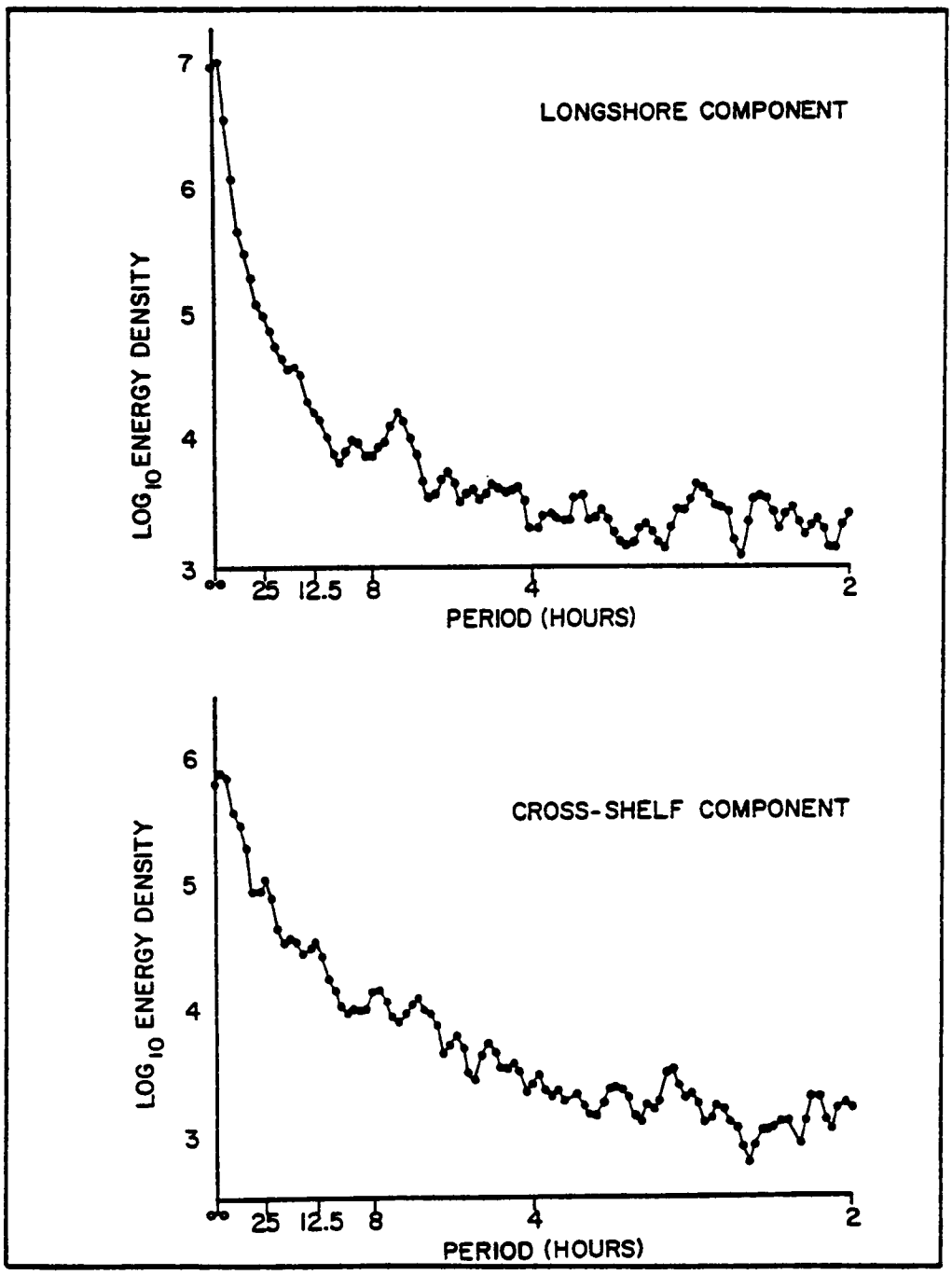


Figure 10. Energy Density Spectra of Longshore and Cross-Shelf Current Components Measured 7 m above the Bottom, 16 December 1976 to 25 January 1977. Vertical axis in $(cm/sec)^2/cph$. Spectral Resolution is 0.003 cph.

the longest periods, however, energy levels from the longshore components are nearly an order of magnitude lower than those computed for the 2-m level currents. Again, no tidal/inertial period motion is indicated in the longshore components. Slight tidal/inertial oscillations are indicated in the cross-shelf components.

At mid-depth (Figure 11), a significant feature appears in the spectrum computed from the longshore components. A slight spike appears at the diurnal tidal/inertial period, as well as at the semi-diurnal tidal period. In the cross-shelf component spectrum, the exponential decrease in energy levels is interrupted slightly at a diurnal period, but no distinct peak appears. Long-period cross-shelf motion is over half an order of magnitude greater than that found in the lower half of the water column.

The spectra computed from the top current time series 23-m above bottom and 10 m below the surface (Figure 12) is nearly identical with that computed from mid-depth currents, with one exception. Diurnal tidal/inertial period motions and semi-diurnal tidal period variations appear to be well developed in the cross-shelf component of the current. Both the longshore and cross-shelf component spectra become somewhat ragged at shorter periods, but again these peaks are not believed to reflect real physical processes.

A coherence spectrum was computed first for the longshore components recorded at top and bottom levels, then again for the cross-shelf components of the current at these two levels. The results indicate how the water column reacts uniformly or differently to shelf forcing. Figure 13 indicates that highest coherences are found in the long-period portion of the spectrum computed from the longshore current components. It appears that very long period variations in the longshore current occur in a similar manner through the water column. This is consistent with the fact that all four

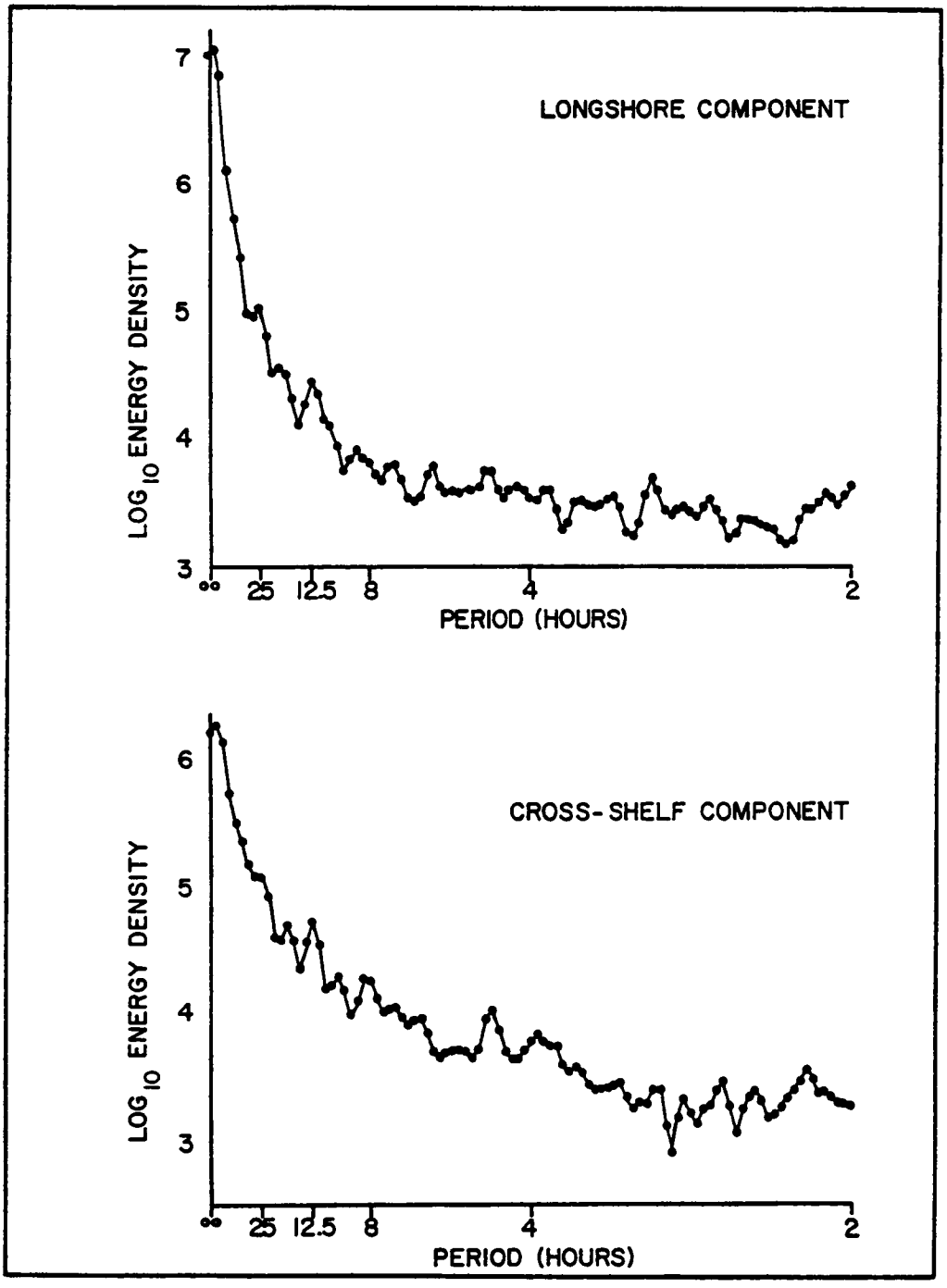


Figure 11. Energy Density Spectra of Longshore and Cross-Shelf Current Components Measured 16 m Above the Bottom, 16 December 1976 to 25 January 1977. Vertical axis in $(cm/sec)^2/cph$. Spectral Resolution is 0.003 cph.

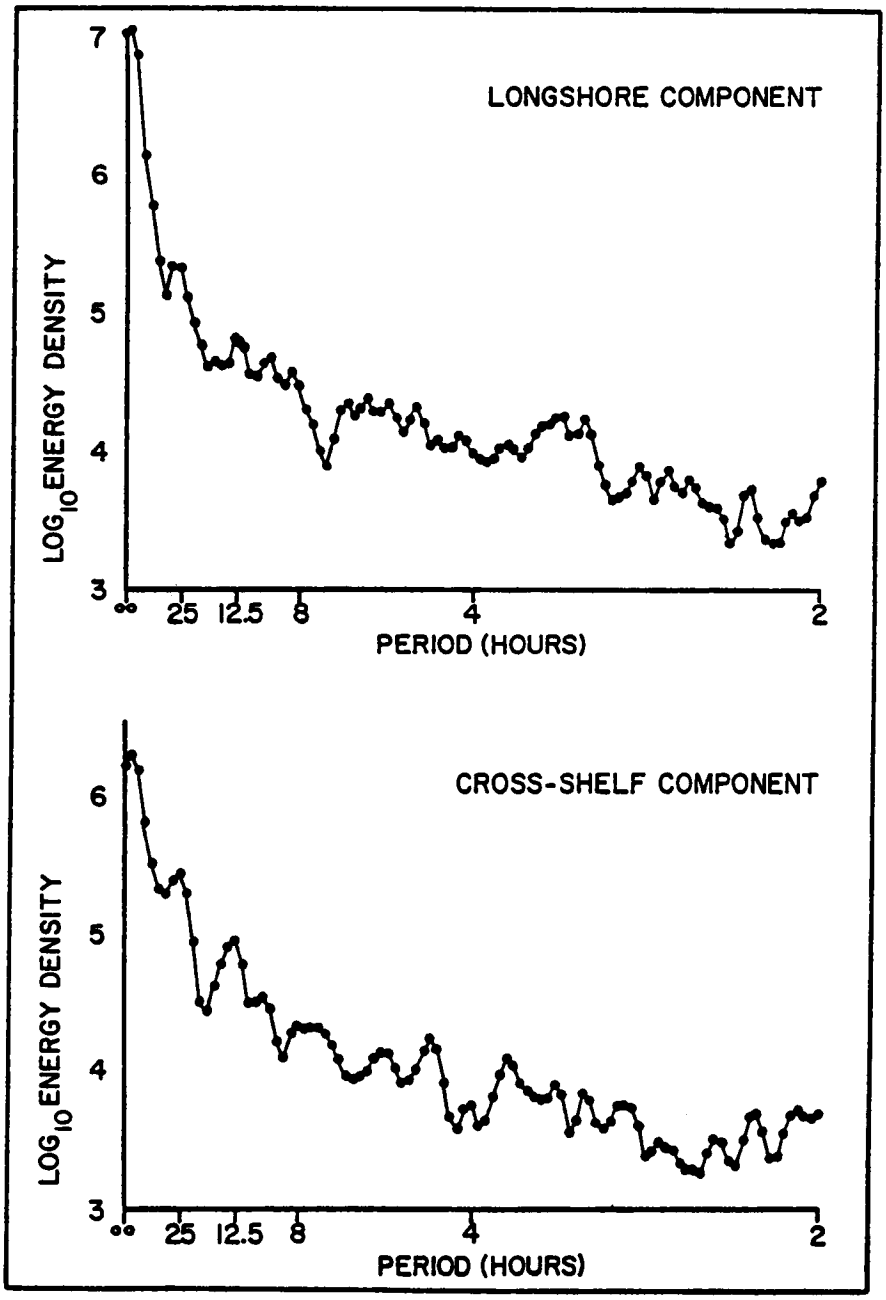


Figure 12. Energy Density Spectra of Longshore and Cross-Shelf Current Components Measured 23 m Above the Bottom, 16 December 1976 to 25 January 1977. Vertical axis in $(cm/sec)^2/cph$. Spectral Resolution is 0.003 cph.

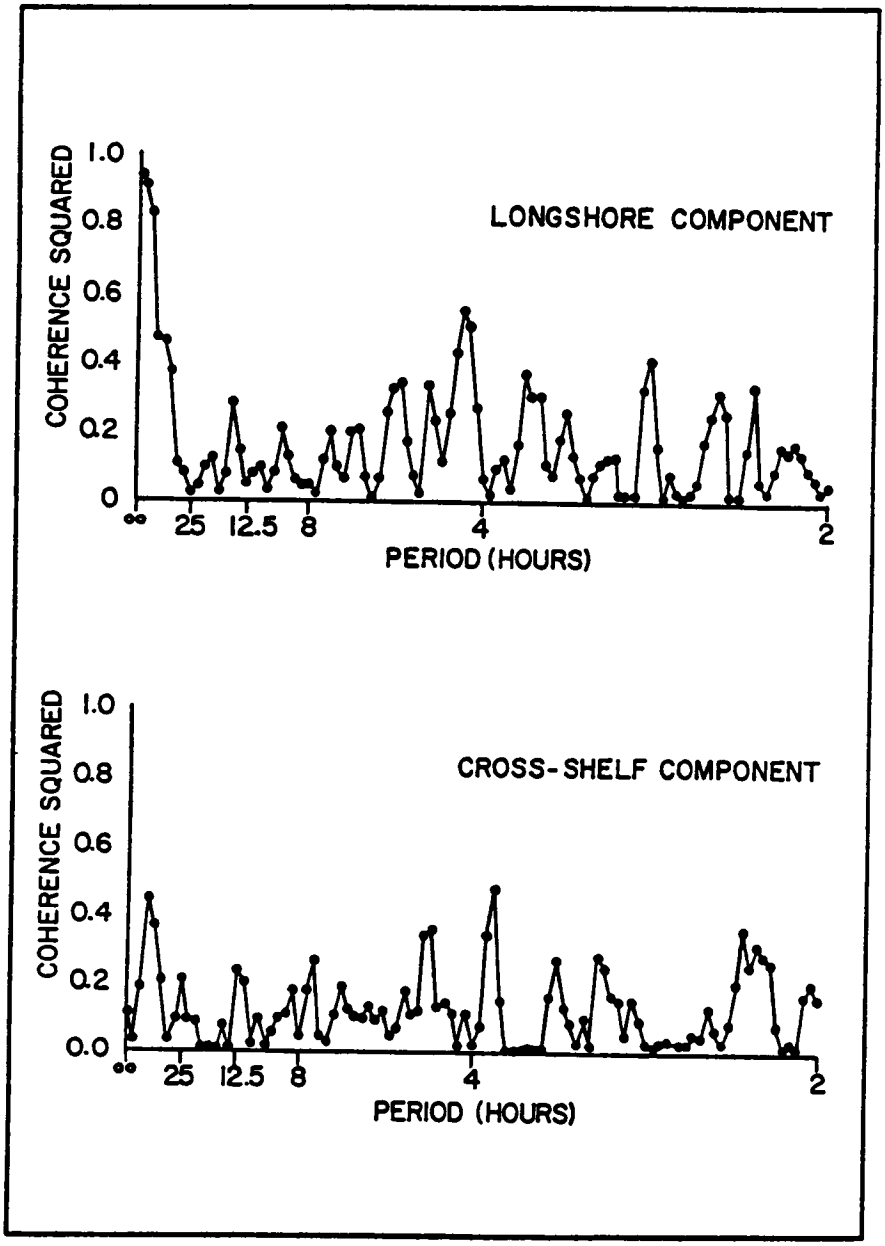


Figure 13. Coherence-Squared Spectra for Longshore and Cross-Shelf Current Components from Time Series Measured 2 and 23 m Above the Bottom.

of the progressive vector diagrams (Figures 1-4) indicate essentially the same features in spite of the fact that the cross-isobath motion appears to be depth-dependent. The spectrum computed from the cross-shelf components of the current at these two levels shows no such high coherences in the long-period portion of the spectrum. At periods below about 25 hours, there does not appear to be both statistically significant and physically realistic coherences relating motion at these levels.

Tidal Computations

Results of the harmonic analysis of the longshore and cross-shelf current component time series are summarized for the principal tidal constituents in Table 1. Only the amplitudes are presented, as there is considerable difficulty in reliably determining the crest, and thus the phase angle, of a low-amplitude sine wave. All calculated amplitudes are less than 1.9 cm/sec which is well within the ± 2.7 cm/sec precision of the current meter. There is some indication that the principal diurnal constituents are greater than the two principal semi-diurnal constituents. This is consistent with the dominance of diurnal water level variations in the northwestern Gulf of Mexico (Smith, 1974), though the diurnal period amplitudes may be influenced in a non-random way by inertial period oscillations in the current (local inertial period of 25.78 hours at the study site). If this were the case, one would expect greater amplitudes computed at near-surface levels. Table 1 suggests that this is in fact the case, casting further doubt on the reality of the computed tidal constituent amplitudes. Certainly the significance of tidal motions at the study site is minor.

TABLE 1

AMPLITUDES (IN cm/sec) OF THE PRINCIPAL TIDAL CONSTITUENTS FROM 29 DAYS OF DATA, STARTING 0001 CST, 17 DECEMBER 1976

	K_1	O_1	M_2	S_2
2 m Above Bottom				
Longshore Component	0.7	0.6	0.3	0.1
Cross-Shelf Component	0.9	1.5	0.7	0.1
7 m Above Bottom				
Longshore Component	0.8	0.4	0.5	0.2
Cross-Shelf Component	0.9	1.6	0.9	0.4
16 m Above Bottom				
Longshore Component	1.5	0.3	0.9	0.4
Cross-Shelf Component	1.2	1.6	1.5	0.1
23 m Above Bottom				
Longshore Component	1.5	0.8	1.4	0.8
Cross-Shelf Component	1.9	1.9	1.6	0.8

Note: K_1 and O_1 are the principal diurnal tidal constituents, with periodicities of 23.93 and 25.82 hours, respectively; M_2 and S_2 are the principal semi-diurnal constitutents, with periodicities of 12.42 and 12.00 hours, respectively.

Temporal Variability in Windstress

Coastal wind data, recorded in analog form at the Port Aransas Marine Laboratory, were used to construct time series of longshore and cross-shelf windstress components. Time plots of these two data files, reconverted to analog form, are shown in Figures 14 and 15. Several features are noteworthy. First, there appears to be more energy contained in the longshore than in cross-shelf windstress components, with negative values significantly greater than positive values. This may mean that the most available form of energy for generating or maintaining a wind-driven shelf circulation during this time was windstress-directed toward the south-southwest. This is consistent with the quasi-steady longshore flow observed in the progressive vector diagrams. Longshore windstress directed toward 033° rarely exceeds 3 dynes/cm^2, while windstress toward 213° exceeds 6 dynes/cm^2 on five occasions. These transient bursts may play an important part in driving the nearshore circulation. The low-frequency variations in longshore and cross-shelf windstress components are aperiodic, however, one can detect maxima and minima spaced over time intervals on the order of 3 to 6 days throughout the record.

Cross-shelf windstress directed onshore (positive values) is particularly weak at this time of year. With only four to five periods of significant onshore winds recorded, the time plot is in effect bounded by the zero axis. The characteristics of the cross-shelf component of the windstress vector are important, as sub-surface cross-shelf motion may occur as a return flow to a cross-shelf wind drift.

Coherence Between Windstress and Sub-Surface Circulation

Results of the coherence computations for selected pairs of windstress and current vector components are summarized in Table 2. Only time scales

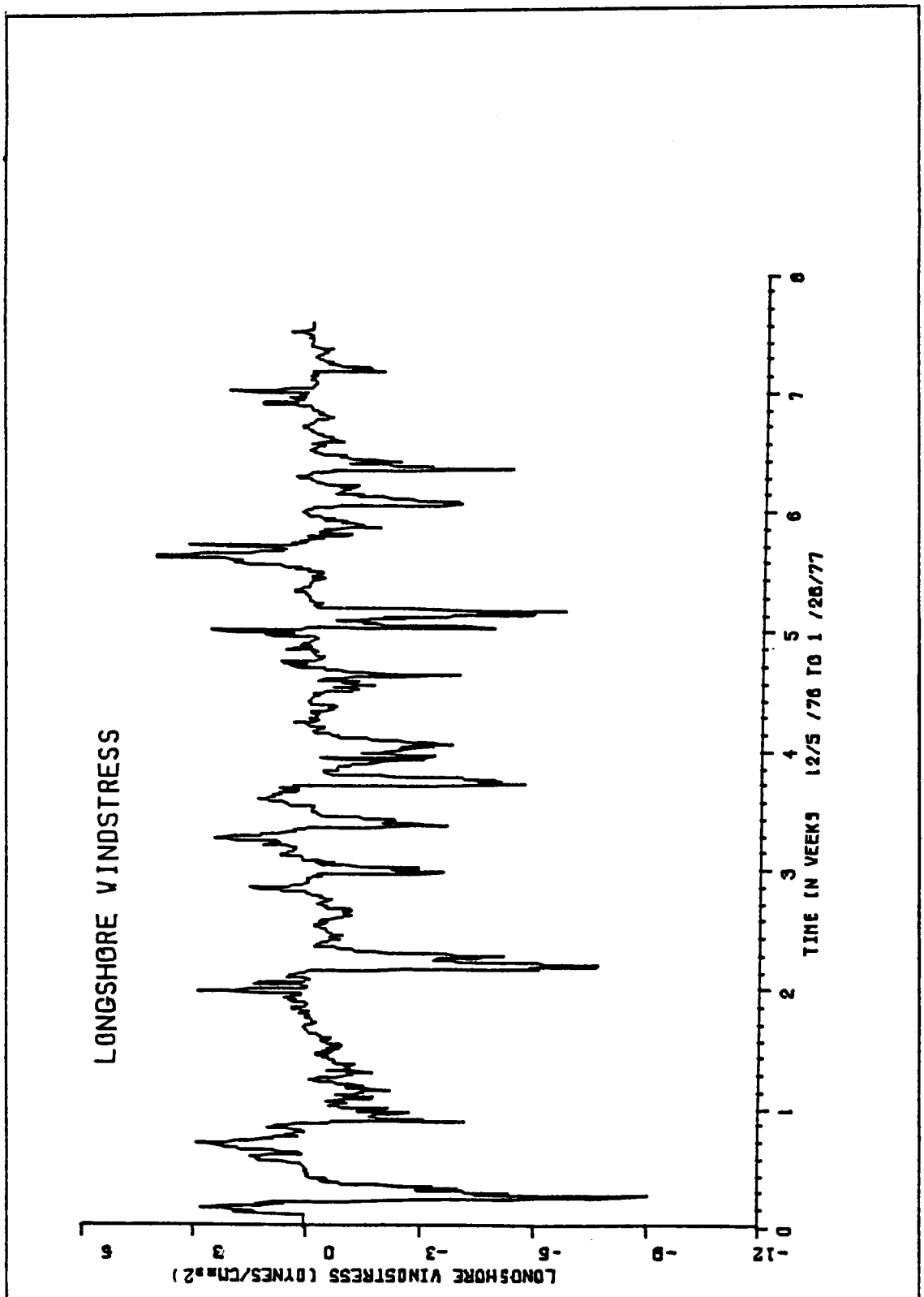


Figure 14. Longshore Windstress Component, in dynes/cm ^{2}, 5 December 1976 to 26 January 1977.

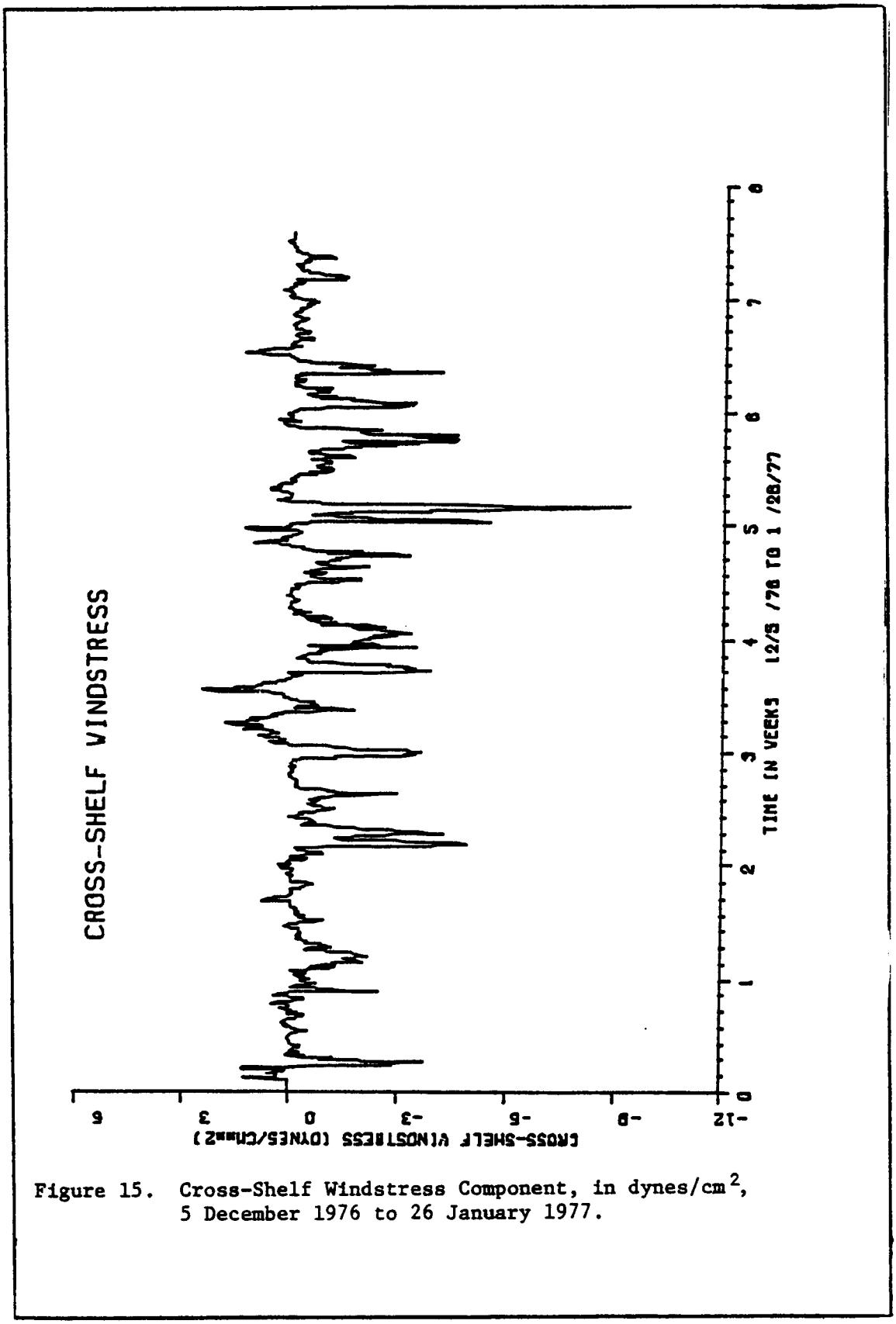


Figure 15. Cross-Shelf Windstress Component, in dynes/cm^2, 5 December 1976 to 26 January 1977.

TABLE 2

COHERENCE-SQUARED VALUES FOR SELECTED PAIRS OF WINDSTRESS VECTOR COMPONENTS AND CURRENT VECTOR COMPONENTS, 16 DECEMBER 1976 THROUGH 25 JANUARY 1977. SPECTRAL RESOLUTION IS 0.0036 cph; 95 PERCENT CONFIDENCE LIMIT IS 0.217; 99 PERCENT CONFIDENCE LIMIT IS 0.314

	Period (Hours)				
	140	93	70	56	47
Upper Level (23 m Above Bottom)					
Longshore Windstress					
with longshore current	0.020	0.028	0.227	0.275	0.152
with cross-shelf current	0.026	0.094	0.270	0.284	0.171
Cross-Shelf Windstress					
with longshore current	0.172	0.394	0.379	0.272	0.111
with cross-shelf current	0.282	0.370	0.260	0.288	0.096
Lowest Level (2 m Above Bottom)					
Longshore Windstress					
with longshore current	0.067	0.042	0.107	0.225	0.345
with cross-shelf current	0.232	0.272	0.061	0.016	0.113
Cross-Shelf Windstress					
with longshore current	0.113	0.203	0.064	0.162	0.289
with cross-shelf current	0.199	0.328	0.115	0.004	0.028

on the order of 2 to 6 days, commonly associated with meteorologically forced shelf processes, have been considered. Statistically significant coherence-squared values are found at the 95%, and in some cases the 99% confidence limit for each of the current/windstress component pairs.

There is little consistency apparent in Table 2, making interpretation somewhat difficult. Highest coherence-squared values are computed for the cross-shelf components recorded at the upper level. It appears that the 3 to 4 day pulsing of the near-surface current occurs in response to the alternations in cross-shelf winds preceeding and following frontal passages. Interestingly, the coherence between longshore windstress and the longshore near-surface current is statistically significant only at the 95 percent confidence limit. This would suggest that the longshore current is in response to more than local forcing.

At the lower level, there is an apparent differential response to wind forcing for the longshore and cross-shelf current components. The longshore component of the current is most coherent with both cross-shelf and longshore windstress components over time scales on the order of two days. At the same time, the cross-shelf component of the current is more coherent with both windstress components over time scales of just under 4 days. The explanation for this difference in the response characteristics of the two current components is not readily apparent.

DISCUSSION

Accumulated ship drift calculations and drift bottle studies provide a historical setting for this study, and it is appropriate to begin with a comparison to put the Rig Monitoring current data in a proper perspective. Charts for Gulf of Mexico waters (Hydrographic Office, 1942) show currents toward the southwest and west-northwest during the months of December and

January, respectively. Multi-year monthly average surface current speeds for December and January are approximately 18 and 7 cm/sec, respectively. No information is available on either speed or direction for subsurface levels. These surface currents relate in a general way to surface winds at this time of year which characteristically blow out of the east or northeast over the Texas shelf. Occasional frontal passages produce northerly or north-westerly winds.

Drift bottle study results from winter months also reflect winds out of the northeast quadrant characteristic of this season. Due to the relatively short time intervals involved for a given drop, considerably more scatter is to be expected in both the observed speeds and directions. Drift trajectories may be strongly influenced by transient wind events which may or may not be normal for the season. A review of net surface drift patterns, presented by Watson and Behrens (1970) and Hunter *et al.* (1974) among others, supports the general picture of a southwesterly drift in the winter months, but indicates at the same time a substantial number of recoveries reported along the coast north of a given drop site. Smith (1977) has shown that subsurface motion along the central Texas coast is well correlated with coastal winds. Thus, under appropriate wind conditions, longshore motion in either direction could be expected. Alternating longshore motion was indeed recorded in the winter of 1973-1974, and the scatter in the drift bottle data may reflect the effects of low-frequency variations in coastal winds. By the same token, the averages of all accumulated ship drift calculations may both obscure the alternating nature of longshore motion along the central Texas coast, and produce a resultant surface current vector which does not well represent the instantaneous motion.

The four approximately 40-day time series obtained in the Rig Monitor-

ing Study are consistent with the concept of a net drift to the southwest, but three periods of reverse flow are noted during the study. The progressive vectors indicate longshore motion to the northeast of 78, 19 and 33 km past the top current meter, and transport of 48, 30 and 32 km past the bottom current meter. The magnitude of the reversals in the net southwesterly flow make them an important feature of the winter shelf circulation patterns.

An interesting aspect of the time series, though one that cannot be resolved with the available data, is the increasing onshore deflection of the resultant current vector with increasing height above the bottom. It is apparent that there is not a local balance of cross-shelf transport through the water column at this point. The pattern that emerges is one of a substantial onshore transport, occurring primarily in the upper part of the water column. The pattern could be explained by a longshore current which is accelerating, with the difference between the import and the export being provided by the onshore transport from further offshore, but this explanation can only be postulated with the available data.

It is clear from the energy density computations, and from the calculations of the harmonic constants of the principal tidal constituents that neither tidal nor inertial motions make up a significant component of the observed total motion. The increase in diurnal period variations noted with increasing height above the bottom suggests that there may be measurable inertial motions in the surface layer. Tidal motions seem to be insignificant at this location throughout the water column.

With insignificant tidal currents, minor inertial motion, and no permanent coastal boundary current affecting the central Texas coast, it is safe to conclude that the circulation of the Texas outer continental shelf

is predominantly wind-driven and varies most generally in response to seasonally changing wind patterns. It is to be expected that the shelf circulation responds over shorter time scales to specific meteorological events as well. The details of this air-sea coupling over intermediate time scales are of substantial interest but await a more detailed study.

LITERATURE CITED

Bennett, A. 1976. Conversion of *in situ* measurements of conductivity to salinity. Deep-Sea Res. 23:157-165.

Bullard, F. 1942. Source of beach and river sands on the Gulf coast of Texas. Bull. geol. Soc. Am. 53(7):1021-1043.

Dennis, R., and E. Long. 1971. A user's guide to a computer program for harmonic analysis of data at tidal frequencies. NOAA Tech. Rept. No. 41. 31pp.

Fee, E. 1969. Digital computer programs for spectral analysis of time series. Univ. of Wisconsin, Milwaukee. Center for Great Lakes Studies, Special Rept. No. 6. 17pp.

Groves, G. 1955. Numerical filters for discrimination against tidal periodicities. Trans., Am. Geophys. Union 36(6):1073-1084.

Hayes, M. 1965. Sedimentation on a semi-arid, wave-dominated coast (South Texas) with emphasis on hurricane effects. Ph.D. Thesis, The Univ. of Texas, Austin.

Hunter, R., G. Hill, and L. Garrison. 1974. Drift patterns along the South Texas coast, 1970-1973. USGS Misc. Field Studies Map, Mf-623, 2 sheets.

Hydrographic Office, 1942. Central American waters: Current charts. H.O. Misc. No. 10. 690-1.

Kimsey, J., and R. Temple. 1962. Currents on the continental shelf of the northwestern Gulf of Mexico. Annual Lab. Rept. Circ. Fish Wildl. Serv., Wash. 161:23-27.

Leipper, D. 1954. Physical oceanography of the Gulf of Mexico. *In* Gulf of Mexico, its origin, waters and marine life. Fish. Bull. No. 89. Fish. and Wildl. Serv. 55:119-137.

Panofsky, H., and G. Brier. 1958. Some applications of statistics to meteorology. First Edition. Penn. St. Univ. 224pp.

Smith, N. 1977 (In Press). Low-frequency reversals in nearshore currents in the northwestern Gulf of Mexico. Contr. Mar. Sci. 21.

_____. 1975. Seasonal variations in nearshore circulation in the northwestern Gulf of Mexico. Contr. Mar. Sci. 19:49-65.

_____. 1974. Intracoastal tides of Corpus Christi Bay. Contr. Mar. Sci. 18:205-219.

Van Andel, T., and D. Poole. 1960. Sources of recent sediments in the northern Gulf of Mexico. J. Sed. Petrol. 30:91-122.

Watson, R., and E. Behrens. 1970. Nearshore surface currents, southeastern Texas Gulf coast. Contr. Mar. Sci. 15:133-143.

_____. 1968. Origin of shell beaches. Padre Island, Texas. M.A. Thesis, the Univ. of Texas, Austin.

Wu, J. 1969. Windstress and surface roughness at air-sea interface. Jour. Geophys. Res. 74(2):444-455.

CHAPTER FOUR

TRANSMISSOMETRY PROJECT

Department of Geological Oceanography
Texas A&M University

Principal Investigator:

Richard E. Rezak

ABSTRACT

Transmissivity profiles were scheduled to be taken at five stations (DS or 100 m from DS in the sediment plume, N-1000, E-1000, S-1000 and W-1000), during pre-, during- and post-drilling surveys. However, due to equipment failure, profiles for the during and post-drill surveys were not obtained. Salinity, temperature, and depth data were also obtained at these stations. A very thin layer (2-2.5 m) of turbid water, the nepheloid layer, was observed on the bottom in the drill site area during the pre-drilling survey.

INTRODUCTION

Transmissivity profiles were scheduled to be taken during the pre-, during- and post-drilling surveys. Profiles were to be taken at the drill site (100 m from the drill site, in the sediment plume for the during-drilling survey) N-1000, E-1000, S-1000 and W-1000. Unfortunately, profiles were only obtained for the pre-drilling stations due to a malfunction of the transmissometer. Salinity and temperature profiles were also taken with the pre-drilling transmissivity profiles.

METHODS AND MATERIALS

The transmissometer used for these measurements was a MARTEK model XMS with a 1-m folded light path. The output from this instrument was connected to a Hewlett-Packard X-Y recorder so that a continuous and permanent graph was recorded for each lowering.

Salinity, temperature, and depth data were acquired with a PLESSEY 9006 system. This system incorporates a signal processor unit coupled with a graphic printer to give a permanent record of events in relation to depth. These data were also checked through the use of surface salinity and temperature readings taken with a salinometer and bucket thermometer.

The pre-drilling survey was conducted aboard the R/V GYRE during cruise 76G8.

RESULTS AND DISCUSSION

Temperature, salinity and transmissivity values for the five pre-drilling survey stations are listed in Tables 1-5 and plotted against depth in Figures 1-5. A very thin (2.0-2.5 m) layer of turbid water was

TABLE 1

PRE-DRILL
SALINITY, TEMPERATURE AND TRANSMISSIVITY OBSERVATIONS AT STATION-DS (DRILL SITE)[1]

Depth (m)	Temperature (°C)	Depth (m)	Salinity (ppt)	Depth (m)	Transmissivity (%)
0.38	24.83	0.75	34.05	0.54	55.99
4.13	24.83	9.75	34.56	4.95	55.59
5.63	24.91	10.88	34.54	7.47	54.79
7.50	24.87	13.13	34.64	10.08	56.39
9.00	24.90	18.75	34.79	13.68	60.98
10.13	24.85	19.13	34.66	15.30	61.98
18.38	24.85	20.25	34.79	16.65	59.28
19.88	24.92	20.63	34.80	19.08	62.57
20.25	24.87	21.00	34.93	21.69	63.07
21.00	24.89	22.50	34.93	24.12	63.47
22.50	24.89			26.64	60.48
				26.91	55.99
				28.26	4.29

[1]Water depth at Station DS was 28.30 m (as recorded by transmissometer).

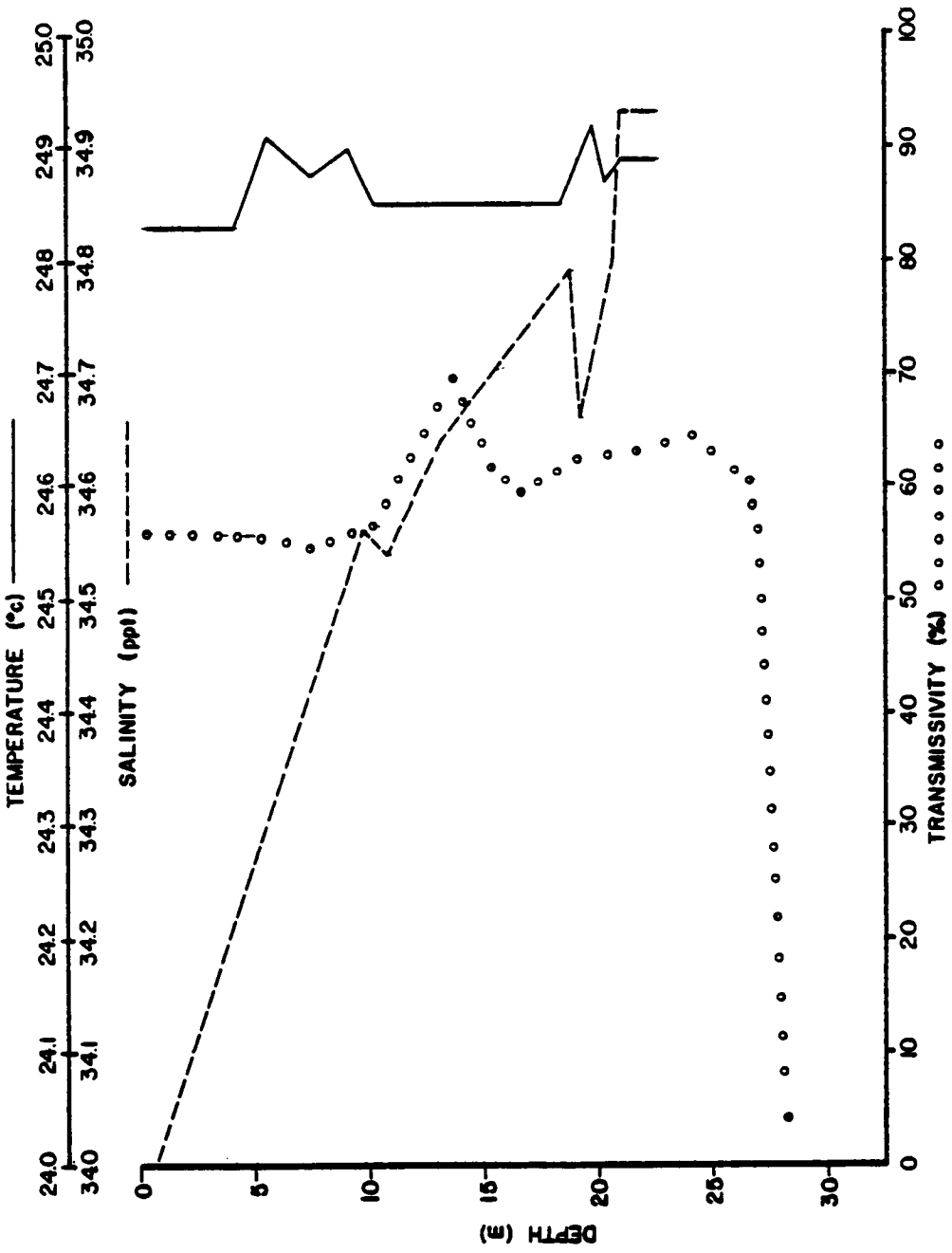


Figure 1. Pre-Drill Salinity, Temperature, and Transmissivity Profile at Drill Site.

TABLE 2

PRE-DRILL
SALINITY, TEMPERATURE AND TRANSMISSIVITY OBSERVATIONS AT STATION N-1000[1]

Depth (m)	Temperature (°C)
0.47	24.81
3.72	24.80
9.78	24.93
10.24	24.90
12.57	24.90
13.97	24.87
18.62	24.87
22.34	24.91
23.28	24.79
23.74	24.88
24.21	24.90
26.53	24.87

Depth (m)	Salinity (ppt)
0.50	33.92
13.06	34.57
22.10	34.73
23.11	34.75
26.12	35.33

Depth (m)	Transmissivity (%)
2.53	46.36
2.89	50.75
9.65	56.83
10.19	59.12
26.96	61.71
27.87	56.23
29.85	6.18

[1]Water Depth at Station N-1000 was 29.85 m (as recorded by transmissometer).

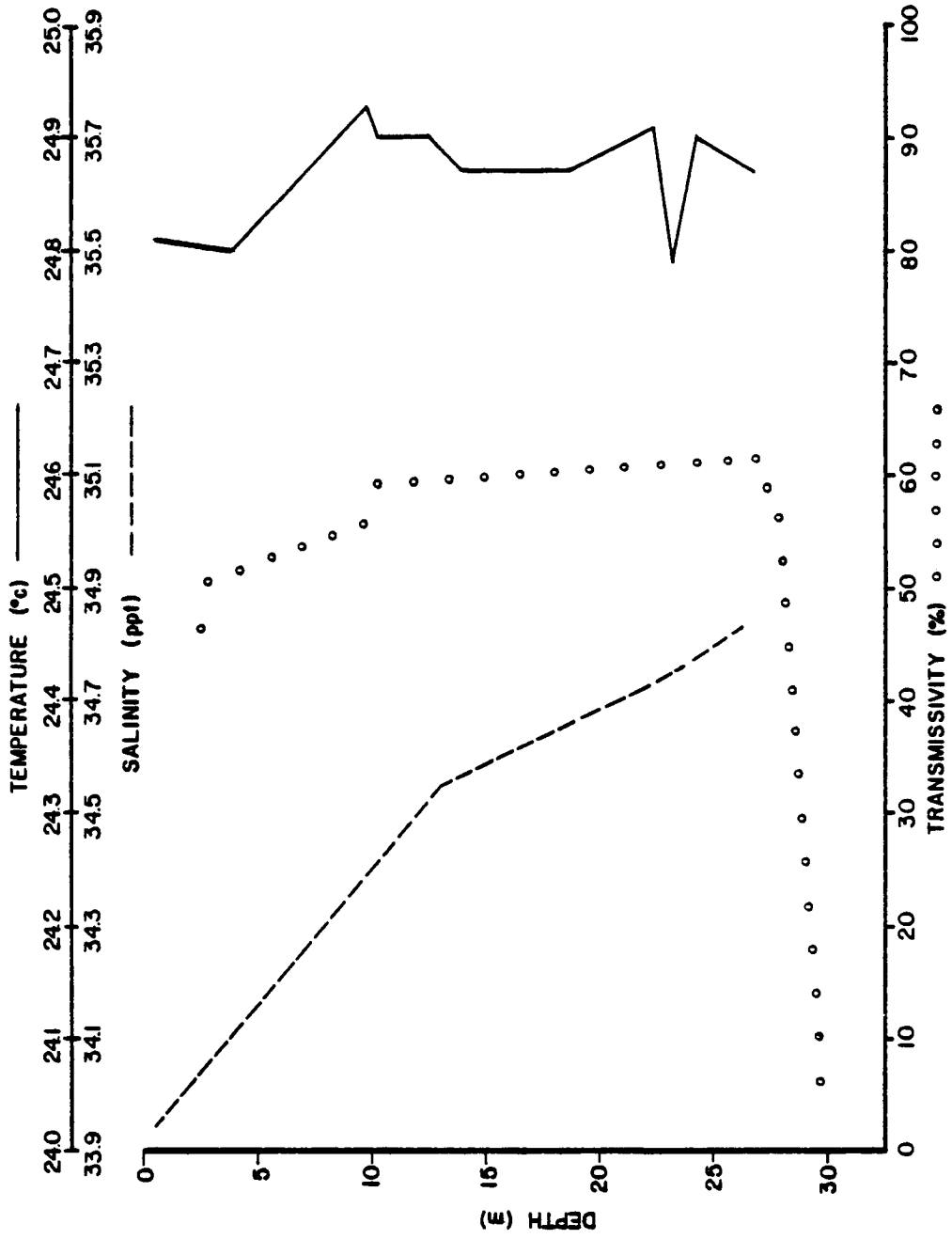


Figure 2. Pre-Drill Salinity, Temperature, and Transmissivity Profile at Station N-1000.

TABLE 3

PRE-DRILL
SALINITY, TEMPERATURE AND TRANSMISSIVITY OBSERVATIONS AT STATION E-1000[1]

Depth (m)	Temperature (°C)	Depth (m)	Salinity (ppt)	Depth (m)	Transmissivity (%)
0.00	24.71	0.75	33.81	0.09	0.10
0.38	24.74	3.75	34.42	2.07	51.65
2.25	24.75	6.38	34.51	8.91	55.64
4.50	24.88	10.13	34.54	11.16	59.44
6.00	24.81	12.00	34.70	19.35	59.94
12.75	24.82	15.10	34.76	20.97	58.04
15.75	24.85	22.13	35.76	23.49	59.74
19.50	24.83			24.93	58.04
21.75	24.57			26.73	52.15
24.38	24.57			27.99	43.46
				29.61	5.00
				30.42	3.60

[1]Water depth at Station E-1000 was 30.5 m (as recorded by transmissometer).

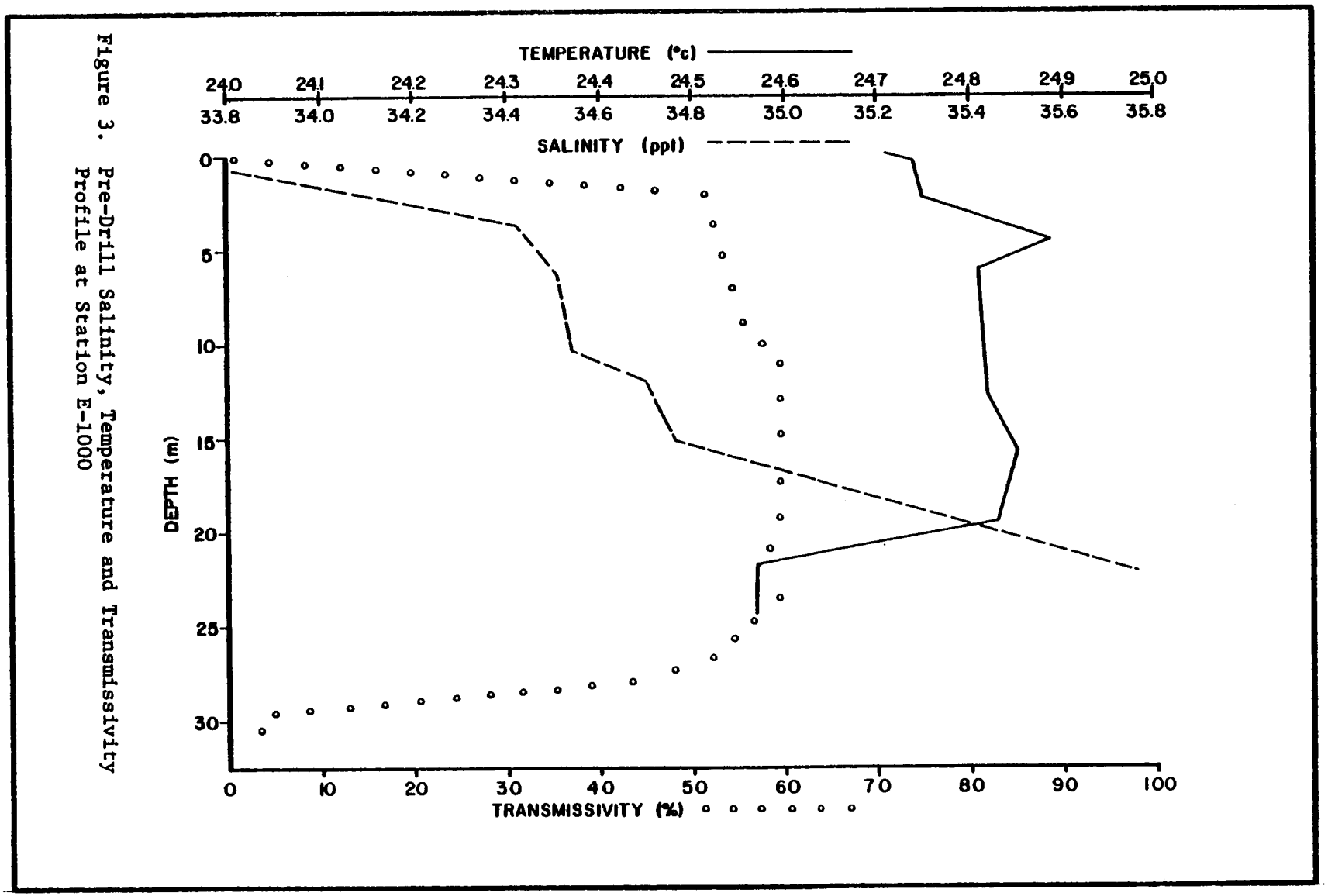


Figure 3. Pre-Drill Salinity, Temperature and Transmissivity Profile at Station E-1000

TABLE 4

PRE-DRILL
SALINITY, TEMPERATURE AND TRANSMISSIVITY OBSERVATIONS AT STATION S-1000[1]

Depth (m)	Temperature (°C)	Depth (m)	Salinity (ppt)	Depth (m)	Transmissivity (%)
0.00	24.78	0.75	33.94	1.08	55.49
6.00	24.78	3.00	34.26	6.12	56.39
11.25	24.86	6.37	34.56	9.90	56.19
19.88	24.86	10.12	34.65	13.14	59.98
21.00	24.72	12.37	34.66	15.84	63.87
21.38	24.81	14.25	34.71	22.41	64.87
		19.75	36.17	27.09	64.57
		20.38	36.23	29.16	51.90
				29.20	23.65

[1]Water depth at Station S-1000 was 29.25 m (as recorded by transmissometer).

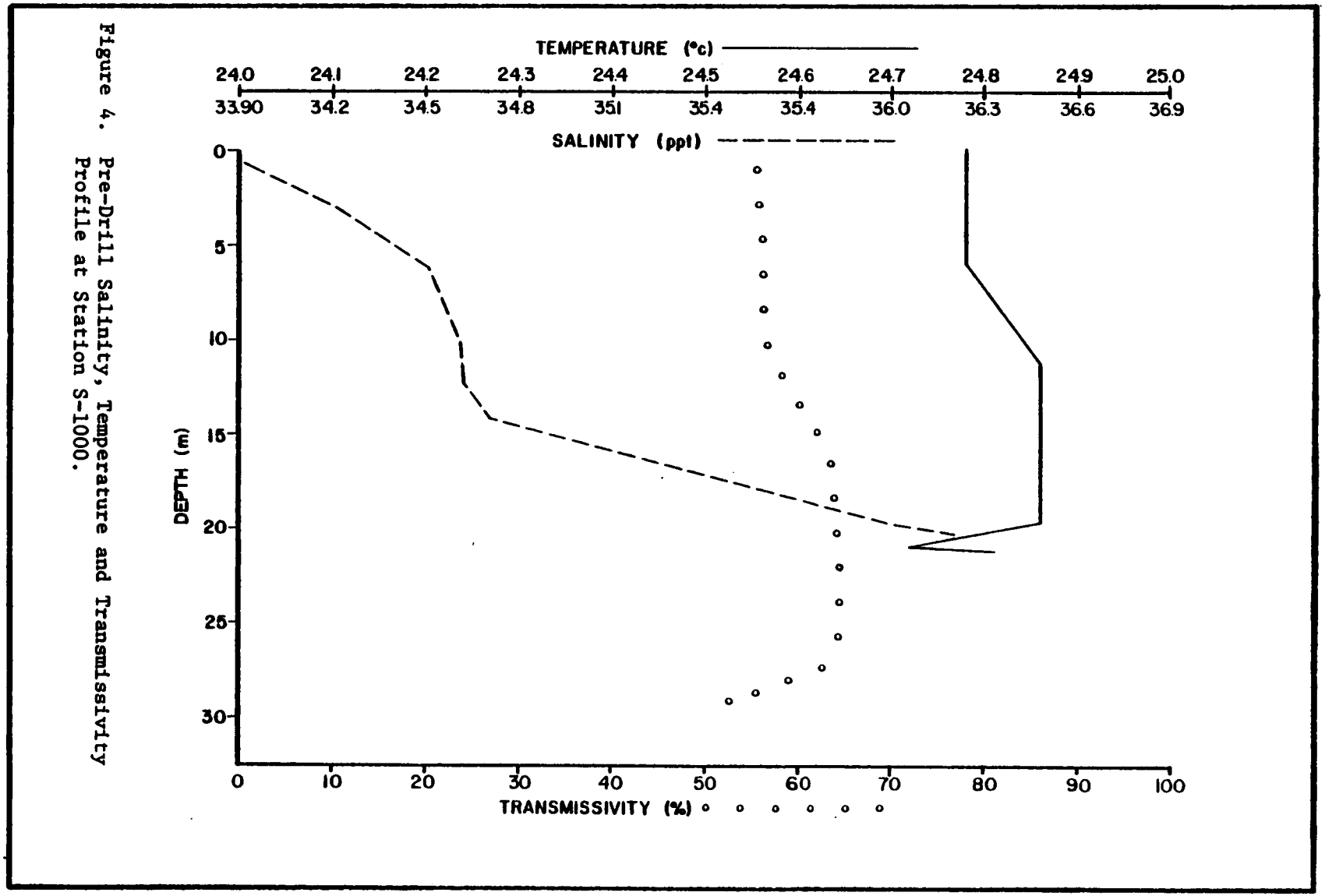


Figure 4. Pre-Drill Salinity, Temperature and Transmissivity Profile at Station S-1000.

TABLE 5

PRE-DRILL
SALINITY, TEMPERATURE AND TRANSMISSIVITY OBSERVATIONS AT STATION W-1000[1]

Depth (m)	Temperature (°C)	Depth (m)	Salinity (ppt)	Depth (m)	Transmissivity (%)
0.00	24.86	0.38	33.94	1.36	51.39
2.63	24.85	15.75	34.75	4.88	49.80
7.50	24.92	16.88	34.75	6.33	54.08
9.75	24.91	20.63	35.42	8.77	56.87
10.88	24.94	22.13	35.42	9.85	58.86
13.88	24.90			14.46	60.16
16.50	24.93			15.45	58.86
18.00	25.02			18.90	55.98
19.50	24.84			20.36	47.71
22.13	24.84			22.30	6.37

[1]Water Depth at Station W-1000 was 22.5 m (as recorded by transmissometer).

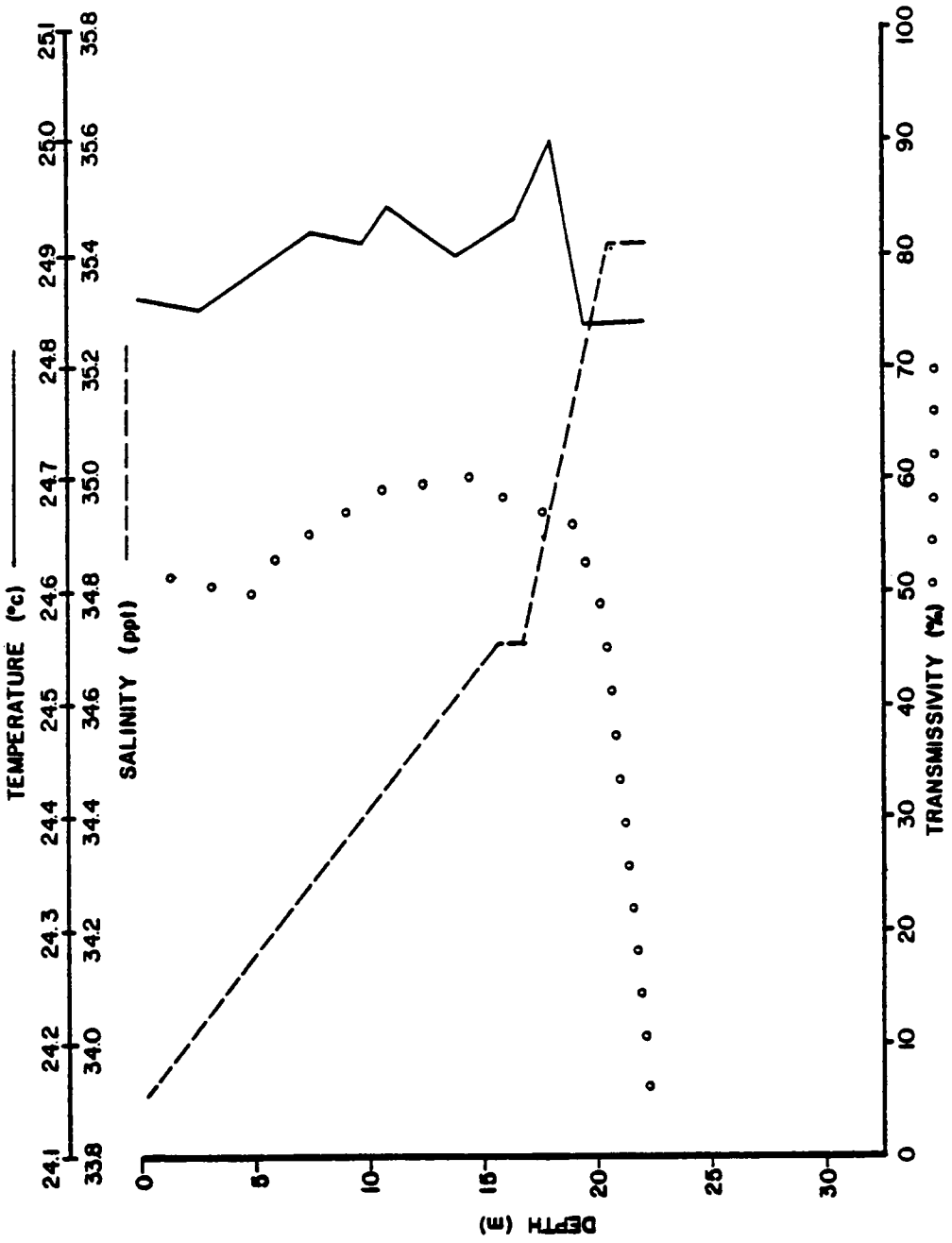


Figure 5. Pre-Drill Salinity, Temperature, and Transmissivity Profile at Station W-1000.

observed on the bottom in the area of the drill site. On only one lowering at Station W-1000 did the STD probe penetrate the nepheloid layer. The measurements at this station (Table 5) showed the presence of a mixed layer of isothermal and isohaline water lying up to two to three meters above the bottom. The coincidence of the top of the mixed layer with the top of the nepheloid layer is a very common occurrence on the Texas outer continental shelf and indicates that the same forces that cause the mixing are responsible for the re-suspension of the bottom sediments to form the nepheloid layer.

It is rather unfortunate that the transmissometer malfunction prevented the acquisition of transmissometry data for the during-drilling survey. With such a thin nepheloid layer, it would have been relatively easy to trace the sediment plume from the drilling rig.

CHAPTER FIVE

SELECTED WATER COLUMN MEASUREMENTS: LOW-MOLECULAR-WEIGHT HYDROCARBONS

Department of Oceanography
Texas A & M University

Principal Investigators:

William M. Sackett
James M. Brooks

Associate Investigators:

Bernie B. Bernard
H. Abdel-Rehim

ABSTRACT

No anomalies in low-molecular-weight hydrocarbon concentrations were observed at the rig monitoring site during the pre-, during- and post-drilling surveys. Drilling platforms are not significant sources of light hydrocarbons to the surrounding waters, unless a catastrophic event such as a well blowout occurs. Since the drilling at the rig monitoring site was only an exploratory well, no additions of light hydrocarbons were expected and none were observed. Production platforms, *not* drilling platforms, are the major sources of light hydrocarbons from offshore operations.

INTRODUCTION

Light hydrocarbon inputs from drilling platforms have been reported previously by Brooks *et al.* (1977) and Brooks (1975) to be negligible. Possible sources of LMWH from drilling platforms are resuspension of bottom sediments containing higher levels of LMWH, discharge of drilling muds containing these volatiles, or loss of gas or fluids (*e.g.*, brine or oil) from the drill stem. On previous occasions samples have been taken within mud plumes created by drilling platforms on the Louisiana shelf with a hydrocarbon "sniffer". On these occasions little effect was observed of the drilling mud on LMWH levels in the water column. The loss of hydrocarbons from a drilling rig occurs to a significant extent only as the result of a catastrophic event, such as a well blowout or platform fire. Although these events are rare, several incidents have been observed in the northwest Gulf of Mexico by the P.I.'s over the last seven years. The most recent of these was a well blowout and drilling platform loss in the High Island Area by Pennzoil Oil Company in November 1976. Brooks and Bernard (1977) studied the gas seepage, light gaseous and liquid hydrocarbon effects, and sediment redistribution resulting from the loss of this drilling platform and creation of a 350-ft deep crater. In this particular case, there were significant inputs of C_1-C_{15} hydrocarbons. These inputs could be observed several miles distance from the 400,000 ft^3/day volume of gas emanating from the crater almost four months after loss of the platform. Aside from catastrophic events, however, drilling platforms have been found previously *not* to be significant sources of LMWH.

The major additions of LMWH to shelf waters from offshore operations come from offshore productions platforms, not drilling platforms (Brooks *et al.*, 1977; Sackett and Brooks, 1975; Brooks and Sackett, 1977). On

the Louisiana shelf, very large inputs of light hydrocarbons are observed from petroleum production operations. These inputs result in very dramatic and complex temporal and spatial distributions of light hydrocarbons on this shelf. The major sources of volatile hydrocarbons from offshore operations are the underwater venting of waste gases and brine discharges. These sources selectively discharge the most immediately toxic component of petroleum, the light liquid aromatic hydrocarbons. These sources are apparently responsible for the two-orders-of-magnitude increase in Louisiana shelf waters over open ocean levels of the light hydrocarbons. Over 2×10^8 ft^3 of gas and 320,000 barrels of brine are discharged into Louisiana shelf waters daily. These discharges from producing platforms contain a wide spectrum of gaseous and gasoline-range hydrocarbons that are unregulated in content.

MATERIALS AND METHODS

The drilling platform was surveyed pre-, during- and post-drilling for low-molecular-weight hydrocarbons (LMWH). The sampling pattern at the site consisted of one station at the anticipated drill site and 48 stations located on transects radiating outward from the drill site forming a pattern as indicated in Tables 1-5. The sampling stations were located at distances of 100, 500, 1000 and 2000 m from the drill site. The drill site (DS) and four stations (North, East, South and West) 1000-m distant from the DS were sampled for the pre-drilling survey, whereas for the during- and post-drilling surveys 48 and 49 stations were occupied, respectively.

Samples were taken by standard hydrographic casts using Nansen bottles lowered to 2 m below the sea surface. After retrieval, the sea water samples were transferred by gravity flow into 200 ml bottles. The bottles .e capped so as to avoid entrapment of gas bubbles. Samples were poisoned with sodium azide to inhibit bacterial alteration.

The LMW hydrocarbon concentrations were determined by a modification of the Swinnerton and Linnenbom (1967) method. The samples of sea water were purged by a hydrocarbon-free helium stream and the LMW hydrocarbons were adsorbed on a trap cooled to liquid nitrogen temperature. The trap was then isolated, heated, and coupled by a slide valve to the gas chromatographic stream for analysis. The hydrocarbons were separated on a 1.8 m, 1.5 mm I.D. Porapak Q column and detected with a flame ionization detector (FID). Sensitivity of the method is 0.5 nl hydrocarbons/ℓ seawater, and precision is generally better than ± 5% for methane.

RESULTS AND DISCUSSION

Tables 1 through 6 show LMWH concentrations in the drilling site area pre-, during-, and post-drilling. Methane concentrations (Table 1) were relatively constant in surface water at approximately 90, 80 and 130 nl/ℓ for the pre-, during-, and post-drilling, respectively. The changes in average methane concentrations from pre- to post-drilling periods are not of concern since, depending on currents, sea state, and wind conditions, the turbidity of water ranged from being fairly low in suspended matter to the typical "green" nearshore waters. This type of change greatly affects methane concentrations since methane can be produced *in situ* from suspended matter. Thus, the approximately 75 to 250% supersaturation in methane concentrations with respect to the partial pressure in the atmosphere can be explained by the changing turbidity of the water and not inputs

TABLE 1

METHANE CONCENTRATIONS (nl/ℓ) PRE-, DURING-, AND POST-DRILLING

Direction	(Drill Site)			100 m			500 m			1000 m			2000 m		
	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post
N				78	118		77	117		89	79	122		79	113
NNE				-	-		-	-			82	117		80	117
NE				82	118		78	137			78	138		83	132
ENE				-	-		-	-			78	120		78	120
E				79	127		77	117		91	80	129		82	-
ESE				-	-		-	-			82	121		83	132
SE				78	127		77	134			82	121		80	110
SSE				-	-		-	-			80	136		83	135
S				77	138		78	116		87	78	119		80	130
SSW				-	-		-	-			80	137		81	134
SW				82	122		79	136			79	119		79	119
WSW				-	-		-	-			79	140		78	140
W				77	134		80	131		89	77	125		82	126
WNW				-	-		-	-			78	141		78	126
NW				82	112		78	138			79	104		82	131
NNW				-	-		-	-			78	134		82	134
DS*	96		132												

*Samples were taken at a depth of 2 m.
*Drill site

TABLE 2

ETHENE CONCENTRATIONS (nl/ℓ) PRE-, DURING-, AND POST-DRILLING

Direction	Drill Site			100 m			500 m			1000 m			2000 m	
	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post
N				2.9	6.0		3.3	4.8		4.9	2.9	3.5		3.2	3.4
NNE				-	-		-	-			3.4	3.9		3.1	3.0
NE				3.3	4.9		3.0	5.0			3.1	4.3		3.1	4.3
ENE				-	-		-	-			3.3	4.1		3.1	3.7
E				3.8	6.1		3.0	6.2		4.5	3.1	4.2		3.1	-
ESE				-	-		-	-			3.3	4.0		2.9	4.3
SE				3.0	4.5		3.1	5.5			2.9	4.5		3.0	3.4
SSE				-	-		-	-			2.9	4.1		2.9	4.0
S				3.3	4.6		3.4	5.1		4.9	2.6	3.9		3.4	3.8
SSW				-	-		-	-			2.9	3.2		3.2	3.1
SW				3.9	4.8		3.5	6.0			2.4	4.0		3.3	3.6
WSW				-	-		-	-			2.6	4.0		3.5	3.6
W				3.3	4.8		3.1	5.5		4.7	3.3	3.5		3.8	4.4
WNW				-	-		-	-			3.5	3.6		2.7	3.4
NW				3.5	3.8		3.1	4.8			3.1	3.0		3.3	3.8
NNW				-	-		-	-			3.3	3.5		3.2	4.0
DS*	4.9		4.2												

Samples were taken at a depth of 2 m.
*Drill Site

TABLE 3

ETHANE CONCENTRATIONS (nl/ℓ) PRE-, DURING-, AND POST-DRILLING

Direction	Drill Site			100 m			500 m			1000 m			2000 m		
	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post
N				0.8	0.9		0.9	0.9		0.7	0.9	0.7		0.8	0.7
NNE				-	-		-	-			0.9	0.7		1.3	1.0
NE				1.0	0.8		0.9	2.6			0.8	2.0		1.0	0.8
ENE				-	-		-	-			0.9	0.7		1.0	1.2
E				1.3	2.4		0.9	0.9		0.6	0.9	1.9		0.8	-
ESE				-	-		-	-			0.9	0.7		0.9	1.2
SE				1.0	0.9		0.9	2.7			0.9	0.9		0.8	0.7
SSE				-	-		-	-			0.8	2.0		0.8	1.3
S				1.0	3.3		0.9	0.9		1.0	0.9	0.7		0.9	0.7
SSW				-	-		-	-			0.9	2.4		0.9	1.3
SW				1.0	1.3		1.0	3.2			1.0	0.7		0.9	0.9
WSW				-	-		-	-			1.0	2.2		1.0	1.4
W				0.9	1.0		0.9	1.9		0.7	0.9	0.7		1.0	0.9
WNW				-	-		-	-			0.9	2.2		0.8	1.0
NW				1.0	3.6		0.9	2.7			0.9	0.7		1.0	0.9
NNW				-	-		-	-			0.8	1.8		1.0	1.1
DS*	0.7		2.6												

Samples were taken at a depth of 2 m.
*Drill Site

TABLE 4

PROPENE CONCENTRATIONS (nl/ℓ) PRE-, DURING-, AND POST-DRILLING

Direction	Drill Site			100 m			500 m			1000 m			2000 m	
	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post
N				0.7	2.1		0.8	1.9		1.4	0.9	1.5		1.0	1.5
NNE				-	-		-	-			0.8	1.7		1.2	1.4
NE				0.7	2.2		0.8	1.9			0.9	1.8		0.8	1.7
ENE				-	-		-	-			0.9	1.8		1.0	1.2
E				0.8	2.3		0.8	2.7		1.3	0.9	1.7		0.8	-
ESE				-	-		-	-			1.0	1.6		0.9	1.7
SE				0.8	2.2		0.8	2.3			0.8	1.7		1.0	1.5
SSE				-	-		-	-			0.8	1.9		0.8	1.5
S				0.8	2.6		1.0	2.4		1.2	0.8	1.6		1.0	1.9
SSW				-	-		-	-			0.7	1.6		0.9	1.6
SW				1.3	3.9		0.8	2.5			0.8	1.6		0.9	1.5
WSW				-	-		-	-			0.8	1.8		0.9	1.7
W				0.8	2.1		0.8	1.6		1.3	0.9	1.5		0.9	1.7
WNW				-	-		-	-			1.0	1.6		1.0	1.4
NW				1.3	7.8		0.9	1.8			0.8	1.3		1.2	1.5
NNW				-	-		-	-			0.8	1.6		0.9	1.6
DS*	1.5		3.3												

Samples were taken at a depth of 2 m.
*Drill Site

TABLE 5

PROPANE CONCENTRATIONS (nl/ℓ) PRE-, DURING-, AND POST-DRILLING

Direction	Drill Site			100 m			500 m			1000 m			2000 m		
	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post	Pre	During	Post
N				0.9	0.9		0.9	1.4		0.9	1.3	1.0		1.2	0.9
NNE				-	-		-	-			1.5	1.1		0.9	0.9
NE				0.9	0.9		1.0	1.1			1.0	0.7		0.6	0.8
ENE				-	-		-	-			1.0	1.1		1.2	0.7
E				1.4	1.3		1.0	1.2		0.6	1.2	1.0		1.0	-
ESE				-	-		-	-			1.2	0.7		1.0	0.8
SE				0.8	0.7		0.9	1.0			1.0	0.8		1.2	1.2
SSE				-	-		-	-			1.0	0.7		1.1	0.9
S				0.7	1.0		0.9	0.9		0.8	1.0	0.7		1.2	1.0
SSW				-	-		-	-			0.9	1.4		1.0	0.7
SW				1.7	1.3		0.9	0.8			1.0	0.8		0.9	0.7
WSW				-	-		-	-			1.0	0.8		1.0	1.1
W				0.9	1.3		1.0	1.0		0.6	1.0	0.8		1.3	1.1
WNW				-	-		-	-			1.2	1.1		1.0	1.0
NW				0.8	1.4		0.9	1.0			1.0	1.3		1.2	1.3
NNW				-	-		-	-			0.9	0.8		0.9	1.0
DS*	0.9		1.6												

Samples were taken at a depth of 2 m.
*Drill Site

TABLE 6

LMWH PROFILE AT DRILLING SITE
PRIOR TO DRILLING[1]

Depth (m)	Methane (nl/ℓ)	Ethene (nl/ℓ)	Ethane (nl/ℓ)	Propene (nl/ℓ)	Propane (nl/ℓ)
0	90	4.2	0.5	1.4	0.7
10	82	4.2	0.5	1.4	0.6
20	92	4.2	0.4	1.4	0.5
30	377	6.4	0.8	0.8	0.5

[1]Samples taken 3-X-76

from the platform.

Table 6 shows a vertical profile taken at the drilling site in [illegible]ber 1976. All hydrocarbon concentrations were fairly uniform in the top 20 m, but methane showed a four-fold increase near the bottom. This was probably the result of an increase with increasing suspended load due to *in situ* production from particulate organic matter.

Unsaturated low-molecular-weight hydrocarbon levels would not be expected to increase even in the event of petroleum additions, since unsaturated hydrocarbons are not detectable in oil or gas. The unsaturated hydrocarbons found in the waters around the drilling site reflect *in situ* biological activity. Ethene and propene are both produced as metabolic products from biological activity in the water column. Ethane (Table 3) and propane (Table 5) are typically found in petroleum inputs into coastal waters. Their concentrations in coastal waters are controlled by a small amount of *in situ* biological production, air sea exchange, and man-derived inputs (*e.g.*, transportation losses, offshore platforms, and river runoff). The levels found at the rig monitoring site were within the range established for nearshore coastal waters by the STOCS monitoring study. No additions were noted from the drilling rig.

CONCLUSIONS

No additions of low-molecular-weight hydrocarbons were observed at the rig monitoring site during the pre-, during-, and post-drilling surveys. The concentrations of hydrocarbons in the waters around the drilling site were typical of nearshore shelf waters at all three samplings. The drilling rig at Mustang Island Area Block 755 was *not* adding measurable quantities of light hydrocarbons to the surrounding waters.

LITERATURE CITED

Brooks, J. M. 1975. Sources, sinks, concentrations, and sublethal effects of light aliphatic and aromatic hydrocarbons in the Gulf of Mexico. Tech. Rept. 75-3-T, Dept. of Oceanography, Texas A&M Univ. 342pp.

_____., and B. B. Bernard. 1977. Geochemical study around a platform blowout in High Island South Addition Block 563. A report to Pennzoil Oil Co. through Decca Survey Systems, Inc.

_____., and W. M. Sackett. 1977 (In Press). Input of low-molecular-weight hydrocarbons from petroleum operations into the Gulf of Mexico. *In* Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, proceedings of a symposium held at Seattle, Wash., 1976.

_____., and W. M. Sackett. 1977 (In Press). Significance of low-molecular-weight hydrocarbons in coastal waters. *In* Advances in Organic Geochemistry, 1975.

Sackett, W. M., and J. M. Brooks. 1975. Origin and distribution of low-molecular-weight hydrocarbons in Gulf of Mexico coastal waters. *In* Marine Chemistry in the Coastal Environment, Tom Church (ed.), ACS Symposium Series 18, pp. 211-230, American Chemical Society, Wash., D. C., 1975.

Swinnerton, J. W., and V. J. Linnenbom. 1967. Determination of C_1-C_4 hydrocarbons in sea water by gas chromatography. J. Gas. Chromotogr. 5:570.

CHAPTER SIX

TRACE METAL AND MINERALOGICAL ANALYSES OF SUSPENDED AND BOTTOM SEDIMENT

U. S. Geological Survey, Corpus Christi, Texas
and
Texas A&I University, Corpus Christi, Texas

Principal Investigators:

Charles W. Holmes (USGS)
Steven S. Barnes (Texas A&I)

Associate Investigators:

E. Ann Martin
Cynthia A. Rice

ABSTRACT

The trace metal content of suspended sediments fell within the range established during the environmental phase of the South Texas Outer Continental Shelf study with the exception of cadmium and zinc. It is suspected that the high and variable values obtained for these metals were a result of sampling or procedural contamination. Three clay minerals were detected in these samples: montmorillonite; illite; and, kaolinite. The presence of montmorillonite in the samples from the during-drilling phase may have resulted from the drill fluid sinking to the sea floor as previous work has shown that early spring waters in the region are almost devoid of montmorillonite.

Chromium, copper, manganese, and nickel levels in the sediment, showed no apparent change as a result of drilling activity. Levels of iron and vanadium, co-variant elements, were somewhat lower, while lead showed a two-fold increase after the drilling activity. Zinc, barium and cadmium were directly tied to drilling activity as these elements showed a marked increase at the drill site following drilling operations.

INTRODUCTION

This report presents the results of the sampling for suspended material taken on cruises before (September 25-27, 1976), during (January 7 and 14, 1977), and after (February 28-March 1, 1977) the operation of the drilling rig. The benthic sediment samples were taken only prior to and after the drilling operation.

METHODS AND MATERIALS

Sampling

The sampling effort for this study was systematized by the establishment of a circular grid around the drill site. Samples for benthic trace metal analysis were taken at the drill site and at 1000 m north, east, south and west. Suspended sediment samples were taken at five depths at the drill site, both before and after the operation of the rig. During drilling activity, the suspended sediments of the water column were sampled both within and opposite the plume. It should be noted that sample sites for prior and post operations were not identical as explained in Chapter 1, page 1-18, under Sampling Problems.

Benthic samples of the upper 5 cm were taken by a Smith-McIntyre sampler and transmitted to the laboratory in polyethylene sample containers. Suspended sediment samples were taken with a 30-ℓ Niskin sample bottle and transferred to precleaned polyethylene two gallon bottles and frozen prior to transportation to the laboratory. All samples were taken by personnel of the University of Texas Marine Science Institute, Port Aransas Marine Laboratory, from the R/V LONGHORN.

Suspended Sediments (Trace Metals)

In the laboratory, the samples were thawed and concentrated by fil-

tration. Filtration was accomplished by an adaptation of the *in situ* filters to a laboratory procedure. Filters were made by heat-sealing 0.4 μm NUCLEOPORE filter material to make bags 3.5 cm in diameter by 7 cm length. The filter bags were encapsulated in polyethylene vials to which entrance and exit tubes had been selaed at each end. The in-line filter capsules were washed with 1:1 nitric acid and deionized water before use. The filters were attached to polyethylene bottles containing the water to be filtered by means of polyethylene fittings sealed to the bottle cap. Approximately 10 ℓ of seawater were then allowed to flow through the filter. Once filtration was complete, the encapsulated filters were sealed in polyethylene bags and frozen.

Analytical preparation was performed in an ENVIRCO clean bench which utilizes a filtered air flow to isolate the interior of the bench from the remainder of the laboratory. All weighings were made on a PERKIN-ELMER AD-2 Autobalance readable to 0.1 μg placed in the clean bench. Only deionized water and redistilled nitric acid (G. Fredrick Smith Chemical Co.) were used in the analytical procedure. All labware was washed with 1:1 nitric acid and deionized water before use.

The filter capsules were opened and the filter bags carefully inverted. A jet of deionized water was then directed onto the exposed filtering surface. The water and dislodged particulate material was collected in a 100 ml polyethylene beaker; 70 to 100 ml of deionized water was used in this step. The procedure serves the double purpose of transferring the particulate material and removing any residual salt. This suspension was then filtered under vacuum on a 25 mm diameter, 0.4 μm pore size NUCLEOPORE filter which had been acid washed, dried over

anhydrous magnesium perchlorate and weighed. The filters with sample material were then placed in a desiccator over anhydrous magnesium perchlorate for 24 hours and then reweighed.

The filter and sample were then placed in a 50 ml teflon beaker. Two ml of concentrated nitric acid were added and the samples taken to dryness under infrared lamps at a temperature of 80°C. One ml of concentrated nitric acid was then pipetted onto the dry sample. The sample and acid were allowed to equilibrate for one-half hour and were then transferred to an acid-washed lucite sample cup. This solution was then used for analysis by atomic absorption spectroscopy.

All analyses were performed on a PERKIN-ELMER model 303 atomic absorption spectrophotometer using a model 2100 HGA graphite furnace. Dilutions were made when necessary with concentrated nitric acid.

Blank values were determined for all metals analyzed on the deionized water and redistilled nitric acid. Two procedural blanks were determined by taking one of the original acid-washed filter capsules through the entire procedure as if it were a sample. The averages of these blank values were used in all calculations.

The sample size, 0.1 to 15 mg total weight, made contamination a critical problem in the analysis. Contamination can be divided into three types: contamination associated with the ship, *i.e.* paint chips, stack cinders, or rust which might have fallen into the water and been included in the sample; contamination associated with the filtering and analytical procedure, *i.e.*, atmospheric dust in the laboratories or metals used in the manufacture of the filters, beakers, pipette tips, etc., and not removed; and finally, impure reagents.

Atmospheric contamination was kept to a minimum by performing sample preparation in a clean bench which utilizes filtered forced air flow to eliminate atmospheric dust. Metal contamination from the laboratory ware was not so easily controlled. Sommerfeld *et al.* (1975) have shown that both zinc and iron are contaminants of disposable pipette tips of the type commonly used to introduce a sample into the graphite furnace. Robertson (1968) has shown that a number of plastics and glasses commonly used for the manufacture of laboratory ware contain traces of metals. For this reason, all laboratory ware was washed in 1:1 nitric acid before use. However, it was determined that the disposable pipette tips and lucite sample cups had to be washed in concentrated nitric acid before an acceptable blank could be obtained.

Two reagents used in processing the samples were deionized water and redistilled nitric acid from G. Fredrick Smith Co. The deionized water showed concentration levels of all metals too low to quantitatively determine. In the acid, only iron, zinc, and cadmium showed determinable levels (Table 1). These values were probably due to pipette tip contamination since the procedural blank was lower in zinc and iron than the acid blank.

In view of the several sources of contamination, a procedural blank was run. This was done by taking an acid washed encapsulated filter, sealing it in a polyethylene bag, freezing it, and then placing it in the normal processing stream with the samples (Table 1). These were the blank values used in calculating dry weight concentrations. Procedural blanks for all elements except zinc were negligible. The zinc blanks were sufficiently high to make the data useless and these data are not included in this study. The origin of the contamination is unknown.

TABLE 1

BLANK VALUES

	Cd	Fe	Zn	Pb
Redistilled nitric acid	0.8 ppb	0.3 ppm	12ppb	-
Procedural Blank	0.8 ppb	0.24ppm	>100ppb	0.14ppm

	Cu	Cr	Ni	V	Mn
Redistilled nitric acid	-	-	-	-	-
Procedural Blank	60ppm	40ppb	.04ppm	11ppb	10ppb

Suspended Sediments

Mineralogy

The mineralogical samples were filtered through a 27 mm silver filter with a nominal pore diameter of 0.4 μm (SELAS FLOTRONICS). The mineralogy was then determined by X-ray diffraction techniques. The samples were analyzed via a DIANO automatic diffraction X-ray system (XRD-8300AD). This latter instrument allows for greater precision in the determination of peak areas and "d" spacing used to identify the minerals present. The procedure used for mineralogical identification was the same as outlined by Carroll (1970). The method of quantification was a modification of the procedure used by Biscaye (1965).

Benthic Sediments

Trace Metals

The concentration of trace metals in the sediment samples were determined by atomic absorption techniques. Triplicate subsamples from all 14 samples were run; more than three runs were made on randomly selected subsamples. The procedure of analysis was as follows: in the laboratory, the entire sample was removed from the sampling container, placed in a porcelain dish, mixed and dried at 100°C under infrared lamps. The sample was then removed and ground in a porcelain mortar to pass through a 200 mesh SPEX nylon screen. After homogenization, three subsamples were extracted, placed in a crucible and heated to 450°C for four hours to ash the organic component of the sample. The sample was then reweighed, transferred to an acid-washed culture tube and leached with concentrated nitric acid at 105°C until oxidation ceased. This method was used for

all elements except barium. Barium was brought into solution by a 1:1 mixture of concentrated nitric acid and 30% peroxide. The resultant solution was then analyzed by atomic absorption spectrophotometer. Table 2 gives the parameters used in the analysis of the metals.

A measure of analytical precision was obtained by statistical analysis of the results of the triplicate analyses. As these results were obtained from the concurrent "runs", they were a measure of sample homogeneity and reproducibility of the instruments and operator. A further measure of analytical accuracy was obtained by statistical analysis of all "runs" run more than three times. As these were obtained from different "runs", often weeks apart and by different analysts, the approach was a measure of the "accuracy" of the method. The results are summarized in Table 3.

RESULTS AND DISCUSSION

Suspended Sediments (Trace Metals)

The trace metal content of the suspended sediments is given in Table 4. As noted above, zinc values were not recorded due to procedural contamination. Of the remaining metals, cadmium also appeared to be severely contaminated. During the environmental phase of the South Texas Outer Continental Shelf study, cadmium in suspended sediments averaged 5 ppm with a maximum of 100 ppm. The average for cadmium in the pre-drilling samples was 370 ppm with a maximum value of 740 ppm. Other sampling sets in the rig monitoring program had higher than expected values for cadmium. Procedural blanks for cadmium were negligible. It is, therefore, suspected that the high and variable results for cadmium are the result of contamination during sampling. Results for other metals listed in Table 4 fell within the range established in the environmental study. However, the results were highly variable and did not appear to fit any pattern.

TABLE 2

INSTRUMENT PARAMETERS AND MODE OF ANALYSIS
(303PE WITH AN HG2100 GRAPHITE FURNACE)

Element	Wave Length	Dilution	Mode	Dry Temp.	Ashing Temp.	Atom. Temp.
Ba	2776	1:20 (1:200)	Flameless	100°C	1200°C	2700°C
Cd	2293	1:10	Flameless	100°C	250°C	2100°C
Cu	3262	1:10	Flame	100°C	900°C	2700°C
Cr	3589	1:100	Flameless	100°C	1200°C	2700°C
Fe	2483	1:1000	Flame	-	-	-
Mn	2801	1:1000	Flame	-	-	-
Ni	2330	1:10	Flame	100°C	1200°C	2500°C
Pb	2842	1:10	Flameless	100°C	550°C	2000°C
V	3194	1:10	Flameless	100°C	1700°C	2700°C
Zn	2146	1:100	Flame	-	-	-

TABLE 3

PERCENT DEVIATION FROM THE MEAN VALUE OF TRACE METAL ANALYSES
(DATA REPORTED AS PERCENT DEVIATION FROM MEAN VALUE)

Element	Analysis in triplicate		Analysis run more than three times	
	Mean (ppm)	Standard Deviation	Mean (ppm)	Standard Deviation
Ba	-	-	7.22	5.39
Cd	8.11	6.76	21.63	12.40
Cu	5.64	4.67	11.64	8.18
Cr	7.32	5.10	14.61	6.32
Fe	4.87	4.10	11.91	6.78
Mn	2.08	2.40	9.21	6.08
Ni	4.70	3.87	15.91	7.93
Pb	5.19	4.26	13.36	8.06
V	8.88	5.62	15.80	5.65
Zn	4.03	3.27	10.68	5.19
Average	5.64		13.86	

TABLE 4

TRACE METALS (ppm) IN SUSPENDED SEDIMENTS

PRE-DRILLING		Cd	Cr	Cu	Fe	Mn	Ni	Pb	V
	SURF	8.4	305	69.5	12700	128	TR	82.8	TR
	8m	380.0	174	56.0	47000	116	TR	128.0	TR
	16m	405.2	188	82.8	10900	1293	TR	258.6	TR
	24m	744.1	255	94.0	12500	1185	TR	86.2	TR
	32m	305.7	32	18.9	21300	2779	27	30.2	24
DURING-DRILLING									
	SURF	9.9	173	76.1	22700	128	TR	173.1	TR
in	8m	61.9	69	42.1	19500	605	26	522.6	41
Sed.	16m	15.8	189	68.6	16200	366	TR	58.2	TR
Plume	24m	1.8	470	642.1	16800	71	761	15.2	TR
	32m	411.0	106	27.0	15300	55	TR	19.6	TR
	SURF	511.9	172	61.4	15600	60	TR	51.2	TR
opp.	8m	16.7	266	61.8	18000	116	TR	40.0	TR
Sed.	16m	22.5	46	23.3	17400	337	TR	45.0	TR
Plume	24m	3.8	62	27.7	14600	57	TR	35.2	TR
	32m	0.7	93	38.2	18600	212	40	62.4	136
POST-DRILLING									
	SURF	0.8	291	64.1	13000	501	TR	62.9	267
	8m	1.2	263	67.4	15700	444	TR	38.3	139
	16m	13.2	2417	TR	17200	139	TR	TR	TR
	24m	7.3	1287	93.3	12700	220	TR	46.7	TR
	32m	7.0	1011	425.8	21800	387	247	224.1	588
	BLK A	0.0	0.0	0.0	0	0	0	0	0
	BLK B	0.0	0.0	0.0	0	0	0	0	0

In summary, there does not appear to be any conclusions that can be drawn from this data concerning the effect of drilling on trace metal content of suspended sediments. This is in part due to contamination during sampling and, with respect to zinc, during the analytical procedure. The fact noted earlier that samples taken from the drilling plume did not show any increase in sample size also leads one to suspect a sampling problem that would negate the data.

Suspended Sediments (Clay Mineralogy)

Table 5 lists the percent clay minerals in the suspended sediment samples. Three clay minerals were detected in the samples; montmorillonite (17Å), illite (10Å) and kaolinite (7Å). Montmorillonite was present only in samples taken during the post-drilling period and in the lower level samples taken during the drilling operation. During the pre-drilling period, the montmorillonite appeared to be concentrated in the surface and near bottom zone, being depleted in the midwater layer. The distribution may be explained as resulting from the fresher bay-derived water spreading out on the shelf during the fall-winter storm period. The concentration in the lower levels was a result of the stirring action, again caused by the winter storm conditions. The montmorillonite in samples from the during-drilling phase may have been the result of other storm stirring or sinking of drilling mud. Based on previous work, early spring waters in the region are almost devoid of montmorillonite and thus, the presence of montmorillonite during this period suggests that the expandable 17Å clay, identified as montmorillonite may be the drill fluid sinking to the sea floor. The sampling scheme was not designed for dynamic studies, thus the rates of sedimentation could not be estimated.

TABLE 5

CLAY MINERALOGY

Pre-drilling

Sample Depth	% Montmorillonite	% Illite	% Kaolinite
Surface	55	-	44
8	13.6	-	86
16	-	-	100
24	13.2	-	86
32	40	-	59

During Drilling
(No Plume)

Surface	-	52	47
8		75	24
16	23	53	23
24	9.2	50	40
32	9.1	62	28

During Drilling
(Out of Plume)

Surface	-	54	45
8	-	52	47
16	4	54	41
24	1.6	62	35
32	11	35	52

Post-Drilling

Surface			
8		58	41
16		50	50
24		33	66
32		37	62
			100

Benthic Sediments (Trace Metals)

The analytical results for trace metals are listed in Table 6. Chromium, copper, manganese, and nickel levels apparently did not change in the sediment as a result of drilling activity. Iron and vanadium, co-variant elements, appeared to be somewhat lower, but since identical sites were not sampled because of the change in drill site, it is difficult to make any statement on the significance of these changes. Lead, however, had a two-fold increase at all stations. These values were rerun with the same results, indicating no analytical error and that the increase was real. It is conceivable that this increase may be the result of drilling activity, possibly by the direct input via the fuel used by the rig and the supply vessels. The data are inconclusive as to the direct cause.

Zinc, barium, and cadmium were the only elements which could be directly tied to drilling activity. These elements had a marked increase in concentration at the drill site and low levels similar to those taken before drilling in the sediment 300 m from the drill site. The variances in the data (Table 6) were a result of the three different samples taken at the drill site. These replicate samples were not homogenous, as indicated by the different concentrations of three distinctly colored sediments. Two samples had a high concentration of red and green clay mixed with the normal tan sediment of the area. The third sample (DS-3) had very little of this extraneous material. X-ray analysis of these materials indicated that the red clay was a mixed-layered expandable clay, probably vermiculite; the green clay was a pure illite, with the tan sediment being the same as the surrounding sediment. The concentration of these clays and

TABLE 6

TRACE METALS - BENTHIC SEDIMENTS (PPM)

Pre-Drilling

Site	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	Code
DS	110.8	0.07	23.8	5.9	20200	312	14.3	7.6	17.7	64.7	TAK
N-1000	112.2	0.07	25.3	6.5	20500	320	17.7	7.1	17.6	69.4	TCX
E-1000	107.0	0.06	19.6	4.9	18200	279	17.0	6.0	17.3	61.0	TGB
S-1000	95.1	0.08	31.4	6.8	22100	275	16.5	6.3	20.3	71.0	TJB
W-TMB	89.0	0.08	40.9	5.4	19000	292	13.6	6.1	15.9	66.1	TMB
TQT	94.8	0.07	29.7	6.0	21000	293	15.6	6.4	18.2	69.6	TQT
TQZ	104.4	0.08	29.1	5.9	21400	252	14.6	7.4	15.9	69.5	TQZ

Post-Drilling

DS-1	470.7	0.61	21.5	6.7	16400	279	12.3	20.5	9.2	168.6	BDSM
-2	512.7	0.49	16.9	5.0	14200	260	9.0	18.3	8.4	219.6	BDSU
-3	77.8	0.22	23.3	6.3	18700	308	12.7	15.8	11.9	68.6	BDEW
N-1000	50.0	0.11	19.5	6.8	19000	313	14.1	12.1	12.4	62.2	BDHQ
E-1000	46.5	0.03	21.9	5.9	17400	280	14.7	11.8	12.3	58.1	BDTR
S-1000	52.6	0.04	20.6	6.7	18300	291	12.6	12.9	13.7	62.7	BDWB
W-1000	59.2	0.04	21.6	6.8	19300	319	14.5	14.5	11.7	63.8	BDHL

the increase in concentrations of barium, zinc, and cadmium were the direct result of drilling activity. The lower values of barium at the sample sites 1000 m from the drill site during the post-drilling period may be the result of either the seasonal variability (Holmes, *In* Berryhill *et al.*, BLM Geologic Element Report, 1977) or the samples not taken at the same level due to differences in rig location. The seasonal data also show such variation in the region near the drill site.

CONCLUSIONS

The results of this study indicate that there was some increase in the sediment of substances that could be attributed to drilling activity. However, this increase was not apparent in the suspended sediment, as indicated either by the trace metal levels or the clay mineralogy. The post-drill sampling was performed too soon after the removal of the rig to detect any geological changes.

LITERATURE CITED

Biscaye, P. E. 1965. Mineralogy and sedimentation of recent deep sea clay in the Atlantic Ocean and adjacent seas. Geol. Soc. America Bull., 76:803-832.

Carroll, D. 1970. Clay minerals and a guide to their X-ray identification. Geol. Soc. America Spec. Paper 126, p. 80.

Robertson, D. E. 1968. Role of contamination in trace metals analyses of sea water. Analytical Chem. 40:1067-1072.

Sommerfeld, M. R., T. D. Love, and R. D. Olsen. 1975. Trace metal contamination in disposable pipette tips. Atomic Absorption Newsletter 14:31.

CHAPTER SEVEN

HIGH-MOLECULAR-WEIGHT HYDROCARBONS IN SEDIMENT

University of Texas Marine Science Institute
Port Aransas Marine Laboratory

Principal Investigators:

Patrick L. Parker
Richard S. Scalan
J. Kenneth Winters

Associate Investigators:

Terrence D. Burton
Sharon Cameron
Luis DeLa Rosa
Donna Lammey
Stephen A. Macko
Milton Porterfield
Della Scalan

ABSTRACT

Saturated and non-saturated high-molecular-weight hydrocarbons were measured in benthic sediment samples from five pre- and five post-drilling stations. The pre-drill samples indicated no evidence of oil pollution. One of the seven post-drilling samples was apparently contaminated with petroleum hydrocarbons. This sample was one of three samples taken at the drill site. Whether this contamination resulted directly from drilling operations, oil from another source, or just drill cuttings from ancient shales could not be determined.

INTRODUCTION

Background

The study, and this report, deal with hydrocarbons in the molecular-weight range of C-15 to C-36, saturated, unsaturated and aromatic, isolated from sediments taken at a drilling site prior to and after drilling.

Useful environmental insights most likely result when the overall organic geochemistry of systems is considered. This is especially true for the sediment oil pollution problem since sediments are made complex by the long time interval of exposure. One must keep in mind that all petroleum had its origin in sediment much like that observed today. The organic geochemistry of sediments is well studied with regard to the occurrence and chemical transformations of fatty acids, amino acids, fatty alcohols, stable carbon isotopes and kerogen (Eglinton, 1969; Yen, 1977). Table 1 describes an idealized Gulf of Mexico shelf sediment based on data gathered in this laboratory over a 10 year period of time. As shown in Table 1, hydrocarbons constitute a minor fraction of the total organic matter in surface sediment. In general, a suitable working hypothesis is that aromatic hydrocarbons are absent or very low and normal paraffins are mostly of odd carbon numbers. Hydrocarbon patterns are complex because bacteria and infauna have added their own special hydrocarbon composition to sediment over the decades of deposition. Thus, sediment may be viewed as the time-integrated organic record. If oil pollution is added to sediment, the record will persist for some time, whether for days, weeks or months is not known. The sediment hydrocarbon data gathered under this program is considered in this framework.

As stated above, hydrocarbons constitute a small but ubiquitous fraction of the organic matter of sediments. Hydrocarbon geochemistry has

TABLE 1

MATERIAL BALANCE IN AN IDEALIZED GULF OF MEXICO SURFACE SEDIMENT[1]

Dry Weight	16 g
Total Organic Carbon	100 mg
Non-Lipid Carbon	95 mg
Total Lipid Carbon	5 mg
Total Non-Saponifiables	3 mg
Total Fatty Acids	0.4 mg
Total Sterols	0.1 mg
Total Fatty Alcohols	0.1 mg
Total Saturated Hydrocarbons	0.03 mg

[1]from Parker (1967), Parker (1969), and Sever and Parker (1969)

received a good deal of attentinn but of a somewhat uneven nature. Two approaches have been taken: one with the purpose of characterizing petroleum with the intent of learning the factors which control its distribution; and, a second approach based on the model of biclogical (bio-lipids) molecules going into and surviving in sediments for geological time periods. Biological molecules (geo-lipids) are of interest to those concerned with the record of life (paleo-bio-geochemistry). A number of excellent studies have been made in these two areas and specific situations are well-understood. However, no general picture exists for hydrocarbon geochemistry, especially not on the broad geographical scale needed by BLM (Eglinton, 1969).

By combining these two approaches, as well as borrowing their techniques, a conceptual model useful for environmental quality considerations can be stated. The essential elements of the model are: (1) Organic matter including hydrocarbon is being continuously supplied to recent sediment from the biota in the water column. The sedimentary hydrocarbon pattern might be expected to mirror the biota hydrocarbons. If so, n-C_{17} and pristane would greatly dominate, but the observed pattern is much more complex (Blumer, Guillard and Chase, 1971). (2) Therefore, other hydrocarbons are being generated. It is established that bacteria and infauna synthesize new hydrocarbons, thus adding to the complexity of the hydrocarbon pattern. Bacteria can add methyl branched and high molecular weight hydrocarbons (Davis, 1968; Tornabene and Markey, 1971). (3) Other sources of hydrocarbon for nearshore sediments are higher plants, seagrasses and benthic algae. These plants add C_{20} and C_{36} alkanes and alkenes to sediment (Youngblood *et al.*, 1971; Attaway *et al.*, 1970; Stransky *et al.*, 1967). (4) Petroleum must be recognized as another potential source of sedimentary hydrocarbon. While a large data base on the composition of petroleum is lacking, the

general picture is known (Whitehead, 1963). Petroleum usually contains a full suite of n-paraffins, iso- and anteiso- paraffins, cycloalkanes, isoprenoids, and aromatic hydrocarbons plus heteroatom compounds. The problem of recognizing petroleum in recent sediment is to determine whether these substances are present and to decide whether biotic sources could supply them (Meinschein, 1961). (5) In this study, a decision was made to establish the general hydrocarbon composition of a small suite of samples, five before and five after drilling, and to look for gross hydrocarbon contaminations making use of the large data base on sedimentary hydrocarbon obtained in other BLM studies.

With this background information, several parameters were selected which might enable a decision as to the probability that a sample or group of sediment samples are petroleum contaminated. These parameters are:

The concentration of total saturated hydrocarbon;

The even-odd ratio of n-paraffins;

The concentration of non-saturated hydrocarbons;

The presence of specific aromatic hydrocarbons;

The presence of isoprenoids, pristane and phytane, and their ratios to n-hydrocarbons.

These parameters for the sedimentary hydrocarbons are discussed, evaluated and compared to similar studies in later sub-sections.

METHODS AND MATERIALS

The rig monitoring field sampling plan was designed to provide samples from a drill site before, during and after drilling. Sediment samples for high-molecular-weight (HMW) hydrocarbons were taken before and after drilling. The sampling grid for benthic sampling was based on eight (8) tran-

sects originating at the drill site and radiating to the north, south, east, west, northeast, northwest, southeast and southwest. Stations were located at distances of 0, 100, 500, 1000 and 2000 m from the drill site. The station at the drill site was identified as "Station DS". Other stations were identified by transect and distance from DS, *i.e.*, Station NW-500, etc. (Table 2).

The hydrocarbon parameters recorded for these samples included: total alkanes and total non-saturates recovered (based on GLC peak areas); normal paraffins detected; non-saturates identified; and isoprenoids (pristane and phytane) and the odd-even preference index (OEP). As exhibited by the data in this report, essentially all parameters were determined for every sample.

Sample Collection

Sediment samples were obtained as subsamples of a Smith-McIntyre grab. Each subsample, approximately 1 kg, was taken from the top 5 cm of the grab. The samples were placed in precleaned glass jars with teflon lid liners, taking care not to fill each jar over one-half full. The samples were frozen on board ship and kept frozen until analysis. Obvious marine animals were seldom encountered in the sediment, but were discarded when found. If the sample was a pooled sample, pooling was accomplished at sea prior to freezing. In cases where chemical analysis was possible within a few days after collection, the samples were maintained at 0°C to avoid the risk of the jar breaking due to freezing.

Extraction Procedures

The sediment samples were freeze-dried as the first step of laboratory analysis. This was accomplished by spreading the sample as a thin paste on stainless steel trays. The freeze drier used in the early work was a

TABLE 2

SUMMARY OF RIG-MONITORING
HIGH-MOLECULAR-WEIGHT HYDROCARBON ANALYSIS PLAN

Pre-Drilling

Sample Code	Sample Location
ATAJ	DS (Drill Site)
ATCW	N-1000
ATGA	E-1000
ATMA	W-1000
ATQU	W-1000
ATRA	W-1000
ATJA	S-1000

Post-Drilling

BDEV	DS
BDSL	DS
BDST	DS
BDHP	N-1000
BDTQ	E-1000
BDWA	S-1000
BDYK	W-1000

small unit (Virtis model 10-PR) which was fitted with an oversized vacuum pump and a double cold trap so as to accelerate drying. Later, a Virtis model 25 SRC was used without modification as factory installed.

Hydrocarbons were isolated from sediments and purified using the method described in Attachment A, Contract AA550-CT6-17 (Appendix F) with the reflux option. This procedure is given in the following. The freeze-dried sediment sample (200-300 g) was placed in a large round-bottomed flask (1-ℓ) and covered with approximately 200 ml of a toluene-methanol azeotrope (3:7) using care that the flask was not more than one-half full to avoid severe bumping on the steambath. The flask was placed in reflux on a steam bath for seven hours. The solvent, while warm, was then decanted through a pre-washed filter (Whatman 541) and set aside for later analysis. Fresh solvent any sediment on the filter paper were added to the flask and the reflux extraction repeated for 7-10 hours. Finally, the sediment was filtered onto a Buchner funnel, washed with warm hexane and all extracts combined. The sediment was dried at 45°C and weighed.

The combined extracts were taken to just dryness on a rotary-evaporator and taken up in hot KOH-methanol (0.5 N) for saponification. Saponification was carried out according to the procedure described in BLM Contract AA550-CT6-17, Attachment A (Appendix F). No severe problem was encountered with the formation of methyl esters, but in cases where GC or GC/MS indicated ester formation, the samples were resaponified. Texas coastal sediment is not high in organic matter relative to California basin sediments for which reason elemental sulfur was not indicated to be a problem in this study. The non-saponifiable fraction obtained in the hexane extract of the saponification mixture was taken to dryness and weighed, yielding the weight of non-saponifiable lipids.

The non-saponifiable lipids were submitted to silica-gel-alumina column chromatography according to the scheme described in BLM Attachment A. Several times during the column chromatography of sediments it appeared that the saturated hydrocarbons were not completely eluted with the two column volumes of hexane. It was necessary to repeat the column chromatography. This problem deserves special care, because often the hexane used was rich in cyclohexane which, being more polar, should cause even faster elution. Other workers may wish to use more solvent for this elution.

The two hydrocarbon fractions isolated from sediments and purified, saturated and non-saturated, were finally taken up in a small volume of hexane (0.05 to 0.5 ml) and used for GLC and GC/MS analysis.

Instrumentation

Gas Chromatographic Analyses

The primary tool for component identification and quantification used in this project was the gas chromatograph (GLC). Identification by GLC is accomplished by comparison of the relative retention times of the unknown compounds with those of selected known standard compounds. Such identification techniques are reasonably valid if the mixtures are not complex and expected components are encountered.

The GLC instruments used in this study were a Perkin-Elmer[1] Model 900 and a Varian Model 3700. Both instruments were equipped with dual column flame ionization detectors and electronic integration of peaks. An Infotronics Model CRS-204 and Columbia Scientific Industries Model CSI-38 digital integrators were used to quantify the GLC separate components.

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[1]Use of brand names does not constitute an endorsement but is included for descriptive purposes only.

Both GLC instruments used 0.32 cm (1/8 in.) by 183 cm (6 ft.) dual, packed columns to effect the separation. The column packing material was 60-80 mesh Gas-Chrom Q (acid-washed) with a 5%, by weight, loading of FFAP (product of Varian Corp.) as the stationary liquid-phase. Generally, the operating conditions were as given in Table 3. These columns and conditions were used for virtually all analyses of STOCS samples. On occasion, lower initial temperatures and longer initial or final hold times were used.

The high temperature to which these columns were subjected was higher than that recommended by the liquid-phase manufacturer. For this reason, the columns had a large amount of column "bleed" at the high temperature which shortened the useful life. Approximately 100 samples could be analyzed before the resolution was considered too poor to permit further analysis.

Instrument sensitivity and resolution were checked daily by running a standard mixture of components. When the resolution fell below that recommended in Attachment A (BLM Contract AA550-CT6-17), the GLC columns were replaced. The daily standard check was used to establish the sensitivity of the instrumentation to allow quantification of the GLC peak data.

GLC peak data are recorded for each sample in this report. The data consist of a listing of peak retention indices and concentrations in the sample for each of the two analyzed fractions: hexane eluate and benzene eluate from liquid column chromatography. The retention index used is normalized to the relative retention times of the n-alkanes. Thus, for example, the hydrocarbon n-hexadecane has a relative retention index

TABLE 3

OPERATING CONDITIONS FOR GLC ANALYSIS

Carrier Gas	Helium
Carrier flow rate	30 ml/min.
Flame detector gas flow rates	
Hydrogen	30 ml/min.
Air	300 ml/min.
Temperature programming	
Initial temperature	70°C
Initial temperature hold time	6 min.
Program rate of rise	6°C/min.
Final temperature	270°C
Final temperature hold time	24 min.

equal to 1600, n-heptadecane equal to 1700, etc. Hydrocarbons having intermediate retention times between n-alkanes are assigned interpolated retention indices; for example, pristane (19 carbon atoms) has a retention index of 1670 and phytane (20 carbon atoms) a retention index of 1780 in as much as their peaks are eluted prior to elution of n-heptadecane and n-octadecane, respectively, on the columns in this study. Retention indices depend upon the nature and molecular size of the component being eluted. Thus, on FFAP, branched chain hydrocarbons elute earlier than the straight chain homologs of the same molecular weight while unsaturation of carbon to carbon bonds will cause the component to elute later than the saturated compound having the same number of carbon atoms.

Gas Chromatography-Mass Spectrometer-Computer Analyses

Where complex component mixtures are to be analyzed it is necessary to augment the chromatographic technique with other organic compound identification methods. One of the more powerful methods is mass spectrometry. Gas chromatography combined with mass spectrometry (GC/MS) was applied to many of the samples also characterized by gas chromatography alone. A computerized data system was used to assist with data acquisition and data analysis.

The instrument used was a DuPont Instruments Model 21-491 GC/MS with a DuPont Instruments Model 21-094B MS Data System. The chromatograph associated with this instrument was a Varian-Aerograph Model 2700 modified by DuPont for this service. The effluent from the single chromatographic column was split 9:1 with the major portion of the sample going to the mass spectrometer and the minor portion to a flame ionization detector.

The chromatographic column and conditions used for GC/MS analysis were identified to those used in standard GLC techniques.

It was recognized that for this column these conditions were not necessarily the best for general GC/MS work and that column "bleed" above 220°C was high for GC/MS analyses. However, these parameters were the same as those used in the standard GLC analyses of the samples and, thus, the interpretation of the data was enhanced by direct comparison of the two data sets.

The mass spectrometer was operated with a source temperature of 200°C, electron accelerating potential of 70 volts and an ion accelerating potential of approximately 1400 volts. The mass range from above m/e = 500 to below m/e = 40 was continuously scanned.

The instrument is capable of unit resolution at m/e $\geq$ 1100 but slits and focusing parameters were adjusted for maximum sensitivity at m/e $\sim$ 600. Sensitivity was estimated at better than 1.5 ng hydrocarbon at molecular weight 282 in the reconstructed chromatogram. Specific ion mass-chromatograms effectively allowed even better sensitivity.

Samples for GC/MS analysis were not selected randomly, but rather were selected to provide information about peaks which consistently were found prominent in many samples. The retention index-concentration data for all analyses were manipulated by a computer program to sort out those chromatographic peaks of "importance" and to flag those samples which could be used to characterize the peak by GC/MS analyses. Such lists of "important" peaks were prepared for each sample type (zooplankton, sediment, water) in the STOCS study and each fraction type (saturated, nonsaturated). This list is given in Tables 4 and 5 for the rig monitoring sediment samples. Included in these tables are the peak identifications as determined (or

TABLE 4

GAS CHROMATOGRAPHIC PEAKS OF SIGNIFICANCE
IN HEXANE ELUATES OF SEDIMENT EXTRACTS[1]

Retention Index	Formula	Identification by GC/MS
1444	$C_{14}H_{28}$	Tetradecene (probably straight chain)
1647	$C_{16}H_{32}$	Hexadecene (probably straight chain)
1742	$C_{17}H_{34}$(?)	Heptadecene (?) (probably straight chain)
1848	$C_{18}H_{36}$	Octadecene (probably straight chain)
1955	$C_{18}H_{37}OH$	Octadecanol
1972	?	Unknown
2054	?	Unknown
2147	$C_{21}H_{42}$	Heneicosene (probably straight chain)
2241	?	Unknown
3054	$C_{30}H_{50}$	Squalene

[1]The frequently occurring n-alkanes and isoprenoids are omitted from this table.

TABLE 5

GAS CHROMATOGRAPHIC PEAKS OF SIGNIFICANCE
IN BENZENE ELUATES OF SEDIMENT EXTRACTS[1]

Retention Index	Formula	Identification by GC/MS
1883	?	Unknown
2008	?	Branched? - Unsaturated?
2041	$C_{14}H_{29}COOCH_3$	Methyl ester of C_{15} fatty acid
2067	$C_{22}H_{46}$	Branched (isoprenoid?)
2107	$C_{16}H_{29}OH(?)$	Possible C_{16}:2 alcohol
2150	?	Branched, unsaturated
2205	$C_{18}H_{35}OH(?)$	Possible C_{18}:1 alcohol
2321	$C_{19}H_{38}$	Zamenes
2422	$C_{19}H_{35}OH(?)$	Possible C_{19}:2 alcohol
2618	$C_{18}H_{33}COOCH_3$	Methyl ester of C_{19}:2 fatty acid
2643	$C_{30}H_{52}(?)$	Highly branched (dihydro squalene?)
2830	$C_{24}H_{38}$ or $C_{21}H_{39}OH$	C_{24}:6 hydrocarbon or possible C_{21}:2 alcohol
2862	$C_{20}H_{30}(?)$	C_{20}:6 hydrocarbon (?)
3010	$C_{23}H_{47}COOCH_3$	Methyl Ester of C_{24} fatty acid
3044	$C_{25}H_{38}(?)$	C_{25}:7 hydrocarbon (?)
3222	$C_{20}H_{37}COOCH_3$	Methyl ester of C_{21}:2 fatty acid

[1]Fatty acid methyl esters are generally artifacts of the saponification procedure and many of the more commonly occurring esters are omitted from this list.

confirmed) by GC/MS analyses. Not all peaks were identified. Not included in these tables are the most commonly encountered and easily identified n-alkanes and pristane.

Peak identifications were made from analysis of the mass spectrum of the component. Interpretive techniques such as those given in McLafferty (1973) were used. Various "libraries" of mass spectral data were used to assist in interpretation of spectra. Computer searches were frequently made of three separate data bases: (1) Atlas of Mass Spectral Data (purchased from DuPont Instruments, Inc.) including 7054 mass spectra, most of which are from the Atlas published by John Wiley and Sons, Inc.; (2) MSSS (Mass Spectral Search System), a data base maintained by the Environmental Protection Agency, National Institutes of Health and National Bureau of Standards which contains over 30,000 mass spectra and which is made available through the commercial time sharing computer company - Cybernetics Division of ADP Network Services; and (3) a library and search algorithm maintained by Dr. Conrad Cone, Chemistry Department, University of Texas at Austin containing over 6000 mass spectra and available through the UT-Taurus interactive computer system. In addition, frequent use was made of the four volume Registry by Stenhagen *et al.* (1974).

Intercalibration, Blanks and Controls

Throughout the course of this study of hydrocarbons from sediment, experimental care to prevent contamination was an overriding concern. A previously unused suite of laboratories in a new building was dedicated to the study. The technical personnel were experienced in low-level organic work and care was taken to insure clean glassware and use of pure chemicals and distilled solvents.

Quality control with respect to blanks was assumed by two approaches.

First, blanks on solvents, critical operations and the total analytical scheme were run. At no time was a severe blank problem encountered, although the presence of cyclohexane in hexane was confirmed and the random presence of benzene was suspected. The second approach used to minimize error was to use the same laboratory, including glassware, chemicals, solvents and GLC for this and similar analyses of hydrocarbon in seawater and zooplankton. Thus, seawater hydrocarbons at the sub-part-per-billion level served as control experiments for sediment and zooplankton hydrocarbons which were at the part-per-million level. The group of blank and control experimental gas chromatograms shown in Figures 1 and 2 include ones for solvent methanol, a freeze drier blank using silica gel, a test of a teflon wash bottle, a hexane blank, a hexane extract of fired sand and a hexane extract of freeze-dried, fired sand.

To provide background data for an assessment of the level of contamination which might have occurred on shipboard during collection and processing, ship's fuel oil, lube oil and oily bilge water were characterized. The gas chromatographic patterns of hydrocarbon constituents of these are given in Figures 3-5. Since these are petroleum products, they are rich in hydrocarbons. However, no such GLC patterns routinely appeared in the sample analyses so that systematic contamination by the ship was judged to be absent.

A series of control experiments were conducted on sediments to test the recovery of added (spike) hydrocarbons. Fifty-one (51) wet sediment samples were spiked with approximately 30 µg of n-C_{24}, the normal paraffin with 24 carbon atoms. Recoveries ranged from 2 to 173% based on GLC analyses of the sediment using the methods described. The average recovery was 34%. Fifty (50) percent of the samples had yields

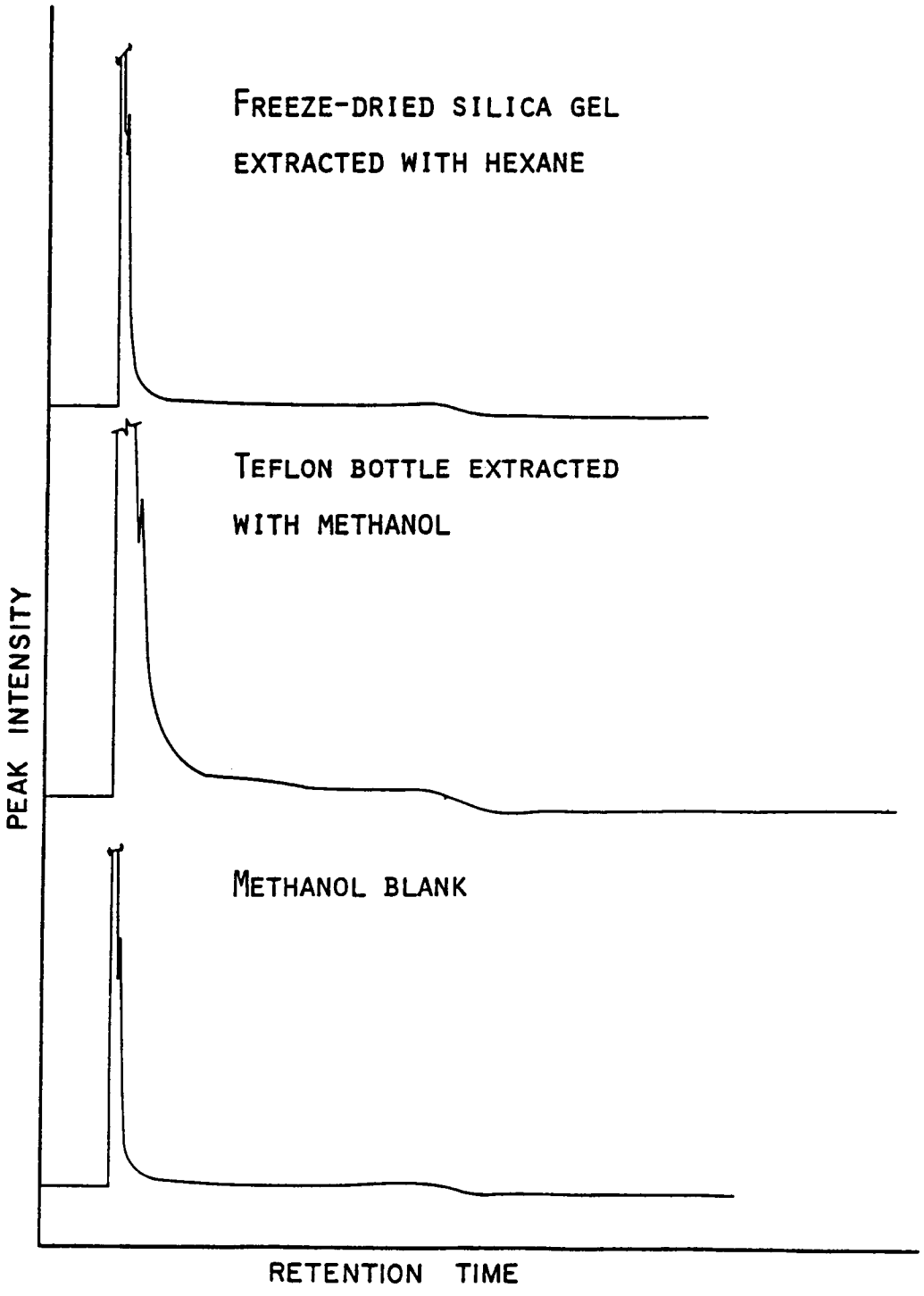


Figure 1. Gas Chromatograms of Procedural "Blanks" and "Tests".

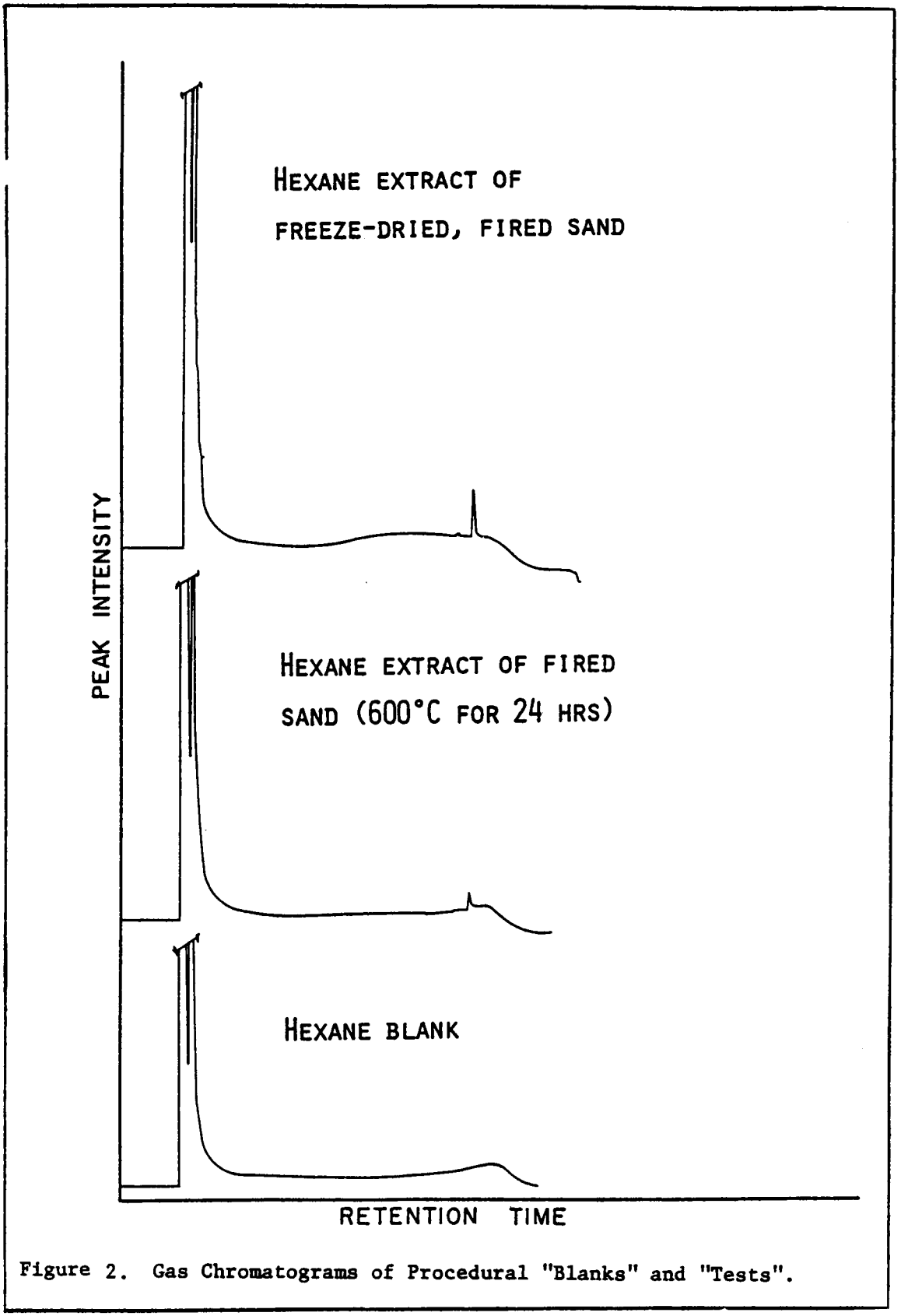


Figure 2. Gas Chromatograms of Procedural "Blanks" and "Tests".

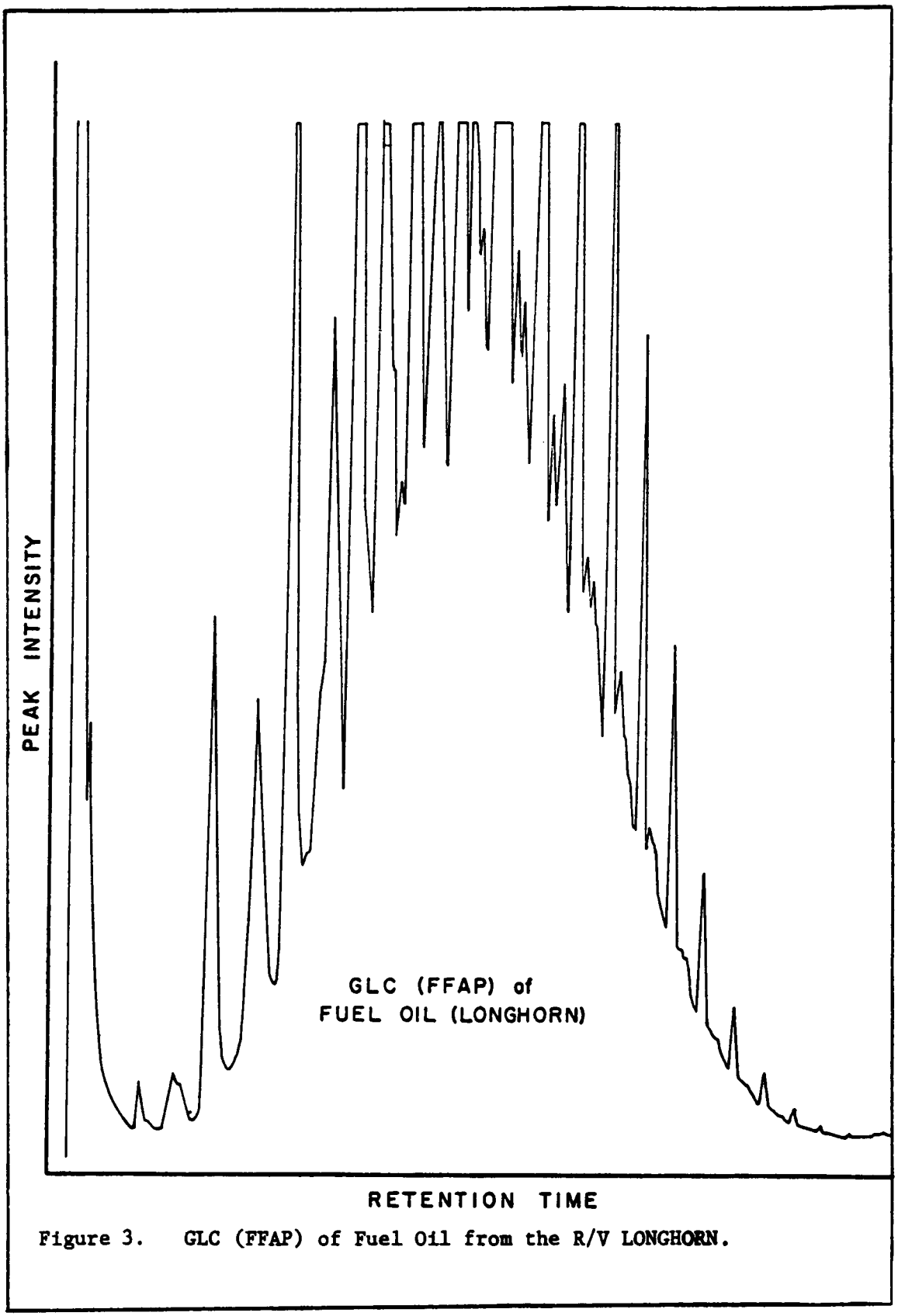


Figure 3. GLC (FFAP) of Fuel Oil from the R/V LONGHORN.

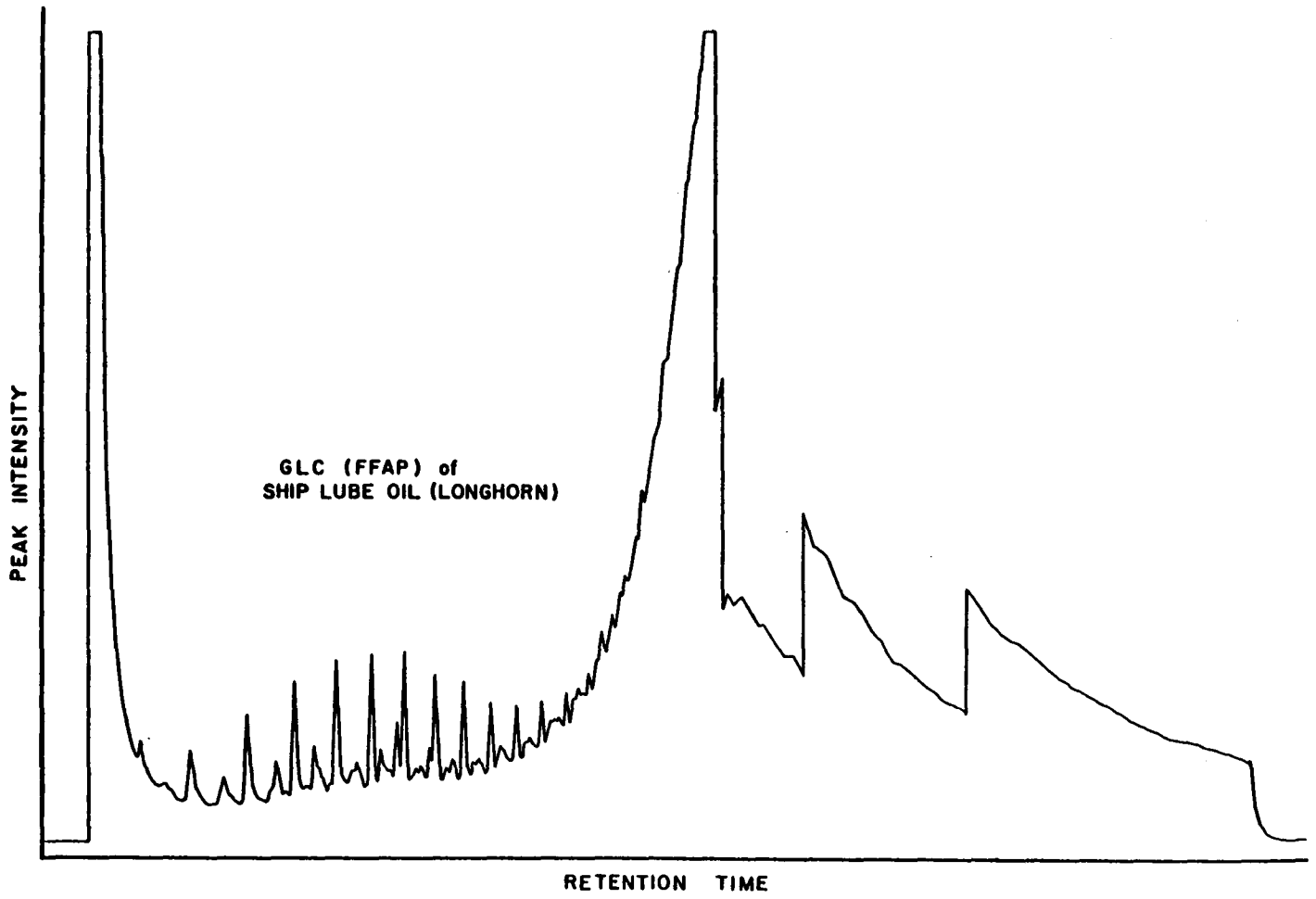


Figure 4. GLC (FFAP) of Ship's Lube Oil from the R/V LONGHORN.

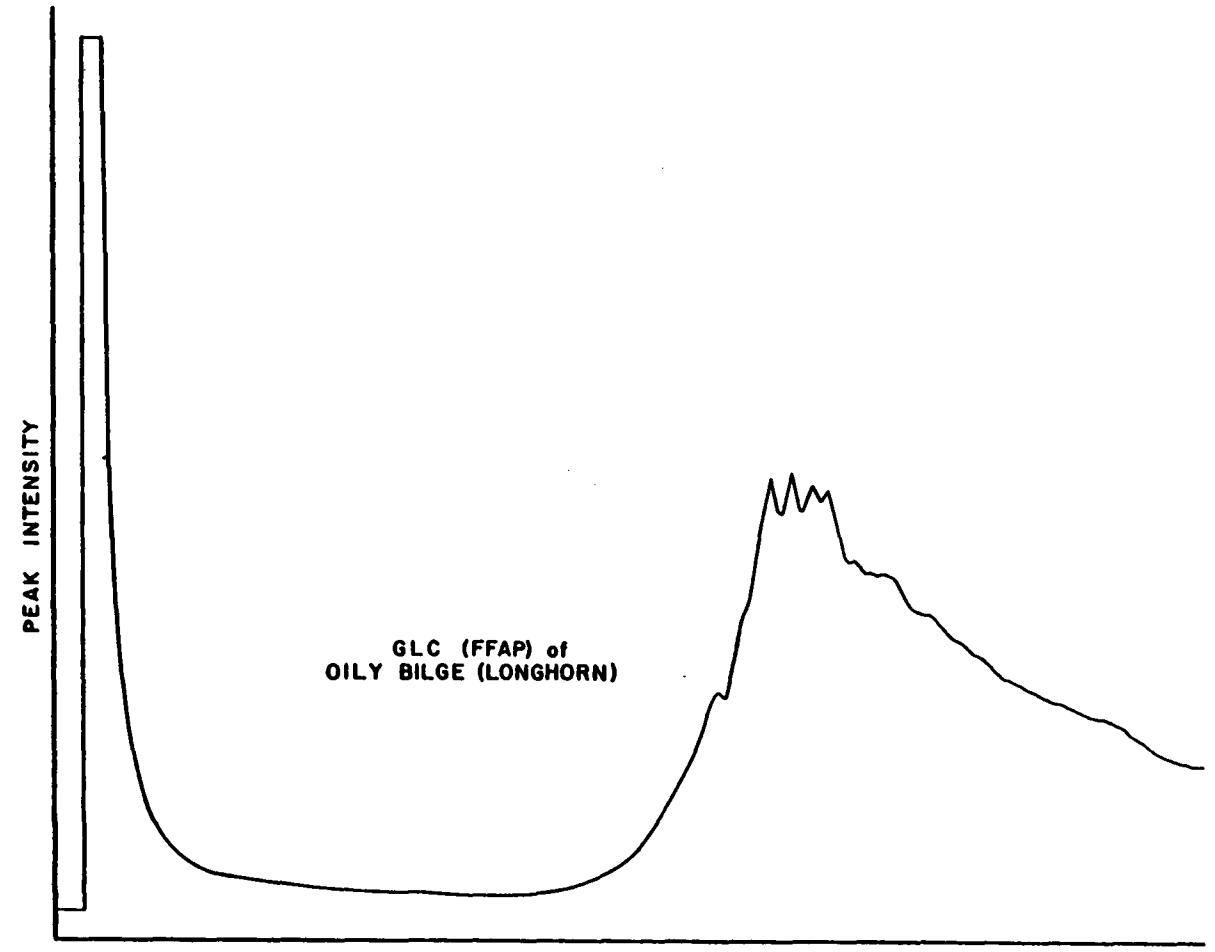


Figure 5. GLC (FFAP) of Oily Bilge Water from the R/V LONGHORN.

between 30 and 90%. These data at face value indicate that recoveries were incomplete with, on the average, about one-third of n-C_{24} being recovered. That was probably the case for the spiked n-C_{24}. However, the recovery of the spike should not be viewed as the extraction efficiency of hydrocarbons native to the sample. Spike recoveries are generally low in this type experiment, as judged by previous experience on fatty acids. The reason relates to the fact that the spike cannot be added so as to be naturally present in the sediment matrix. The data for hydrocarbons in sediments in this report are estimated to represent 50 percent of the sediment hydrocarbons. If more severe extraction techniques, such as HF decomposition were used, this probably could be raised but would also degrade the hydrocarbons so that some structural information would be lost.

Several formal and informal inter-laboratory comparisons were made during the course of this project. Useful information was gleaned from each one, however, they all suffered from the unfortunate fact that no certified standard materials for petroleum hydrocarbons were available. Such materials are available for trace metals and for low levels of radionuclides. Thus, the inter-laboratory experiments were comparisons which served to improve our techniques, not to test them.

Three inter-laboratory comparison studies were undertaken:

-hydrocarbon in Alaskan sediment-National Bureau of Standards;

-hydrocarbon in spiked California sediment-BLM via Dr. I. Kaplan, UCLA;

-hydrocarbon in Texas Oysters-Exchanged with Dr. C. S. Giam, TAMU and Dr. J. Farrington, WHOI.

The results of these studies were reported in an earlier report to BLM.

In summary, a substantial effort was made to produce high quality hydrocarbon analyses through blanks, controls, inter-laboratory comparisons and especially experience. One of us (PLP) is on the BLM Hydrocar-

bon Methodology Review Group which serves as a useful forum to help resolve some of the technique problems which have arisen and to accelerate communication among chemists dealing with BLM samples.

RESULTS AND DISCUSSION

Saturated and non-saturated hydrocarbon patterns were measured for samples from five pre- and five post-drilling stations. The gas chromatographic data are given in Tables 1.1 through 1.14, Appendix B. Two of the samples were submitted to gas chromatography/mass spectrometry (GC/MS) and these results are given in Figures 6 through 21, 22 through 26, and 27 through 30. Results which have been derived from these data, including the odd-even preference index and the ratio of several individual HC to each other are given in Tables 6 and 7.

One of the seven post-drilling samples was apparently contaminated with petroleum hydrocarbons. This sample (BDST) was one of three samples taken at the drill site (DS), and was the only one to show significant presence of oil. At this time, rather than deal with the statistical significance of one of seven samples being contaminated, we wish to stress the qualitative evidence allowing one to judge that oil is present. Such evidence is summarized below.

The GLC of Sample BDST and a pre-drilling sample (ATAJ) are shown in Figure 31. Analysis of Sample BDST showed a well-defined hump with a present average OEP (1.04) that is characteristic of oil, while pre-drilling samples had values in the range of 2.47 - 5.56. In fact the OEP evidence taken alone suggests that all of the post-drilling samples (1.04 - 2.68) are suspect of some oil pollution. The various pristane and phytane ratios in Tables 6 and 7 suggest that the post-drilling samples were on the average richer in phytane, but no clear trend was obvious.

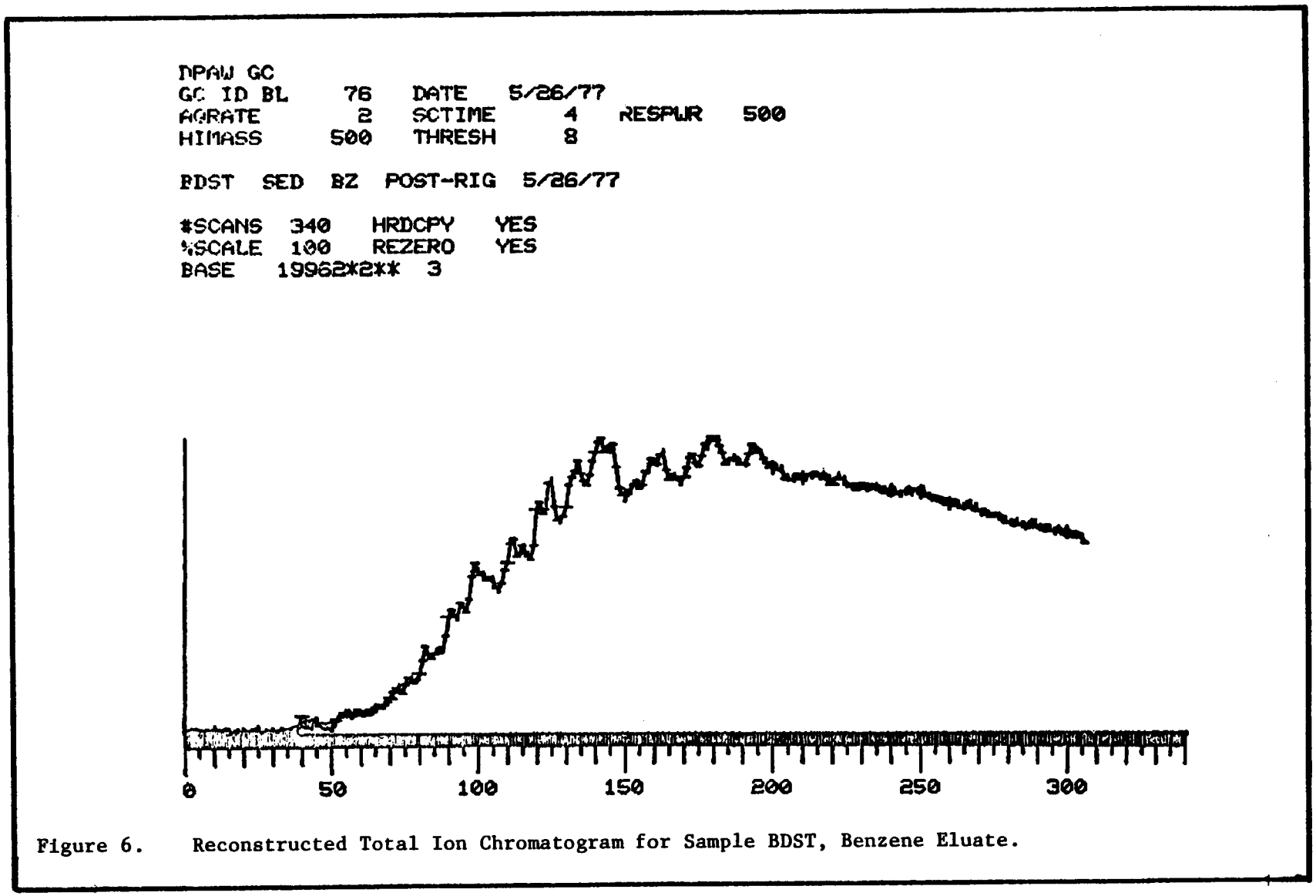


Figure 6. Reconstructed Total Ion Chromatogram for Sample BDST, Benzene Eluate.

```
SIGNFPK
GC ID BL     76    DATE    5/26/77
AQRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

BDST  SED  BZ  POST-RIG  5/26/77

IGNORE        0,     0,     0,     0
MILOUT   100  HRDCPY   YES

  MASS    MAX    FIRST    SUM
         INTN    OCCUR   IONS *2** 7

    41    1000        1    6934
    43    1000        7   10205
    45    1000      117   20836
    57    1000       24    4122
    85    1000       81     946
   155    1000       94    1446
   156    1000       76     786
   170    1000       90     868
   141     773       76    1186
   169     750      112    1491
    55     721       92    4612
   173     645       64     891
   119     617       61    2606
   105     588       69    1889
   133     582       54    3121
    56     574       19    1123
    71     561       41    1965
```

Figure 7. Significant Peak Index for Sample BDST, Benzene Eluate.

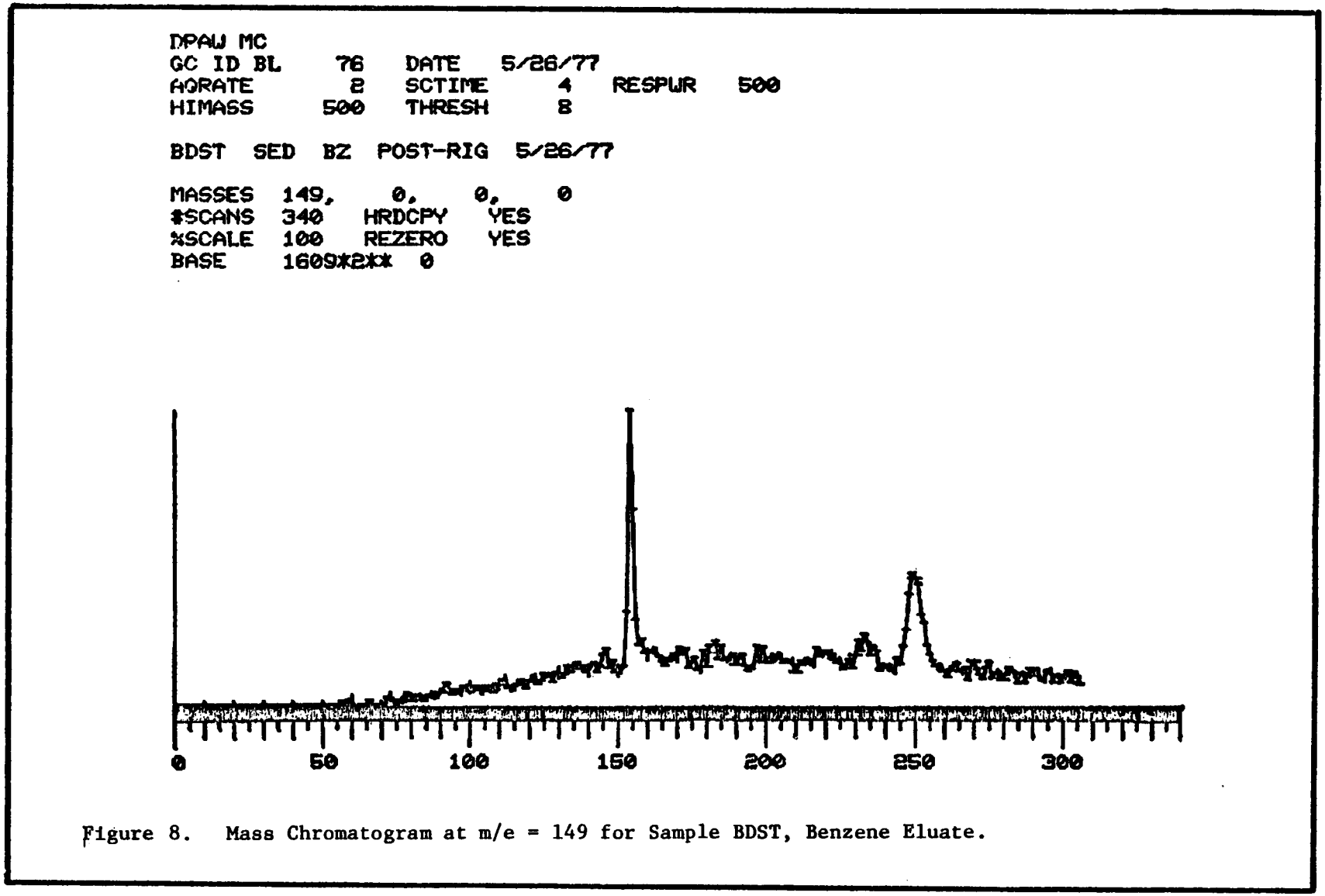


Figure 8. Mass Chromatogram at m/e = 149 for Sample BDST, Benzene Eluate.

```
DRAW MC
GC ID BL     76    DATE    5/26/77
AQRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

BDST  SED  BZ  POST-RIG  5/26/77

MASSES  156,     0,     0,     0
#SCANS  340    HRDCPY    YES
%SCALE  100    REZERO    YES
BASE    1918*2**  0
```

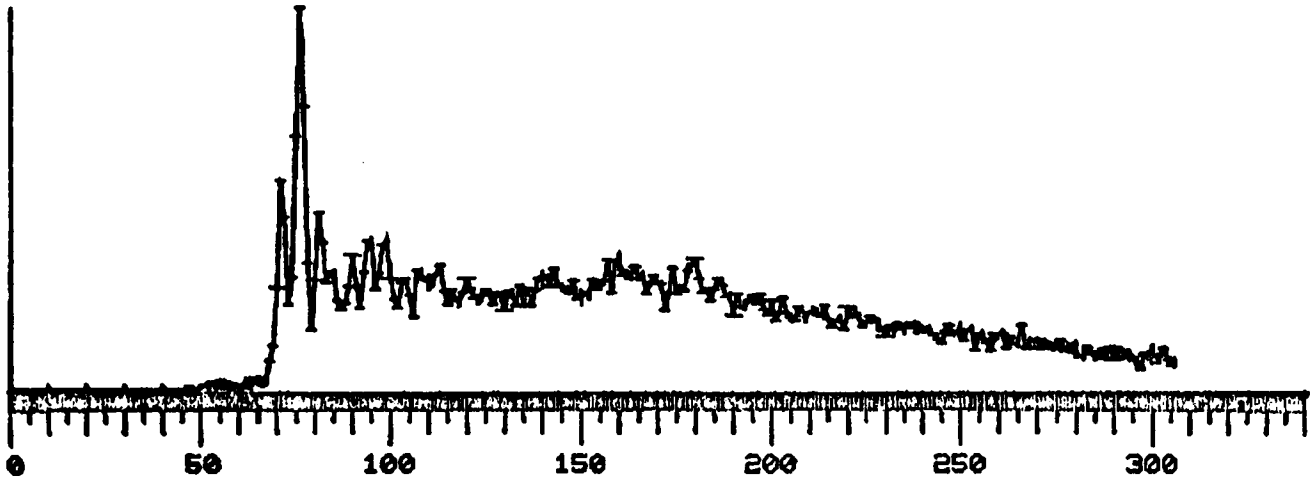


Figure 9. Mass Chromatogram at m/e = 156 for Sample BDST, Benzene Eluate.

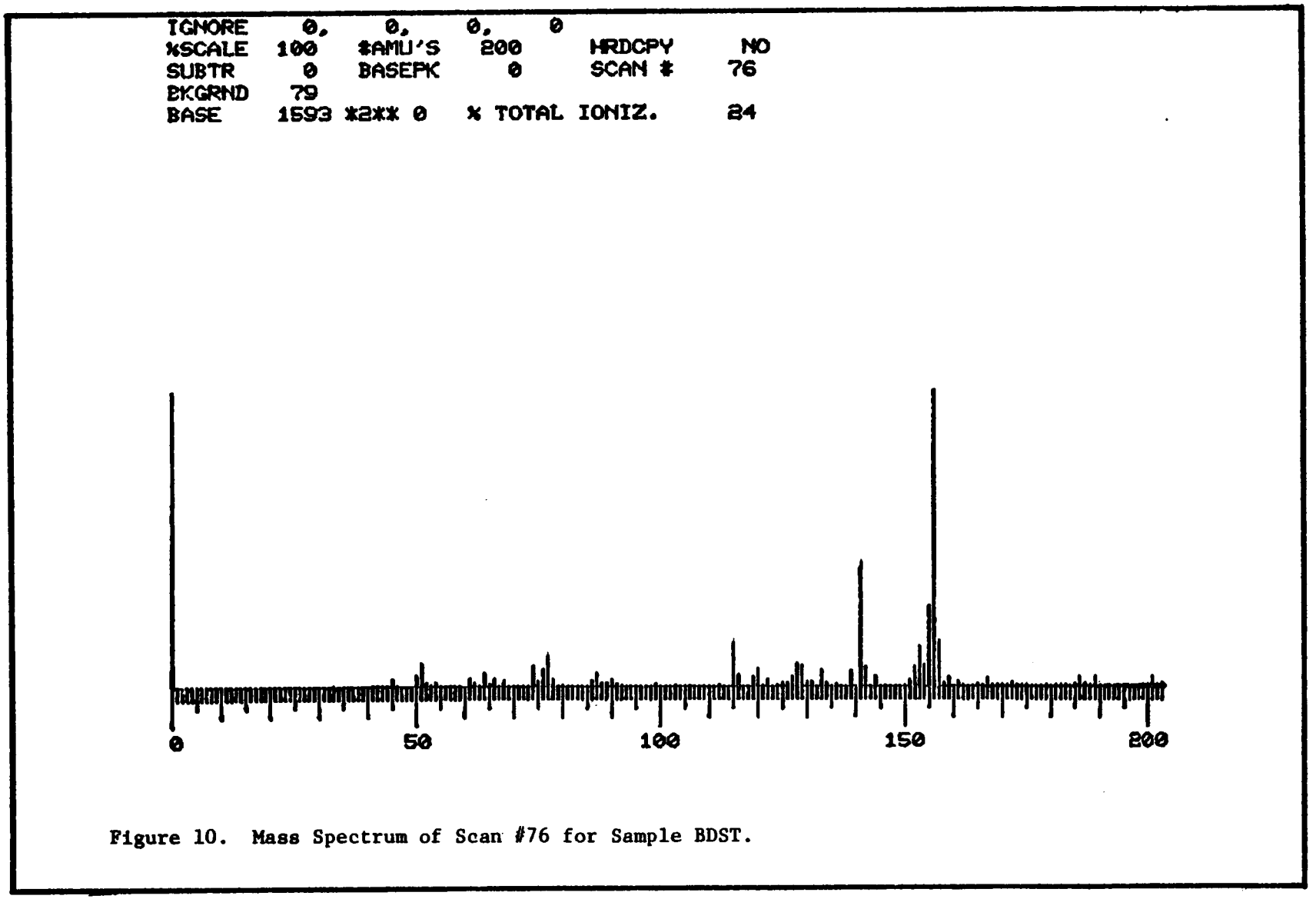


Figure 10. Mass Spectrum of Scan #76 for Sample BDST.

```
DRAW MC
GC ID BL     76    DATE    5/26/77
AQRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

BDST  SED  BZ  POST-RIG  5/26/77

MASSES  170.     0.     0.     0
#SCANS  340    HRDCPY    YES
%SCALE  100    REZERO    YES
BASE    4021*2**  0
```

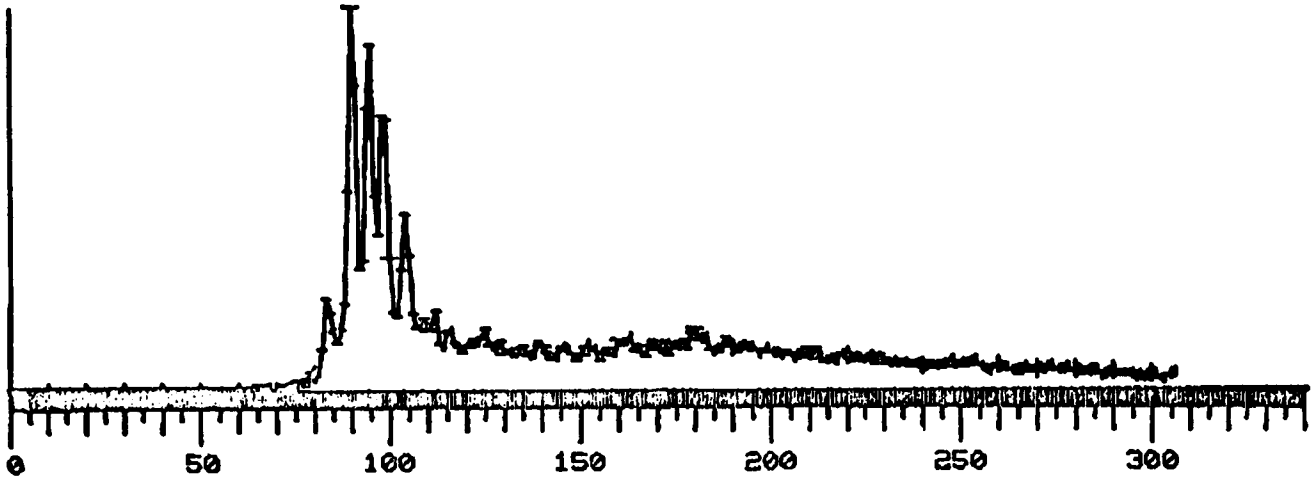


Figure 11. Mass Chromatogram at m/e = 170 for Sample BDST, Benzene Eluate.

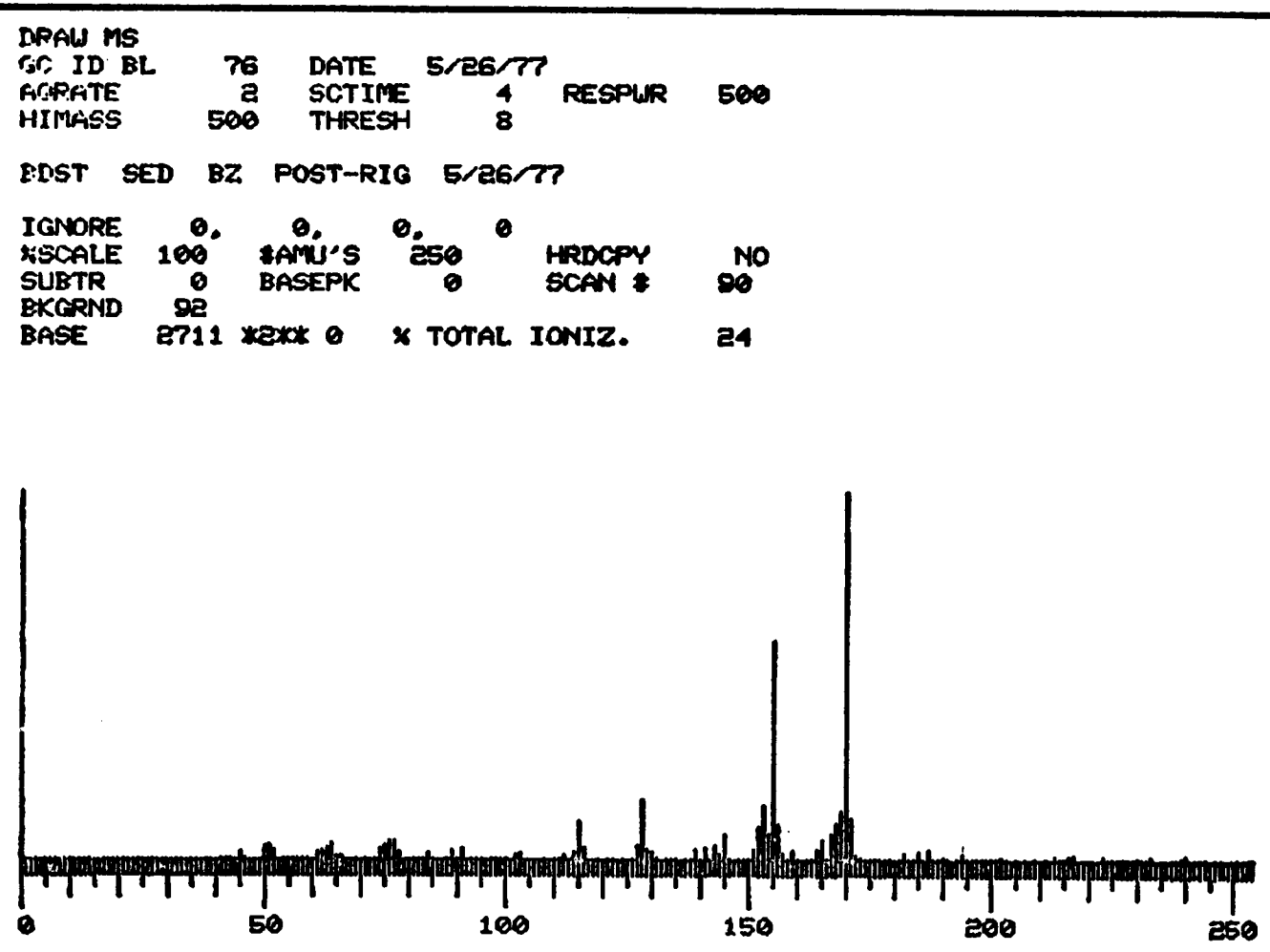


Figure 12. Mass Spectrum of Scan #90 for Sample BDST, Benzene Eluate.

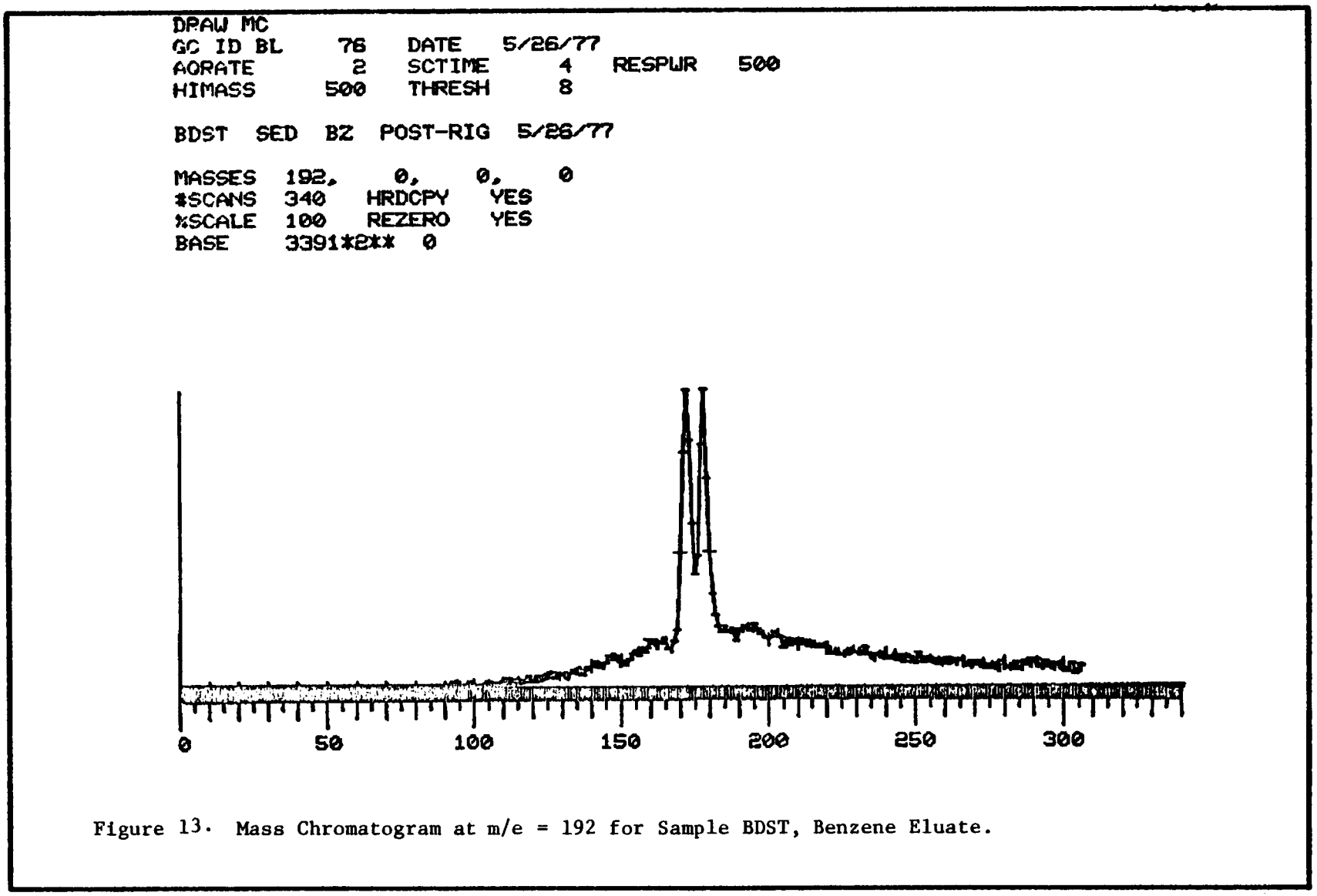


Figure 13. Mass Chromatogram at m/e = 192 for Sample BDST, Benzene Eluate.

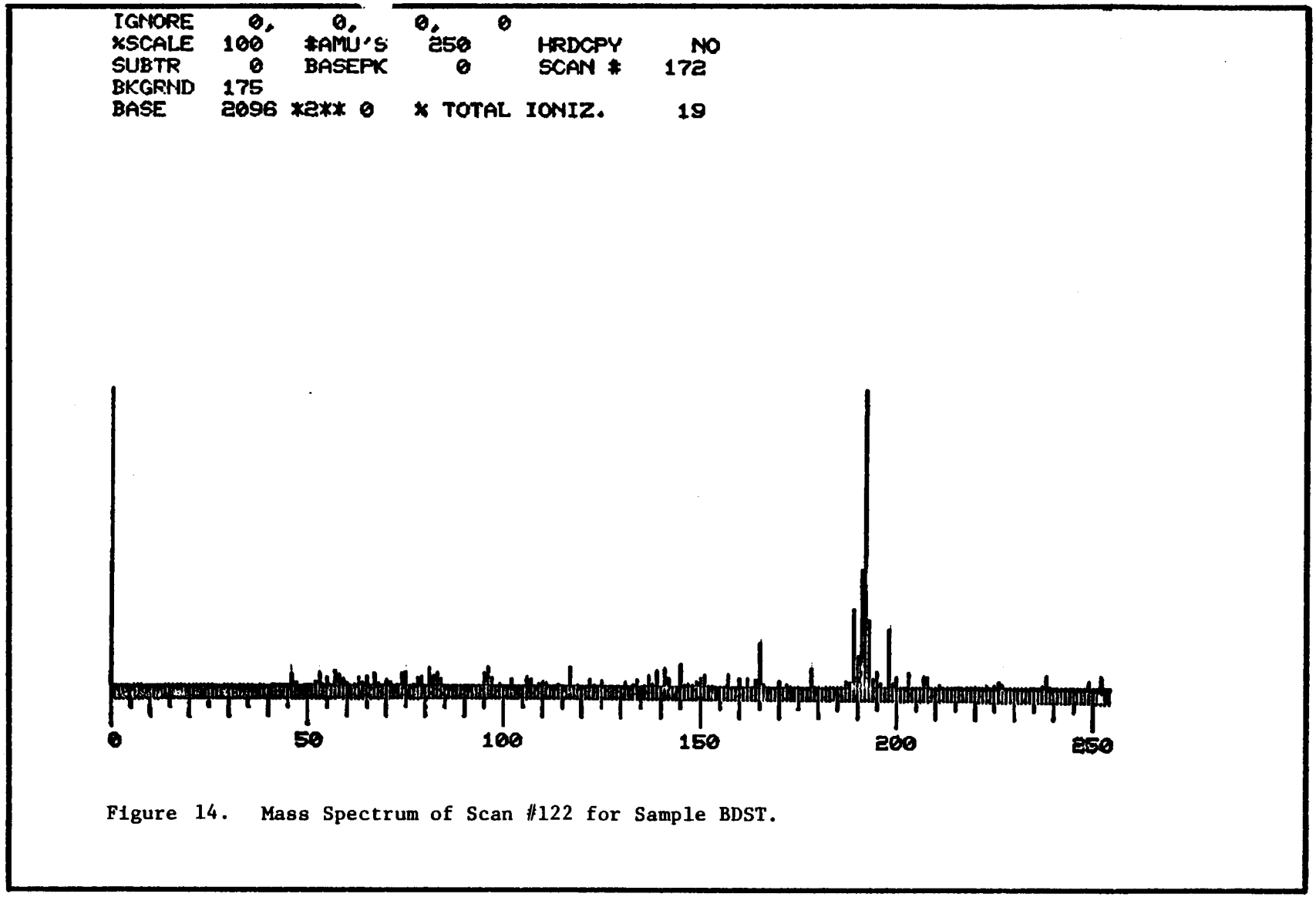


Figure 14. Mass Spectrum of Scan #122 for Sample BDST.

```
IGNORE     0,     0,     0,     0
%SCALE   100    #AMU'S   250      HRDCPY      NO
SUBTR      0    BASEPK     0      SCAN #    178
BKGRND   183
BASE    2694 *2** 0    % TOTAL IONIZ.      21
```

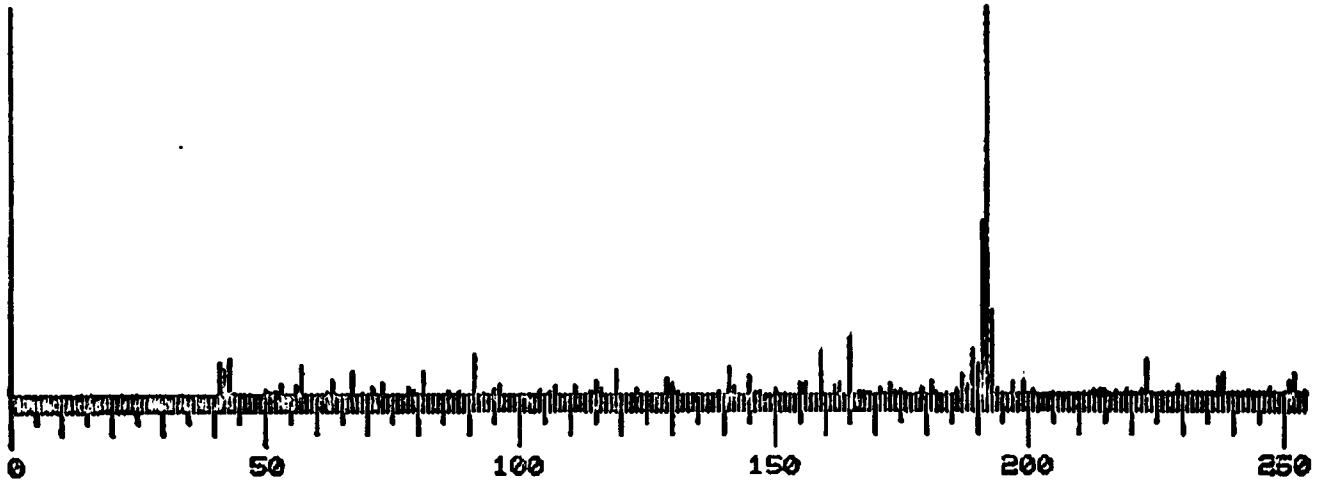


Figure 15. Mass Spectrum of Scan #178 for Sample BDST.

```
DRAW MC
GC ID BL     76    DATE    5/26/77
AQRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

BDST  SED  BZ  POST-RIG  5/26/77

MASSES  206,     0,     0,     0
#SCANS  340    HRDCPY    YES
%SCALE  100    REZERO    YES
BASE    3384*2** 0
```

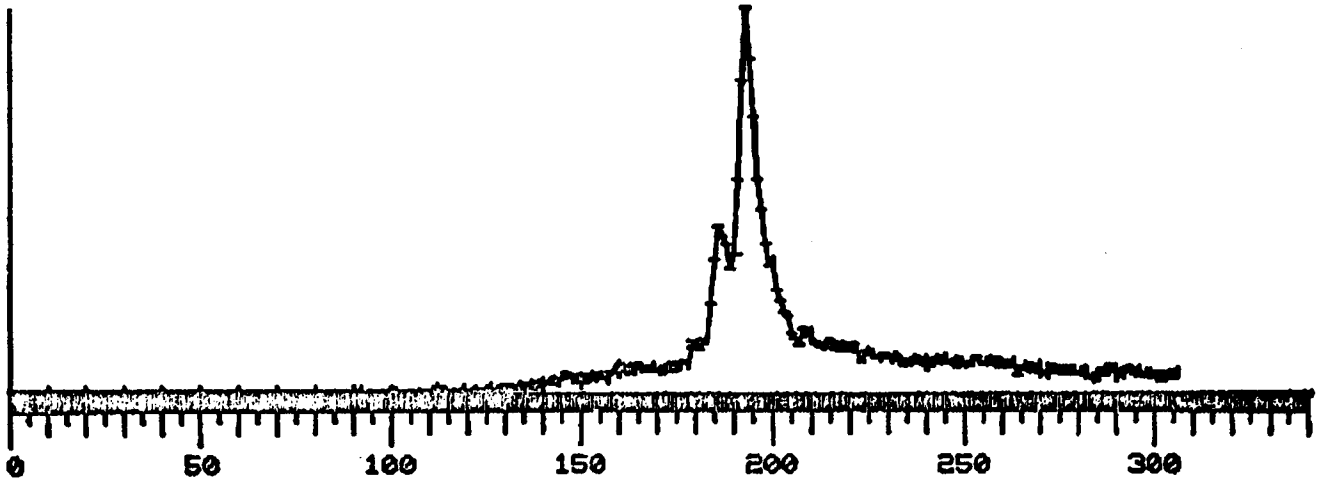


Figure 16. Distribution of Dimethyl Isomers of Mass 206 in Sample BDST, Benzene Eluate.

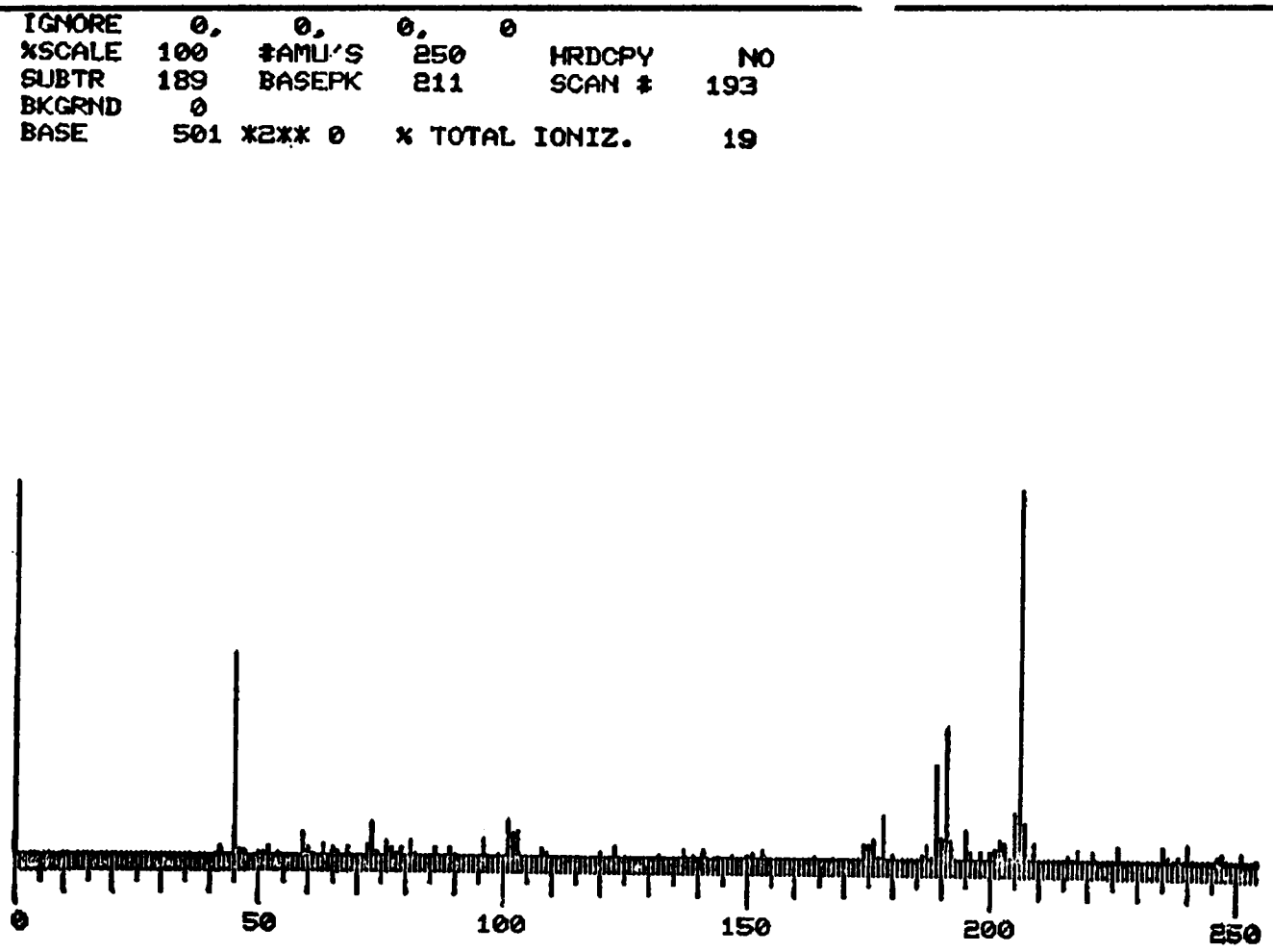


Figure 17. Mass Spectrum of Scan #193 for Sample BDST.

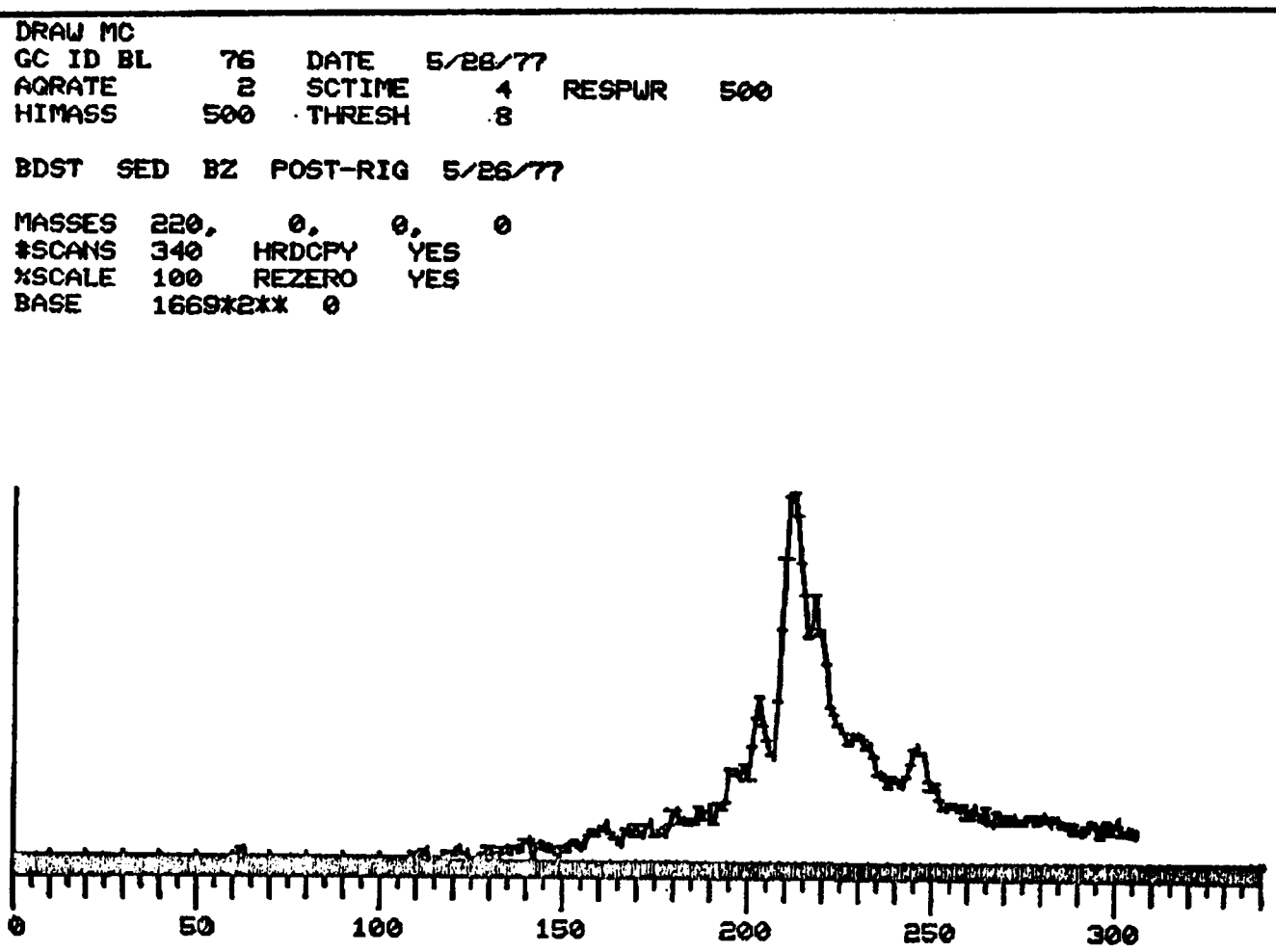


Figure 18. Trimethyl Isomer Mass Chromatogram for Sample BDST, Benzene Eluate.

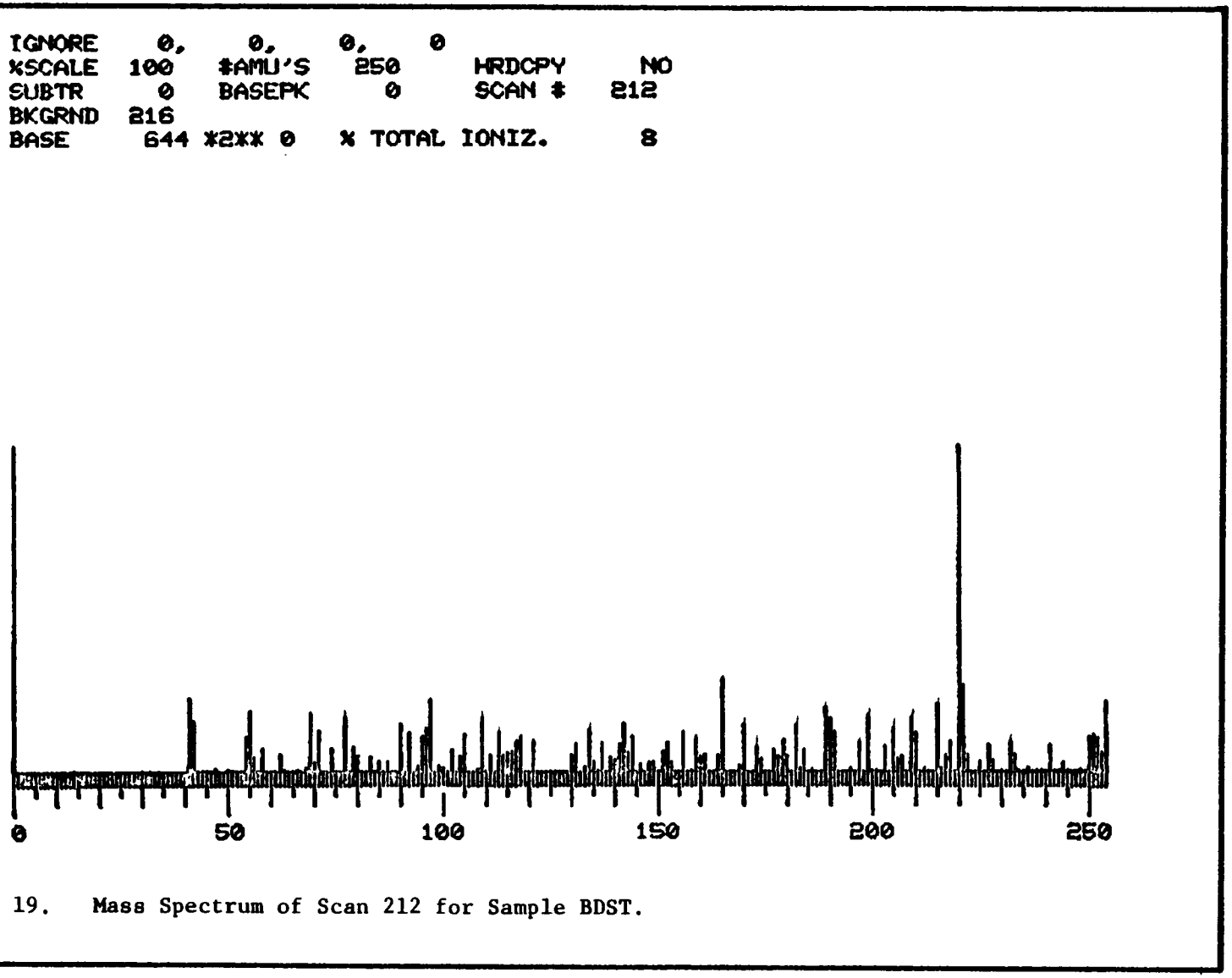


Figure 19. Mass Spectrum of Scan 212 for Sample BDST.

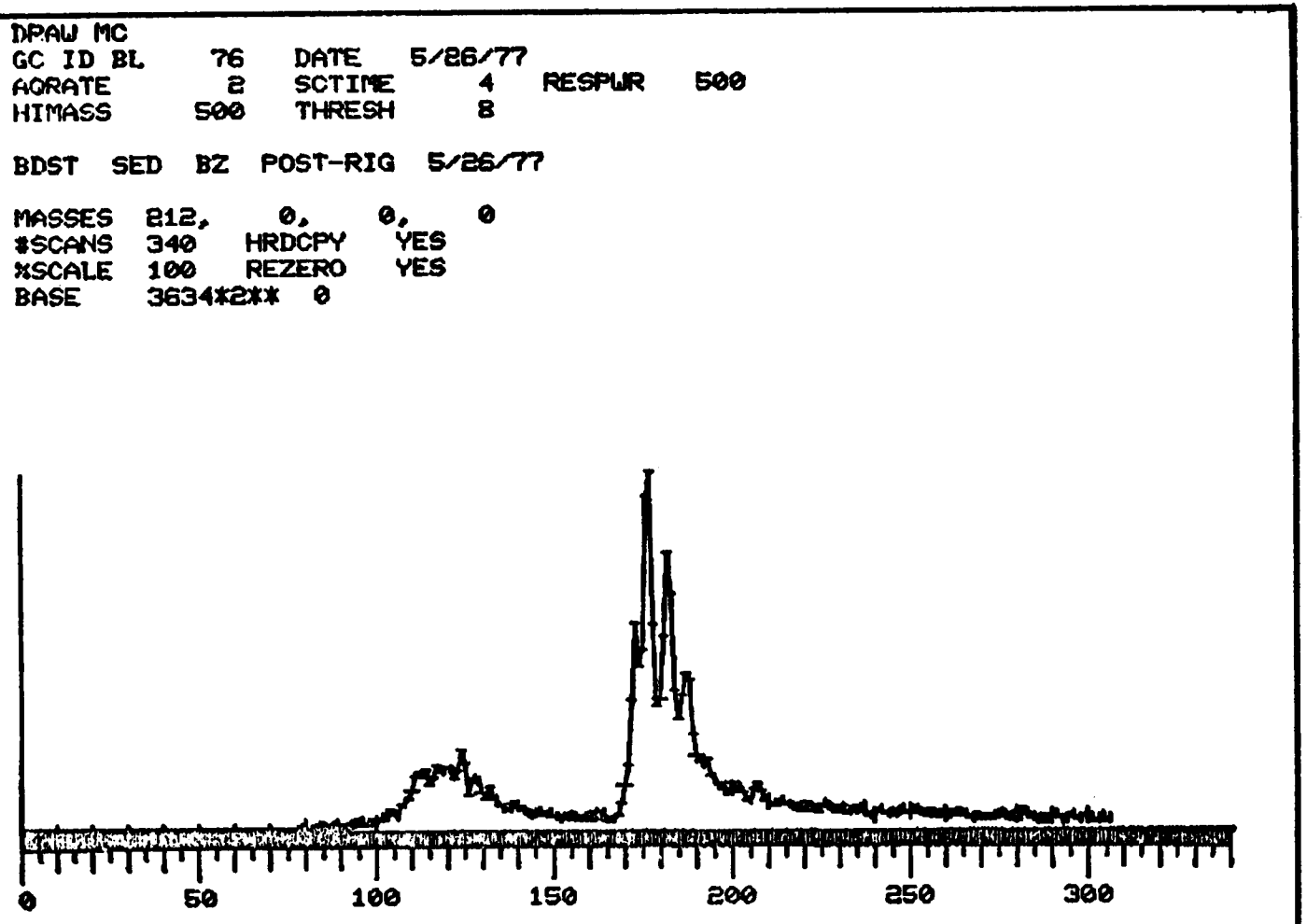


Figure 20. Mass Chromatogram at m/e = 212 for Sample BDST, Benzene Eluate.

```
IPAW MS
GC ID BL     76    DATE   5/26/77
AQRATE        2    SCTIME      4   RESPWR   500
HIMASS      500    THRESH      8

BDST  SED  BZ  POST-RIG  5/26/77

IGNORE     0,     0,     0,     0
%SCALE   100    $AMU'S   250      HRDCPY     NO
SUBTR      0    BASEPK     0      SCAN #   177
BKGRND   179
BASE    2362 *2** 0    % TOTAL IONIZ.     22
```

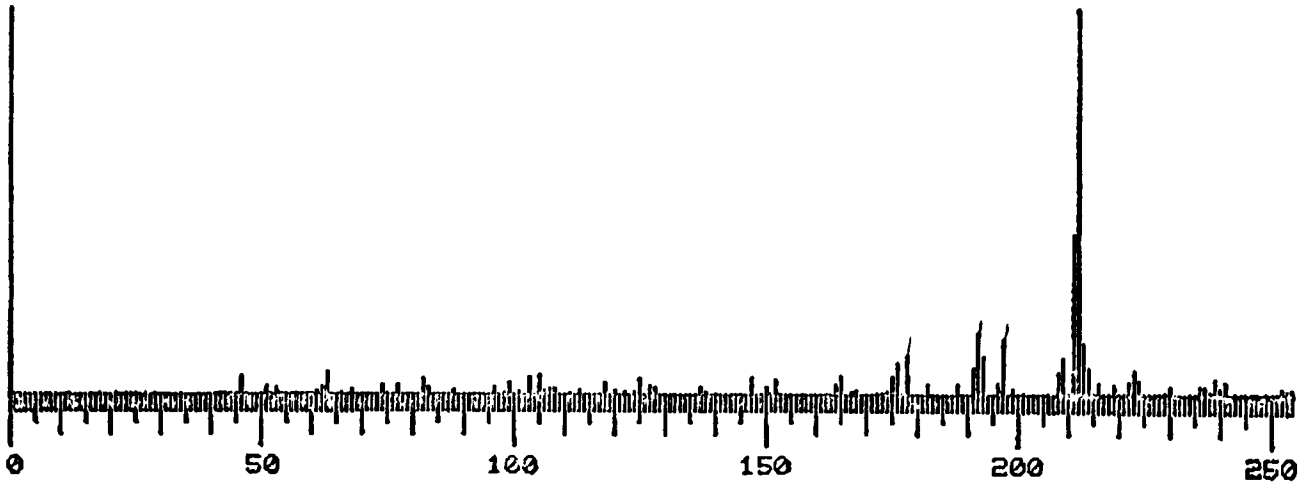


Figure 21 Mass Spectrum of Scan #177 for Sample BDST, Benzene Eluate.

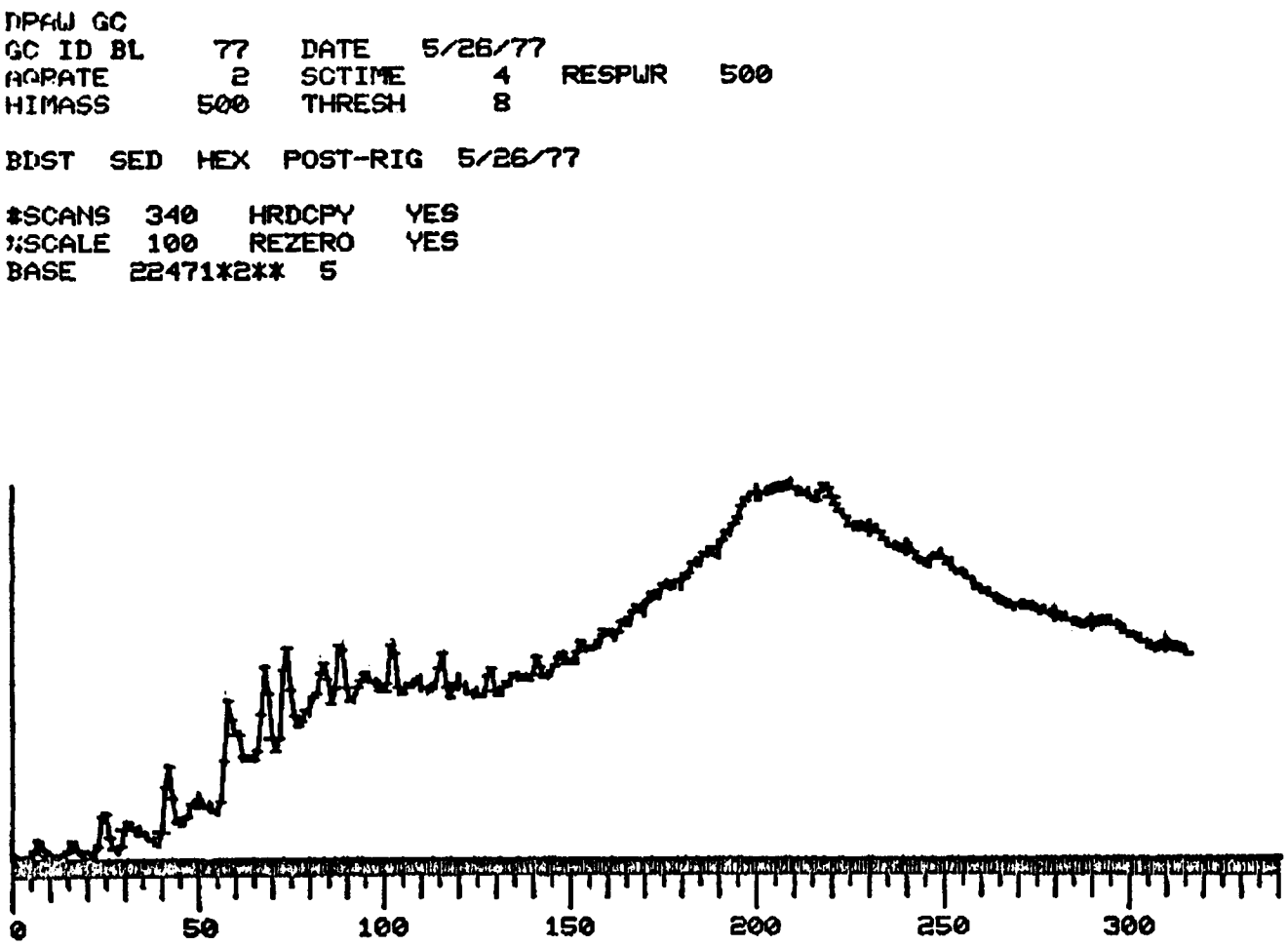


Figure 22. Total Ion Gas Chromatogram for Sample BDST, Hexane Eluate.

```
SIGNFPK
GC ID BL     77    DATE    5/26/77
AGPATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

BDST  SED  HEX  POST-RIG  5/26/77

IGNORE       0,     0,     0,     0
MILOUT  100  HRDCPY   YES

  MASS    MAX    FIRST    SUM
         INTN    OCCUR   IONS *2** 8

    43    1000        3   24860
    45    1000      307    8888
    57    1000        1   23515
    41     981        2   19236
    55     979      107   19822
    69     921      105   16669
    71     848       85   17181
    83     730      106   13464
    97     730      162   12876
    85     698      103   12531
    81     615      205   11223
    95     597      203   10597
   111     585      193    9035
    56     532        4    8966
    67     509      205    8782
   109     446      203    7175
    70     427       96    6983
```

Figure 23. Significant Peak Index for Sample BDST, Hexane Eluate.

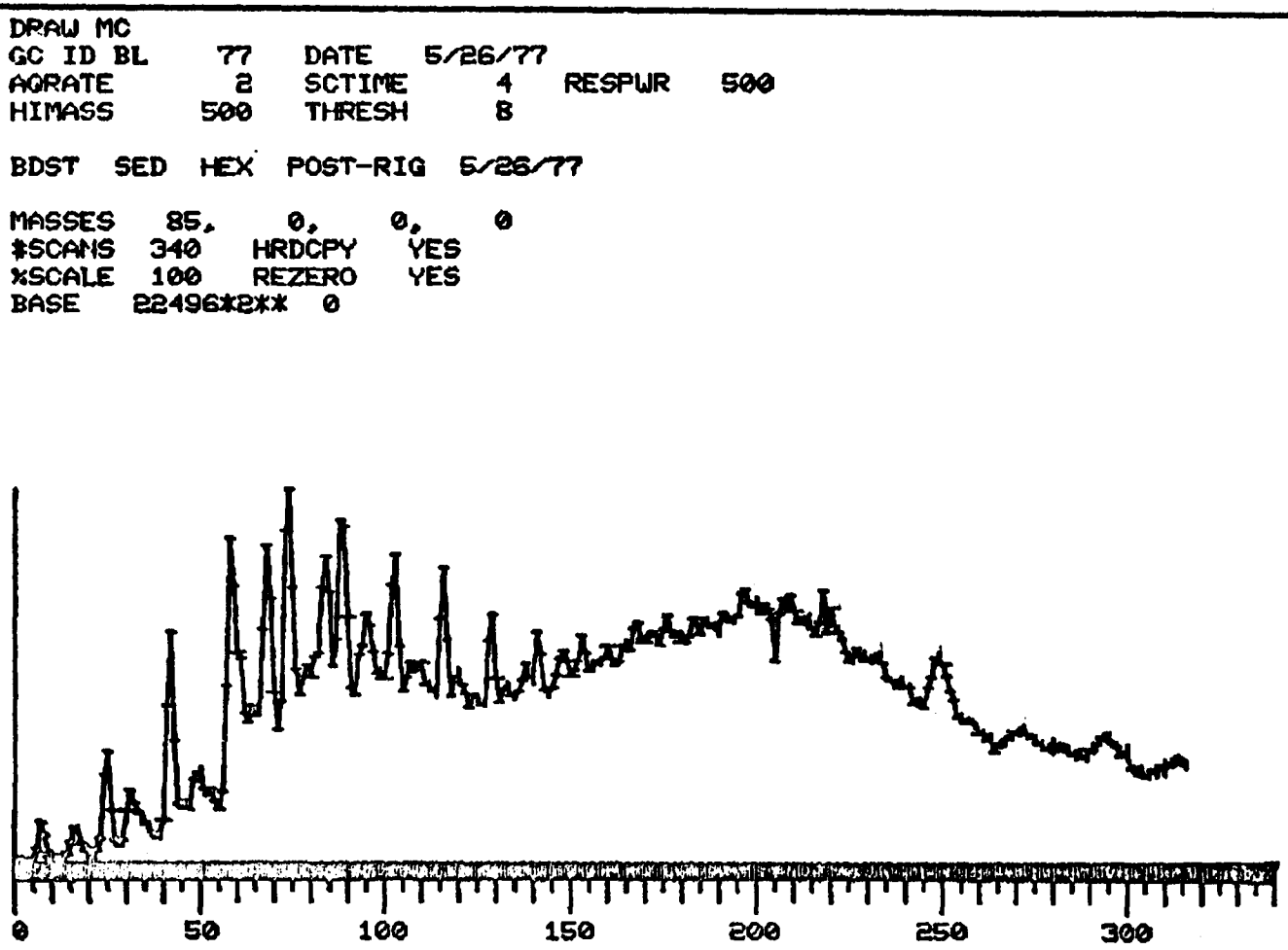


Figure 24. Mass Chromatogram at m/e = 85 for Sample BDST, Hexane Fraction.

IGNORE 0, 0, 0, 0
%SCALE 100 #AMU'S 268 HRDCPY NO
SUBTR 0 BASEPK 0 SCAN # 68
BKGRND 71
BASE 13062 **** 0 % TOTAL IONIZ. 8

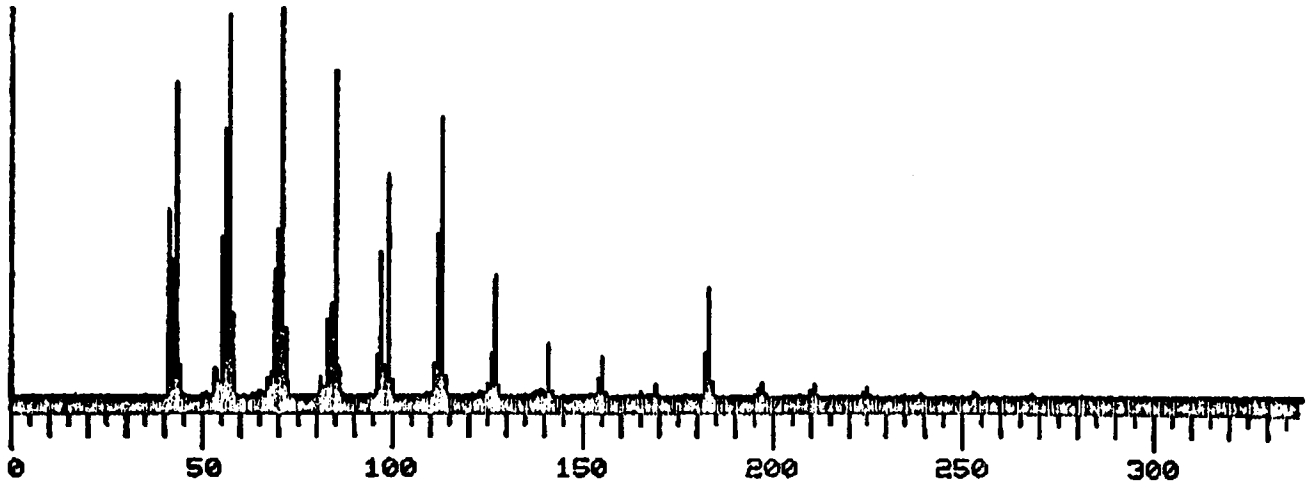


Figure 25. Mass Spectrum of Scan #68 for Sample BDST.

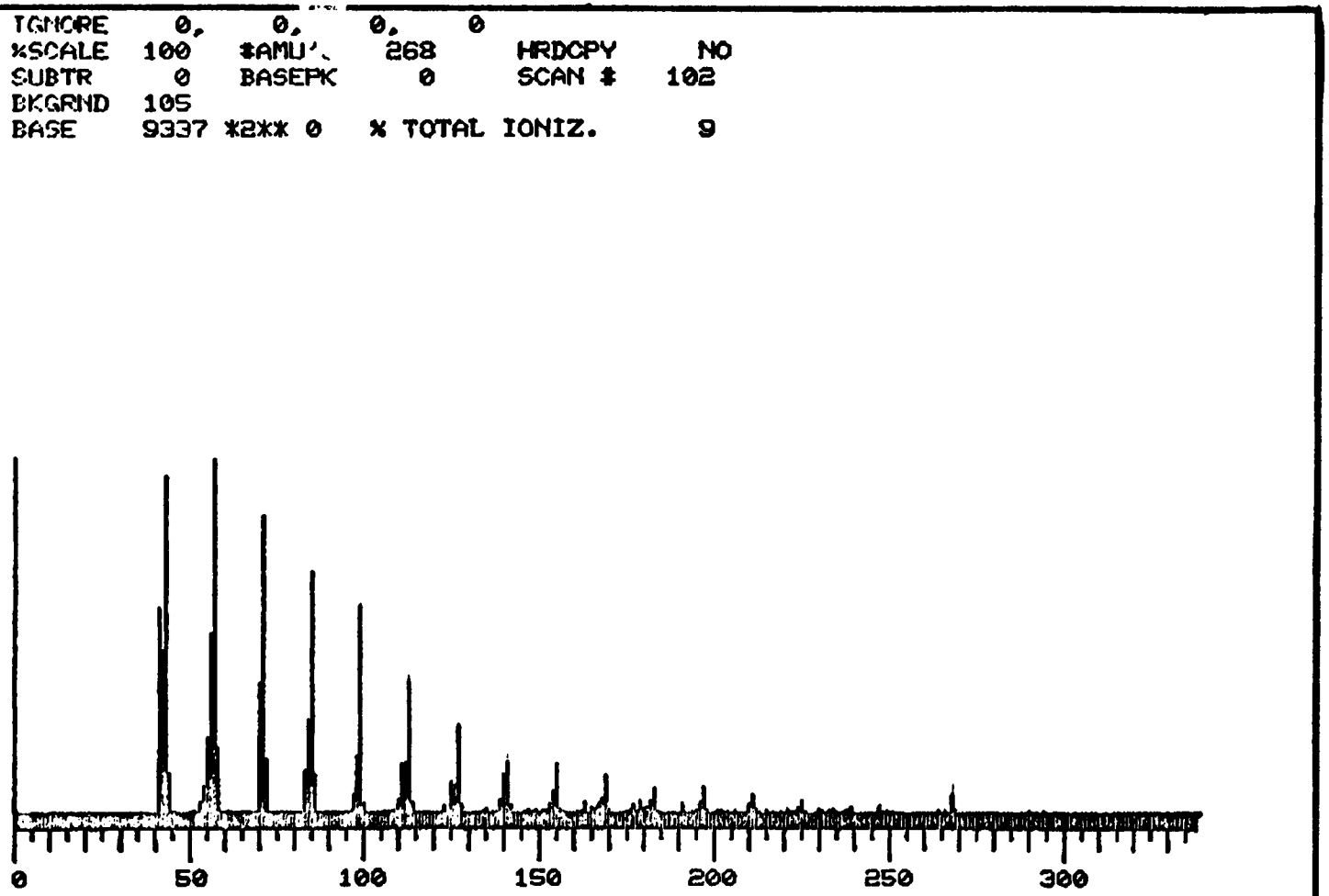


Figure 26. Mass Spectrum of Scan #102 for Sample BDST.

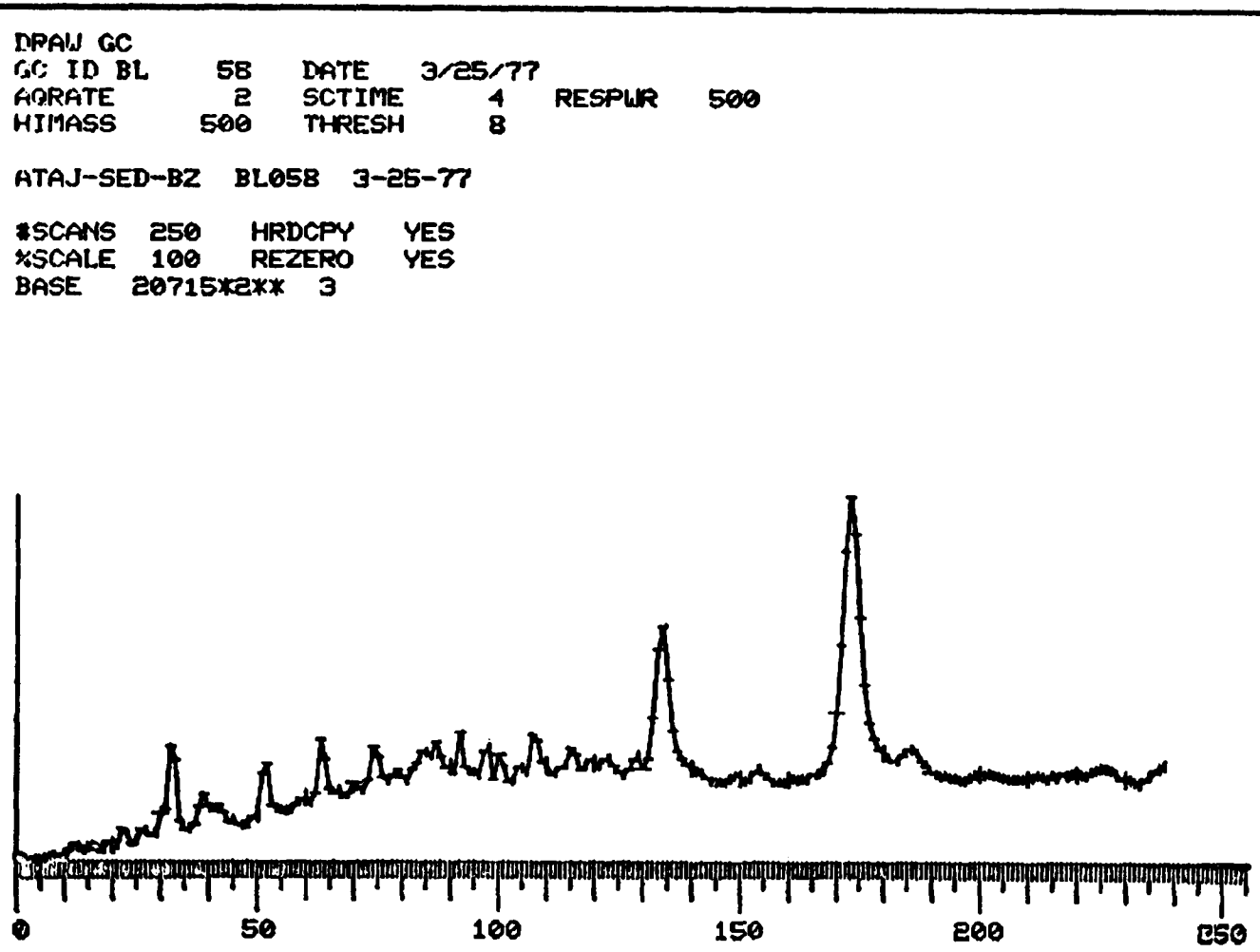


Figure 27. Total Ion Gas Chromatogram of Sample ATAJ, Benzene Eluate.

```
DRAW MS
GC ID BL     58    DATE   3/25/77
AQRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

ATAJ-SED-BZ  BL05B  3-25-77

IGNORE     0,     0,     0,     0
%SCALE   100    #AMU'S   250      HRDCPY      NO
SUBTR      0    BASEPK     0      SCAN #    111
BKGRND   113
BASE     195 *2** 0    % TOTAL IONIZ.       5
```

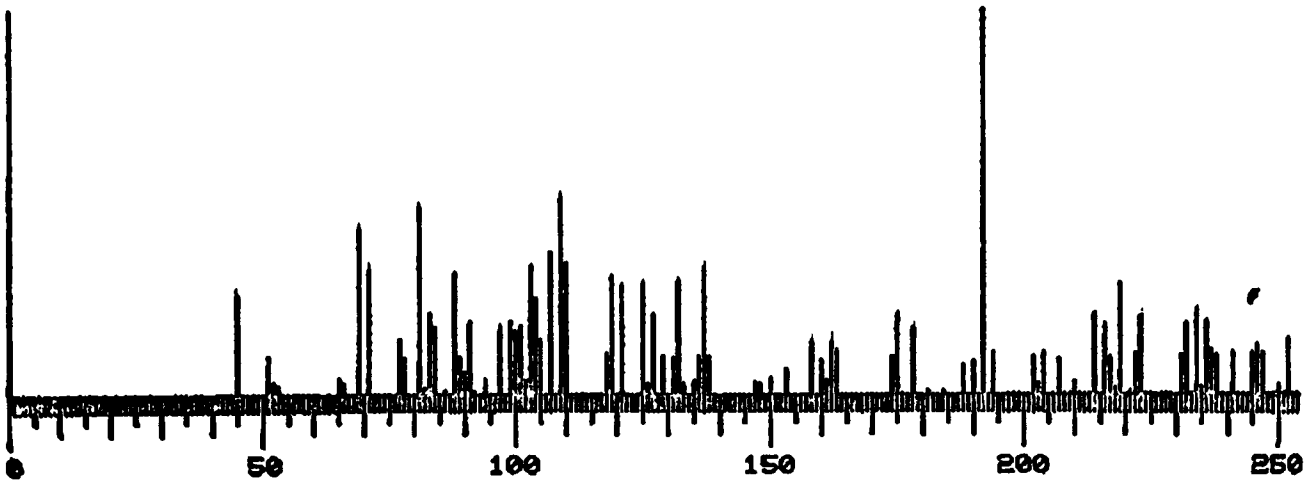


Figure 28. Mass Spectrum of Scan #111 for Sample ATAJ.

```
DRAW GC
GC ID BL     57    DATE    3/25/77
AGRATE        2    SCTIME      4    RESPWR    500
HIMASS      500    THRESH      8

ATAJ-SED-HX  BL057  3-25-77

$SCANS   250    HRDCPY    YES
%SCALE   100    REZERO    YES
BASE    25944*2** 3
```

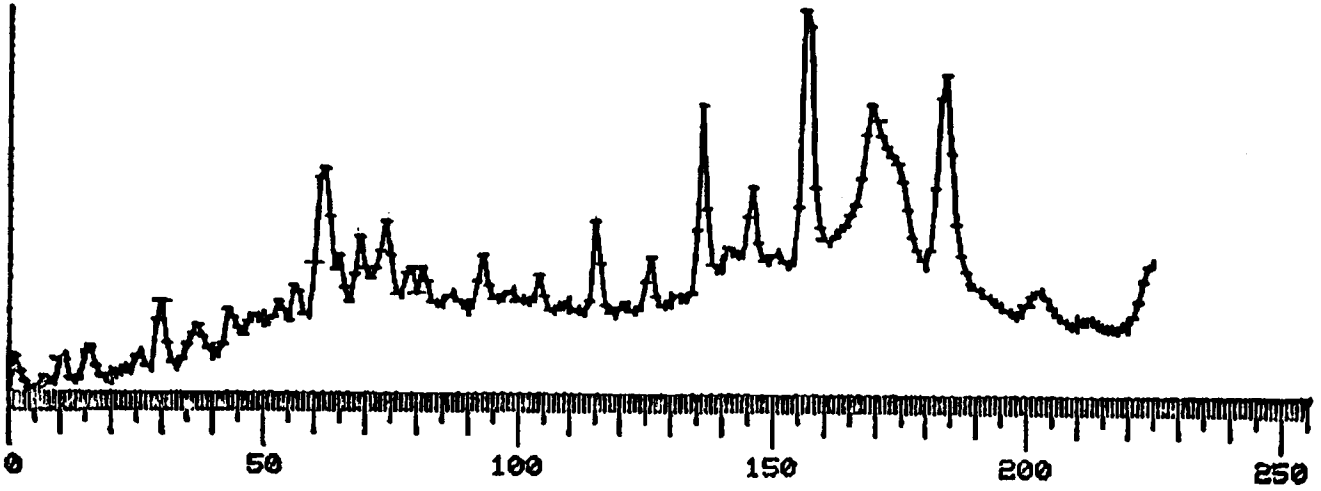


Figure 29. Total Ion Gas Chromatogram of Sample ATAJ, Hexane Eluate.

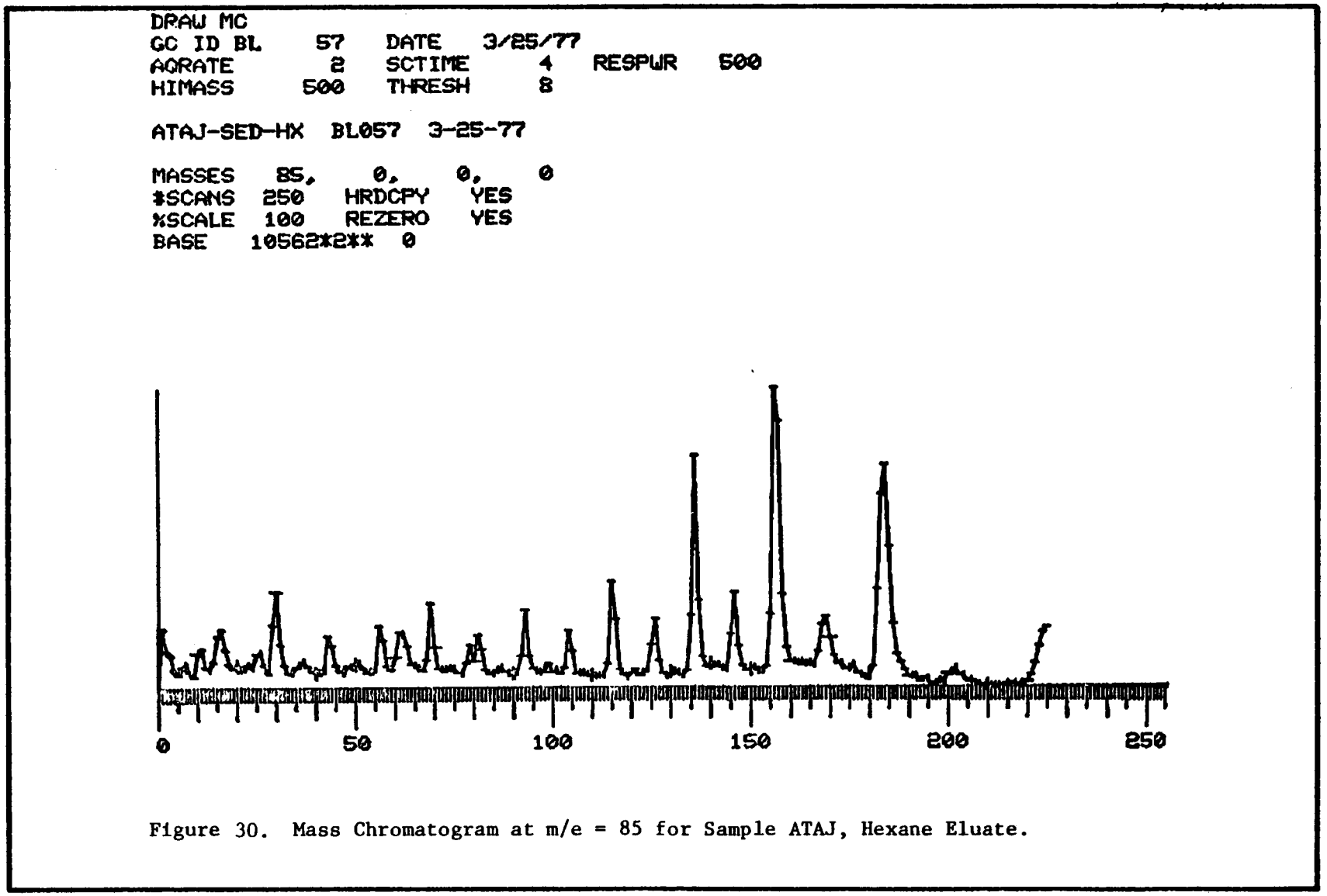


Figure 30. Mass Chromatogram at m/e = 85 for Sample ATAJ, Hexane Eluate.

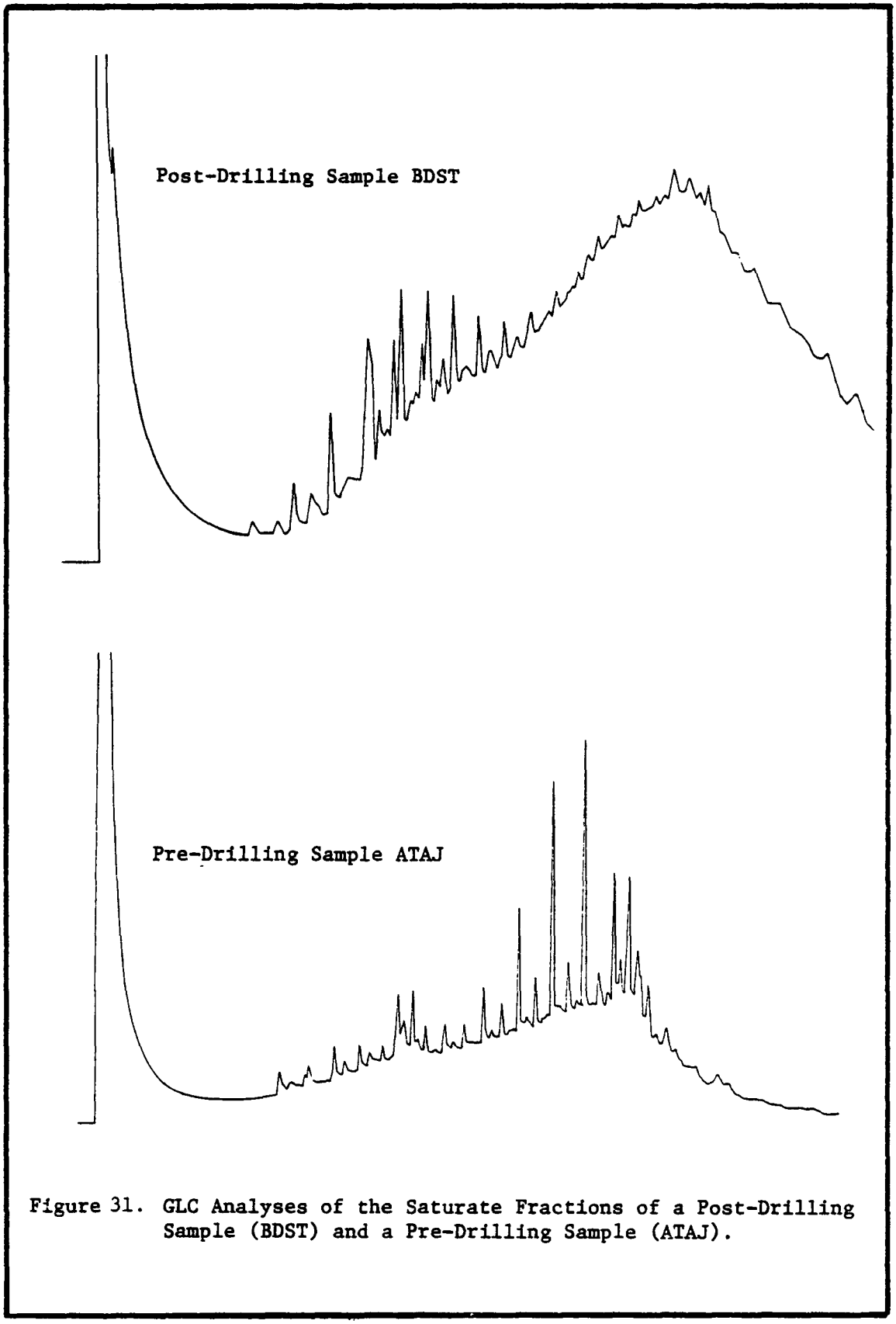


Figure 31. GLC Analyses of the Saturate Fractions of a Post-Drilling Sample (BDST) and a Pre-Drilling Sample (ATAJ).

TABLE 6

SEDIMENT RATIOS OF INDIVIDUAL HYDROCARBONS
AND AVERAGE OEP VALUES IN PRE-DRILLING SAMPLES

CODE	LOCAT.	PR / PH	PR/C-17	PH/C-18	OEP
ATAJ	1 / RIG	1.47	.37	.13	2.47
ATCA	30 / RIG	3.08	.32	.07	3.18
ATGA	32 / RIG	4.62	.81	.42	3.87
ATJA	34 / RIG	2.87	.42	.14	4.11
ATMA	36 / RIG	8.17	.57	.08	4.96
ATQU	36 / RIG	1.50	.29	.16	4.62
ATRA	36 / RIG	2.65	.22	.10	5.56

Explanation of Columns:

Column 1 Code = Unique Sample Code
Column 2 Locat. = Location from Drill Site (DS); 1=DS; 30=N-1000 m; 32=E-1000 m; 34=S-1000 m; 36=W-1000 m.
Column 3 PR/PH = Pristane/Phytane Ratio
Column 4 PR/C-17 = Pristane/C17 Ratio
Column 5 PH/C-18 = Phytane/C18 Ratio
Column 6 OEP = Odd-Even Preference Indice Value

TABLE 7

SEDIMENT RATIOS OF INDIVIDUAL HYDROCARBONS
AND AVERAGE OEP VALUES IN POST-DRILLING SAMPLES

CODE	LOCAT.	PR / PH	PR/C-17	PH/C-18	OEP
BDEV	1 / RIG	1.30	.53	.39	2.68
BDSL	1 / RIG	1.84	.72	.44	2.04
BDST	1 / RIG	1.84	.62	.44	1.84
BDHP	30 / RIG	2.19	.45	.41	2.42
BDTQ	32 / RIG	2.67	.67	.38	2.61
BDWA	34 / RIG	6.15	1.70	.27	1.94
BDYK	36 / RIG	4.26	.87	.21	2.04

Explanation of Columns:

Column 1 Code = Unique Sample Code
Column 2 Locat. = Location from Drill Site (DS); 1=DS; 30=N-1000 m; 32=E-1000 m; 34=S-1000; 36=W-1000 m.

Column 3 PR/PH = Pristane/Phytane Ratio
Column 4 PR/C-17 = Pristane/C17 Ratio
Column 5 Ph/C-18 = Phytane/C18 Ratio
Column 6 OEP = Odd-Even Preference Indice Value

A complete GC/MS analysis was carried out for two samples, one pre-drilling and the post-drilling sample which showed oil pollution by GC. The results are given below.

GC/MS of Post-Drilling Sample BDST

Figure 6 is a total ion chromatogram of the sample BDST. Major peaks are not prominent above the very large unresolved envelope of peaks. Mass fragment ions of significance are given in Figure 7.

Figure 8 shows a mass chromatogram for fragment ion m/e = 149. This ion fragment is characteristic of phthalate esters commonly used as plasticizers and are frequently encountered in organic samples, probably as a laboratory contaminant. Comparison of Figure 8 with Figure 6 shows that the "large" peak at scan #154 is insignificant in the total ion chromatogram.

A mass chromatogram at m/e = 156 is shown in Figure 9. This mass is the molecular weight of dimethylnaphthalenes and a check of the mass spectrum (Figure 10) shows that the largest peak of the groups at Scan 76 is typical of dimethylnaphthalene. The next higher homolog, trimethylnaphthalene has a molecular weight of 170. At m/e = 170, mass chromatogram is shown in Figure 11 with the mass spectrum of the peak at Scan #90 shown in Figure 12. The largest peak of Figure 11 is, indeed, a trimethylnaphthalene.

The mass chromatogram at m/e = 192 in Figure 13 is characteristic of methylphenanthene and methylanthracene. Practically identical mass spectra obtained for the two prominent peaks of Figure 13 are shown in Figure 14 and 15. Neither the chromatographic retention times nor the mass spectra permit distinguishing between the phenanthrene and anthracene isomers. The distribution of dimethyl isomers of mass 206 is shown in Figure 16 with a characteristic mass spectrum shown in Figure 17.

The possible trimethyl isomer mass chromatogram with corresponding mass spectrum are given in Figure 18 and 19, respectively.

The mass chromatogram of Figure 20 of mass fragment m/e = 212 is characteristic of dimethyldibenzothiophene or the dimethylnaphthothiophene isomer. The mass spectrum of Figure 21 is very much like those shown in the literature.

Figure 22 is the total ion chromatogram of the hexane fraction of the contaminated "post-rig" sample, BDST. The chromatogram appears to be a large envelope of unresolved peaks with a few more prominent peaks, especially in the lower molecular size (C_{14} - C_{22}) range. An index of some "significant" fragment ions is given in Figure 23.

Saturated alkanes are emphasized in the m/e = 85 mass chromatogram given in Figure 24. These are typical normal and isoprenoid hydrocarbons encountered in petroleum-like organic matter. The mass spectra of Figure 25 and 26 are the C_{19} isoprenoid (pristane) and normal hydrocarbons located at scans #68 and 102, respectively. The C_{20} isoprenoid hydrocarbon (phytane) at scan #84 is rather large relative to the pristane concentration, suggesting petroleum as the source of organic contaminant in this sample.

GC/MS of Pre-Drill Sample ATAJ

As a comparison with the above, apparently contaminated, sample, the pre-drilling sample ATAJ was also analyzed by GC/MS. Sample ATAJ is from the same location as sample BDST but shows little, if any contamination with petroleum-like organic matter.

Figure 27 is the total ion chromatogram of the benzene eluate (non-saturate) fraction of pre-rig sample ATAJ. The largest peak is the plasticizer, dioctylphthalate, a suspected laboratory contaminant. The other

prominent peak at scan #134 is squalene, a compound frequently encountered in sediments. A trace quantity of methylphenanthrene may exist at scan #111 (no apparent peak in the gas chromatogram). The mass spectrum at this scan number is shown in Figure 28. The spectrum is mostly "noise" peaks but the possible molecular ion of m/e = 192 is seen to predominate. This sample is apparently uncontaminated with any large quantities of petroleum-like organic matter.

Figure 29 is the total ion chromatogram of the hexane eluate fraction of this same sample. Prominent peaks corresponding to n-alkanes are present. The saturated alkanes are emphasized in the m/e = 85 mass chromatogram shown in Figure 30. The predominance of alkanes having odd numbers of carbon atoms in their molecules in scans #115, 136, 156 etc., is evident. This is typical of uncontaminated, pristine sediment samples of the Gulf of Mexico.

Distributions of the n-alkanes are given graphically in the left-hand portion of Figures 1.1 through 1.14, Appendix B. In every case but one, the predominance of n-alkanes having odd numbers of carbon atoms in the molecule is evident. This characteristic is typical of pristine samples of Recent sediments. The curve corresponding to the ratio of odd to even chain lengths as a function of carbon number is given in the right-hand portion of these figures for each sample.

For the one case of sample BDST (Figure 1.11) the predominance of odd carbon numbered alkanes is diminished and the OEP curve lies close to a value of unity. This indicates a presence of petroleum-like hydrocarbons in this one sample.

In summary, this rig monitoring study has shown that the approach taken is capable of detecting petroleum contamination of sediment. A program to accomplish this on a routine basis would include the following elements:

-A summary statistical analysis of all the BLM sedimentary hydrocarbon data.

-A summary of a few in-depth analyses of control sediment samples.

-A modest study (75-100 samples) of several drilling and producing sites using the parameters in this report.

-An in-depth study of those sites for which the above survey indicated pollution. This would require holding a large sample in the frozen state until the quick survey analysis could be completed.

Finally, it should be pointed out that oil itself, or just drill cuttings from ancient shales, could cause the type contamination which has been discussed.

LITERATURE CITED

Attaway, D. H., P. L. Parker, and J. A. Mears. 1971. Normal alkanes of five coastal spermatophytes. Contr. in Mar. Sci. 15.

Blumer, M., R. R. L. Guillard, and T. Chase. 1971. Hydrocarbons of marine phytoplankton. International Jour. on Life in Oceans and Coastal Waters. 8(3):183-189.

David, J. B. 1968. Paraffinic hydrocarbons in the sulfate-reducing bacterium *Desulfovibric desulfuricans*. Chem. Geol. 3:155-160.

Eglinton, G., and M. T. J. Murphy (Eds.). 1969. Organic geochemistry.

McLafferty, F. W. 1973. Interpretation of mass spectra. 2nd Edition. W. A. Benjamin, Inc., Reading, Mass.

Meinschein, W. G. 1961. Significance of hydrocarbons in sediments and petroleum. Geochimica et Cosmochimica Acta 22(1):58-64.

Parker, P. L. 1967. Fatty acids in recent sediment. Contr. in Mar. Sci. 12:135.

_____. 1969. Fatty acids and alcohols, in organic geochemistry. Methods and Results. Springer-Verlag, New York.

Sever, J., and P. L. Parker. 1969. Fatty acids (normal and isoprenoid) in sediments. Sci. 164:1052.

Stransky, K., M. Streibl, and V. Herout. 1967. Distribution of wax hydrocarbons in plants at different evolutionary levels. Collection Czechoslov. Commun. 32.

Stenhagen, E., S. Abrahamsson, and F. W. McLafferty. 1974. Registry of mass spectral data. John Wiley and Sons, New York.

Tornabene, T. G., and S. P. Markey. 1971. Characterization of branched monounsaturated hydrocarbons of *Sarcina lutea* and *Sarcina flava*. Lipids 6(3).

Whitehead, W. L., and I. A. Breger. 1963. Geochemistry of Petroleum. *In* Organic geochemistry (Monograph No. 16-Earth Science Series)". MacMillan Co., New York.

Yen, T. F. (Editor). 1977. Chemistry of marine sediments. Ann Arbor Sci. Publ. Inc., Ann Arbor, Mich.

CHAPTER EIGHT

BENTHIC SEDIMENT TEXTURAL ANALYSES

U. S. Geological Survey
Corpus Christi, Texas

Principal Investigator:

Gerald L. Shideler

ABSTRACT

Comparisons of textural variability between composite pre-drilling and post-drilling sample suites were made. The results suggest that statistically significant differences occur between the two suites for the following textural parameters: skewness, silt percentage, clay percentage, silt/clay ratio, and mean diameter. The post-drilling suite was significantly coarser-grained, had a higher silt/clay ratio, and was less coarsely skewed than the pre-drilling suite. No meaningful inferences can be formulated regarding causative factors as the observed sea-floor textural changes could potentially have resulted from a combination of modified sampling procedures, analytical variability, natural seasonal variability, and drilling-rig operations.

INTRODUCTION

This report presents the results of the benthic sediment textural analyses conducted as part of the South Texas OCS Rig Monitoring Study. The objectives of this study were (1) to provide supportive sediment textural data to aid in interpretation of the results of benthic geochemical analyses, and (2) to determine the spatial and temporal variability of sea floor sediment textures within the immediate local environment of an exploratory drilling rig. This was accomplished by comparing the textures of pre-drilling and post-drilling sediment sample suites.

METHODS AND MATERIALS

All field sampling for the pre-drilling and post-drilling suites was done by personnel of the University of Texas Marine Science Institute, Port Aransas Marine Laboratory. The two sample suites were delivered to the USGS, Corpus Christi, office for textural analyses. A total of 38 samples were received and analyzed; this consisted of 24 pre-drilling and 14 post-drilling samples. The sediment grain-size distributions were determined at a 0.5 Ø interval, using a Rapid Sediment Analyzer for the sand fraction (2 mm - 63 μm), and a Coulter Counter (Model TA) for the mud fractions (63-0.6 μm). Specific analytical techniques were the same as those used by the USGS for textural analyses in the FY'75 STOCS baseline study; these techniques are outlined in detail by Berryhill *et al.* (1976). Following grain-size analyses, textural parameters were determined by computer. Derived parameters included sand percent, silt percent, clay percent, sand/mud ratio, silt/clay ratio, and the four moment measures (mean diameter, standard deviation, skewness, kurtosis).

The mean values of each size parameter for the pre-drilling and post-drilling sample suites were then statistically compared to determine any significant textural differences between the two suites. Comparisons were made with an analysis of variance (ANOVA) program, using an F-statistic (*e.g.*, Barr *et al.*, 1976). In view of the relatively small size of the two sample suites, the ANOVA results were verified by a nonparametric Wilcoxon two-sample test using a U-test statistic (Sokal and Rohlf, 1969). Statistical comparisons of textural variations among stations within either of the two suites generally were not feasible because of insufficient replicate sampling at individual stations. Most stations were represented by only two replicate samples for textural analyses which was judged to be inadequate for a reliable evaluation of "within station" variability. Consequently, intra-suite station comparisons were made largely on the basis of the observed textural variations, without any reference to their statistical significance.

RESULTS AND DISCUSSION

The results of the textural analyses are tabulated in Table 1, Appendix C.

Inter-Suite Variability

Comparisons of textural variability between the composite pre-drilling and post-drilling sample suites are summarized by the ANOVA results presented in Table 1. These results suggest that statistically significant differences (95% confidence level) occurred between the two suites for the following textural parameters: skewness, silt percentage, clay percentage, silt/clay ratio, and mean diameter. The post-drilling suite

TABLE 1

ANALYSIS OF VARIANCE FOR PRE-DRILLING
AND POST-DRILLING SUITE COMPARISONS

Hypothesis: Ho: $U_1 = U_2$
Statistic: F
Risk of Type 1 Error: $\alpha = 5\%$
Critical Region: $F > F_{5\%}$ (1,36 d.f.); $F_{5\%} = 4.12$

Parameter	F-value
Sand % ($\bar{x}_1 = 4.67$, $\bar{x}_2 = 6.08$)+	1.58
Silt % ($\bar{x}_1 = 45.47$, $\bar{x}_2 = 55.09$	14.97*
Clay % ($\bar{x}_1 = 49.82$, $x_2 = 38.82$)	22.93*
Sand/Mud ratio ($\bar{x}_1 = 0.049$, $\bar{x}_2 = 0.068$)	1.87
Silt/Clay ratio ($\bar{x}_1 = 0.931$, $\bar{x}_2 = 1.556$)	17.98*
Mean Diameter ($\bar{x}_1 = 7.72$, $\bar{x}_2 = 7.13$)	24.25*
Standard Deviation ($\bar{x}_1 = 2.04$, $x_2 = 2.15$)	3.80
Skewness ($\bar{x}_1 = -0.157$, $\bar{x}_2 = -0.008$	7.41*
Kurtosis ($\bar{x}_1 = -0.947$, $\bar{x}_2 = -0.822$	0.70

+ $\bar{x}_1$ = pre-drilling mean, $\bar{x}_2$ = post-drilling mean

* = significant difference

was significantly coarser-grained, had a higher silt/clay ratio, and was less coarsely skewed than the pre-drilling suite. All other parameters indicated no significant differences at the specified confidence level. These ANOVA results were reproduced and substantiated by the nonparametric Wilcoxon test.

Although the foregoing comparisons suggest some textural differences between the pre-drilling and post-drilling suites, no valid conclusions can be presently formulated regarding the causes of the textural differences. This inconclusiveness is attributed to the following factors:

1) The pattern and number of post-drilling sample sites were substantially modified from the pre-drilling suite without being coordinated through the USGS Corpus Christi office. The stations 500 m from the drilling site sampled in the pre-drilling suite were totally deleted from the post-drilling sample suite. In addition, the number of replicate samples at the drilling site (DS) was different for both suites. This change in sampling format casts some doubt on the significance of the ANOVA results.

2) The seasonal monitoring of STOCS benthic-sediment textures during the FY'76 program illustrated substantial natural variability along Transect II (Berryhill *et al.*, in prep.), which is in close proximity to the rig monitoring site. As the pre-drilling (9/25/76) and post-drilling (3/1/77) sampling dates encompassed a period exceeding five months, much of the observed textural variability might be attributed to natural variations in the hydraulic regime. The variability observed at the rig site is compatible with the natural textural trends observed on a seasonal basis along Transect II. Since no control samples were obtained near the rig site

to evaluate natural variability over the same monitoring period, natural effects cannot be differentiated from any possible rig-induced effects.

3) The post-drilling sample site (27°44'21.12"N, 96°42'58.86"W) had been relocated approximately 25 m away from the pre-drilling sample site (27°44'21.12"N, 96°42'58.86"W). In itself, this relocation could have resulted in some textural variability.

Intra-Suite Variability

The textural variability between individual stations within each sample suite could not be effectively evaluated statistically because of inadequate sample replication. However, some comparisons can be made on the basis of the observed mean parameter values at each station. Since mean diameter and silt/clay ratios are the most significant parameters that varied between suites, the mean values of these two parameters at each station were compared (Table 2).

Within the pre-drilling suite, the benthic sediments were coarsest-grained (mean diameter = 7.45 Ø) at Station E-1000, and finest-grained (8.05 Ø) at Station N-1000. These two stations, respectively, also had the highest (1.21) and lowest (0.70) silt/clay ratios. The only pair of stations that had sufficient sample replication for a statistical inter-station comparison were Stations E-500 and S-500. A nonparametric Wilcoxon test conducted on the mean diameters and silt/clay ratios of this sample pair indicated no significant differences; this suggests an absence of significant local variations over the 700-m distance separating the two stations during the sampling period.

Within the post-drilling sample suite, the sediments were coarsest-grained (mean diameter = 6.45 Ø) at Station E-1000, and finest-grained (7.65 Ø) at Station S-1000. These two stations, respectively, also had

TABLE 2

MEAN VALUES OF SILT/CLAY RATIOS
AND MEAN DIAMETERS AT INDIVIDUAL STATIONS

Suite	Station	Silt/Clay Ratio ($\bar{x}$)	Mean Diameter (Ø) ($\bar{x}$)
Pre-Drilling	DS	1.01	7.67
	N-1000	0.70	8.05
	E-500	0.91	7.65
	E-1000	1.21	7.45
	S-500	0.91	7.76
	S-1000	1.05	7.73
	W-1000	0.85	7.83
Post-Drilling	DS	1.55	6.98
	N-1000	1.29	7.57
	E-1000	2.46	6.45
	S-1000	0.93	7.65
	W-1000	1.58	7.27

the highest (2.46) and lowest (0.93) silt/clay ratios. The drilling site station (DS) exhibited intermediate values for both parameters. Although the relatively coarsest-grained and most silty station (E-1000) was the same during both the pre-drilling and post-drilling sampling periods, the finest-grained station shifted southward in the post-drilling period.

CONCLUSIONS

The textural analyses of pre-drilling and post-drilling sample suites delivered to the USGS Corpus Christi office were successfully completed, and the resulting textural data are herein presented. Although the sampling format was not particularly conducive to a statistical evaluation of textural parameters, an analysis of variance performed on the generated data suggested some significant textural differences between the two sample suites. However, no meaningful inferences presently can be formulated regarding causative factors. The observed sea-floor textural changes could potentially result from a combination of modified sampling procedures, analytical variability, natural seasonal variability, and drilling rig operations. However, effects from each potential source of variation cannot presently be differentiated.

LITERATURE CITED

Barr, A. J., J. H. Goodnight, J. P. Sail, and J. T. Helwig. 1976. A user's guide to SAS-76. SAS Inst., Inc., Raleigh, N.C.

Berryhill, H. L., Jr., G. L. Shideler, C. W. Holmes, G. W. Hill, S. S. Barnes, and R. G. Martin, Jr. 1976. Environmental studies, South Texas Outer Continental Shelf, 1975: Geology: U.S. Dept. Commerce. NTIS Publ. no. PB 251-341. 350pp.

Berryhill, H. L., Jr., G. L. Shideler, C. W. Holmes, G. W. Hill, S. S. Barnes, R. G. Martin, Jr., and C. Pyle. In Preparation. Environmental Studies, South Texas Outer Continental Shelf, 1976: Geology: Draft Final Rept. to BLM.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco. 776pp.

CHAPTER NINE

SEDIMENT DEPOSITION AND TEXTURE

University of Texas Marine Science Institute
Geophysics Laboratory

Principal Investigator:
E. William Behrens

Laboratory Assistants:
K. M. Berg
B. E. Aleman

ABSTRACT

Two cores and one grab sample at the drill site station contained obvious foreign material deposited in connection with drilling operations. Other sediment textural changes had low statistical significance but suggested that some coarse (sandy) material was added to stations generally west and south of the drill site while clays were transported from the drill site to stations northward and eastward. These transport directions were the same as the two modes of current flow measured directly with recording current meters.

INTRODUCTION

This report compares pre-drilling and post-drilling sediments in terms of grain size distributions of grab samples and macroscopic structures and textures of cores. Objectives of the study were (1) to determine the distribution of any drill muds and cuttings which may have been deposited around the drill site, and (2) to provide supportive sediment textural data to aid in interpretation of results of benthic biological analyses.

METHODS

Subsamples of grab samples were analysed for grain size distribution by the following procedure: the sample was homogenized by kneading in the plastic sample bag. Twenty (20) cc were extracted, dispersed in hydrogen peroxide, diluted to about 0.5 ℓ and allowed to stand for 2 to 3 days. The clearer supernate was decanted through a 1.2 μm MILLIPORE filter and the filtered sediment was returned to the beaker. The sediment was resuspended and poured through a 0.062 mm screen. The screen (preweighed) and trapped sand were dried, weighed, and set aside for later settling tube analysis.

The mud fraction was transferred to a graduated cylinder and the sample was diluted to 1 ℓ, stirred, and allowed to stand overnight. If no flocculation occurred (none ever did), the temperature was measured, settling rates were calculated by Stoke's Law, and withdrawal times and depths were calculated to obtain nine intervals from 4 to 10 phi. Twenty (20) ml samples were pipetted at the appropriate times, transferred to preweighed beakers, oven dried, weighed, and size fraction weights calculated. The last pipette measurement defines the quantity of material finer than 10 phi. Extrapolation of the cumulative curve beyond 10 phi very commonly indicates that all of the sediment is coarser than 14 phi.

Therefore, a common computational procedure is to extrapolate cumulative curves to 100% at 14 phi. Grain size distribution parameters were calculated using this convention.

A representative portion of the sand fraction was introduced into a settling tube and fall times were recorded continuously. Graphs were read for the proportion of sand at each 0.25 phi interval.

These data were used to compute moment and graphic grain size parameters by standard methods.

Seven samples were analyzed from the drill site and from each of eight stations 500 and 1000 m north, east, south and west of the drill site (DS). Six samples were analyzed from each of eight stations 100 and 2000 m north, east, south, and west of the drill site and from each of four stations 1000 m northeast, southeast, southwest, and northwest of the drill site. Total sampling effort was 7 grabs x 9 stations x 2 sampling periods + 6 grabs x 12 stations x 2 sampling periods = 270 samples.

Piston cores were taken in 3-inch PVC barrels without core catcher so as not to disturb core tops. Cores were kept in the barrels in which they were taken and were kept in a vertical position until extruded and examined in the laboratory. Immediately after extrusion, they were slabbed, trimmed with an electric knife, photographed (black and white) and logged at 1/10 scale. Cores were taken at five stations preceding drilling (DS and 1000 m to the north, south, east, and west). Three replicates were taken at each site. After drilling, one core was taken at each of 10 stations: 1000 m north, northeast, southeast, south, southwest and northwest of the drill site and 100 m and 500 m north and south of the drill site. Two cores were taken at each of two stations: 100 m west of and at the drill site. Three cores were taken at each of five stations: 100 and 500 m west of the drill site and 100, 500, and 1000 m east of the drill site. The total sampling effort was 15 pre-drilling + 29 post-drilling = 44 cores.

RESULTS

Cores

The pre-drilling cores were uniformly, evenly textured muds in the upper 10 cm. Between 10 and 35 cm, a majority (10/15) had a sandy zone which was sometimes well-bedded, but which was sometimes only vaguely apparent as indistinct mottles or wispy swirls, and was sometimes totally absent. The upper 50 cm contained common open burrows with 1 to 4-mm circular openings surrounded by about twice that thickness of wall which was considerably firmer than the surrouding mud, probably due to compaction and/or mucus cementation. More rarely, these burrows appeard in other parts of the cores from the surface down to over 1-m depth.

The most consistently present feature was indistinct mottles of clayey muds discernable only by a slightly softer texture and subtle color differences from the surrounding mud. The mottles were usually a slightly lighter grey than their matrix. These undoubtedly biogenic structures were most prevalent between 40 and 100-cm depths. They were often concentrated either above, below, or occasionally between two sandy zones which were even more discontinuous than the upper sand unit. One generally occurred between 50 and 60-cm depth and the other from 75 to 95-cm depth with the lower of the two about twice as common as the upper.

Two of the 15 pre-drilling cores showed vertical lamination: one from E-1000 at depths of 118 cm to the core base at 142 cm, and one from the drill site from depths of 35 cm to the core base at 135 cm. This structure results from sediment being sucked from the core barrel when the piston is pulled up the barrel at the beginning of retrieval of the corer. This may occur when there is incomplete penetration by the corer, when the slack loop in the wire rope is measured too long, or when the corer falls over rather than falling vertically into the bottom (these phenomena, especially

the latter, commonly result from too rapid lowering of the corer by the winch operator). Unfortunately this occurred on all but two of the 29 post-drilling cores.

Although results were poor for this part of the study, sufficient evidence exists for some reasonable conclusions. The two cores from the drill site showed foreign material at the tops of the cores. The foreign material consisted of orange and green pebbles, the texture of which was clay or sandy clay. In one core this layer was only one pebble thick (2 to 3 mm) and not continuous. In the other DS core, the layer was 23 to 28 mm thick. The pebbles were much more cohesive than the mud at the tops of the pre-drilling cores, but they were not indurated and could be completely disaggregated by rubbing them between finger and thumb under water. No other cores had surficial material that appeared different from the pre-drilling muds and sands.

All but two other post-drilling cores showed signs of compression. Contrasting shades of grey that distinguished the soft mottles in the pre-drilling cores occurred mostly as only irregular lenses or laminae in the post-drilling cores. The smaller, open, walled burrows occurred but much more rarely in post-drilling cores. The two post-drilling cores which appeared totally undisturbed were from Station W-100. Both contained abundant soft, indistinct mottles; and each one contained a sandy zone at the depth of one or the other of the two lower sands common in the pre-drilling cores. Neither of these cores showed foreign material at the surface.

Grab Samples

Textural data for subsamples of grab samples are presented in Appendix D. Table 1, Appendix D, contains data for all pre-drilling samples, Table 2, Appendix D, for all post-drilling samples, and Tables 3 and 4, Appendix D,

contain station summaries for the pre- and post-drilling data, respectively. All parameters were calculated by the moment method and by using the extrapolation to 100% at 14 phi convention.

Based on pre-drilling data, the sediment in the rig monitoring study area was slightly sandy (8%), clayey (42%), and silty (49%). Somewhat more than one-fourth of the sediment (27.5%) was clay finer than 10.6 phi constituting about two-thirds (65%) of all clay.

T tests showed that only a few stations with maximum differences for any particular textural parameter were significantly different from each other at above 95% confidence; the number of such station pairs was only about 5% of all possible station comparisons. Thus, there was really no strong statistical evidence that the area did not have uniform sediment texture.

Lack of significant differences between stations derived largely from the large standard deviation of each parameter for the six or seven replicate grab samples at each station. The standard deviation of parameters within stations were commonly from 1 1/2 to 2 times as large as the standard deviations of means of parameters between stations.

However, some consistent trends, although not of high statistical significance, were noted. Both the total clay and the fine clay fractions increased from low values in the northern and northeastern quadrants to high values in the southernmost and westernmost stations. Conversely, sand content was highest toward the north-northeast and lowest from the central to the southern parts of the study area.

One grab sample contained coarse material clearly very different from all pre-drilling sediment samples. DS-3 (BDFI) contained material similar to that at the tops of the DS cores. In addition to the green and orange sandy clay particles, this sample also had a much coarser sand and abundant

shell fragments. The coarse fraction mean was 1.68 phi (medium grained) compared to an average 3.75 phi (s.d. = 0.22)(very fine grained) for all other samples from all stations. It was also much more poorly sorted than other coarse fractions [sample standard deviation = 1.26 phi cf. 0.47 phi (s.d. = 0.08) for all other stations].

Beyond this difference, only very subtle changes are suggested between pre- and post-drilling samples. Again, large standard deviations make the statistical differences between stations generally insignificant, *e.g.*, even for DS where obviously foreign material made up most of one sample's coarse fraction, T for the difference between pre- and post-drilling means was not significant at the 80% confidence level.

However, more or less consistent trends suggest that some real changes occurred between pre- and post-drilling sampling. For example, all stations within 100 m of the drill site, and all stations but one from northwest of and to the south of the drill site (going counter-clockwise) became coarser, while all other stations to the north, northeast and east became finer. This change was reflected in relatively large increases in sand content 100 m north, west and south of the drill site, as well as at the drill site and 1000 m northwest of it, and moderate increases in sand content southwest of a line running from northwest to southeast through the drill site, while small decreases in sand content prevailed northeast of this line. Conversely, both total clay and fine clay increased generally from north to southeast (going clockwise) of the drill site and decreased at the drill site and at most stations within 100 m and to the south and west.

DISCUSSION AND CONCLUSIONS

A cause for the high standard deviations between samples for all

parameters was apparent in the pre-drilling cores. The sporadic occurrence of sandy beds, especially in the upper 30 cm from which the sediment texture subsamples are taken, led to very erratic sand contents (1.5 to 33%). Not apparent in the macroscopic appearance of the cores was a cause for the wide range of silt:clay ratios (from 1/2 to almost 3). It is possible that the coarse bed or zone in the upper 30 cm is present everywhere but varies itself in texture from fine sand to silt. Detailed textural analyses of distinguishable core units would be required to draw further conclusions concerning causes of textural variability.

The occurrence of obviously foreign sediments resulting directly from drilling operations was apparently restricted to the drill site, and did not completely cover the area sampled at this station. The evidence for this was based largely on the presence of this material in only one of the drill site grab samples. This conclusion is also based on the presence of the foreign material on the top of the DS cores and the absence in the two undisturbed cores from Station W-100. This absence is particularly significant, because Station W-100 had one of the three largest increases in sand content (11.1% at DS; 11.7% at W-100; and 11.9% at NW-1000) from pre- to post-drilling sampling. The distribution of other sand increases showed that the apparent transport of coarse material was generally westerly with increases of at least 4% at Stations DS, N-100, W-100, S-100, S-500, NW-1000, W-1000, SW-1000 and S-2000, and changes of less than 2.75% at all but one of the 12 other stations. Thus, W-100 would be the most likely of all stations other than DS to have the more obvious, coarse, drilling debris. Its absence from the two good, undisturbed cores from this station means that the bad cores from all other stations probably did not have any visible drilling debris.

The type of debris cannot be compared with drill cuttings of drilling mud, because none of these materials were provided for examination. The pebbly nature of the core-top material makes it unlikely that it was used in drilling mud. On the other hand the unconsolidated nature of the muddy pebbles makes it unliekly that they were cuttings from deeply buried formations. Their most plausible origin may be as pieces of shallowly buried strata that were thrown up during the initial spudding-in phase of the drilling operation.

Silt percentages exhibited no apparent patterns of pre-drilling distribution, post-drilling distribution, or distribution of changes. Yet the bulk of the total increase in sand in the study area was offset by an almost equal decrease in silt throughout the area. Clays, on the other hand, had little net change.

Between pre- and post-drilling sampling clays decreased in abundance in a pattern very similar to that of increasing sand percentages. This loss could be attributed to dilution by the added sand. However, the very small net change suggests that clays were also added to some study area sediments as a result of drilling. All stations beyond 100 m of the drill site to the north and east did show increases in clay, especially in the coarser clays. Thus, the direction of transport of the fine fraction of the materials added to the environment as a result of drilling seems to have been generally northeastward. This suggestion is strengthened by the coincidence of this direction of transport with one of the two directions of currents measured directly by recording current meters.

CHAPTER TEN

MEIOFAUNA PROJECT

Department of Oceanography
Texas A&M University

Principal Investigator:

Willis E. Pequegnat

Associate Investigator:

Walter B. Sikora

Assistant Investigators:

Ronald Britton
Isabel Hine
Richard Titgen
Cynthia Venn

ABSTRACT

Meiofaunal samples were collected and analyzed from nine stations during the pre- and post-drilling surveys. Two stations that could have been affected by drilling operations when the characteristic longshore current underwent reversals produced lower than expected meiofaunal populations and markedly higher harpacticoid/nematode ratios.

INTRODUCTION

Purpose

The primary objective of this facet of the rig monitoring study was to ascertain whether or not the drilling operations produced environmental changes that had impacts upon meiofauna populations at the drill site and up to 1000 m away from the site. In general, if such an impact did occur it was reasoned that it might well result in a reduction in the size of the meiofauna populations. More specifically, if the principal effect of drilling operations was on sediment composition, then it would be expected that the harpacticoid/nematode population ratio would show some increase. The secondary objective of the study was to attempt to account for any observed changes by application of those physical or biological parameters that were measured during the study. It was anticipated that the three important factors would be sediment composition, current speed and direction, and seasonal response to meiofauna populations.

METHODS AND MATERIALS

Sampling Stations

The meiofauna samples were collected with a Smith-McIntyre grab at nine stations: the drill site and 500 and 1000 m north, south, east, and west from the drill site. It is important to note that the eight concentric stations were located on the cardinal east-west and north-south lines that intersected at the drill site (Chapter 1, Figures 6 and 8). This meant that no meiofauna samples were taken in between these points; *i.e.*, to the northeast (33°) or southwest (213°) of the drill site. This is significant in that these were the directions of the longshore flow of water measured 2 m off the bottom for some days during the interval between pre- and post-drilling sampling (Chapter 3).

For the meiofaunal element of the STOCS monitoring project, the study area has been divided into five depth zones (Groover, 1977, Final Report to the BLM). The rig monitoring site was located within Zone B in a line between Station 2, Transect I and Station 4, Transect II (Figure 1).

Sampling Periods

The pre-drilling samples were taken in late September 1976 which is near a low point for meiofauna populations in this region (Pequegnat, *In* Groover, 1977). No during-drilling samples were taken for meiofauna.

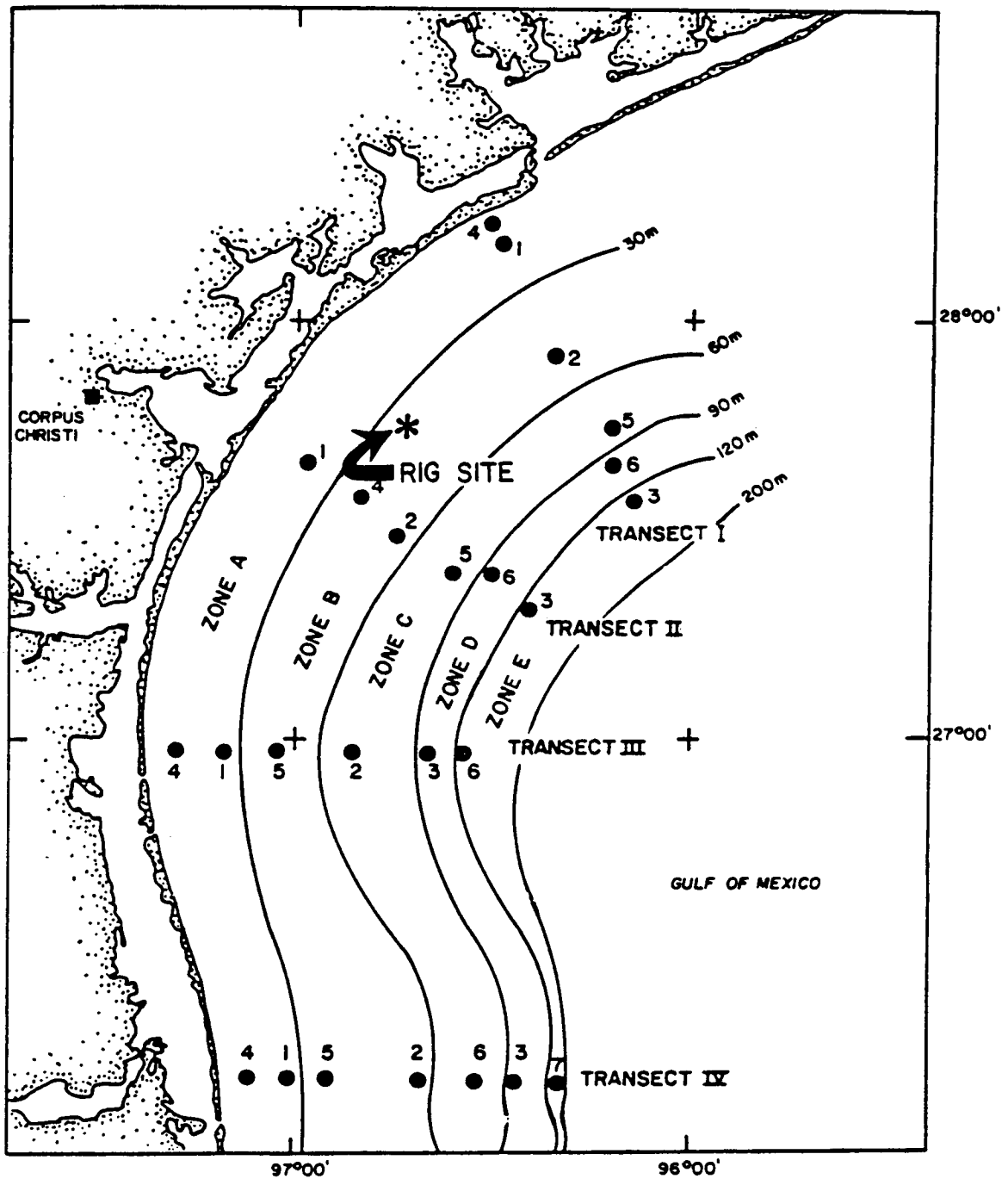
The post-drilling samples were taken in early March 1977. Unfortunately, the post-drilling stations were located a significant distance SW (21.18 m) from the pre-drilling stations as explained in Chapter 1, page 1-18, of this report.

Two replicate samples were taken from each grab for laboratory analysis; hence a total of 36 samples were analyzed.

Analysis of Samples

Shipboard

All meiofauna samples were removed from the grab by means of a plexiglass core tube of 3.42 cm diameter (area = 9.187 cm^2), which was pushed into the sediment to a depth of 5 cm. Four such cores were taken and the enclosed sediment was extruded into 8 oz. glass jars. One sample was frozen immediately. The remaining three samples were anesthetized in isotonic $MgCl_2$ for 10 minutes. One of these samples was preserved with 10% buffered formalin and archived. The other two samples were preserved with 10% buffered formalin containing rose bengal stain and then processed.



LOCATION OF TRANSECTS, SAMPLING STATIONS, AND ZONES

Figure 1. Location of the Exploratory Drill Site (DS) as Mentioned in the Text. Its Position is Shown Relative to Stations on Transects I and II of the South Texas Outer Continental Shelf Baseline Study.

Laboratory

In the laboratory the stained samples were sieved through 8-inch diameter 500 and 62 μm sieves. The material retained on the 62 μm sieve was washed into 2 oz. squat jars with 10% buffered formalin, to which 10 ml of rose bengal in formalin (200 mg/ℓ) was added. After the sample had been allowed to stain (1-2 days), it was first washed in a 3-inch diameter, 62 μm mesh sieve to remove excess stain and then aliquoted into an 80 x 40 mm rectangular sorting dish marked off in a 7 mm square grid. The whole sample was then examined microscopically and the sorted animals placed in vials. When the number of nematodes exceeded 150, the first 150 were vialed and the remainder were only counted.

RESULTS

Population Changes

Comparisons were made of the numbers of individuals per 10 cm^2 for the five numerous taxa between the pre-drilling and post-drilling sampling periods (Table 1). An increase in the post-drilling samples in all groups except Polychaeta was noted. All stations except W-500 and E-1000 showed increases in the post-drill samples as compared to the pre-drill samples. Although there was no significant difference between the mean values of the two replicates of true meiofauna between the pre- and post-drilling samples (Table 2), the reductions in the W-500 and E-1000 stations may be indicative of some traceable environmental perturbation. This possibility is strengthened by the likelihood that seasonal increases of meiofauna would partially balance reductions due to environmental impact.

Seasonal Influence

Previous work (Pequegnat, *In* Groover, 1977) has demonstrated that

TABLE 1

ANALYSIS OF THE POPULATIONS OF THE FIVE PRINCIPAL GROUPS OF MEIOFAUNA COLLECTED IN SEPTEMBER 1976 AND MARCH 1977 AT THE RIG MONITORING SITE ON THE SOUTH TEXAS CONTINENTAL SHELF. NUMBERS REPRESENT THE AVERAGE NUMBER OF INDIVIDUALS PER 10 cm^2

	DRILL-SITE	NORTH RADIUS		EAST RADIUS		WEST RADIUS		SOUTH RADIUS		TAXON TOTALS
		500m	1000m	500m	1000m	500m	1000m	500m	1000m	
SEPTEMBER 1976										
Nematoda	36	25	15	69	84	138	38	46	21	= 472
Harpacticoida	1	1	2	2	2	1	1	1	4	= 15
Foraminifera	1	1	0	6	2	33	7	4	20	= 74
Polychaeta	4	3	1	5	3	4	7	2	2	= 31
Kinorhyncha	0	0	0	1	0	0	1	0	1	= 3
Totals	42	30	18	83	91	176	54	53	48	
MARCH 1977										
Nematoda	54	105	137	120	35	33	68	93	178	= 823
Harpacticoida	1	3	7	1	3	0	2	4	0	= 21
Foraminifera	15	7	1	21	3	7	8	46	4	= 112
Polychaeta	1	1	3	3	2	2	2	4	3	= 21
Kinorhyncha	0	1	2	0	2	0	1	1	1	= 8
Totals	71	117	150	145	45	42	81	148	186	

TABLE 2

COMPARISON OF MEAN NUMBERS OF TRUE MEIOFAUNA AT THE NINE RIG MONITORING STATIONS IN SEPTEMBER 1976 AND MARCH 1977. THE PAIRED t TEST SHOWED NO SIGNIFICANT DIFFERENCE. ($t = 1.39$, 8 d.f., $p = 0.20$)

Station	Pre-Drill September 1976	Post-Drill March 1977
DS	36.5	50.5
N-500	25.5	102.0
N-1000	16.0	136.0
E-500	65.0	110.5
E-1000	83.5	35.0
S-500	45.0	90.0
S-1000	24.0	165.0
W-500	133.5	30.0
W-1000	37.5	64.5
	$\bar{x} =$ 52.3	$\bar{x} =$ 87.5

meiofauna populations at a depth comparable to that of the drill site (33 m) were approaching a major low in late September and October and a secondary high in March. This may be a partial explanation of the increase of the March 1977 (post-drilling) population over the September 1976 (pre-drilling) populations. In addition, it was found that the March 1977 meiofauna populations at Station 4, Transect II (the closest transect station to the drill site) were substantially higher than those of March 1976 (Table 3). Thus, the increase in meiofauna populations between pre- and post-drilling can be accounted for both by normal seasonal trends and an annual difference. This observation was strengthened by testing the data in Table 2 and comparing it with the seasonal changes at Station 4, Transect II. Using a mean of 52.3 true meiofauna individuals in the nine pre-drill samples and a mean of 87.5 for the post-drill samples, then the post-drill sample increase was significantly lower (Chi^2 test) than that shown by Station 4, Transect II for the same time.

Nematode Taxa

Thirty-four genera of nematodes were noted in the study. Twenty-one of these were represented by more than a single individual. The predominant of these in order of frequency were:

Sabatieria
Terschellingia
Theristus
Sphaerolaimus
Dorylaimopsis metatypica
Laimella
Neotonchus
Halalaimus
Mesotheristus
Tricoma

Kinorhynch Taxa

Five genera of kinorhynchs were collected during the study. These

TABLE 3

COMPARISON OF MEAN POPULATIONS OF FIVE MEIOFAUNA TAXA SAMPLED AT STATION 4 OF TRANSECT II IN MARCH 1976 AND MARCH 1977

Taxon	$\bar{X}/cm^2$	
	1976	1977
Nematoda	30	170
Harpacticoida	0	8
Foraminifera	1	21
Polychaeta	2	7
Kinorhyncha	1	3

were the same as those noted in the continental shelf baseline work, *viz.*:

Echinoderes
Pycnophyes
Trachydemus
Semnoderes
Centroderes

Polychaeta Taxa

As expected, the polychaetes were the principal group of the temporary meiofauna. The predominant species collected were:

Pilargidae
Ancistrosyllis papillosa
Sigambra tentaculata
Syllidae
Exogone dispar
Exogone gemmifera
Exogone verrugera
Odontosyllis enopla
Sphaerosyllis erinaceus
Sphaerosyllis pirifera
Lumbrineridae
Lumbrinereis parvapedata
Dorvilleidae
Protodorvillea sp. A
Spionidae
Laonice cirrata
Paraprionospio pinnata
Prionospio cirrobranchiata
Prionospio sp.
Cirratulidae
Chaetozone setosa
Tharyx annulosus
Tharyx setigera
Paraonidae
Aricidea cerruti
Cirrophorus branchiatus
Paraonis gracilis
Cossuridae
Cossura delta

DISCUSSION

Currents

The bottom current during the drilling period was in a longshore direction toward 213° (Chapter 3). However, there were three significant reversals of this current to the northeast during this period, each

lasting for about four days. If, as these reversals occurred, the currents traversed a swing to the right (which would be onshore in shifting from SW to NE and offshore during the reciprocal shift), they would cross some of the meiofauna sampling stations.

The above is significant to this extent: during the normal flow of the bottom current to the southwest across the drill site, any deleterious influences of the drilling process would be transported between the south and east meiofauna sampling stations. However, the swings of the current during the reversals, would cause the currents to tend to cross the sampling stations noted to have some lower populations. The question still presents itself as to why the true meiofauna post-drill population was not more markedly affected at the drill-site (Table 1) where one would expect a major influence.

A possible explanation of this situation may be found in the work of Behrens (Chapter 9). Referring to the drill-site station his study shows that "foreign sediments resulting directly from drilling operations did not completely cover the area sampled at this station." Foreign sediment material was found in one of the drill site grab samples.

Harpacticoid/Nematode Ratio

The harpacticoid/nematode ratio at those stations most vulnerable to drilling activities increased from .01 in the pre-drilling samples to a high of .09 in the post-drilling samples. A possible explanation of this is the general increase of sands in the sediments of the westerly stations. Harpacticoids tend to increase in coarse sandy sediments.

CONCLUSIONS

Based on the sampling pattern it is concluded that the exploratory

drilling in about 33 m of water off the coast of South Texas had detectable depressing effect on the populations of true meiofauna at two stations 500 and 1000 m from the drill site but not at the point of drilling. The explanation of this appears to be attributable to the pattern of meiofauna stations relative to the predominant bottom currents, which were such as to carry drill products to meiofauna stations only at times of current reversal. Such reversals occurred on three four-day occasions during the drilling operations.

LITERATURE CITED

Groover, R. D. (Ed.) 1977. Environmental studies, south Texas outer continental shelf, biology and chemistry. 1976 Final Report to the Bureau of Land Management, Washington, D.C. 6 vols.

Pequegnat, W. E. 1977. Meiofauna Project, pages 8-1 through 8-58, Vol. I, *In* Groover, R. D. 1977. Environmental studies, south Texas outer continental shelf, biology and chemistry. 1976 Final Report to the Bureau of Land Management, Washington, D. C. 6 vols.

CHAPTER ELEVEN

INVERTEBRATE EPIFAUNA AND MACROINFAUNA

University of Texas Marine Science Institute
Port Aransas Marine Laboratory

Principal Investigator:
J. S. Holland

Associate Investigators:
Joan Holt
Scott Holt
Rick Kalke
Mark Poff

Assistant Investigators:
Steve Cornelius
Allen Dixon
Nancy Rabalais
Steve Rabalais
Granvil Treece

Lab Research Assistants:
Kellis Chandler
Norman Hannebaum
Evan R. Parker
Joyce Pulich
Lynn Tinnin
Nancy Wohlschlag

ABSTRACT

Benthic samples from around a drill site were taken before and after drilling. Analyses of benthic populations showed a high degree of similarity among pre-drill samples. Post-drill samples, although slightly separated along a north-east to south-west line through the study area, also showed a high degree of similarity.

Differences between pre-drill and post-drill samples were attributed to drilling operations and seasonality. Benthic populations were definitely diminished at the drill site, presumably due to direct impact from drilling operations. All other post-drill stations were fairly distinct from pre-drill stations due to several groups of organisms that appeared to have some members that are seasonal.

Analysis of individual species distribution patterns indicated that many species were apparently distributed on a small scale relative to the size of the study area.

INTRODUCTION

The effects of oil production drilling operations on level-bottom infaunal invertebrate communities of the Texas continental shelf were investigated as a part of the South Texas Outer Continental Shelf study funded by the Bureau of Land Management. While the effects of oil pollution on benthic organisms have received considerable attention (Sanders, Grassle and Hampson, 1972; Moore and Dwyer, 1974), the effects of drilling operations seem to be lacking in pertinent literature. One study (Bascom. Mearns and Moore, 1976) of several platforms off Santa Barbara, California, reported an initial lack of utilization of well cuttings by benthic populations but found high density populations in the cuttings after three years.

In our study, a series of 21 stations at and around a drill site were sampled for benthic invertebrates immediately prior to and after drilling operations. Possible effects of drilling procedures were assessed.

METHODS AND MATERIALS

Collection of benthic macroinfauna consisted of six replicate samples taken with a Smith-McIntyre grab sampler (0.1 m^2) at each station. Sampling stations included the drill site and 20 stations arranged in concentric circles around it. The circles were located 100, 500, 1000 and 2000 m from the drill site. Stations were located on cardinal compass points on all circles, and also at intermediate points (NE, NW, SE and SW) on the 1000-m circles (Figure 1). Stations were located using LORAC navigation. A buoy was dropped at each station (water depth was approximately 33 m) and used as a reference point for sampling. A LORAC reading was taken each time the Smith-McIntyre grab sampler was dropped to provide information on the position of each sample relative to the other samples of that suite.

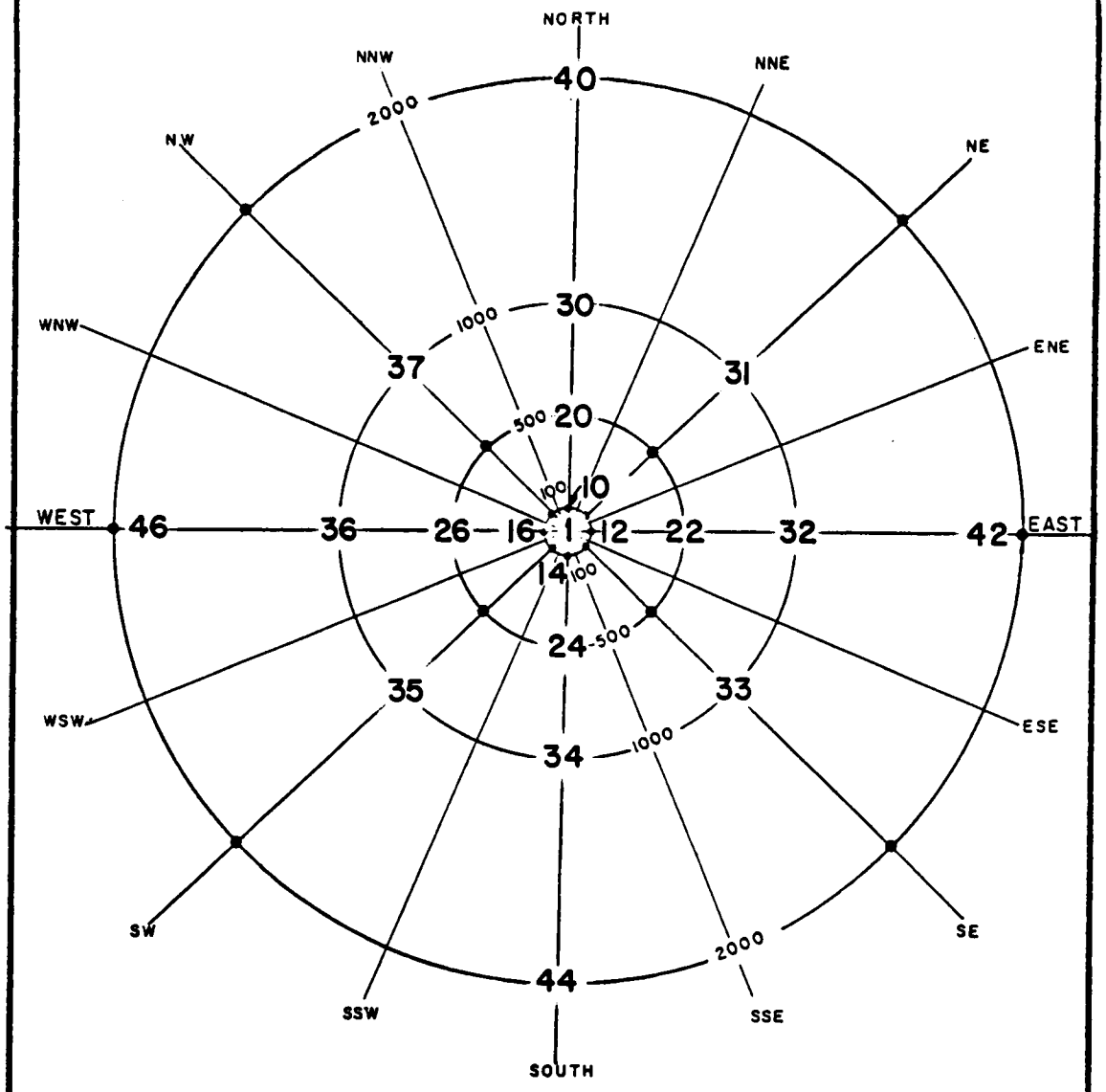


Figure 1. Map of the Rig Monitoring Study Area Showing Location of Macroinfauna Collection Stations (Bold Numbers).

All infaunal samples were washed through a 0.5 mm mesh screen. Material retained on the screen was treated with magnesium sulfate to narcotize the organisms and preserved in 10% formalin. In the laboratory, the invertebrates were separated from the debris, identified to the lowest possible taxon, and counted and preserved in 70% alcohol (isopropanol, ethanol or methanol).

Six epifaunal samples were taken with a 35-ft (10.7 m) otter trawl.[1] Pre- and post-drill samples were taken at the drill site and a post-drill sample was taken at each cardinal point station on the 1000-m circle. Epifaunal samples were initially preserved in formalin, identified to the lowest possible taxon, and counted and preserved in 70% alcohol.

Analysis techniques included standard statistical procedures, including analysis of variance (ANOVA) and chi-square tests of the variability of species numbers and the distribution characteristics of individual species between different stations, respectively. An index of dispersion ($\frac{S^2}{\bar{x}}$) was also employed to examine distribution patterns of individual species at a given station (Gage and Geekie, 1973). Prior to completion of the laboratory analysis of the pre-drill samples, a series of similarity (dissimilarity) indices were utilized to compare samples from the drill site and the cardinal compass point stations on the 1000-m circle. These same indices were used to compare stations from Transect II of the BLM-STOCS study to assess the degree of similarity among rig-monitoring stations and those on Transect II. Similarity indices used included coefficients proposed by Sokal and Sneath and Czekanowski, as recorded by Clifford and Stephenson (1975). Dissimilarity indices included those proposed by Bray and Curtis, and Lance and Williams, as recorded by Clifford and

[1]Due to a misinterpretation of Contract No. AA550-CT6-17, only one trawl per day, rather than the two required, were taken at each station.

Stephenson (1975). Cluster analyses using the Canberra Metric dissimilarity index and flexible sorting (Boesch, 1973; Clifford and Stephenson, 1975) with b = -0.25 were completed using both normal and inverse modes for pre-drill data, post-drill data and both combined. Two-way tables were also generated to aid in interpreting the cluster analyses. Sediment and bottom current data from other BLM-STOCS investigators were examined to provide further perspective to the data.

RESULTS

During the laboratory analysis of pre-drill samples, it became apparent that a high degree of similarity existed between stations. Data from the drill site and four stations 1000 m from the drill site were tested for similarity (Table 1). For purposes of comparison, data from temporally analogous infaunal collections from Transect II were similarly analyzed (Table 2). The high degree of similarity among stations at the rig monitoring site led to the cessation of laboratory analysis of further pre-drill samples. All six replicates for these five pre-drill samples and all 21 post-drill stations were analyzed.

Analysis of variance of chi-square statistics were employed to further corroborate the lack of significant differences between pre-drill stations. Based on numbers of species, ANOVA comparisons of variability within stations (between replicate samples) and between stations showed no significant difference (95% confidence level) between pre-drill stations. There was a great deal more variation within stations (between replicate samples) than between stations. ANOVA of the 21 post-drill stations showed the same results, *i.e.*, no significant differences between stations based on number of species per station with a high degree of variability between numbers of species collected by replicate samples at a given station.

TABLE 1

SIMILARITY INDICES FOR PRE-DRILL RIG MONITORING STATIONS

	Drill Site	N1000	S1000	E1000	W1000
a. Species Co-Occurrence					
DS	60				
N-1000	34	51			
S-1000	34	34	48		
E-1000	31	29	28	43	
W-1000	39	38	36	30	54
b. Sokal and Sneath					
DS	1.0				
N-1000	0.71	1.0			
S-1000	0.74	0.81	1.0		
E-1000	0.73	0.77	0.78	1.0	
W-1000	0.77	0.82	0.81	0.76	1.0
c. Czekanowski					
DS	1.0				
N-1000	0.61	1.0			
S-1000	0.63	0.69	1.0		
E-1000	0.60	0.62	0.62	1.0	
W-1000	0.68	0.72	0.71	0.62	1.0
d. Bray-Curtis					
DS	0.0				
N-1000	0.34	0.0			
S-1000	0.36	0.44	0.0		
E-1000	0.37	0.42	0.37	0.0	
W-1000	0.39	0.37	0.46	0.40	0.0
e. Canberra Metric					
DS	0.0				
N-1000	0.53	0.0			
S-1000	0.52	0.52	0.0		
E-1000	0.56	0.57	0.46	0.0	
W-1000	0.52	0.50	0.51	0.56	0.0

TABLE 2

SIMILARITY INDICES FOR TRANSECT II STATIONS JULY 1976

Stations	1	2	3	4	5	6
a. Species Co-Occurrences						
1	41					
2	26	56				
3	17	19	82			
4	28	33	21	48		
5	14	17	22	19	37	
6	17	24	38	24	26	71
b. Sokal and Sneath						
1	1.0					
2	0.84	1.0				
3	0.63	0.57	1.0			
4	0.89	0.87	0.64	1.0		
5	0.82	0.78	0.71	0.84	1.0	
6	0.69	0.69	0.70	0.73	0.80	1.0
c. Czekanoswki						
1	1.0					
2	0.54	1.0				
3	0.28	0.28	1.0			
4	0.63	0.63	0.32	1.0		
5	0.36	0.37	0.37	0.45	1.0	
6	0.30	0.38	0.50	0.40	0.48	1.0
d. Bray-Curtis						
1	0.0					
2	0.71	0.0				
3	0.86	0.77	0.0			
4	0.67	0.45	0.74	0.0		
5	0.95	0.69	1.00	0.70	0.0	
6	0.86	1.00	0.70	0.86	0.60	0.0
e. Canberra Metric						
1	0.0					
2	0.66	0.0				
3	0.72	0.70	0.0			
4	0.73	0.55	0.71	0.0		
5	0.71	0.69	0.66	0.69	0.0	
6	0.72	0.68	0.59	0.69	0.63	0.0

Analysis of individual species distribution patterns were made using chi-square analysis and the ratio of the variance to the mean as an index of dispersion. Chi-square analysis showed little deviation from the normal distribution pattern of species analyzed over the five pre-drill stations. A much higher proportion of species assayed showed significant deviations from the expected distribution pattern when all 21 post-drill stations were included in the analysis. The index of dispersion ($\frac{S^2}{\bar{x}}$) was calculated for numerically dominant species at all stations to assess species distribution within a station. In both pre- and post-drill data sets, more species were indicated as being non-randomly distributed about a station than across the study area.

Cluster analyses resulted in dendrograms describing station and species groups for the combined pre- and post-drill data (Figures 2 and 3). Pre-drill stations clustered together and were separate from post-drill stations. Among the post-drill stations, the drill site was the most dissimilar. The remainder of the post-drill stations generally separated into two geographic zones. Group A1 was composed of stations north and east of the drill site. Group A2 was composed primarily of stations south and west of the drill site.

A condensed two-way constancy table (Figure 4) which indicates how consistently a species group is collected at stations within a station group was used to interpret observed clusters. It was apparent that differences between pre-drill (C) and post-drill station groups were mainly due to the high constancy of Species Group 2 at post-drill stations and of Species Group 4 at pre-drill stations. A comparison of species in Groups 2 and 4 to those at nearby transect stations indicated that these differences were due in part to seasonal changes. Species in Group 2,

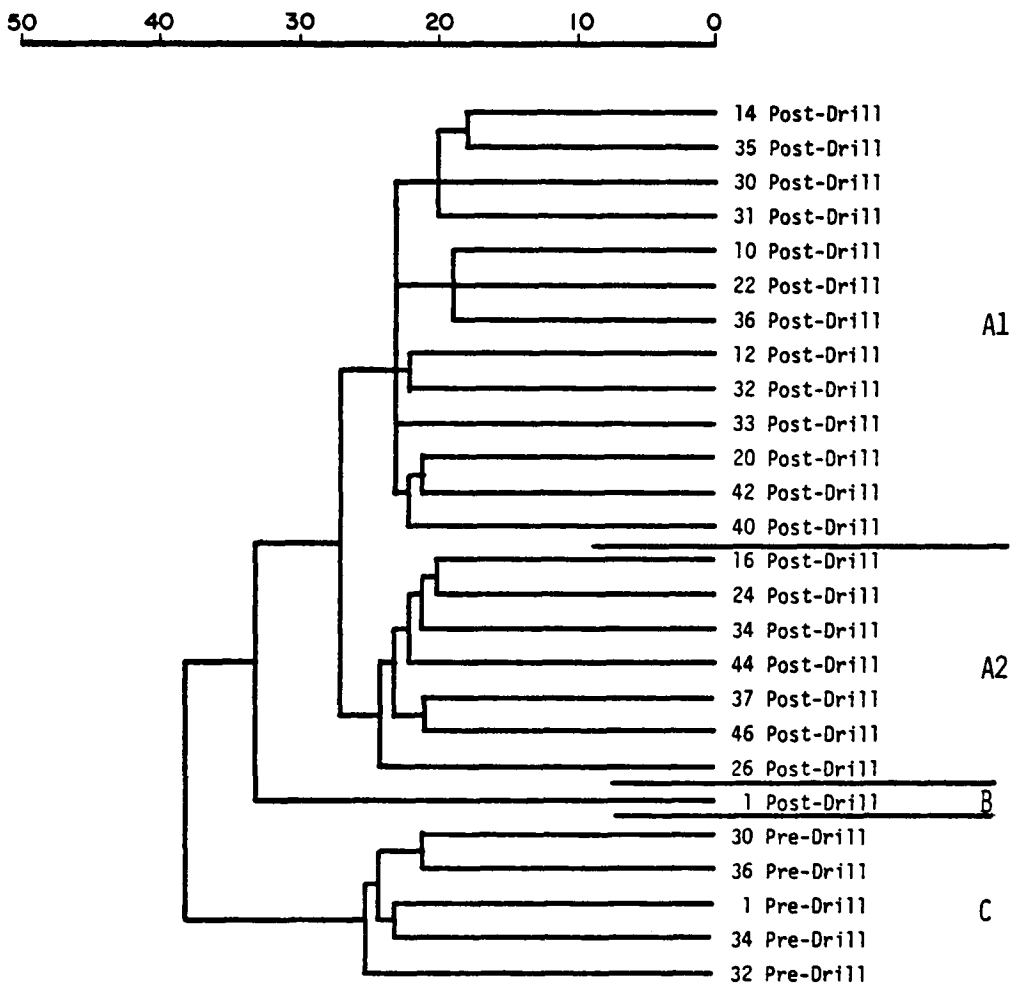


Figure 2. Normal Dendrogram from Cluster Analysis of Pre- and Post-Drill Data. Numbers Refer to Stations. Letters Designate Station Groups.

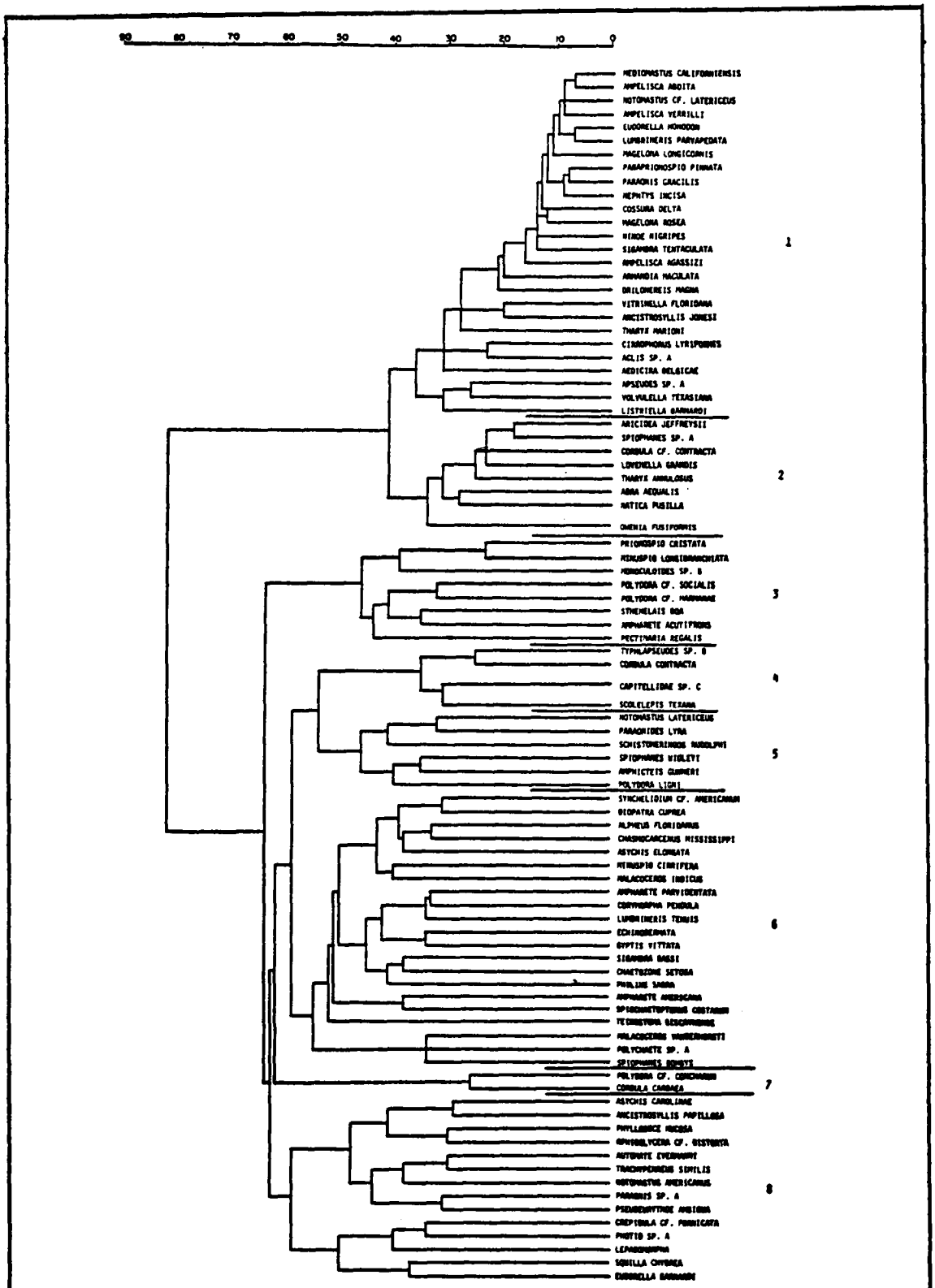


Figure 3. Species Dendrogram from Inverse Analysis. Numbers Refer to Species Groups.

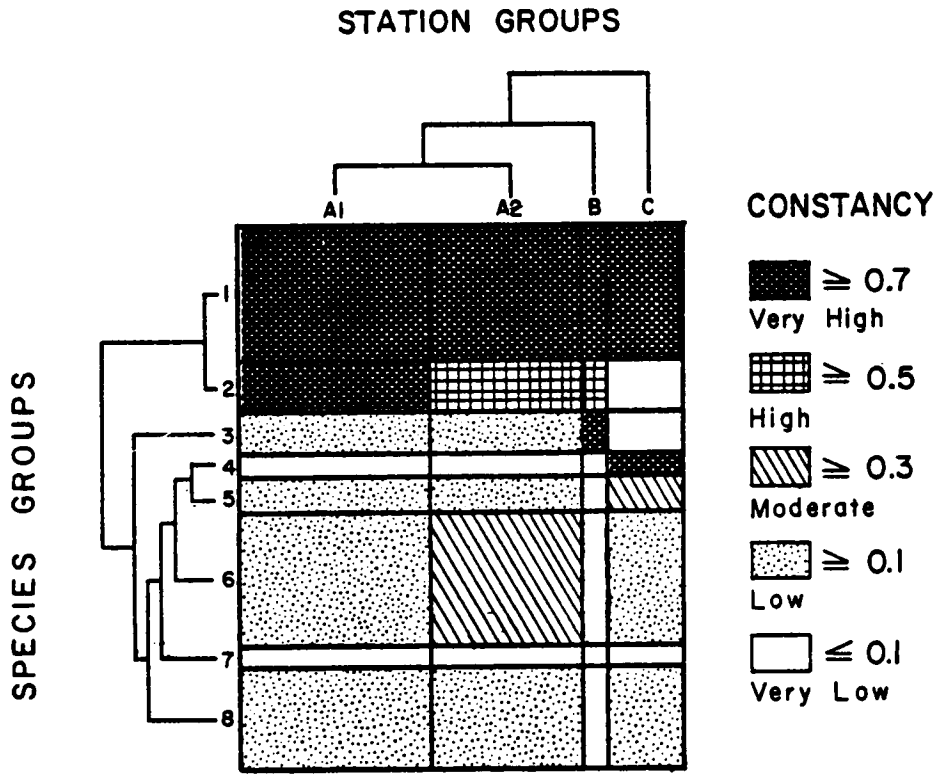


Figure 4. Nodal Constancy in a Two-Way Table of Species Groups (From Inverse Analysis) in Station Groups (From Normal Analysis).

such as *Aricidea jeffreysii, Tharyx annulosus* and *Natica pusilla* were rare or absent in fall (time of pre-drill collection) on Transect I and II and were more abundant in winter. Other species, such as *Spiophanes* sp. A and *Lovenella grandis*, were rarely ever collected in the STOCS study area and were only collected on Transects III and IV and at the post-drill station. Species Group 4, which showed high constancy to pre-drill stations, included Capitellidae sp. C, which was rarely taken in the STOCS study area.

The post-drill site (B) was separated from other post-drill stations because of the absence of many species at the drill site. Total number of species, individuals and species diversity at the post-drill site were less than in the pre-drill collection (Appendix E, Table 1). The numbers of individuals in post-drill collections at the drill site was low as compared to other nearby post-drill stations. Species notably reduced in number at the post-drill drill site were the filter feeding cumacean, *Eudorella monodon*, the tube-dwelling amphipod, *Ampelisca agassiz*, and the generally numerically dominant polychaete, *Nephtys incisa*.

The invertebrate epifaunal samples showed no unusual species present in the invertebrate epifaunal trawls at the Rig Monitoring stations (Appendix E, Table 2). As far as can be determined with the paucity of data present, the epifaunal populations are generally similar to temporally analogous populations at similar depths on Transect II. The one pre-drill and five post-drill trawls taken were not analyzed in detail since they did not provide enough data for a reliable comparison.

DISCUSSION

The five suites of pre-drill samples were very similar. The various analyses showed no significant differences in numbers of species; that distribution patterns of dominant macroinfaunal species were generally very similar, that aggregations at the five stations were more similar

(less dissimilar) than analogous aggregations from different transect stations and that they were more similar to one another than to samples at the same stations taken at a different time. The same degree of similarity was not shown by the 21 suites of post-drill data. The high degree of similarity in the pre-drill data was probably indicative of the rig monitoring study area at the time of pre-drill collection. Several alternative hypothesis for this apparent similarity were explored. First, it may not exist, *i.e.*, the five suites of samples and the analyses presented may falsely indicate a high degree of similarity. Second, it does exist and is perhaps the result of the timing of the collection. Sampling occurred at or near the end of one of the most stable hydrographic periods of the year. Water temperature was fairly well stabilized at this depth for several months prior to September. The sea state, in terms of wave height and storm-induced turmoil, is calm during the late summer and early fall months (barring the occurrence of a hurricane) in the study area. These conditions, along with the small area encompassed by the rig monitoring study, and the similarity of water depths and sediment types may well lead to a short term (in a geological sense) stable point allowing for similar aggregations to occur.

A major reason for examining the similarity of the pre-drill data is the apparent dissimilarities occurring within the post-drill data. The difference between the drill site and all other post-drill data was apparent and is discussed below. The differences between post-drill stations groups A1 and A2 were much more subtle. There apparently were differences in sediment particle size distribution patterns from pre-drill to post-drill. Our analysis of the sediment data and that of Dr. Behrens indicate an enrichment of some of the A2 sites with sand. Dr. Behrens

was able to assess changes in clay over the study area as well. The major current patterns during the drilling operation were in a north-easterly to south-westerly direction according to Dr. Smith's data. Currents and subtle shifts in sediment particle size distribution may account for the division of post-drill sites into Groups A1 and A2. The difference was slight, consisting of minor changes in abundance or constancy of species between groups. If this difference is small enough to be discounted, then the similarity of pre-drill data is the general pattern.

The exception to the general pattern is seen in a real dissimilarity between the post-drill site (Station 1) data and other post-drill station data. Dissimilarity was shown primarily in the smaller populations of species and the lack of a number of species found at other post-drill stations. These observations were apparently a direct result of the drilling process. Several observations by various study personnel indicated a direct impact on the sediment in the vicinity of the drilling platform. These include the finding of what appeared to be welding slag in the macroinfaunal samples by the technicians and the orange and green clays observed by Behrens, presumed to be drilling muds. We do not know where the well cuttings were dumped or at what level in the water column. We do have reason to believe that something associated with the drilling process caused a diminishment of benthic invertebrate populations at the drill site. Stations 100 m from the drill site were apparently not affected at the time of the post-drill collection.

There was a seasonal trend which influenced the distinct separation between the pre-drill and post-drill stations. Two groups of species, Groups 4 and 5 showed very high and moderate constancy for the pre-drill stations. Group 4 was found only in the pre-drill collections and was

probably composed of several organisms limited to the late summer-fall hydrographic regime on Transects I and II. Group 5 showed moderate constancy in the pre-drill site at which it showed very low constancy. Group 2 had very high to high constancy for the post-drill stations with very high constancy being limited to station Group 1A, the north-east quadrant of the study area. This group included species which were normally more abundant in the winter than in the fall on Transects I and II, and a few species which were never collected on Transects I and II.

The distribution patterns of the species analyzed by both chi-square and the dispersion index indicated that the scale of distribution of many species in this study area was very small. The high variability in species numbers within a given site and the relatively high proportion of the species showing non-random distribution patterns with a given suite of samples leads to the conclusion that many species are distributed in small patches on the scale of a few meters or less. When the individual species observed from all six replicates were totaled, or averaged, and analyzed for distribution across a larger area, the results tended to indicate a more normal distribution pattern for most species which is the expected result in a comparison of replicate sampling in a small-scale patchy distribution.

CONCLUSIONS

1. Seasonality may play a role in the short-term stability patterns and subsequent faunal distribution patterns of the South Texas Outer Continental Shelf macroinfauna.

2. Drilling operations had a definite negative impact on benthic populations in the vicinity of the drilling rig.

3. Some macro-infaunal species were distributed on a very small scale, perhaps a few meters, on the STOCS.

LITERATURE CITED

Bascom, W., A. J. Mearns, and M. D. Moore. 1976. A biological survey of oil platforms in the Santa Barbara Channel. Proc. 1976 Offshore Technology Conf. 2:27-36.

Boesch, D. F. 1973. Classification and community structure of macrobenthos in the Hampton Roads area, Virginia. Mar. Biol. 21:226-244.

Clifford, H. T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229pp.

Gage, J., and A. D. Geekie. 1973. Community structure of the benthos in Scottish sea-lochs. II. Spatial pattern. Mar. Biol. 19:41-53.

Moore, S. F., and R. L. Dwyer. 1974. Effects of oil on marine organisms: a critical assessment of published data. Wat. Res. 8:819-827.

Sanders, H. L., J. F. Grassle, and G. R. Hampson. 1972. The west Falmouth oil spill. I. Biology. Tech. Rept. to EPA Grant No. 15080FMW, WHOI-72-20.

CHAPTER 12

DEMERSAL FISHES

University of Texas Marine Science Institute
Port Aransas Marine Laboratory

Principal Investigator:

Donald E. Wohlschlag

Associate Investigators:

James F. Cole
Elizabeth F. Vetter
Marks Dobbs
Edgar Findley

ABSTRACT

Analysis of pre- and post-drilling trawl data revealed numerical and biomass declines up to a radius of 1 km about the drill site, in relation to the general trends in the STOCS study area in 1975 and 1976. The data, however, were not statistically definitive. There were also post-drilling declines in diversity, equitability and probability of interspecific encounter. The need for additional and more comparable sampling during such surveys is discussed.

INTRODUCTION

The purpose of this study was to assess pre- and post-drilling abundance and distributional patterns of benthic fishes at the rig monitoring site. Studies on the benthic fishes of this area (Wohlschlag, 1976; 1977) by standardized trawling procedures were available for general baseline attributes of abundance and distribution. The major premise of the "before-and-after" drilling comparisons is that disturbance of an enrivonment tends to reduce both the quantity of animal life and its diversity. While this premise has widespread general utility, this study was originally pursued with the hope of detecting any effects on fishes, which a given amount of benthic disturbance might cause.

METHODS AND MATERIALS

The drill site was first sampled with a standard 15-minute bottom trawl on 27 September 1976 at 1627-1642 hrs, before actual drilling operations from December 1, 1976 to January 20, 1977. Following the drilling operations, another set of standard trawls was made March 1, 1977, at the drilling site at 1900-1915 hrs, 1 km due north at 1945-2000 hrs, 1 km due east at 2030-2045 hrs, 1 km due south at 2105-2120 hrs, and 1 km due west at 2145-2200 hrs.[1]

Each trawl was as identical as possible at each time and location. The trawl was a standard 35-ft (10.7 m) Gulf Coast flat trawl with a 12.2 m ground line and a 9.1 m head line, each of 12.7 mm "steel impregnated" rope. There was a 0.9 m separation between the net wings and the 76.2 cm by 152.4 cm otter boards fitted with steel runners. The net was constructed of untreated white nylon line. Wings and main body were 44.5 mm stretched mesh No. 18 nylon twine. The 3.0 m bag was 44.5 mm No. 36 stretched mesh

[1]Due to a misinterpretation of Contract No. AA550-CT6-17, only one trawl per day, rather than the two required, were taken at each station.

nylon twine. Chafing gear surrounding the net was 50.8 mm stretched mesh of 3.2 mm polypropylene twine. The trawl samples were from the twin-screwed R/V LONGHORN at 900 rpm, which with net drag was equivalent to a trawling speed of about 2 knots.

Fish were separated from invertebrates immediately after each trawl, field-sorted and iced. After bulk weights for the total catches were made in the laboratory at the end of each cruise, the fish were frozen before subsequent identification, counting and weighing.

Each fish was identified using the keys published by Gallaway *et al.* (1972), weighed to the nearest 0.1 g, and measured to the nearest 1.0 mm in standard, total, and fork lengths (where applicable). For each station, species lists with numbers of individuals and total weights were compiled (Tables 1-6).

To assess the diversity within each of the samples, several diversity measures were calculated. The Shannon numerical diversity index (Shannon, 1948; Wiener, 1948; and Shannon and Weaver, 1963) was estimated by

$$H_n'' = \Sigma(n_i/N) \log_e(n_i/N),$$

where n_i is the number of individuals in the i^{th} species and N is the total number of individuals. In this form, the diversity units are in natural bels per individual. By utilizing the weights instead of the numbers for each species, a ponderal H_w'' was also calculated after the suggestions by Wilhm (1968). Since some investigators have criticized the Shannon diversity index as a nonconcept (*e.g.* Hurlbert, 1971), the probability of interspecific encounter (PIE) was also calculated after

the method of Hurlbert (1971) as

$$PIE = \left(\frac{N}{N-1}\right)\left(1 - \sum_{i=1}^{s} \pi_i^2\right),$$

where

n_i = number of individuals in the i^{th} species in the collection,

$N = \Sigma n_i$ = total number of individuals in the collection,

$\pi_i = n_i/N$, and

s = number of species in the sample.

The evenness, or equitability E, of the species distribution was determined for each sample as related to the Shannon index and the number of species observed (Lloyd and Ghelardi, 1964, Table 1).

The data were analyzed by comparing the five post-drilling sample means with the corresponding value from the pre-drilling sample, with the use of appropriate transformations. These comparisons involved the square root of the number of individuals, $\log_{10}$ weights, H_n", H_w", $\sin^{-1}$ of the square root of E as a percentage, and the $\sin^{-1}$ of the square root of PIE as a percentage. For each comparison, the mean of five post-drilling values plus or minus two standard errors was calculated to determine whether the single corresponding pre-drilling values was inside or outside these limits, which could include approximately the 95% confidence limits.

Further interpretation of the data was based on the distribution and abundance patterns of demersal fish in the STOCS study area as described for the 1975 and 1976 collections (Wohlschlag, 1976; 1977).

RESULTS AND DISCUSSION

The pre-drilling sample data are presented in Table 1 and the post-

drilling data in Tables 2-6. Table 7 contains the summary of weights and numbers and the derived H_n", H_w", E, and PIE values for all collections. Table 8 contains data for the statistical comparisons.

From an inspection of the species in Tables 1-6, it was apparent that there was considerable diversity in the species composition. Species such as *Peprilus burti* and *Syacium gunteri* were fairly ubiquitous and numerous. The occurrence of most other species was less frequent and spotty. Obviously the number of samples would have to be increased greatly to evaluate the patchy, or contagious, nature of distributions of individual species. The greatest single deficiency in sampling was having only the single pre-drilling sample for comparison.

Two other deficiencies associated with sampling involved comparisons at different seasons and at different times of day. The results of both 1975 and 1976 sampling efforts and analyses indicated clearly that there could be statistically significant differences both between day (pre-drilling) and night (post-drilling) samples and between autumn (pre-drilling) and spring (post-drilling) samples (Wohlschlag, 1976; 1977). From these analyses of distribution and abundance data at nearby stations (Transect II, Stations 2 and 4) for 1975 and 1976, it was apparent that numbers of species and numbers of individuals, hence diversities, tended to be lowest in late summer and autumn and highest in spring. The rig monitoring data for numbers and weights of samples did not change seasonally to the same extent as that indicated by overall sampling in nearby areas. From the Table 7 summary, the autumn to spring increases in numbers and weights were insufficient to equal comparable increases in similar seasonal collections (Wohlschlag, 1976; 1977). In Table 8, the comparisons of both pre- and post-drilling means would indicate that increases in numbers and biomasses

TABLE 1

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES
COLLECTED DURING THE PRE-DRILLING SURVEY,
27 SEPTEMBER 1976, 1627-1642 hrs

Species	No. of Individuals	Total Weight (g)
Peprilus burti	16	741.0
Cynoscion nothus	5	354.0
Syacium gunteri	3	59.9
Stenotomus caprinus	3	40.2
[illegible]odus foetens	2	264.0
Chloroscombrus chrysurus	2	49.1
Serranus atrobranchus	6	54.8
Diplectrum bivittatum	1	20.0
Lutjanus campechanus	1	31.2
Totals, 9 species	39	1614.2

TABLE 2

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES COLLECTED DURING THE POST-DRILLING SURVEY AT THE DRILL SITE, 1 MARCH 1977, 1900-1915 hrs

Species	No. of Individuals	Total Weight (g)
Peprilus burti	78	1568.3
Cynoscion arenarius	3	228.6
Centropristis philadelphica	1	23.4
Diplectrum bivittatum	3	39.9
Synodus poeyi	2	12.0
Bollmannia communis	2	12.7
Synodus foetens	1	35.5
Syacium gunteri	5	139.7
Chaetodipterus faber	1	10.2
Larimus fasciatus	1	37.7
Scorpaena calcarata	1	13.9
Totals, 11 species	98	2121.9

TABLE 3

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES COLLECTED 1000 m NORTH OF THE DRILL SITE DURING THE POST-DRILLING SURVEY, 1 MARCH 1977, 1945-2000 hrs

Species	No. of Individuals	Total Weight (g)
Peprilus burti	151	2904.6
Opisthonema oglinum	41	3752.5
Syacium gunteri	1	7.5
Totals, 3 species	193	6664.6

TABLE 4

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES COLLECTED 1000 m EAST OF THE DRILL SITE DURING THE POST-DRILLING SURVEY, 1 March 1977, 2030-2045 hrs

Species	No. of Individuals	Total Weights (g)
Synodus foetens	1	153.2
Syacium gunteri	26	498.2
Engyophrys senta	1	9.2
Peprilus burti	2	48.6
Scorpaena calcarata	2	10.7
Centropristis philadelphica	2	52.6
Diplectrum bivittatum	1	20.6
Saurida brasiliensis	1	8.0
Synodus poeyi	1	4.2
Halieutichthys aculeatus	1	17.0
Sphoeroides parvus	1	4.0
Totals, 11 species	39	826.4

TABLE 5

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES COLLECTED 1000 m SOUTH OF THE DRILL SITE DURING THE POST-DRILLING SURVEY, 1 March 1977, 2105-2120 hrs

Species	No. of Individuals	Total Weights (g)
Orthopristis chrysoptera	1	58.2
Syacium gunteri	9	111.6
Centropristis philadelphica	1	23.5
Scorpaena calcarata	2	13.1
Halieutichthys aculeatus	1	7.0
Engyophrys senta	1	5.2
Cynoscion arenarius	1	65.9
Peprilus burti	29	633.5
Totals, 8 species	45	918.0

TABLE 6

SPECIES LIST, NUMBERS AND WEIGHTS FOR DEMERSAL FISHES COLLECTED 1000 m WEST OF THE DRILL SITE DURING THE POST-DRILLING SURVEY, 1 MARCH 1977, 2145-2200 hrs

Species	No. of Individuals	Total Weights (g)
Peprilus burti	49	918.0
Cynoscion arenarius	4	307.3
Diplectrum bivittatum	4	57.4
Bollmannia communis	3	14.7
Orthopristis chrysoptera	1	80.0
Syacium gunteri	1	3.8
Synodus foetens	1	86.0
Totals, 7 species	63	1467.2

TABLE 7

SUMMARY OF PRE- AND POST-DRILLING SAMPLE DATA WITH MEASURES OF DEMERSAL FISH DISTRIBUTION AND ABUNDANCE

Collection Data	No. of Species	No. of Individuals	Weight (g)	H_n"	H_w"	E	PIE
Pre-Drilling							
Drill Site, 27 Sept. 1976	9	39	1614.6	1.803	1.552	0.556	0.793
Post-Drilling							
Drill Site, 1 Mar. 1977	11	98	2121.9	0.939	0.994	0.181	0.375
N-1000 "	3	193	6664.6	0.548	0.693	0.666	0.334
E-1000 "	11	39	826.4	1.384	1.335	0.272	0.557
S-1000 "	8	45	918.0	1.166	1.097	0.375	0.552
W-1000 "	7	63	1467.2	0.887	1.134	0.285	0.390

TABLE 8

PRE-DRILLING AND POST-DRILLING DEMERSAL FISH COMPARISONS (SEE TEXT)

	Number N of Individuals $\sqrt{N}$	Log_{10} Wts(g)	Numerical Shannon Diversity Index H_n''	Ponderal Shannon Diversity Index H_w''	Equitability, E% $\sin^{-1}\sqrt{E}$	Probability of Interspecific Encounter, PIE% $\sin^{-1}\sqrt{PIE}$
Pre-Drill:						
One Observation	6.245	3.208	1.803	1.552	48.22	62.94
Post-Drill:						
Mean	8.9362	3.2394	0.9848	1.0506	36.270	41.584
Standard Error of Mean	1.3909	0.1636	0.1405	0.1051	5.0210	2.7058
Range of Mean						
-2 Std. Errors	6.1544	2.9122	0.7039	0.8403	26.2281	36.1723
+2 Std. Errors	11.7180	3.5666	1.2657	1.2609	46.3119	46.9957

were not statistically significant, which should probably be the case had there been no drilling disturbance. From Table 8, it was also apparent that there were statistically nonsignificane decreases in numerical and ponderal diversity indices following drilling, while the 1975 and 1976 seasonal data indicated increases in diversity from fall to spring. The Table 8 data also indicate that there may be a statistically "interesting" decline in equitability E and PIE after drilling. These types of declines might well be explained on the basis of disrupted community structures brought about by environmental disturbance, the relatively rare species that (a) have not yet recolonized completely in their former communities, or (b) are "foreign" species that have found new niches either as a consequence of the disturbances of a lack of competition in initial stages of environmental recovery.

In Table 9 the composite comparisons of all the species lists show the nature of species occurrences among the separate collections. Quite obviously the only pre-drilling station species that occurred in all the post-drilling samples were *Peprilus burti* and *Syacium gunteri*, although it should be noted that *Synodus foetens* and *Diplectrum bivittatum* occurred in three of the five post-drilling stations. The average fraction of species occurrences in the five post-drilling collections was 0.36 of the nine species at the pre-drilling station.

To assess the comparisons among the four post-drilling peripheral stations as compared to the post-drilling site station the average fraction of species occurrences was 0.48. While this average would indicate a greater species commonality after drilling, it should be noted that the north station had only three of 11 common species with *Peprilus burti* and the only collection of *Opisthonema oglinum* having overwhelming predominance. The north peripheral station had only three common species and the south

TABLE 9

COMPARISON OF SPECIES COMPOSITION, WEIGHTS AND NUMBERS OF INDIVIDUALS AT PRE- AND POST-DRILLING SITES

Species	Table 1 Predrilling Site No.	Table 1 Predrilling Site Wt(g)	Table 2 Postdrilling Site No.	Table 2 Postdrilling Site Wt(g)	Table 3 1 km North Site No.	Table 3 1 km North Site Wt(g)	Table 4 1 km East Site No.	Table 4 1 km East Site Wt(g)	Table 5 1 km South Site No.	Table 5 1 km South Site Wt(g)	Table 6 1 km West Site No.	Table 6 1 km West Site Wt(g)
Peprilus burti	16	741.0	78	1568.3	151	2904.6	2	48.6	29	633.5	49	918.0
Serranus atrobranchus	6	54.8	0	0	0	0	0	0	0	0	0	0
Cynoscion nothus	5	354.0	0	0	0	0	0	0	0	0	0	0
Synodus gunteri	3	59.9	5	139.7	1	7.5	26	498.2	9	111.6	1	3.8
Stenotomus caprinus	3	40.2	0	0	0	0	0	0	0	0	0	0
Synodus foetens	2	264.0	1	35.5	0	0	1	153.2	0	0	1	86.0
Chloroscombrus chrysurus	2	49.1	0	0	0	0	0	0	0	0	0	0
Diplectrum bivittatum	1	20.0	3	39.9	0	0	1	20.6	0	0	4	57.4
Lutjanus campechanus	1	31.2	0	0	0	0	0	0	0	0	0	0
Totals 9 spp.	39	1614.2	-	-	-	-	-	-	-	-	-	-
Cynoscion arenarius			3	228.6	0	0	0	0	1	65.9	4	307.3
Centropristis philadelphica			1	23.4	0	0	2	52.6	1	23.5	0	0
Synodus poeyi			2	12.0	0	0	0	0	0	0	0	0
Bollmannia communis			2	12.7	0	0	1	4.2	0	0	3	14.7
Chaetodipterus faber			1	10.2	0	0	0	0	0	0	0	0
Larimus fasciatus			1	37.7	0	0	0	0	0	0	0	0
Scorpaena calcarata			1	13.9	0	0	2	10.7	2	13.1	0	0
Totals 11 spp.			98	2121.9	-	-	-	-	-	-	-	-
Opisthonema oglinum					41	3752.5	0	0	0	0	0	0
Totals 3 spp.					193	6664.6	-	-	-	-	-	-
Engyophrys senta							1	9.2	1	5.2	0	0
Saurida brasiliensis							1	8.0	0	0	0	0
Halieutichthys aculeatus							1	17.0	1	7.0	0	0
Sphoeroides parvus							1	4.0	0	0	0	0
Totals 11 spp.							39	826.4	-	-	-	-
Orthopristis chrysoptera									1	58.2	1	80.0
Totals 8 spp.									45	918.0	-	-
Totals 7 spp.											63	1467.2

station had only five species in common with the post-drilling drill site station. Also it should be emphasized that all the other post-drilling samples contained few species that had more than one or two examples. Why the north and south stations were rather depauperate in numbers of species, and why the north station had larger numbers of individuals and larger biomass than the south station, is, however not clear unless the effects of the drilling activities had a north-south gradient over and above the vagaries of sampling.

There was also an intersting combination of confounding effects of general sampling variability and the effects of day-night (diel) activity, inasmuch as the pre-drilling collection was made in daytime and the post-drilling collections in the early evening. Obviously some species (*e.g.*, *Peprilus burti*) that are predominantly diurnal also occur in lesser frequencies at night, while the reverse is true for the predominantly nocturnal *Syacium gunteri*. See Wohlschlag (1977) for comparisons of abundances of diurnal and nocturnal species; also see Vetter (MA Thesis, in preparation) for a more complete discussion of day-night differences among benthic fishes of the STOCS area.

CONCLUSIONS

There were definite suggestions, but not statistically definitive conclusions, that disturbances up to a radius of 1 km about the drill site resulted in both numerical and biomass declines of benthic fishes in relation to general trends of abundance at nearby areas in both 1975 and 1976. Further suggestions of disruption were indicated by declines in diversity, equitability, and probability of interspecific encounter. There were also suggestions that day-night predominance patterns changed over and above normal seasonal trends. It is recommended that the above conclusions be accepted tentatively.

LITERATURE CITED

Gallaway, B. J., J. C. Parker, and E. Moore. 1972. Key to the estuarine and marine fishes of Texas. TAMU-SG-72-402. xiii + 177pp.

Hurlbert, S. H. 1971. A nonconcept of species diversity: a critique and alternative parameters. Ecol. 52:577-586.

Lloyd, M., and R. J. Ghelardi. 1964. A table for calculating the "equitability" component of species diversity. J. Anim. Ecol. 33:217-225.

Shannon, C. E. 1948. A mathematical theory of communication. Bell. Systm. Tech. Jour. 27:379-423.

_____., and W. Weaver. 1963. The mathematical theory of communication. Univ. Illinois Press, Urbana. 117pp.

Wiener, N. 1948. Cybernetics. Wiley, New York. 194pp.

Wilhm, J. L. 1968. Use of biomass units in Shannon's formula. Ecol. 49: 153-156.

Wohlschlag, D. E. 1976. Benthic Project-Epifaunal Fishes, pages 250-330. *In* Environmental studies, south Texas outer continental shelf, 1975, biology and chemistry. Final Report submited to the Bureau of Land Management, Washington, D. C., Contract AA550-CT5-16.

_____. 1977. Demersal Fishes, pages 10-1 - 10-142. *In* Environmental studies, south Texas outer continental shelf, biology and chemistry. 1976. Final Report submitted to the Bureau of Land Management, Washington, D.C., Contract AA550-CT6-17.

CHAPTER THIRTEEN

HEAVY MOLECULAR WEIGHT HYDROCARBONS IN MACROEPIFAUNA

Department of Oceanography
Texas A&M University

Principal Investigators:

C. S. Giam
H. S. Chan

Associate Investigators:

Elliot Atlas
Grace Neff

Assistant Investigators:

Mrs. Yang Hrung
Mrs. Darlene Garey

Technical Assistant:

Sue Newman

ABSTRACT

Three pre-drilling and three post-drilling samples of macroepifauna were analyzed for heavy hydrocarbons. The three pre-drilling specimens, squid, rough scad and Atlantic croaker, contained no evidence of petroleum hydrocarbons. The n-alkane distributions in three post-drilling samples, butterfish, shoal flounder, and shrimp, were petroleum-like, most notably in the shrimp. Also, the shrimp sample had a hydrocarbon content 150% higher than the range for this species in the surrounding areas. In all these samples no aromatic compounds were detected. Thus, there may be an indication of a low level petroleum contamination of post-drilling samples but more analyses are needed to verify this observation and the sources of contamination.

INTRODUCTION

The purpose of this project was to analyze macropepifauna from the vicinity of a drilling site on the South Texas Outer Continental Shelf for heavy molecular weight hydrocarbons. These species were collected for analysis from the rig site prior to drilling and another three species were obtained after drilling had begun. The samples were analyzed by the techniques outlined in Attachment A of Contract AA550-CT6-17 (Appendix F) and detailed in the following section. Interpretation of the data was based on previous experience (Giam, *In* Groover, 1977; Giam, *In* Parker, 1976; Giam *et al.*, 1976; Farrington *et al.*,1972; Farrington *et al.*, 1976) and on the report of Clark (1974).

METHODS AND MATERIALS

Materials[1]

Solvents used in the procedure were Mallinckrodt Nanograde^{R} and were used as received or re-distilled when required. Silica gel (Woelm, 70-230 mesh) and Aluminum Oxide Woelm Neutral (Activity Grade 1) were activated at 200°C for at least 24 hr before use. Hydrocarbon standards were obtained from Analabs and PolyScience Co.

Instrumentation

A Hewlett-Packard 5830 GC equipped with dual flame ionization detectors and a programmable integrator was used for analyses. It was equipped with 2 m x 3 mm outside diameter stainless steel columns of 5% FFAP on Gas Chrom Q 100/120. The injector was at 280°C and the detector at 350°C. The column oven was temperature programmed from 100° to 250°C at 5°/min.

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[1]Trade names of reagents, solvents and equipment and addresses for sellers are included to facilitate recognition by interested users of what we happen to use; there is no implication that these are solely recommended.

Procedure

Background Reduction

Prior to actual sample analyses, procedure blanks and recovery studies were performed. All solvents to be used in the procedure were concentrated to the extent required by the procedure and analyzed by gas chromatography. Any solvent exhibiting any impurities in the hydrocarbon region of the spectrum was rejected or redistilled in an all glass system. Solid reagents were purified by heating in a 325°C oven for at least 24 hrs; concentrates of solvent rinses of these materials were inspected by gas chromatography as for solvents. Glassware and equipment were washed with Micro cleaning solution (International Products Corp.) and distilled water, rinsed with acetone, methanol and hexane and heated overnight at 325°C. After heating, they were rinsed with two portions of benzene and two of hexane. The final hexane rinse was concentrated and checked by gas chromatography. If any impurities were present, rinsing was repeated as needed to obtain an acceptable blank. Glassware checks accompanied each sample run and procedure blanks were performed at frequent intervals.

Extraction of Macrofauna

Approximately 100 g of tissue were used for all analyses. When possible, a minimum of five organisms or portions thereof were used for an analysis to minimize the natural variability of hydrocarbon content in conspecifics. The weighed sample was cut into smaller pieces and an aliquot of the sample was removed and placed in a tared beaker and dried at 60°C until a constant weight was obtained. In this manner, the wet weight and dry weight of the sample was obtained. The remainder of the sample was saponified.

Saponification

Saponification was carried out by refluxing the sample with 0.05 g KOH/g tissue in approximately 50 ml methanol. The saponification was continued until the tissues were digested. After the completion of digestion, an equal volume of purified water was added to the mixture. The mixture was then refluxed overnight. Upon completion of the hydrolysis, the mixture was diluted with an equal volume of a saturated NaCl solution. The mixture was then extracted three times with n-pentane. The volume of n-pentane used for each extraction was equivalent to the volume of methanol initially used in the saponification. The n-pentane fractions were then combined and washed with an equal volume of water. The solvent was removed from the pentane extract (for weight determination) prior to column chromatographic separation.

Column Chromatography

A weight ratio of about 100 parts alumina to one (1) part lipid sample and 200 parts silica gel to one (1) part lipid sample was used. The column had a length to inside diameter ratio of approximately 20:1. Both the silica gel and the neutral alumina were Activity I. The column was packed in hexane and rinsed with one column volume of n-pentane. At no time was the column allowed to run dry. The extract taken up in a small volume of n-pentane was then applied to the column and the aliphatic fraction eluted with two column volumes of n-pentane. This was followed by elution of aromatics with two column volumes of benzene. The eluates from the two fractions were then taken to near dryness. They were then transferred to screw cap vials with teflon-lined caps, and the remainder of the solvent was removed with a stream of purified nitrogen. Following column chromatography, all eluates were analyzed by gas chromatography.

Gas Chromatography Separations

Each eluted fraction obtained from the column chromatographic separation was quantitatively dissolved in a small volume of carbon disulfide for injection into the GC. A stainless steel column (2 m x 3 mm outside diameter) packed with 5% FFAP on Gas Chrom Q (100/120 mesh) and a 50 m SE30-WCOT glass column were used for the analysis. The columns resolved n-C_{17} from pristane and n-C_{18} from phytane with a resolution (R) of approximately unity, where

$$R = 2d/(w_1 + w_2) \text{ and,}$$

w is the width of each peak at the base of one phase for both pairs of components, and

d is the distance between apices.

The columns were also capable of resolution of hydrocarbons from n-C_{14} through n-C_{36}. To assist identification, the following compounds were used as standards to match the retention times of peaks in the gas chromatogram: aliphatic hydrocarbons C_{15} - C_{32}, trimethylbenzene, 1,2,3,5-tetramethylbenzene, 1,2,3,4-tetramethylbenzene, naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, 1,5-dimethylnaphthalene, 2,3-dimethylnaphthalene, 4-phenyltoluene, 3,3'dimethylbiphenyl, 4,4'dimethylbiphenyl, fluorene, 1-methylfluorene, phenanthrene, anthracene, 9-methylanthracene, fluoranthene, and chrysene.

RESULTS

The analytical results are detailed in Tables 1 through 6 as total concentration of heavy alkanes, total n-paraffins, the levels of pristane and phytane, the ratios of pristane/phytane, pristane/C_{17}, phytane/C_{18} and the CPI ratios. In the pre-drilling samples, the C_{15} and C_{17} n-paraffins were the dominant hydrocarbons, totaling more than 50% of the n-para-

TABLE 1

CONCENTRATION OF ALKANES[1] IN RIG MONITORING MACROEPIFAUNA (PRE-DRILLING SAMPLES) FROM THE SOUTH TEXAS OCS (1976)

Station/ Transect	Sample Code	Species	Sample Wt. (g)	Conc. in ppm (µg/g dry wt.)
DS	TBE	Squid *Loligo pealei*	92.1	0.91
DS	TBF	Rough scad *Trachurus lathami*	58.4	7.18
DS	TBG	Atlantic croaker *Micropogon undulatus*	97.9	10.89

[1]Total Alkanes includes total paraffins, pristane and phytane.

TABLE 2

ORGANS AND INDIVIDUALS ANALYZED IN RIG MONITORING MACROEPIFAUNA (PRE-DRILLING SAMPLES) FROM THE SOUTH TEXAS OCS (1976)

Station/ Transect	Sample Code	Species	Organ Used [a]	No. of Individuals
DS	TBE	Squid *Loligo pealei*	W-p	8
DS	TBF	Rough scad *Trachurus lathami*	M	5
DS	TBG	Atlantic croaker *Micropogon undulatus*	M	4

[a] W-p = whole less pen

M = muscle only

TABLE 3

PERCENT DISTRIBUTION OF n-PARAFFINS IN
RIG MONITORING MACROEPIFAUNA (PRE-DRILLING SAMPLES)
FROM THE SOUTH TEXAS OCS (1976)

STATION	DS	DS	DS
SAMPLE CODE	TBE	TBF	TBG
CARBON NO.			
14	-	-	-
15	-	8.9	66.5
16	-	3.1	1.8
17	59.0	51.6	17.9
18	5.1	4.5	1.1
19	17.9	11.0	3.5
20	-	1.6	0.8
21	10.3	5.2	1.7
22	-	1.3	0.7
23	7.7	11.5	1.9
24	-	1.3	0.7
25	-	-	0.7
26	-	-	0.6
27	-	-	0.6
28	-	-	0.4
29	-	-	0.4
30	-	-	0.7
31	-	-	-
32	-	-	-
n-paraffins (ppm)	0.12	0.38	5.65
Pristane (ppm)	0.79	6.80	5.24
Phytane (ppm)	-	-	-
Pr/Py	-	-	-
Pr/C_{17}	11.2	34.7	5.2
Py/C_{18}	-	-	-
CPI_{14-20}	15.1	8.6	27.0
CPI_{20-32}	-	5.2	1.5
Total alkanes	0.91	7.18	10.89

TABLE 4

CONCENTRATION OF ALKANES[1] IN RIG MONITORING MACROEPIFAUNA (POST-DRILLING SAMPLES) FROM THE SOUTH TEXAS OCS (1977)

Station/ Transect	Sample Code	Species	Sample Wt. (g)	Conc. in ppm (µg/g dry wt.)
DS	BDFZ	Butterfish *Peprilus burti*	69.7	6.49
DS	BDGA	Brown shrimp *Penaeus aztecus*	56.7	0.61
DS	BDGB	Shoal flounder *Syacium gunteri*	58.2	1.14

[1]Total Alkanes includes total paraffins, pristane and phytane.

TABLE 5

ORGANS AND INDIVIDUALS ANALYZED IN RIG MONITORING
EPIFAUNA (POST-DRILLING SAMPLES) FROM THE SOUTH TEXAS OCS (1976)

Station/ Transect	Sample Code	Species	Organ Used [a]	No. of Individuals
DS	BDFZ	Butterfish *Peprilus burti*	M	5
DS	BDGA	Brown shrimp *Penaeus aztecus*	M	5
DS	BDGB	Shoal flounder *Syacium gunteri*	M	5

[a] M = muscle only

TABLE 6

PERCENT DISTRIBUTION OF n-PARAFFINS IN
RIG MONITORING MACROEPIFAUNA (POST-DRILLING SAMPLES)
FROM THE SOUTH TEXAS OCS (1977)

STATION	DS	DS	DS
SAMPLE CODE	BDFZ	BDGA	BDGB
CARBON NO.			
14	0.6	-	-
15	33.0	6.3	7.4
16	2.4	9.7	6.5
17	45.0	12.3	16.3
18	7.0	10.6	7.5
19	4.5	7.2	8.0
20	0.7	5.6	4.5
21	0.7	5.1	6.7
22	0.6	5.6	3.3
23	1.0	4.7	4.7
24	0.6	4.7	4.3
25	1.3	5.0	8.2
26	0.6	4.9	4.7
27	0.7	3.2	6.3
28	0.7	3.6	4.7
29	-	-	5.1
30	0.6	5.0	1.8
31	-	-	-
32	-	6.5	-
n-paraffins (ppm)	3.60	0.56	0.51
Pristane (ppm)	2.87	0.04	0.60
Phytane (ppm)	0.02	0.01	0.03
Pr/Py	143.5	4.0	20.0
Pr/C_{17}	1.8	0.6	7.5
Py/C_{18}	0.1	0.2	0.8
CPI_{14-20}	8.2	1.1	2.0
CPI_{20-32}	1.1	0.6	1.5
Total alkanes	6.49	0.61	1.14

ffins. In the post-drilling specimens, the C_{15} and C_{17} hydrocarbons constituted more than 50% of the n-paraffins in butterfish; in shrimp and shoal flounder, they accounted for approximately 20% of the total n-paraffins. Pristane was present in all samples and phytane was present in all three post-drilling samples. The pristane/phytane ratios were 143.5 for butterfish, 4.0 for shrimp and 20.0 for shoal flounder. The pristane/C_{17} ratios were higher for the pre-drilling sample than for the post-drilling samples. The phytane/C_{18} ratios in the post-drilling samples were 0.1, 0.2, and 0.8. The CPI_{14-20} ratios were 15.1, 8.6 and 27.0 for the pre-drilling samples; they were 8.2, 1.1 and 2.0 for the post-drilling samples.

DISCUSSION

The analytical methods used for this study yielded excellent procedure blanks and good recoveries of the heavy hydrocarbons reported for this study.

The pre-drilling samples obtained for this study were squid, rough scad and Atlantic croaker; the post-drilling samples were butterfish, brown shrimp and shoal flounder. Due to seasonal variability in species composition of epifaunal and demersal fish populations, it is difficult to draw conclusions as to the effects of drilling on the heavy hydrocarbon content of the samples, but several trends are apparent (see Holland, Chapter 11, and Wohlschlag, Chapter 12). The levels of n-alkanes in the pre-drilling samples were within the ranges found in other samples from the South Texas OCS. This was also true of the butterfish and shoal flounder from the post-drilling samples; the shrimp, however, had a concentration of 0.51 ppm of n-paraffins, while the range for this species was 0 to 0.32 ppm in other areas. The distribution pattern of the n-alkanes

was petroleum-like in all three post-drilling specimens and was most notably so in the shrimp. Phytane, which is generally considered to be from petroleum rather than from biogenesis (Farrington *et al.*, 1972), was present in the post-drilling samples. Thus, the pattern of n-alkanes and the presence of phytane is consistent with the presence of hydrocarbons from petroleum contamination. However, if there was petroleum contamination, it had to be very low because the levels of phytane were very low and aromatic hydrocarbons were not detected. Also, phytane has been present relatively frequently in near-shore samples, making the source of contamination difficult to assess. Thus, more samples need to be analyzed to confirm this observation.

The pristane/phytane, pristane/C_{17} and pristane/C_{18} ratios are frequently used to identify sources of oil pollution and are often similar to organisms exposed to a single petroleum source. There is some indication that biogenic hydrocarbons can affect these ratios (Farrington and Medeiros, 1975) and the species variation in the samples may account for the variation in the pristane/phytane and pristane/C_{17} ratios in the samples analyzed. However, the phytane/C_{18} ratios of 0.1, 0.2 and 0.8 for the post-drilling samples may be taken as indicative of a single source of petroleum contamination in the samples.

Another index of the presence of petroleum are odd-even ratios. In this study, carbon preference indices (CPI) have been used as a measure of odd-carbon dominance. They are calculated as follows:

$$CPI_{20-32} = 1/2 \left\{ \frac{\sum_{n=21}^{n=31} \text{HC odd}}{\sum_{n=22}^{n=32} \text{HC even}} + \frac{\sum_{n=21}^{n=31} \text{HC odd}}{\sum_{n=20}^{n=30} \text{HC even}} \right\}$$

$$CPI_{14-20} = 1/2 \left\{ \frac{\sum_{n=15}^{n=19} \text{HC odd}}{\sum_{n=16}^{n=20} \text{HC even}} + \frac{\sum_{n=15}^{n=19} \text{HC odd}}{\sum_{n=14}^{n=18} \text{HC even}} \right\}$$

The CPI_{20-32} is generally of the same order of magnitude for petroleum (mean 1.2) and for biological organisms (mean 1.0-1.5), but the CPI_{14-20} more accurately reflects the odd-carbon dominance of biological samples that is absent in petroleum. The CPI_{14-20} is almost always >2 for organisms, while it averages <1.0 for petroleum (Clark, 1974).

The CPI_{14-20} ratios were 15.1, 8.6 and 27.0 for the pre-drilling samples, indicating biogenic hydrocarbons. This value was also high (8.2) for butterfish in the post-drilling samples, but was 1.1 for shrimp and 2.0 for shoal flounder indicating the probable presence of petroleum hydrocarbons. The butterfish may also contain petroleum hydrocarbons, but due to its naturally high content of biogenic alkanes, it is a poor species for monitoring the presence of trace amounts of petroleum contamination.

CONCLUSIONS

The pre-drilling samples contained no evidence of petroleum contamination upon analysis for heavy hydrocarbons, while the post-drilling samples, especially shrimp, did contain phytane and had n-paraffin distributions strongly suggestive of petroleum. As noted in our other OCS studies, shrimp appear to be one of the best species for detecting the presence of petroleum pollution. In this study, the post-drilling shrimp yielded an n-paraffin pattern and a CPI_{14-20} ratio suggestive of petroleum. The other two post-drilling species, shoal flounder and butterfish also contained phytane

and a wide range of n-paraffins. However, the probable effect of petroleum hydrocarbons on the n-paraffins pattern was not as distinct as in shrimp due to the more complex biogenic hydrocarbon content of these fish. Aromatic hydrocarbons were not detected in any samples, which may imply a relatively low level of petroleum contamination in the drilling area or a low level of petroleum contamination in the drilling area or a low level of aromatics in the oil source. It is important that more samples be analyzed to confirm if the post-drilling samples were indeed contaminated with petroleum. Also, samples from varying distances from the rig would be important for determining the source of this contamination, *e.g.*, the source may be from adjacent contaminated locations.

LITERATURE CITED

Clark, R. C., Jr. 1974. Methods for establishing levels of petroleum contamination in organisms and sediment as related to marine pollution monitoring. NBS Spec. Publ. 409, Marine Pollution Monitoring (Petroleum). Proceedings of a Symposium and Workshop held at NBS, Gaithersburg, MD, 189-194.

Farrington, J. W., C. S. Giam, G. R. Harvey, P. Parker and J. Teal. 1972. Analytical techniques for selected organic compounds. Marine Pollution Monitoring: Strategies for a National Program Workshop sponsored by NOAA at Santa Catalina Marine Biological Laboratory, Oct. 25-28, pp. 152-176.

_____., and G. C. Medeiros. 1975. Evaluation of some methods of analysis for petroleum hydrocarbons in marine organisms. Proceedings of the 1975 Conference on Prevention and Control of Oil Pollution, San Francisco, CA., pp. 115-121.

_____., J. M. Teal, and P. L. Parker. 1976. Petroleum hydrocarbons. Strategies for Marine Pollution Monitoring, Edited by E. D. Goldberg, A Wiley Interscience Publication.

Giam, C. S., H. S. Chan, and G. S. Neff. 1976. Distribution of n-paraffins in selected marine benthic organisms. Bull. Environ. Contam. Toxicol. 16:37-43.

_____. 1977. Heavy molecular weight hydrocarbons in macroepifauna and macronekton, pages 17-1 through 17-28. *In* Groover, R. D., Environmental studies, south Texas outer continental shelf. 1976 Final Report to the Bureau of Land Management, Washington, D.C. 6 vols.

_____. 1976. Heavy Hydrocarbon Project, pages 374-442. *In* Parker, P.L., Environmental studies, south Texas outer continental shelf, 1975, biology and chemistry. 1975 Final Report to the Bureau of Land Management, Washington, D.C. Contract AA550-CT5-17, 3 vols.

CHAPTER FOURTEEN

TRACE METALS IN EPIFAUNA

Department of Oceanography
Texas A&M University

Principal Investigators:

B. J. Presley
P. N. Boothe

ABSTRACT

Three samples or organisms were collected in the immediate vicinity of an exploratory oil drilling site in the STOCS area both before and after (a total of six samples) actual drilling operations. The concentrations of 10 metals were determined in the samples using flame atomic absorption spectroscopy (AAS)(Cu, Fe, Zn), flameless AAS (Cd, Cr, Ni, Pb) and neutron activation analysis (Al, Ca, V).

The trace metals data set did not permit a realistic assessment of the possible impact of drilling operations on the levels of trace metals in organisms inhabiting the immediate vicinity. Not enough samples were collected and only one species occurred in both pre- and post-drilling sample groups. The species collected were all very mobile and their period of exposure to the ambient environment of the rig was probably variable and very limited.

Considering these limitations, the data suggest that drilling activities had no significant effect on the levels of trace metals in organisms in the area.

INTRODUCTION

As part of the rig monitoring study, a limited effort was made to determine if any differences in organismal trace metals concentrations before and after drilling operations could be detected. Three samples of epifauna and demersal fishes were collected before and after drilling activities and concentrations of 10 trace metals (Al, Ca, Cd, Cr, Cu, Fe, Ni, Pb, V, Zn) were determined in each sample. The purpose of this report is to present and discuss this trace metals data.

METHODS AND MATERIALS

All samples were collected by personnel of the University of Texas, Port Aransas Marine Laboratory using a 35-ft (10.7-m) Texas box otter trawl. The pre-drilling samples were collected on 27 September 1976 and the post-drilling samples on 2 March 1977. Every reasonable precaution was taken to avoid contamination during sampling. The samples were placed in polyethylene bags. When potentially contaminating sediment or other foreign material was adhering to the exterior surfaces of the organisms collected, they were rinsed prior to being put into the polyethylene bags. To avoid any release of metals from the organisms caused by microbial activity, all samples were immediately frozen on board ship and remained frozen during transportation and storage until prepared for analysis.

Sample Preparation

Non-contaminating procedures used to prepare each of the sample types (*i.e.*, shrimp, squid and fish flesh) are detailed below.

Fish and macroinvertebrate samples were thawed just prior to being prepared for freeze drying. They were rinsed with deionized water as

necessary to remove any mud or other foreign material adhering to the exterior surfaces of the organisms. The deionized water used for all work was prepared by passing distilled water through an ultrapure, mixed-bed demineralizer column (BARNSTEAD D0809). All dissections were done in a clean room on acrylic plastic cutting boards using stainless steel scalpels, scissors and nylon or teflon tweezers as required. At no point during the dissection were the preparer's fingers allowed to touch the tissue to be analyzed. All dissecting equipment was thoroughly rinsed with 1 N nitric acid (HNO_3) and deionized water between preparation of each sample. At the end of each sample preparation, all equipment was thoroughly cleaned in a Na_2CO_3 solution and rinsed with 1 N HNO_3 and deionized water. The equipment was stored in polyethylene bags until the next use. The acryiic boards were soaked in 0.5 N HNO_3 between each use.

Muscle tissue from all fish, shrimp, and squid collected were prepared for analysis. A maximum amount of the appropriate tissue from each individual was prepared for freeze drying as described below. This action was taken to insure that extra freeze-dried material would be available for repeat analyses when necessary and to avoid having material from the same sample stored in two different ways for long periods. An equivalent wet weight tissue aliquot was taken from five or more individuals in the sample (if available) and pooled in a tared plastic, snap-cap vial to give a total wet weight if possible of 6-12 g. After dehydration this pooled sample yielded a dry weight of 1-3 g, all of which was analyzed for trace metals. Pooled samples were prepared in this manner to insure that the trace metals concentrations in the pooled sample represented a true average of the concentrations existing in each of the individual organisms included in the sample, and also to avoid having to homogenize a large,

pooled sample with a ball mill or mortar and pestle and risk contamination. If sufficient tissue remained, reserve pooled samples identical to the first were prepared in separate vials. If there was insufficient tissue remaining to prepare a second replicate pooled sample, or if there was still tissue left over after the preparation of the additional replicates, the remaining tissue from each individual was placed in separate vials for possible future use.

The abdominal musculature was removed from whole shrimp for analysis. The total length (from rostrum to tail) and sex (whenever possible) were determined for each individual prior to dissection. The head and thorax were cut off and discarded. The abdominal musculature was removed by making a mid-ventral incision with scissors and peeling off the exoskeleton. The mid-ventral artery was removed from the surface of the muscle and the digestive tract and dorsal artery excised by making a mid-dorsal incision. This procedure was done to reduce the variability in sample trace metal concentration since vascular and digestive tissue could have significantly different trace metals content than the muscle tissue. The muscle tissue was rinsed sparingly with deionized water to remove any remnants of the arteries or digestive tract and was then handled as described below.

For squid, the mantle length (from the dorsal anterior margin to the tip of the tail) and the sex (whenever possible) of each was determined. The mantle was slit from the funnel to the tail and laid open. The pen, viscera, exterior skin and tail fins were removed. The remaining mantle tissue was rinsed sparingly as required with deionized water to remove any remnants of viscera, etc. and treated as described below.

The standard length and sex (whenever possible) of each individual fish was determined. In dissecting out the lateral trunk musculature, a

concerted effort was made to avoid contamination of the muscle sample which could occur if the sample came into contact with the exterior surface of the skin. On each side of the fish, a dorso-ventral incision was made along the anterior margin of the lateral trunk musculature. This incision was continued posteriorly just lateral to the mid-dorsal and mid-ventral planes. The skin was flayed off and discarded. The muscle was cut away from the axial skeleton, and, when sufficient tissue was available, the margins, where possible contact with the exterior skin could occur, were trimmed off and discarded. If there was insufficient tissue available, these margins were rinsed sparingly with deionized water.

To check possible sources of contamination during sample preparation, the following experiment was conducted. Eight replicate aliquots of flesh from a single red snapper (*Lutjanus campechanus*) were preapred as described above. Two replicates were frozen immediately. Four aliquots were refrigerated for 18 hours and then frozen. During refrigeration, one replicate received no further treatment. The blade end of a scalpel which had been used in numerous previous dissections was put directly into the second replicate. The blade end of a similar scalpel which had never been used was put into the third replicate. The cutting blades of a pair of dissecting scissors were put into the fourth aliquot. The remaining two aliquots were exposed to an acrylic cutting board or WHATMAN Number 1 filter paper for 20 minutes at room temperature and then frozen. All samples were then handled as described below. The only significant contamination observed was a $\geq$ 30-fold increase in the Cr concentration of the aliquot exposed to the scissors. The use of dissecting scissors in sample preparation throughout this study was minimized. However, the time of contact between tissue and dissecting instruments during this

experiment was much longer than would ever occur during actual sample preparation. This experiment suggests that the preparation techniques were not a source of sample contamination for the eight metals measured.

At the end of each sample dissection, the tissue sample(s) was placed immediately in a tared snap-cap vial and weighed immediately to determine wet weight. The samples were covered with parafilm and placed in a freezer. When a sufficient number of samples had accumulated, all samples were freeze-dried for 24 to 96 hours to a constant weight. After removal from the freeze dryer, the samples were reweighed to determine dry weight and the percentage of moisture lost by each sample was calculated. Samples were then stored in a desiccator until analyzed.

Digestion (Wet Oxidation) of Samples

Freeze-dried samples were prepared to atomic absorption spectrophotometric (AAS) analysis using a nitric (HNO_3): perchloric ($HCLO_4$) acid digestion procedure as described in Method 3 of Attachment B, Contract AA550-CT6-17 (Appendix G). Unacceptably high procedural blanks for Cd, Cr and Pb were observed in preliminary sample digestions using this method.

The primary source of contamination was perchloric acid ($HCLO_4$, double redistilled) and to a much lesser extent nitric acid (HNO_3, double redistilled) since up to 25 ml HNO_3 were being used per sample digested. To minimize this blank problem, a new lot of $HCLO_4$ containing considerably lower concentrations of Cd, Cr and Pb was obtained and the amount of HNO_3 and $HCLO_4$ used to digest each sample was significantly reduced. This reduction was realized by changing to an essentially closed refluxing system. A 1-3 g dry-weight sample was placed in a spoutless, electrolytic style pyrex beaker and 4-5 ml of 70% HNO_3 per gram of sample and 1 ml total of $HCLO_4$ were added. The beaker was covered with a 75 mm, non-ribbed pyrex

watchglass and allowed to sit overnight at room temperature. The mixture was then refluxed at low heat on a hotplate for 6-24 hours. A bent glass rod was placed between the beaker lip and the watchglass and the heat increased to permit HNO_3 evaporation. At the first sign of white $HCLO_4$ fumes (*i.e.*, when most of the HNO_3 was gone), the glass rod was removed, allowing the watchglass to again rest flush on top of the beaker. The sample was allowed to reflux until cleared completely. If the sample did not clear, an additional 1 ml HNO_3 and 0.5 ml $HCLO_4$ were added and the refluxing continued until clearing occurred. This step was repeated once if necessary. Finally, the watchglass was removed and the mixture was allowed to evaporate to near dryness.

Each digested sample was transferred to a tared 30 ml Oak Ridge type, screw-top polypropylene centrifuge tube by washing the beaker several times with 0.1 N HNO_3 (BAKER ULTREX grade) and pouring the resultant solutions into the centrifuge tube. Each sample was brought to approximately 25 ml, thereby diluting the original dry weight sample 10-20 times. The volume of each sample was determined by reweighing the filled sample tube and making a small correction (*e.g.*, 1.01 - 1.04, pH $\sim$ 0.5 - 1) for the specific gravity of the sample solution which was determined for each digestion. Further dilutions from the original solution were made on a weight/weight basis in a 5 dram snap-cap vial using 0.1 N HNO_3.

All digestion glassware was soaked immediately after use in a solution of "Micro" detergent and distilled water in covered polyethylene pans for up to several days. The glassware was then rinsed thoroughly with deionized water and soaked in 3 N reagent grade HNO_3 in covered polyethylene or polypropylene pans until the next use. The centrifuge tubes were prepared for use by cleaning in a "Micro" solution. They were then filled

with 5 N reagent grade HNO_3, heated for several days at 50°C and stored in room temperature until used. Prior to use, the tubes were emptied, rinsed thoroughly with deionized water and tared. The 5 dram snap-cap vials used for further dilutions were filled with 1 N reagent grade HNO_3 and allowed to sit at room temperature for several days. Prior to use they were emptied, rinsed with deionized water and tared.

These rig monitoring samples were analyzed as part of the STOCS monitoring study trace metals project. About 50 samples and blanks were digested at any one time using the above procedure. Three to five procedural blanks were included in each digestion to determine the amount of each metal contributed to the samples by the digestion glassware and reagents. These blanks received the same reagents and treatment as the tissue samples. An aliquot of the 0.1 N HNO_3 used to transfer and dilute the sample was placed in a centrifuge tube and analyzed with each digestion as a diluent/tube blank. Reagent blanks were analyzed for all bottles of acid prior to their use in sample digestion. These blanks were prepared by taking $\geq$ 10 ml of acid, evaporating it to near dryness in digestion glassware and transferring the residue to a centrifuge tube in the same manner described above. For each series of dilutions made using 5 dram vials, one or more vial blanks were prepared and analyzed.

To determine if any of the mantle of interest were being lost from samples during digestion, spike recovery experiments were conducted during four different digestions. Three experiments used aliquots of fish flesh and one used shrimp flesh. In each experiment two replicate aliquots of tissue were placed in separate beakers and digested as described above. One aliquot was spiked during initial heating with the following amounts of metals: Cd (.025 µg), Cr (0.25 µg), Cu (50 µg), Fe (50 µg),

Ni (2 µg), Pb (0.5 µg) and Zn (50 µg). Replicate aliquots of the spike were placed in two separate tared centrifuge tubes and brought to 25 ml with 0.1 N HNO_3 diluent. These two samples were analyzed to determine the actual amount of each metal in the spike. The unspiked tissue sample was analyzed to determine the amount of each metal in the sample itself. The total amount of each metal expected in the spiked sample was calculated using these two values. Percent recovery was determined by comparing the expected amount of each metal with the actual amount measured in the spiked sample. The average percent recovery was as follows: Cd 93%, Cr 94%, Cu 107%, Fe 93%, Ni 95%, Pb 103% and Zn 107%. Considering the low levels of metals used in the spikes and the precision of the analyses, these results were quite acceptable. They indicate that there was no significant loss of any of the metals studied during the digestion procedure.

Atomic Absorption Spectroscopy (AAS) Procedures

Eight elements (Cd, Cr, Cu, Fe, Ni, Pb, V and Zn) were analyzed in the biological samples from the rig monitoring study. Cadmium, Cr, Ni and Pb, which occurred at low levels, were measured using flameless AAS. These analyses were made using a PERKIN-ELMER Model 306 atomic absorption spectrophotometer equipped with an HGA-2100 graphite furnace atomizer. A summary of the instrumental operating conditions and the average procedural blanks for all eight digestions are given in Table 1. External and internal furnace purge gas flow rates were verified at specified levels of 0.9 and 0.3 ℓ per minute, respectively, at 40 psi delivery pressure. Injection volume was 25 µℓ. The furnace temperature gauge was calibrated using a clamp-on (inductive) ammeter and an optical pyrometer. Dry, char and atomization temperature and times were optimized for each metal using selected representative samples according to the manufacturer's recommenda-

TABLE 1

SUMMARY OF OPERATING CONDITIONS FOR FLAMELESS ATOMIC ABSORPTION ANALYSIS

Element	Wavelength (nm)	Source[1]	Temperature (°C) Time (seconds) dry	char	atomize	Minimum Detectable Concentration[3] (ppb)	Sensitivity[2] (pg)	Average Procedural Blank (ng)
Cd	228.8	EDL (5) HCL (8)	85° 60 sec	300° 60 sec	1800° 8 sec	0.025	9	6
Cr	357.9	HCL (10)	85° 60 sec	800° 30 sec	2600° 8 sec	1	25	<27
Ni	232.0	HCL (20)	85° 60 sec	1200° 30 sec	2500° 8 sec	4	100	<107
Pb	283.3	EDL (9)	85° 60 sec	500° 60 sec	2000° 8 sec	0.3	25	39

[1] Electrodeless discharge lamp (EDL). Numbers in parentheses are source energy in watts. Hollow Cathode Lamp (HCL). Numbers in parentheses are source current in milliamps.

[2] Average amount of metal injected giving a signal of .0044 absorbance units.

[3] At 10x scale expansion and approximately 1 chart unit; except Ni at 3x and 2 chart units.

tions (Anon., 1974). Non-resonance lines used for this optimization to estimate the magnitude of broad band molecular absorption for various sample types were 226.5 (Cd), 231.6 (Ni), 282.0 (Pb) and 352.0 (Cr) nm. Corrections for non-specific or broad band molecular absorption were made by a deuterium arc background corrector. For Cd and Pb, sample dilutions $\geq$ 1/50 were used for quantitation, and for Cr and Ni, dilutions of $\leq$ 1/50. Chemical interference was evaluated and corrected as necessary by frequent use of the standard additions technique and check dilutions. Mixed standard metal solutions were prepared in dilute HNO_3 (BAKER ULTREX grade) by diluting concentrated commercial atomic absorption standards. Samples were quantitated by peak height comparison with bracketing standards injected before and after the sample. Consideration was given to temporal variations in instrumental sensitivity, non-linearity between bracketing standards and gross differences in peak shape.

Copper, Fe and Zn were analyzed by flame AAS using a JARRELL-ASH Model 810 atomic absorption spectrophotometer. Analyses were carried out following the manufacturer's recommended procedure (Anon., 1971; 1972). A summary of the operating parameters for these analyses is given in Table 2. Non-specific absorption was monitored by measuring simultaneously the absorbance of non-resonance line and the analytical line of the element of interest. A fairly lean air-acetylene flame with flow rates of circa 7 and 2.5 ℓ per minute, respectively, were used for all three elements. Aspiration rate was generally 5 to 6 ml per minute. Chemical interference was checked by use of the standard additions technique. Mixed standards used were prepared as described above.

The accuracy and precision of AAS analysis was evaluated by analyzing two NBS standard biological reference materials (*i.e.*, #1571 orchard leaves and #1577 bovine liver) with each digestion. The results of these analyses

TABLE 2

SUMMARY OF OPERATING CONDITIONS FOR FLAME ATOMIZATION ATOMIC ABSORPTION ANALYSIS

Element	Analytical Wavelength (nm)	Non-resonance Wavelength (nm)	Sensitivity[1] (ppm)	Average Procedural Blank (ng)
Cu	324.7	322.9	0.05	< 75
Fe	248.3	247.3	0.07	<100
Zn	213.9	220.2	0.02	< 75

[1] Average concentration giving a signal of .0044 absorbance units. Minimum detectable concentration was generally about one half of the sensitivity.

as compared to NBS values are given in Table 3. These results indicate the AAS techniques used were acceptable. The only significant deviation occurred with Fe in orchard leaves. We were consistently below this NBS value using a variety of different batches of AA standards. We feel that this plant material may be resistant to complete dissolution by HNO_3:$HCLO_4$ and are trying other digestion procedures.

Analysis of Vanadium in Organisms

The sensitivity for V determination by AAS analysis is very low with a minimum detectable quantity of $\geq$ 100 ng. Instrumental neutron activation analysis (INAA) was prescribed by BLM in Attachment B, Contract AA550-CT6-17 (Appendix G) in an effort to improve the sensitivity of V analysis. The primary difficulty that must be overcome when using INAA for V in marine organisms is interference from Na-24 and Cl-38 background levels produced during irradiation. BLM prescribed the use of sulfuric acid (H_2SO_4) and hydrated antimony pentoxide (HAP) as pre-irradiation chemistry reagents for the removal of Cl and Na, respectively, from acid digests of organism samples.

These pre-irradiation chemical separations required considerable effort to implement in the laboratory. A method had to be developed for the synthesis of HAP ($Sb_2O_5 \cdot 4H_2O$) since the sole commercial source of HAP is in Italy, delivery is slow and the product variable in Na affinity. Also, large amounts of Cl, which are very difficult to remove, are introduced into the samples by using $HCLO_4$ as the oxidizing agent. To keep Cl below the interference level in the samples, it was necessary to do separate, duplicate digestions of each sample for V analysis using hydrogen peroxide (H_2O_2) as an oxidizing agent (*i.e.*, Method 2, Attachment B, Contract AA550-CT6-17, Appendix G). Chlorine concentrations after this digestion proce-

TABLE 3

ACCURACY AND PRECISION OF ATOMIC ABSORPTION ANALYSIS

Standard Reference Material	Concentration (ppm dry weight ± 1 standard deviation)						
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Bovine liver (NBS No. 1577)							
This study (8)	0.31 ± .03	0.08 ± .01	198 ± 22	257 ± 68	0.09 ± .03	0.39 ± .09	130 ± 13
NBS values	0.27 ± .04	<0.2[2]	193 ± 10	270 ± 20	<0.2[2]	0.34 ± .08	130 ± 10
Precision[1]							
This study	10	13	11	26	33	23	10
NBS values	15	NA	5	7	NA	24	8
Orchard Leaves (NBS No. 1571)							
This study (8)	0.11 ± .02	2.2 ± 0.4	12 ± 1	220 ± 40	1.1 ± 0.1	43 ± 3	24 ± 6
NBS values	0.11 ± .02	2.6 ± 0.2	12 ± 1	300 ± 20	1.3 ± 0.2	45 ± 3	25 ± 3
Precision[1]							
This study	18	18	8	18	9	7	25
NBS values	18	8	8	7	15	7	12

[1] Precision expressed as percent coefficient of variation *i.e.* std. dev./mean x 100.

[2] Not certified values.

dure were at acceptable levels and no further treatment was required. The HAP procedure was modified from Girardi and Sabbioni (1968). A batch method was used to remove Na from the sample digests. The HNO_3:H_2O_2 digest of a 0.5 to 1 g dry-weight sample was added to a 50 ml screw-top, polyethylene centrifuge tube containing from 0.1 to 0.5 g of HAP. Enough 70% HNO_3 was added to provide a final acid concentration of about 10 N. After shaking for five minutes, the samples were centrifuged and the supernatant poured into a 50 ml teflon beaker. This step was repeated using 10 ml of 70% HNO_3. The teflon beaker contents were then evaporated to a volume which could conveniently be poured into a 1.5 ml irradiation polyvial used by the Texas A&M University Nuclear Science Center. The vial was heat-sealed to prevent sample loss during analysis.

Each sample was irradiated separately for two minutes by a 1 MW TRIGA REACTOR. This process was facilitated by a pneumatic transport system which can rapidly transfer samples in and out of the reactor core. The sample was first placed in a secondary poly vial, together with an aluminum flux monitor, before being transported to the core for irradiation. Standards prepared from commercial AAS standards or pure metals were used.

After return of the sample and a 1-minute delay, the aluminum flux monitor was counted by a multi-channel pulse height analyzer. After an appropriate delay period (usually 3-5 minutes, so that the dead time was < 30%), the irradiated sample was placed on an ORTEC GE (Li) detector and counted using a separate GEOS Quanta 4096 channel pulse height analyzer. After a 5-minute counting period, the spectrum was stored on magnetic tape.

Data reduction was done using the program HEVESY (Schlueter, 1972). This program calculates peak intensities and converts them to concentration by comparison with standards. Corrections were made for varying delay times, dead times and neutron fluxes.

In spite of achieving acceptable levels of Na and Cl in the sample digests, the average minimum detectable quantity (MDQ) for V was about 60 ng. Many samples were below the limit of detection. This relatively poor sensitivity was apparently due to interference from the considerable remaining sample matrix. This problem was exacerbated by the fact that the concentration in many samples was low (*i.e.* < 0.3 ppm), and relatively large samples were required to get a sufficient amount of V for analysis. Another problem on a small percentage of samples was Sb carryover to the treated samples. Although Sb lends no direct interference to INAA determination of V, its neutron cross-section is large enough to render the sample sufficiently "hot" after even two minutes irradiation to increase the dead time to a prohibitive level. Sometimes this situation can be compensated for by altering the counting geometry. In either case, the sensitivity for detecting V-52 is severely reduced and most often no useable data derived.

One characteristic of INAA is its capability for analyzing several elements from a single irradiation. Concurrent with V analysis, the concentrations of Al, Ca and Cu were determined. However, the analytical conditions could not be optimized for all four elements during a single irradiation. The sensitivity for Al was good and the Al concentration data satisfactory. However, the sensitivity for Ca was marginal and many of the samples were below the detection limit which was quite variable and often very high. The sensitivity for Cu was very poor and almost all the samples were below the elevated detection limit. These less-than values were consistent with Cu concentrations for the same samples determined by AAS analysis, but are of no practical use.

RESULTS AND DISCUSSION

Table 4 gives the trace metals concentrations data for the six rig monitoring samples. To give some basis for comparison, especially for the species occurring in only one sample group (*i.e.*, either pre- or post-drilling) the mean trace metals concentrations for all samples of each species collected from the STOCS study area during 1976 are also given in the table. These averages were calculated using all less-than values at the indicated limit of detection to avoid excluding too much data from consideration. Consequently, the true 1976 means are lower than indicated values.

This data set is of very limited use as a means of detecting changes in organismal trace metals concentrations as a result of drilling operations. Only three species were collected before and after rig operations, and only one species, *Loligo pealei* (squid), occurred in both pre- and post-drilling sample groups. Due to seasonal variability in species composition of epifaunal and demersal fish populations, it is difficult to draw conclusions as to the effects of drilling on the trace metals content of the samples, but several trends are apparent (see Holland, Chapter 11 and Wohlschlag, Chapter 12). The species sampled are all quite mobile and capable of traveling considerable distances during the time the rig was in operation. The residence time of the organisms sampled within the immediate vicinity of the rig is unknown but could have been very limited.

A few observations can be made from the data in Table 4. The trace metals levels in organisms from the rig monitoring area, both before and after rig operation, are generally similar to levels in samples of the species from outside the area. *Loligo pealei* collected before and after drilling activity had similar trace metals concentrations. The levels in

TABLE 4

TRACE METALS CONCENTRATIONS IN MUSCLE TISSUE FROM ORGANISMS COLLECTED BEFORE AND AFTER OIL RIG DRILLING OPERATIONS COMPARED TO ANNUAL MEAN CONCENTRATIONS FOR ALL SAMPLES OF THE SAME ORGANISMS COLLECTED DURING 1976 THROUGHOUT THE STOCS STUDY AREA

Species	Sample Code or Year	Number of Samples	Concentration (µg/g dry weight ± 1 standard deviation)									
			Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	Al	Ca
PRE-DRILLING												
Loligo pealei (squid)	TBH	1	1.3	<0.05	11	3.6	<0.09	<0.03	<0.1	50	70	590
	1976	12	0.18±0.20	0.03±0.02	13±13	4.6±4.5	0.16±0.13	0.13±0.10	0.2±0.2	47±9	30±15	450±250
Peprilus burti (butterfish)	TBJ	1	0.02	<0.03	1.5	5.4	0.07	0.20	<0.1	20	31	660
	1976	4	0.09±0.05	0.03±0.01	0.9±0.3	6.3±1.3	0.13±0.10	0.06±0.06	0.2±0.7	11±1.4	32±9	320±210
Trachurus lathami (rough scad)	TBI	1	0.02	<0.03	2.0	9.6	0.11	0.02		23		
	1976	12	0.05±0.03	0.04±0.05	2.1±0.7	13±6.1	0.13±0.10	0.07±0.04	0.1±0.1	21±4.1	20±8	710±246
POST-DRILLING												
Loligo pealei (squid)	BDGD	1	0.29	0.06	22	4.0	0.27	0.02	<0.5	43		
	1976	12	0.18±0.20	0.03±0.02	13±13	4.6±4.5	0.16±0.13	0.13±0.10	0.2±0.2	47±9	30±15	450±250
Penaeus aztecus (brown shrimp)	BDGE	1	0.02	0.07	29	2.2	0.16	0.08	<0.3	48		
	1976	9	0.08±0.04	0.04±0.02	30±5	3.7±3.4	0.17±0.11	0.07±0.06	0.3±0.2	58±6	27±7	960±650
Syacium gunteri (shoal flounder)	BDGC	1	<0.01	<0.07	0.5	4.5	<0.20	<0.02	<0.7	14		
	1976	8	0.01±0.00	0.05±0.02	0.7±0.1	3.5±0.8	0.12±0.03	0.03±0.01	0.2±0.1	6.6±3.1	30±6	690±170

Penaeus aztecus (brown shrimp) and *Syacium gunteri* (shoal flounder) collected only after rig operation were not significantly different from the mean concentrations in samples of these species collected outside the rig monitoring area during 1976.

CONCLUSIONS

The trace metals data set reported herein is too limited in size and too variable in sample composition to permit a realistic assessment of the possible impact which offshore oil drilling operations have on the trace metals concentrations in organisms living in the immediate vicinity of the rig. Keeping these limitations in mind, the data set suggests that drilling operations have no effect on the concentrations of trace metals in organisms in the immediate vicinity.

LITERATURE CITED

Anonymous. 1971. Instruction Manual for Jarrell-Ash Model 810 atomic absorption spectrophotometer (Engineering Pub. #82-810). Jarrell-Ash Division, Fisher Scientific Company, Waltham, Massachusetts. 54 p.

_____. 1972. Atomic Absorption Analytical Methods. Jarrell-Ash Division, Fisher Scientific Company, Waltham, Massachusetts.

_____. 1974. Analytical methods for atomic absorption spectroscopy using the HGA-2100 graphite furnace (#990-9972). Perkin-Elmer Corporation, Norwalk, Conneticut. 43 p.

_____. 1976. BLM STOCS Monitoring Study Contract No. 08550-CT6-17. Bureau of Land Management, Washington, D.C. 109 p.

Girardi, F. and E. Sabbioni. 1968. Selective removal of radio-sodium from neutron-activated materials by retention on hydrated antimony pentoxide. J. Radio. and Chem. 1:169-178.

Schlueter, D. J. 1972. HEVESY, a general activation analysis computer program. Report TEES. 9002-1972-1. Texas A&M University, College Station, Texas 41 p.

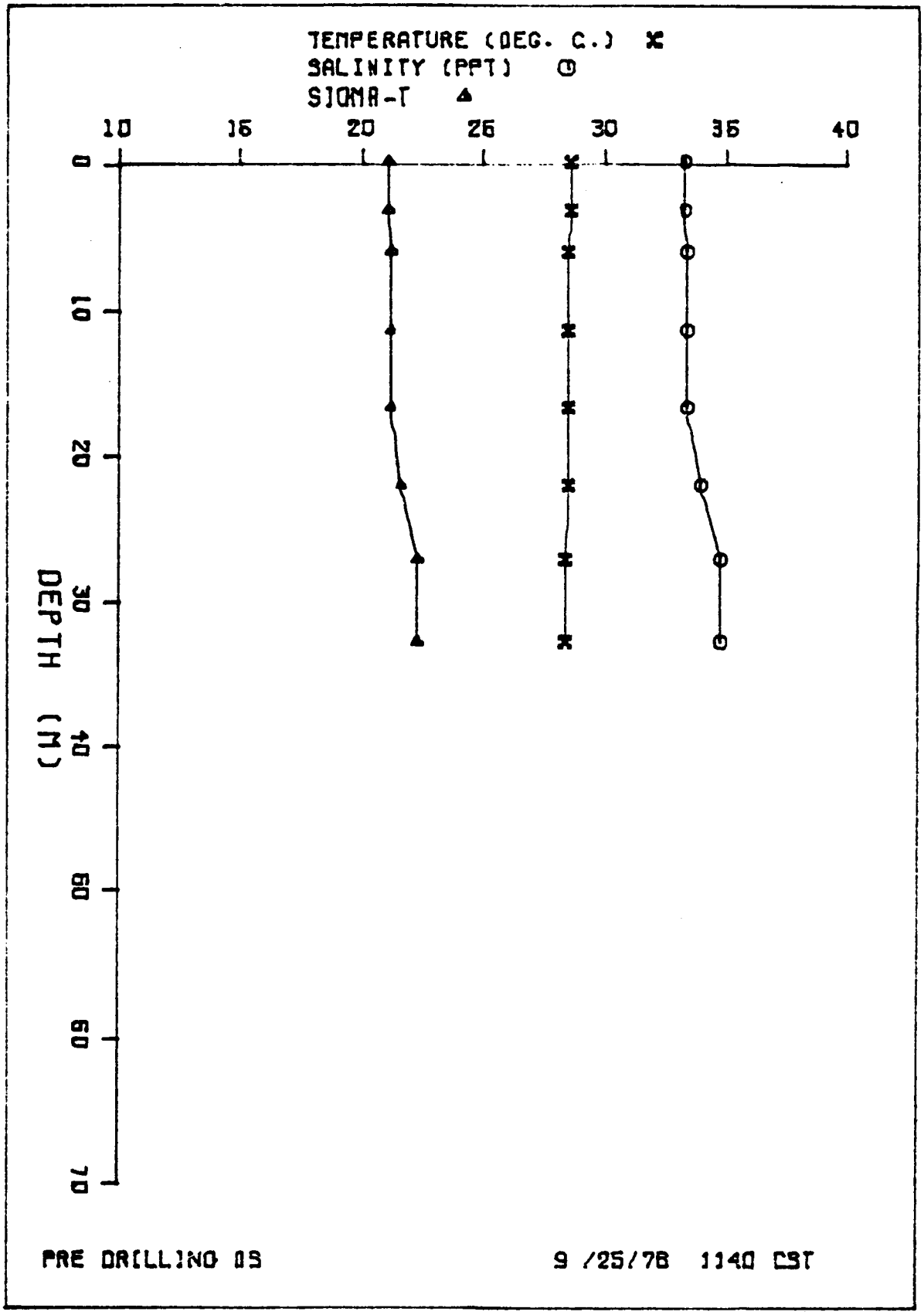
APPENDIX A

HYDROGRAPHIC DATA

Calibrated and computed hydrographic variables are presented in the following tables. Depth is in meters, temperature (TEMP) is in degrees centigrade, salinity (SALIN) is in parts per thousand, Sigma-t is defined by (density -1) x 10^3 in gm/cm^3, specific volume anomaly (SVA) is in cm^3/gm, the dynamic height anomaly (DLTA D) is in dynamic-centimeters, the potential energy anomaly (POT EN) is in gm m^2 (sec^2) the speed of sound (SOUND VEL) is in m/sec, and the Brunt-Vaisala frequency (BV FRQ) is in cycles/hour.

HYDROGRAPHIC CAST DATA PKE DRILLING DS
9/25/76 1140 CST SAMPLE CODE ATAA

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	28.43	33.22	20.94	684.5	0.00	0.00	1540.6	0.0
3.4	28.43	33.22	20.94	685.0	.23	.00	1540.7	42.9
6.2	28.33	33.29	21.02	677.1	.42	.01	1540.6	42.9
11.5	28.33	33.29	21.02	677.4	.78	.05	1540.7	0.0
16.8	28.33	33.26	21.02	677.7	1.14	.10	1540.7	73.3
22.1	28.33	33.90	21.48	633.8	1.49	.17	1541.5	115.4
27.2	28.23	34.72	22.13	571.6	1.80	.24	1542.2	88.9
32.9	28.23	34.72	22.13	572.0	2.12	.34	1542.3	0.0

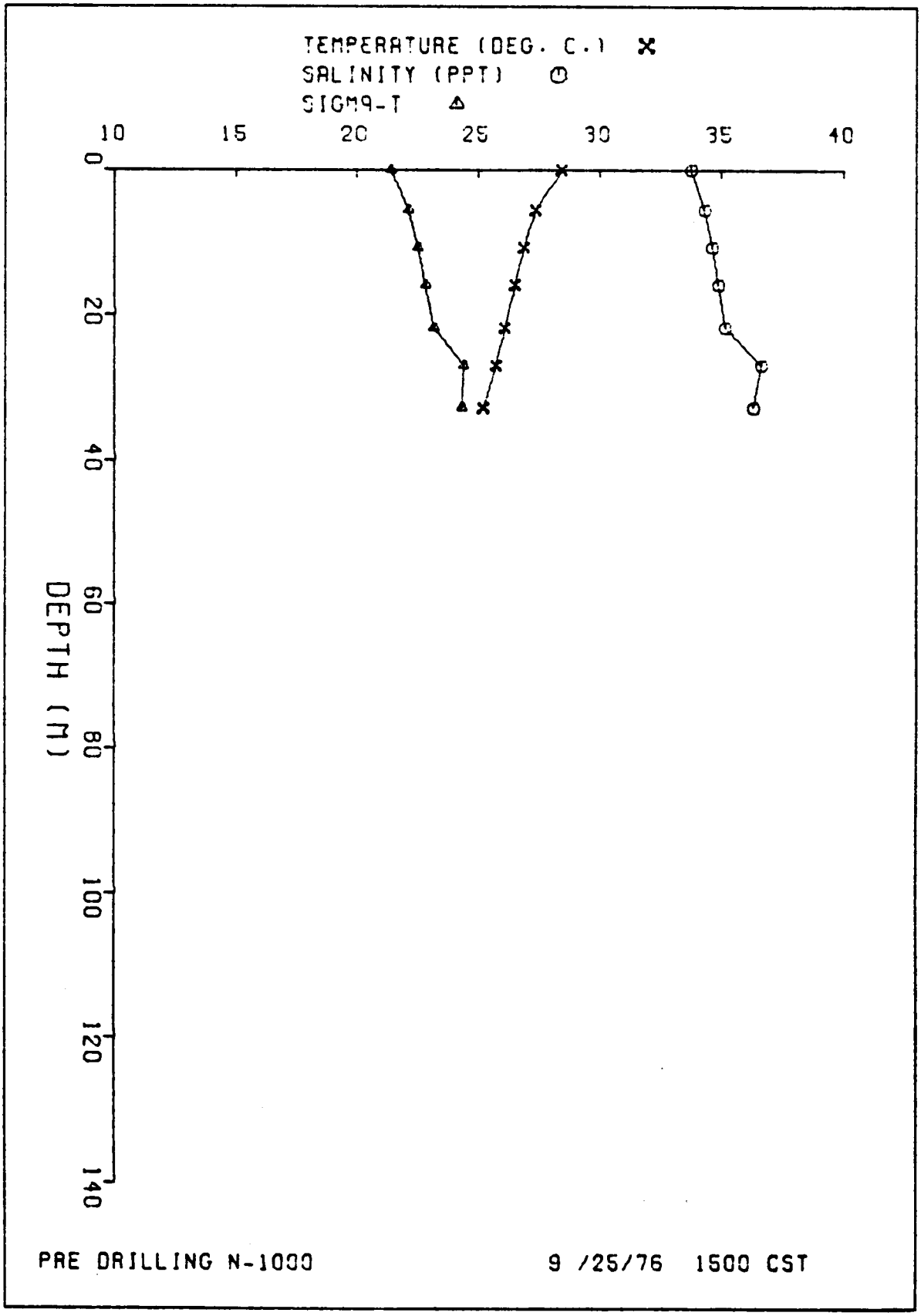

TEMPERATURE (DEG. C.) ✱
SALINITY (PPT) ⊙
SIGMA-T ▲
10
15
20
25
30
35
40
0
10
20
30
40
60
80
70
DEPTH (M)
PRE DRILLING 05
9/25/78 1140 CST

HYDROGRAPHIC CAST DATA PRE DRILLING N-1000
9/25/76 1500 CST SAMPLE CODE ATCO

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	28.42	33.51	21.16	663.3	0.00	0.00	1540.9	133.6
5.5	27.33	34.09	21.95	588.1	.34	.01	1539.2	118.1
10.7	26.86	34.45	22.37	547.9	.64	.03	1538.7	95.1
15.9	26.49	34.74	22.71	515.9	.91	.07	1538.2	89.6
21.8	26.07	35.08	23.09	479.6	1.21	.13	1537.8	138.1
27.0	25.70	36.60	24.36	359.2	1.43	.18	1538.7	120.1
32.8	25.19	36.31	24.30	365.1	1.64	.25	1537.3	57.8
32.9	25.18	36.32	24.31	364.5	1.64	.25	1537.3	89.2

HYDROGRAPHIC CAST DATA PRE DRILLING E-1000
9/26/76 1240 CST SAMPLE CODE ATFS

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	28.35	33.56	21.22	657.5	0.00	0.00	1540.8	104.3
8.6	27.12	34.03	21.98	586.0	.53	.02	1538.7	117.8
13.4	26.33	34.57	22.63	523.6	.80	.05	1537.6	117.3
20.0	25.38	34.93	23.20	469.7	1.13	.11	1536.0	102.8
26.5	24.45	35.29	23.75	417.3	1.42	.18	1534.3	126.4
32.9	23.53	36.39	24.86	311.9	1.65	.25	1533.4	146.4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SALINITY (PPT) ⊙
SIGMA-T △
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15
20
25
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35
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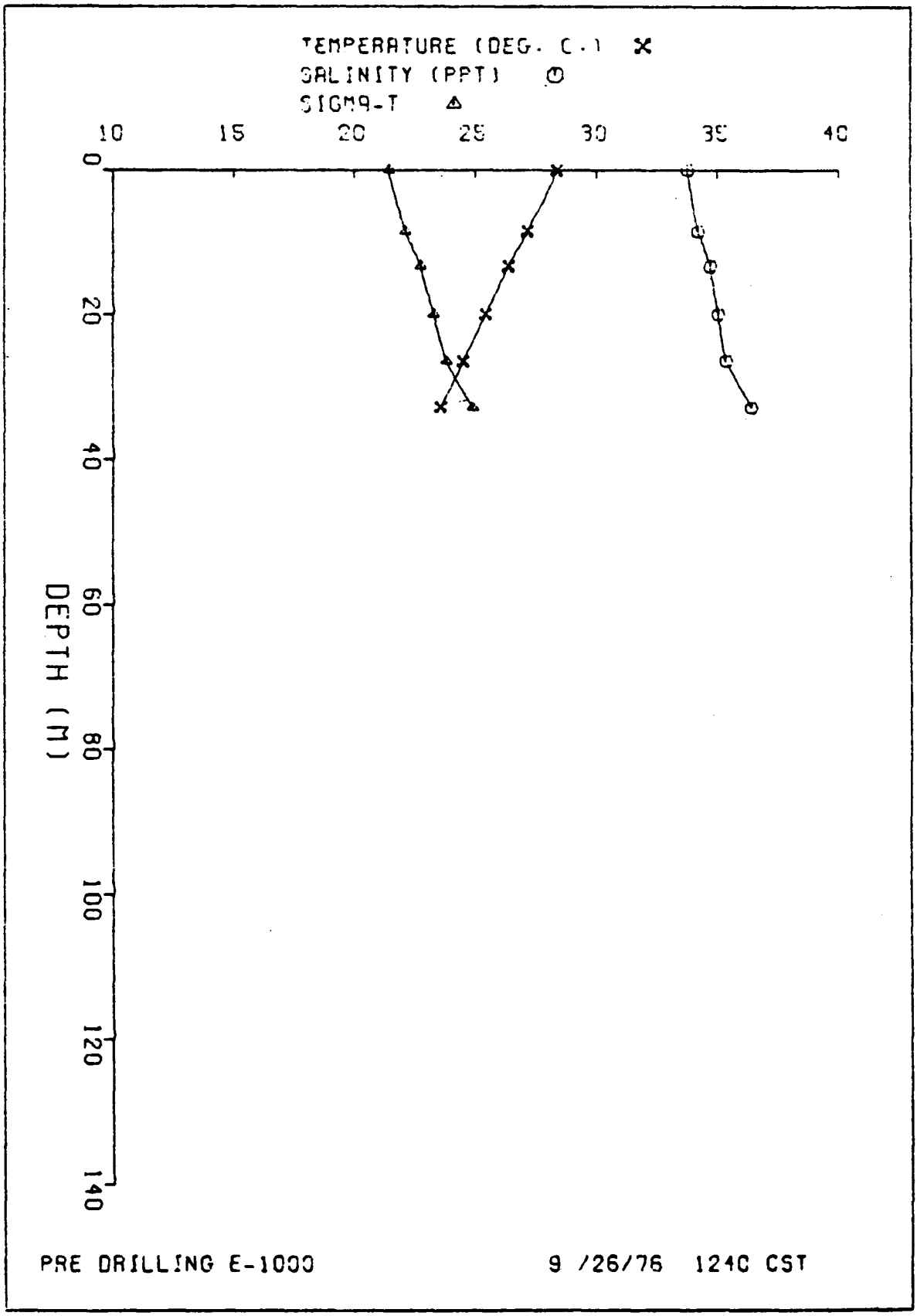
20
40
60
80
100
120
140
DEPTH (M)
PRE DRILLING N-1000
9 /25/76 1500 CST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SALINITY (PPT) ⊙
SIGMA-T △
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35
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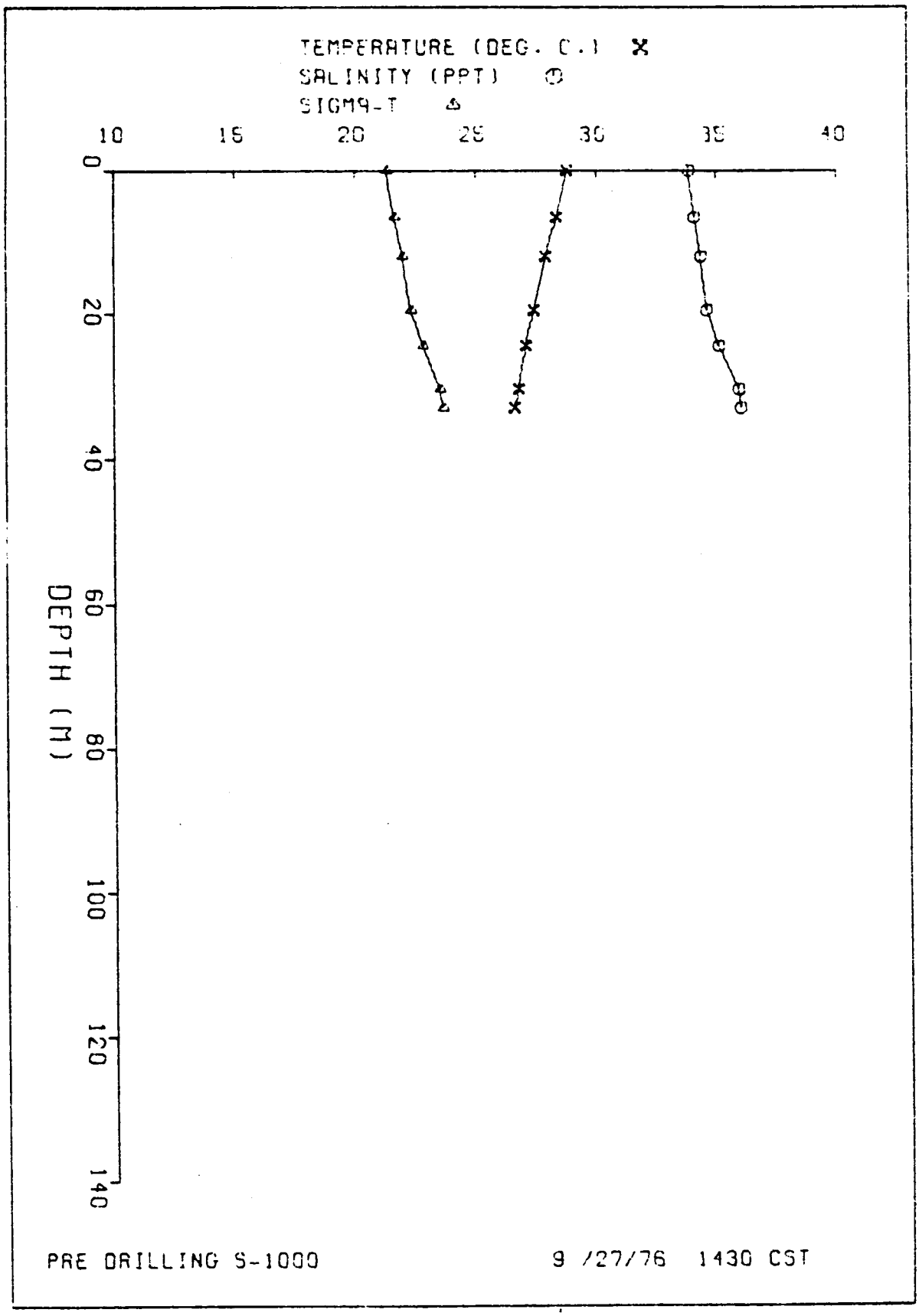
0
20
40
60
80
100
120
140
DEPTH (M)
PRE DRILLING E-1000
9 /26/76 1240 CST

HYDROGRAPHIC CAST DATA PRE DRILLING S-1000
9/27/76 1430 CST SAMPLE CODE ATIS

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	28.76	33.27	20.87	691.3	0.00	0.00	1541.4	86.7
6.6	28.32	33.61	21.27	653.5	.44	.01	1540.9	92.0
12.1	27.86	33.97	21.69	613.8	.79	.05	1540.4	91.8
19.5	27.37	34.35	22.13	571.5	1.23	.12	1539.8	103.5
24.4	27.05	34.94	22.66	518.9	1.50	.18	1539.9	123.0
30.4	26.75	35.87	23.47	443.7	1.79	.26	1540.3	109.0
32.9	26.59	36.00	23.62	429.5	1.90	.29	1540.1	86.2

HYDROGRAPHIC CAST DATA PRE DRILLING W-1000
9/25/76 700 CST SAMPLE CODE ATLS

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	27.97	33.48	21.29	651.4	0.00	0.00	1539.9	110.9
7.0	27.37	34.15	21.98	585.4	.45	.01	1539.4	107.9
11.7	27.17	34.61	22.40	545.7	.70	.04	1539.5	121.3
17.1	26.70	35.48	23.20	469.2	.97	.08	1539.6	121.9
22.2	26.27	35.92	23.67	424.9	1.20	.13	1539.1	106.3
27.7	25.80	36.39	24.17	377.3	1.42	.18	1538.7	82.0
32.9	25.25	36.29	24.26	368.8	1.62	.24	1537.4	46.6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SIGMA-T Δ
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15
20
25
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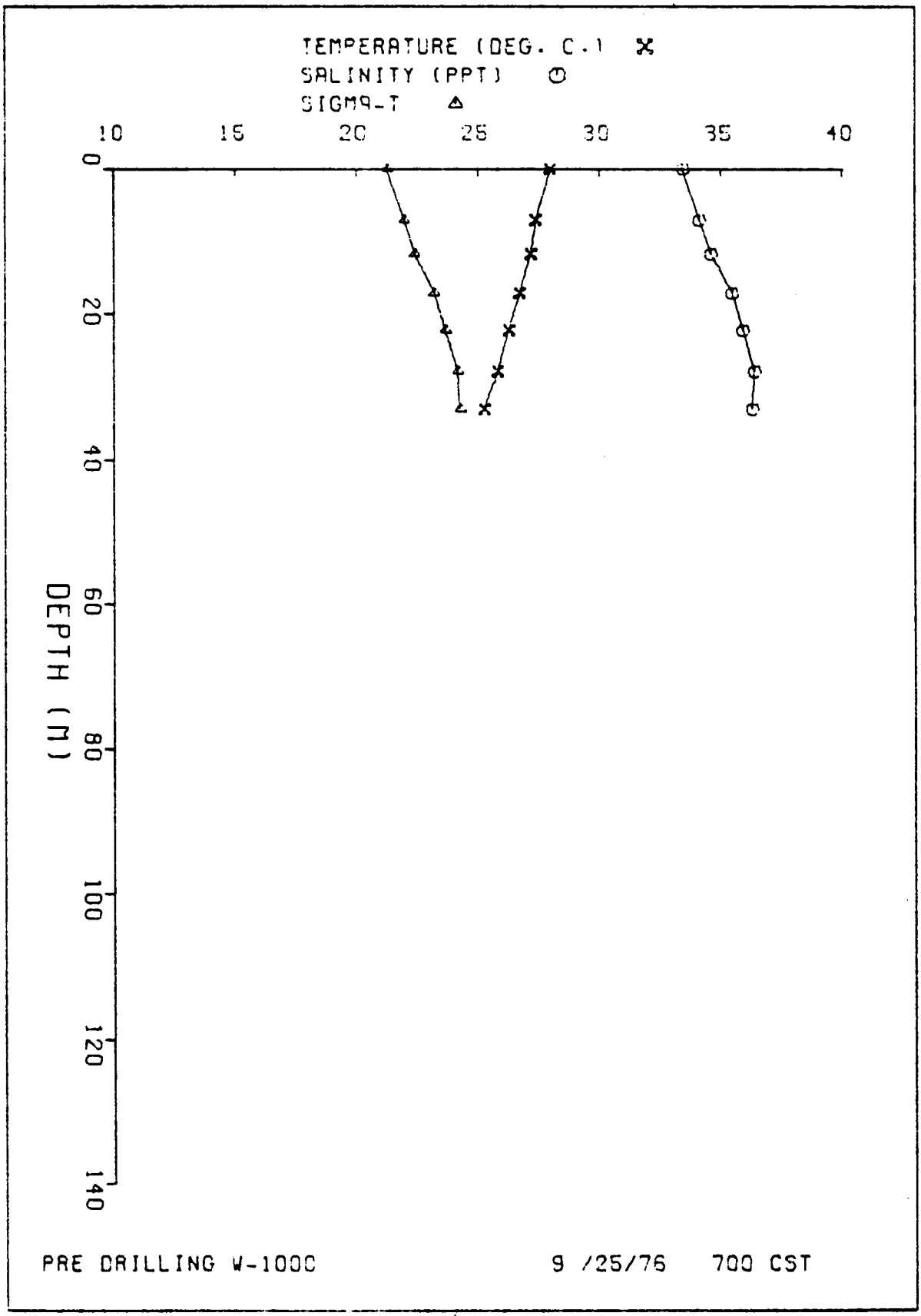
20
40
60
80
100
120
140
DEPTH (M)
PRE DRILLING S-1000
9 /27/76 1430 CST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SALINITY (PPT) O
SIGMA-T Δ
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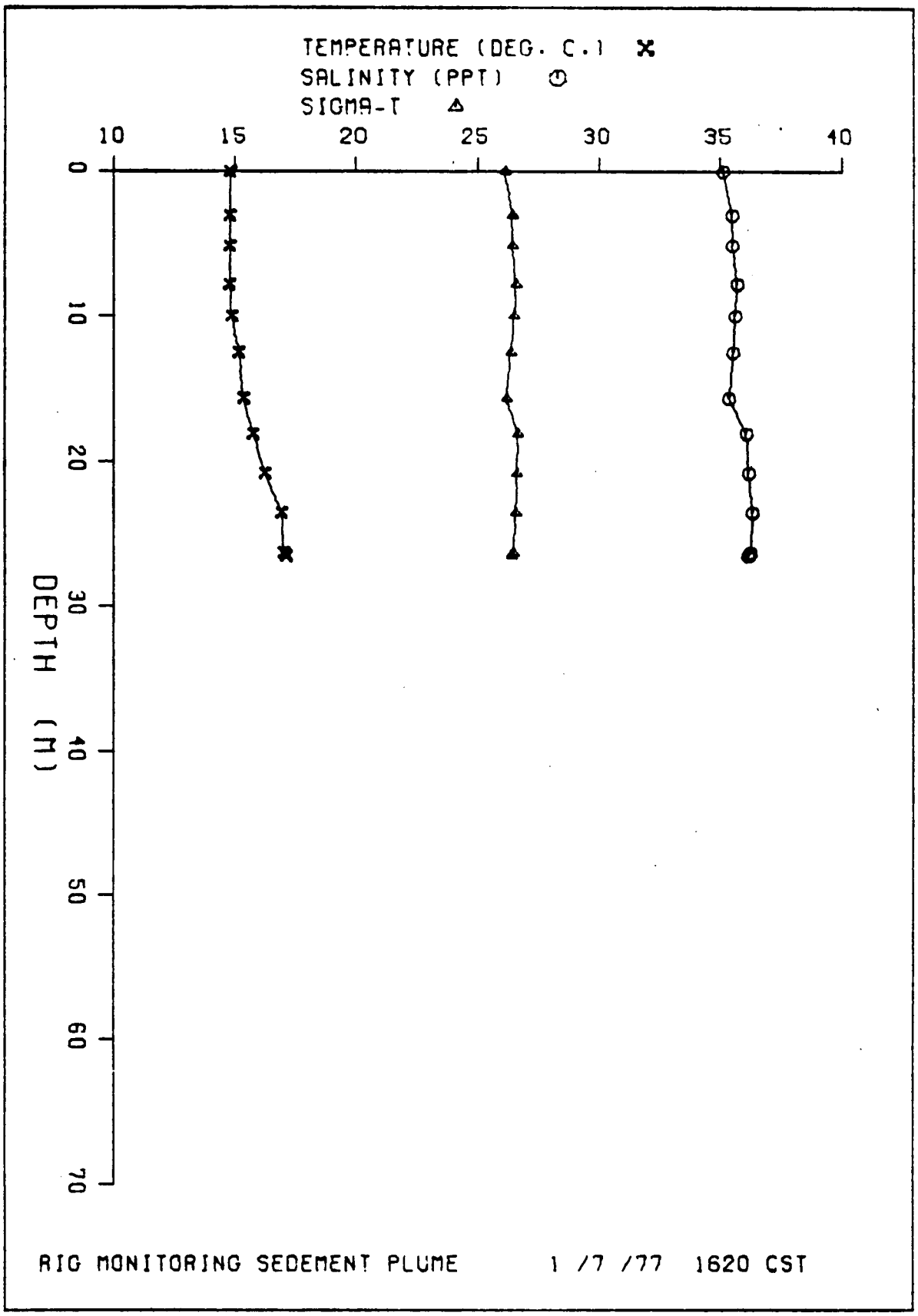
15
20
25
30
35
40
0
20
40
60
80
100
120
140
DEPTH (M)
PRE DRILLING W-1000
9 /25/76 700 CST

HYDROGRAPHIC CAST DATA RIG MONITORING SEDIMENT PLUME

1/ 7/77 162? CST SAMPLE CODE AZUJ

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	14.78	35.10	26.12	190.4	0.00	0.00	1506.8	110.3
3.0	14.77	35.48	26.41	162.7	.05	.02	1507.3	79.4
5.1	14.77	35.49	26.42	162.0	.09	.03	1507.3	60.8
7.8	14.77	35.69	26.57	147.7	.13	.04	1507.6	32.6
10.0	14.86	35.60	26.49	155.9	.16	.01	1507.9	0.0
12.5	15.16	35.52	26.36	168.4	.20	.01	1508.7	0.0
15.6	15.35	35.35	26.18	185.2	.26	.02	1509.2	90.4
18.1	15.75	36.08	26.65	140.4	.30	.03	1511.3	102.8
20.8	16.24	36.16	26.61	145.0	.34	.04	1513.0	0.0
23.5	16.94	36.33	26.57	148.7	.38	.04	1515.3	0.0
26.3	17.03	36.25	26.48	156.8	.42	.06	1515.6	0.0
26.5	17.13	36.16	26.39	165.7	.42	.06	1515.8	0.0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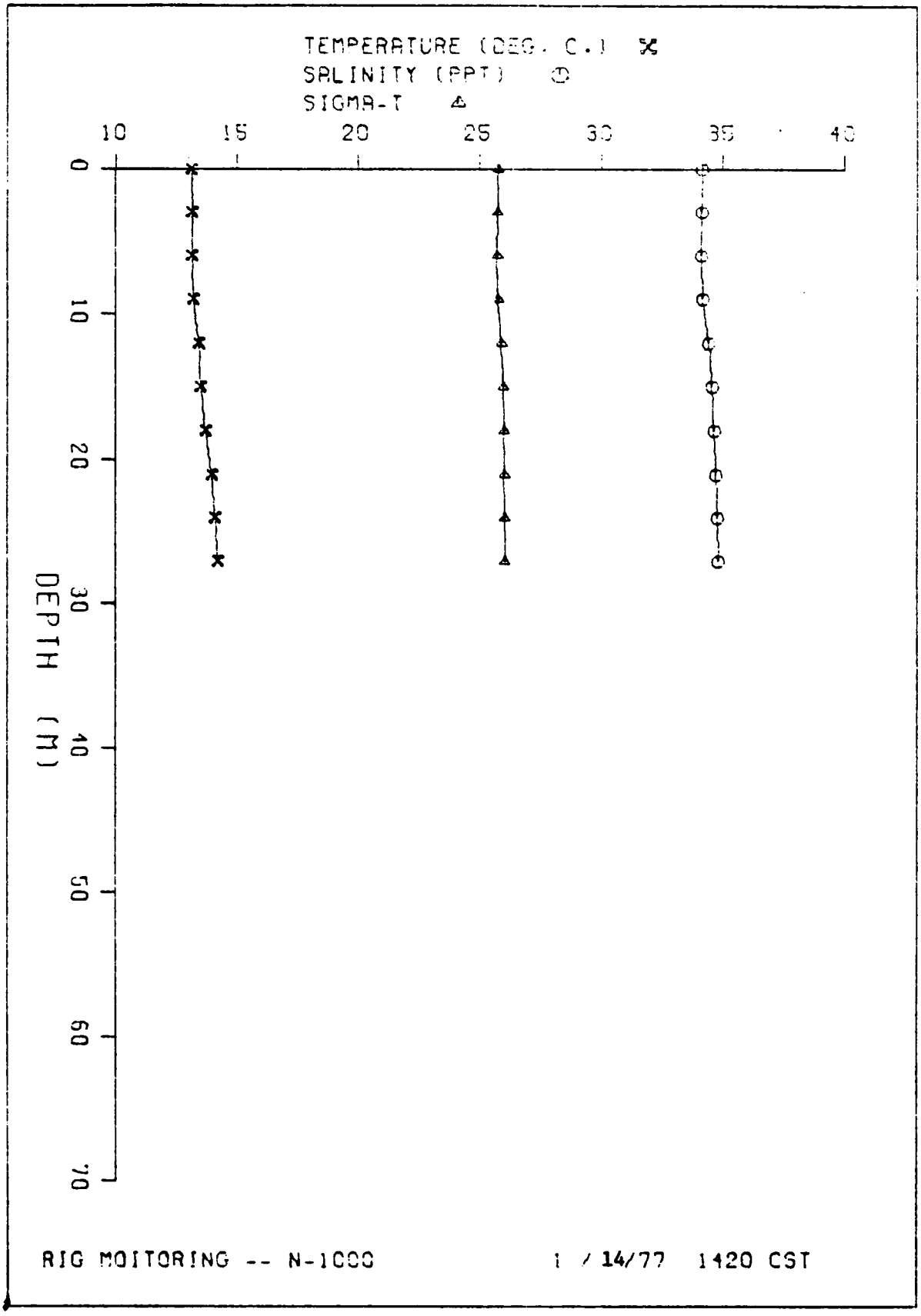
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
RIG MONITORING SEDEMENT PLUME
1 /7 /77 1620 CST

HYDROGRAPHIC CAST DATA RIG MOITORING -- N-1000
1/14/77 142° CST SAMPLE CODE AZVA

TH	TEMP	SALIN	SIGMA T	SVA	DELTA D	POT EN	SOUND VEL	BV FRQ
0.0	13.11	34.14	25.73	227.5	0.00	0.00	1500.2	0.0
3.0	13.14	34.12	25.71	229.8	.07	.00	1500.3	0.0
6.0	13.15	34.11	25.70	230.5	.14	.00	1500.4	19.0
9.0	13.19	34.16	25.72	228.3	.21	.01	1500.6	59.5
12.0	13.42	34.41	25.87	214.3	.27	.02	1501.7	69.2
15.0	13.51	34.54	25.96	206.3	.34	.03	1502.2	49.0
18.0	13.70	34.63	25.99	203.4	.40	.04	1503.0	28.8
21.0	13.96	34.72	26.00	202.7	.46	.05	1504.0	19.8
24.0	14.11	34.77	26.01	201.8	.52	.06	1504.6	16.6
27.0	14.21	34.80	26.01	201.6	.58	.08	1505.1	11.4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SALINITY (PPT) ⊙
SIGMA-T △
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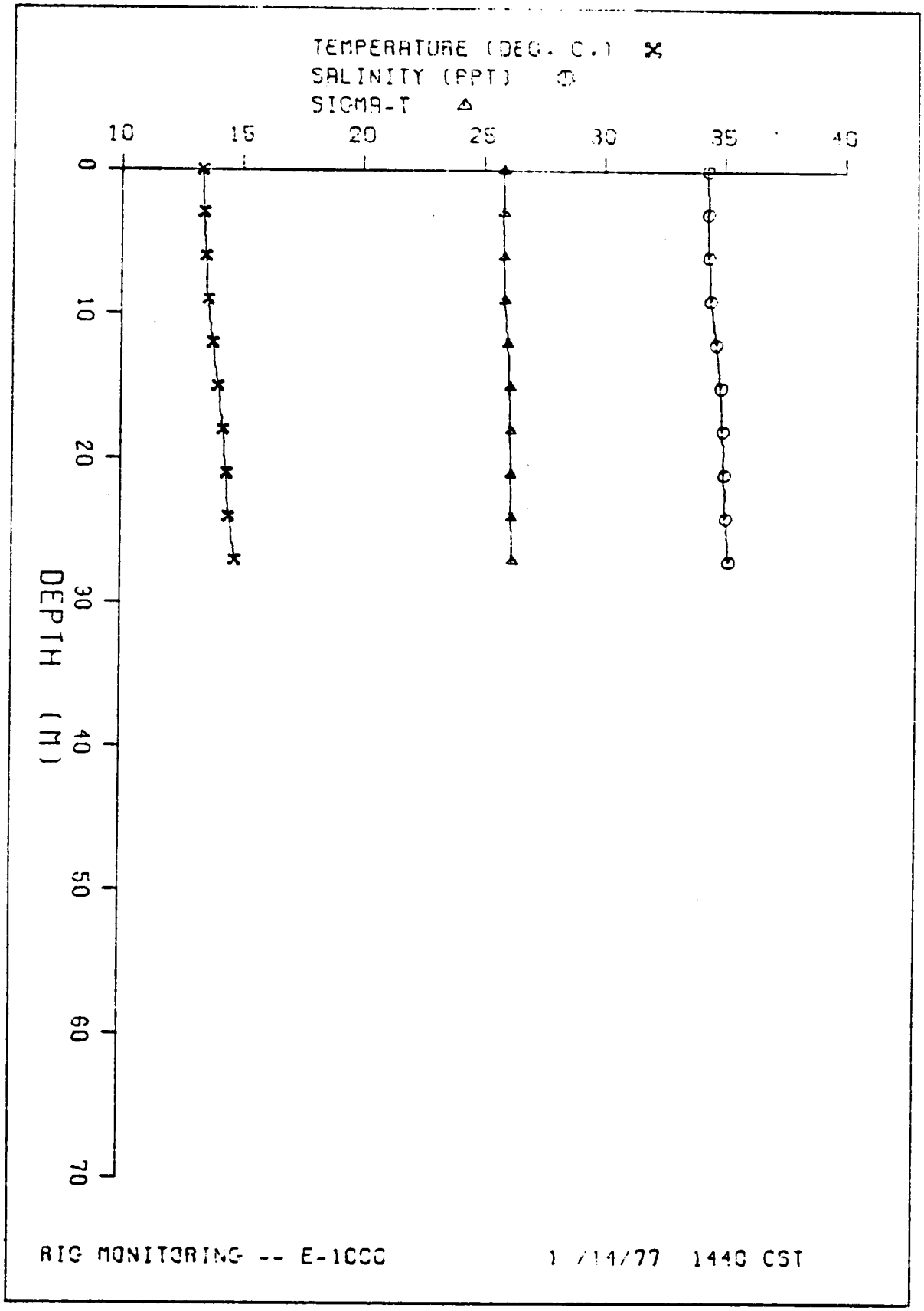
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
RIG MOITORING -- N-1000
1 / 14/77 1420 CST

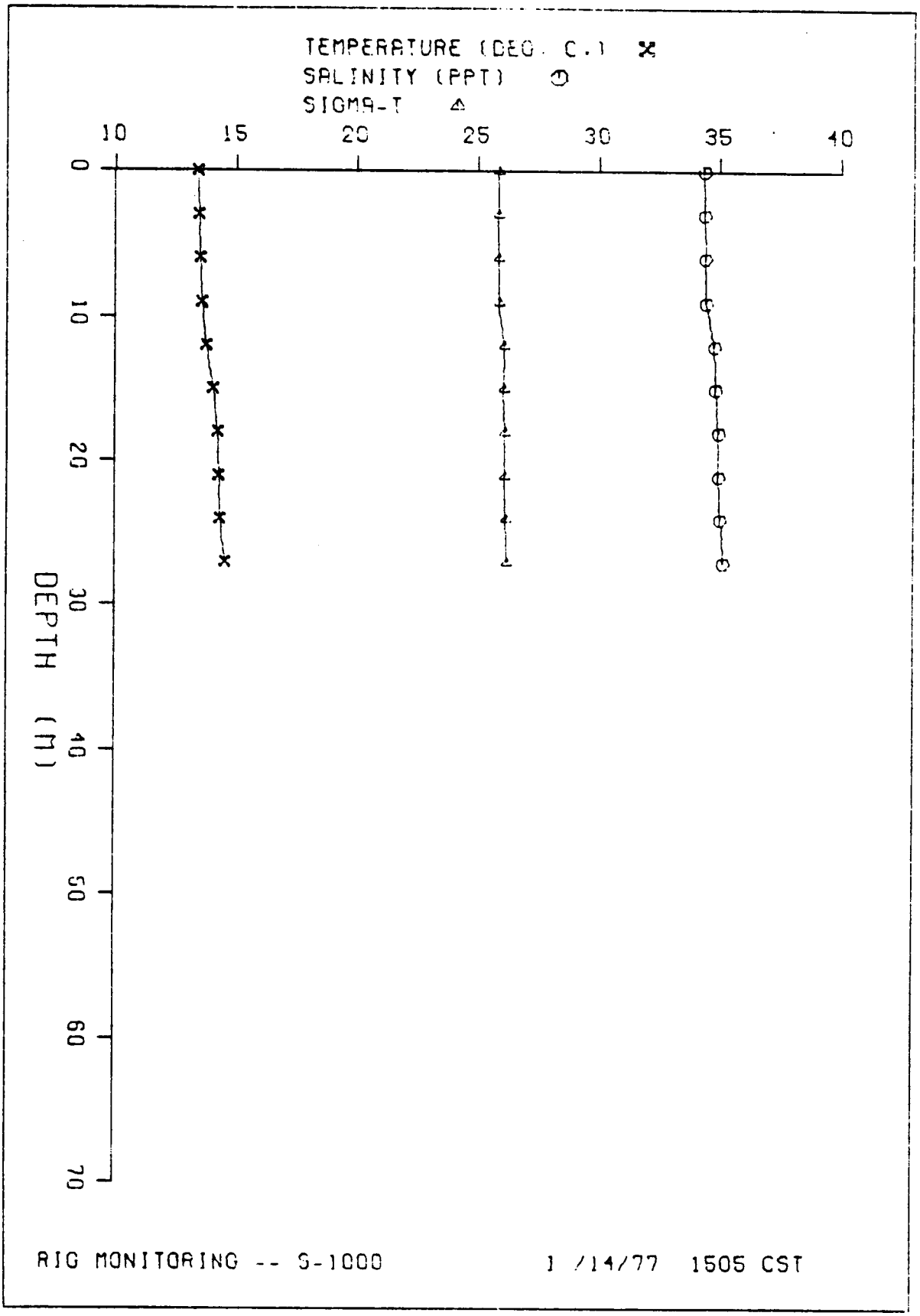
HYDROGRAPHIC CAST DATA RIG MONITORING -- E-1000
1/14/77 1445 CST SAMPLE CODE AZVD

DEPTH	TEMP	SALIN	SIGMA T	SVA	DELTA D	POT EN	SOUND VEL	BV FRQ
0.0	13.31	34.27	25.79	221.6	0.00	0.00	1501.0	8.1
3.0	13.37	34.29	25.79	221.8	.07	.00	1501.3	11.8
6.0	13.45	34.32	25.80	221.4	.13	.00	1501.6	32.9
9.0	13.55	34.41	25.84	217.0	.20	.01	1502.1	62.1
12.0	13.76	34.65	25.98	203.7	.26	.02	1503.2	71.3
15.0	13.99	34.84	26.09	193.7	.32	.02	1504.2	53.2
18.0	14.20	34.94	26.12	190.8	.38	.03	1505.0	31.4
21.0	14.33	35.00	26.14	189.3	.44	.05	1505.6	27.9
24.0	14.44	35.06	26.16	187.4	.49	.06	1506.1	38.2
27.0	14.70	35.20	26.21	182.8	.55	.07	1507.1	45.4


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
RIG MONITORING -- E-1000
1/14/77 1440 CST

HYDROGRAPHIC CAST DATA RIG MONITORING -- S-1000
1/14/77 1500 CST SAMPLE CODE AZVG

DEPTH	TEMP	SALIN	SIGMA T	SVA	DELTA D	POT EN	SOUND VEL	BV FRQ
0.0	13.40	34.34	25.82	218.3	0.00	0.00	1501.4	0.0
3.0	13.45	34.35	25.82	219.1	.07	.00	1501.6	13.6
6.0	13.49	34.38	25.83	217.9	.13	.00	1501.8	23.1
9.0	13.57	34.41	25.85	216.8	.20	.01	1502.2	70.6
12.0	13.76	34.76	26.07	195.1	.26	.02	1503.3	65.0
15.0	14.04	34.81	26.05	197.5	.32	.02	1504.3	26.6
18.0	14.23	34.94	26.11	192.0	.38	.03	1505.1	33.2
21.0	14.28	34.94	26.10	192.5	.43	.05	1505.4	27.6
24.0	14.33	35.01	26.15	188.7	.49	.06	1505.7	41.8
27.0	14.55	35.13	26.19	184.6	.55	.07	1506.6	42.3


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
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15
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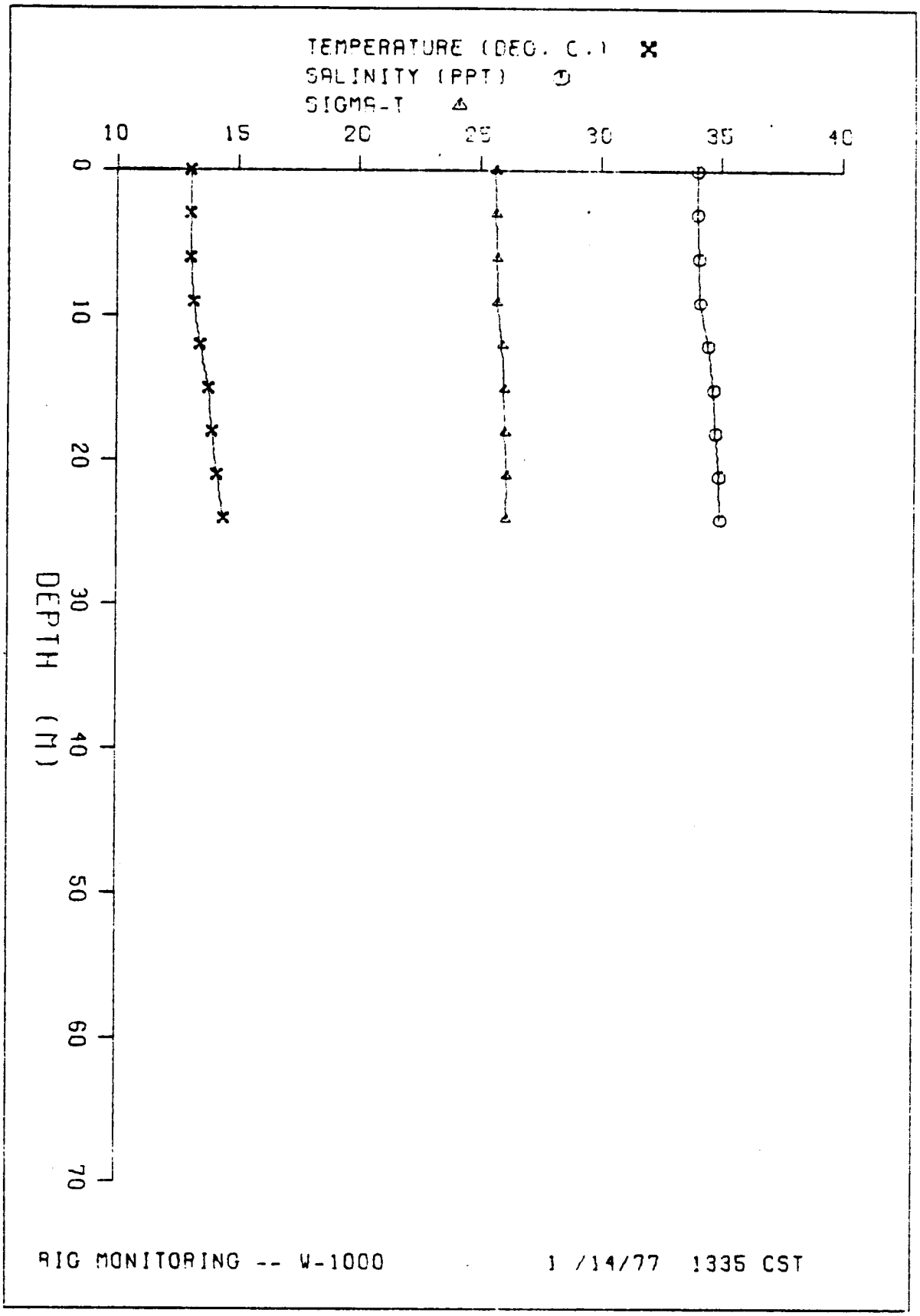
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
RIG MONITORING -- S-1000
1 /14/77 1505 CST

HYDROGRAPHIC CAST DATA RIG MONITORING -- W-1000
1/14/77 1335 CST SAMPLE CODE AZVJ

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	13.02	33.99	25.63	237.0	0.00	0.00	1499.7	12.8
3.0	13.02	33.99	25.63	237.0	.07	.00	1499.7	33.4
6.0	13.02	34.06	25.68	232.3	.14	.00	1499.9	34.3
9.0	13.16	34.10	25.69	231.7	.21	.01	1500.4	67.4
12.0	13.42	34.45	25.90	211.5	.28	.02	1501.8	80.6
15.0	13.77	34.67	26.00	201.9	.34	.03	1503.3	51.8
18.0	13.93	34.75	26.03	199.7	.40	.04	1503.9	43.6
21.0	14.14	34.89	26.10	193.3	.46	.05	1504.8	31.1
24.0	14.40	34.94	26.08	195.4	.52	.06	1505.8	0.0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SALINITY (PPT) ⊙
SIGMA-T △
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10
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30
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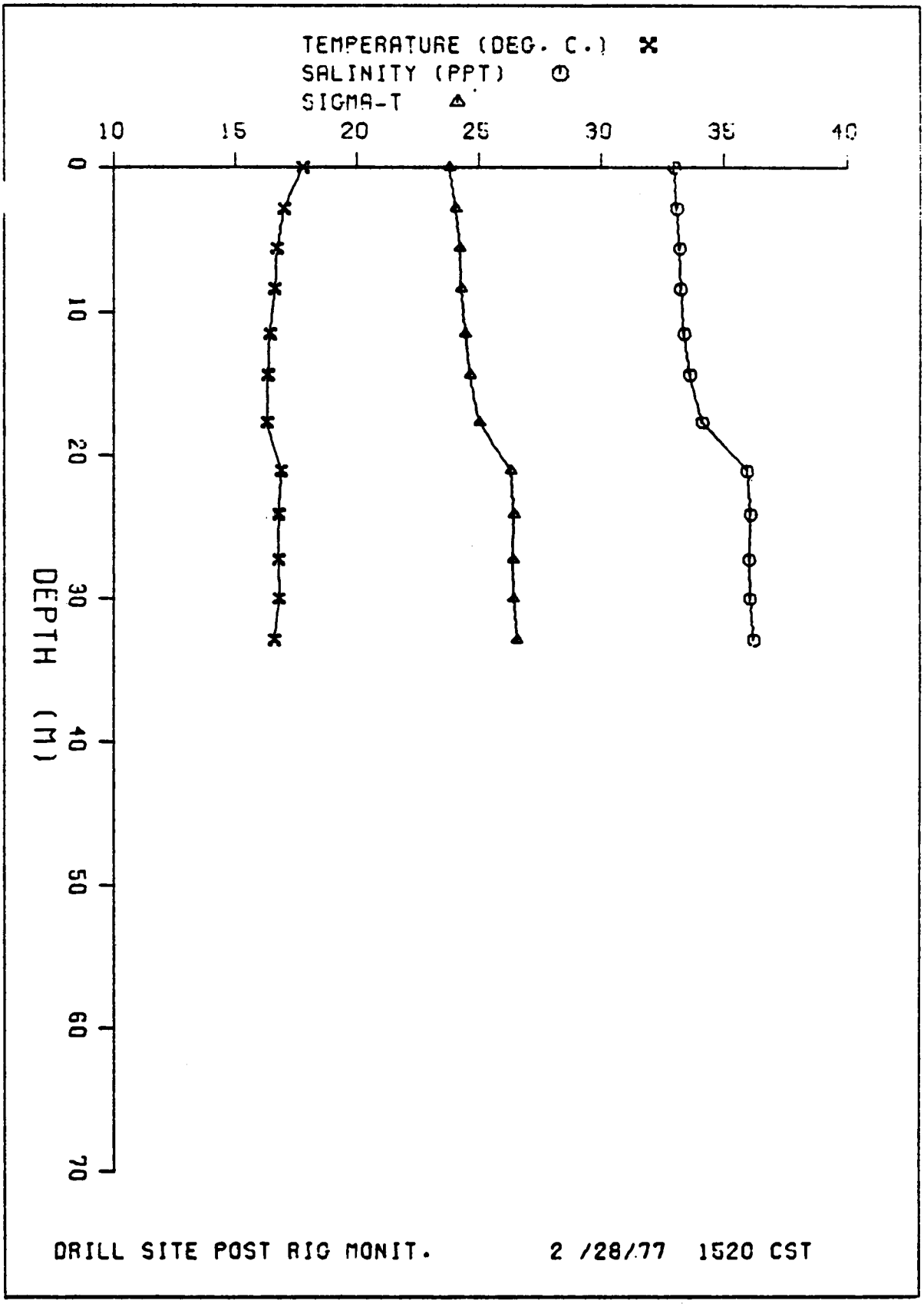
50
60
70
DEPTH (M)
RIG MONITORING -- W-1000
1 /14/77 1335 CST

HYDROGRAPHIC CAST DATA POST RIG MON. DRILL SITE
2/28/77 152? CST SAMPLE CODE HDCA

DEPTH	TEMP	SALIN	SIGMA T	SVA	DELTA D	POT EN	SOUND VEL	BV FRQ
0.0	15.77	33.93	24.73	369.7	.00	.00	1507.3	98.7
2.8	15.15	33.94	24.45	349.1	.10	.01	1505.5	87.4
5.6	15.04	33.17	24.58	337.3	.20	.01	1505.4	56.0
8.4	15.12	33.22	24.60	335.7	.29	.01	1505.7	50.7
11.5	15.10	33.35	24.71	325.3	.39	.02	1505.9	74.5
14.4	15.19	33.58	24.86	310.4	.49	.04	1506.5	99.7
17.7	15.37	34.09	25.21	277.1	.59	.05	1507.7	171.5
21.1	16.15	35.94	26.46	158.9	.66	.07	1512.5	155.9
24.1	16.23	36.08	26.54	151.2	.71	.09	1512.9	10.4
27.2	16.41	36.33	26.46	158.9	.75	.09	1513.5	0.0
30.0	16.60	36.06	26.45	160.4	.80	.11	1514.1	43.8
32.9	16.58	36.20	26.55	150.5	.84	.12	1514.3	67.1


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
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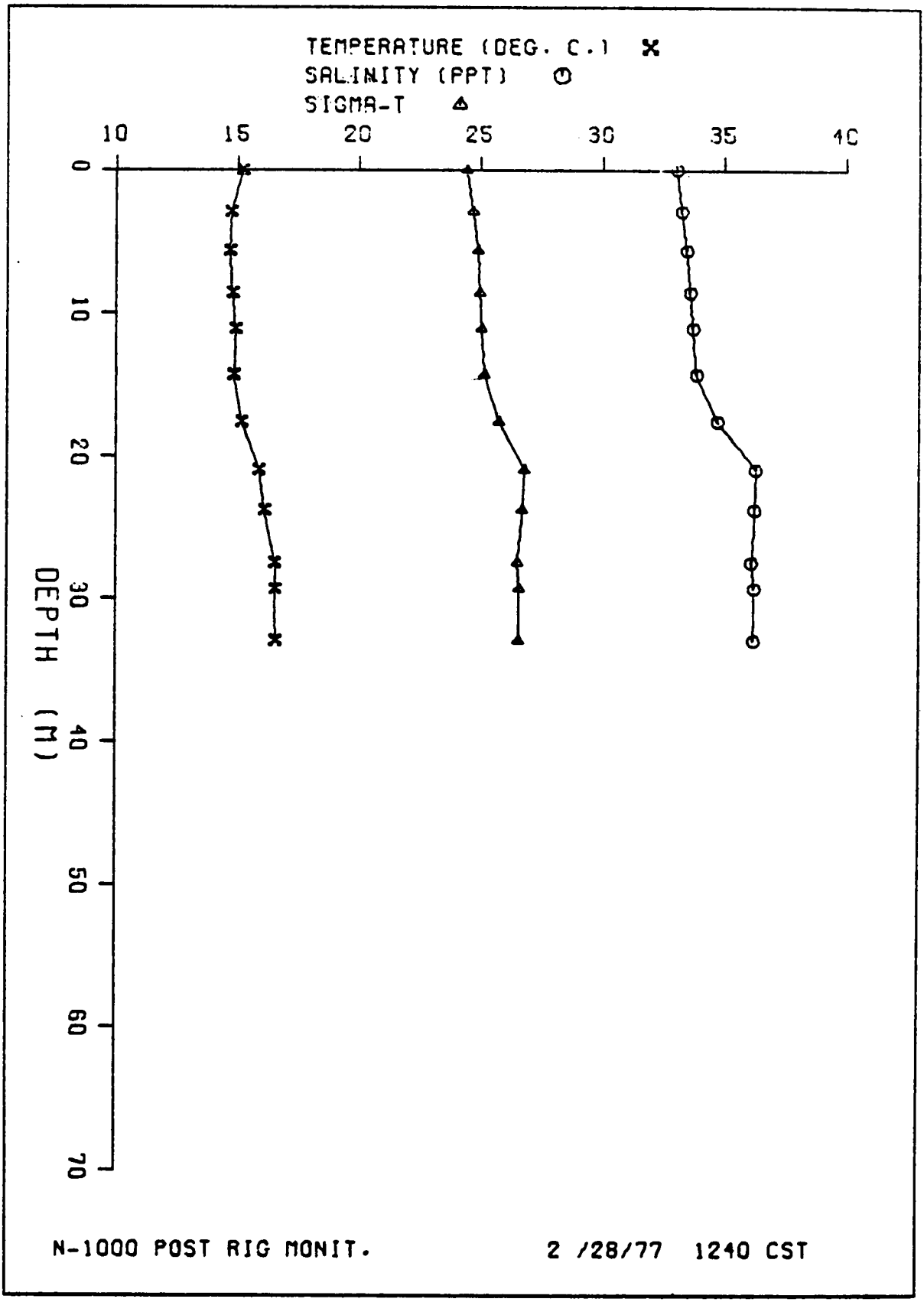
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
DRILL SITE POST RIG MONIT.
2 /28/77 1520 CST

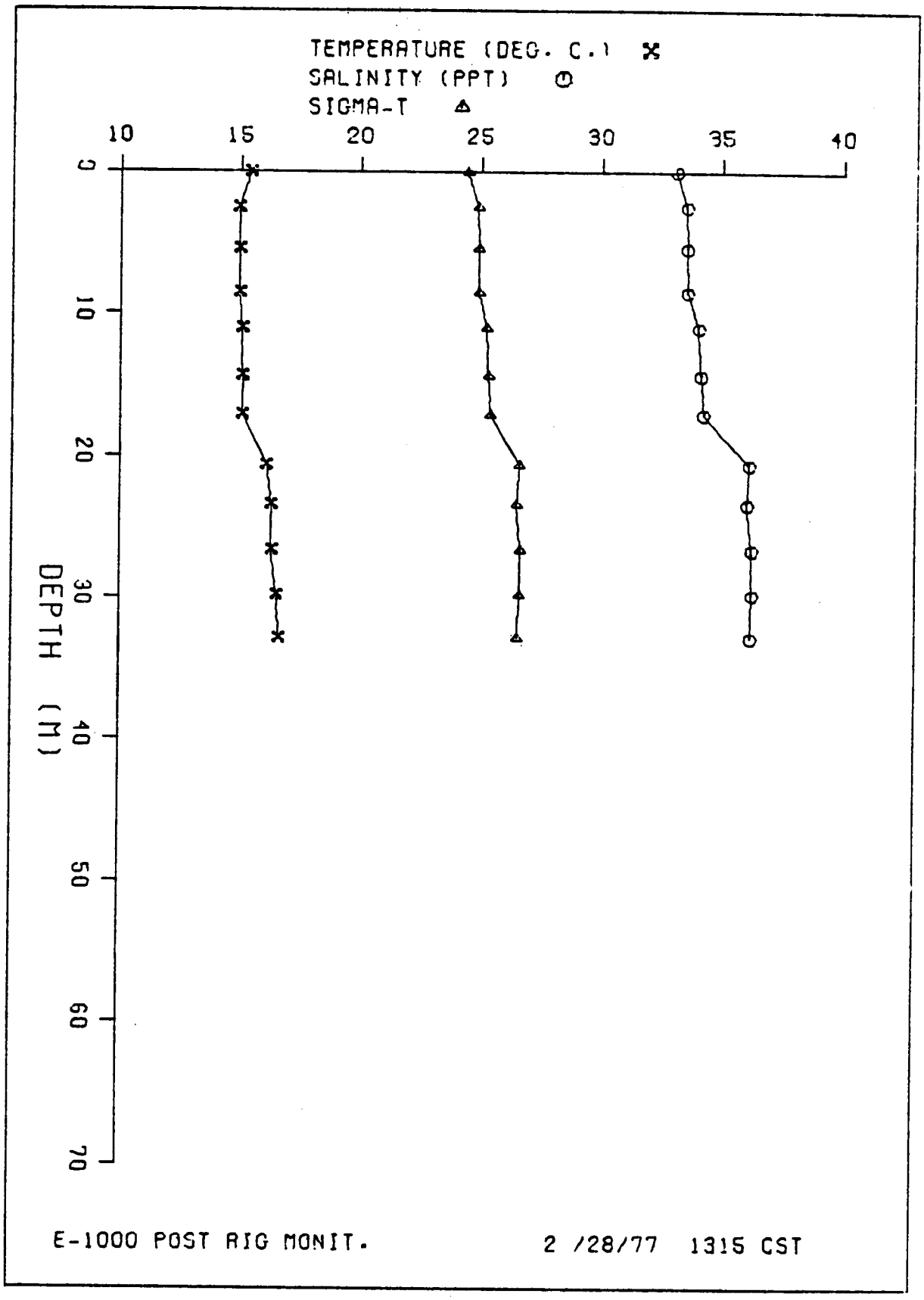
HYDROGRAPHIC CAST DATA POST RIG MON. N-1000
2/28/77 1345 CST SAMPLE CODE RDCH

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	15.38	33.14	24.48	345.9	0.00	0.00	1506.3	0.0
3.2	15.18	33.04	24.45	349.6	.11	.00	1505.6	59.2
5.5	15.09	33.22	24.60	334.9	.19	.01	1505.6	80.2
8.7	15.19	33.40	24.72	323.9	.30	.01	1506.2	58.0
11.3	15.29	33.49	24.77	319.5	.38	.02	1506.7	32.3
14.1	15.30	33.49	24.76	319.9	.47	.03	1506.7	92.0
17.6	15.30	34.12	25.25	274.0	.57	.05	1507.5	159.3
20.8	16.31	35.55	26.12	191.3	.65	.06	1512.5	149.7
23.8	16.31	35.90	26.39	165.7	.70	.08	1512.9	76.4
26.9	16.51	35.98	26.4[illegible]	164.6	.75	.09	1513.7	0.0
30.[illegible]	16.62	35.98	26.3[illegible]	174.9	.81	.11	1514.0	29.6
32.9	16.62	36.06	26.44	161.5	.85	.12	1514.2	75.2


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
N-1000 POST RIG MONIT.
2 /28/77 1240 CST

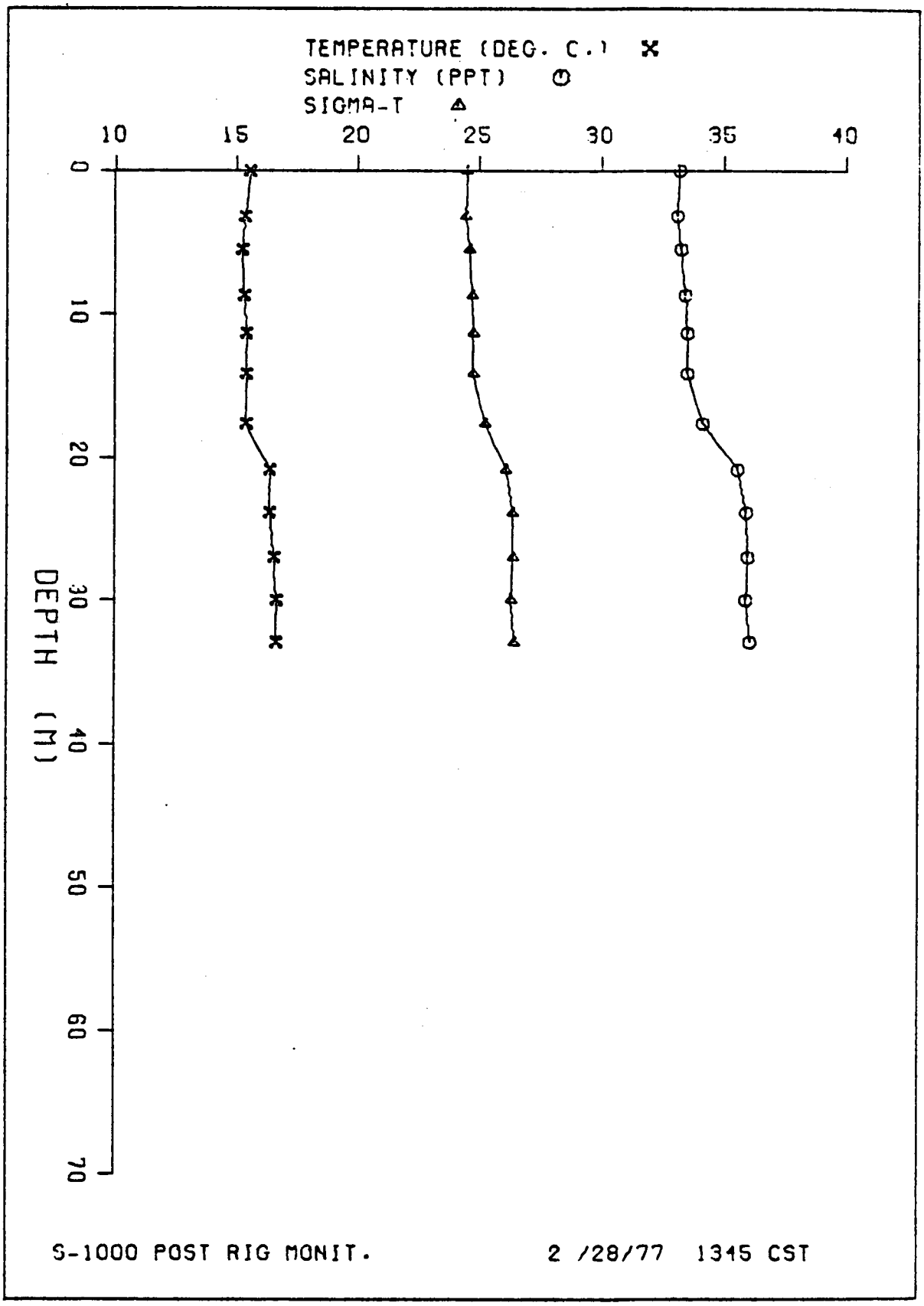
HYDROGRAPHIC CAST DATA POST RIG MON. E-1008
2/28/77 1315 CST SAMPLE CODE HDCJ

DEPTH	TEMP	SALIN	SIGMA T	SVA	ULTA U	POT EN	SOUND VEL	BV FRQ
0.0	15.40	33.06	24.41	352.9	0.00	0.00	1506.3	149.2
2.5	14.91	33.50	24.86	310.4	.08	.00	1505.3	106.6
5.4	14.92	33.52	24.87	309.4	.17	.00	1505.4	21.5
8.5	14.93	33.54	24.88	308.4	.27	.01	1505.5	92.7
11.0	15.04	34.01	25.22	276.3	.34	.02	1506.5	99.3
14.4	15.06	34.12	25.31	268.6	.44	.03	1506.7	57.6
17.1	15.07	34.23	25.38	261.1	.51	.04	1506.9	153.9
20.6	16.08	36.13	26.62	143.7	.58	.06	1512.5	139.4
23.4	16.29	36.25	26.51	154.1	.62	.07	1513.1	21.5
26.6	16.31	36.25	26.66	140.2	.67	.08	1513.4	45.7
29.8	16.52	36.26	26.62	144.1	.71	.09	1514.1	0.0
32.9	16.63	36.19	26.54	152.0	.76	.11	1514.4	0.0


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
E-1000 POST RIG MONIT.
2 /28/77 1315 CST

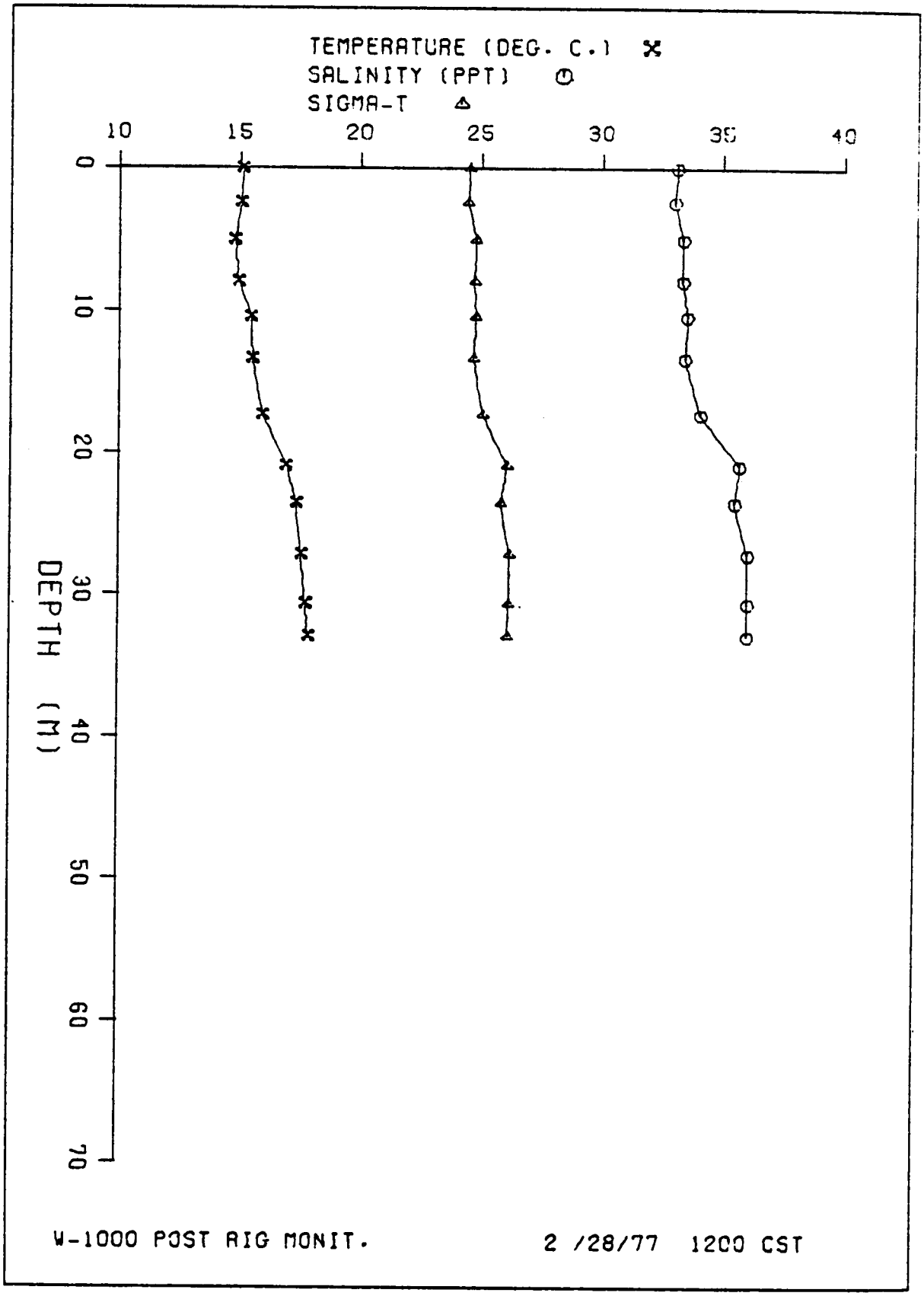
HYDROGRAPHIC CAST DATA POST RIG MON. S-1000
2/28/77 1245 CST SAMPLE CODE BDCL

DEPTH	TEMP	SALIN	SIGMA T	SVA	DELTA D	POT EN	SOUND VEL	BV FRQ
0.0	15.21	33.02	24.42	351.6	0.00	[illegible]	1505.6	105.4
2.9	14.73	33.22	24.68	327.1	.10	.00	1504.4	99.[illegible]
5.6	14.65	33.44	24.87	309.6	.18	.01	1504.5	76.9
8.6	14.78	33.58	24.95	301.9	.28	.01	1505.1	59.6
11.1	14.90	33.71	25.03	294.8	.35	.02	1505.7	64.9
14.3	14.82	33.85	25.15	283.3	.44	.03	1505.6	116.5
17.6	15.15	34.72	25.75	226.4	.53	.05	1507.8	175.7
20.9	15.88	36.30	26.80	127.0	.59	.06	1512.1	132.7
23.7	16.11	36.25	26.70	135.8	.63	.07	1512.7	0.0
27.4	16.53	36.12	26.50	155.0	.68	.08	1513.9	0.0
29.3	16.54	36.23	26.59	146.9	.71	.09	1514.1	47.5
32.9	16.57	36.20	26.56	150.1	.76	.1[illegible]	1514.2	0.0


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
S-1000 POST RIG MONIT.
2 /28/77 1345 CST

HYDROGRAPHIC CAST DATA POST RIG MON. W-1000
2/28/77 12?5 CST SAMPLE CODE BDCN

DEPTH	TEMP	SALIN	SIGMA T	SVA	DLTA D	POT EN	SOUND VEL	BV FRQ
0.0	15.10	33.06	24.48	346.5	0.00	0.0	1505.3	0.0
2.4	15.03	32.96	24.42	352.4	.08	.01	1505.0	79.4
5.0	14.77	33.32	24.75	321.2	.17	.01	1504.7	84.4
7.9	14.93	33.32	24.71	324.3	.27	.01	1505.2	11.2
10.4	15.46	33.51	24.75	321.3	.35	.02	1507.2	0.0
13.3	15.52	33.42	24.66	329.3	.44	.03	1507.3	66.7
17.3	15.93	34.07	25.07	291.1	.57	.05	1509.4	154.1
20.9	16.92	35.70	26.09	194.3	.66	.07	1514.5	107.5
23.5	17.36	35.51	25.84	218.2	.71	.08	1515.6	13.4
27.2	17.56	36.05	26.20	183.5	.78	.10	1516.9	72.9
30.6	17.75	36.05	26.16	187.8	.85	.12	1517.5	0.0
32.9	17.87	36.05	26.13	190.7	.89	.13	1517.9	0.0


TEMPERATURE (DEG. C.) ✕
SALINITY (PPT) ⊙
SIGMA-T △
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
DEPTH (M)
W-1000 POST RIG MONIT.
2 /28/77 1200 CST

APPENDIX B

HIGH-MOLECULAR-WEIGHT HYDROCARBONS IN SEDIMENT

Table of Contents

TABLE 1.1

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATAJ- (D.S.) PERIOD : PRE-RIG
LOCATION : STATION - 1 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.05310	2143	.08980
1670	.01060	2386	.02990
1700	.02900	2623	.03270
1780	.00720	2792	.05490
1800	.05360	3027	.26700
1900	.04410	3218	.11300
2000	.02130	3282	.11900
2073	.15800	3345	.04100
2100	.01270	3409	.12900
2144	.08050	3445	.04780
2200	.02960	3736	1.66000
2300	.04380		
2400	.03430		
2500	.08870		
2600	.06120		
2700	.18900		
2800	.06080		
2900	.40300		
3000	.10300		
3100	.52200		
3200	.10700		
3300	.27500		
3345	.03460		
3400	.32300		
3455	.17400		
3527	.09180		
TOTAL	3.01090	TOTAL	2.58410

TABLE 1.2

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATCW- (N-1000) PERIOD : PRE-RIG
LOCATION : STATION -30 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.03470	2147	.01050
1670	.00770	2160	.01700
1700	.02440	2247	.01570
1780	.00250	2652	.06140
1800	.03430	2756	.03220
1900	.01450	2770	.02370
2000	.03140	2858	.02090
2047	.21100	2925	.01440
2100	.03060	2992	.01960
2150	.16000	3067	.21800
2200	.00830	3358	.03780
2300	.02380		
2400	.01230		
2500	.05120		
2600	.02430		
2700	.08710		
2800	.03030		
2900	.15400		
3000	.02080		
3100	.11400		
3200	.00660		
3300	.03360		
TOTAL	1.11740	TOTAL	.47120

TABLE 1.3

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATGA⁻ (E-1000) PERIOD : PRE-RIG
LOCATION : STATION -32 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.03080	1573	.01920
1670	.02080	1627	.03870
1700	.03570	1700	.02580
1780	.00450	1800	.01080
1800	.03820	1933	.01480
1900	.02080	2173	.07060
2000	.02010	2659	.04830
2047	.09490	2763	.02800
2065	.01460	2867	.02210
2100	.02580	3075	.21900
2131	.00820	3367	.05840
2200	.00230		
2300	.02050		
2400	.00900		
2500	.03400		
2600	.02300		
2700	.06310		
2800	.01200		
2900	.11900		
3000	.01640		
3100	.08910		
3200	.00450		
3300	.02890		
TOTAL	.73620	TOTAL	.55570

TABLE 1.4

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATMA - (W-1000) PERIOD : PRE-RIG
LOCATION : STATION -36 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.02330	1928	.00560
1670	.00980	2240	.01020
1700	.01710	2444	.00420
1780	.00120	2659	.05100
1800	.01530	2763	.02960
1868	.00610	2867	.05530
1900	.00780	3075	.30700
1953	.00680	3317	.02030
2000	.01080	3358	.02550
2047	.04850		
2100	.00940		
2150	.04870		
2200	.00330		
2300	.01200		
2400	.00810		
2500	.03700		
2600	.01230		
2700	.05590		
2800	.01710		
2900	.20100		
3000	.01970		
3100	.30100		
3200	.01750		
3300	.13700		
TOTAL	1.02670	TOTAL	.50870

TABLE 1.5

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATQU- (W-1000) PERIOD : PRE-RIG
LOCATION : STATION -36 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.03740	2160	.00850
1670	.00420	2333	.00750
1700	.01470	2585	.00700
1780	.00280	2662	.01850
1800	.01710	2908	.00900
1900	.01030	3000	.01070
1953	.00370	3075	.04600
2000	.00990	4600	.19300
2047	.03580		
2100	.01020		
2150	.02730		
2200	.00350		
2300	.00830		
2400	.00490		
2500	.02200		
2600	.00320		
2700	.04410		
2800	.01260		
2900	.08470		
3000	.01010		
3100	.08310		
3200	.00220		
3300	.02700		
TOTAL	.47910	TOTAL	.30020

TABLE 1.6

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATRA - (W-1000) PERIOD : PRE-RIG
LOCATION : STATION -36 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.01180	2327	.00750
1670	.00530	2654	.02290
1700	.02400	2900	.02550
1780	.00200	2992	.02260
1800	.02090	3067	.05870
1900	.01160	3092	.05000
2000	.00980	3208	.00630
2048	.03280	3333	.01720
2100	.00980		
2155	.02700		
2200	.00250		
2300	.01180		
2400	.00430		
2500	.03140		
2600	.00940		
2700	.05770		
2800	.01270		
2900	.09900		
3000	.00710		
3100	.11000		
3200	.00500		
3300	.03150		
TOTAL	.53740	TOTAL	.21070

TABLE 1.7

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : ATJA - (S-1000) PERIOD : PRE-RIG
LOCATION : STATION -34 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.02450	2004	.00360
1670	.00660	2154	.02800
1700	.01590	2425	.01530
1780	.00230	2648	.03220
1800	.01610	2762	.02080
1900	.01070	2834	.00710
1953	.00680	3028	.05250
2000	.01200	3354	.01880
2047	.05030		
2100	.01140		
2153	.02740		
2200	.00280		
2300	.01180		
2400	.00590		
2500	.02130		
2600	.01510		
2700	.04890		
2800	.01210		
2900	.10400		
3000	.01300		
3100	.11000		
3200	.00200		
3300	.04130		
TOTAL	.57220	TOTAL	.17830

TABLE 1.8

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDEV (DS) PERIOD : POST-RIG
LOCATION : STATION - 1 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00400	2198	.00110
1670	.00300	2231	.00080
1700	.00600	2309	.00110
1780	.00230	2563	.00130
1800	.00590	2753	.00110
1860	.00300	2816	.00110
1900	.00560	2958	.00160
1980	.00190	3026	.00410
2000	.00270	3147	.00160
2050	.00740	3274	.00140
2100	.00500	3436	.00290
2147	.00890		
2200	.00330		
2300	.00730		
2400	.00550		
2500	.01310		
2600	.00850		
2700	.03010		
2800	.01180		
2900	.05020		
3000	.01080		
3100	.05200		
3200	.00540		
3250	.00180		
3300	.02220		
TOTAL	.27770	TOTAL	.01810

TABLE 1.9

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDSL (DS) PERIOD : POST-RIG
LOCATION : STATION - 1 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1300	.00230	2002	.00210
1356	.00180	2106	.00190
1400	.00830	2148	.00350
1447	.00250	2401	.00330
1500	.01290	2525	.00150
1600	.01470	2614	.00220
1627	.00470	2900	.00250
1670	.01270	3045	.00290
1700	.01760	3274	.00340
1780	.00690	3464	.00220
1800	.01570		
1863	.00600		
1900	.01520		
2000	.00470		
2055	.00270		
2100	.00450		
2151	.00210		
2200	.00360		
2300	.00410		
2400	.00250		
2500	.00410		
2600	.00240		
2700	.00670		
2800	.00260		
2900	.01090		
3000	.00320		
3100	.01090		
3200	.00160		
3300	.00540		
TOTAL	.19330	TOTAL	.02550

TABLE 1.10

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDST (DS) PERIOD : POST-RIG
LOCATION : STATION - 1 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1300	.01820	1996	.00730
1370	.02040	2106	.00840
1400	.06700	2283	.00580
1447	.02040	2405	.01610
1500	.12000	2516	.00580
1558	.01130	2774	.00730
1600	.13200	2930	.00580
1659	.01070	3063	.00390
1670	.07120		
1700	.11400		
1704	.00750		
1716	.01070		
1780	.03870		
1800	.09660		
1866	.02950		
1900	.08720		
2000	.05250		
2100	.01680		
2200	.00630		
2300	.00660		
2400	.00950		
2500	.00810		
2600	.01290		
2700	.01290		
2800	.01160		
2900	.02320		
3000	.01440		
3100	.02090		
TOTAL	1.05110	TOTAL	.06040

TABLE 1.11

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDHP -(N-1000) PERIOD : POST-RIG
LOCATION : STATION -30 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1500	.00260	1776	.00800
1600	.00310	1859	.00790
1670	.00590	2002	.00430
1700	.01300	2203	.00470
1780	.00270	2406	.00430
1800	.00660	2433	.00380
1864	.00580	2645	.01340
1900	.00400	2761	.00590
1941	.00580	2844	.00800
1981	.00520	2913	.00590
2000	.00160	2977	.00800
2054	.00790	3040	.02750
2100	.00460	3174	.00730
2141	.02130	3294	.01120
2200	.00230		
2300	.00430		
2400	.00260		
2500	.00390		
2600	.00410		
2700	.01250		
2800	.00780		
2900	.02390		
3000	.00510		
3100	.02390		
3200	.00280		
3300	.01060		
3456	.01150		
3605	.00600		
TOTAL	.21140	TOTAL	.12020

TABLE 1.12

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDTQ- (E-1000) PERIOD : POST-RIG
LOCATION : STATION -32 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1500	.00070	1959	.01880
1600	.00070	2084	.01060
1670	.00080	2138	.01060
1700	.00120	2190	.01750
1780	.00030	2299	.01580
1800	.00080	2428	.00970
1863	.00090	2631	.03490
1900	.00060	2733	.02420
1940	.00050	2831	.02290
1986	.00060	2958	.01270
2000	.00020	3026	.04330
2054	.00200	3277	.01530
2100	.00070	3605	.01530
2144	.00340		
2200	.00030		
2300	.00060		
2400	.00040		
2500	.00110		
2600	.00060		
2700	.00220		
2800	.00100		
2900	.00350		
3000	.00080		
3100	.00330		
3200	.00050		
3300	.00160		
3400	.00140		
3500	.00110		
TOTAL	.03180	TOTAL	.25160

TABLE 1.13

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDWA - (S-1000) PERIOD : POST-RIG
LOCATION : STATION -34 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00350	2060	.00190
1500	.00770	2198	.00150
1600	.00650	2227	.00230
1670	.01600	2399	.00200
1700	.00940	2420	.00200
1780	.00260	2620	.00660
1800	.00970	2753	.00610
1864	.00800	2973	.00370
1900	.00540	3055	.00410
1977	.00240	3169	.00250
2000	.00100	3355	.00330
2051	.00640	3443	.00570
2100	.00440		
2200	.00150		
2300	.00650		
2400	.00520		
2500	.00480		
2600	.00560		
2700	.01520		
2800	.00880		
2900	.02610		
3000	.01200		
3068	.00040		
3100	.02850		
3200	.00920		
3300	.02120		
TOTAL	.22800	TOTAL	.04170

TABLE 1.14

HEAVY HYDROCARBON ANALYSIS - STOCS - 1976

SAMPLE TYPE : SED
SAMPLE CODE : BDYK - (W-1000) PERIOD : POST-RIG
LOCATION : STATION -36 LINE -RIG

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00580	2149	.01790
1500	.00900	2225	.01590
1600	.01030	2519	.02710
1670	.01790	2639	.03090
1700	.02050	2759	.01220
1780	.00420	2854	.01420
1800	.01960	2963	.02730
1835	.01630	3035	.03850
1900	.01410	3159	.01830
1944	.01090	3279	.01830
2000	.00700	3445	.02630
2087	.02790		
2100	.01590		
2179	.04580		
2200	.01000		
2300	.02320		
2400	.01350		
2500	.04060		
2600	.02710		
2700	.07390		
2800	.04050		
2900	.12600		
3000	.04660		
3100	.13600		
3200	.02830		
3300	.06270		
TOTAL	.85360	TOTAL	.24690

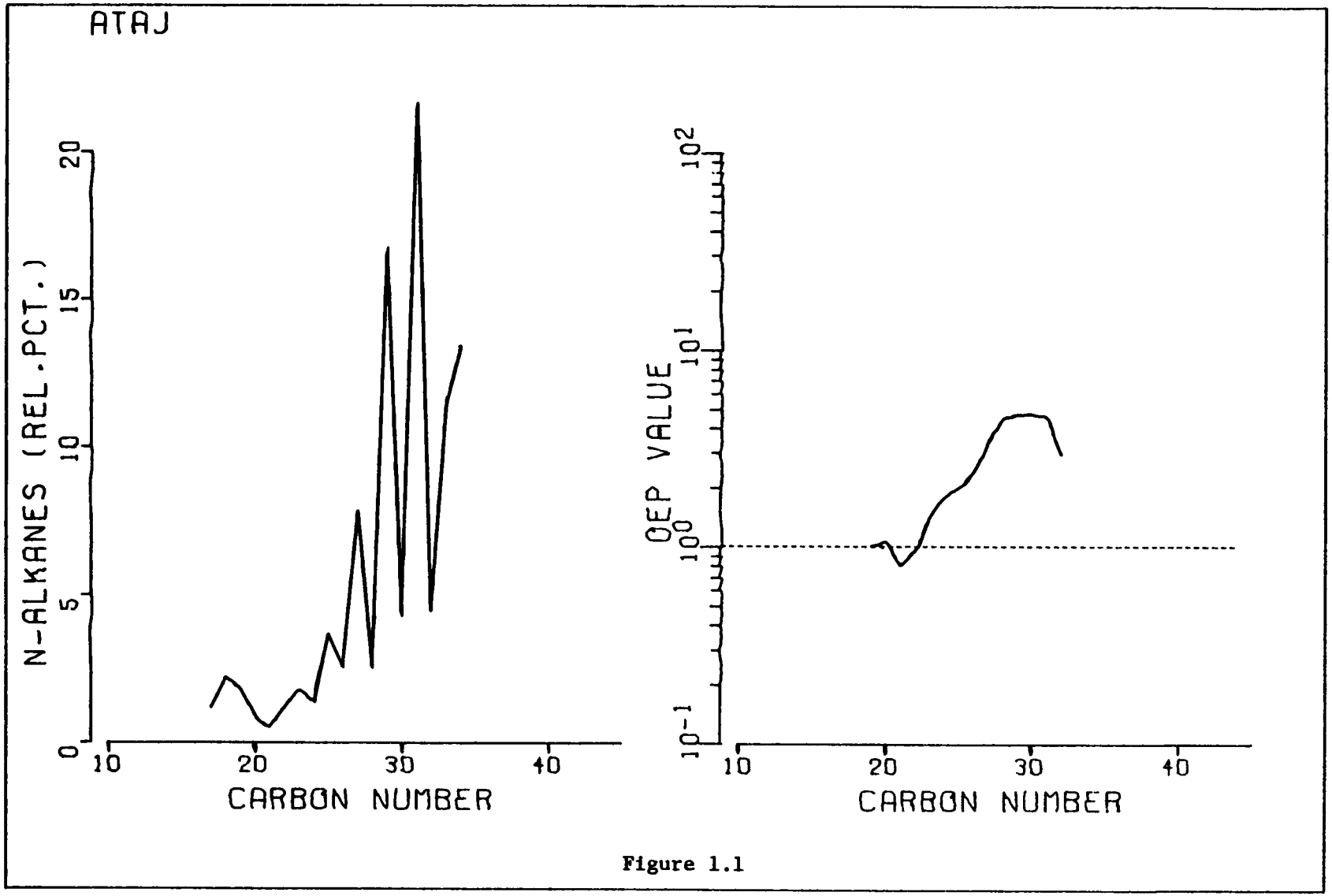
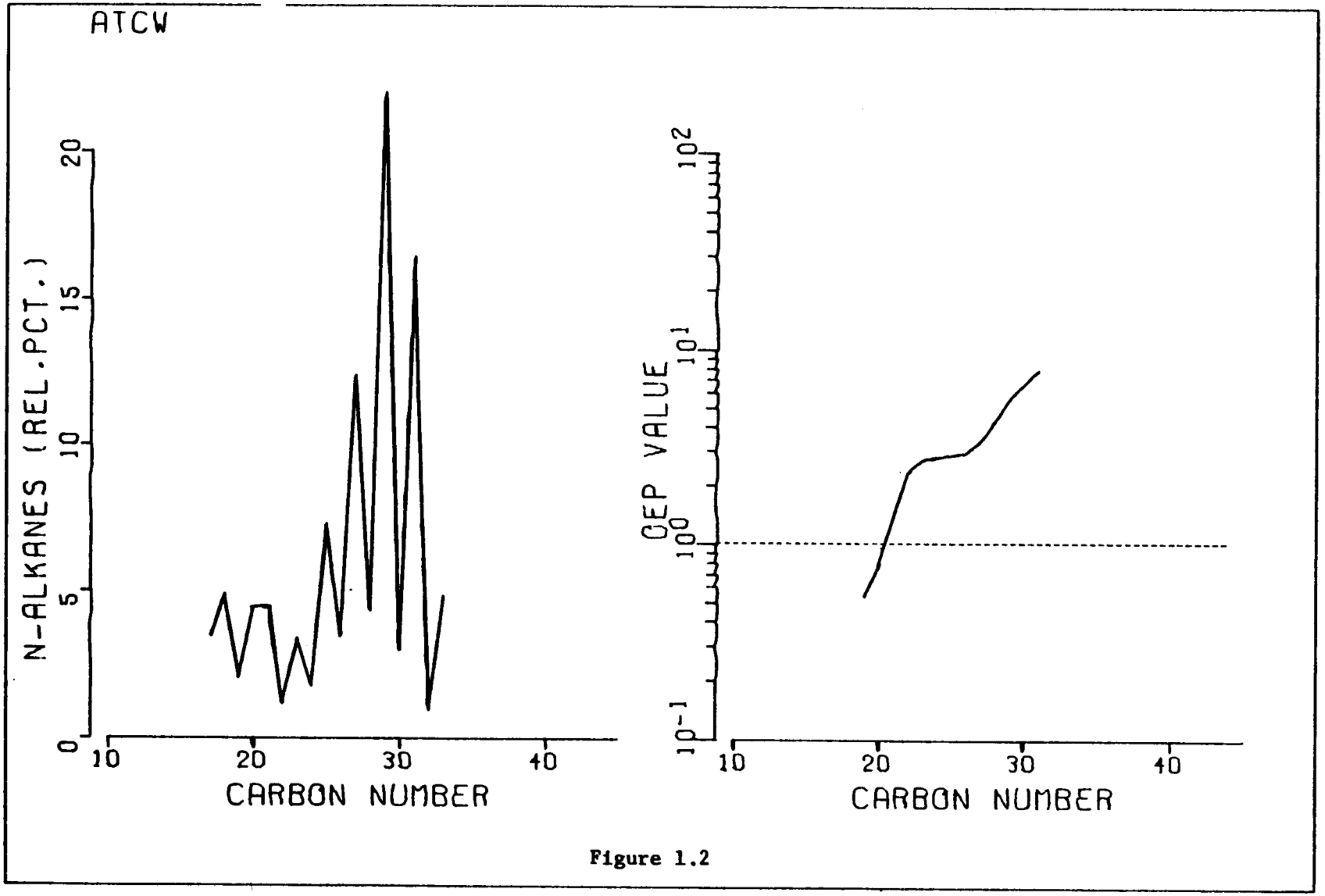

ATAJ
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{2}
10^{1}
10^{0}
10^{-1}
10
20
30
40
CARBON NUMBER

Figure 1.1


ATCW
N-ALKANES (REL.PCT.)
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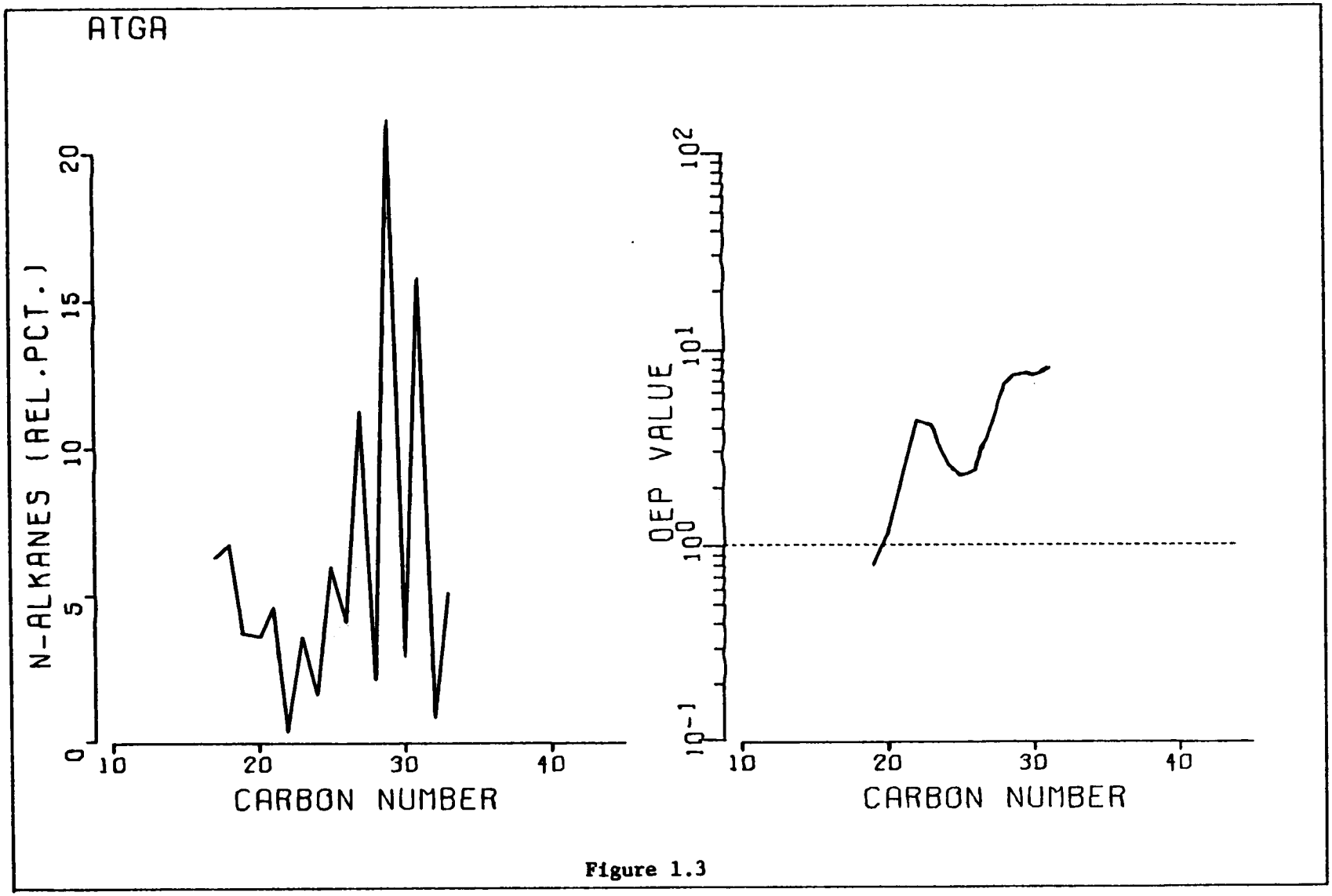
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.2


ATGA
N-ALKANES (REL.PCT.)
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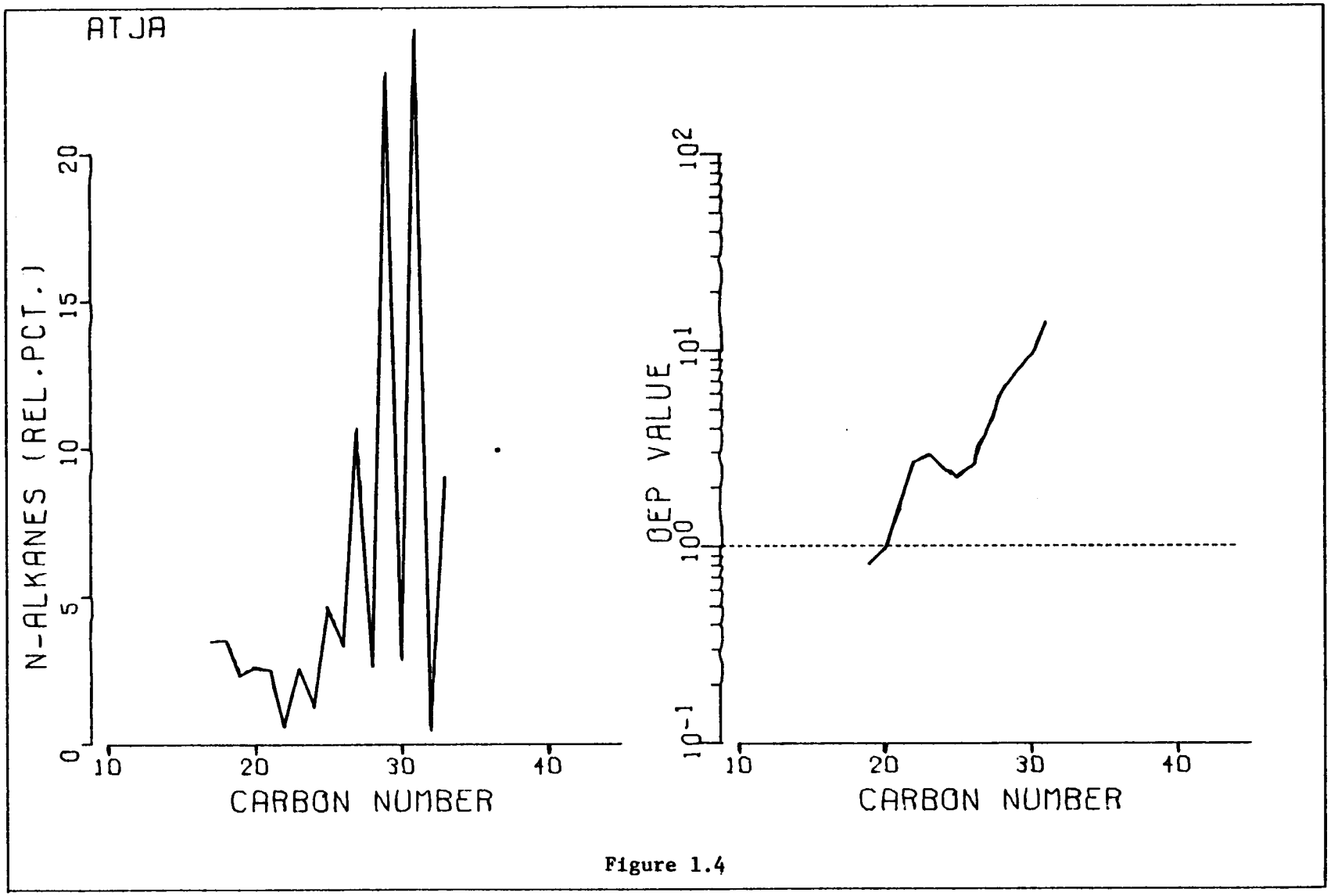
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.3


ATJA
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10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.4

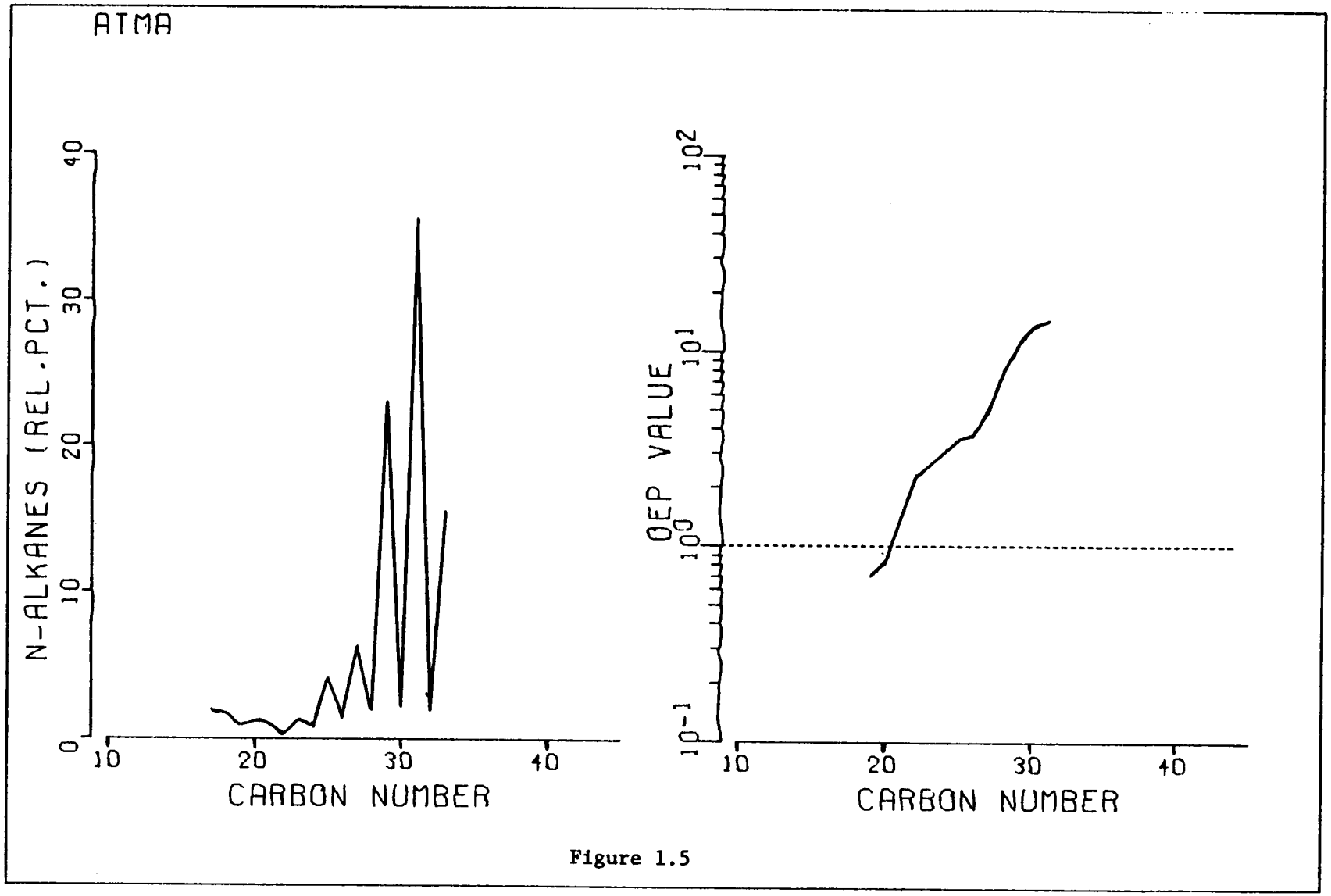

ATMA
N-ALKANES (REL.PCT.)
0
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.5

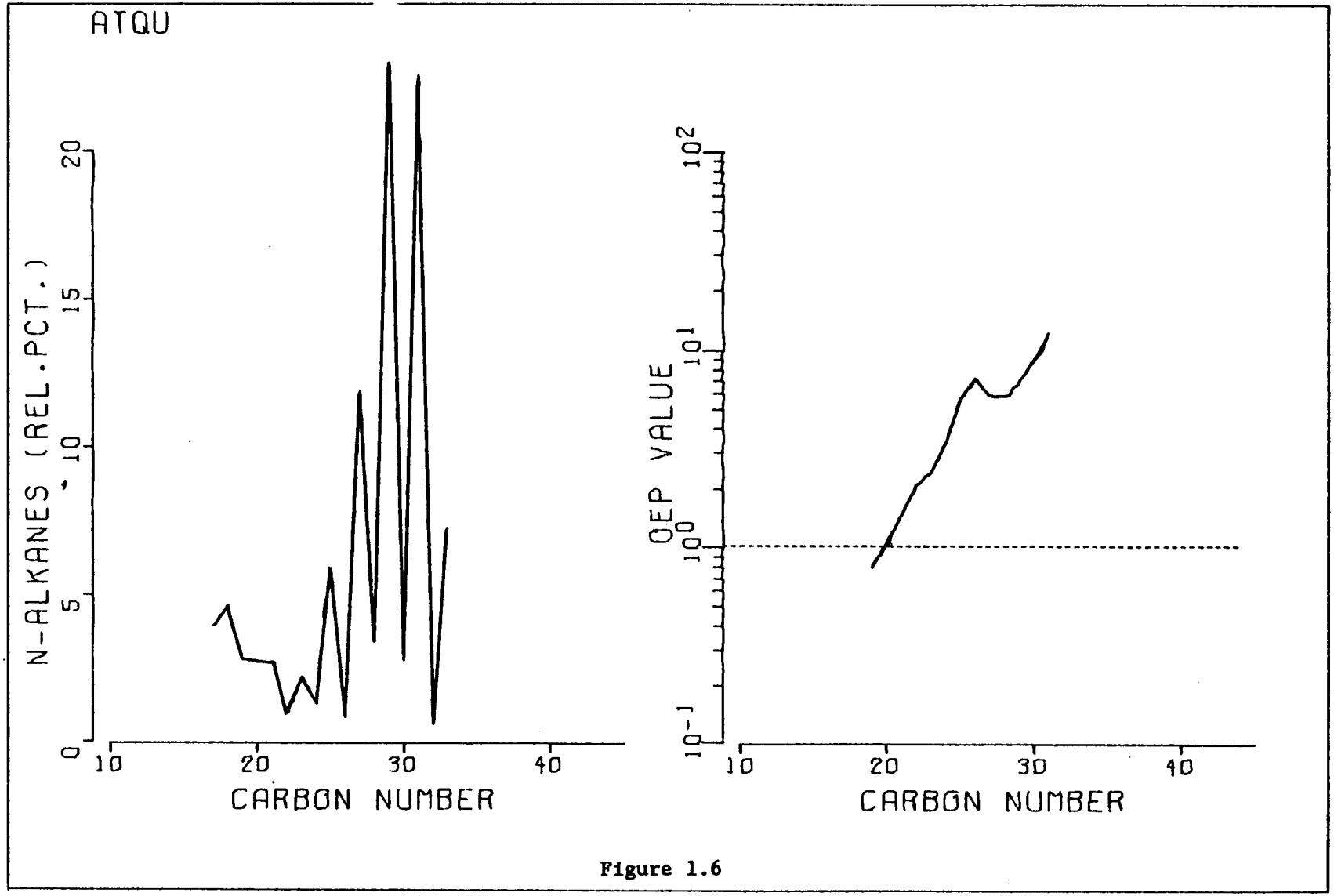
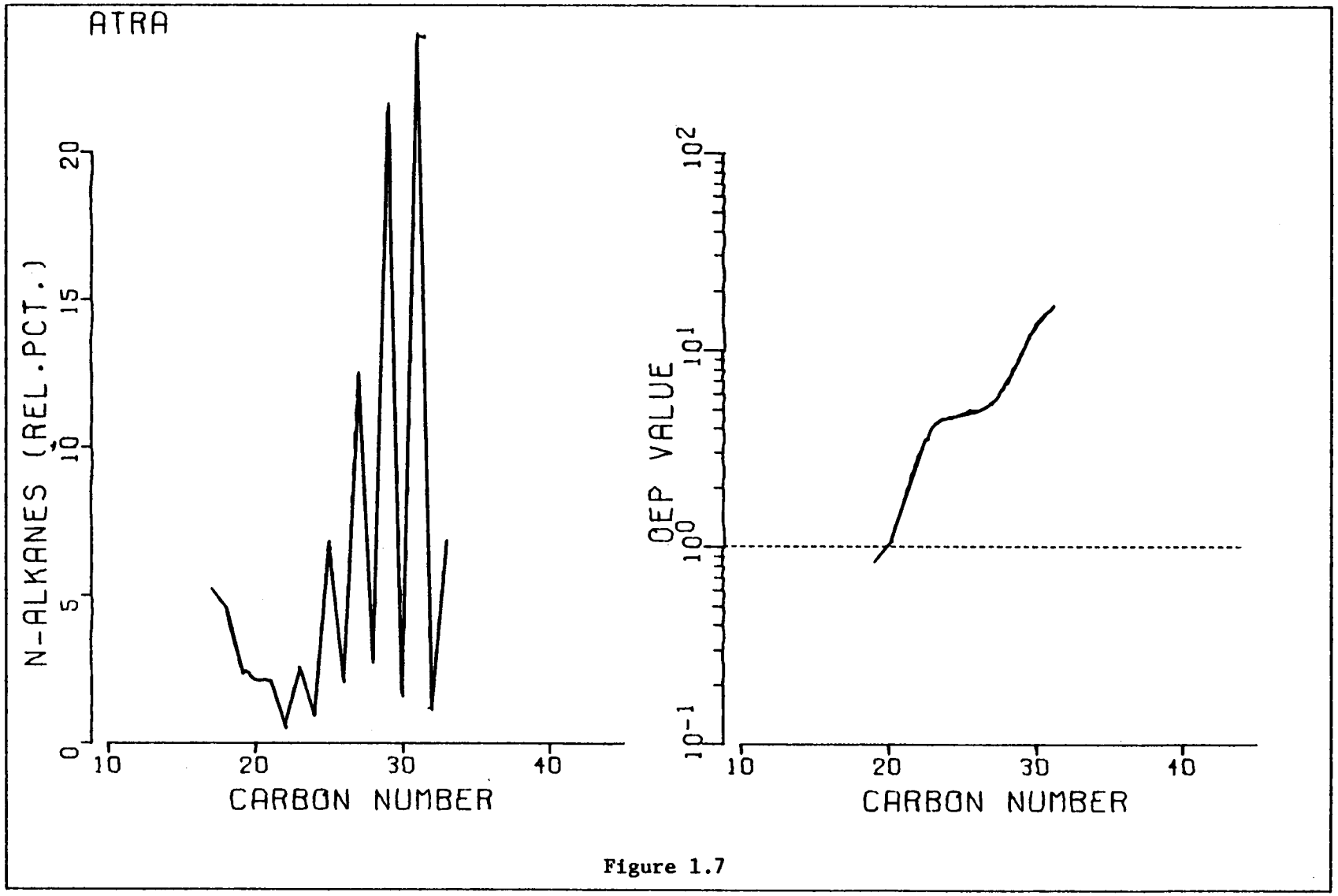

ATQU
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.6


ATRA
N-ALKANES (REL.PCT.)
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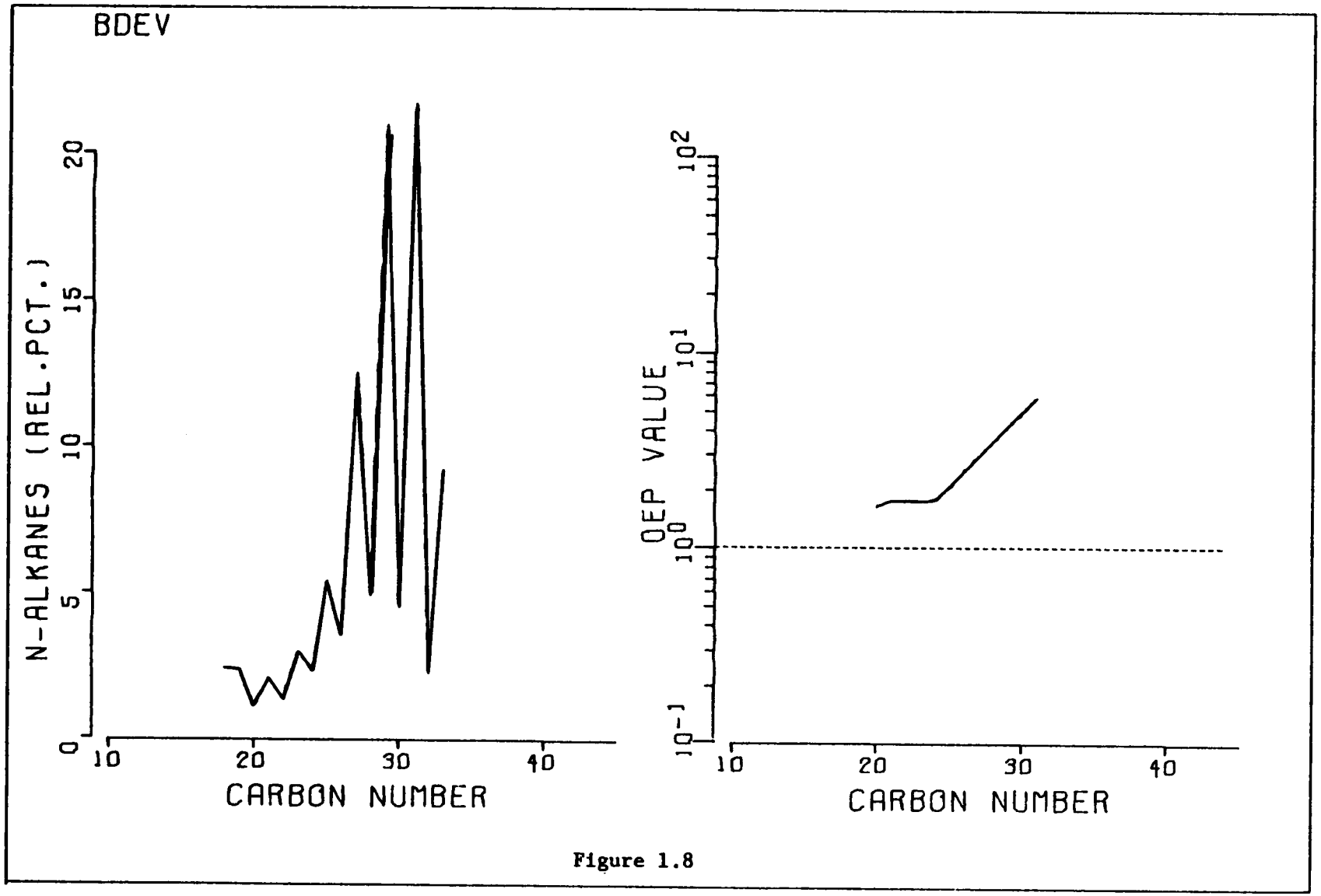
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{2}
10^{1}
10^{0}
10^{-1}
10
20
30
40
CARBON NUMBER

Figure 1.7


BDEV
N-ALKANES (REL.PCT.)
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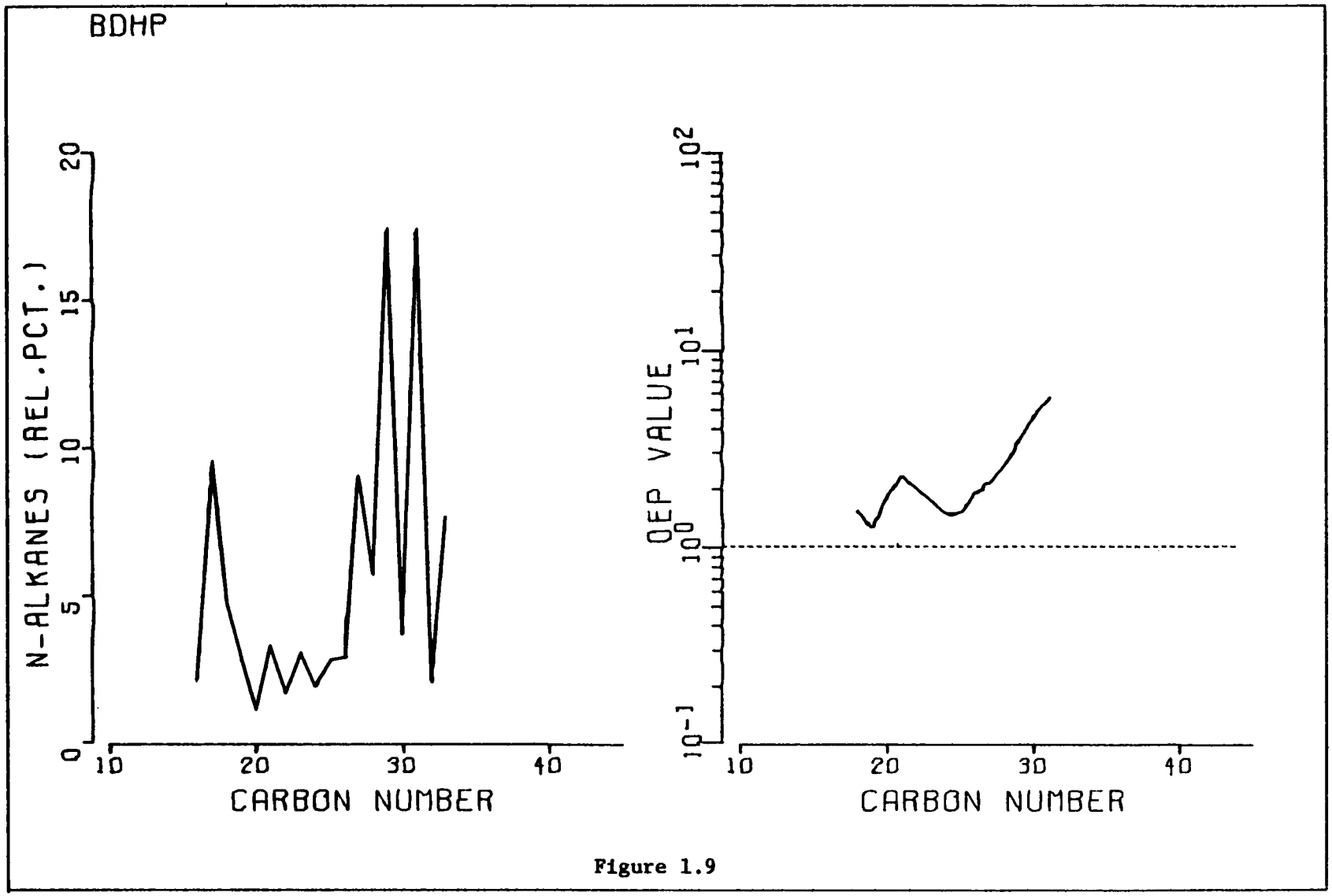
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.8


BDHP
N-ALKANES (REL.PCT.)
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5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{2}
10^{1}
10^{0}
10^{-1}
10
20
30
40
CARBON NUMBER

Figure 1.9

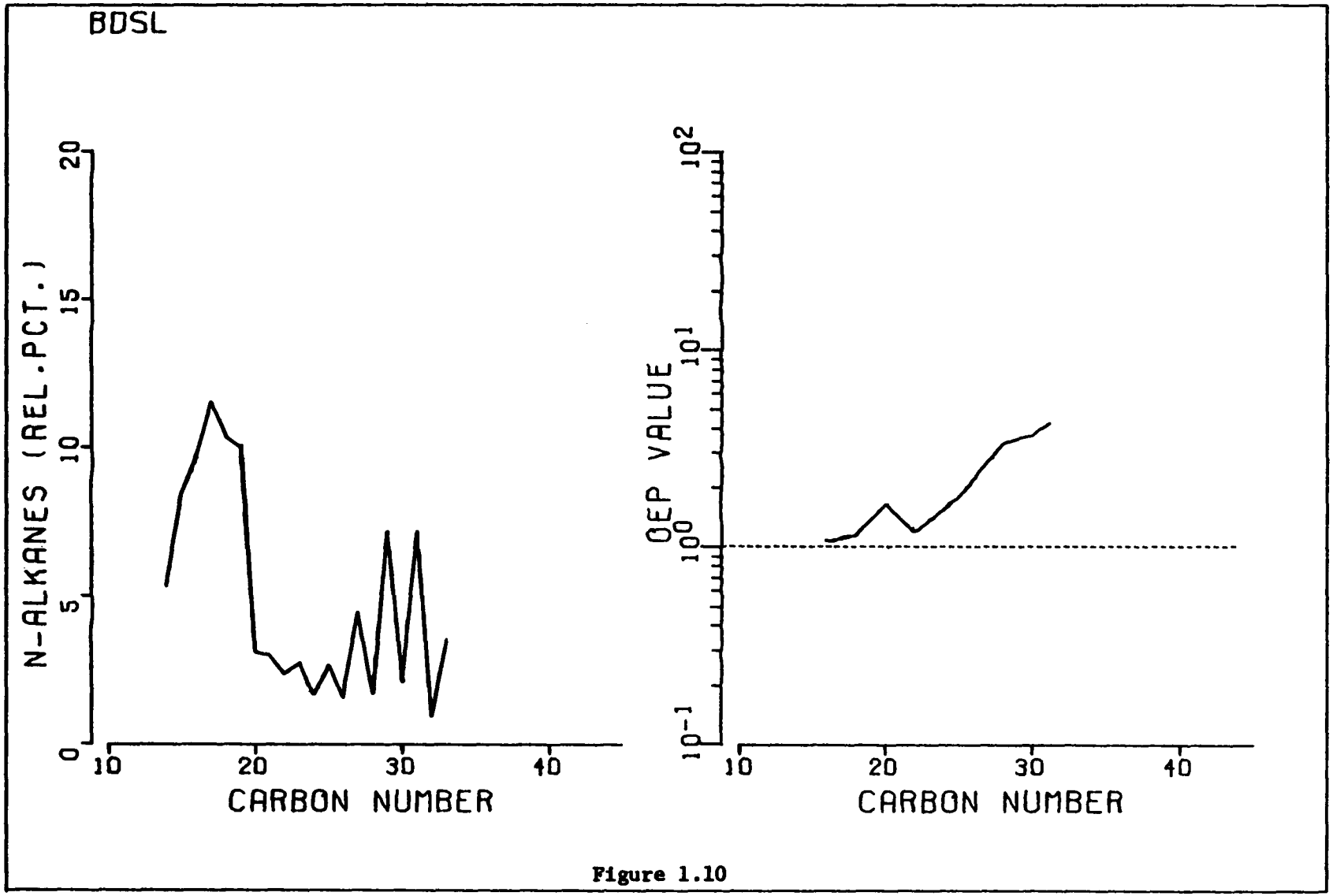
BDSL
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{2}
10^{1}
10^{0}
10^{-1}
10
20
30
40
CARBON NUMBER

Figure 1.10

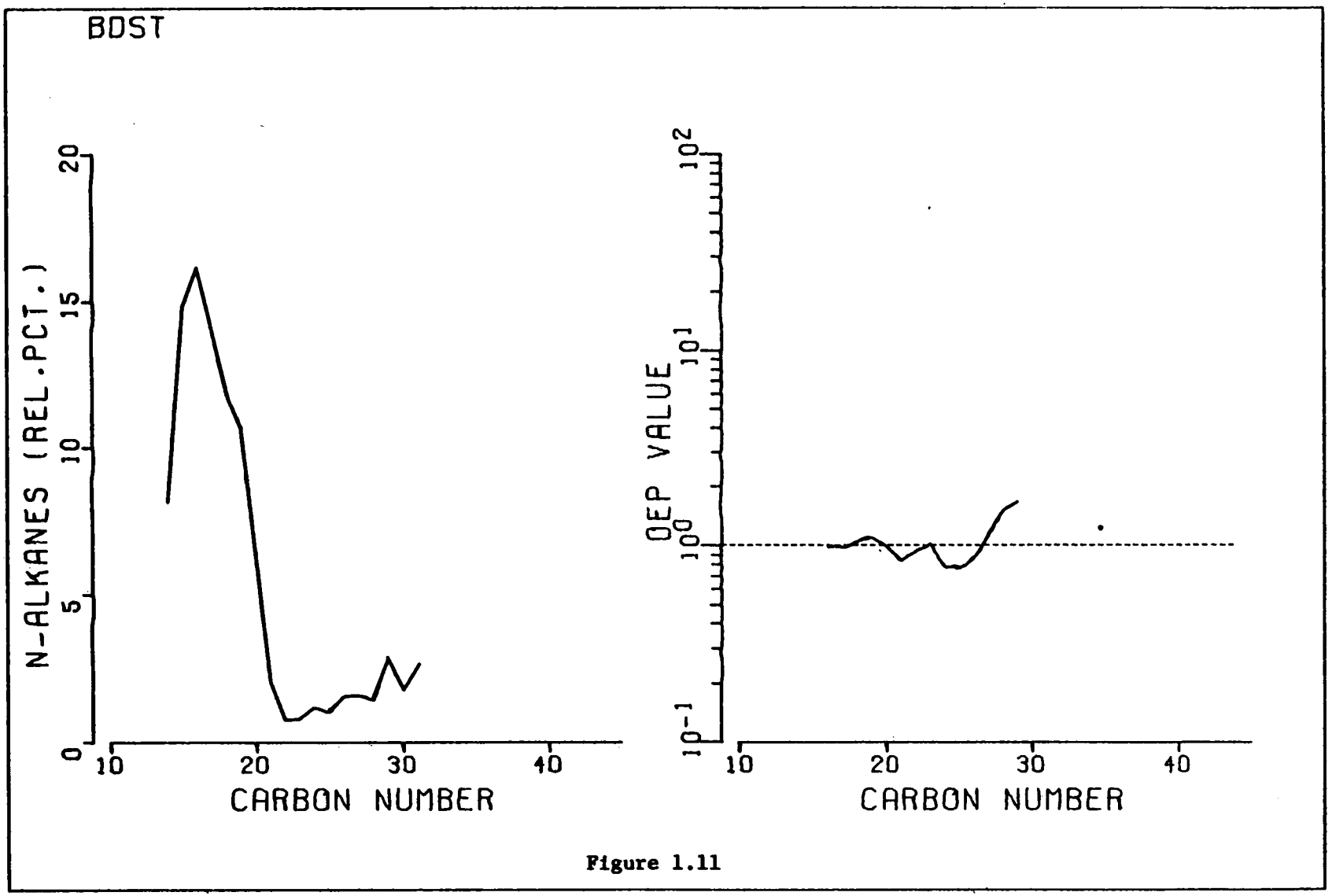
BDST
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.11

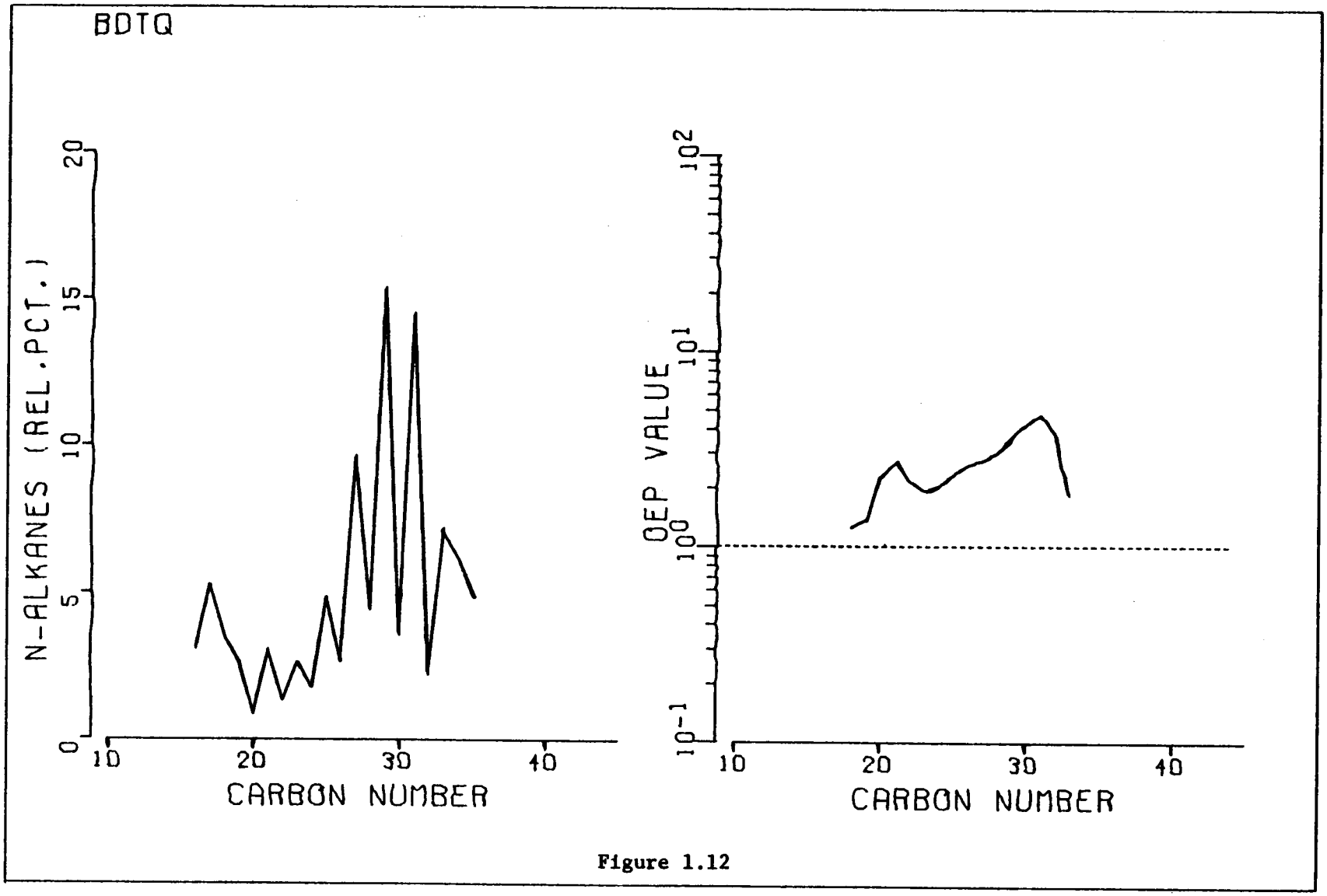
BDTQ
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.12

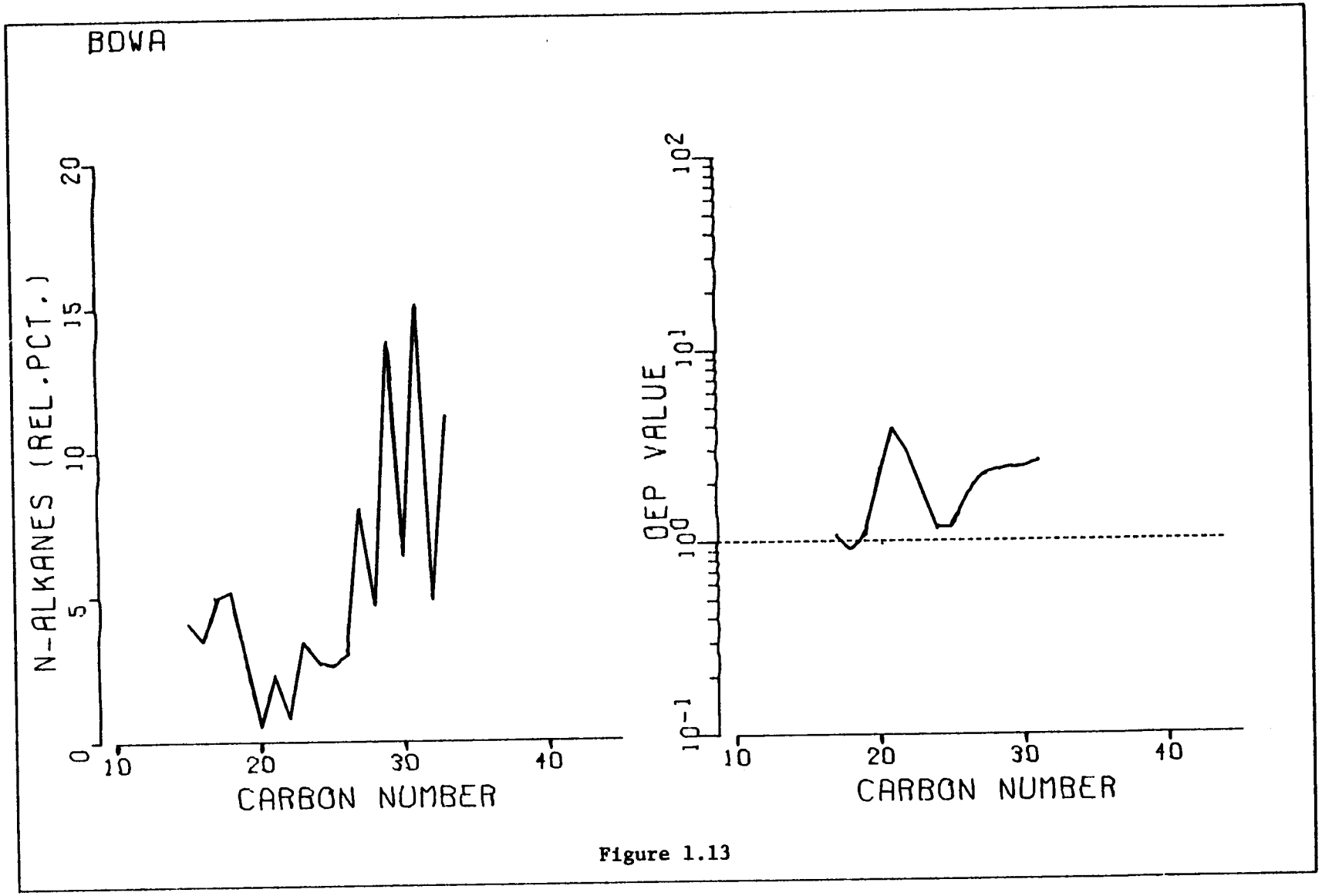
BOWA
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.13

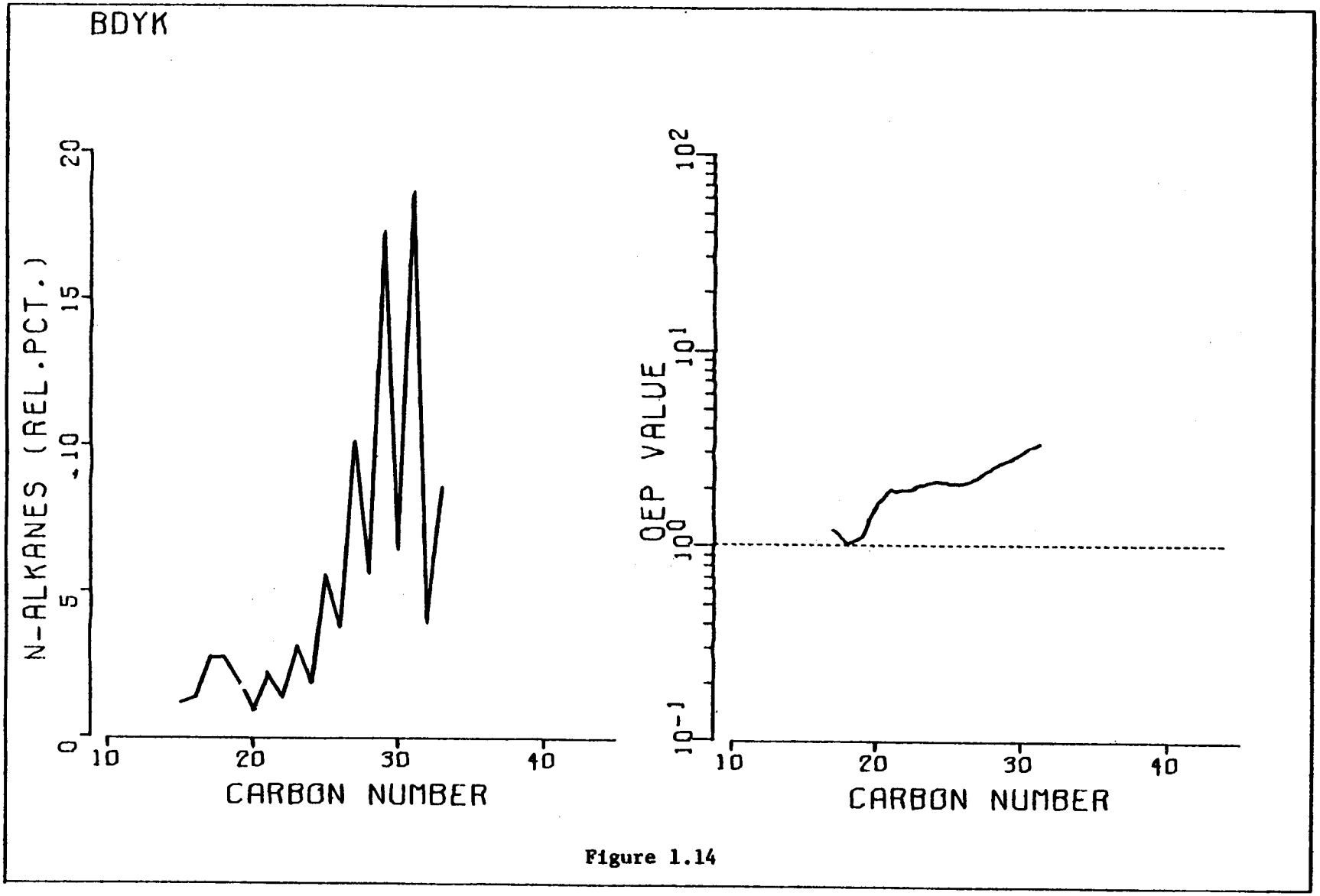
BDYK
N-ALKANES (REL.PCT.)
0
5
10
15
20
10
20
30
40
CARBON NUMBER
OEP VALUE
10^{-1}
10^{0}
10^{1}
10^{2}
10
20
30
40
CARBON NUMBER

Figure 1.14

APPENDIX C

BENTHIC SEDIMENT TEXTURAL ANALYSES

List of Tables

Explanation of Table 1:

Column 1 - Sample station number (Univ. of Texas Marine Science Institute designation)
Column 2 - Sample station number (USGS designation)
Column 3 - Sand percentage (%)
Column 4 - Silt percentage (%)
Column 5 - Clay percentage (%)
Column 6 - Sand/mud ratio
Column 7 - Silt/clay ratio
Column 8 - Mean diameter in phi units (first moment)
Column 9 - Data sheet designation number (#1 - first sheet)
Column 10- Sample station number reiteration (UTMSI designation)
Column 11- Sample station number reiteration (USGS designation)
Column 12- Standard deviation in phi units (second moment)
Column 13- Skewness (third moment)
Column 14- Kurtosis (fourth moment)
Column 15-Data sheet designation number (#2 - second sheet)

TABLE 1

BENTHIC SEDIMENT TEXTURAL PARAMETERS
PRE-DRILLING SAMPLE SUITE

1	2	3	4	5	6	7	8	9
DS-TAE	RM-DS-A	2.61	47.78	49.61	0.03	0.96	7.75	1
DS-TAG	RM-DS-B	2.82	49.68	47.50	0.03	1.05	7.58	1
N-1000-TCR	RM-N-1-A	2.76	41.11	56.13	0.03	0.73	8.10	1
N-1000-TCT	RM-N-1-B	4.09	38.53	57.38	0.04	0.67	8.00	1
E-500-TRT	RM-E-5-A	6.31	40.79	52.90	0.07	0.77	7.87	1
E-500-TRU	RM-E-5-B	8.07	39.80	52.12	0.09	0.76	7.80	1
E-500-TRV	RM-E-5-C	4.83	44.26	50.19	0.05	0.87	7.79	1
E-500-TRW	RM-E-5-D	5.09	48.62	46.30	0.05	1.05	7.47	1
E-500-TRX	RM-E-5-E	4.84	46.93	48.23	0.05	0.97	7.65	1
E-500-TRY	RM-E-5-F	5.83	44.72	49.45	0.06	0.90	7.63	1
E-500-TRZ	RM-E-5-G	9.24	46.90	43.86	0.10	1.07	7.35	1
E-1000-TFV	RM-E-1-A	4.65	57.36	38.00	0.05	1.51	7.10	1
E-1000-TFX	RM-E-1-B	4.79	45.18	50.03	0.05	0.90	7.79	1
S-500-TSA	RM-S-5-A	3.64	52.41	43.95	0.04	1.19	7.47	1
S-500-TSB	RM-S-5-B	3.78	54.42	41.80	0.04	1.30	7.42	1
S-500-TSC	RM-S-5-C	5.23	41.38	53.39	0.05	0.77	7.94	1
S-500-TSD	RM-S-5-D	4.49	38.46	57.04	0.05	0.67	8.05	1
S-500-TSE	RM-S-5-E	5.40	40.36	54.24	0.06	0.74	7.90	1
S-500-TSF	RM-S-5-F	4.71	40.13	55.16	0.05	0.73	7.95	1
S-500-TSG	RM-S-5-G	4.65	46.63	48.72	0.05	0.96	7.57	1
S-1000-TIV	RM-S-1-A	3.91	52.98	43.10	0.04	1.23	7.47	1
S-1000-TIX	RM-S-1-B	3.09	44.89	52.02	0.03	0.86	7.98	1
W-1000-TLV	RM-W-1-A	4.45	41.53	54.01	0.05	0.77	7.86	1
W-1000-TLX	RM-W-1-B	2.62	46.65	50.53	0.03	0.92	7.80	1

TABLE 1 CONT.'D

PRE-DRILLING SAMPLE SUITE

10	11	12	13	14	15
DS-TAF	RM-DS-A	2.00	-0.12	-1.13	2
DS-TAG	RM-DS-B	2.06	-0.07	-1.25	2
N-1000-TCH	RM-N-1-A	1.95	-0.24	-0.62	2
N-1000-TCI	RM-N-1-B	1.97	-0.30	-0.58	2
F-500-TRT	RM-F-5-A	2.02	-0.25	-0.70	2
F-500-TRU	RM-F-5-B	2.12	-0.24	-0.84	2
F-500-TRV	RM-F-5-C	2.04	-0.20	-0.92	2
F-500-TRW	RM-F-5-D	2.19	-0.07	-1.10	2
F-500-TRX	RM-F-5-E	2.07	-0.15	-0.94	2
F-500-TRY	RM-F-5-F	2.17	-0.16	-1.09	2
F-500-TRZ	RM-F-5-G	2.24	-0.07	-1.21	2
F-1000-TFV	RM-F-1-A	2.17	0.08	-1.31	2
F-1000-TFX	RM-F-1-C	2.02	-0.16	-0.94	2
S-500-TSA	RM-S-5-A	2.07	-0.03	-1.21	2
S-500-TSB	RM-S-5-B	2.04	-0.02	-1.15	2
S-500-TSC	RM-S-5-C	1.99	-0.24	-0.65	2
S-500-TSD	RM-S-5-D	1.95	-0.30	-0.55	2
S-500-TSE	RM-S-5-E	2.04	-0.24	-0.82	2
S-500-TSF	RM-S-5-F	2.01	-0.26	-0.71	2
S-500-TSG	RM-S-5-G	2.18	-0.14	-1.17	2
S-1000-TIV	RM-S-1-A	2.06	-0.05	-1.10	2
S-1000-TIA	RM-S-1-B	1.86	-0.19	-0.70	2
W-1000-TLV	RM-W-1-A	2.05	-0.23	-0.89	2
W-1000-TLX	RM-W-1-B	1.95	-0.13	-1.07	2

TABLE 1 CONT.'D

POST-DRILLING SAMPLE SUITE

1	2	3	4	5	6	7	8	9
DS-ADEO	RM-DS-A	19.92	43.33	36.76	0.25	1.18	6.61	1
DS-ADES	RM-DS-B	4.73	65.98	29.29	0.05	2.25	6.63	1
DS-ADSU	RM-DS-C	4.45	64.59	30.96	0.05	2.09	6.42	1
DS-ADSI	RM-DS-D	6.12	55.67	38.21	0.06	1.46	7.07	1
DS-ADSO	RM-DS-F	10.33	36.08	53.59	0.12	0.67	7.62	1
DS-ADSU	RM-DS-F	2.31	60.40	37.30	0.02	1.62	7.14	1
N-1000-ADHK	RM-PN-A	1.96	50.81	47.23	0.02	1.08	7.67	1
N-1000-ADHM	RM-PN-B	0.62	59.64	39.74	0.01	1.50	7.47	1
F-1000-ADTL	RM-PF-A	5.89	71.74	22.36	0.06	3.21	6.20	1
F-1000-ADTN	RM-PF-B	13.06	54.74	32.21	0.15	1.70	6.69	1
S-1000-ADVV	RM-PS-A	3.49	43.62	52.89	0.04	0.82	7.89	1
S-1000-ADVX	RM-PS-B	5.67	48.16	46.17	0.06	1.04	7.40	1
W-1000-ADYF	RM-PW-A	2.87	64.80	32.34	0.03	2.00	6.95	1
W-1000-ADYH	RM-PW-B	3.81	51.71	44.48	0.04	1.16	7.58	1

TABLE 1 CONT.'D

POST-DRILLING SAMPLE SUITE

10	11	12	13	14	15
DS-RDEG	RM-DS-A	2.81	-0.26	-0.27	2
DS-RDFS	RM-DS-B	2.11	0.24	-1.03	2
DS-RDSJ	RM-DS-C	2.07	0.14	-1.00	2
DS-RDST	RM-DS-D	2.21	0.04	-1.29	2
DS-RDSO	RM-DS-E	2.49	-0.60	1.33	2
DS-RDSQ	RM-DS-F	2.09	0.09	-1.22	2
N-1000-RDHK	RM-PN-A	2.06	-0.10	-0.97	2
N-1000-RDHM	RM-PN-B	1.84	0.07	-1.15	2
F-1000-RDTL	RM-PF-A	2.02	0.39	-0.63	2
F-1000-RDTN	RM-PF-B	2.23	0.09	-1.13	2
S-1000-RDVV	RM-PS-A	1.99	-0.22	-0.79	2
S-1000-RDVX	RM-PS-B	2.21	-0.07	-1.31	2
W-1000-RDYF	RM-PW-A	2.00	0.17	-1.07	2
W-1000-RDYH	RM-PW-B	2.02	-0.08	-0.98	2

APPENDIX D

SEDIMENT TEXTURE AND DEPOSITION

List of Tables

TABLE 1

SEDIMENT PARAMETERS COMPUTED BY MOMENT MEASURES USING THE 14 PHI EXTRAPOLATION (PRE-DRILL)

Key to Table:

PERIOD	Pre-Drill
STA	Station
SAMP REP	Sample Code and Replicate Number
MEAN	Mean
S.D.	Standard Deviation
SKEW	Coefficient of Skewness
KURT	Coefficient of Excess (Kurtosis)
SAND SILT CLAY	Percentage of Total Weight in the Sand, Silt and Clay Categories
SA/MUD	Ratio of sand weight to mud weight
SI/CL	Ratio of silt weight to clay weight
>10.6	Percentage of Total Weight in the fraction greater than 10.6 phi

TABLE 1

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
PRE DRILL	1	ATAQ	1	7.92	3.23	.37	.69	5.28	50.56	44.16	.06	1.14	27.6
PRE DRILL	1	ATAS	2	9.26	3.05	-.06	.70	2.52	35.80	61.68	.03	.58	39.8
PRE DRILL	1	ATAU	3	6.71	3.07	.72	.85	9.01	63.29	27.70	.10	2.28	17.8
PRE DRILL	1	ATAW	4	7.36	3.12	.57	.74	4.40	60.37	35.23	.05	1.71	22.0
PRE DRILL	1	ATAY	5	6.97	3.32	.58	.68	18.06	48.44	33.50	.22	1.45	21.8
PRE DRILL	1	ATBA	6	7.86	3.20	.41	.69	4.42	53.29	42.28	.05	1.26	27.8
PRE DRILL	1	ATSH	7	6.55	2.75	.54	.75	9.48	57.76	32.76	.10	1.76	4.8
PRE DRILL	46	ATMT	1	7.59	3.46	.35	.62	13.90	43.16	42.94	.16	1.01	28.8
PRE DRILL	46	ATMV	2	8.50	3.37	.03	.69	6.20	40.28	53.52	.07	.75	34.1
PRE DRILL	46	ATMX	3	8.61	3.37	-.07	1.24	7.22	13.14	79.64	.08	.16	33.2
PRE DRILL	46	ATMZ	4	8.25	3.33	.13	.65	5.37	44.90	49.73	.06	.90	31.4
PRE DRILL	46	ATNB	5	7.40	3.34	.48	.65	10.12	50.37	39.51	.11	1.27	25.7
PRE DRILL	46	ATND	6	8.25	3.27	.17	.68	5.53	45.38	49.08	.06	.92	29.2
PRE DRILL	37	ATNF	1	9.06	3.07	-.00	.67	1.37	39.81	58.83	.01	.68	37.8
PRE DRILL	37	ATNH	2	7.84	3.15	.44	.70	2.91	56.13	40.96	.03	1.37	27.6
PRE DRILL	37	ATNJ	3	7.28	3.00	.64	.80	2.91	65.65	31.44	.03	2.09	20.7
PRE DRILL	37	ATNL	4	8.16	3.15	.28	.69	2.28	50.80	46.91	.02	1.08	27.4
PRE DRILL	37	ATNN	5	7.80	3.32	.36	.66	6.47	50.26	43.27	.07	1.16	29.1
PRE DRILL	37	ATNP	6	7.16	3.19	.46	.75	11.98	57.41	30.61	.14	1.88	19.9
PRE DRILL	36	ATMH	1	9.25	3.07	-.08	.74	3.30	34.60	62.09	.03	.56	38.4
PRE DRILL	36	ATMJ	2	7.06	3.18	.59	.73	9.02	57.10	33.88	.10	1.69	19.8
PRE DRILL	36	ATML	3	6.92	3.18	.63	.78	10.70	59.34	29.96	.12	1.98	20.1
PRE DRILL	36	ATMN	4	9.16	3.10	-.05	.68	1.56	38.03	60.40	.02	.63	40.4
PRE DRILL	36	ATMP	5	8.16	3.29	.19	.67	4.99	46.95	48.06	.05	.98	29.5
PRE DRILL	36	ATMR	6	7.89	3.31	.34	.64	5.11	50.56	44.34	.05	1.14	28.9
PRE DRILL	36	ATSK	7	6.61	3.09	.68	.99	15.31	59.23	25.46	.18	2.33	17.6
PRE DRILL	26	ATLH	1	9.24	3.10	-.07	.70	4.44	34.25	61.31	.05	.56	42.0

TABLE 1

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
PRE DRILL	26	ATLJ	2	5.82	2.81	.77	1.65	31.60	50.38	18.02	.46	2.80	13.3
PRE DRILL	26	ATLL	3	7.91	3.44	.28	.65	8.80	45.39	45.81	.10	.99	32.0
PRE DRILL	26	ATLN	4	8.71	3.17	.11	.69	3.21	43.57	53.22	.03	.82	35.9
PRE DRILL	36	ATLP	5	8.09	3.35	.22	.63	4.95	47.42	47.63	.05	1.00	31.3
PRE DRILL	36	ATLR	6	8.75	3.28	-.01	.62	3.95	41.30	54.76	.04	.75	36.5
PRE DRILL	26	ATSL	7	8.59	3.26	.06	.68	3.82	41.67	54.52	.04	.76	34.2
PRE DRILL	16	ATKR	1	6.52	3.06	.71	1.19	15.60	61.81	22.59	.18	2.74	17.1
PRE DRILL	16	ATKT	2	8.48	3.12	.19	.66	1.50	48.25	50.25	.02	.96	31.4
PRE DRILL	16	ATKV	3	8.23	3.21	.21	.69	4.08	47.80	48.12	.04	.99	28.9
PRE DRILL	16	ATKX	4	7.67	3.30	.40	.67	7.30	52.77	39.93	.08	1.32	26.9
PRE DRILL	16	ATKZ	5	8.45	3.27	.15	.66	3.73	45.77	50.51	.04	.91	34.1
PRE DRILL	16	ATLB	6	7.21	3.21	.56	.71	8.35	56.40	35.25	.09	1.60	22.1
PRE DRILL	44	ATJT	1	7.90	3.30	.30	.67	6.04	49.13	44.83	.06	1.10	28.0
PRE DRILL	44	ATJV	2	8.54	3.28	.05	.68	5.07	41.72	53.21	.05	.78	31.7
PRE DRILL	44	ATJX	3	8.61	3.29	.05	.66	4.67	41.89	53.44	.05	.78	35.5
PRE DRILL	40	ATDZ	4	8.58	3.22	.08	.69	3.90	43.20	52.90	.04	.82	31.9
PRE DRILL	44	ATKB	5	8.48	3.32	.07	.65	4.58	43.31	52.11	.05	.83	33.6
PRE DRILL	44	ATKD	6	8.46	3.35	.07	.67	5.87	41.67	52.46	.06	.79	34.2
PRE DRILL	33	ATHF	1	7.10	3.20	.60	.73	8.95	58.52	32.54	.10	1.80	21.6
PRE DRILL	33	ATHH	2	7.09	3.15	.61	.74	6.11	61.85	32.04	.07	1.93	21.0
PRE DRILL	33	ATHJ	3	6.84	3.26	.65	.73	16.77	52.70	30.53	.20	1.73	21.1
PRE DRILL	33	ATHL	4	7.79	3.32	.34	.67	7.12	49.56	43.31	.08	1.14	27.9
PRE DRILL	33	ATHN	5	7.22	3.31	.54	.67	11.79	51.34	36.87	.13	1.39	23.8
PRE DRILL	33	ATHP	6	8.72	3.22	.01	.70	4.81	39.05	56.14	.05	.70	32.5
PRE DRILL	24	ATKF	1	6.63	3.27	.73	.74	21.54	48.74	29.72	.27	1.64	20.2
PRE DRILL	24	ATKH	2	8.22	3.36	.17	.62	6.55	44.60	48.85	.07	.91	32.3
PRE DRILL	35	ATKJ	3	8.10	3.30	.24	.65	5.27	47.59	47.14	.06	1.01	30.5
PRE DRILL	35	ATKL	4	7.44	3.28	.50	.66	5.94	54.86	39.20	.06	1.40	25.2

TABLE 1

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
PRE DRILL	35	ATKN	5	7.06	3.43	.54	.65	20.90	42.90	36.20	.26	1.19	24.1
PRE DRILL	35	ATKP	6	8.67	3.28	.08	.65	3.57	42.97	53.46	.04	.80	39.6
PRE DRILL	14	ATHR	1	7.03	3.40	.59	.65	18.54	47.14	34.32	.23	1.37	24.7
PRE DRILL	14	ATHT	2	8.58	3.23	.10	.68	4.24	43.61	52.15	.04	.84	33.2
PRE DRILL	14	ATHV	3	7.65	3.39	.37	.63	9.14	48.40	42.46	.10	1.14	28.3
PRE DRILL	14	ATHX	4	7.66	3.03	.56	.73	1.89	60.73	37.39	.02	1.62	24.2
PRE DRILL	14	ATHZ	5	7.77	3.18	.44	.69	3.68	55.24	41.08	.04	1.34	26.4
PRE DRILL	14	ATIB	6	8.19	3.20	.29	.67	2.83	50.69	46.48	.03	1.09	30.6
PRE DRILL	24	ATID	1	7.22	3.27	.56	.68	9.52	53.80	36.68	.11	1.47	23.5
PRE DRILL	24	ATIF	2	7.58	3.33	.41	.66	8.50	50.43	41.06	.09	1.23	26.2
PRE DRILL	24	ATIH	3	7.38	3.27	.50	.67	7.49	54.33	38.17	.08	1.42	24.5
PRE DRILL	24	ATIJ	4	7.85	3.41	.29	.62	8.14	46.49	45.37	.09	1.02	30.3
PRE DRILL	24	ATIL	5	7.80	3.32	.33	.66	7.03	49.08	43.89	.08	1.12	27.7
PRE DRILL	24	ATIN	6	8.34	3.44	.15	.62	6.41	43.77	49.82	.07	.88	42.0
PRE DRILL	24	ATSP	7	7.66	3.36	.38	.64	8.14	49.69	42.17	.09	1.18	27.7
PRE DRILL	34	ATJH	1	8.32	3.28	.13	.67	4.75	45.02	50.23	.05	.90	30.3
PRE DRILL	34	ATJJ	2	8.45	3.26	.14	.66	3.96	45.25	50.78	.04	.89	33.4
PRE DRILL	34	ATJL	3	7.18	3.29	.64	.67	8.48	53.12	38.40	.09	1.38	24.1
PRE DRILL	34	ATJN	4	9.11	3.07	-.02	.70	4.06	36.85	59.10	.04	.62	37.6
PRE DRILL	34	ATJP	5	9.15	3.14	-.09	.71	2.42	36.49	61.09	.02	.60	37.9
PRE DRILL	34	ATJR	6	8.20	3.40	.11	.66	8.08	42.11	49.82	.09	.85	30.5
PRE DRILL	34	ATSO	7	8.71	3.29	.01	.69	5.79	39.51	54.70	.06	.72	35.3
PRE DRILL	40	ATDP	1	6.72	3.00	.69	1.00	8.15	66.15	25.69	.09	2.57	17.3
PRE DRILL	40	ATDR	2	8.13	3.26	.27	.65	3.36	49.82	46.82	.03	1.06	31.1
PRE DRILL	40	ATDT	3	7.24	3.30	.56	.67	9.39	54.65	35.96	.10	1.52	24.6
PRE DRILL	40	ATDV	4	6.31	2.69	.69	1.72	8.15	72.48	19.37	.09	3.74	13.7
PRE DRILL	40	ATDX	5	7.17	3.28	.60	.67	8.94	56.19	34.87	.10	1.61	23.9
PRE DRILL	40	ATDZ	6	7.40	3.25	.54	.68	6.00	57.09	36.91	.06	1.55	25.3

TABLE 1

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
PRE DRILL	12	ATEN	1	7.02	3.17	.63	.74	8.63	59.14	32.23	.09	1.84	20.5
PRE DRILL	12	ATEP	2	7.59	3.34	.39	.65	9.10	49.00	41.90	.10	1.17	26.6
PRE DRILL	12	ATER	3	7.34	3.33	.52	.66	9.88	51.55	38.57	.11	1.34	25.3
PRE DRILL	12	ATET	4	7.96	3.35	.26	.63	5.86	48.41	45.73	.06	1.06	30.1
PRE DRILL	12	ATEV	5	7.45	3.28	.47	.68	7.69	52.93	39.38	.08	1.34	24.7
PRE DRILL	12	ATEX	6	7.41	3.22	.56	.68	5.20	58.30	36.50	.05	1.60	24.8
PRE DRILL	22	ATFF	1	8.25	3.33	.14	.66	6.07	44.49	49.45	.06	.90	31.0
PRE DRILL	22	ATFH	2	8.05	3.38	.20	.65	7.93	44.59	47.49	.09	.94	30.2
PRE DRILL	22	ATFJ	3	8.40	3.39	.06	.65	5.94	42.19	51.88	.06	.81	34.0
PRE DRILL	22	ATFL	4	7.09	3.19	.57	.75	9.43	57.65	32.92	.10	1.75	21.0
PRE DRILL	22	ATFN	5	7.31	3.30	.52	.68	9.91	53.20	36.89	.11	1.44	24.7
PRE DRILL	22	ATFP	6	7.23	3.34	.54	.65	11.98	49.69	38.33	.14	1.30	24.3
PRE DRILL	22	ATSM	7	7.18	3.20	.58	.70	7.06	58.55	34.39	.08	1.70	22.0
PRE DRILL	42	ATGT	1	7.09	3.35	.54	.67	17.18	48.33	34.49	.21	1.40	23.3
PRE DRILL	42	ATGV	2	7.81	3.35	.33	.67	7.61	47.63	44.76	.08	1.06	28.7
PRE DRILL	42	ATGX	3	8.49	3.31	.06	.68	5.50	41.60	52.90	.06	.79	32.4
PRE DRILL	42	ATGZ	4	8.90	3.22	-.03	.68	3.36	39.71	56.93	.03	.70	36.7
PRE DRILL	42	ATHB	5	7.13	3.09	.63	.77	5.48	62.71	31.81	.06	1.97	20.4
PRE DRILL	42	ATHD	6	7.74	3.33	38	.66	7.12	50.19	42.69	.08	1.18	28.3
PRE DRILL	32	ATGH	1	8.04	3.43	.22	.62	8.27	44.56	47.18	.09	.94	35.8
PRE DRILL	32	ATGJ	2	8.02	3.44	.19	.62	9.02	43.91	47.07	.10	.93	31.0
PRE DRILL	32	ATGL	3	7.73	3.42	.30	.64	11.16	44.51	44.33	.13	1.00	28.2
PRE DRILL	32	ATGN	4	7.21	3.37	.53	.65	14.34	47.79	37.86	.17	1.26	24.5
PRE DRILL	32	ATGP	5	8.43	3.38	.04	.67	6.88	40.11	53.00	.07	.76	32.6
PRE DRILL	32	ATGR	6	7.01	3.18	.60	.75	10.05	57.43	32.52	.11	1.77	20.1
PRE DRILL	32	ATSN	7	7.95	3.39	.24	.63	8.24	45.10	46.65	.09	.97	29.4
PRE DRILL	20	ATCD	1	6.68	3.45	.61	.68	33.35	35.73	30.92	.50	1.16	21.8
PRE DRILL	20	ATCF	2	8.89	3.29	-.04	.70	4.88	36.16	58.96	.05	.61	40.2

TABLE 1

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
PRE DRILL	20	ATCH	3	6.41	3.03	.78	1.09	16.07	59.98	23.95	.19	2.50	10.4
PRE DRILL	20	ATCJ	4	8.07	3.40	.16	.66	8.86	43.27	47.87	.10	.90	29.7
PRE DRILL	20	ATCL	5	6.22	3.13	.75	1.04	28.65	47.35	24.00	.40	1.97	15.9
PRE DRILL	20	ATCN	6	6.52	3.16	.74	.84	18.79	54.25	26.97	.23	2.01	17.7
PRE DRILL	20	ATSI	7	6.94	3.33	.63	.69	16.28	50.69	33.03	.19	1.53	22.6
PRE DRILL	10	ATBL	1	7.35	3.32	.51	.66	9.97	51.77	38.26	.11	1.35	24.9
PRE DRILL	10	ATBN	2	8.38	3.24	.17	.66	3.49	46.59	49.92	.04	.93	31.7
PRE DRILL	10	ATBP	3	7.53	3.32	.43	.66	8.74	50.64	40.62	.10	1.25	25.8
PRE DRILL	10	ATBR	4	7.58	3.40	.37	.65	11.54	47.44	41.02	.13	1.16	27.8
PRE DRILL	10	ATBT	5	8.80	3.30	-.02	.69	5.99	38.24	55.77	.06	.69	38.0
PRE DRILL	10	ATBV	6	7.76	3.28	.40	.68	6.55	50.38	43.07	.07	1.17	27.3
PRE DRILL	30	ATDD	1	7.69	3.33	.40	.66	7.05	51.89	41.05	.08	1.26	28.5
PRE DRILL	30	ATDF	2	5.77	2.58	.74	2.06	19.24	63.48	17.28	.24	3.67	12.1
PRE DRILL	30	ATDH	3	6.15	2.95	.77	1.41	23.83	55.28	20.89	.31	2.65	14.7
PRE DRILL	30	ATDJ	4	8.23	3.41	.13	.63	6.92	43.55	49.52	.07	.88	33.6
PRE DRILL	30	ATDL	5	7.07	3.33	.59	.68	13.48	52.73	33.79	.16	1.56	23.6
PRE DRILL	30	ATDN	6	8.96	3.22	-.05	.71	4.05	36.23	59.72	.04	.61	37.5
PRE DRILL	30	ATSJ	7	6.72	3.43	.65	.68	25.31	40.24	34.45	.34	1.17	21.6
PRE DRILL	31	ATEB	1	7.95	3.50	.17	.63	12.55	40.41	47.05	.14	.86	31.0
PRE DRILL	31	ATED	2	7.84	3.35	.31	.64	7.24	48.12	44.64	.08	1.08	28.7
PRE DRILL	31	ATEF	3	7.86	3.28	.35	.66	4.52	51.07	44.40	.05	1.15	28.5
PRE DRILL	31	ATEH	4	6.42	2.95	.76	1.17	12.70	63.95	23.35	.15	2.74	15.7
PRE DRILL	31	ATEJ	5	6.22	2.80	.72	1.51	11.89	65.39	22.72	.13	2.88	13.5
PRE DRILL	31	ATEL	6	7.06	3.29	.61	.68	12.28	52.46	35.26	.14	1.49	23.1

TABLE 2

SEDIMENT PARAMETERS COMPUTED BY MOMENT MEASURES
USING THE 14 PHI EXTRAPOLATION (POST-DRILL)

Key to Table:

PERIOD	Post-Drill
STA	Station
SAMP REP	Sample Code and Replicate Number
MEAN	Mean
S.D.	Standard Deviation
SKEW	Coefficient of Skewness
KURT	Coefficient of Excess (Kurtosis)
SAND, SILT, CLAY	Percentage of Total Weight in the Sand, Silt and Clay categories
SA/MUD	Ratio of Sand Weight to Mud Weight
SI/CL	Ratio of Silt Weight to Clay Weight
>10.6	Percentage of Total Weight in the Fraction Greater than 10.6 phi

TABLE 2

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
POST DRILL	01	BDFC	1	6.79	3.25	.63	.81	16.31	54.58	29.11	.19	1.88	20.1
POST DRILL	01	BDFF	2	7.61	3.50	.32	.63	14.54	43.36	42.09	.17	1.03	28.5
POST DRILL	01	BDFI	3	4.96	4.15	.27	.78	48.12	25.37	26.50	.93	.96	9.7
POST DRILL	01	BDFL	4	7.54	3.29	.45	.70	9.39	52.63	37.99	.10	1.39	25.6
POST DRILL	01	BDFO	5	7.06	3.61	.44	.67	21.02	40.62	38.36	.27	1.06	26.6
POST DRILL	01	BDFR	6	7.75	3.22	.37	.73	6.86	49.58	43.56	.07	1.14	23.8
POST DRILL	01	BDFU	7	6.79	3.24	.65	.75	16.81	52.45	30.74	.20	1.71	19.7
POST DRILL	10	BDZP	1	7.53	3.48	.34	.66	13.77	44.83	41.40	.16	1.08	26.6
POST DRILL	10	BDZS	2	7.13	3.22	.57	.73	7.62	58.89	33.49	.08	1.76	21.5
POST DRILL	10	BDZV	3	6.91	3.49	.53	.65	26.41	37.51	36.08	.36	1.04	22.9
POST DRILL	10	BDZY	4	7.46	3.44	.41	.66	14.90	45.39	39.71	.18	1.14	28.0
POST DRILL	10	BEAB	5	8.09	3.39	.23	.68	7.70	46.47	45.83	.08	1.01	32.3
POST DRILL	10	BEAE	6	8.11	3.43	.19	.66	9.58	43.48	46.94	.11	.93	33.4
POST DRILL	20	BDGN	1	5.77	2.51	.71	2.14	17.44	65.33	17.23	.21	3.79	13.1
POST DRILL	20	BDGQ	2	7.47	3.34	.43	.68	9.49	51.74	38.77	.10	1.33	25.3
POST DRILL	20	BDGT	3	7.20	3.53	.43	.65	21.03	39.88	39.09	.27	1.02	24.8
POST DRILL	20	BDGW	4	7.87	3.58	.17	.62	16.55	36.46	46.98	.20	.78	32.7
POST DRILL	20	BDGZ	5	7.09	3.33	.60	.69	11.69	52.73	35.58	.13	1.48	23.3
POST DRILL	20	BDHC	6	8.04	3.38	.15	.67	9.94	42.38	47.68	.11	.89	27.4
POST DRILL	20	BDHF	7	7.47	3.37	.45	.65	8.58	51.60	39.82	.09	1.30	26.5
POST DRILL	30	BDHW	1	8.58	3.35	.01	.63	3.41	42.66	53.94	.04	.79	35.1
POST DRILL	30	BDHZ	2	8.29	3.17	.29	.65	2.04	50.16	47.81	.02	1.05	32.2
POST DRILL	30	BDIC	3	8.48	3.07	.25	.65	1.63	49.00	49.37	.02	.99	32.0
POST DRILL	30	BDIF	4	6.21	3.14	.75	.98	32.99	42.89	24.12	.49	1.78	16.1
POST DRILL	30	BDII	5	8.11	3.18	.33	.66	2.40	52.22	45.38	.02	1.15	29.6
POST DRILL	30	BDIL	6	6.88	3.25	.62	.73	15.36	53.65	30.99	.18	1.73	19.7
POST DRILL	30	BDIO	7	7.02	3.31	.60	.71	14.37	52.95	32.68	.17	1.62	23.1

TABLE 2

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
POST DRILL	40	BEFZ	1	7.01	3.12	.53	.88	11.86	60.31	27.83	.13	2.17	18.7
POST DRILL	40	BEGC	2	8.69	3.13	.10	.65	1.09	45.31	53.60	.01	.85	34.0
POST DRILL	40	BEGF	3	7.30	3.21	.56	.74	8.61	54.93	36.46	.09	1.51	22.8
POST DRILL	40	BEGI	4	8.93	3.12	.02	.68	1.63	41.63	56.74	.02	.73	37.1
POST DRILL	40	BEGL	5	8.24	3.16	.28	.66	1.27	51.37	47.36	.01	1.08	30.0
POST DRILL	40	BEGO	6	8.16	3.18	.33	.65	2.77	51.24	45.98	.03	1.11	30.7
POST DRILL	31	BEAK	1	6.81	3.41	.60	.70	20.94	46.09	32.97	.26	1.40	22.1
POST DRILL	31	BEAN	2	8.17	3.50	.10	.65	11.01	39.35	49.64	.12	.79	34.0
POST DRILL	31	BEAQ	3	7.29	3.30	.55	.68	7.51	55.93	36.56	.08	1.53	25.9
POST DRILL	31	BEAT	4	7.11	3.46	.48	.66	19.98	43.21	36.82	.25	1.17	23.1
POST DRILL	31	BEAW	5	8.40	3.32	.10	.66	5.55	43.01	51.44	.06	.84	32.7
POST DRILL	31	BEAZ	6	8.59	3.18	.08	.70	2.26	44.36	53.38	.02	.83	30.0
POST DRILL	12	BEBF	1	6.83	3.15	.64	.86	11.48	60.24	28.28	.13	2.13	19.1
POST DRILL	12	BEBI	2	7.07	3.19	.61	.77	8.30	59.96	31.74	.09	1.89	21.1
POST DRILL	12	BEBL	3	6.89	3.23	.63	.78	14.11	55.52	30.37	.16	1.83	20.5
POST DRILL	12	BEBO	4	7.08	3.14	.63	.79	7.61	63.04	29.35	.08	2.15	20.8
POST DRILL	12	BEBR	5	7.85	3.19	.44	.68	4.07	54.38	41.55	.04	1.31	27.8
POST DRILL	12	BEBU	6	7.19	3.46	.48	.68	16.83	46.14	37.04	.20	1.25	25.1
POST DRILL	22	BDJA	1	7.94	3.45	.23	.64	10.81	43.95	45.24	.12	.97	32.3
POST DRILL	22	BDJD	2	7.72	3.39	.35	.66	10.09	44.98	44.93	.11	1.00	28.1
POST DRILL	22	BDJG	3	8.55	3.31	.15	.66	5.42	44.77	49.81	.06	.90	33.7
POST DRILL	22	BDJJ	4	7.82	3.39	.32	.64	7.22	48.68	44.10	.08	1.10	30.1
POST DRILL	22	BDJM	5	7.29	3.38	.52	.67	12.73	49.53	37.74	.15	1.31	25.7
POST DRILL	22	BDJP	6	8.11	3.33	.24	.65	5.36	47.66	46.98	.06	1.01	31.6
POST DRILL	22	BDJS	7	7.98	3.36	.29	.65	6.73	47.52	45.75	.07	1.04	30.3
POST DRILL	32	BDTX	1	7.91	3.46	.24	.65	11.35	43.06	45.58	.13	.94	30.9
POST DRILL	32	BDUA	2	7.97	3.41	.26	.66	6.76	45.63	47.61	.07	.96	31.7
POST DRILL	32	BDUD	3	7.51	3.33	.48	.66	7.66	52.64	39.70	.08	1.33	26.3

TABLE 2

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
POST DRILL	32	BDUG	4	7.45	3.48	.41	.66	14.02	45.55	40.43	.16	1.13	27.9
POST DRILL	32	BDUJ	5	7.94	3.39	.28	.66	7.33	47.24	45.43	.08	1.04	30.8
POST DRILL	32	BDUM	6	8.50	3.34	.11	.62	4.43	44.16	51.40	.05	.86	38.5
POST DRILL	32	BDUP	7	8.32	3.34	.15	.62	4.34	45.79	49.88	.05	.92	34.4
POST DRILL	42	BEGR	1	7.20	3.42	.53	.68	14.42	50.61	34.97	.17	1.45	26.4
POST DRILL	42	BEGU	2	7.20	3.39	.49	.69	15.77	46.60	37.63	.19	1.24	23.3
POST DRILL	42	BEGX	3	7.21	3.44	.48	.68	17.14	44.19	38.67	.21	1.14	25.3
POST DRILL	42	BEHA	4	8.10	3.30	.25	.64	4.96	49.09	45.95	.05	1.07	31.1
POST DRILL	42	BEHD	5	8.34	3.27	.18	.65	3.09	47.66	49.25	.03	.97	31.9
POST DRILL	42	BEHG	6	8.60	3.25	.10	.66	3.62	44.29	52.09	.04	.85	36.0
POST DRILL	33	BECA	1	7.61	3.53	.31	.62	16.69	38.21	45.09	.20	.85	29.9
POST DRILL	33	BECD	2	8.86	3.26	.01	.66	4.39	40.20	55.41	.05	.73	40.7
POST DRILL	33	BECG	3	8.64	3.41	-.02	.70	8.55	37.05	54.40	.09	.68	36.2
POST DRILL	33	BECJ	4	7.88	3.51	.19	.64	15.18	39.27	45.54	.18	.86	30.3
POST DRILL	33	BECM	5	8.54	3.43	.00	.67	9.61	37.06	53.33	.11	.69	35.9
POST DRILL	33	BECP	6	7.76	3.49	.27	.64	14.69	40.80	44.51	.17	.92	29.6
POST DRILL	14	BECV	1	7.13	3.42	.52	.68	16.50	48.33	35.17	.20	1.37	24.3
POST DRILL	14	BECY	2	6.71	3.29	.63	.78	19.14	50.86	30.00	.24	1.70	19.6
POST DRILL	14	BEDB	3	8.24	3.32	.15	.68	7.29	43.34	49.37	.08	.88	30.2
POST DRILL	14	BEDE	4	7.01	3.38	.58	.68	17.83	47.48	34.69	.22	1.37	23.4
POST DRILL	14	BEDH	5	6.96	3.31	.60	.72	15.58	51.47	32.95	.18	1.56	21.8
POST DRILL	14	BEDK	6	6.85	3.27	.61	.77	16.76	52.78	30.46	.20	1.73	20.5
POST DRILL	24	BDUY	1	8.03	3.46	.19	.66	8.78	44.00	47.22	.10	.93	30.1
POST DRILL	24	BDVB	2	8.40	3.38	.10	.67	6.92	42.31	50.78	.07	.83	34.1
POST DRILL	24	BDVE	3	8.94	3.25	-.07	.68	3.50	36.33	60.17	.04	.60	38.1
POST DRILL	24	BDVH	4	7.88	3.48	.22	.65	12.96	40.97	46.07	.15	.89	28.4
POST DRILL	24	BDVK	5	7.72	3.48	.28	.65	14.33	41.32	44.35	.17	.93	28.4
POST DRILL	24	BDVN	6	8.54	3.39	.01	.69	8.47	37.48	54.05	.09	.69	33.8

TABLE 2

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
POST DRILL	24	BDVQ	7	6.97	3.55	.48	.63	28.32	35.04	36.63	.40	.96	24.0
POST DRILL	34	BDWH	1	8.00	3.29	.30	.65	4.22	49.92	45.86	.04	1.09	29.7
POST DRILL	34	BDWK	2	6.44	2.89	.69	1.39	7.83	69.68	22.49	.08	3.10	14.4
POST DRILL	34	BDWN	3	9.05	3.10	-.00	.67	1.08	39.78	59.14	.01	.67	38.6
POST DRILL	34	BDWQ	4	6.84	3.25	.62	.83	14.35	56.60	29.04	.17	1.95	20.5
POST DRILL	34	BDWT	5	7.26	3.29	.56	.72	8.48	56.86	34.67	.09	1.64	24.3
POST DRILL	34	BDWW	6	8.05	3.55	.15	.65	11.64	40.49	47.87	.13	.85	33.0
POST DRILL	34	BDWZ	7	7.86	3.25	.40	.67	5.25	50.24	44.52	.06	1.13	28.4
POST DRILL	44	BEHJ	1	8.34	3.50	.04	.69	9.42	39.00	51.59	.10	.76	34.7
POST DRILL	44	BEHM	2	8.81	3.29	-.02	.68	5.80	38.72	55.48	.06	.70	37.3
POST DRILL	44	BEHP	3	8.22	3.51	.09	.67	13.08	37.13	49.78	.15	.75	33.7
POST DRILL	44	BEHS	4	8.26	3.42	.13	.68	10.95	39.75	49.30	.12	.81	33.3
POST DRILL	44	BEHV	5	8.85	3.27	.01	.67	5.14	38.61	56.24	.05	.69	40.6
POST DRILL	44	BEHY	6	6.96	3.40	.53	.71	17.97	47.33	34.70	.22	1.36	22.4
POST DRILL	35	BEDQ	1	7.21	3.39	.49	.70	14.67	47.34	37.99	.17	1.25	22.7
POST DRILL	35	BEDT	2	6.27	3.29	.67	.99	28.41	47.24	24.35	.40	1.94	17.1
POST DRILL	35	BEDW	3	7.69	3.44	.35	.68	9.44	48.36	42.20	.10	1.15	28.5
POST DRILL	35	BEDZ	4	6.65	3.24	.62	.88	19.29	54.25	26.46	.24	2.05	18.5
POST DRILL	35	BEEC	5	7.95	3.46	.23	.67	9.11	44.45	46.44	.10	.96	30.6
POST DRILL	35	BEEF	6	8.61	3.44	-.06	.69	7.08	40.09	52.83	.08	.76	32.5
POST DRILL	16	BEEM	1	6.85	3.35	.55	.75	18.43	49.58	31.99	.23	1.55	20.4
POST DRILL	16	BEEP	2	8.53	3.33	.06	.67	5.38	41.95	52.67	.06	.80	34.7
POST DRILL	16	BEES	3	6.78	3.39	.55	.71	25.22	42.66	32.11	.34	1.33	20.0
POST DRILL	16	BEEV	4	7.89	3.52	.19	.68	14.48	38.09	47.42	.17	.80	31.0
POST DRILL	16	BEEY	5	6.95	3.45	.48	.71	22.25	44.57	33.19	.29	1.34	22.4
POST DRILL	16	BEFB	6	6.96	3.47	.52	.66	25.10	38.65	36.26	.34	1.07	23.3
POST DRILL	26	BDXI	1	7.83	3.36	.32	.67	6.38	49.27	44.35	.07	1.11	28.3
POST DRILL	26	BDXL	2	8.23	3.44	.11	.64	8.85	41.29	49.85	.10	.83	33.4

TABLE 2

PERIOD	STA	SAMP	REP	MEAN	S.D.	SKEW	KURT	SAND	SILT	CLAY	SA/MUD	SI/CL	>10.6
								PERCENTS			RATIOS		
POST DRILL	26	BDXO	3	8.81	3.19	.03	.67	3.24	40.97	55.80	.03	.73	36.2
POST DRILL	26	BDXR	4	7.11	3.34	.55	.71	13.47	49.28	37.25	.16	1.32	22.7
POST DRILL	26	BDXU	5	7.03	3.32	.57	.71	14.96	48.92	36.12	.18	1.35	21.1
POST DRILL	26	BDXX	6	7.44	3.44	.39	.66	15.76	43.13	41.11	.19	1.05	26.2
POST DRILL	26	BDYA	7	7.02	3.26	.62	.74	12.01	54.75	33.23	.14	1.65	22.1
POST DRILL	36	BDYR	1	8.87	3.22	-.02	.66	2.91	40.88	56.21	.03	.73	37.4
POST DRILL	36	BDYU	2	9.21	3.08	-.08	.68	1.18	37.60	61.22	.01	.61	40.4
POST DRILL	36	BDYX	3	8.99	3.30	-.13	.68	4.48	35.60	59.91	.05	.59	38.6
POST DRILL	36	BDZA	4	6.60	3.16	.63	.90	19.46	53.61	26.93	.24	1.99	17.4
POST DRILL	36	BDZD	5	7.46	3.44	.40	.67	13.17	46.75	40.08	.15	1.17	26.4
POST DRILL	36	BDZG	6	6.38	3.26	.65	.86	28.81	44.60	26.58	.40	1.68	17.3
POST DRILL	36	BDZJ	7	6.83	3.15	.62	.87	13.20	57.97	28.83	.15	2.01	18.6
POST DRILL	46	BEIB	1	6.80	3.25	.58	.85	17.03	55.03	27.94	.21	1.97	19.5
POST DRILL	46	BEIE	2	8.52	3.37	.05	.68	6.15	41.46	52.40	.07	.79	35.0
POST DRILL	46	BEIH	3	8.77	3.25	.01	.68	4.47	40.46	55.07	.05	.73	36.4
POST DRILL	46	BEIK	4	8.19	3.47	.11	.67	8.48	42.14	49.38	.09	.85	32.4
POST DRILL	46	BEIN	5	8.12	3.42	.17	.67	10.11	42.17	47.72	.11	.88	29.8
POST DRILL	46	BEIQ	6	8.09	3.57	.12	.66	13.30	38.13	48.57	.15	.78	35.3
POST DRILL	37	BEFH	1	7.66	3.17	.46	.73	5.67	56.43	37.90	.06	1.49	24.7
POST DRILL	37	BEFK	2	7.13	3.53	.48	.64	22.10	39.75	38.15	.28	1.04	26.2
POST DRILL	37	BEFN	3	8.23	3.41	.16	.66	8.82	42.83	48.35	.10	.89	33.1
POST DRILL	37	BEFQ	4	6.08	2.89	.66	1.40	27.86	52.24	19.90	.39	2.63	13.5
POST DRILL	37	BEFT	5	5.58	2.60	.72	1.85	33.41	49.39	17.20	.50	2.87	11.7
POST DRILL	37	BEFW	6	9.20	3.06	-.05	.69	1.55	38.93	59.51	.02	.65	36.9

TABLE 3

MEANS AND STANDARD DEVIATIONS OF THE SIX OR SEVEN GRAB SAMPLES TAKEN AT EACH STATION FOR THE RIG MONITORING, PRE-DRILLING STUDY USING THE DATA FROM TABLE 1

Key to Table:

MEAN	Mean
S.D.	Standard Deviation
SKEW	Coefficient of Skewness
KURT	Coefficient of Excess (Kurtosis)
% SAND, % SILT, % CLAY, % >10.6 (Percents)	Percentage of total weight in the sand, silt and clay categories and in the fraction greater than 10.6 phi.

TABLE 3

PRE-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	% >10.6 PHI
DS	MEAN	7.61	3.09	.57	- .93	7.60	52.8	39.6	23.1
	S.D.	.89	.15	.37	.35	5.3	9.2	6.7	10.7
N-100	MEAN	8.00	3.24	.34	-1.26	7.71	47.5	44.8	29.3
	S.D.	.52	.07	.22	.67	2.9	5.0	6.7	4.9
N-500	MEAN	7.11	3.25	.71	- .72	18.1	46.8	35.1	23.5
	S.D.	1.05	.12	.49	.53	10.1	9.1	13.3	8.8
N-1000	MEAN	7.48	3.24	.68	- .58	12.2	49.1	38.8	26.0
	S.D.	.96	.17	.62	1.04	9.0	9.5	12.7	7.8
N-2000	MEAN	7.21	3.30	.80	- .65	7.33	59.4	33.3	22.7
	S.D.	.68	.26	.42	.84	2.3	3.3	9.6	6.2
NE-1000	MEAN	7.28	3.19	.71	- .73	10.2	53.6	36.2	23.5
	S.D.	.86	.19	.49	.83	3.5	9.6	11.0	7.3
E-100	MEAN	7.57	3.26	.54	-1.15	7.73	53.2	39.1	25.3
	S.D.	.32	.06	.17	.19	1.9	4.6	4.6	3.1
E-500	MEAN	7.73	3.25	.45	-1.15	8.33	50.1	41.6	26.8
	S.D.	.55	.06	.27	.22	2.2	6.6	7.8	5.0
E-1000	MEAN	7.85	3.31	.36	-1.26	9.71	47.2	43.1	28.6
	S.D.	.49	.08	.24	.22	2.5	5.6	6.8	4.8

TABLE 3

PRE-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	% >10.6 PHI
E-2000	MEAN	7.93	3.21	.38	-1.17	7.71	48.4	43.9	28.4
	S.D.	.70	.10	.32	.24	4.9	8.1	9.9	5.9
SE-1000	MEAN	7.52	3.20	.58	-1.00	9.26	52.2	38.6	24.7
	S.D.	.68	.08	.31	.23	4.4	7.9	9.8	4.7
S-100	MEAN	7.89	3.20	.44	-1.21	6.72	51.0	42.31	27.9
	S.D.	.51	.15	.21	.15	6.3	6.1	6.4	3.5
S-500	MEAN	7.72	3.30	.41	-1.27	7.89	49.7	42.5	28.8
	S.D.	.46	.05	.17	.14	1.02	3.8	4.4	6.3
S-1000	MEAN	8.50	3.16	.06	-1.27	5.36	42.6	52.0	32.7
	S.D.	.58	.12	.14	.08	2.2	5.8	7.5	4.9
S-2000	MEAN	8.48	3.18	.14	-1.34	5.02	43.5	51.5	32.5
	S.D.	.23	.05	.10	.04	.82	2.9	3.3	2.6
SW-1000	MEAN	7.76	3.29	.43	-1.20	10.6	46.9	42.4	28.7
	S.D.	.76	.09	.30	.26	8.3	4.6	8.9	6.9
W-100	MEAN	7.80	3.14	.50	-1.03	6.76	52.1	41.1	26.75
	S.D.	.83	.08	.39	.52	5.0	6.1	11.0	6.2
W-500	MEAN	8.20	3.14	.30	-1.02	8.68	43.3	47.9	32.2
	S.D.	1.12	.15	.54	.84	10.3	5.2	14.1	9.0

TABLE 3

PRE-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	%>10.6 PHI
W-1000	MEAN	7.90	3.12	.44	- .97	7.14	49.4	43.5	27.8
	S.D.	1.0	.11	.48	.41	4.8	10.1	14.5	9.2
W-2000	MEAN	8.24	3.23	.16	-1.21	8.06	39.5	52.4	30.4
	S.D.	.57	.17	.29	.25	3.4	13.3	14.3	3.1
NW-1000	MEAN	7.92	3.09	.49	-1.06	4.65	53.3	42.0	27.1
	S.D.	.71	.11	.32	.29	4.0	8.7	10.5	2.5

TABLE 4

MEANS AND STANDARD DEVIATIONS OF THE SIX OR SEVEN GRAB SAMPLES TAKEN AT EACH STATION FOR THE RIG MONITORING, POST-DRILLING STUDY USING THE DATA FROM TABLE 2

Key to Table:

MEAN		Mean
S.D.		Standard Deviation
SKEW		Coefficient of Skewness
KURT		Coefficient of Excess (Kurtosis)
% SAND % SILT % CLAY % > 10.6	Percents	Percentage of total weight in the sand, silt and clay categories and in the fraction greater than 10.6 phi

TABLE 4

POST-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	% >10.6 PHI
DS	MEAN	7.01	3.43	.58	-1.03	19.0	45.5	35.5	21.4
	S.D.	.90	.31	.20	.26	13.7	10.3	6.7	5.9
N-100	MEAN	7.63	3.37	.43	-1.23	13.3	46.1	40.6	25.8
	S.D.	.46	.10	.20	.18	7.1	7.0	5.3	4.6
N-500	MEAN	7.38	3.31	.59	- .90	13.5	48.6	37.9	23.7
	S.D.	.71	.24	.47	.96	4.8	9.8	10.1	6.8
N-1000	MEAN	7.73	3.19	.51	-1.06	10.3	48.3	41.4	25.8
	S.D.	.98	.13	.38	.45	11.5	4.8	12.0	8.2
N-2000	MEAN	8.09	3.11	.40	-1.16	4.59	50.8	44.6	27.7
	S.D.	.76	.06	.32	.34	4.5	6.7	10.8	7.7
NE-1000	MEAN	7.78	3.31	.39	-1.22	11.2	45.4	43.5	26.7
	S.D.	.69	.15	.27	.17	7.7	5.6	9.0	5.6
E-100	MEAN	7.19	3.21	.74	- .86	10.4	56.6	33.0	21.3
	S.D.	.41	.10	.20	.28	4.7	6.1	5.2	3.8
E-500	MEAN	7.99	3.33	.31	-1.35	8.4	46.7	44.9	28.6
	S.D.	.31	.06	.12	.07	2.9	2.1	3.7	2.8
E-1000	MEAN	8.04	3.36	.28	-1.37	8.0	46.3	45.7	29.6
	S.D.	.35	.06	.13	.07	3.6	3.1	4.4	3.8

TABLE 4

POST-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	% > 10.6 PHI
E-2000	MEAN	7.84	3.30	.42	-1.25	9.3	47.2	43.5	27.8
	S.D.	.51	.08	.20	.11	6.2	2.6	6.6	5.1
SE-1000	MEAN	8.30	3.35	.13	-1.38	11.5	38.8	49.7	31.9
	S.D.	.46	.12	.15	.03	4.8	1.6	5.2	4.5
S-100	MEAN	7.22	3.31	.64	-1.00	15.4	49.1	35.4	22.3
	S.D.	.52	.06	.23	.24	4.2	3.4	7.1	4.4
S-500	MEAN	8.15	3.35	.18	-1.34	11.9	39.6	48.5	30.1
	S.D.	.60	.13	.20	.07	8.1	3.4	7.5	5.0
S-1000	MEAN	7.68	3.20	.52	- .97	7.6	51.9	40.5	25.6
	S.D.	.91	.18	.45	.61	4.5	10.4	12.5	8.9
S-2000	MEAN	8.31	3.30	.15	-1.30	10.4	40.1	49.5	31.7
	S.D.	.66	.09	.26	.15	4.8	3.7	7.8	6.5
SW-1000	MEAN	7.44	3.32	.52	-1.00	14.7	47.0	38.4	24.4
	S.D.	.89	.07	.42	.48	8.1	4.7	11.2	7.8
W-100	MEAN	7.41	3.36	.50	-1.10	18.5	42.6	38.9	24.2
	S.D.	.68	.07	.28	.23	7.6	4.2	8.9	6.5
W-500	MEAN	7.74	3.29	.42	-1.19	10.7	46.8	42.5	26.1
	S.D.	.65	.09	.27	.18	4.7	5.1	8.1	6.3

TABLE 4

POST-DRILLING STATION SUMMARY

Station		Mean	S.D.	Skew	Kurt	% Sand	% Silt	% Clay	% > 10.6 PHI
W-1000	MEAN	7.78	3.18	.45	- .94	11.9	45.3	42.8	26.8
	S.D.	1.24	.13	.53	.46	10.0	8.2	16.0	12.0
W-2000	MEAN	7.97	3.37	.31	-1.26	9.9	43.2	46.8	29.9
	S.D.	.77	.21	.36	.34	4.6	6.0	9.7	7.0
NW-1000	MEAN	7.37	3.13	.69	- .54	16.6	46.6	36.8	23.5
	S.D.	1.32	.25	.65	1.14	13.0	7.2	16.3	12.1

APPENDIX E

INVERTEBRATE EPIFAUNA AND MACROINFAUNA

List of Tables

TABLE 1

LIST OF MACROINFAUNAL SPECIES AND THEIR ABUNDANCES
FOR EACH REPLICATE GRAB.
SPECIES ARE RANKED BY ABUNDANCE

Explanation of Table 1:

RANK	Species ranked by total abundance in all six replicates
REPLICATE	Number of individuals in each replicate
TOTAL INDIVIDUALS	Total number of individuals in all six replicates
TOTAL OCCURRENCES	Number of replicates in which the species occurred
DIVERSITY	Shannon-Wiener diversity index
PIE	Hurlbert's Probability of Interspecific Encounter
EQUITABILITY	Lloyd and Ghelardi's measure of evenness

TABLE 1 CONT.'D

STATION 1 TRANSECT RIG PERIOD PRE-RIG

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NEPHTYS INCISA	10		3	2	7	16	38	5
2	PARAPRIONOSPIO PINNATA	4	5		4	7	9	29	5
3	AMPELISCA AGASSIZI	1			1	3	21	26	4
4	NEMERTINEA	2		2		2	9	15	4
5	EUDORELLA MONODON	1	1		3	4	6	15	5
6	SPIONIDAE			1	1	6	5	13	4
7	NOTOMASTUS CF LATERICEUS	1	1		6	3	2	13	5
8	PARAONIS GRACILIS	2	1		1	1	7	12	5
9	CORBULA CONTRACTA		3			9		12	2
10	MAGELONA LONGICORNIS	1	1	2	3	1	2	10	6
11	COSSURA DELTA	2		2	2	1	2	9	5
12	MEDIOMASTUS CALIFORNIENSIS	1	2	1	1		4	9	5
13	LUMBRINERIS PARVAPEDATA				1	1	5	7	3
14	NEREID (NICON) SPA	1			1		5	7	3
15	MAGELONA ROSEA	4		1	1	1		7	4
16	SIGAMBRA TENTACULATA		1		2	2	2	7	4
17	TYPHLAPSEUDES SPB					7		7	1
18	AMPELISCA ABDITA	2					4	6	2
19	PINNOTHERIDAE		1			2	3	6	3
20	PARAONIDAE		1				3	4	2
21	AMPELISCA VERRILLI					1	2	3	2
22	MALACOCEROS SP					2	1	3	2
23	POLYDORA LIGNI						3	3	1
24	AUTOMATE EVERMANNI			1		2		3	2
25	THARYX ANNULOSUS						2	2	1
26	CIRROPHORUS LYRIFORMIS			1	1			2	2

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
27	DRILONEREIS MAGNA	1	1					2	2
28	NOTOMASTUS CF AMERICANUS			2				2	1
29	ARMANDIA MACULATA						2	2	1
30	LISTRIELLA BARNARDI				1	1		2	2
31	NEPHTYIDAE					2		2	1
32	ACLIS SP				2			2	1
33	SCOLELEPIS TEXANA		2					2	1
34	PARAONIS SP					2		2	1
35	POLYNOIDAE	1		1				2	2
36	AGLAOPHAMUS CIRCINATA		2					2	1
37	SIPUNCULA	2						2	1
38	CAPITELLIDAE SPC						1	1	1
39	CIRRATULIDAE	1						1	1
40	PARAONIDES LYRA	1						1	1
41	ANCISTROSYLLIS JONESI						1	1	1
42	GONIADA TERES					1		1	1
43	STHENELAIS BOA						1	1	1
44	POLYCHAETE SPA						1	1	1
45	GLYCERA CAPITATA					1		1	1
46	GONEPLACIDAE					1		1	1
47	CHAETOZONE SETOSA		1					1	1
48	ORELIA SPA				1			1	1
49	SCHISTOMERINGOS RUDOLPHI					1		1	1
50	SPIOPHANES WIGLEYI	1						1	1
51	OPHIUROIDEA		1					1	1
52	VITRINELLA FLORIDANA	1						1	1
53	ASYCHIS SP	1						1	1
54	NINOE NIGRIPES				1			1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
55	NOTOMASTUS LATERICEUS	1						1	1
56	TELLINIDAE				1			1	1
57	THARYX MARIONI			1				1	1
58	AMPHICTEIS GUNNERI			1				1	1
59	LUMBRINERIDAE					1		1	1
60	SIGAMBRA BASSI						1	1	1
	NO. OF SPECIES	22	15	13	20	27	27		
	NO. OF INDIVIDUALS	42	24	19	36	72	120	313	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
1	RIG	60	313	4.9930	.9546	.8000

1

TABLE 1 CONT.'D

STATION 30 TRANSECT RIG PERIOD PRE-RIG

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NEPHTYS INCISA	4	7	12	4	13	17	57	6
2	PARAONIS GRACILIS	1	2	5		18	10	36	5
3	PARAPRIONOSPIO PINNATA	15	4		3	7	6	35	5
4	AMPELISCA AGASSIZI			20	1	6	1	28	4
5	MEDIOMASTUS CALIFORNIENSIS	1		2	3	10	8	24	5
6	TEINOSTOMA BISCAYNENSE					19		19	1
7	LUMBRINERIS PARVAPEDATA			7		4	2	13	3
8	NEMERTINEA	1		4	1	3	3	12	5
9	EUDORELLA MONODON	5	1	4		1	1	12	5
10	SPIONIDAE	7	1		2			10	3
11	COSSURA DELTA		1	1	3	3	1	9	5
12	MINUSPIO CIRRIFERA					9		9	1
13	SIGAMBRA TENTACULATA	2				4	3	9	3
14	CAPITELLIDAE SPC	2		1		2	3	8	4
15	NOTOMASTUS CF LATERICEUS				3	2	2	7	3
16	ARMANDIA MACULATA	2	1	1		1	1	6	5
17	AMPELISCA ABDITA			4		2		6	2
18	NATICIDAE	1		1		1	2	5	4
19	AMPELISCA VERRILLI	2	1	1		1		5	4
20	AUTOMATE EVERMANNI				1	2	1	4	3
21	THARYX MARIONI			2		2		4	2
22	DRILONEREIS MAGNA	2				1	1	4	3
23	MALACOCEROS SP	1					2	3	2
24	DIOPATRA CUPREA					1	2	3	2
25	OPHIUROIDEA				1		1	2	2
26	TELLINIDAE				1		1	2	2

TABLE 1 CONT.'D

27	ALPHEIDAE			2			2	1
28	TYPHLAPSEUDES SPB				1	1	2	2
29	MAGELONA ROSEA	1	1				2	2
30	AEDICIRA BELGICAE		1		1		2	2
31	THARYX ANNULOSUS					2	2	1
32	NINOE NIGRIPES	1		1			2	2
33	MALACOCEROS INDICUS					2	2	1
34	ACLIS SP		2				2	1
35	ALPHEUS SP					1	1	1
36	ARICIDEA JEFFREYSII				1		1	1
37	TRACHYPENAEUS SIMILIS				1		1	1
38	LEPIDASTHENIA SPA		1				1	1
39	LISTRIELLA BARNARDI					1	1	1
40	NOTOMASTUS AMERICANUS	1					1	1
41	ANCISTROSYLLIS GROENLANDICA		1				1	1
42	MAGELONA LONGICORNIS	1					1	1
43	NEREID (NICON) SPA			1			1	1
44	CAPITELLIDAE			1			1	1
45	SCOLELEPIS TEXANA		1				1	1
46	TEREBELLIDAE		1				1	1
47	SIGAMBRA BASSI				1		1	1
48	VITRINELLA FLORIDANA		1				1	1
49	PINNOTHERIDAE		1				1	1
50	LUMBRINERIS TENUIS	1					1	1
51	ANCISTROSYLLIS JONESI				1		1	1

NO. OF SPECIES	19	11	20	15	28	25	
NO. OF INDIVIDUALS	51	21	72	28	118	75	365

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
30	RIG	51	365	4.6075	.9376	.7255

1

TABLE 1 CONT.'D

STATION 32 TRANSECT RIG PERIOD PRE-RIG

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NEPHTYS INCISA	1	5	7	6	15	3	37	6
2	TYPHLAPSEUDES SPB	11	5	1		8		25	4
3	PARAPRIONOSPIO PINNATA	2	5	2	12	3	1	25	6
4	EUDORELLA MONODON		2		7	4	6	19	4
5	PARAONIS GRACILIS	4	2	1	4	8		19	5
6	COSSURA DELTA	2	2	2	2	6	1	15	6
7	AMPELISCA AGASSIZI	6	3	3	2	1		15	5
8	MEDIOMASTUS CALIFORNIENSIS		3		2	5		10	3
9	MAGELONA LONGICORNIS	1		3	2	2		8	4
10	NINOE NIGRIPES	1	1		1	1	1	5	5
11	ARMANDIA MACULATA		1	1		2	1	5	4
12	SPIONIDAE					5		5	1
13	THARYX MARIONI		1		1	3		5	3
14	CORBULA CONTRACTA	3	2					5	2
15	AMPELISCA ABDITA				3		1	4	2
16	AEDICIRA BELGICAE	3			1			4	2
17	NEMERTINEA	1	2			1		4	3
18	LUMBRINERIS TENUIS	1	1			1		3	3
19	NOTOMASTUS CF LATERICEUS		1		1	1		3	3
20	MAGELONA ROSEA		1		1	1		3	3
21	GONEPLACIDAE		2				1	3	2
22	LUMBRINERIS PARVAPEDATA		2		1			3	2
23	AMPELISCA VERRILLI				1	2		3	2
24	CIRROPHORUS LYRIFORMIS	1				1		2	2
25	VITRINELLA FLORIDANA					2		2	1
26	SIGAMBRA TENTACULATA		1			1		2	2

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	CAPITELLIDAE SPC		2					2	1
28	SPIOPHANES WIGLEYI	1	1					2	2
29	CARIDEA					2		2	1
30	PARAONIS SPA					1		1	1
31	NEREID (NICON) SPA					1		1	1
32	MINUSPIO CIRRIFERA	1						1	1
33	MALACOCEROS VANDERHORSTI	1						1	1
34	AMPHICTEIS GUNNERI			1				1	1
35	MALACOCEROS SP					1		1	1
36	SCOLELEPIS TEXANA						1	1	1
37	TELLINIDAE				1			1	1
38	ASYCHIS ELONGATA			1				1	1
39	MINUSPIO LONGIBRANCHIATA					1		1	1
40	ALPHEIDAE					1		1	1
41	LUMBRINERIDAE					1		1	1
42	DIOPATRA CUPREA						1	1	1
43	ACTINARIA		1					1	1
44	CERIANTHARIA					1		1	1
	NO. OF SPECIES	16	22	10	17	29	10		
	NO. OF INDIVIDUALS	40	46	22	48	82	17	255	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
32	RIG	44	255	4.5377	.9388	.7955

1

TABLE 1 CONT.'D

STATION 34 TRANSECT RIG PERIOD PRE-RIG

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	TYPHLAPSEUDES SPB	1	1		40	8		50	4
2	NEPHTYS INCISA	13	5	7	8	2	5	40	6
3	PARAPRIONOSPIO PINNATA	2	2	1	15	7	5	32	6
4	CORBULA CONTRACTA	2	1		16	1		20	4
5	EUDORELLA MONODON	2	3	3	4		3	15	5
6	NEMERTINEA		2	2	4	3	2	13	5
7	AMPELISCA AGASSIZI	1	2	3	1	1	3	11	6
8	SIGAMBRA TENTACULATA	2	2	1	1	2	2	10	6
9	NOTOMASTUS CF LATERICEUS	3	1	1	2	3		10	5
10	AMPELISCA ABDITA	2	3	2	1	1		9	5
11	MEDIOMASTUS CALIFORNIENSIS	1	3	1	3		1	9	5
12	AMPELISCA VERRILLI		2	1	4			7	3
13	NEPHTYIDAE		3			2		5	2
14	MAGELONA ROSEA	1				4		5	2
15	LUMBRINERIS PARVAPEDATA		3		2			5	2
16	NINOE NIGRIPES	1		1	1	1		4	4
17	ARMANDIA MACULATA			1	1	2		4	3
18	NATICIDAE			2	1			3	2
19	LISTRIELLA BARNARDI				3			3	1
20	MAGELONA LONGICORNIS		2			1		3	2
21	PARAONIS GRACILIS	1		1			1	3	3
22	PARAONIDAE			2				2	1
23	CHASMOCARCINUS MISSISSIPPIENSIS				1		1	2	2
24	MINUSPIO CIRRIFERA				2			2	1
25	TELLINIDAE				2			2	1
26	OPHIUROIDEA		1	1				2	2

TABLE 1 CONT.'D

RANK	%	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27		ACLIS SP				2			2	1
28		NOTOMASTUS AMERICANUS		2					2	1
29		COSSURA DELTA	1		1				2	2
30		ANCISTROSYLLIS PAPILLOSA						1	1	1
31		PARAONIS SPA	1						1	1
32		PSEUDEURYTHOE AMBIGUA					1		1	1
33		PARAONIDES LYRA	1						1	1
34		CAPITELLIDAE SPB						1	1	1
35		DRILONEREIS MAGNA				1			1	1
36		MALACOCEROS INDICUS						1	1	1
37		SIGAMBRA HASSI					1		1	1
38		CAPITELLIDAE SPC	1						1	1
39		DIOPATRA CUPREA	1						1	1
40		AUTOMATE EVERMANNI			1				1	1
41		SOUILLA CHYDAEA	1						1	1
42		LUMBRINERIDAE						1	1	1
43		BRADA SP	1						1	1
44		NOTOMASTUS SP					1		1	1
45		LUMBRINERIS TENUIS	1						1	1
46		CIRROPHORUS LYRIFORMIS			1				1	1
47		THARYX MARIONI	1						1	1
48		TRACHYPENAEUS SIMILIS		1					1	1
		NO. OF SPECIES	22	18	19	22	17	13		
		NO. OF INDIVIDUALS	41	39	33	115	41	27	296	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
34	RIG	48	296	4.4490	.9273	.6875

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TABLE 1 CONT.'D

STATION 36 TRANSECT RIG PERIOD PRE-RIG

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	6	8		5	21	13	53	5
2	NEPHTYS INCISA	6	6	1	3	8	6	30	6
3	MEDIOMASTUS CALIFORNIENSIS	1	4	2	8	3	4	22	6
4	PARAONIS GRACILIS	2	6		7	2	5	22	5
5	AMPELISCA ABDITA	1	2		4	6	6	19	5
6	EUDORELLA MONODON	3	1		3	9	3	19	5
7	AMPELISCA AGASSIZI		1		4	4	7	16	4
8	NEMERTINEA	1		2	5	1	6	15	5
9	LUMBRINERIS PARVAPEDATA	2		1	3	2	3	11	5
10	SIGAMBRA TENTACULATA	1		3	4		3	11	4
11	AMPELISCA VERRILLI	1	1		1	5	2	10	5
12	ARMANDIA MACULATA	2	3	1		2	2	10	5
13	ACLIS SP				8		2	10	2
14	COSSURA DELTA	1	2	1	2	2	1	9	6
15	CAPITELLIDAE SPC		2	2	3	2		9	4
16	THARYX MARIONI	2			5	2		9	3
17	NOTOMASTUS CF LATERICEUS	1	3	1			1	6	4
18	CORBULA CONTRACTA	1				3	2	6	3
19	MALACOCEROS INDICUS	2	3					5	2
20	NEREID (NICON) SPA	1	2		2			5	3
21	AEDICIRA BELGICAE	1			3			4	2
22	ANCISTROSYLLIS JONESI	1	1		2			4	3
23	SPIONIDAE		1				2	3	2
24	TYPHLAPSEUDES SPB			3				3	1
25	TELLINIDAE					2	1	3	2
26	MINUSPIO CIRRIFERA				2			2	1

TABLE 1 CONT.'D

27	NATICIDAE	1		1			2	2
28	MAGELONA LONGICORNIS	1			1		2	2
29	NEPHTYIDAE				2		2	1
30	LISTRIELLA BARNARDI					2	2	1
31	CAPITELLIDAE					2	2	1
32	VOLVULELLA TEXASIANA					2	2	1
33	SIPUNCULA	1	1				2	2
34	PINNOTHERIDAE		1		1		2	2
35	MAGELONA ROSEA		1			1	2	2
36	SQUILLA CHYDAEA	1					1	1
37	DRILONEREIS MAGNA			1			1	1
38	GONEPLACIDAE				1		1	1
39	OBELIA SPA		1				1	1
40	SPIOPHANES BOMBYX	1					1	1
41	BRADA SP					1	1	1
42	LEIOCHRUS SPA				1		1	1
43	OPHIUROIDEA			1			1	1
44	PARAONIDAE		1				1	1
45	AMPHIPOD SPA			1			1	1
46	PITAR CORDATUS				1		1	1
47	DIOPATRA CUPREA	1					1	1
48	NUCULANA ACUTA			1			1	1
49	NINOE NIGRIPES				1		1	1
50	CIRROPHORUS LYRIFORMIS		1				1	1
51	MALACOCEROS SP			1			1	1
52	SCOLELEPIS TEXANA			1			1	1
53	AUTOMATE EVERMANNI		1				1	1

NO. OF SPECIES	25	23	12	24	23	23	
NO. OF INDIVIDUALS	42	53	19	79	82	77	352

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
36	RIG	53	352	4.7830	.9470	.7925

TABLE 1 CONT.'D

STATION 10 TRANSECT RIG PERIOD POST DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	AMPELISCA AGASSIZI	5	16	4	6	6	10	47	6
2	COSSURA DELTA	6		10	3	4	13	36	5
3	PARAPRIONOSPIO PINNATA	5	10	7	4	2	6	34	6
4	SPIONIDAE	1	10	3	6	9	3	32	6
5	NOTOMASTUS CF LATERICEUS	6	6	7	4	2	3	28	6
6	NEPHTYS INCISA	3	8	2	3	9	3	28	6
7	PARAONIS GRACILIS		5	5	4	4	6	24	5
8	AMPELISCA ABDITA	5	3	6	5	2	3	24	6
9	MEDIOMASTUS CALIFORNIENSIS		8	4	1	8	3	24	5
10	EUDORELLA MONODON	5	7	2	2	3	5	24	6
11	ARICIDEA JEFFREYSII		10	1	2	1	6	20	5
12	AMPELISCA VERRILLI	2	7	4	1	3	2	19	6
13	SIGAMBRA TENTACULATA		2	8	3	3	1	17	5
14	NEMERTINEA	2	6	3	3		3	17	5
15	CORBULA CF CONTRACTA	6	5	1				12	3
16	LUMBRINERIS PARVAPEDATA		1	3	1	2	3	10	5
17	MAGELONA LONGICORNIS	1			1	2	3	7	4
18	GONEPLACIDAE	5						5	1
19	CIRROPHORUS LYRIFORMIS	2		1		1		4	3
20	NATICA SP			1		1	2	4	3
21	ARMANDIA MACULATA	2				2		4	2
22	THARYX ANNULOSUS		1		2			3	2
23	NINOE NIGRIPES			1		2		3	2
24	VITRINELLA FLORIDANA		2	1				3	2
25	MAGELONA ROSEA					2	1	3	2
26	OPHIUROIDEA		1		1	1		3	3

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
27	ANCISTROSYLLIS JONESI			1	1			2	2
28	APSEUDES SPA	1				1		2	2
29	SCHISTOMERINGOS RUDOLPHI				2			2	1
30	MACOMA PULLEYI					2		2	1
31	ACLIS SPA				1	1		2	2
32	DRILONEREIS MAGNA						2	2	1
33	SPIOPHANES SPA		2					2	1
34	NEREID(NICON) SPA		1					1	1
35	PHOTID SPA	1						1	1
36	POLYDORA SP			1				1	1
37	GLYCERIDAE			1				1	1
38	CERIANTHARIA						1	1	1
39	LISTRIELLA BARNARDI	1						1	1
40	LUCINA AMIANTUS						1	1	1
41	NEPHTYIDAE			1				1	1
42	TELLINA SP						1	1	1
43	VOLVULELLA TEXASIANA						1	1	1
44	PHYLLODOCE MUCOSA						1	1	1
45	STHENELAIS SP		1					1	1
46	OWENIA FUSIFORMIS						1	1	1
47	PRIONOSPIO CRISTATA						1	1	1
48	OPHIOGLYCERA CF DISTORTA	1						1	1
49	LOVENELLA GRANDIS		1					1	1
50	SPIOPHANES WIGLEYI		1					1	1
51	CHAETOPTERIDAE		1					1	1
52	GLYCERA SPB		1					1	1
53	MULINIA LATERALIS	1						1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
54	ANADARA TRANSVERSA				1			1	1
55	AMPHARETIDAE						1	1	1
	NO. OF SPECIES	20	25	24	22	24	27		
	NO. OF INDIVIDUALS	61	116	78	57	73	86	471	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
10	RIG	55	471	4.7156	.9588	.7273

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TABLE 1 CONT.'D

STATION 12 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	AMPELISCA AGASSIZI	5	7	1	3	8	39	63	6
2	NEMERTINEA	2	2	4	4	17	4	33	6
3	AMPELISCA VERRILLI	6	4	1	7	6	6	30	6
4	PARAPRIONOSPIO PINNATA	4	5	8	1	2	9	29	6
5	AMPELISCA ABDITA	6	5	1	6		9	27	5
6	MEDIOMASTUS CALIFORNIENSIS	6	2	4	2	2	6	22	6
7	NOTOMASTUS CF LATERICEUS	3	4		11		4	22	4
8	SPIONIDAE	12			5			17	2
9	PARAONIS GRACILIS	5	1	3	2	2	2	15	6
10	EUDORELLA MONODON	7		2	3		3	15	4
11	VITRINELLA FLORIDANA			1	1	12		14	3
12	NEPHTYS INCISA	3	2	3	2		3	13	5
13	LUMBRINERIS PARVAPEDATA	2		3	2	1	4	12	5
14	SIGAMBRA TENTACULATA	3		5	1		2	11	4
15	SPIOPHANES SPA	1	2	3	3		2	11	5
16	CORBULA CF CONTRACTA	1		1	6	1		9	4
17	MAGELONA LONGICORNIS	1	2		1	2	1	7	5
18	COSSURA DELTA	1	2	1		1	2	7	5
19	VENERIDAE	4			1			5	2
20	ARICIDEA JEFFREYSII		1	1	2			4	3
21	THARYX MARIONI		1		3			4	2
22	ARMANDIA MACULATA	1	2	1				4	3
23	ANCISTROSYLLIS JONESI	1				3		4	2
24	POLYDORA CF CONCHARUM				3			3	1
25	NINOE NIGRIPES	1	1			1		3	3
26	LOVENELLA GRANDIS	1		1		1		3	3

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	ORILONEREIS MAGNA	1	1				1	3	3
28	AFDICIRA BELGICAE				1	2		3	2
29	SIPUNCULA	2			1			3	2
30	ABRA AEQUALIS					2		2	1
31	POLYDORA LIGNI		2					2	1
32	ONUPHIDAE	1	1					2	2
33	ALPHEUS FLORIDANUS	1					1	2	2
34	SIGAMBRA SP			2				2	1
35	NATICA PUSILLA				1		1	2	2
36	SPIOPHANES WIGLEYI						2	2	1
37	CORBULA CARIBAEA					1	1	2	2
38	NAGELONA ROSEA					1	1	2	2
39	APSEUDES SPA				1		1	2	2
40	NEREIS SPA				1			1	1
41	BRADA SP						1	1	1
42	ECHINODERMATA				1			1	1
43	ALPHEUS SP	1						1	1
44	MEGALOMMA CF QUADRIOCULATUM					1		1	1
45	CHASMOCARCINUS MISSISSIPPIENSIS						1	1	1
46	GONEPLACIDAE	1						1	1
47	PARANDALIA INDICA	1						1	1
48	AMPHICTEIS GUNNERI				1			1	1
49	CIRROPHORUS LYRIFORMIS						1	1	1
50	MALACOCEROS INDICUS	1						1	1
51	POLYDORA CF SOCIALIS			1				1	1
52	ACLIS SPA				1			1	1
53	PHILOMEDES SPC	1						1	1
54	ARACHIOPOD SPA			1				1	1
55	PHYLLODOCE MUCOSA						1	1	1
56	NATICA SP		1					1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
57	PARAONIDAE			1				1	1
58	DOSINIA ELEGANS		1					1	1
59	DIOPATRA CUPREA		1					1	1
60	MALACOCEROS SP			1				1	1
61	NEREID(NICON) SPA		1					1	1
62	TELLINIDAE				1			1	1
63	ACTINARIA					1		1	1
64	LISTRIELLA BARNARDI				1			1	1
65	VOLVULELLA TEXASIANA	1						1	1
	NO. OF SPECIES	32	23	23	31	20	26		
	NO. OF INDIVIDUALS	87	51	50	79	67	108	442	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
12	BIG	65	442	4.8980	.9490	.6923

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TABLE 1 CONT.'D

STATION 14 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
1	NOTOMASTUS CF LATERICEUS	5	10	13	7	2	5	42	6
2	NEPHTYS INCISA	3	8	6	7	9	8	41	6
3	AMPELISCA AGASSIZI	2	13	1	11	6	6	39	6
4	AMPELISCA ABDITA	1	13	3	4	10	3	34	6
5	MEDIOMASTUS CALIFORNIENSIS	4	5	12		4	7	32	5
6	PARAPRIONOSPIO PINNATA	7	7	5		3	6	28	5
7	ARICIDEA JEFFREYSII	1	4		1	17	2	25	5
8	EUDORELLA MONODON	2	12	1	1	6	3	25	6
9	PARAONIS GRACILIS	2	5	7	2	5	4	25	6
10	COSSURA DELTA	5	7	1	2	3	3	21	6
11	LUMBRINERIS PARVAPEDATA	2	6	3	2	5	3	21	6
12	AMPELISCA VERRILLI	1	4	3	1	7	3	19	6
13	SPIONIDAE		6	7	1	1	1	16	5
14	NEMERTINEA	1	2	2	5	1	4	15	6
15	SPIOPHANES SPA	1	1			11		13	3
16	VENERIDAE			2		10	1	13	3
17	MAGELONA LONGICORNIS	1	3	2	2	1	1	10	6
18	ABRA AEQUALIS		4			5	1	10	3
19	CORBULA CF CONTRACTA		3		1	5		9	3
20	SIGAMBRA TENTACULATA		2	2		1	2	7	4
21	OWENIA FUSIFORMIS	1	3			2	1	7	4
22	OPHIUROIDEA				1		6	7	2
23	THARYX MARIONI	1	4					5	2
24	ARMANDIA MACULATA		2		1	2		5	3
25	VITRINELLA FLORIDANA		1			3		4	2
26	NINOE NIGRIPES	1	1	1		1		4	4

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
27	ACLIS SPA	1			1	1		3	3
28	MINUSPIO LONGIBRANCHIATA					3		3	1
29	PRIONOSPIO CRISTATA					3		3	1
30	SYNCHELIDIUM CF AMERICANUM					2	1	3	2
31	MAGELONA ROSEA		1		1	1		3	3
32	AEDICIRA BELGICAE		1				1	2	2
33	NATICA PUSILLA		1			1		2	2
34	ONUPHIDAE	1				1		2	2
35	LUMBRINERIS TENUIS	1		1				2	2
36	SCOLELEPIS TEXANA			1		1		2	2
37	ASYCHIS SP			2				2	1
38	SPIOCHAETOPTERUS COSTARUM	1				1		2	2
39	AMPHARETIDAE					2		2	1
40	THARYX ANNULOSUS					1	1	2	2
41	POLYDORA CF HARTMANAE					2		2	1
42	LOVENELLA GRANDIS		1			1		2	2
43	DRILONEREIS MAGNA					1	1	2	2
44	NATICA SP		1		1			2	2
45	NEREIDONICON) SPA				1			1	1
46	APSEUDES SPA	1						1	1
47	SPIOPHANES WIGLEYI					1		1	1
48	MONOCULOIDES SPB				1			1	1
49	SPIOPHANES LONGICIRRUS					1		1	1
50	LIMA LOCKLINI				1			1	1
51	ALPHEUS FLORIDANUS			1				1	1
52	ANCISTROSYLLIS JONESI						1	1	1
53	AMPHARETE PARVIDENTATA					1		1	1
54	SIPUNCULA						1	1	1
55	ANCISTROSYLLIS PAPILLOSA						1	1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
56	MALACOCEROS SP	1						1	1
57	LEPTOCHELA CF BERMUDENSIS					1		1	1
58	DIASTYLIS SP					1		1	1
59	LIMNORIA SP		1					1	1
60	DIOPATRA CUPREA	1						1	1
61	STHENELAIS BOA					1		1	1
62	SIGAMBRA SP			1				1	1
63	LISTRIELLA BARNARDI			1				1	1
64	PYCNOGONIDA					1		1	1
65	MINUSPIO CIRRIFERA					1		1	1
66	POLYDORA CF SOCIALIS		1					1	1
67	GYPTIS VITTATA			1				1	1
68	NUNNA SP					1		1	1
	NO. OF SPECIES	25	31	24	22	47	27		
	NO. OF INDIVIDUALS	48	133	79	55	150	77	542	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
14	R16	68	542	5.0406	.9592	.7353

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TABLE 1 CONT.'D

STATION 16 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	AMPELISCA AGASSIZI	15	6	5	5	8	1	40	6
2	SPIONIDAE		4	25	5		1	35	4
3	NOTOMASTUS CF LATERICEUS	7	5	6	2	1	8	29	6
4	MEDIOMASTUS CALIFORNIENSIS	4	2	12	1		6	25	5
5	PARAPRIONOSPIO PINNATA	5	6	9	1			21	4
6	NEMERTINEA	1	1	4	6		8	20	5
7	COSSURA DELTA	1	3	4	2	1	7	18	6
8	PARAONIS GRACILIS	2	1	6		1	7	17	5
9	EUDORELLA MONODON	7	4	3		2		16	4
10	AMPELISCA ABDITA	7			1	4	4	16	4
11	AMPELISCA VERRILLI	3	3	5		2	3	16	5
12	LUMBRINERIS PARVAPEDATA	5	4	3		2	1	15	5
13	NEPHTYS INCISA	2		3	1	4	5	15	5
14	MAGELONA LONGICORNIS	4		2	1	2	1	10	5
15	CORBULA CF CONTRACTA		1		3	1	4	9	4
16	SIGAMBRA TENTACULATA		1	3	1	1		6	4
17	THARYX ANNULOSUS			5				5	1
18	ARICIDEA JEFFREYSII			5				5	1
19	SYNCHELIDIUM CF AMERICANUM	1		2			1	4	3
20	MAGELONA ROSEA			1	2		1	4	3
21	VENERIDAE	2	1	1				4	3
22	OPHIUROIDEA			1			1	2	2
23	SPIOPHANES SPA			2				2	1
24	NINOE NIGRIPES	1					1	2	2
25	VITRINELLA FLORIDANA	1					1	2	2
26	APSEUDES SPA					2		2	1

TABLE 1 CONT.'D

27	ECHINODERMATA		1		1			2	2
28	ALPHEUS FLORIDANUS			1	1			2	2
29	LOVENELLA GRANDIS	1				1		2	2
30	AMPHARETE PARVIDENTATA		1					1	1
31	SIGAMBRA SP	1						1	1
32	ACLIS SPA				1			1	1
33	MALACOCEROS VANDERHOESTI		1					1	1
34	MALACOCEROS INDICUS					1		1	1
35	GONEPLACIDAE						1	1	1
36	PINNOTHERIDAE			1				1	1
37	NEREID(NICON) SPA	1						1	1
38	ARABELLA IRICOLOR						1	1	1
39	AMPHARETIDAE						1	1	1
40	NATICA PUSILLA		1					1	1
41	DRILONEREIS MAGNA						1	1	1
42	AEDICIRA BELGICAE				1			1	1
43	BRADA SP				1			1	1
44	LISTRIELLA BARNARDI			1				1	1
45	ANCISTROSYLLIS JONESI				1			1	1
46	LEPADOMORPHA			1				1	1
47	CIRROPHORUS LYRIFORMIS			1				1	1
48	STHENELAIS BOA		1					1	1
49	PSEUDEURYTHOE AMBIGUA			1				1	1
50	POLYDORA SP						1	1	1
51	LUMBRINERIS TENUIS						1	1	1
52	UNCIOLA SERRATA						1	1	1
53	ONUPHIDAE		1					1	1

NO. OF SPECIES	20	20	27	19	14	26	
NO. OF INDIVIDUALS	71	48	113	37	32	69	374

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
16	RIG	53	374	4.6951	.9494	.7358

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TABLE 1 CONT.'D

STATION 20 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA		9	1	11	10	13	44	5
2	AMPELISCA ABDITA	5	6	3	9	6	5	34	6
3	APSEUDES SPA	4	14		5	6	1	30	5
4	NEPHTYS INCISA	5	8		6	3	8	30	5
5	NOTOMASTUS CF LATERICEUS	3	3	1	8	6	2	23	6
6	MEDIOMASTUS CALIFORNIENSIS	1	7	3	6	3	1	21	6
7	PARAONIS GRACILIS	1	13	3	1	1	2	21	6
8	AMPELISCA AGASSIZI	1	2	2		1	15	21	5
9	NEMERTINEA	3	6	3		3	1	16	5
10	ARICIDEA JEFFREYSII		9		4		2	15	3
11	AMPELISCA VERRILLI	1	1		4	3	4	13	5
12	EUDORELLA MONODON	2	1	1	2	5	2	13	6
13	COSSURA DELTA		2	2	3	1	2	10	5
14	LUMBRINERIS PARVAPEDATA	1	4		1	1	1	8	5
15	ONUPHIDAE		4		3		1	8	3
16	MAGELONA ROSEA	3		2		2	1	8	4
17	MAGELONA LONGICORNIS	1	3	1	1		2	8	5
18	CORBULA CF CONTRACTA		5		1			6	2
19	SPIOPHANES SPA		3		2		1	6	3
20	SPIONIDAE		3		1	1		5	3
21	CIRRATULIDAE		4					4	1
22	VOLVULELLA TEXASIANA		1		1		2	4	3
23	MALDANIDAE		2		1			3	2
24	LISTRIELLA BARNARDI	1	1		1			3	3
25	ABRA AEQUALIS		3					3	1
26	AMPHARETE PARVIDENTATA				1		2	3	2

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	SPIOPHANES WIGLEYI		3					3	1
28	ASYCHIS CAROLINAE						2	2	1
29	SIGAMBRA TENTACULATA		1	1				2	2
30	THARYX ANNULOSUS				2			2	1
31	PARAONIDAE				2			2	1
32	NINOE NIGRIPES	1				1		2	2
33	CORYMORPHA PENDULA				2			2	1
34	PHYLLODOCE MUCOSA		1			1		2	2
35	LUMBRINERIS TENUIS	1				1		2	2
36	NEREID(NICON) SPA					1	1	2	2
37	AMPHARETE ACUTIFRONS				1			1	1
38	PARAMPHINOME PULCHELLA					1		1	1
39	ECHINODERMATA					1		1	1
40	HEMICYCLOPS SP		1					1	1
41	ARMANDIA MACULATA				1			1	1
42	OPHIUROIDEA				1			1	1
43	AEDICIRA BELGICAE				1			1	1
44	GYPTIS VITTATA		1					1	1
45	AMPHARETIDAE				1			1	1
46	TEREBELLIDES STROEMII				1			1	1
47	OPHIOGLYCERA CF DISTORTA	1						1	1
48	VENERIDAE	1						1	1
49	SICYONIA DORSALIS					1		1	1
50	AMPHICTEIS GUNNERI						1	1	1
51	CERIANTHARIA				1			1	1
52	OPLOPHIZA CF PARVULA		1					1	1
53	EUNICIDAE				1			1	1
54	LOVENELLA GRANDIS					1		1	1
55	TRACHYPENAEUS SIMILIS				1			1	1
56	DIASTYLIS SP			1				1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
57	ACLIS SPA				1			1	1
58	NOTOMASTUS AMERICANUS					1		1	1
59	ANCISTROSYLLIS PAPILLOSA				1			1	1
60	PRIONOSPIO CRISTATA						1	1	1
61	OWENIA FUSIFORMIS				1			1	1
62	CIRROPHORUS LYRIFORMIS			1				1	1
63	SABELLIDAE				1			1	1
64	STHENELAIS BOA		1					1	1
65	TELLINA SP			1				1	1
	NO. OF SPECIES	18	31	15	37	24	24		
	NO. OF INDIVIDUALS	36	123	26	91	61	73	410	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
20	RIG	65	410	4.9394	.9538	.7251

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TABLE 1 CONT.'D

STATION 22 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	11	14	8	6	19		58	5
2	AMPELISCA ABDITA	1	7	1	11	11	2	33	6
3	NEPHTYS INCISA	1	9	2	4	5	5	26	6
4	NEMERTINEA	8	3	2	1	11		25	5
5	SPIONIDAE		17		5	1		23	3
6	MEDIOMASTUS CALIFORNIENSIS	8	5	1	1	3	4	22	6
7	EUDORELLA MONODON	2	7	1	2	6	2	20	6
8	NOTOMASTUS CF LATERICEUS	3	1	6	2	3	3	18	6
9	PARAONIS GRACILIS	3	2		1	6	2	14	5
10	ARICIDEA JEFFREYSII	3				10		13	2
11	AMPELISCA AGASSIZI	4	2	1	3		2	12	5
12	LUMBRINERIS PARVAPEDATA	2			1	5	3	11	4
13	COSSURA DELTA		2	1		4	3	10	4
14	MAGELONA LONGICORNIS		2		1	5	1	9	4
15	AMPELISCA VERRILLI		2	1	2	3		8	4
16	SIGAMBRA TENTACULATA	4					2	6	2
17	ACLIS SPA	1	3			1		5	3
18	VITRINELLA FLORIDANA		1			2	1	4	3
19	AEDICIRA BELGICAE		2			2		4	2
20	SPIOPHANES SPA	1	2		1			4	3
21	VOLVULELLA TEXASIANA					3		3	1
22	THARYX ANNULOSUS	2				1		3	2
23	CIRROPHORUS LYRIFORMIS		2				1	3	2
24	ONUPHIDAE	1	2					3	2
25	OPHIUROIDEA		2				1	3	2
26	MAGELONA ROSEA		1	1			1	3	3

TABLE 1 CONT.'D

27	LOVENELLA GRANDIS		1			1		2	2
28	ARMANDIA MACULATA		1		1			2	2
29	LISTRIELLA BARNARDI	1				1		2	2
30	DRILONEREIS MAGNA			1			1	2	2
31	NINOE NIGRIPES				1	1		2	2
32	NEREID(NICON) SPA		1			1		2	2
33	HESIONIDAE		1					1	1
34	PYCNOGONIDA		1					1	1
35	PECTINARIA REGALIS				1			1	1
36	MUNNA SP				1			1	1
37	AMPHARETIDAE				1			1	1
38	ABRA AEQUALIS				1			1	1
39	SIPUNCULA					1		1	1
40	OWENIA FUSIFORMIS	1						1	1
41	LUMBRINERIDAE		1					1	1
42	PARAONIDAE		1					1	1
43	SPIOCHAETOPTERUS SP		1					1	1
44	NATICA PUSILLA					1		1	1
45	ANCISTROSYLLIS JONESI			1				1	1
46	MINUSPIO CIRRIFERA		1					1	1
47	ARABELLA IRICOLOR		1					1	1
48	THARYX MARIONI		1					1	1
49	CORBULA CF CONTRACTA	1						1	1
	NO. OF SPECIES	19	32	13	20	24	17		
	NO. OF INDIVIDUALS	58	99	27	47	106	35	372	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
22	RIG	49	372	4.6004	.9406	.7551

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TABLE 1 CONT.'D

STATION 24 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NEPHTYS INCISA	3	12	8	7	4	6	40	6
2	AMPELISCA AGASSIZI	3	23	2	4		2	34	5
3	NOTOMASTUS CF LATERICEUS		12	3	6	5	6	32	5
4	PARAPRIONOSPIO PINNATA	3	8	1	4	4	5	25	6
5	LUMBRINERIS PARVAPEDATA	2	4	1	4	4	5	20	6
6	AMPELISCA ABDITA	2	4	3	6		5	20	5
7	NEMERTINEA	1	7	2	1	5	2	18	6
8	COSSURA DELTA	1	5	3	6	2		17	5
9	MEDIOMASTUS CALIFORNIENSIS		3		11		2	16	3
10	AMPELISCA VERRILLI		4	3	3	2	3	15	5
11	EUDORELLA MONODON		5		5		3	13	3
12	PARAONIS GRACILIS		2	1	8			11	3
13	ARICIDEA JEFFREYSII				6		4	10	2
14	SPIOPHANES SPA		1		6		1	8	3
15	VENERIDAE				5		3	8	2
16	THARYX ANNULOSUS		1		5		1	7	3
17	SPIONIDAE		2		4		1	7	3
18	MALDANIDAE				5	1	1	7	3
19	MAGELONA LONGICORNIS		1	1	1	2	1	6	5
20	CORBULA CF CONTRACTA			1	3		1	5	3
21	APSEUDES SPA	2	2			1		5	3
22	SIGAMBRA TENTACULATA	1	3					4	2
23	MAGELONA ROSEA				2	1	1	4	3
24	SIGAMBRA SP		2	1				3	2
25	CORYMORPHA PENDULA				3			3	1
26	ONUPHIDAE				3			3	1

TABLE 1 CONT.'D

27	ARMANDIA MACULATA			2	1			3	2
28	NATICA PUSILLA	1	1					2	2
29	AMPHARETE PARVIDENTATA				2			2	1
30	ABRA AEQUALIS				2			2	1
31	SIGAMBRA BASSI						2	2	1
32	POLYCHAETE SPA		1				1	2	2
33	PINNOTHERIDAE			1	1			2	2
34	NINOE NIGRIPES		1					1	1
35	VITRINELLA FLORIDANA				1			1	1
36	LUMBRINERIS TENUIS				1			1	1
37	CIRRATULIDAE				1			1	1
38	ONENIA FUSIFORMIS					1		1	1
39	ALPHEUS FLORIDANUS					1		1	1
40	OPHIUROIDEA				1			1	1
41	DRILONEREIS MAGNA		1					1	1
42	AMAEANA TRILOBATA		1					1	1
43	MALACOCEROS INDICUS			1				1	1
44	ACTINARIA				1			1	1
45	PHILINE SAGRA						1	1	1
46	SYNCHELIDIUM CF AMERICANUM			1				1	1
47	LOVENELLA GRANDIS				1			1	1
48	ECHINODERMATA			1				1	1
49	CHAETOZONE SETOSA				1			1	1
50	DIOPATRA CUPREA		1					1	1
51	PYCNOGONIDA			1				1	1
52	SABELLIDAE				1			1	1
53	GYPTIS VITTATA		1					1	1
54	CIRROPHORUS LYRIFORMIS		1					1	1

NO. OF SPECIES	10	27	19	35	13	22	
NO. OF INDIVIDUALS	19	109	37	122	33	57	377

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
24	RIG	54	377	4.8156	.9521	.7963

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TABLE 1 CONT.'D

STATION 26 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NOTOMASTUS CF LATERICEUS		3	16	7	10	8	44	5
2	MEDIOMASTUS CALIFORNIENSIS	7	7	8	8	4	2	36	6
3	PARAPRIONOSPIO PINNATA	5	4	13	4	3	3	32	6
4	AMPELISCA ABDITA	1	4	18	5	4		32	5
5	EUDORELLA MONODON	1	6	13	2	1		23	5
6	AMPELISCA VERRILLI	3	3	9	1	3	1	20	6
7	NEMERTINEA	2	2	4	3	4	4	19	6
8	NEPHTYS INCISA	1	2	5	2	4	2	16	6
9	LUMBRINERIS PARVAPEDATA		1	10	3		2	16	4
10	AMPELISCA AGASSIZI		1	6	4	2	2	15	5
11	ARMANDIA MACULATA		3	9	1		1	14	4
12	PARAONIS GRACILIS	2		5	3	2		12	4
13	AMPHARETE PARVIDENTATA	1	1	10				12	3
14	SPIONIDAE	3		1			7	11	3
15	MAGELONA LONGICORNIS	1	2	5	1	2		11	5
16	COSSURA DELTA	1		1	3	3	2	10	5
17	ARICIDEA JEFFREYSII			7				7	1
18	OPHIUROIDEA			4	1	1		6	3
19	SPIOPHANES SPA			5	1			6	2
20	VENERIDAE	1		4	1			6	3
21	CORYMORPHA PENDULA		4	2				6	2
22	ABRA AEQUALIS			5		1		6	2
23	ONUPHIDAE			3		2		5	2
24	APSEUDES SPA		2		2		1	5	3
25	CORBULA CF CONTRACTA				2	3		5	2
26	ACLIS SPA	1	1			2		4	3

TABLE 1 CONT.'D

27	ASYCHIS ELONGATA			4			4	1
28	SIGAMBRA TENTACULATA	1	2			1	4	3
29	THARYX ANNULOSUS	2		1			3	2
30	AEDICIRA BELGICAE	1		2			3	2
31	MALDANIDAE			3			3	1
32	VOLVULELLA TEXASIANA	1		1	1		3	3
33	MAGELONA ROSEA			1	1	1	3	3
34	THARYX MARIONI			1		1	2	2
35	CIRROPHORUS LYRIFORMIS				1	1	2	2
36	SIGAMBRA BASSI			2			2	1
37	SYNCHELIDIUM CF AMERICANUM			2			2	1
38	DIOPATRA CUPREA		2				2	1
39	EPHESEILLA CF MIXTA				2		2	1
40	AUTOMATE SP					2	2	1
41	PRIONOSPIO CRISTATA			1			1	1
42	LIMA LOCKLINI					1	1	1
43	VITRINELLA FLORIDANA		1				1	1
44	LOVENELLA GRANDIS			1			1	1
45	MINUSPIO LONGIBRANCHIATA			1			1	1
46	MONOCULOIDES SPB				1		1	1
47	PARAONIDAE				1		1	1
48	PECTINARIA REGALIS					1	1	1
49	AMPHARETIDAE				1		1	1
50	PHILINE SAGRA			1			1	1
51	HEMICYCLOPS SP			1			1	1
52	NINOE NIGRIPES					1	1	1
53	PENDATULACEA			1			1	1

NO. OF SPECIES	18	19	38	23	22	18	
NO. OF INDIVIDUALS	35	51	186	59	56	42	429

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
26	RIG	53	429	4.9147	.9557	.8679

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TABLE 1 CONT.'D

STATION 34 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	6	6	8	17	13	7	57	6
2	APSEUDES SPA		52	1			3	56	3
3	NEPHTYS INCISA	2	15	14	7	8	9	55	6
4	AMPELISCA ABDITA	2	14	4	8	15	5	48	6
5	MEDIOMASTUS CALIFORNIENSIS	3	1	1	16	13	10	44	6
6	SPIONIDAE	6	3		23	2	2	36	5
7	AMPELISCA AGASSIZI	2	2	4	16	6	2	32	6
8	NOTOMASTUS CF LATERICEUS	3	2	5	5	3	6	24	6
9	PARAONIS GRACILIS	1	2	2	4	7	7	23	6
10	NEMERTINEA	2	4	1	7	1	7	22	6
11	EUDORELLA MONODON		7	3		6	3	19	4
12	ARICIDEA JEFFREYSII			1	7	4	6	18	4
13	LUMBRINERIS PARVAPEDATA		3	3	3	3	4	16	5
14	AMPELISCA VERRILLI		3	1	4	5	1	14	5
15	SIGAMBRA TENTACULATA	1	1	2	3	3	1	11	6
16	COSSURA DELTA	1	4		2	3		10	4
17	SPIOPHANES SPA	1			4	3	2	10	4
18	MAGELONA LONGICORNIS	2	1		2	1	3	9	5
19	HEMICYCLOPS SP		8					8	1
20	VITRINELLA FLORIDANA	1			1	1	4	7	4
21	AMPHARETIDAE		1			5	1	7	3
22	VOLVULELLA TEXASIANA		1	1		1	3	6	4
23	SIGAMBRA BASSI	6						6	1
24	LISTRIELLA BARNARDI		6					6	1
25	CORBULA CF CONTRACTA		4				1	5	2
26	ARMANDIA MACULATA		2		1	2		5	3

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
27	VENERIDAE				2	3		5	2
28	MINUSPIO CIRRIFERA				5			5	1
29	OPHIPHIDAE		1		1	2		4	3
30	THARYX ANNULOSUS				4			4	1
31	MINUSPIO LONGIBRANCHIATA				4			4	1
32	AMRA AEQUALIS					2	2	4	2
33	THARYX MARIONI					1	3	4	2
34	NEREID(NICON) SPA	1		1	1			3	3
35	OPHIUROIDEA	1		1	1			3	3
36	PRIONOSPIO CRISTATA				1		2	3	2
37	SYNCHELIDIUM CF AMERICANUM		1				2	3	2
38	NATICA PUSILLA		2					2	1
39	LOVENELLA GRANDIS				1	1		2	2
40	ANCISTROSYLLIS JONESI	1				1		2	2
41	MAGELONA ROSEA			1	1			2	2
42	SCOLELEPIS TEXANA				1	1		2	2
43	AMPHICTEIS GUNNERI	1				1		2	2
44	AMPHARETE AMERICANA		1		1			2	2
45	OPHELIIDAE						1	1	1
46	CHAETOPTERIDAE						1	1	1
47	STHENOLEPIS SP		1					1	1
48	PECTINARIIDAE						1	1	1
49	PEONATOLACEA	1						1	1
50	ANCISTROSYLLIS GROENLANDICA	1						1	1
51	AEDICIRA BELGICAE				1			1	1
52	SPIOCHAETOPTERUS COSTARUM				1			1	1
53	ASYCHIS SP					1		1	1
54	NATICA SP		1					1	1
55	GYPTIS VITTATA					1		1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
56	NINOE NIGRIPES					1		1	1
57	MALDANIDAE	1						1	1
58	CHASMOCARCINUS MISSISSIPPIENSIS					1		1	1
59	ALPHEUS FLORIDANUS			1				1	1
60	PHYLLODOCE MUCOSA						1	1	1
61	CHAETOZONE SETOSA				1			1	1
62	DRILONEREIS MAGNA						1	1	1
63	LUMBRINERIDAE	1						1	1
64	SICYONIA DORSALIS			1				1	1
65	PARAONIDAE					1		1	1
	NO. OF SPECIES	23	28	20	33	34	30		
	NO. OF INDIVIDUALS	47	149	56	156	122	101	631	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
30	RIG	65	631	4.9076	.9522	.7077

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TABLE 1 CONT.'D

STATION 31 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	13	6	4	20	19	5	67	6
2	NEPHTYS INCISA	10		7	11	12	5	45	5
3	MEDIOMASTUS CALIFORNIENSIS	10	9	3	1	6	14	43	6
4	NOTOMASTUS CF LATERICEUS	5	4	7	5	13	6	40	6
5	AMPELISCA AGASSIZI	1	7	4	14	4	10	40	6
6	AMPELISCA ABDITA	7	4	9	10	6	1	37	6
7	APSEUDES SPA	1				31		32	2
8	NEMERTINEA	5	5	1		3	11	25	5
9	EUDORELLA MONODON	8	2	1	6	4	2	23	6
10	PARAONIS GRACILIS	5	1		2	6	8	22	5
11	ARICIDEA JEFFREYSII	8		1		3	6	18	4
12	SPIONIDAE	2	1	1		7	6	17	5
13	AMPELISCA VERRILLI	3	2	4	3	2	1	15	6
14	LUMBRINERIS PARVAPEDATA	2	2		5	3	2	14	5
15	VITRINELLA FLORIDANA	3	1			6	2	12	4
16	COSSURA DELTA	3		1	2	2	3	11	5
17	SIGAMBRA TENTACULATA		1		5	3	2	11	4
18	MAGELONA LONGICORNIS	3		1	2	2	2	10	5
19	CORBULA CF CONTRACTA				2	3	1	6	3
20	THARYX ANNULOSUS					6		6	1
21	VOLVULELLA TEXASIANA		1	1		2	1	5	4
22	SPIOPHANES SPA					5		5	1
23	ABRA AEQUALIS		1			2	1	4	3
24	LOVENELLA GRANDIS	1		1		1	1	4	4
25	ONUPHIDAE			2		1		3	2
26	ASYCHIS CAROLINAE	3						3	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
27	HEMICYCLOPS SP					2	1	3	2
28	ANCISTROSYLLIS JONESI					2	1	3	2
29	ANCISTROSYLLIS PAPILLOSA		1				2	3	2
30	AMPHARETIDAE			2				2	1
31	THARYX MARIONI	1	1					2	2
32	ARMANDIA MACULATA					2		2	1
33	NATICA PUSILLA			1		1		2	2
34	MAGELONA ROSEA						2	2	1
35	ASYCHIS ELONGATA						2	2	1
36	DIOPATRA CUPREA				1			1	1
37	CORYMORPHA PENDULA			1				1	1
38	LUMBRINERIS TENUIS					1		1	1
39	SPIOPHANES WIGLEYI		1					1	1
40	CAPRELLID			1				1	1
41	DRILONEREIS MAGNA						1	1	1
42	CIRROPHORUS LYRIFORMIS					1		1	1
43	ONUPHIS SPD					1		1	1
44	MALACOCEROS SP			1				1	1
45	SAMYTHELLA ELIASONI		1					1	1
46	NEREIO(NICON) SPA					1		1	1
47	ACLIS SPA	1						1	1
48	SIGAMBRA SP					1		1	1
49	MALDANIDAE					1		1	1
50	LUMBRINERIDAE			1				1	1
51	NASSARIIDAE				1			1	1
52	PARAONIDAE				1			1	1
53	ARGISSA HAMATIPES					1		1	1
54	OWENIA FUSIFORMIS				1			1	1
55	CHASMOCARCINUS MISSISSIPPIENSIS					1		1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
56	VENERIDAE				1			1	1
57	SYNCHELIDIUM CF AMERICANUM					1		1	1
58	AMPHARETE PARVIDENTATA					1		1	1
59	TELLINA SP				1			1	1
61	ANADARA TRANSVERSA						1	1	1
61	PYCNOGONIDA				1			1	1
62	ALPHEUS FLORIDANUS						1	1	1
63	PECTINARIA GOULDII					1		1	1
	NO. OF SPECIES	21	19	22	21	40	29		
	NO. OF INDIVIDUALS	95	51	55	95	170	101	567	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
31	RIG	63	567	4.7486	.9477	.6568

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TABLE 1 CONT.'D

STATION 32 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NEPHTYS INCISA	3	6	7	6	12	12	46	6
2	PARAPRIONOSPIO PINNATA	4	10	5	7	6	6	38	6
3	MEDIOMASTUS CALIFORNIENSIS	7	10		8	9	2	36	5
4	AMPELISCA ABDITA	7	7	3	9	2	2	30	6
5	PARAONIS GRACILIS	1	8	2	4	6	8	29	6
6	LUMBRINERIS PARVAPEDATA	2	8	6	6	4	3	29	6
7	EUDORELLA MONODON	7	6	4	5	2	1	25	6
8	NEMERTINEA	2	4	2	5	6	2	21	6
9	NOTOMASTUS CF LATERICEUS	3	5	3	3	1	5	20	6
10	AMPELISCA AGASSIZI	1	6	1	7	1	3	19	6
11	APSEUDES SPA	1	1	1	5	5		13	5
12	SIGAMBRA TENTACULATA	2	3		4		4	13	4
13	VENERIDAE	9		1	1		2	13	4
14	AMPELISCA VERRILLI	2	1	2	2	2	2	11	6
15	MAGELONA LONGICORNIS	4		2	2	1	2	11	5
16	MALDANIDAE	3	1			1	1	6	4
17	MAGELONA ROSEA	1	1	1	2	1		6	5
18	THARYX MARIONI		2		4			6	2
19	COSSURA DELTA		2		1	1	1	5	4
20	VITRINELLA FLORIDANA				3		2	5	2
21	VOLVULELLA TEXASIANA		2		2	1		5	3
22	OPHIUROIDEA	3		1				4	2
23	DRILONEREIS MAGNA		1	1	1	1		4	4
24	AMPHARETIDAE	3					1	4	2
25	CORBULA CF CONTRACTA		2				2	4	2
26	SPIOPHANES SP		3					3	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	SPIONIDAE		1		2			3	2
28	ARICIDEA JEFFREYSII	1	1			1		3	3
29	ARMANDIA MACULATA	1	1	1				3	3
30	LOVENELLA GRANDIS		1		1	1		3	3
31	NINOE NIGRIPES		1			1		2	2
32	CIRROPHORUS LYRIFORMIS		1			1		2	2
33	PARAONIDAE		1			1		2	2
34	ONUPHIDAE			1	1			2	2
35	AEDICIRA BELGICAE	1	1					2	2
36	MINUSPIO CIRRIFERA				1		1	2	2
37	ACLIS SPA				2			2	1
38	SPIOPHANES SPA					2		2	1
39	ASYCHIS ELONGATA				1			1	1
40	SYNCHELIDIUM CF AMERICANUM		1					1	1
41	OWENIA FUSIFORMIS	1						1	1
42	POLYCHAETE SPA						1	1	1
43	ANCISTROSYLLIS PAPILLOSA					1		1	1
44	CAULLERIELLA SPP					1		1	1
45	ERYCINA SPA						1	1	1
46	HIPPOMEDON CF SERRATUS			1				1	1
47	ALPHEUS FLORIDANUS		1					1	1
48	PHORONIDA	1						1	1
49	CHASMOCARCINUS MISSISSIPPIENSIS					1		1	1
50	DIOPATRA CUPREA				1			1	1
51	MUNNA SP				1			1	1
52	MALACOCEROS VANDERHORSTI				1			1	1
53	SPIOPHANES BOMBYX				1			1	1
54	OPLORHIZA CF PARVULA						1	1	1
55	PENNATULACEA						1	1	1
56	AMPHICTEIS GUNNERI				1			1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
57	CAPITELLIDAE	1						1	1
58	ACTINARIA	1						1	1
	NO. OF SPECIES	26	31	19	32	27	24		
	NO. OF INDIVIDUALS	72	99	45	100	72	66	454	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
32	R1G	58	454	4.8309	.9518	.7414

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TABLE 1 CONT.'D

STATION 33 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	EUDORELLA MONODON	7	6	2	7	5	20	47	6
2	SPIONIDAE	6	3	1	2	13	20	45	6
3	NEMERTINEA	4	12	4	2	6	15	43	6
4	NEPHTYS INCISA	8	3	5	11	4	10	41	6
5	AMPELISCA ABDITA	8	9	3	1	3	16	40	6
6	PARAPRIONOSPIO PINNATA	9	1	13	2	8	6	39	6
7	NOTOMASTUS CF LATERICEUS	2	1	1	16	5	6	31	6
8	APSEUDES SPA	1	1	1	24	2	1	30	6
9	LUMBRINERIS PARVAPEDATA	4	5	1	11	2	7	30	6
10	MEDIOMASTUS CALIFORNIENSIS	2	1	9	7	2	6	27	6
11	PARAONIS GRACILIS	4		6	4	1	8	23	5
12	COSSURA DELTA	5	2	5	2	2	4	20	6
13	ARICIDEA JEFFREYSII	1		3	3		9	16	4
14	AMPELISCA AGASSIZI	2	2	1	1	1	7	14	6
15	AMPELISCA VERRILLI	2		4	3	1	2	12	5
16	VENERIDAE		3		2		7	12	3
17	ASYCHIS ELONGATA	1			4		5	10	3
18	CORBULA CF CONTRACTA	1	1		3	4		9	4
19	VITRINELLA FLORIDANA		2	1	1	1	2	7	5
20	VOLVULELLA TEXASIANA	1	2		2		2	7	4
21	THARYX ANNULOSUS					1	6	7	2
22	MAGELONA LONGICORNIS			1		2	3	6	3
23	SPIOPHANES SPA	1			2	1	2	6	4
24	OPHIUROIDEA	1	2		3			6	3
25	SIGAMBRA TENTACULATA	2		1	2	1		6	4
26	LISTRIELLA BARNARDI				5			5	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	MAGELONA ROSEA			2		1	1	4	3
28	PARAONIDAE		1		1		2	4	3
29	ONUPHIDAE				3		1	4	2
30	THARYX MARIONI			3				3	1
31	CHASMOCARCINUS MISSISSIPPIENSIS			1			2	3	2
32	ABRA AEQUALIS	1		1			1	3	3
33	AMPHARETE AMERICANA				2		1	3	2
34	CIRROPHORUS LYRIFORMIS					1	2	3	2
35	DIOPATRA CUPREA		1	2				3	2
36	NINOE NIGRIPES		1			1	1	3	3
37	DRILONEREIS MAGNA		1	1	1			3	3
38	POLYDORA LIGNI		1	2				3	2
39	ACLIS SPA				1		1	2	2
40	AMPHARETE ACUTIFRONS				1		1	2	2
41	NATICA PUSILLA					1	1	2	2
42	LOVENELLA GRANDIS--				1	1		2	2
43	CAPRELLID						2	2	1
44	CERIANTHARIA					1		1	1
45	LAONICE CIRRATA			1				1	1
46	AUTOMATE EVERMANNI					1		1	1
47	AMPHARETE PARVIDENTATA				1			1	1
48	PARAONIS SPA		1					1	1
49	TELLINA SP						1	1	1
50	SPIOPHANES SP				1			1	1
51	EUCERAMUS PRAELONGUS						1	1	1
52	SIPUNCULA						1	1	1
53	SIGAMBRA SP		1					1	1
54	TRACHYPENAEUS SIMILIS						1	1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
55	CORBULA CARIBAEA		1					1	1
56	POLYCHAETE SPA					1		1	1
57	MUNNA SP		1					1	1
58	MALACOCEROS VANDERHORSTI					1		1	1
59	NEREID(NICON) SPA						1	1	1
60	AMPHARETIDAE						1	1	1
61	OWENIA FUSIFORMIS						1	1	1
62	ANCISTROSYLLIS JONESI				1			1	1
63	PILONOTHERIDAE					1		1	1
	NO. OF SPECIES	22	26	26	34	30	41		
	NO. OF INDIVIDUALS	73	65	75	133	75	187	608	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
33	R16	63	608	4.9444	.9564	.7468

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TABLE 1 CONT.'D

STATION 34 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	AMPELISCA AGASSIZI	1		32		1		34	3
2	MEDIOMASTUS CALIFORNIENSIS	4	7	7		5	1	24	5
3	NOTOMASTUS CF LATERICEUS	4	6	2	2	4	1	19	6
4	APSEUDES SPA		12	1			4	17	3
5	AMPELISCA ABDITA	2	2	9			1	14	4
6	PARAPRIONOSPIO PINNATA	3	3	5		1	1	13	5
7	COSSURA DELTA	2	2		2	2	5	13	5
8	NEPHTYS INCISA	1	4	4		1	1	11	5
9	SIGAMBRA TENTACULATA	1	6		1		2	10	4
10	EUDORELLA MONODON	1	1	8				10	3
11	MAGELONA LONGICORNIS	2	3	1		3		9	4
12	PARAONIS GRACILIS	2	2		1	1	3	9	5
13	AMPELISCA VERRILLI		2	3		2		7	3
14	LUMBRINERIS PARVAPEDATA		3	2			2	7	3
15	NEMERTINEA	1	1	1	1	1	1	6	6
16	SPIOPHANES SPA	1	3	1				5	3
17	VITRINELLA FLORIDANA					4		4	1
18	ARMANDIA MACULATA	3		1				4	2
19	MAGELONA ROSEA		1	2		1		4	3
20	THARYX ANNULOSUS	1	2			1		4	3
21	AEDICIRA BELGICAE	1	1			1		3	3
22	VENERIDAE			1			2	3	2
23	MINUSPIO LONGIBRANCHIATA	2						2	1
24	CIRROPHORUS LYRIFORMIS			1		1		2	2
25	HEMICYCLOPS SP		2					2	1
26	ANCISTROSYLLIS JONESI		2					2	1

TABLE 1 CONT.'D

27	LOVENELLA GRANDIS					1	1	1	
28	LISTRIELLA BARNARDI		1				1	1	
29	MALACOCEROS VANDERHORSTI			1			1	1	
30	SYNCHELIDIUM CF AMERICANUM					1	1	1	
31	AMPHICTEIS GUNNERI					1	1	1	
32	ECHINODERMATA			1			1	1	
33	NINOE NIGRIPES	1					1	1	
34	ARICIDEA TAYLORI				1		1	1	
35	PARAONIDAE			1			1	1	
36	LUMBRINERIS TENUIS			1			1	1	
37	GYPTIS VITTATA					1	1	1	
38	ARABELLA MUTANS					1	1	1	
39	ARICIDEA JEFFREYSII			1			1	1	
40	APOPRIONOSPIO PYGMAEA				1		1	1	
41	POLYDORA LIGNI		1				1	1	
42	OLIGOCHAETA				1		1	1	
43	DIOPATRA CUPREA		1				1	1	
44	MALACOCEROS SP			1			1	1	
45	SIPUNCULA	1					1	1	
46	CERIANTHARIA					1	1	1	

NO. OF SPECIES	19	23	21	7	18	18	
NO. OF INDIVIDUALS	34	68	85	9	32	30	258

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
34	RIG	46	258	4.6848	.9485	.8478

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TABLE 1 CONT.'D

STATION 35 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	9	11	6	7	8	15	56	6
2	MEDIOMASTUS CALIFORNIENSIS	2	15	3	5	16	12	53	6
3	EUDORELLA MONODON	6	17	4	11		8	46	5
4	NEPHTYS INCISA	5	9	7	5	2	11	39	6
5	AMPELISCA ABDITA	3	7	9	6	4	4	33	6
6	AMPELISCA AGASSIZI	2	1	1	18	5	4	31	6
7	NOTOMASTUS CF LATERICEUS		10	9	2	2	4	27	5
8	ARICIDEA JEFFREYSII		7		4	11	4	26	4
9	PARAONIS GRACILIS		9	2	2	1	11	25	5
10	LUMBRINERIS PARVAPEDATA	4	5	1	4	3	3	20	6
11	COSSURA DELTA	3	3	7		3	3	19	5
12	AMPELISCA VERRILLI		9	3	5	1		18	4
13	NEMERTINEA	1	2	2	2	5	1	13	6
14	MAGELONA LONGICORNIS	3	2		1	1	2	9	5
15	SIGAMBRA TENTACULATA	2	1		2		1	6	4
16	SPIONIDAE		2	2	1			5	3
17	SPIOPHANES SPA		2	2		1		5	3
18	VITRINELLA FLORIDANA				2	2		4	2
19	NINOE NIGRIPES	1		1			2	4	3
20	THARYX ANNULOSUS					2	2	4	2
21	NOTOMASTUS LATERICEUS	4						4	1
22	ARMANDIA MACULATA		1	1			2	4	3
23	SYNCHELIDIUM CF AMERICANUM		3					3	1
24	APSEUDES SPA	1	1				1	3	3
25	VOLVULELLA TEXASIANA		1			1	1	3	3
26	MAGELONA ROSEA			1	2			3	2

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	LUMBRINERIDAE	3						3	1
28	ORILONEREIS MAGNA		1				2	3	2
29	ACLIS SPA		2					2	1
30	ABRA AEQUALIS		1				1	2	2
31	CORYMORPHA PENDULA		1				1	2	2
32	CERIANTHARIA				1	1		2	2
33	LUMBRINERIS TENUIS		1		1			2	2
34	PRIONOSPIO CRISTATA						2	2	1
35	CORBULA CF CONTRACTA					1	1	2	2
36	MICROSPIO LONGIBRANCHIATA					2		2	1
37	THARYX MARIONI						2	2	1
38	LOVENELLA GRANDIS					1		1	1
39	CIRRATULIDAE		1					1	1
40	PARAONIDES LYRA					1		1	1
41	MALDANIDAE				1			1	1
42	PARAMETOPELLA TEXENSIS			1				1	1
43	COLLODES LEPTOCHELES			1				1	1
44	NASSARIIDAE					1		1	1
45	SIGAMBRA BASSI				1			1	1
46	PHYLLODOCE MUCOSA				1			1	1
47	PILARGIDAE			1				1	1
48	NEREID(NICON) SPA		1					1	1
49	CIRROPHORUS LYRIFORMIS				1			1	1
50	HEMICYCLOPS SP				1			1	1
51	SIPHONELAIS BOA		1					1	1
52	MONOCULOIDES SP6					1		1	1
53	NATICA PUSILLA					1		1	1
54	SIGALIONIDAE						1	1	1
55	VERIDAE			1				1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
56	CHAETOPTERIDAE		1					1	1
57	ANCISTROSYLLIS JONESI		1					1	1
58	ACTINARIA		1					1	1
59	PARAONIDAE					1		1	1
	NO. OF SPECIES	15	32	21	24	26	26		
	NO. OF INDIVIDUALS	49	130	65	86	78	101	509	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
35, 1	RIG	59	509	4.6380	.9429	.6441

TABLE 1 CONT.'D

STATION 36 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	2	1	7	18	4	5	37	6
2	NOTOMASTUS CF LATERICEUS	4	9	6	4	4	6	33	6
3	MEDIOMASTUS CALIFORNIENSIS		4	5	10	8	2	29	5
4	AMPELISCA ABDITA		4	4	14	3		25	4
5	NEPHTYS INCISA	3	4	1	2	9	4	23	6
6	NEMERTINEA	2	4	1	9	3	3	22	6
7	PARAONIS GRACILIS	2	4		8	5	2	21	5
8	EUDORELLA MONODON	1	3	2	5	3	3	17	6
9	LUMBRINERIS PARVAPEDATA	5	1		6	2	1	15	5
10	SPIONIDAE		1		13	1		15	3
11	AMPELISCA AGASSIZI	7	1	1	2		3	14	5
12	AMPELISCA VERRILLI		3		6	3	2	14	4
13	VITRINELLA FLORIDANA		11		3			14	2
14	COSSURA DELTA	4		2		3	2	11	4
15	SIGAMBRA TENTACULATA	1		2	3	1	1	8	5
16	SPIOPHANES SPA				7	1		8	2
17	ARICIDEA JEFFREYSII		1		6			7	2
18	ARMANDIA MACULATA			2	5			7	2
19	MAGELONA LONGICORNIS	1	1	1	2	2		7	5
20	MALACOCEROS VANDERHORSTI	3		1		2		6	3
21	MAGELONA ROSEA			1	1	2	1	5	4
22	VOLVULELLA TEXASIANA				3	2		5	2
23	AMPHARETIDAE					5		5	1
24	AEDICIRA BELGICAE					3	2	5	2
25	SPIOPHANES BOMBYX		5					5	1
26	CIRROPHORUS LYRIFORMIS	1		1		2		4	3

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	NEREID(NICON) SPA				3	1		4	2
28	VENERIDAE	1	2	1				4	3
29	NINOE NIGRIPES			1	1		1	3	3
30	MALDANIDAE	1	1		1			3	3
31	POLYCHAETE SPA					3		3	1
32	SIGAMBRA SP	2						2	1
33	THARYX ANNULOSUS	1		1				2	2
34	THARYX MARIONI				2			2	1
35	ACLIS SPA		2					2	1
36	LUMBRINERIDAE				2			2	1
37	ONUPHIDAE		1			1		2	2
38	ANCISTROSYLLIS JONESI				2			2	1
39	OWENIA FUSIFORMIS				1			1	1
40	CF EPIDIOPATRA SP				1			1	1
41	PELECYPOD SPD		1					1	1
42	APSEUDES SPA						1	1	1
43	DRILONEREIS MAGNA				1			1	1
44	ASYCHIS SP				1			1	1
45	ALPHEIDAE						1	1	1
46	AMPHARETE AMERICANA			1				1	1
47	SYNCHELIDIUM CF AMERICANUM				1			1	1
48	LOVENELLA GRANDIS				1			1	1
49	PROCESSIDAE			1				1	1
50	TRACHYPENAEUS SIMILIS					1		1	1
51	CAPRELLID			1				1	1
52	PARAONIDAE				1			1	1
53	DIOPATRA CUPREA						1	1	1
54	SPIOPHANES WIGLEYI						1	1	1
55	ONUPHIS SP				1			1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
56	NEREIDAE			1				1	1
57	PINNOTHERIDAE						1	1	1
	NO. OF SPECIES	17	21	22	34	25	20		
	NO. OF INDIVIDUALS	41	64	44	146	74	43	412	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
36	RIG	57	412	4.9860	.9588	.8421

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TABLE 1 CONT.'D

STATION 37 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	PARAPRIONOSPIO PINNATA	10	16	6	8	3	3	46	6
2	NOTOMASTUS CF LATERICEUS	16	1	5	4	2	14	42	6
3	NEPHTYS INCISA	13	1	8	5	5	5	37	6
4	MEDIOMASTUS CALIFORNIENSIS	3	12	5	1	6		27	5
5	SPIONIDAE			8	3	5	6	22	4
6	AMPELISCA ABDITA	3		5	2	2	7	19	5
7	AMPELISCA VERRILLI	4	1	2	4	5	3	19	6
8	CORBULA CF CONTRACTA			1	3	2	13	19	4
9	APSEUDES SPA						18	18	1
10	EUDORELLA MONODON	2		4	3	3	4	16	5
11	MAGELONA LONGICORNIS	1	2	2	4	1	3	13	6
12	LUMBRINERIS PARVAPEDATA	3	3	1	4	2		13	5
13	NEMERTINEA		4	4	1	3	1	13	5
14	PARAONIS GRACILIS	3	2		1	3	2	11	5
15	AMPELISCA AGASSIZI		2	2	1	1	4	10	5
16	SIGAMBRA TENTACULATA	3	3	3				9	3
17	ARICIDEA JEFFREYSII	2	2	2		1	2	9	5
18	COSSURA DELTA	1	2	3	1		1	8	5
19	VITRINELLA FLORIDANA		1	5	1			7	3
20	THARYX MARIONI		5	2				7	2
21	ARMANDIA MACULATA				1	2	2	5	3
22	SPIOPHANES SPA	1	2					3	2
23	SYNCHELIDIUM CF AMERICANUM	1					1	2	2
24	NINOE NIGRIPES	1				1		2	2
25	NATICA PUSILLA		1			1		2	2
26	GLYCERIDAE		2					2	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
27	MAGELONA ROSEA		1			1		2	2
28	AUTOMATE EVERMANNI			2				2	1
29	ABRA AEQUALIS						1	1	1
30	POLYDORA CF SOCIALIS			1				1	1
31	MACOMA TENTA					1		1	1
32	DIOPATRA CUPREA			1				1	1
33	ANCISTROSYLLIS JONESI						1	1	1
34	PHOTIS SPA						1	1	1
35	BRADA SP	1						1	1
36	DRILONEREIS MAGNA				1			1	1
37	TRACHYPENAEUS SIMILIS	1						1	1
38	SIGAMBRA HASSI				1			1	1
39	LISTRIELLA BARNARDI						1	1	1
40	AMPHARETE ACUTIFRONS	1						1	1
41	NUCULANA ACUTA		1					1	1
42	ORBINIDAE						1	1	1
43	VOLVULELLA TEXASIANA	1						1	1
	NO. OF SPECIES	24	20	21	19	20	22		
	NO. OF INDIVIDUALS	71	64	72	49	50	94	400	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
37	R1G	43	400	4.5381	.9445	.8140

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TABLE 1 CONT.'D

STATION 40 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	MEDIOMASTUS CALIFORNIENSIS	4	7	18	2	7	5	43	6
2	PARAPRIONOSPIO PINNATA	4	9	12	9	4	4	42	6
3	SPIONIDAE	36	1	2	1			40	4
4	APSEUDES SPA				1	1	34	36	3
5	NEMERTINEA	14	4	2	2	6	2	30	6
6	NEPHTYS INCISA	1	13	7	3	1	2	27	6
7	NOTOMASTUS CF LATERICEUS	7	5	2	1	8	4	27	6
8	ARICIDEA JEFFREYSII	1	7	9		3	1	21	5
9	PARAONIS GRACILIS	3	2	6	4	5	1	21	6
10	AMPELISCA ABDITA	6	2	4	2		6	20	5
11	COSSURA DELTA	1	2	7	3	3	2	18	6
12	EUDORELLA MONODON	3		5	2	1	1	12	5
13	SIGAMBRA TENTACULATA	1	2	2	3	1	1	10	6
14	AMPELISCA VERRILLI	1	4	3		2		10	4
15	AMPELISCA AGASSIZI		2	3	4		1	10	4
16	SPIOPHANES SPA		2	4	1	1	1	9	5
17	VOLVULELLA TEXASIANA	3	1	1			3	8	4
18	LUMBRINERIS PARVAPEDATA	3	3	1		1		8	4
19	MAGELONA LONGICORNIS		1	3	1	1		6	4
20	ARMANDIA MACULATA	1	2				2	5	3
21	LISTRIELLA BARNARDI	1	1		1		1	4	4
22	THARYX ANNULOSUS			4				4	1
23	CORBULA CF CONTRACTA				1	1	2	4	3
24	EUDORELLA BARNARDI		3					3	1
25	NINOE NIGRIPES		1	1			1	3	3
26	AEDICIRA BELGICAE			1			1	2	2

TABLE 1 CONT.'D

27	DRILONEREIS MAGNA					1	1	2	2
28	HEMICYCLOPS SP						2	2	1
29	ONUPHIDAE						2	2	1
30	NATICA SP		2					2	1
31	MAGELONA ROSEA		1				1	2	2
32	ANCISTROSYLLIS JONESI		2					2	1
33	LEPADOMORPHA						2	2	1
34	OPHIODROMUS OBSCURUS						1	1	1
35	MINUSPIO LONGIBRANCHIATA	1						1	1
36	HYDROZOA						1	1	1
37	AMPHARETE ACUTIFRONS						1	1	1
38	SOUILLA CHYDAEA	1						1	1
39	CIRRATULID-B	1						1	1
40	ONUPHIS SPA						1	1	1
41	PECTINARIA SP					1		1	1
42	PINNOTHERIDAE	1						1	1
43	ECHINODERMATA					1		1	1
44	VENERIDAE	1						1	1
45	PRIONOSPIO CRISTATA			1				1	1
46	SPIOPHANES LONGICIRRUS		1					1	1
47	OPHIUROIDEA				1			1	1
48	DIOPATRA CUPREA		1					1	1
49	VITRINELLA FLORIDANA		1					1	1
50	CAPRELLID				1			1	1
51	THARYX MARIONI		1					1	1
52	NATICA PUSILLA						1	1	1
53	STHENELAIS BOA	1						1	1

NO. OF SPECIES	23	28	22	19	19	30	
NO. OF INDIVIDUALS	96	83	98	43	49	88	457

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
40	BIG	53	457	4.6762	.9479	.7358

1

TABLE 1 CONT.'D

STATION 42 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	SPIONIDAE	30	1	3	3		11	48	5
2	PARAPRIONOSPIO PINNATA	6	6	6	8	3	12	41	6
3	PARAONIS GRACILIS	3	7	8	13	3	5	39	6
4	NOTOMASTUS CF LATERICEUS	6	7	7	2	2	12	36	6
5	MEDIOMASTUS CALIFORNIENSIS	9	9	3	7	1	4	33	6
6	NEPHTYS INCISA	2	5	5	4	14		30	5
7	AMPELISCA ABDITA	6	1	6	2	9	5	29	6
8	EUDORELLA MONODON	1		3	7	3	6	20	5
9	NEMERTINEA	10	3	3		2	1	19	5
10	ARICIDEA JEFFREYSII		14	1		1	2	18	4
11	CORBULA CF CONTRACTA	10		2	2		2	16	4
12	LUMBRINERIS PARVAPEDATA	2	3	2	2	4	3	16	6
13	AMPELISCA VERRILLI	2		1	3	6	2	14	5
14	AMPELISCA AGASSIZI	1	8		2	2		13	4
15	SIGAMBRA TENTACULATA		3	3	3		2	11	4
16	COSSURA DELTA	2	1	3	1	2	1	10	6
17	VITRINELLA FLORIDANA		1	8		1		10	3
18	MAGELONA ROSEA	4	1		2	1		8	4
19	AMPHARETE PARVIDENTATA	2	4		1	1		8	4
20	APSEUDES SPA	4		2		1		7	3
21	CIRROPHORUS LYRIFORMIS	2	1	2	1	1		7	5
22	VENERIDAE			1	2	3	1	7	4
23	THARYX MARIONI			1	4		2	7	3
24	MAGELONA LONGICORNIS	3	1		1	1		6	4
25	ASYCHIS CAROLINAE		4				2	6	2
26	THARYX ANNULOSUS	2	2	1				5	3

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE						TOTAL	
		1	2	3	4	5	6	INDIVIDUALS	OCCURRENCES
27	NINOE NIGRIPES	1	1			2	1	5	4
28	AEDICIRA BELGICAE	1	1	1				3	3
29	SPIOPHANES SPA		1	1		1		3	3
30	ARMANDIA MACULATA	2				1		3	2
31	ANCISTROSYLLIS JONESI	1	1	1				3	3
32	ASYCHIS ELONGATA			1	2			3	2
33	VOLVULELLA TEXASIANA				1	1	1	3	3
34	PHYLLODOCE MUCOSA			1	1			2	2
35	ALPHEUS FLORIDANUS	1					1	2	2
36	ONUPHIDAE		1				1	2	2
37	AUTOMATE EVERMANNI	1					1	2	2
38	LOVENELLA GRANDIS			1			1	2	2
39	ANCISTROSYLLIS PAPILLOSA	2						2	1
40	HEMICYCLOPS SP	2						2	1
41	LISTRIELLA BARNARDI						2	2	1
42	ORILONEREIS MAGNA	1				1		2	2
43	OPHIUROIDEA					2		2	1
44	MALDANIDAE			1				1	1
45	MALACOCEROS INDICUS		1					1	1
46	MALACOCEROS SP	1						1	1
47	AMPHARETIDAE						1	1	1
48	OPHIOGLYCERA CF DISTORTA	1						1	1
49	ALPHEIDAE				1			1	1
50	ACLIS SPA					1		1	1
51	NATICA PUSILLA					1		1	1
52	ECHINODERMATA	1						1	1
53	MONNA SP						1	1	1
54	PARAONIS SPA				1			1	1
55	MIDDSPIO LONGIBRANCHIATA				1			1	1

TABLE 1 CONT.'D

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
56	MYTILIDAE					1		1	1
57	GONEPLACIDAE			1				1	1
58	LEPADOMORPHA				1			1	1
59	PRIONOSPIO CRISTATA		1					1	1
60	TRACHYPENAEUS SIMILIS						1	1	1
61	DIOPATRA TRIDENTATA		1					1	1
62	PSEUDEURYTHOE AMBIGUA		1					1	1
63	LUMBRINERIS TENUIS	1						1	1
64	OWENIA FUSIFORMIS			1				1	1
65	PYCNOGONIDA					1		1	1
66	PINNOTHERIDAE	1						1	1
67	NEREID(NICON) SPA			1				1	1
	NO. OF SPECIES	34	29	31	27	39	27		
	NO. OF INDIVIDUALS	124	91	81	78	73	84	531	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
42	RIG	67	531	5.0347	.9575	.7463

1

TABLE 1 CONT.'D

STATION 44 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NOTOMASTUS CF LATERICEUS	6	1	12	6	2	6	33	6
2	PARAPRIONOSPIO PINNATA	5	3	7	9	2	3	29	6
3	LUMBRINERIS PARVAPEDATA	2	2	13			3	20	4
4	EUDORELLA MONODON	2	7	1	8	1		19	5
5	AMPELISCA ABDITA	2	12	3	1			18	4
6	MEDIOMASTUS CALIFORNIENSIS			1	2	2	13	18	4
7	NEPHTYS INCISA	4	7	1	3	1	1	17	6
8	PARAONIS GRACILIS	3	2	3	4		4	16	5
9	VITRINELLA FLORIDANA				6	10		16	2
10	COSSURA DELTA	3	3		5	3	1	15	5
11	APSEUDES SPA		2	2	5			9	3
12	VENERIDAE	3	4		2			9	3
13	SIGAMBRA TENTACULATA	1	2	3	2			8	4
14	AMPELISCA VERRILLI	1	4		3			8	3
15	ACLIS SPA	2		1		4		7	3
16	AMPELISCA AGASSIZI		3	1	2	1		7	4
17	NEMERTINEA	1	2	1			2	6	4
18	MAGELONA LONGICORNIS		2	1			3	6	3
19	OPHIUROIDEA	2	1				1	4	3
20	PINNOTHERIDAE	2		1	1			4	3
21	THARYX ANNULOSUS		1	2			1	4	3
22	ARMANDIA MACULATA	2	1					3	2
23	ANCISTROSYLLIS JONESI			1			2	3	2
24	NINOE NIGRIPES		1	1		1		3	3
25	SPIONIDAE	1			2			3	2
26	PARAONIDAE		1	1	1			3	3

TABLE 1 CONT.'D

27	MAGELONA ROSEA		1		1	1		3	3
28	VOLVULELLA TEXASIANA	1	2					3	2
29	LUMBRINERIS TENUIS		1	1	1			3	3
30	GYPTIS VITTATA		1		1			2	2
31	CIRROPHORUS LYRIFORMIS		1	1				2	2
32	PHILINE SAGRA		2					2	1
33	SPIOPHANES SPA		2					2	1
34	CORBULA CF CONTRACTA		1					1	1
35	HYDROZOA				1			1	1
36	AMPHARETIDAE				1			1	1
37	ASYCHIS ELONGATA		1					1	1
38	PHORONIDA		1					1	1
39	NALACOCEROS SP			1				1	1
40	SIGAMBRA SP			1				1	1
41	NEPHTYIDAE			1				1	1
42	NOTOMASTUS LATERICEUS	1						1	1
43	CIENOCHELES SP				1			1	1
44	DIOPATRA TRIDENTATA		1					1	1
45	ARICIDEA JEFFREYSII		1					1	1
46	DRILONEREIS MAGNA		1					1	1
47	ONUPHIDAE		1					1	1
48	ALPHEUS FLURIDANUS				1			1	1
49	HIPPOMEDON CF SERRATUS				1			1	1
50	DIOPATRA CUPREA						1	1	1
51	ARKA AEQUALIS		1					1	1
52	POLYDORA LIGNI						1	1	1
53	NATICA PUSILLA		1					1	1

NO. OF SPECIES	19	36	24	25	11	14	
NO. OF INDIVIDUALS	44	88	61	70	28	42	325

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
44	RIG	53	325	4.8874	.9558	.8491

1

TABLE 1 CONT.'D

STATION 46 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	OCCURRENCES
1	NOTOMASTUS CF LATERICEUS	2	9	2		16	12	41	5
2	EUDORELLA MONODON	4	16	4	1		1	26	5
3	PARAPRIONOSPIO PINNATA	8	7	2	2	5	2	26	6
4	MEDIOMASTUS CALIFORNIENSIS	6	4	5	8	1	2	26	6
5	AMPELISCA ABDITA	8	6		2		4	20	4
6	NEPHTYS INCISA	5	3	1	3	2		14	5
7	LUMBRINERIS PARVAPEDATA	4	2	2	2	3		13	5
8	COSSURA DELTA	2	4	3	2	2		13	5
9	PARAONIS GRACILIS	2	4		1	1	3	11	5
10	APSEUDES SPA	2				1	8	11	3
11	AMPELISCA AGASSIZI	4	2			2	2	10	4
12	NEMERTINEA	1	2	1	1	1	4	10	6
13	MAGELONA LONGICORNIS	2	2	1	2	1	1	9	6
14	ARMANDIA MACULATA	2	3		1		1	7	4
15	CREPIDULA CF FORNICATA			5				5	1
16	AMPELISCA VERRILLI	1	2		2			5	3
17	MAGELONA ROSEA		1			2	1	4	3
18	SPIONIDAE	2	1				1	4	3
19	VITRINELLA FLORIDANA				1	3		4	2
20	LEPADOMORPHA			1			2	3	2
21	PARAONIDAE				3			3	1
22	ACLIS SPA	1			1	1		3	3
23	NATICA PUSILLA	1		1		1		3	3
24	PHOTID SPA		2					2	1
25	CIRROPHORUS LYRIFORMIS	1				1		2	2
26	ONUPHIDAE	1	1					2	2

TABLE 1 CONT.'D

27	SIPUNCULA				1		1	2	2
28	LUMBRINERIS TENUIS			1			1	2	2
29	CORBULA CF CONTRACTA	2						2	1
30	VENERIDAE	2						2	1
31	CORYMORPHA PENDULA	2						2	1
32	PHYLLODOCE MUCOSA		1					1	1
33	CLYTIA LONGICYATHA		1					1	1
34	ARICIDEA JEFFREYSII	1						1	1
35	OPHIUROIDEA						1	1	1
36	VOLVULELLA TEXASIANA			1				1	1
37	LISTRIELLA BARNARDI	1						1	1
38	LOVENELLA GRANDIS						1	1	1
39	OXYUROSTYLIS SP		1					1	1
40	SIGAMBRA BASSI			1				1	1
41	SIGAMBRA TENTACULATA					1		1	1
42	AUTOMATE EVERMANNI			1				1	1
43	GAMMARUS MUCRONATUS						1	1	1
44	AEDICIRA BELGICAE	1						1	1
45	NINOE NIGRIPES				1			1	1
46	SPIOPHANES SPA	1						1	1
47	MACOMA TENTA	1						1	1
48	ANCISTROSYLLIS JONESI	1						1	1
49	PYCNOGONIDA	1						1	1
50	DRILONEREIS MAGNA					1		1	1
51	AMPHARETE PARVIDENTATA		1					1	1
52	THARYX MARIONI	1						1	1

NO. OF SPECIES	31	22	16	17	18	19	
NO. OF INDIVIDUALS	73	75	32	34	45	49	308

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
46	RIG	52	308	4.7187	.9461	.7692

TABLE 1 CONT.'D

STATION 1 TRANSECT RIG PERIOD POST-DRILL

RANK	SPECIES	REPLICATE 1	2	3	4	5	6	TOTAL INDIVIDUALS	TOTAL OCCURRENCES
1	AMPELISCA ABDITA	3			17	4	1	25	4
2	NOTOMASTUS CF LATERICEUS	3	1	5	4		8	21	5
3	VITRINELLA FLORIDANA	6	7				2	15	3
4	MEDIOMASTUS CALIFORNIENSIS	4		2	7		2	15	4
5	PARAPRIONOSPIO PINNATA	3			6		5	14	3
6	COSSURA DELTA	6	1		2		3	12	4
7	SIGAMBRA TENTACULATA	2		4	2	1	1	10	5
8	SPIONIDAE	4		1	3		2	10	4
9	GONEPLACIDAE				4	4	1	9	3
10	NEMERTINEA	2		1	4		2	9	4
11	SPIOPHANES SPA				8			8	1
12	PARAONIS GRACILIS	1			4		1	6	3
13	AMPELISCA AGASSIZI	3			1			4	2
14	POLYDORA SP			1		3		4	2
15	NEPHTYS INCISA	3						3	1
16	MAGELONA ROSEA				3			3	1
17	EUDORELLA MONODON	2			1			3	2
18	LUMBRINERIS TENUIS			1	1		1	3	3
19	PRIONOSPIO CRISTATA			1	2			3	2
20	NATICA SP				2		1	3	2
21	AUTOMATE SP				1	1		2	2
22	MAGELONA LONGICORNIS				2			2	1
23	NINOE NIGRIPES	1					1	2	2
24	AEDICIRA BELGICAE				2			2	1
25	AMPHARETE ACUTIFRONS			2				2	1
26	LUMBRINERIS PARVAPEDATA	1					1	2	2

TABLE 1 CONT.'D

27	AMPELISCA VERRILLI	2					2	1
28	POLYDORA CF SOCIALIS			1		1	2	2
29	POLYDORA CF HARTMANAE			1			1	1
30	PARAONETOPELLA TEXENSIS				1		1	1
31	OPHIOGLYCERA GIGANTEA				1		1	1
32	PECTINARIA REGALIS			1			1	1
33	NEREID(NICON) SPA	1					1	1
34	STHENELAIS BOA					1	1	1
35	AMPHARETE PARVIDENTATA			1			1	1
36	CIRROPHORUS LYRIFORMIS	1					1	1
37	DRILONEREIS MAGNA					1	1	1
38	CERIANTHARIA		1				1	1
39	VENERIDAE					1	1	1
40	MALACOCEROS SP			1			1	1
41	THARYX ANNULOSUS				1		1	1
42	PAGURINAE					1	1	1
43	OWENIA FUSIFORMIS			1			1	1
44	CHAETOPTERIDAE				1		1	1
45	CORBULA CF CONTRACTA					1	1	1
46	CIRRATULIDAE	1					1	1
47	ARMANDIA MACULATA			1			1	1
48	ABRA AEQUALIS			1			1	1

NO. OF SPECIES	19	4	13	26	8	20	
NO. OF INDIVIDUALS	49	10	22	82	16	37	216

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
1	RIG	48	216	4.7748	.9518	.8750

TABLE 2

LIST OF INVERTEBRATE EPIFAUNAL SPECIES AND THEIR ABUNDANCES FOR EACH TRAWL COLLECTION. SPECIES ARE RANKED BY ABUNDANCE

Explanation of Table 2:

RANK	Species ranked by total day-night abundances
M	Males
FM	Females
FAE	Females with eggs
DIVERSITY	Shannon-Wiener diversity index
PIE	Hurlbert's Probability of Interspecific Encounter
EQUITABILITY	Lloyd and Ghelardi's measure of evenness

TABLE 2

STATION 1 TRANSECT 7 PERIOD PRE-RIG

RANK	SPECIES	DAY TOTAL	DAY M	DAY FM	DAY F∧E	NIGHT TOTAL	NIGHT M	NIGHT FM	NIGHT F∧E	TOTAL INDIV	TOTAL M	TOTAL FM	TOTAL F∧E
1	SICYONIA DORSALIS	6	2	4	0	0	0	0	0	6	2	4	0
2	CALLINECTES SIMILIS	3	1	1	1	0	0	0	0	3	1	1	1
3	PENAEUS AZTECUS	2	1	1	0	0	0	0	0	2	1	1	0
	NO. OF SPECIES	3				0				3			
	NO. OF INDIVIDUALS	11	4	6	1	0	0	0	0	11	4	6	1

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
1	7	3	11	1.4378	.6545	1.0000

TABLE 2 CONT.'D

STATION 36 TRANSECT 7 PERIOD POST-RIG

		DAY				NIGHT				TOTAL			
RANK	SPECIES	TOTAL	M	FM	F∧E	TOTAL	M	FM	F∧E	INDIV	M	FM	F∧E
1	TRACHYPENAEUS SIMILIS					29	3	26		29	3	26	
2	SQUILLA CHYDAEA					14	3	11		14	3	11	
3	PENAEUS AZTECUS					5	1	4		5	1	4	
4	SICYONIA DORSALIS					4	1	3		4	1	3	
	NO. OF SPECIES					4				4			
	NO. OF INDIVIDUALS					52	8	44		52	8	44	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
36	7	4	52	1.5916	.6131	1.0000

TABLE 2 CONT.'D

STATION 1 TRANSECT 7 PERIOD POST-RIG

RANK	SPECIES	DAY TOTAL	DAY M	DAY FM	DAY F∧E	NIGHT TOTAL	NIGHT M	NIGHT FM	NIGHT F∧E	TOTAL INDIV	TOTAL M	TOTAL FM	TOTAL F∧E
1	TRACHYPENAEUS SIMILIS					68	2	66		68	2	66	
2	SQUILLA CHYDAEA					10	4	6		10	4	6	
3	SICYONIA DORSALIS					9	2	7		9	2	7	
4	PENAEUS AZTECUS					6	4	2		6	4	2	
5	SQUILLA EMPUSA					3	1	2		3	1	2	
6	PORTUNUS GIBBESII					2	1	1		2	1	1	
7	CALLINECTES SIMILIS					1	1			1	1		
8	SICYONIA BREVIROSTRIS					1		1		1		1	
	NO. OF SPECIES					8				8			
	NO. OF INDIVIDUALS					100	15	85		100	15	85	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
1	7	8	100	1.6670	.5196	.5000

TABLE 2 CONT.'D

STATION 30 TRANSECT 7 PERIOD POST-RIG

RANK	SPECIES	DAY TOTAL	DAY M	DAY FM	DAY F^E	NIGHT TOTAL	NIGHT M	NIGHT FM	NIGHT F^E	TOTAL INDIV	TOTAL M	TOTAL FM	TOTAL F^E
1	TRACHYPENAEUS SIMILIS					30	1	29		30	1	29	
2	PENAEUS AZTECUS					5	4	1		5	4	1	
3	SICYONIA DORSALIS					2	1	1		2	1	1	
	NO. OF SPECIES					3				3			
	NO. OF INDIVIDUALS					37	6	31		37	6	31	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
30	7	3	37	.8645	.3303	.6667

TABLE 2 CONT.'D

STATION 34 TRANSECT 7 PERIOD POST-RIG

RANK	SPECIES	DAY TOTAL	DAY M	DAY FM	DAY F&E	NIGHT TOTAL	NIGHT M	NIGHT FM	NIGHT F&E	TOTAL INDIV	TOTAL M	TOTAL FM	TOTAL F&E
1	TRACHYPENAEUS SIMILIS					33		33		33		33	
2	SQUILLA CHYDAEA					12	5	7		12	5	7	
3	SICYONIA DORSALIS					9	4	5		9	4	5	
4	PENAEUS AZTECUS					6	3	3		6	3	3	
5	PORTUNUS GIBBESII					3	1	2		3	1	2	
6	SICYONIA BREVIROSTRIS					1	1			1	1		
	NO. OF SPECIES					6				6			
	NO. OF INDIVIDUALS					64	14	50		64	14	50	

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
34	7	6	64	1.9677	.6786	.8333

TABLE 2 CONT.'D

STATION 32 TRANSECT 7 PERIOD POST-RIG

RANK	SPECIES	DAY TOTAL	DAY M	DAY FM	DAY F∧E	NIGHT TOTAL	NIGHT M	NIGHT FM	NIGHT F∧E	TOTAL INDIV	TOTAL M	TOTAL FM	TOTAL F∧E
1	TRACHYPENAEUS SIMILIS					46	5	41		46	5	41	
2	SICYONIA DORSALIS					36	17	19		36	17	19	
3	SQUILLA CHYDAEA					16	5	11		16	5	11	
4	ASTROPECTEN DUPLICATUS					8				8			
5	PENAEUS AZTECUS					7	5	2		7	5	2	
6	PORTUNUS GIBBESII					7	2	5	3	7	2	5	3
7	CALLINECTES SIMILIS					5	6	2		5	6	2	
8	PORCELLANA SAYANA					3		3	2	3		3	2
9	SQUILLA EMPUSA					1	1			1	1		
10	LIBINIA EMARGINATA					1	1			1	1		
11	SICYONIA BREVIROSTRIS					1	1			1	1		
	NO. OF SPECIES					11				11			
	NO. OF INDIVIDUALS					131	43	83	5	131	43	83	5

STATION	TRANSECT	SPECIES	INDIVIDUALS	DIVERSITY	PIE	EQUITABILITY
32	7	11	131	2.5807	.7806	.8182

APPENDIX F

ATTACHMENT A
METHODS FOR HYDROCARBON ANALYSES
Bureau of Land Management
Contract No. AA550-CT6-17

ATTACHMENT A

METHODS FOR HYDROCARBON ANALYSES

Bureau of Land Management
9 June 1976

Contractors shall carry out all extraction steps as described in the following sections to obtain the aliphatic and aromatic hydrocarbons from the samples prior to analysis by gas chromatography-mass spectrometry-computer techniques. When alternate procedures are permitted, the Contractors shall select and use only one procedure for all samples for the duration of the contract. At least ten percent of all gas chromatographic separations conducted in performance of the contracts shall be analyzed by mass spectrometric computer techniques. Additional analyses may be requested if significant qualitative variations are noted by the Contractor during the process of the analytical program.

Frequent analyses shall be performed on the reagents and solvents used in the laboratory, including, without fail, each batch of solvents. This will be accomplished by processing a blank completely through the analytical procedure such that glassware, chemicals and techniques may be monitored. Samples of fuels and lubricants used on the ship during the cruise shall also be analyzed since they are possible sources of contamination. Extraction and recovery procedures shall be checked periodically by spiking a native sample with appropriate n-alkane and polycyclic aromatic standards.

1. Extraction of Sediment Samples. The recommended minimum sample weight is 100 g. This amount can be increased for sediments found to be low in extractable organics. Every fifth sample shall be spiked with a 0.1 µg hydrocarbon spike/g sediment using an appropriate n-alkane or isoalkane standard and a polycyclic aromatic standard which falls outside of the spectra of the compounds being measured. Alternately a radioactive tracer may be used.

The sediment sample is then freeze-dried.[1] This procedure serves to minimize sample manipulation. The freeze dried sediment is then extracted by either (a) the soxhlet technique, or (b) the reflux technique.

(a) The Soxhlet Extraction

The freeze dried sediment is placed in a soxhlet thimble[2] and extraction is allowed to proceed for 100 hours, or 300 turnovers,

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[1]Remove sample when dry. Contamination occurs during prolonged pumping on a dry sample. A complete column chromatographic-gas chromatographic analysis of the more volatile components of the vacuum pump oil should be performed to aid in the detection of contamination.

[2]The Soxhlet thimbles are thoroughly extracted for 72 hours using the toluene and weighed prior to addition of sample. If possible, glass fiber thimbles should be used.

with one solvent change after twenty-four hours. The solvent system to be used is a toluene:methanol (3:7) azeotrope. The extracts obtained from the sediment extraction and water washing are then combined and reduced in volume.[3] The dry weight of the extracted sediments is determined while in the thimble after oven drying at 80°C to constant weight.

b. The Reflux Extraction

The freeze dried sediment sample is extracted with at least 200 ml of a toluene:methanol (3:7) azeotrope by refluxing for at least seven hours. The extract is then decanted and then replaced with another equal volume of toluene:methanol (3:7) which is refluxed for an additional seven hours. The toluene/methanol extract is then decanted and the residual sediment is then washed with 50 ml of n-heptane at 50°C. The extract obtained from the sediment wash is then decanted.

If no sedimentary material is noticed in the extracts, they can be combined immediately and reduced in volume. If sedimentary material is noticed in the extracts, they should be centrifuged for 15 minutes at 1500 xg or filtered. The supernatants are then decanted and combined. The residual material will be washed with n-heptane at 50°C and then centrifuged or filtered. Following centrifugation (filtration) the supernatant (filtrate) and the extract obtained from the water washing of the sediment are added to the combined n-heptane/toluene extract and reduced in volume. Additionally, the dry weight of the extracted sediment is determined after oven drying at 80°C to constant weight.

The presence of elemental sulfur is determined on at least one sample per suite by dipping activated copper wire into the extract. If the wire becomes coated immediately, all samples shall be tested for sulfur. The sulfur shall be removed by reaction with activated copper. The solvent is reduced in volume and then saponified in accordance with the procedure described in section 7. The sample is transferred to a tared vial and the remaining solvent removed with pre-purified N_2 and weighed. The sample is then dissolved in a small volume of n-haptane[4] for column chromatographic analysis.

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[3]Techniques recommended for concentration of solvent extracts include the use of rotary evaporators, Kuderna-Danish evaporators, purified nitrogen stream, etc. If a hot plate is used, it should be adjusted to no more than 40°C to accelerate the removal of the residual solvent.

[4]n-hexane and n-pentane can be substituted for n-heptane in all applications.

2. Extraction of Macroinfauna/Flora. Approximately 100 grams of tissue shall be used for all analyses. When possible, a minimum of five organisms or portions thereof should be used for an analysis to minimize the natural variability of hydrocarbon content in conspecifics. The samples shall be handled according to either Method (a) or Method (b) below:

(a) Method A. The weighed samples will be homogenized along with any water present and an aliquot of the homogenate will be removed and placed in a tared beaker and dried at 60°C until a constant weight is obtained. In this manner, the weight and dry weight of the sample is obtained. The remainder of the homogenate will be saponified and extracted according to the procedure described in section 7.

(b) Method B. The sample shall be transferred after defrosting for a short period to a tared round bottom flask. Small samples shall be used whole; while large samples may be cut into smaller pieces as needed for transfer into flasks. The flask with sample shall then be re-weighed. Representative aliquots of the sample shall be dried to constant weight at 60°C. In this manner a wet and dry weight of the sample is obtained.

In the flask shall be added 0.05 g KOH/g tissue and approximately 50 ml of methanol. The sample shall then be refluxed for four hours. At the end of this period, the contents of the flask shall be inspected and if the digestion of the tissue is not complete, heating shall be continued until no tissue remains. When the digestion appears complete, a volume of doubly distilled water equal to the initial solution shall be added to the flask and the mixture shall be refluxed for an additional hour.

After the final reflux has been completed, the mixture shall be diluted with an equal volume of a saturated NaCl solution and extracted as described in the saponfication procedure found in section 7.

Upon recovery of the non-saponified lipid extract, it will be transferred to tared vials and the remaining solvent removed under a gentle purified nitrogen stream. The weight of the non-saponifiable lipid residue is then determined.

Following weight determination, the non-saponifiable lipid residue is dissolved in a small volume of n-heptane and fractionated in accordance with the column chromatography procedure (section 8).

3. Extraction of Suspended Particulate Material. Filters containing the particulate hydrocarbon samples shall be thawed and then refluxed with 50 ml of n-heptane for one hour. The extract shall be decanted and replaced with 50 ml of $CHCl_3$ and refluxed for an additional hour. The extracts will be combined and reduced to near dryness. A gentle stream of purified N_2 will be used to remove the remainder of the solvent. The weight of the lipid material will then be determined.

Following a weight determination, the sample will be dissolved in n-heptane and fractionated as described under column chromatography (section 8).

4. Extraction of Plankton. The frozen zooplankton sample will be thawed in the original container and then poured into a pre-cleaned cellulose extraction thimble (Whatman, single thickness, 33x80 mm) and allowed to drain relatively free of seawater. The sample will be placed in a Soxhlet extractor and continuously extracted for 10 to 20 hours with a methanol-toluene azeotrope. The solvent is to be replaced and the extraction repeated from an additional 10 to 20 hours to remove the remaining hydrocarbons. The extracted residue is then dried to constant weight at 80°C and weighed.

The extracts are to be combined and the excess solvent removed using a rotary evaporator under partial vacuum at a temperature no greater than 50°C. This total extract is then saponified and fractioned in accordance with the procedure described in sections 7 and 8, respectively.

5. Extraction of Water Samples. The filtered water samples will be extracted with $CHCl_3$. The extraction efficiency will be demonstrated prior to any analyses being accomplished, and shall be greater than 90% for aliphatic and aromatic compounds. The $CHCl_3$ extract shall then be reduced in volume and then taken to dryness with a gentle stream of purified N_2. The lipid residue will be weighed and then re-dissolved in n-heptane for column chromatography.

6. Contaminant Sample Analysis. Samples of fuels, lube oils, and oily bilge water shall be fractionated via column chromatography as described in section 8 and the fractions characterized via gas chromatography as described in section 9. Oily bilge water samples shall be extracted with chloroform prior to the column chromatographic separation.

7. Saponification. All samples requiring saponification will be handled as described below. Saponificiation will be carried out by refluxing the sample with a 1:1:1 mixture of 0.5 N KOH in methanol:toluene:water or a 0.5 N KOH in methanol. This mixture will be refluxed either under purified N_2 or with a filter of molecular sieve of silica gel to prevent contamination from external hydrocarbons in the laboratory. The saponification reaction shall be continued for at least four hours. Following the saponification with .5 N KOH in methanol an equal volume of water shall be added and this mixture shall be refluxed for an additional hour. (If GC-MS analyses indicates the presence of methyl esters the water shall be added to the initial reflux solution.)

Upon completion of the saponification reaction, the mixture shall be diluted with an equal volume of saturated NaCl solution. If no emulsion exists, the toluene layer shall be decanted, followed by these extractions of the aqueous mixture with n-heptane. If toluene is not used, the saponification mixture is simply extracted three times with a n-heptane. The volume of n-heptane used for such extractions shall be equivalent to the volume of methanol initially used in the saponification. The toluene and n-heptane fractions are then combined and reduced in volume.

If an emulsion exists, the entire mixture shall be extracted three times with the n-heptane (occasionally, an emulsion will break by simple standing). The extracts obtained shall be placed in glass centrifuge tubes with teflon-lined caps and then spun down so that the phases can be easily separated. The organic phases will then be combined and back extracted with an equal volume of saturated sodium chloride solution. The saturated sodium chloride solution will then be re-extracted once with n-heptane and all the organic phases will be combined. The organic solvents will then be reduced in volume prior to column chromatographic separation.

8. Column Chromatography. All sample types will be chromatographed in the manner described below. A weight ratio of about one hundred (100) parts alumina to one (1) part lipid sample and 200 parts silica gel to one (1) part lipid sample will be used. The column should have a length to i.d. ratio of approximately 20:1. Both the silica gel and the neutral alumina will be Activity 1. The column should be rinsed with at least two column volumes of n-heptane.

At no times should the column be allowed to run dry. The extract will then be applied to the column in a small volume of n-heptane and the aliphatic fraction eluted with two column volumes of n-heptane. This will be followed by elution of aromatics with two column volumes of benzene. The eluates from the two fractions will then be taken to near dryness. They will then be transferred to screw cap vials with either aluminum or teflon lined caps, and the remainder of the solvent removed with a stream of purified nitrogen. The weight of each fraction is then determined prior to GC analysis.

Following column chromatography, all eluates will be analyzed by gas chromatography.

9. Gas Chromatography Separations. Each eluted fraction obtained from the column chromatographic separation will be quantitatively dissolved in a small volume of n-heptane or other suitable solvent for injection into the GC. Stainless steel capillary columns coated with Apiezon L, OV-101, DEGS or SE-30 should be used for the analysis. The capillary columns should be high resolution. When the capability does not exist to use SCOT capillary columns, packed columns using liquid phases such as FFAP and OV-101 will be permitted providing the required resolution is achieved.

The column(s) should resolve n-C_{17} from pristane and n-C_{18} from phytane with a resolution (R) of approximately unity, where

$$R = 2d/w_1 + w_2 \text{ and,}$$

w is the width of each peak at the base of one phase for both pairs of components, and

d is the distance between apices.

Further, the column(s) must be capable of resolution of hydrocarbons from n-C_{14} through at least n-C_{32}. When necessary, a second column may be employed to clarify unresolved components.

The gas chromatograph shall be capable of linear temperature programming and will be operated with a hydrogen flame detection with a sensitivity of at least 5 x 10^{-11} gms/sec for n-decane at a signal to noise ration of 5:1. It is recommended that an electronic integration be used for quantitation of peak areas. Retention indices may be computed based on known standards.

The gas chromatographic analysis should allow for isolation and characterization of the following: normal alkanes from C_{14} to at least C_{32}; branched and isoprenoid alkanes from C_{14} to at least C_{32}; condensed and non-condensed cycloalkanes (in a cursory way, if present); and homologous series of alkyl benzenes and alkyl-substituted polycyclic aromatics such as chrysene with retention time up to n-C_{32}, when such identification is certain.

10. Gas Chromatographic-Mass Spectrometric (GC-MS) Instrumentation.

Identification of organic components will be by GC-MS techniques using the same gas chromatographic columns described above. Most mass spectra will be obtained by low resolution methods (unit resolution at m/e=1000). The resolution (R) is defined ($R=m/\Delta m$) where m is the mass of the first peak in a doublet and Δm is the difference in the masses of the two peaks. A 10% valley is assumed between the two peaks measured. The GC-MS systems employed will have the ability to produce recognizable spectra at the aforementioned resolution for 20 ng of methyl stearate at a scanning rate of 4 sec/decade when the sample is introduced through the GC inlet and the instrument is operated in the low resolution mode. Calibration of the mass spectrometer should be performed by use of a perfluorokerosene or other fluorinated material.

Interpretation will be verified as often as possible by comparison with the following low resolution mass spectrometry references in addition to the usual literature sources and/or through comparison with previously obtained spectra for standard compounds.

(a) Eight Peak Index of Mass Spectra (Mass Spectrometry Data Center, Atomic Weapons Research Establishment, Aldermaston, England, 1970). Vols. 1 and 2.

(b) Stenhagen, E., S. Abrahamsson, and R. W. McLafferty, Atlas of Mass Spectra Data. (Interscience, New York, 1969). Vols. 1 and 3.

(c) American Petroleum Institute Project 44 Selected Mass Spectra Data (Thermodynamics Research Center, Texas A&M University).

Where positive identification cannot be made, the compound shall be identified as unknown or the molecular weight (deduced from MS) shall be given. If other literature sources or reference compounds are

employed for qualitative purposes the Contractor shall so specify as part of the final report. Information on instrument operating conditions shall also be provided in the final report such as source temperature, source pressure, acceleration voltage, type and temperature of molecular separator, and scan rates.

11. Computer Instrumentation. All GC-MS instrumentation will be computer supported. The computer will be capable of on-line acquisition of data and storage of raw data on magnetic tape or disc.

The computers are capable of several different output functions to provide data in a form that facilitates interpretation. Such functions include: (a) correction of mass spectrum for background signal; (b) plotting of total ion chromatogram; (c) plotting of normalized mass spectrum, and (d) print-out of normalized data in digital form.

In addition, the subtraction of any one spectrum from another as well as the enhancement of selected portions of a specific spectrum is possible. Input/Output devices include a teletype, a hard copy unit and an oscilloscope display. All mass spectral data will be stored intact and catalogued in such a way as to be retrievable at a later date for further interpretation, evaluation and comparison to specific gas chromatographic separations.

12. Archives for Data. Both GC and MS raw data will be catalogued and stored in either hard copy, magnetic tape and/or disc form for a period of two years following its generation in the laboratory, or until notified by the COAR as to their proper disposition.

13. Interlaboratory Calibration. Interlaboratory calibration shall be performed between all laboratories participating in HMW hydrocarbons analyses. Four standard crude oils (API oils) and aliquots of at least four environmental samples collected under this contract will be distributed to all participating laboratories for analysis.

14. Report Format. The Contractor shall report results of all analyses of reagents, blanks, solvents, standards, spiked samples, fuels, lubricants, and interlaboratory comparisons.

The qualitative and quantitative data shall be presented in a tabular form. Also, illustrations of typical gas chromatographic separations, as well as any separations showing unusual components, shall be included in the final report. Illustrations shall include as a minimum one for each sample type (*i.e.*, sediment, water, particulates, and fauna) and one for each type of column used. The use of white chromatographic paper is recommended since it facilitates photographic reproduction of the original.

Each major gas chromatographic peak shall be identified by some sequential system with identifiers referring to specific compounds by name, formula, or retention index in the corresponding table. A quantitative value calculated from gas chromatographic data shall be presented for each compound so noted. Values shall be expressed as follows: µg/g dry weight of sample for all but particulate and water samples which will

be expressed as µg/liter of sample.

As a minimum, the following information shall also be tabulated:

Pristane/phytane ratio,
pristane/n-C_{17} ratio,
phytane/n-C_{18} ratio,
total alkanes recovered, by weight
total unsaturates recovered, by weight, and
ratios within homologous series.

Weights for total alkanes and aromatics shall be determined gas chromatographically. When other data, such as total lipids, can be determined they should also be reported. The use of correlative relations such as: odd-even ratios, odd-even predominance (OEP) ratios, and unresolved complex mixture (UCM)/resolved components, etc., shall be used whenever possible.

The Contractor shall develop a standard reporting format for use by all principal investigators doing high molecular weight hydrocarbon analyses.

The final report shall contain data results of each analysis to include: a summary of compounds suspected of being contaminants, and, if possible, their source, the report shall contain recommendations for eliminating contaminants from samples. The report shall contain extraction efficiency and analysis recovery information. The report shall contain specific details for all methods used and shall include all instrumental operating conditions for all sample analyses.

APPENDIX G

ATTACHMENT B
METHODS FOR TRACE METALS ANALYSES
Bureau of Land Management
Contract No. AA550-CT6-17

ATTACHMENT B

Bureau of Land Management Methods for Trace Metal Analysis

22 March 1976

The Contractor shall analyze samples in accordance with the following procedures. All water utilized shall be doubly-distilled and deionized (or equivalently non-contaminating). All acids used shall be of such quality that the reagent blanks contain insignificant amounts of sought after or interferring elements. As a minimum, acids should meet or exceed the specifications of analysis on J.T. Baker "Ultrex" grade acids (this may be accomplished through the use of a sub-boiling silica still). All glass and plasticware employed must be vigorously cleaned by detergent washing followed by 5 rinses. The soaking in nitric acid (1:1), followed by 5-10 rinses with distilled water. Finally, the labware must be washed in hot hydrochloric acid (1:1), and rinsed with copious amounts of distilled water. The labware is then air-dried at room temperature over a metal-free surface.

It should be noted that the amount of sample employed or reagents used, as described in the following stepwise procedures, can be modified to achieve lower detection limits, more sensitive analyses, or more complete sample dissolutions.

It should be emphasized that the above is a minimum set of general analytical specifications, which must be adhered to consistently.

1. Zooplankton. A large portion of the sample (10 g) is dried to a constant weight at 60°C (or freeze-dried) and reweighed to determine dry weight biomass.

(a) Method 1. The dried samples shall be ground with an acid-rinsed, agate-lined mortar and pestle, and a 0.5 to 1 g subsample taken and ashed in an oxygen-plasma system until ashing is complete. The entire amount of ashed material shall then be transferred, on a clean bench, to a Teflon (T.F.E.) bomb, to which 3-4 ml of 70% nitric acid has been added. The sealed bomb is then placed in a water bath at 90-100°C for two (2) hours. The bomb is then opened and rinsed out with doubly distilled, deionized water in two or three washes (both cap and cylinder) into a centrifuge tube. Filtration through 0.47 μ Nucleopore filters can be substituted for centrifugation to eliminate suspended matter in all biological digestates. After centrifugation (or filtration) transfer the supernatant (or filtrate) to a Teflon or polyethylene 50 ml volumetric flask and bring iron (Fe), chromium (Cr), nickel (Ni), zinc (Zn), cadmium (Cd), copper (Cu) and lead (Pb) using either flame or flameless atomic absorbtion spectrophometric (AAS) technique. The choice of techniques will depend on the element being analyzed, its concentration, and the sample size; however, it is anticipated that the analysis for Cd, as a minimum will require the use of flameless techniques. Barium (Ba) and Vanadium (V) shall be determined using an alternative instrumental technique described in section 5.

(b) Method 2. A 1-2 g subsample of the dried biological material is weighed out, ground and homogenized as described above and 1 g placed in a refluxing system. Five (5) mls of 70% nitric acid (HNO_3) shall be placed in the system and allowed to digest the material at room temperature for 1-2 hours. Five (5) mls of concentrated sulfuric acid (H_2SO_4) may be added if deemed appropriate, in order to remove any residual traces of lipid material. After the frothing subsides, apply low heat and allow sample to reflux for 30 minutes. Open the system under a clean hood and allow the sample to evaporate to dryness. (NOTE: When the sample is nearly dry, reduce heat to prevent spattering.) When smoking ceases, increase the heat to 340°C. (NOTE: Increase the heat slowly to prevent ignition and possible loss of volatiles.) After cooling the sample, the residue shall be redissolved with an additional five (5) ml of 70% HNO_3 and heated slowly. At this low temperature purified 30% hydrogen peroxide (H_2O_2) shall be added dropwise until the solution becomes clear and pale yellow in color. After clearing, evaporate the solution to approximately 3 ml (NOTE: If the solution begins to darken, add additional (H_2O_2). The solution shall then be transferred to a polyethylene 25 ml volumetric flask and brought up to volume with distilled water. The elements to be analyzed for and the techniques to be employed are described in Method 1 above.

(c) Method 3. A 1-2 g subsample of the dried biological material is weighed out, ground and homogenized and 1 g placed in a refluxing system. Add 10 ml of 3:1 HNO_3:$HClO_4$ per gram of sample. Refluxing should continue until $HClO_4$ fumes are evolved. The mixture should be evaporated to near-dryness (NOTE: If charring occurs, add additional HNO_3.) After each rinse, pour the washings into a centrifuge tube and spin down the particulate matter or remove it by Nucleopore filtration. Dilute to volume with distilled water. The elements to be analyzed for and the techniques to be employed are described in Method 1 above. Obviously, this method should be employed only where a perchloric hood is available.

2. Suspended Particulate Matter. The preweighed 0.47 μ Nucleopore filter pads containing the particulate matter shall be removed in a clean bench from the filter holders with Teflon coated forceps and placed in acid-rinsed Teflon or polyethylene jars. These jars will be placed in a dessicator over silica gel, sealed and then dried for 48 hours. After drying to constant weight, the filters should be weighed on a six-decimal place (one microgram) balance so that a calculation of the mass of suspended particulate matter can be made.

(a) Weak Acid Soluble Materials. To remove carbonate and absorbed elements, the filters should be leached for two hours with 25% V/V acetic acid. Leaching shall be carried out in a clean bench, and during the two hour leaching period the samples should be covered so that they are not contaminated by fallout from the flow spoilers or other easily degraded materials on the bench. The supernate is drained through the filter into an acid-cleaned Teflon or polyethylene 25 ml volumetric flask and the filter pad rinsed twice with distilled water, which is added to the flask as well.

Five hundred (500) µl of HCl should be injected into the solution to prevent absorbtion of metals and brought up to volume with distilled water. The resulting solution shall be analyzed directly, or extracted and analyzed, by flameless AAS techniques. The elements to be analyzed for are listed in section 1(a) with the exception that Ba and V will not be determined for the weak acid soluble fraction, but will be determined by INAA for the refractory portion described below.

(b) Analysis of Refractory Suspended Matter. The suspended matter which remains after the leach with acetic acid is dissolved as follows: an Eppendorf or other comparable micropipette is used to inject 750 µl of concentrated HCl into an all Teflon bomb containing the suspended matter and Nucleopore filter membrane on which it was collected. The bomb is then sealed and heated in a water bath at 90-100°C for 30 minutes. The bomb is then cooled, opened and injected with 250 µl of concentrated HNO_3, resealed and immersed for an additional 30 minutes in the water bath. After final cooling the sample is transferred to a Teflon or polyethylene 100 ml volumetric flask and diluted to volume with distilled water. The elements to be analyzed for an instrumental techniques to be employed for this final solution are listed in section 1(a).

3. Sediments. In order to evaluate the "biological availability" of selected trace metals as well as their total concentration in sediments, two procedures, discussed below in detail, will be employed.

(a) "Partial" Digestion. The techniques described herein will be used for all sediment samples. In preparing the sediment samples, the entire sediment core obtained shall be thawed to room temperature in an acid-cleaned beaker. The wet sediment is mixed by stirring with an acid-cleaned glass rod. Approximately 20 g of the mixed wet sediment is then transferred to a tared beaker and large particles (3 mm) are removed. A 2-10 g subsample, as appropriate, of the dried sediment will be leached for two (2) hours in a covered beaker with 25% V/V acetic acid. In view of the varying geochemistries found in the different study areas, the Contractor may, at his discretion, substitute a 5N HNO_3. Once the selection has been made, however, the method chosen must be utilized for all samples. Particulate matter will be separated from the leachate by either contrifugation or filtration as described in section 1. The resultant solution shall be analyzed for the elements listed in section 1, according to the techniques described therein. Further information on the preparation of samples for analysis of Ba and V by alternate instrumental techniques is provided below in section 5.

(b) "Total" Digestion. These additional analyses will be performed on only 25% of the total number of sediment samples, to evaluate the environment significance of partial versus total analysis data. A 10-18 g subsample of the dried sediment samples (prepared as described for the "partial" digestion method above) shall be transferred to an acid-washed, agate-lined mortar and pestle (or a non-mesh non-metallic sieve). A 1-10 g subsample, as appropriate, is then digested in all Teflon refluxing system (which may consist of a Teflon beaker and watchglass) with

concentrated HCl for 1 hour at 90-100°C, on a clean bench apparatus. The solution is cooled, the system opened, and concentrated HNO_3 introduced in a 1:3 ratio to the HCl; the resulting solution is heated for an additional 30 minutes at 90-100°C. After a second cooling, the system is opened and a sufficient amount of 48% HF introduced to disrupt the crystalline lattice of the sediment samples. The system is then closed and heated to 90-100°C for a minimum of one (1) hour. After a final cooling, the solution is transferred to an appropriate Teflon or polyethylene volumetric flask, and diluted to volume with distilled water. Elements to be analyzed for in the resultant solution and instrumental techniques to be employed are described in section 3(a).

4. Macrofauna. In preparation of the samples for subsequent dissolution and analysis by the techniques described below, those organisms with limited fleshy portions (<100 g) should be used *in toto* after removal of the outer most layer. Individuals selected for pooling should be of approximately the same size, developmental stage and collected from approximately the same area. For larger organisms, the muscle tissue should be used for analysis.

A large portion of the sample (≥ 10 g) is dried to a constant weight at 60°C (or freeze-dried) and reweighed to determine dry-weight biomass.

The Contractor shall then proceed with one of the sample dissolution and analysis procedures described below, at his discretion.

(a) Method 1. See section 1(a).

(b) Method 2. See section 1(b).

(c) Method 3. See section 1(c).

5. Other Instrumental Techniques. Due to the difficulties encountered and lack of sensitivity for Ba and V when employing routine atomic absorbtion spectrophotometric (AAS) techniques, two alternate instrumental techniques have been selected for use in the BLM's program. The choice between these techniques is left to the discretion of the Contractor, however, the analytical procedure to be employed for each are discussed in detail below. Once the selection of techniques has been made, however, it must be employed for all samples.

(a) Instrumental Neutron Activation Analysis (INAA).

(i) Biological Samples. Since the determination of V in marine samples by INAA is interferred with greatly by background activities from ^{24}Na and ^{38}Cl, pre-irradiation chemical separations should be made prior to the determination of V. The chlorine is removed by adding 0.5 ml of concentrated H_2SO_4 to 3 ml of the biological digestate obtained in sections 1 and 2, respectively. These solutions are evaporated until SO_3 fumes are observed.

Na is then removed by redissolving the respective residue in 5 ml of 8M HNO_3 and passing the resulting solutions through a column of hydrated antimony pentoxide (HAP) according to the procedures of Girardi and

Sabbioni (1968)[1]. Trace metals, including V, are quantitatively eluted. The eluates are evaporated to near dryness and diluted to 5 ml with distilled water.

The samples obtained are then heated-sealed in acid-cleaned polyvials and irradiated separately for five minutes. If the neutron flux of the reactor employed varies more than 1% for any individual irradiation, aluminum flux monitors must be included with each sample for V determination. After an appropriate delay period (usually 3-5 minutes, such that the dead time is less than 30%) the ^{52}V activity is measured by counting the 1434-keV gamma rays. A large volume Ge(Li) detector (with gain less than 3 keV/channel) coupled to a multichannel pulse height analyzer of five minutes, after which the entire spectrum shall be stored on magnetic tape for subsequent analysis.

The determination of Ba for these samples shall be accomplished through the measurement of the 12 day ^{131}Ba activity. This allows the interferring ^{24}Na and ^{38}Cl activities to diminish significantly, and thereby obviates the necessity of pre-irradiation chemistry, as described for V analyses. Samples shall consist of 2 ml aliquots of the biological and refractory suspended matter digestates obtained through procedures described in sections 1 and 2, respectively.

The Ba analyses shall be conducted by irradiating the samples described above for a 14 hour period. The samples shall all be heat-sealed in acid-cleaned polyvials and placed on a rotary specimen rack set in the reactor core, together with appropriate standards and blanks. Following irradiation the samples are allowed to "cool" for at least 14 days (but less than 24 days) before the 12 day ^{131}Ba activity is counted through the use of a Ge(Li) gamma ray spectrometer system similar to that described for V analysis above. The ^{131}Ba activity is determined from the intensity of one or both gamma ray lines at 29 keV and 124 keV. After two hour counting period the entire spectrum is stored on magnetic tape.

Peak intensities shall be calculated and converted to concentration by comparison with appropriate standard reference materials containing known amounts of analyte. Corrections shall be made for varying delay times, dead times, and neutron fluxes as necessary.

The characteristic of INAA is its multi-element analytical capability. Therefore, the concentration data on trace metals of interest in the BLM program, which can be determined concurrently with the V and Ba, measurements, should be provided as well. It is anticipated that these elements will include Cu, Al, and Ca for the standard V irradiation and counting procedure, and Cd, Cr, Fe and Zn for the standard Ba determination.

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[1]Girardi, F. and E. Sabbioni, "Selective Removal of Radio-Sodium from Neutron Activated Materials by Retention on Hydrated Antimony Pentoxide", Radio-Anal. Chem. 1:169:178. 1968.

(ii) Sediment Samples.

The procedures to be followed are detailed in section 5(a)(i) with the following modifications. The sensitivity of V determinations in sediment samples will be improved by reducing Cl and Na interferences by rinsing with very pure water. This washed sediment will then be taken through the partial and total dissolution procedures described in sections 3(a) and 3(b), respectively. Aliquots of these two solutions are then quantitatively transferred to an appropriate polyvial and evaporated to dryness. Subsequent irradiation and counting procedures are to be performed as previously described.

(b) Proton Induced X-Ray Emission (PIXE). The usefulness and application of this technique is presently being evaluated in the BLM Mid-Atlantic environmental studies. The simultaneous determination of all elements with atomic number greater than 12 on a wide variety of environmental samples makes this a powerful analytical tool.

While all samples to be analyzed by PIXE can be prepared and analyzed directly, until the evaluation process is completed, samples shall consist of digestates being prepared for AAS analysis as described above. These solubilized biological, sedimentary, and refractory suspended particulate materials (obtained from procedures outlined in sections 1, 4, 3, and 2(b), respectively) shall be made into uniform, thin (500 $\mu g/cm^2$) dry deposits onto a thin (250 $\mu g/cm^2$) high-purity carbon film. This film shall be impregnated with less than 50% (by weight) of clean formvar on nucleopore for extra film strength. The proton source should produce protons with energies of 3 to 4 MeV.

The prepared samples deposited on a thin film, shall be placed in the proton beam in a high-purity helium (He) atmosphere (at least 100 mm Hg) to prevent loss of volatile elements in vacuum. If it is determined during analysis that a certain element is present in such high concentrations, such that its signal masks that of near by elements, then an appropriate X-ray filter should be used to suppress the intense X-rays by a factor commensurate with the concentration of the abundant element.

Since the sensitivity of PIXE analyses increases with the length of exposure time, the intensity of proton beam current, and thickness of the prepared sample; all three of these parameters should be adjusted within permissable limits to yield highest sensitivities for elements in each class of sample.

Due to the possibility of interference by X-ray lines from different elements, the characteristic X-ray spectrum from any sample must be analyzed in conjunction with a computer system using accurately measured single element characteristic X-ray "line" spectra and interactive multi-element data fitting procedures, to ensure the most accurate quantification of various elements.

Finally, using protons with energies of 3-4 MeV, the elements shall be

quantitated using K X-rays for elements with atomic numbers ≤ 56 and with L X-rays for atomic numbers above 56.

6. Quality Control, Data Reporting, and Intercalibration for Trace Metal Analysis. The Contractor shall establish and operate under an analytical quality control program. As a minimum the following considerations should be addressed: All laboratories performing analyses for trace metals shall be required to analyze an appropriate number of labware and reagent blanks, and report the levels of possible contaminants. In addition, procedural blanks shall be employed throughout the analytical process, and any gross contamination thereby recognized and eliminated prior to further sample processing.

Where more than one laboratory is involved in the analytical effort each laboratory shall establish the accuracy and intercomparability of results by analyzing appropriate National Bureau of Standards (NBS) standard reference materials, such as bovine liver and plastic clay, and comparing the results of the analyses. Laboratories shall make exchange samples of various types, analyze them independently and compare results. It is understood that each laboratory will also use suitable numbers of calibration and reference standards to calculate concentration data from.

For AAS analyses, the matrix effects should be evaluated and compensated for through use of the standard additions technique. Also, absorbances should be corrected for false absorbance at the analytical wavelength via use of an internal background corrector and/or use of a nonabsorbing wavelength. All AAS analyses should be performed according to the individual instrument manufacturer's specifications, except where the results can be significantly improved through optimization techniques. In any event, the instrumental settings, and operating conditions shall be reported.

Both instrumental and procedural detection limits, as well as analytical sensitivities shall be reported. Precision shall be reported as ± one standard deviation unit for results from a minimum of five (5) subsamples of a homogenized sample.

Results of all analyses for trace metals in biological samples shall be reported in mg per kg (ppm) on a dry weight basis. Weight loss upon drying shall also be reported in order to ascertain wet weight values as well.

Results of all analyses for trace metals in particulate samples will be reported as dry weight of the metal per volume of water filtered in micrograms per liter (ppb).

Results of all analyses for trace metals in sediment samples will be reported as mg per 1 kg (ppm) of sediment on a dry weight basis. Weight loss upon drying shall also be reported.

Trace metal concentrations not detected by any technique used will be reported as less than the experimentally determined minimum detection limit, stated to two significant figures.

Trace Metals, page 8

The Contractor shall report and document results of all analyses of reagents, blanks, standards, and interlaboratory comparisons.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.