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REPORT TO EPA

Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, 1975-1980

A report to the Environmental Protection Agency on work conducted under provisions of Interagency Agreement EPA-IAG-D5-E693-EO during 1975-1980.

Volume I
SEDIMENTS, PARTICULATES AND VOLATILE HYDROCARBONS

SOUTHEAST FISHERIES CENTER
GALVESTON LABORATORY

GALVESTON, TEXAS

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Center
Galveston Laboratory
Galveston, Texas 77550

NOAA Technical Memorandum NMFS-SEFC-47

Environmental Assessment of Buccaneer Gas and Oil Field In the Northwestern Gulf of Mexico, 1975-1980.

VOL. I-INVESTIGATIONS OF SURFICIAL SEDIMENTS, SUSPENDED PARTICULATES AND VOLATILE HYDROCARBONS AT BUCCANEER GAS AND OIL FIELD

BY

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FOREWORD

Increased petroleum development of the outer continental shelf (OCS) of the United States is anticipated as the U.S. attempts to reduce its dependency on foreign petroleum supplies. To obtain information concerning the environmental consequences of such development, the Federal Government has supported major research efforts on the OCS to document environmental conditions before, during, and after oil and gas exploration, production, and transmission. Among these efforts is the Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, a project funded by the Environmental Protection Agency (EPA) through interagency agreement with the National Oceanic and Atomospheric Administration (NOAA) and managed by the National Marine Fisheries Service (NMFS), Southeast Fisheries Center (SEFC), Galveston Laboratory, in Galveston, Texas. Initiated in the autumn of 1975, the study was completed in 1980. Its major products have been annual reports disseminated by the National Technical Information Service, data files archived and disseminated by NOAA's Environmental Data and Information Service, and research papers written by participating investigators and published in scientific or technical journals. Results have also been made available through EPA/NOAA/NMFS project reviews and workshops attended by project participants, and various governmental (Federal and State), private, and public user groups. The final product are these milestone reports summarizing the findings of the major investigative components of the study.

Objectives of the project were (1) to identify and document the types and extent of biological, chemical and physical alterations of the marine ecosystem associated with Buccaneer Gas and Oil Field, (2) to determine specific pollutants, their quantity and effects, and (3) to develop the capability to describe and predict fate and effects of Buccaneer Gas and Oil Field contaminants. The project used historical and new data and included investigations both in the field and in the laboratory. A brief Pilot Study was conducted in the autumn and winter of 1975-76, followed by an extensive biological/chemical/physical survey in 1976-77 comparing the Buccaneer Gas and Oil Field area with adjacent undeveloped or control areas. In 1977-78, investigations were intensified within Buccaneer Gas and Oil Field, comparing conditions around production platforms, which release various effluents including produced brine, with those around satellite structures (well jackets) which release no effluents. In 1978-79, studies around Buccaneer Gas and Oil Field structures focused on (1) concentrations and effects of pollutants in major components of the marine ecosystem, including seawater, surficial sediments, suspended particulate matter, fouling community, bacterial community, and fishes and macro-crustaceans, (2) effects of circulation dynamics and hydrography on distribution of pollutants, and (3) mathematical modeling to describe and predict sources, fate and effects of pollutants. The final year, 1979-80, of study continued to focus on items (1) and (2) and on preparation of the milestone reports which represented the final products of this study.

This project has provided a unique opportunity for a multi-year investigation of effects of chronic, low-level contamination of a marine ecosystem associated with gas and oil production in a long-established field. In many respects, it represents a pioneering effort. It has been made possible through the cooperation of government agencies, Shell Oil Company (which owns and operates the field) and various contractors including universities and private companies. It is anticipated that the results of this project will impact in a significant way on future decisions regarding operations of gas and oil fields on the OCS.

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1976-1977	Ichthyoplankton	78-0501
1976-1977	Pelagic Fish	78-0501
1976-1977	Plankton	78-0501
1976-1977	Sessile Fauna	78-0501
1976-1977	Total Organics	78-0501
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1976-1977	Trace Metals	78-0501
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1976-1977	Drift Bottle Releases	78-0501

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Year	Data Type	NODC Accession Number
1979-1980	Data being archived, will be available in late 1980	TBA

INTRODUCTION

Location of Study Area

The area selected for study is the operational Buccaneer Gas and Oil Field located approximately 49.6 kilometers (26.8 nautical miles) south southeast of the Galveston Sea Buoy off Galveston, Texas (Figure 1). This field was selected in 1975 as the study area because: (a) the field had been in production for about 15 years, which time had allowed full development of the associated marine communities; (b) it was isolated from other fields which facilitated the selection of an unaltered area (for comparison) within a reasonable distance of the field; (c) it produced both gas and oil that represented sources of pollutants from marine petroleum extraction; (d) its location simplified logistics and reduced the cost of the research; and (e) the Texas offshore area had not been fully developed for gas and oil production but was expected to experience accelerated exploitation in the future.

Operation History of Buccaneer Field

Buccaneer Field was developed by Shell Oil Company in four offshore blocks leased in 1960 and 1968 as follows:

Year	Lease Number	Block Number	Acreage	Hectares
1960	G0709	288	2,790	1,129
1960	G0713	295	4,770	1,930
1960	G0714	296	4,501	1,821
1968	G1783	289	2,610	1,056

In development of the field, 17 structures were built; two are production platforms, two are quarters platforms, and 13 are satellite structures surrounding well jackets. Initial exploratory drilling began about mid-summer of 1960 with mobile drilling rigs. When (as the result of the exploratory drilling) proper locations for platforms were selected, the permanent production platforms were constructed.

There have been no reports of major oil spills from this field. There have been some reported losses of oil due to occasional mechanical failure of various pieces of equipment. The largest reported spill was three barrels in 1973. The reported oil spill chronology and quantity for Buccaneer Field is as follows:

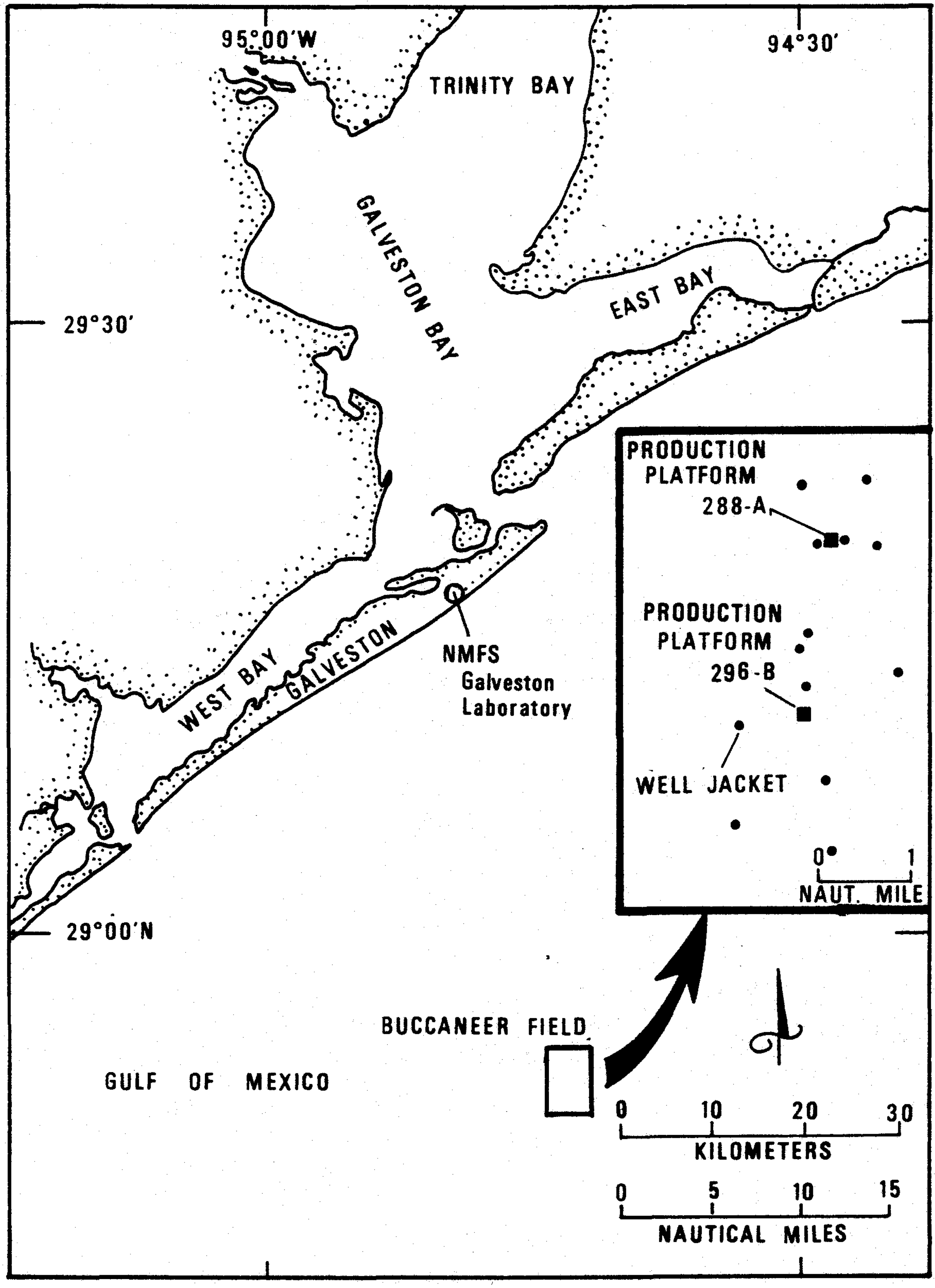

FIGURE 1. LOCATION OF BUCCANEER FIELD

Date	Source	Amount Barrels	Amount Liters
September 1973	Platform 296-B	0.5	79
November 1973	Unknown	3.0	477
July 1974	Platform 296-B	0.5	79
August 1974	Platform 296-B	1.7	265
September 1975	Platform 288-A	0.2-0.4	38-56
Totals		5.9-6.1	938-956

Buccaneer Field first began operations with the production of oil. Later, when significant quantities of gas were found, the field began producing both oil and gas and has continued to do so to date.

The production platforms and satellites (well jackets) are connected by a number of pipelines with a 50.8 centimeters (20-inch) diameter main pipeline connecting the field to shore. All of the pipelines that are 25.4 centimeters (10 inches) or greater in diameter are buried. The Blue Dolphin Pipeline Company was granted a pipeline permit (No. G1381, Blocks 288 and 296) in 1965 and has operated the pipeline since its construction.

Buccaneer Field occupies a limited area (about 59.3 km^2; 22.9 sq. statute miles) leased in the northwestern Gulf of Mexico. Four types of structures are located in Buccaneer Field: production platforms, quarters platforms, satellites (well jackets), and flare stacks. These are shown in Figure 2, which is an oblique aerial photograph of production platform 288-A and vicinity within Buccaneer Field. A map of Buccaneer Field, (Figure 3) depicts the locations of platforms and satellites within the field.

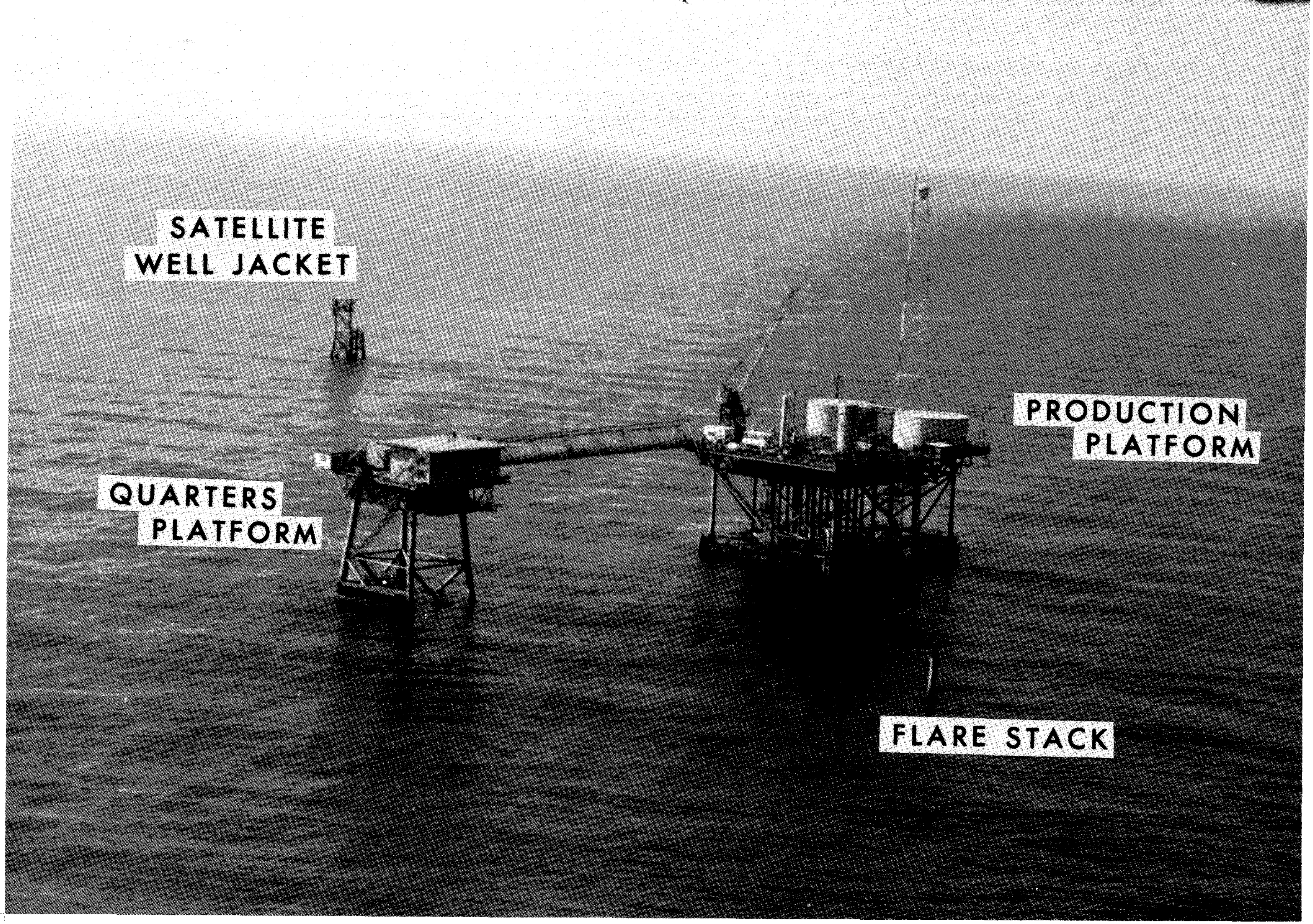

FIGURE 2. BUCCANEER FIELD STRUCTURES

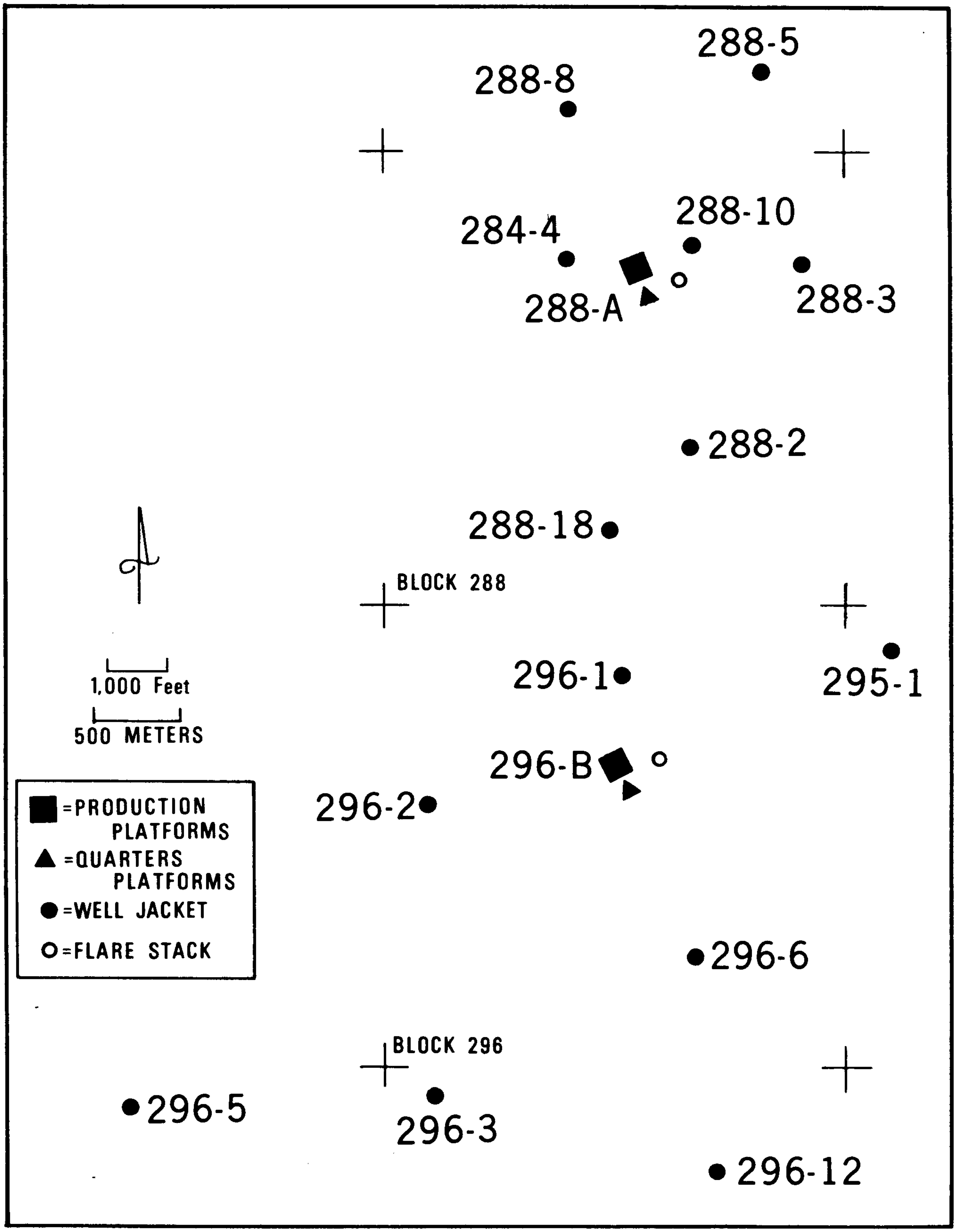

FIGURE 3. SHELL OIL COMPANY'S ALPHANUMERICAL IDENTIFICATION OF BUCCANEER GAS AND OIL FIELD STRUCTURES

WORK UNIT 2.3.2 - INVESTIGATION OF SURFICIAL SEDIMENTS, SUSPENDED PARTICULATES AND VOLATILE HYDROCARBONS AT BUCCANEER GAS AND OIL FIELD

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ABSTRACT

This report describes the results of a four-year study of the surficial sediments, suspended particulate material and volatile organic hydrocarbons around structures in the Buccaneer Gas and Oil Field in the Gulf of Mexico. Although the present investigators were responsible for only the last two years of the project, all four years of the work are summarized. More than five thousand samples were collected and analyzed during the third and fourth years of the study alone.

During the course of this study, large seasonal variations in the suspended material in the water column were observed. These seasonal differences were evident in both the concentration of total suspended matter (TSM) and in the form of the suspended material present in the water column (e.g. clay vs. plankton). The seasonal variations are directly related to several factors including: stratification of the water column, primary productivity, effect of inputs from bays and estuaries, and bottom nepheloid layers concurrent with bottom currents in the study area. These are all natural processes, and the variations in parameters observed are typical of the seasonal changes observed throughout most of the nearshore Gulf coastal area.

The Buccaneer Gas and Oil Field production platforms do not measurably alter the bulk composition of suspended particulates or biological activity (as measured by ATP and chlorophyll) in the water column in their immediate vicinity. These results can be easily explained by the fact that small brine volumes are discharged by the platform compared to the large volumes of sea water transported through the field by natural processes.

In the surficial sediments, decreasing gradients in organic and inorganic carbon away from the platforms were observed. This is the type of distribution that would be expected if a higher degree of productivity is associated with the platforms, a real possibility. Bottom sediments in the Buccaneer Field area consist generally of relict calcereous shell hash, silts and clays of the Beaumont Formation, and sands which are dominated by a strong 3.5Ø fraction.

Most sediments ranged from extremely poorly sorted to poorly sorted, with an increase in sorting with distance away from the platforms. A general decrease in sediment grain size was also found with increasing distance from the platforms. This sedimentological data indicate that there is considerable movement of fine grain material in the area. The presence of near bottom nepheloid layers, as observed by transmissometry during all seasons, confirms the conclusions of the sediment grain size analyses. The fine-grained, surficial sediments within the Buccaneer Field are probably in a continued state of resuspension and reworking. If contaminates from the production platforms were introduced into the sediments, only those contaminates associated with very coarse grained material would be expected to remain permanently in the field.

Gaseous (C_1-C_4) hydrocarbons measured in the water column in the Buccaneer Field were typical of unpolluted waters along the Texas coast. Any input of gaseous hydrocarbons in the water column seems to be rapidly diluted. The gaseous hydrocarbons in the sediment similarly showed no discernable influence due to production platforms. The methane levels seemed to be controlled mainly by sediment particle size, with highest levels associated with a high sediment clay content.

There were significant seasonal and daily variations in the concentration of gaseous and volatile liquid hydrocarbons (VLH) in the Buccaneer oil and brine. In general, one-ring aromatic compounds (e.g., benzene, toluene, ethylbenzene, xylenes) are the major hydrocarbon components in the brine discharge. Benzene, the most soluble VLH, comprised from 40 to 50 % of the volatile hydrocarbons. Taken together, the one-ring aromatics comprised 70 to 90 % of the VLH in the brine. VLH n-alkanes comprised only 2 to 10 % of the VLH in the brine. Although the concentrations of total VLH in the brine varied considerably, one-ring aromatics were always the major fraction. The average aromatic VLH concentration in the brine using our four samples was 16,600 μg/L. Assuming a mean rate of discharge of brine at 95,400 liters per day, the mean rate of discharge of VLH aromatic compounds is 1580 g per day. This compares to 191 g of high-molecular-weight n-alkanes discharged (Middleditch _et al._, 1978).

At a grid of stations between 25 and 50 meters from the brine discharge, VLH ranged from 128 to 6400 ng/L, depending on the current direction. The component composition of the VLH fraction also varied between these stations, indicating different sources of origin for various components. At Platform 288A (no brine discharge), VLH were considerably lower, ranging from 169 to 374 nl/L and consisted of either aromatics or n-alkanes. Low-molecular-weight hydrocarbons near both platforms showed a similar distribution as VLH, indicating a common source--the discharge brine.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ADP - adenosine diphosphate
AMP - adenosine monophosphate
ATP - adenosine triphosphate
BGOF - Buccaneer Gas and Oil Field
BP - before present
BT - bottom or near-bottom
°C - degrees Centigrade
c.f. - compare
chl. - chlorophyll *a*
cm - centimeter
DOC - dissolved organic carbon
dpm - disintegrations per minute
EC - energy charge
EPA - Environmental Protection Agency
g - gram
GOM - Gulf of Mexico
IR - infrared
km - kilometer
L - liter
M - molar
m - meter
MAFLA - Mississippi-Alabama-Florida
MID - mid-depth (10 meters)
min - minutes
mg - milligram
mm - millimeter
ng - nannogram (10^{-9})
nl - 10^{-9} liters
OCS - outer continental shelf
phyto - phytoplankton
Platform A - Platform 288A
Platform B - Platform 296B
POC - particulate organic carbon
POM - particulate organic matter
RPM - revolutions per minute
sec - second
SFC - surface
St. Dev. - standard deviation
TOM - total organic carbon
TSM - total suspended matter
VLH - volatile liquid hydrocarbons
yr - year

SYMBOLS

C_1-C_4 - methane through butane hydrocarbons
$<$ - less than
$>$ - greater than
$^{\circ}/_{\circ\circ}$ - per mill or parts per thousand
$\delta^{13}C$ - ratio of carbon-12 to carbon-13 relative to a standard
ϕ - Phi (unit of grain size)
μ - micro (10^{-6})

ACKNOWLEDGEMENTS

The participation, cooperation and congenial interaction of many persons are required for the successful completion of a project of this magnitude. The most arduous task was the collection of the samples for analyses. The assistance of Rick Weber, Charlie Coleman and Keith Klatt during the sampling cruises is gratefully acknowledged. Laboratory analysis of organic carbon and volatile hydrocarbons were conducted with the assistance of Guy Bodennec, Ron Pflaum, Roger Burke, and Linda G. Shilling. Robert F. Shokes provided the lead-210 dating and Charlie Coleman spent the many hours required to analyze the sedimentological parameters for each of the samples. Dr. Wen Huang of the Department of Geology at Texas A&M University made the clay minerology determinations.

Valuable discussions with other participants in the study were instrumental in understanding the implications of our results. Discussions with Brian S. Middleditch and Benny Gallaway are especially acknowledged. We also wish to thank Charles W. Caillouet, William B. Jackson and others at the National Marine Fisheries Service for their editorial comments on our reporting.

SECTION 1

INTRODUCTION

Although extensive offshore oil and gas development has occurred in the outer continental shelf (OCS) areas of Texas and Louisiana, few multidisciplinary programs have been undertaken to study the environmental consequences of such development. One of the few programs to study the effects of Gulf of Mexico petroleum development is the "Environmental Assessment of the Buccaneer Gas and Oil Field (BGOF) in the Northwestern Gulf of Mexico". This program, initiated in 1975, was funded by the Environmental Protection Agency through interagency agreement with the National Oceanic and Atmospheric Administration and managed by the National Marine Fisheries Service, Southeast Fisheries Center, Galveston Laboratory in Galveston, Texas. Objectives of the project are (1) to identify and document the types and extent of biological, chemical and physical alterations of the marine ecosystem associated with Buccaneer Field, (2) to determine specific pollutants, their quantity and effects, and (3) to develop the capability to describe and predict fate and effects of Buccaneer Field contaminantes. After a survey study initiated in 1975, four successive one year programs were undertaken to study various aspects of biology, chemistry, physics and geology at BGOF.

The BGOF program is unique in that an extended multidisciplinary study was undertaken around this isolated oil field in the northwestern Gulf of Mexico. Although the Bureau of Land Management has undertaken several large baseline studies (South Texas and MAFLA areas) along the Upper Gulf Coast, they undertook only one 1-year platform study in 1978-1979. This program surveyed a large number of platforms, principally on the Louisiana shelf, instead of concentrating efforts at one field. Most other environmental studies around the platforms have been fragmentary in that only narrow components of the environment or ecosystem have been investigated. This study provided a unique opportunity for long-term study of effects of chronic, low-level exposure of the marine ecosystem associated with an established field to various oil field associated contaminants.

This milestone report represents a summary and evaluation of four years of study at BGOF relating to surficial sediments, suspended particulates, and volatile hydrocarbons. The vast majority of this work was performed during the third and fourth years of the program by Texas A&M University. Other work efforts containing surficial and suspended sediment data summarized here include:

Behrens (1977) - total organic carbon, stable carbon isotopes, radiocarbon dates;
Anderson and Schwarzer (1977) - sediment grain size, sediment clay mineralogy, transmissometry, total suspended matter (TSM);
Anderson and Schwarzer (1979) - grain size, sediment traps; and
Danek (1980) - hydrographic measurements, transmissometry, TSM.

Gaseous and volatile hydrocarbons were measured only during the fourth year of the program by Texas A&M University. Other components of the Buccaneer Gas and Oil Field Study are dealt with in companion reports.

SECTION 2

CONCLUSIONS

Typical of most inner shelf regions, the quantity and composition of the suspended particulates in the BGOF show large spatial and temporal variations. TSM varied from ∿300μg/L to several mg/L. Near-bottom nepheloid layers were present in the BGOF during all samplings, except winter 1979 when TSM was high throughout the water column because of complete vertical mixing. The bottom nepheloid layer varied from a few meters to 10 meters in thickness. It was usually associated with a uniform temperature layer beneath a thermocline and resulted from resuspension of bottom sediments. Mid-depth nepheloid layers observed during some samplings also were associated with density surfaces in the water column. Surface nepheloid layers were observed in the spring as a result of fresh water runoff from coastal rivers, bays, and estuaries. Danek (1980) estimated an average flux of material through BGOF at about 2 gm/sec. Seasonal changes in the suspended particulate content of the water column generally reflected changing current and mixing patterns.

The composition of the suspended particulates varied considerably over the sampling periods. Clay was the dominate component of the particulates during all seasons, except summer 1979, when low TSM levels resulting from strong stratification of the water column and low turbulent mixing were accompanied by a large phytoplankton standing crop. The organic fraction of the suspended particulates consisted almost exclusively of cellular material (phytoplankton, zooplankton, and/or bacteria). Only when there was a large fresh water lense at the surface or a very high standing crop of phytoplankton were significant concentrations of particulate non-cellular carbon observed. In most seasons, the cellular material generally constituted 20 to 30 % of the suspended particulates. In summer and winter 1979, due to a dramatic increase in phytoplankton productivity, organic suspended particulates constituted as high as 78 % of the TSM. Almost all the POC during the winter 1979 sampling was phytoplankton. During other seasons, phytoplankton constituted only a minor fraction of the cellular material. Higher phytoplankton standing crops were associated with an increase in the dissolved organic concentrations in the water column by as much as 50 %. Most other DOC concentrations throughout the year were around 1.2 ± 0.2 mgC/L.

Suspended particulate data indicated that the water column was stratified during all samplings except winter. During the summer and fall samplings, a strong pycnocline resulting from temperature stratification apparently existed in the field, effectively inhibiting transport of surface introduced contaminants to the bottom. Only during the winter was the water column thoroughly mixed, due to strong turbulent activity. The stratification of the water column during the majority of the year appears to act as a barrier against introduction of platform contaminants to the sediments near the platforms. Platform derived contaminants in the water must be rapidly removed from the field.

The Buccaneer Field production platforms did not measurably alter the bulk composition of suspended particulates of biological activity (as measured by chlorophyll and ATP) in their immediate vicinity. These results can be explained by considering the small volumes discharged by the platforms (i.e., from the brine, oil spillage, etc.) compared to the large volume of water transported through the field. Pollutants introduced into the water column from the platforms could be rapidly transported out of the system either because of hydrographic conditions or perhaps by attachment to suspended particulates. Once out of the field, rapid dilution would obscure their presence and diminish their effect.

Bottom sediments in the Buccaneer Field area consist of relict calcareous shell hash, silts and clays of the Beaumont Formation, and sands which are dominated by a strong 3.50 fraction (Anderson and Schwarzer, 1977). The Buccaneer Field is a highly dynamic and passive sedimentary environment in which relict sediments are presently being redistributed across the seafloor. Sedimentology observations in the study area indicate considerable variation in textural properties which reflect scour and redeposition by bottom currents and reworking of ancient sediments. The sandy nature of the bottom sediments in the BGOF attest to the high energy bottom conditions which prevail in the field. These conditions are probably sufficient to distribute most contaminated material deposited beneath the platforms over such a large area as to be undetectable.

There was a decreasing concentration of both organic and inorganic carbon in the sediment away from the platform. The gradient reflects high productivity associated with platforms. The distribution of the carbon in surficial sediments was quite variable and showed temporal changes reflecting seasonal current patterns. Sedimentation rates in the field determined by Pb-210 and radioactive dating suggest that erosion of sediments is the dominant process. Over one meter of sediment may have been eroded near BGOF platforms.

Contaminants introduced to the sediments in the Buccaneer field may also be rapidly removed from the platform vicinity by suspension and redeposition. Surficial sediment data indicated that there is considerable movement of the fine grain material in the area. Direction of sediment transport appeared to be controlled by seasonal current patterns. The near-bottom nepheloid layer, observed during all seasons, also indicated that fine grained surficial sediments within the field were in a continual state of resuspension and reworking. Only contaminants associated with very coarse grained material would be expected to permanently remain in the field. These observations were confirmed by trace metal and hydrocarbon studies in the field which show seasonal contamination patterns.

The total amount of gaseous and volatile hydrocarbons in the brine discharged from Platform 296B is quite variable. The relative percentages of various components also changed on a daily basis. These variations were due to the fact that eleven different wells are producing in the Buccaneer Field, and the wells all discharge brine at different rates and times via Platform 296B. In general, one-ring aromatic compounds such as benzene and toluene are the major hydrocarbon components in the brine discharge. Benzene, the most soluble volatile liquid hydrocarbon, comprised 40 to 50 % of the VLH fraction, while n-alkanes comprised only 2 to 10 % of the VLH in the brine. The average mean aromatic VLH concentration (from four samplings) was 16,600 µg/L. With an average discharge rate of 94,500 liters/day, the discharge of VLH aromatics would be about 1600 g/day. This value is over eight times higher than the 191 g/day of high-molecular-weight n-alkanes discharged along with the brine (Middleditch et al., 1978).

In spite of this relatively large input of aromatic VLH compounds into the surface water at Platform 296B, the surface water VHL levels at the Buccaneer Field site are not exceptionally high, compared to other Gulf coastal areas. The VLH levels at Platform 288A, where there is no discharge of brine, are of the same order of magnitude as other near shore Gulf waters measured by Sauer (1978). From these data, it can be concluded that the VLH that is input at Platform 296B is rapidly diluted. Thus any immediate effects of VLH input from the Buccaneer Field brine discharge would not be noticed beyond the periphery of the field.

SECTION 3

RECOMMENDATIONS

Volatile liquid hydrocarbons (C_6-C_{14}) are introduced by producing platforms into marine waters from brine discharges, oil spillage, venting or flaring of gas, and volatilization during platform operations. However, in the northwest Gulf of Mexico, brine discharged into coastal waters from offshore platform operations is by far the biggest source. Since brine is produced along with oil in most operations, some quantity of liquid hydrocarbons in the oil are dissolved into the brine in concentrations depending upon their solubility. Light aromatic hydrocarbons are both the most soluble component of petroleum and the most immediately toxic. These light aromatics (e.g., benzene, toluene, xylene, ethylbenzene) are included on EPA's list of "priority pollutants" because of their high production rates and toxicities. Although these components were determined in Buccaneer Gas and Oil Field brine and oil and were measured in surrounding waters, more information is needed on their sources, sinks and concentrations in the northwest Gulf of Mexico in order to determine their ecological significance. Specifically, more information is needed on the rate of input from brine discharges into Gulf of Mexico waters, significance of minor sources of inputs, rate of volatilization under different sea state conditions, influence of suspended particles as a possible mechanism of transport to deeper water or sediments, and concentration gradients across the northwest Gulf of Mexico.

The surficial and suspended sediment studies indicated that there is considerable transport of particulate material through the field. In Buccaneer field, suspended sediment were not useful in studying the fate of platform introduced contaminants. Studies of surficial sediments in the immediate vicinity of platforms offer the best mechanism of chemically studying the fate of contaminants associated with particulate phases.

SECTION 4

BACKGROUND

4.1 PURPOSE

One objective of the suspended particulate and surficial sediment studies was to determine sediment distribution, movement, and suspension rates of the various fractions of material within the Buccaneer Field. These investigations involved: (1) sampling of surficial sediments to determine particle size distribution, mineralogy, carbonate content, organic carbon content, stable isotopes and sedimentation rates by radio-carbon and Pb-210 dating; (2) estimates of the phytoplankton standing crop via chlorophyll a; (3) estimates of living biomass via ATP and energy charge measurements; and (4) characterization of the suspended load of the water column through determination of total suspended matter, transmissometry, clay mineralogy, particle size, organic carbon, carbonate, and nutrients. A second objective was to determine if anthropogenic organic additions could be detected by organic carbon, stable isotope, or radio-carbon measurements. A third objective was to determine if the platforms were affecting planktonic biomass and viability.

Suspended sediments play an important part in transport of contaminants in an ecosystem. Platform contaminants introduced into the water column can be absorbed or adsorbed by suspended sediments (Meyers, 1976; Meyers and Quinn, 1973). Results of trace metal (Anderson and Schwarzer, 1977, 1979; Tillery, 1980) and hydrocarbon (Middleditch, 1977, 1979, 1980) studies around BGOF indicate these contaminants are concentrated in surficial sediments near the production structures. Clays are largely responsible for scavaging contaminants from seawater (Wheeler, 1977), because of their large surface/area volume ratios and their electrochemical properties. Different clay minerals and grain sizes have different sorption capacities which can influence the distribution of contaminants. The suspended particulates may also be responsible for removing BGOF contaminants from the area. Contaminants introduced into a strongly stratified water column can be adsorbed onto particles and transported out of BGOF before settling through the thermocline and contributing contaminants to surficial sediments. The movement, sedimentation, and bioturbation of surficial sediments can also control the accumulation of BGOF contaminants.

Suspended particulates found within the water column originate from terrigenous runoff, resuspension of bottom sediments, and productivity. The type and quantity of sediment discharged into the Gulf of Mexico from rivers and estuaries are controlled by precipitation and drainage rates. Other important parameters include wind speed and direction, and thermohaline wedging within coastal water bodies (Anderson and Brockstra, 1977). Once introduced into the Gulf, the transport of suspended sediment is dependent upon circulation dynamics within the region and the density stratification of the water column. Pycnoclines in the water column act as a barrier against transport of suspended particulates to the sediments. The increased eddy diffusivity across a pycnocline acts to slow the rate of settling of suspended particulates, often producing particulate maxima at these boundaries. Resuspension of bottom sediments is dependent on current speeds, sediment type, and turbulent mixing.

This study gives further insight into the origin, flux, and distribution of sediments within the Buccaneer field. An assessment of the effects of offshore structures on these sediment processes provides insight into the transport of anthropogenic compounds in the system. The information derived from this study is useful to benthic biological investigations and is important to the hydrocarbon and trace metal studies involving transport of these contaminants within the study area. This study was essential to an understanding of the ecological consequences of offshore oil/gas production since (1) suspended matter could be expected to act as a means of transport of absorbed contaminants, (2) inputs of large amounts of brines may have affected the suspended load of the water at the site, which could greatly affect the biota, (3) the presence, absence, and/or seasonality of a near-bottom nepheloid layer at the site would greatly affect the benthic community, and (4) measurements of biomass and ATP at stations in the study area established whether the brine was having any measureable adverse affect on the primary producers.

Volatile hydrocarbons (C_5-C_{14}) were measured as part of this study because the light aromatics (benzene → naphthalene) are the most immediately toxic components of petroleum (McAullife, 1977; Blumer, 1971). These compounds because of their high solubility, are concentrated in oil field brines and are not effectively removed in oil/brine separators before discharge into the ocean. Several of the light aromatics are on EPA's list of priority pollutants (e.g., benzene, toluene, and xylenes). The light hydrocarbons (C_1-C_4) were studied because they are easily measured tracers of the soluble hydrocarbons (Sauer, 1980; Brooks _et al._, 1977).

4.2 STUDY SITE

The Buccaneer Gas and Oil Field is located approximately 50 km south southeast of Galveston sea buoy (Figure 1). The field was selected because: (1) the field had been in production for about 15 years allowing for full development of oil-field-associated marine communities; (2) it is isolated from other fields; (3) it produces both oil and gas; (4) its location simplified logistics; and (5) the Texas offshore area had not been fully developed for gas and oil production. The field was developed by the Shell Oil Company in four blocks of land that were leased in 1960 and 1968. In the development of the field, 17 structures have been built; two are production platforms two are quarters platforms, and 13 are satellite structures surrounding well jackets. This study involved investigations of the two production platforms and several well jackets and flare stacks. Sampling during the first two years of the program was centered in a study area approximately 12 x 4 km in and around BGOF. Third and fourth year studies were concentrated within 300 meters of Platforms 288A and 296B.

SECTION 5

METHODS

The methods outlined below are those used primarily during the third and fourth years of the program by Texas A&M University. Methodologies used during the first two years of the program are found in Anderson and Schwarzer (1977, 1979) and Behrens (1977).

5.1 SAMPLING

Water column sampling was performed aboard the GUS III and TONYA AND JOE. Surficial sediment samples were collected by divers from LGL Limited - U.S., Inc. and by box corings. The seasonal sampling intervals (summer, fall, winter and spring) were determined by National Marine Fisheries Service and specified by the Statement of Work in the Request for Proposal. The actual sampling period was determined by the availability of the contract vessel and weather conditions. Table 1 gives the dates of the sampling periods.

5.2 WATER COLUMN

Water column samples were taken to determine total suspended matter, clay mineralogy, dissolved and particulate organic carbon, ATP, energy charge, $\delta^{13}C$ [POC], chlorophyll _a_, phaeophytin, $CaCO_3$, silicate, phosphate, nitrate, nitrite, particle size, and C_1-C_{14} hydrocarbons. Water column samples were taken using large Niskin samplers (12-L or 30-L volume).

For total suspended matter measurements, known volumes of seawater were filtered through preweighed 47-mm, 0.40 μm Nuclepore filters. After filtration, the filters were rinsed with distilled, deionized water to remove all salt and then stored in dust-free containers in a desiccator until re-weighing (see Brooks _et al._, 1980).

The continuous suspended material distribution was determined by a Martek Model XMS "In Situ" Transmissometer lowering at each station. This instrument provided a continuous profile of the suspended matter distribution from the surface to near-bottom at each station. Anderson and Schwarzer (1977) used a Hydroproducts Model 410-BR Transmissometer.

Dissolved and particulate organic carbon (DOC, POC) were determined following the method of Fredericks and Sackett (1970).

For chlorophyll and phaeophytin three hundred ml of seawater obtained from the Niskin samplers were filtered through GF/C glass filters (4.5 cm diameter). The filters were desiccated, wrapped in aluminum foil, and frozen with appropriate designations. Chlorophyll and its degradation product phaeophytin were measured using a Turner Fluorometer (Model 111) following the method as described by Yentsch and Menzel (1963) and Holm-Hansen et al. (1965).

Samples for ATP analysis were filtered onto 0.40 μm, 47-mm Nuclepore filters. Immediately after filtration the filters were placed in vials with 5 ml of boiling Tris buffer for 5 minutes. The vials with filters were labeled and frozen at -20°C until analysis. The ATP was determined by the technique of Holm-Hansen and Booth (1966) using a JRB Inc., ATP Photometer.

Samples for energy charge (EC) ratios were filtered onto 0.40 μm, 47-mm Nuclepore filters using a reduced vacuum of not more than 30 cm Hg. Just before the filter was pulled to dryness, it was removed and rapidly placed in 5 ml of boiling (100°C) Tris buffer (0.05 M, pH 7.71) for 3-5 minutes. The extract and filters were quickly frozen at 20°C for subsequent analysis. The frozen adenine nucleotide extract samples were prepared for analysis using the procedures described by Chapman et al. (1971). The mixtures were incubated at 30°C for 15 minutes and then held at 0°C until assayed using an ATP photometer by the method of Holm-Hansen and Booth (1966). ADP and AMP were determined by difference.

Samples for $CaCO_3$ determination were filtered onto 45 μm, 47-mm Nuclepore filters. Calcium carbonate was determined for the summer 1978 samples using a Craig (1953) type system. Because of the low sensitivity of this method, calcium carbonate was determined during the other seasons by acidifying the filter and flushing the CO_2 into an IR analyzer sensitized to CO_2 (Brooks et al., 1980).

Nutrient sampling involved placing unfiltered aliquots of seawater into 6 oz. Whirl-Pak plastic containers and freezing until analysis. Samples for dissolved SiO_2 were filtered through 0.45 μm glass fiber filters. Some of the more important (biologically) forms of the micronutrient elements of nitrogen, phosphorus and silicon were determined with a Technicon Autoanalyzer II. The methods of Strickland and Parsons (1972) were used in these determinations, with specific procedures as given by Technicon Instruments Corporation of Tarytown, New York, Industrial Methods No. 100-70W (NO_2 and NO_3), 161-71W/B (NO_2), 155-71W (PO_4), and 105-71W (SiO_2).

Water samples for clay mineralogy were filtered through 0.45 µm Millipore filters until the filter was clogged. After filtration was completed, each filter was rinsed with ten ml of deionized water to remove salts. The particulates were resuspended and filtered through Selas Flotronic Silver membranes (0.45 µm pore size and 25 mm diameter) for X-ray diffraction analysis. In order to obtain a complete analysis of both clay and non-clay minerals in particulates, the samples were first X-rayed without treatment and then X-rayed following various treatments with ethylene glycol or glycerol and heating (Huang, 1976). Relative percentages of clay and non-clay minerals were determined on a semi-quantitative basis, following the method as described by Huang (1975).

Carbon isotope ratios were determined on particulate organics. Filters containing known weights of particulate material were placed in ceramic or metal combustion boats and treated with dilute hydrochloric acid to eliminate inorganic carbon. After redrying the samples on a hot plate at low heat, each was combusted in a Craig (1953) type system. The stable isotopes were determined by a Nuclide Corp. sixty degree double collecting instrument (see Brooks _et al._, 1980 for greater detail).

Particle size determinations of suspended siliciclastic material in the water column were determined by optical microscopy. Gaseous hydrocarbons were determined by the methods of Brooks _et al._ (1977) and volatile hydrocarbons by Sauer _et al._ (1978).

5.3 SURFICIAL SEDIMENTS

Surficial sediments were collected by divers using one-liter wide mouth plastic jars, also by gravity or box coring. Samples were split in the laboratory for organic carbon, calcium carbonate, carbon isotope, clay mineralogy and particle size determinations. Separate cores were taken for Pb-210 dating. Those cores were taken using a lined gravity core. Samples for C_1-C_4 hydrocarbon analysis were taken in specially-fabricated jars (Bernard, 1978).

Organic carbon samples were freeze-dried and homogenized in an organic carbon-free ball mill. Accurately weighed one gram aliquots of each homogenized sample were placed in ceramic or metal boats and treated with dilute hydrochloric acid to eliminate inorganic carbon. The samples were combusted at >800°C and the CO_2 measured manometrically. Calcium carbonate was determined manometrically in a Craig-type combustion system (see Brooks _et al._, 1980).

For clay mineralogy, each sediment sample was digested in deionized water overnight to insure complete dispersion. The clay fraction (<2µm) was completely separated from the bulk sample by treating with 1 ml of 2.5 M NH_4OH (dispersing agent) prior to centrifuging for 2 minutes at 1000 RPM (Beckman 21C centrifuge with SS3 head). Two oriented clay slides were prepared for each sample by treatment with Mg-glycerate saturation and K-saturation.

To minimize any experimental variation for an estimate of relative percentages of individual clay minerals, a 35 μm clay film was prepared on ceramic tiles for X-ray diffraction analyses. Relative percentages of clay minerals were determined on a semi-quantitative basis following the technique of Huang (1975) modified after Biscaye (1965), Caroll (1970), and others. The refinement of the estimate was made through the standardization of the sample preparation, treatment and X-ray diffraction, the consideration of mass-adsorption coefficient of minerals, and the calibration with known amounts of standard clay samples.

Particle size samples collected during 1975 and 1978-80 were analyzed for particle texture using the sieve and settling tube methodology of Folk (1974). Some samples collected by Anderson and Schwarzer (1977) were also analyzed utilizing this method, while others were analyzed using a Rapid Sediment Analyzer, which determines particle size based on settling velocities. Sample median grain-size, graphic mean grain-size, sorting (inclusive graphic standard deviation), inclusive graphic skewness (measure of sample grain-size distribution asymmetry) and graphic kurtosis (measure of sample departure from a "normal" grain-size population) were determined on samples analyzed using the sieve and settling methodology of Folk. The statistical treatment of some samples collected by Anderson and Schwarzer included the computation of mean grain-size and standard deviation by the Method of Moments (Folk, 1968), while those samples analyzed using Rapid Sediment Analyzer techniques produced size-frequency output data which are not directly comparable to data obtained from the sieve and settling techniques of Folk. Stable carbon isotopes on the organic fraction of the sediment were determined after the method of Sackett _et al_. (1970).

Radio analyses of one cm sediment layers for Pb-210 specific activity ($dpm \cdot g^{-1}$) were conducted throughout the upper 20 to 50 cm of cores from six stations. Analytical procedures followed those of Shokes (1976) using low level beta spectroscopy after a strong acid leach of the sedimentary materials and a chromatographic separation of the Pb-210 from interfering isotopes. The combined precision and analytical error on the scale length of these determinations allow measurement of sedimentation rates within ±.3 $mm\ yr^{-1}$ in the past 45 to 50 years. Gaseous hydrocarbons in surficial sediments were determined after the method of Bernard (1978).

SECTION 6

RESULTS AND DISCUSSION

6.1 SUSPENDED PARTICULATES

Little was known about the composition of suspended particulates within BGOF prior to this study. Manheim et al. (1972) presented a fairly extensive survey of suspended matter in the northern Gulf of Mexico and found TSM levels greater than 1 mg/L were restricted to within 100 km offshore in Texas waters. The mineral composition of surface suspensates from the Texas region were found to consist of montmorillonite-kaolinite mixtures with montmorillonite being most abundant. One of their profiles passing very close to BGOF is presented in Figure 2. There was a sharp boundary between the Galveston Bay sediment plume and offshore waters.

Characterization of the suspended particulates was performed during the third and fourth years of study at BGOF. This will be the primary data presented in the following sections. However, Anderson and Schwarzer (1977) measured several water samples for TSM and turbidity, finding concentrations ranging from <1.0 to 17.0 mg/L. Anderson and Schwarzer (1979) obtained some suspended sediment data using sediment traps attached to the platform legs. Danek (1980) found TSM levels were generally less than 5 mg/L and frequently less than 1.0 mg/L during his study of currents and hydrography in 1978/1979.

6.1.1 Total Suspended Particulates - Transmissometry

Total suspended matter distributions in surface and near-bottom waters reflect closely the profiles obtained by transmissometry. Figures 3 and 4 show representative profiles during six seasonal samplings at Platforms 288A and 296B. There were few variations in transmittance profiles at stations taken around the platforms, indicating no observable effect of the structures on TSM levels. These profiles are typical of the Gulf shelf areas near BGOF. Variations between platforms were only observed in the fall 1978 and summer 1979 samplings (see Figures 3 and 4). The near-bottom nepheloid layer at Platform 288A which was not observed at Platform 296B can be attributed to closer proximity to shore. The difference in the depth of the mid-depth nepheloid layer in summer 1979 between the two platforms results from different thermal structures. No anomalies are present that can be related to either platform presence or brine discharge.

Figure 5 and Table 2 summarize TSM data for the six seasonal samplings during the third and fourth year. Lowest TSM concentrations were obtained in surface waters during the summer samplings, averaging between 200 and 300 μg/L. During the summer months, the Gulf shelf water is well stratified with a shallow thermocline. The low summer TSM levels result from this seasonal stability which inhibits upward flux of suspended sediment. The productivity of the Gulf surface water is also diminished during this period due to nutrient depletion in the surface layer. The low summer TSM levels are consequently reflected in low biomass values at the surface.

TSM increased dramatically in near-bottom waters in the summer samplings, probably from resuspension of sediments by bottom currents. This near-bottom nepheloid layer was very sharp and located within 2 to 3 meters of the bottom during both years. A much smaller mid-depth nepheloid layer was also observed at many of the summer stations. This mid-depth layer may be associated with primary productivity and/or accumulation of particulates at the pycnocline. The temperature profiles obtained in summer 1979 indicate the mid-depth nepheloid layer was associated with a sharp decrease in temperature.

Near-bottom TSM measurements (Table 2) were similar during both summer and fall samplings; however, a much broader nepheloid layer was observed in the fall. Fall transmission records indicate that the bottom nepheloid layer extended from the bottom (20 m) to a depth of about 10 meters (cf. 2-3 meters in the summer). This feature reflects stronger currents during this sampling period along with decreased stability of the water column, both of which would produce increased turbulent mixing. A small surface TSM maximum was observed at many of the fall stations.

Highest surface TSM concentrations and lowest transmission levels were recorded during the winter 1979 sampling. The Gulf shelf water usually overturns and thoroughly mixes after the first winter (or fall) storm lowers surface temperatures and provides sufficient wind energy to drive the mixing process. During December, deeper shelf Gulf water can have a mixed layer depth of 80-100 meters (Wiesenburg and Schink, 1978). Our data indicate that the water column in the Buccaneer field was well mixed during the winter 1979 sampling. The TSM data reflects the water column structure during this sampling. There was little to no structure in transmission records. Temperature profiles (not shown) also show a uniform surface-to-bottom structure. Nearly uniform surface and near-bottom TSM levels were observed. No significant near-bottom nepheloid layer existed during this season. The water column was homogenous, and the TSM data showed no other discernable trends.

During the winter 1980 sampling, overturn of the water column had not occurred. Temperature profiles (Figures 3 and 4) indicated that the bottom ∿5 meters of the water column was 1.5 °C warmer than the overlying water column.

Mixing of cooled surface waters had only penetrated the top 12 meters of the water column. The near-bottom warm layer contained a strong nepheloid layer from resuspension of bottom sediments by currents.

The transmission records during spring 1979 were more complex. Three distinct nepheloid layers were observed in each profile. A surface layer, containing approximately 800 μg/L of TSM, existed in the upper 5 meters of the water column. This maximum results from spring runoff. Anderson and Schwarzer (1977) reported that maximum river discharge on the Sabine, Trinity, and Brazos Rivers generally occurs from March to June. Maximum suspended sediment discharges occurred in May. Transmission levels increased from approximately 40 % to 75 % in the 5 to 8 meter depth interval indicating decreased turbidity. A small but distinct mid-depth nepheloid layer was found around 12 meters. A bottom nepheloid layer was observed in the bottom 2 to 3 meters. The highest TSM levels (∿1600 μg/L) observed during this study were at near-bottom depths during the spring.

The spring TSM distributions reflect a complex interaction of processes. The shelf water is changing from a vertically mixed system to a characteristic seasonal thermocline situation. The mid-depth nepheloid layer is probably associated with the onset of this seasonal thermocline, since sinking particles tend to congregate at density interfaces. The dramatic bottom nepheloid layer is characteristic of this area in all seasons except winter, when it is less pronounced. There is little difference in TSM composition in bottom water between fall and spring samplings (Figure 5). Also, there is no exceptional increase in organic TSM in the spring, which rules out a productivity factor causing the high TSM at the bottom. We must conclude that the bottom nepheloid layer in the spring, as in the fall, results from increased bottom turbulent mixing due to bottom currents.

In general, the TSM distributions observed at the BGOF stations are typical of the Gulf shelf region. No noticable differences between up current and down current stations were observed, at least no significant differences and none that could be attributed to the presence of the production platforms. Danek (1980), using an average TSM for August of 0.5 mg/L and 1.2 mg/L at surface and near-bottom, respectively, estimated a flux of suspended sediment of about 1.92 gm/sec per meter of water surface. Using the same procedure and TSM values for February of 0.92 mg/L (surface) and 0.9 mg/L (bottom), results in an average suspended sediment transport of about 2.86 gm/sec per meter of water surface. Consequently, an average flux of material of about 2 gm/sec per meter of water surface can be expected at the BGOF; however, this value varied considerably under storm conditions when the TSM concentration and the current meter measurements near Platform 296B indicated the currents averaged nearly 60 cm/sec and TSM values varied from 2.0 mg/L to 6.4 mg/L near the bottom. This resulted in a suspended material flux of about 40 gm/sec per meter of water surface (Danek, 1980).

6.1.2 Organic Carbon

Dissolved organic carbon (DOC) concentrations in surface and near-bottom samples showed little vertical or horizontal variations (Table 3).

DOC concentrations, throughout the year, averaged 1.2 ± 0.2 mgC/L. Winter 1979 values, however, were observed to be significantly higher than in other seasons. These winter levels were associated with higher particulate, chlorophyll, and ATP levels. The high DOC levels result from either one of two processes: resuspension of bottom sediments containing high interstitial DOC concentrations, or excretion of dissolved organics by cells associated with the much higher productivity during this period. The latter process is more probable since during this season the phytoplankton contribution to the TSM is almost 50 % (Brooks *et al.*, 1980). The phytoplankton were also distributed similarly to the DOC on a vertical basis. At Platform 288A, the bottom DOC was 8 % higher than the surface while the phytoplankton proportion of the TSM increased from 41 % at the surface to 49 % at the bottom. This relationship may be fortuitous, but there does seem to be an obvious correlation with higher phytoplankton productivity and higher DOC levels in the winter. There were also high DOC levels in the summer 1979 sampling which correlated with higher phytoplankton levels.

Particulate organic carbon (POC) levels showed significant seasonal changes. Summer and fall POC concentrations ranged from 60 to 94 μg/L (Table 4) with only slight vertical gradation. This observation is in direct contrast to the high TSM levels in the bottom waters during these seasons. The relatively uniform POC distributions compared to the variable TSM levels indicate that the high TSM levels in near-bottom waters result from resuspension of bottom sediments containing smaller percentages of organic matter than surface TSM. Thus, the bottom nepheloid layers (discussed in the previous section) are confirmed not to be of organic origin.

During winter 1979, high POC values are associated with an unstable water column, high TSM and increased biological activity. Winter 1980 POC levels were more characteristic of summer and fall values. There is little vertical gradation in POC except in the spring. Spring POC concentrations averaged 50 % higher in surface than near-bottom water. These high levels also reflect the large surface TSM layer observed during this period, a result of fresh water runoff (see previous section). In general, POC levels appeared typical of this region of the Gulf continental shelf.

6.1.3 Biological Indicators

Tables 5 and 6 present average surface and near-bottom chlorophyll *a* and ATP concentrations during the seasonal samplings at stations near Platforms 288A and 296B. Tables 7 and 8 show the particulate organic composition at these platforms. Since carbon constitutes from 40 to 50 % by weight of most marine organic materials, we used (for purposes of our calculations) a factor of 2.25 for conversion of particulate carbon into particulate organic matter (POM). For conversion of chlorophyll *a* and ATP into organic carbon, Holm-Hansen and Paerl (1972) among others have used factors of 100 and 250, respectively. Although these multipliers may vary somewhat under different environmental conditions, they are useful in examining the composition of the suspended particulates. We have used them to calculate POM values from the biological data. Chlorophyll a is used to estimate that fraction of the organic carbon which derives from the primary producers. ATP is an estimate of the living cellular material present, whether from phytoplankton, zooplankton and/or bacteria. These parameters were used to determine the suspended particulate compositions. The equations used for the calculations are given below:

$$\text{POM} = \text{POC} \times 2.25 \qquad (1)$$

$$\text{Biomass} = (\text{ATP} \times 250) \times 2.25 \qquad (2)$$

$$\text{Phyto.} = (\text{Chl } \underline{a} \times 100) \times 2.25 \qquad (3)$$

These equations were used to convert all data from organic carbon concentrations to POM data so the POM component of the TSM could be deciphered. Figures 6 through 9 are pie diagrams which depict the percentage distributions of constituents making up the TSM. Cellular material is equivalent to total biomass (equation 2), while non-cellular material is the difference between POM and biomass, if any. The phytoplankton constituent of the TSM is part of the overall biomass data but can be estimated separately by measuring chlorophyll.

Tables 7 and 8 indicate that very little particulate organic matter is non-cellular material. In most cases, cellular biomass (determined by ATP concentrations) is greater than particulate organic matter determined by POC. An exception, however, is surface water during the spring when as much as 25 % of the POC was non-cellular organics. This is consistent with the surface nepheloid layer which is characterized by high TSM and POC levels during this period. The high levels of non-cellular organics in this layer probably reflects a fresh water inflow from Galveston Bay. Such an inflow would input land plant debris as non-cellular, non-living POC. There also were measurable concentrations in surface waters of non-cellular organics during the winter 1979 and summer 1979 cruises. This could represent excretion of cellular material from the large phytoplankton communities as a result of the very high productivity and resulting inefficient assimilation.

Figures 5 through 9 indicate that during the summer and fall 1979 phytoplankton constituted a very small percentage of the total suspended particulates. Lowest chlorophyll concentrations were also observed during summer 1978 in surface waters. These low values reflect stratification of the water column during the summer months, which results in low productivity. Productivity was considerably higher in bottom waters during summer 1978. There were only small differences between surface and bottom chlorophyll levels during the fall. Winter 1979 chlorophyll concentrations were more than an order of magnitude higher than the previous two seasons. Little vertical gradation in phytoplankton biomass was observed during the winter, a result of strong vertical mixing in the water column. Figures 6 and 8 show that during the winter 1979 sampling virtually all cellular material consisted of phytoplankton, both in surface and bottom waters. Phytoplankton constituted 41 and 49 % of the particulate material in surface and bottom waters, respectively. Although there was a large standing crop in the water column during spring 1979, phytoplankton constituted only 13 and 7 % of the TSM, respectively. The spring phytoplankton population was high, but percentages are lower because of the high TSM levels. The standing crop of phytoplankton in the summer 1979 was only slightly higher than in the spring, but because of the TSM levels, phytoplankton constituted 48 and 25 % of the particulates in the surface and near-bottom waters, respectively. Phytoplankton levels were high in the winter 1980 but do not represent the bloom conditions observed the previous winter.

ATP concentrations are a measure of total cellular material. Table 6 shows that, although less pronounced, ATP concentrations show the same general trends as chlorophyll concentrations. This was expected since bacterrial and zooplankton biomass would be associated with the plankton. The cellular material (bacteria, zooplankton, and phytoplankton) generally constituted between 20 and 35 % of the total suspended particulates. However, during the winter and summer 1979 when the phytoplankton standing crop was high, cellular material consituted as much as 75 % of suspended particulates.

Energy charge ratios determined during the fourth year showed little variation with depth, distance, or direction from the platform. These measurements were in the 0.6-0.8 range which is very typical for biological populations in a stable maintenance state. Chapman _et al_. (1971) showed that maintenance of viability, but not active growth was the state of _Escherichia coli_ at an energy charge between values of 0.8 and 0.5. Energy charge values below 0.5 were imcompatible with maintenance of the minimal levels of homeostasis required for viability, and values above 0.8 were characteristic of active exponentially growing cells. When growth was stopped by exhaustion of the carbon-nutrient source in the medium, energy charge values were between 0.6 and 0.7. Chapman _et al_. (1971) also tabulated a large amount of other investigator's data which supported these general growth state/energy charge relationships, for a wide variety of both plant and animal organisms. This data showed that the energy charge values obtained during the fourth year indicated a nutrient limited environment typical of surface ocean waters.

Calcium carbonate levels were low during all seasons and represent an insignificant fraction of the TSM. Only during the fall were sufficient volumes of water filtered to determine carbonate concentrations. All $CaCO_3$ concentrations were below 0.4 % of the total suspended particulates. The carbonate observed was probably from organisms which have carbonate exoskeletons. The low values observed are thought to be typical of this region of the Gulf.

6.1.4 Nutrients

The general nutrient levels (Table 9) in BGOF measured during this study are typical of inner shelf Gulf coastal areas (Sackett and Brooks, 1978). There are no discernible relationships to either the platforms or direction from the platform. The surface-to-bottom variations that were observed result from inflow of fresh water at the surface and regeneration in the bottom water.

6.1.5 Carbon Isotopes

The carbon isotope values on particulate organic carbon determined the third year of the BGOF program ranged from -20.5 to -25.6 °/₀₀ (see Brooks _et al_., 1980 for data). Values were typical of normal Gulf of Mexico carbon isotope compositions for POC (Eadie and Jeffrey, 1973). There was little isotopic evidence for major terrestrial contributions or organic contamination from the platforms which would result in isotopically light (more negative) carbon. The $\delta^{13}C$ values were significantly more negative in bottom samples at Platform 288A during the fall than other seasons. This corresponded to a large near-bottom nepheloid layer during this season. The lighter values may result from a more terrestrial POC component from the resuspended bottom sediments.

6.1.6 Clay Mineralogy

Table 10 summarizes the seasonal changes in clay mineralogy at BGOF. The summer samples were the highest in smectite. The winter samples were highest in both illite and kaolinite and lowest in smectite concentration. The spring samples showed the illite concentration to be the highest of all. In all the samples, the quartz concentration remains fairly constant to slightly higher towards the bottom of the water column with the highest concentration in the fall.

6.1.7 Particle Size

Particle size data obtained during the third and fourth years of the BGOF program were tested statistically to determine whether any significant temporal or spacial trends existed. Included in these analyses were the delineation of significant:

1. Changes at a sampling site through time;
2. Average changes for a sampling array through time;
3. Changes with depth sample array (Platform);
4. Differences between platforms by sampling sites.

In all of the above analyses, no consistent trends were noted either temporally or spacially. The lack of correlation may be due to the impossiblity of synchronous sampling of a moving water mass or in fact a wide variability in suspended particulate material present. Table 11 lists the mean and standard deviation for suspended siliciclastic particle determinations and illustrates the variability involved.

6.2 SURFICIAL SEDIMENTS

The preliminary sediment sampling of the BGOF was performed by Harper, Scrudato, and Giam in November 1975. Based on 34 sampling stations, the surficial sediments were broadly classified as poorly sorted, fine-grained silty sands containing low concentrations of clay-sized material. It was noted that the sediments became progressively finer-grained toward the northeast within the field and that the fine-grained sand content in the BGOF ranged from 70 to 80 %.

In 1976, Anderson, Schwarzer and Clark undertook a more comprehensive investigation of a $\sim$24 km^2 area around BGOF which involved both geophysical and sedimentological aspects. Surficial sediment was obtained from 93 and 80 sampling stations in 1976/1977 and 1977/1978, respectively, within the BGOF using both grab samplers and short cores. The cores exhibited extreme bioturbation and homogenization, and the agitation of the sediment was believed to contribute to the loss of fine-grained material, as it was continually re-exposed to bottom current activity. Behrens (1977) using these same cores measured total organic carbon and carbon isotopes.

During the third (1978/1979) and fourth (1979/1980) years of the program, Texas A&M University analyzed surficial sediments along transects aligned north, east, south and west of Platforms 288A and 296B with sampling stations at 10, 25, 50 and 100 meters from the brine discharge pipe. Well jacket and flare stack samples were also collected. The mean grain size and skewness (measure of peakedness of the population distribution) were measured six times seasonally over these two years. Percent organic carbon, percent $CaCO_3$ and their respective $\delta^{13}C$ values, and clay mineralogy were determined twice yearly (winter and summer samples). Pb-210 distributions were determined from six cores within the field.

6.2.1 Subbottom Topography

Surficial sediments in many upper Gulf Coast areas are controlled by subsurface tectonic activity. The Buccaneer field is a typical Gulf Coast field producing from a trap created by a salt diapir. Anderson and Schwarzer (1977), using high resolution seismic profiling in the study area, mapped two prominent subbottom reflectors at 50 and 3 meters. These data indicated that the area does contain faults and that these features play a critical role in influencing surface sediment patterns. Figure 10 shows the contoured surface of the "Deep Reflector" indicating approximately 3 meters of structural relief over the area of the survey. The other significant feature of this map is a fault with a relief of approximately 2 meters. Sediments are displaced upward on the north. Anderson and Schwarzer (1977) estimated the rate of uplift of this dome at approximately 15 mm/1000 yrs. Although the effect of the dome's tectonic activity was not clearly visible on the shallow seismic horizon ($\sim$3 meters below the sea floor), the fault was clearly present. As such, it could exert an influence on the sediment distribution pattern. The seismic measurements in BGOF indicated that uplifting and faulting may be active tectonic processes.

6.2.2 Bathymetry

The BGOF is located in a relatively complex area topographically compared to the majority of the northern Gulf inner continental shelf. The long axis of the study area is situated parallel to the axis of a northeast-southwest trending synform (Figure 11) closed to the northeast. The synform is formed by two linear topographic highs which bound it to the north and south. Within the BGOF area, a small closed basin in the nose of the synform is situated in the eastern portion of the study area (Figure 12). The northeast corner of the study area overlaps the ridge which forms the northern flank of the synform. The remainder of the area, particularly in the vicinity of the production field, is relatively featureless lying in a "flat" area between the two linear highs. The topographic features on the shelf are no doubt relict of lower sea level stands during the late Pleistocene. There is little evidence for significant erosional/depositional processes taking place in this area today (Wheeler, 1979).

6.2.3 Sedimentology

A study area of approximately 24 km^2 (see Figure 10 for location) around BGOF was studied by Behrens (1977), and Anderson and Schwarzer (1977, 1979), in order to determine what affect, if any, platform operations were having on sediment geochemistry. Observations in the study area indicated considerable spatial variation in textural properties, which probably reflect scour and redeposition by bottom currents and reworking of ancient sediments. Figure 13 shows a facies map showing the complex geological setting that exists in the study area. In general, the field is divided into a northern portion dominated by relict Pleistocene sediments and a southern portion in which Pleistocene deposits are overlayed by a thin veneer of reworked muddy sands.

Anderson and Schwarzer (1979) characterized the dominate lithologies within the area as:

Unit 1 - a gravel-sized calcareous shell hash (mostly mollusk and bryzoan fragments) confined to the northeastern portion of the BGOF area.

Unit 2 - a fine silt and clay of the Pleistocene Beaumont Formation exposed in the northeastern part of the field. It is characterized by overcompaction, a fossil foraminiferal assemblage, and a high clay content with mean grain size higher than 7.50. This unit lies at or near the surface throughout the field and is commonly exposed in the scour zones around oil field rigs. It probably serves as a major source of clays and silts for the field area.

Unit 3 - a very coarse (0.50 to 1.50), well rounded, frosted quartz sand. This unit occurs only within the scour zones around rigs and is stratigraphically associated with the Beaumont Formation. Individual sand grains are commonly iron stained. The size, texture, mineralogy and fossil foraminifera of this sand unit suggests a high energy wave zone environment of deposition in which the Trinity River was the prime source. The Trinity River has not been an active contributor of sand to the Texas Gulf Coast since its mouth was flooded to form Galveston Bay some 3,500 years ago.

Unit 4 - a very fine (3.50), very angular quartz sand which comprises the most abundant sediment type in BGOF. All the sand facies in the BGOF are dominated by these 3.50 sands. The heavy mineral assemblage of this sand varies only slightly within the field and consists dominately of hornblende (averaging 50 %), with lesser amounts of epidote and pyroxenes (averaging 15 % each).

Figure 14, which illustrates sand/mud ratios for the BGOF suggests transport of fined-grained material. The source of at least some of the transported material is the locally exposed Pleistocene Beaumont Formation. Sediment samples taken in the vicinity of Platforms 288A and 296B generally had a higher sand-sized material content than found on the surrounding seabed and exhibited considerable variation between samples. This variability was attributed to local bottom scouring enhanced probably by current eddies introduced by the platform legs. Scour of sediments around platform piles due to current and oscillatory wave action is a well documented phenomenon (Machemhl and Abad, 1975). Obviously such scouring will seriously influence the sedimentation of contaminated particles near structures (Wheeler et al., 1978). As currents in the area have been observed with velocities in excess of 100cm/sec (Danek, 1980), erosion of consolidated silt and clay-sized material is possible, even excluding the additional velocity imparted to the water mass due to eddy formation beneath the platforms. Anderson and Schwarzer (1979) determined the depth of scouring by mapping the horizon between reworked sediments and undisturbed ancient deposits. The scour zone at both platforms was largest on the down current (southwest) side of the structures. If the Beaumont Formation surface is assumed to be horizontal in the general area of platform A, scouring was calculated to have removed approximately 50 centimeters of sediment from around the structure.

Sampling of surficial sediments between August 1978 and December 1979 was concentrated at Platforms 288A and 296B, with some samples collected at a satellite well jacket and flare stack. Figure 15 illustrates the sampling pattern employed along north, east, south, and west transects.

During summer 1978, the sediments at Platform 288A were poorly to extremely poorly sorted, with sorting being poorest to the northeast. Sedimentary material beneath the platform was relatively coarse grained and exhibited a decrease in mean grain-size with distance from the platform. There was some evidence of removal of fine-grained material by current winnowing, as evidenced by sorting and skewness. Fall 1978 data showed a major increase in particle size except to the south of the platform, indicating an intervening period of high current flow and associated winnowing of sediments, particularly to the east. Sorting values also indicated some deposition of finer-grained material to the north. Winter 1978/1979 data indicated mild erosion of the sediment along the east and west sampling traverses, with deposition to the south and at 10 m east. Data from the spring 1979 cruise indicated widespread deposition of fine-grained material near the platform with mild winnowing occurring only beneath the platform and directly to the east (see Brooks et al., 1980 for data). Summer 1979 data indicated an extreme increase in mean grain size to the immediate north and northwest of Platform 288A, with a corresponding increase in sorting. This indicates effective winnowing of the surficial sediments by current activity had occurred in these areas between spring and summer samplings.

At Platform 296B, the sampling during summer 1978 indicated the surficial sediments were coarser-grained to the east and directly beneath the platform than on the surrounding seabed (Figure 15). The sediments were very poorly sorted beneath the platform but became more highly sorted with increasing distance from the platform. Fall 1978 collections indicated particle size had decreased to the west and north, but increased to the east (Figure 16). Sorting increased to the east and west, but decreased to the north and south.

The data indicated a period of deposition of fine-grained material, particularly to the west of the platform, with winnowing of sediments being particularly effective to the immediate east and less so to the north and south.

Data from the winter cruise in 1978/1979 indicated a general period of deposition of fine-grained material occurred throughout the area (Figure 17), suggesting a period of low current velocities. Spring 1979 collection (Figure 18) suggests a period of winnowing of surficial sediments and indicates the presence of strong current activity beneath the platform. Deposition of fine-grained material was confined to the south transect, suggesting current flow in a general north to south direction, with eddy effects producing erosion beneath the platform. Summer 1979 data (Figure 19) indicated deposition of fine-grained material to the north and south, with winnowing effective beneath and to the northeast of the platform. Winter 1979/1980 data indicated continued winnowing of sediments beneath the platform and deposition of fine-grained material to the northeast.

The dynamic nature of the sediments flux at both platforms is illustrated in Table 12 , which specifies the processes active between each seasonal samplings.

6.2.4 Organic Carbon

Behrens (1977) determined the organic carbon content of surficial sediments in the general area of BGOF (Figure 20). Total organic carbon (TOC) content of the sediments in this study area ranged from less than 0.1 % to near 1.0 %. The mean of 220 analyses was 0.33 % including downcore samples. Higher TOC values over 0.4 % were found in the Beaumont Formation and in surficial sediments in two areas. One area is in the east-northeast corner of the study area. Geophysical evidence indicates this is a down-faulted block which contains muddier and less bioturbated sediment than that in the field. The other area is at the north end of the field. These higher TOC levels are associated with sediments containing higher mud/sand ratios.

Organic carbon measurements on a closely spaced grid around Platforms 288A and 296B showed a decreasing gradient away from the platforms (Figure 21 and 22). Organic carbon varied between 0.05 % to 1.23 % in the immediate vicinity of the platforms. The high TOC levels beneath the structures probably result from high organic productivity associated with the platform. Concentrations of organic platform contaminates are not sufficient to cause a measurable increase in sedimentary organic carbon (Middleditch, 1980).
A seasonal pattern in TOC levels beneath the platforms was apparent during most samplings. Summer samplings showed a fairly predominant northeast flux of organic carbon which may be a reflection of prevailing east-northeast bottom currents during the summer months (Armstrong, 1979). In this case, sediments below and surrounding the platform which are relatively high in organic carbon content were swept away and redeposited in the direction of current flow. Similar contours for the winter data indicated a southerly flux of organic carbon which agreed well with the 180° current change occurring during and lasting through the winter months (Armstrong, 1978).

Behrens (1977) also surveyed the isotopic content of total organic carbon in sediments in the BGOF region in an attempt to determine the extent of pollution by comparison to an unaltered area. The measures he used for determining the effect of oil field activity were stable carbon isotope ratios and radiocarbon ages. If pollution had occurred, it should have rendered the stable carbon isotope ratio more negative than in normal marine sediments because the stable carbon isotope ratio ($\delta^{13}C$) is commonly more negative in hydrocarbons and older sedimentary organic carbon than in modern marine organic matter. Similarly, radiocarbon ages would be anomalously old because older organic carbon would be devoid of C-14. No conclusive evidence was observed using these parameters which indicated pollution had occurred in BGOF.

The $\delta^{13}C$ values in the 217 measurements by Behrens (1977) ranged from -19 to -23°/₀₀, with the bulk of the samples between -20.0 and -21.3°/₀₀. The most negative samples consisted of Beaumont sediment with a mean $\delta^{13}C$ of -22.7. These values are consistent with determinations reported by Brooks et al. (1980). The $\delta^{13}C$ values versus organic carbon (%) were plotted for both summer 1978 and winter 1978/1979 samples collected around Platform 288A (Figure 23). The summer data points all lie within a relatively narrow range of both $\delta^{13}C$ and percent organic carbon and reflect normal open marine pelagic values (Sackett, 1964). Winter data,however, are markedly lighter in isotopic composition and show a general increase in percent organic carbon. One possible explanation for this observation is that the sediments might be receiving a greater terrestrial contribution from coastal bays and estuaries during the winter months. The $\delta^{13}C$ of terrestrial organic carbon is generally about -27°/₀₀,whereas marine values are closer to -20°/₀₀ (Wickman, 1952). An increase in the terrestrial component would tend to lower the observed $\delta^{13}C$ values.

6.2.5 Calcium Carbonate

Calcium carbonate concentrations were anomalously high beneath and near Platforms 288A and 296B. Concentrations ranged from 1.8 to over 70 %, with concentrations directly beneath the platforms ranging from 20 to 74 %. High $CaCO_3$ concentrations associated with the platforms are indicative of the high productivity in the surface waters near the structures and contributions from barnacles and other calcium containing organisms on the platform itself. Concentrations showed a decreasing gradient with distance from the platforms. As with organic carbon, the affect of seasonal current patterns was generally observed in the grids beneath the structures with concentration gradients being skewed to the north and east in summer and to the south in winter. Since most of the surficial sediment $CaCO_3$ particles consisted of shell hash with a large grain size, $CaCO_3$ patterns paralled the changing sedimentological patterns discussed for grain size (see Section 6.2.3 and Figures 24 and 25).

6.2.6 Mineralogy

Surficial sediments in BGOF were analyzed for bulk mineralogy in 1978/1979, clay mineralogy in 1976/1977 and 1978/1979, and heavy minerals in 1976/1977. Only slight trends in mineral distributions were observed with respect to season or position in the field.

The bulk analysis showed that the clay concentrations in both the summer and winter 1978 samplings were low (see Table 13 for typical bulk mineral content). There was less clay around the platforms in the winter samples than in the summer samples, reflecting greater scour of fine grained particles. The distribution of clay at structures 288A, 296B, 288-5 and 296 flare stack appeared to be random. Quartz was more abundant in the winter samples than in the summer samples, reflecting a greater sand content of the sediments. The remaining minerals are either less abundant or approximately equal. Barite was found in only one sample in 1978/1979 at stations in close proximity to the platforms. It was probably due to drilling mud contamination. The occurrence of barite near the platforms was also reported by Anderson and Schwarzer (1979). There are no definite trends in the distribution of the various minerals.

The sediment clay mineralogy from the study area is typical of clay mineral suites from the Gulf of Mexico continental shelf (Grim and Johns, 1954). Table 14 shows typical clay mineral compositions at BGOF. Smectite, an expandable clay mineral, is the most abundant clay fraction, with lesser and approximately equal amounts of illite and kaolinite. Anderson and Schwarzer (1977) found no consistent variations in the clay mineral assembleges between sediment facies, which might suggest differing source areas for the sediments. Although no definite trends in clay mineralogy were observed in BGOF, some variability existed because of the movement of fine grained material beneath the platforms. The percent of smectite was less around Platform 288A than at 296B and less in the winter than in summer samples. Smectite generally follows the same trend as organic carbon, being high beneath the platforms and decreasing away from the structure. The presence of organic matter is known to promote the formation of expandable clays such as smectite. It is conceivable that an increase in organic matter would lead to an increase in smectite. There was also a greater percentage of illite and kaolinite in the winter sediments than in the summer sediments. No relationship between non-expandable clays, such as kaolinite and illite, was found.

Anderson and Schwarzer (1977) found that samples taken from the study area generally contained less than 0.50 % by volume heavy minerals. Hornblende is the most commonly occurring mineral, averaging 50 % of the heavy mineral assemblage. Other commonly occurring heavy minerals included epidote and pyroxenes (averaging 15 % each). Results from heavy mineral analyses for the BGOF are consistent with results of Van Andel and Poole (1960) for this area of the Gulf province and Mississippi province. The former mineralogic province is believed derived from the Colorado River as well as from the Mississippi and Rio Grande Rivers (Van Andel and Poole, 1960).

6.2.7 Sedimentation Rates

Sedimentation rates were determined in BGOF by radiocarbon (Behrens, 1977) and Pb-210 dating techniques (Brooks *et al.*, 1980). The radiocarbon dates reported by Behrens (1976) were obtained on the disseminated total organic carbon in the sediments. Figure 26 shows C-14 dates as a function of depth and distance east from Platform 288A. The uppermost 4-5 cm of the cores examined had successively younger ages with distance east of the field. This indicates that erosion of the bottom had taken place in the field. The average rate of deposition of Holocene sediments based on 21 pairs of dates is 0.1 mm/yr. However, the rates decline systematically upward in the cores. The oldest Holocene sediments lying just above the Beaumont contract date at about 12,000 B.P. Two dates on the Beaumont Formation are 22,112 and 24,810 BP, which confirm that this formation is Pleistocene in age.

Erosion of sediment within BGOF can be estimated by radiocarbon dates and also by the depth of the Beaumont Formation. Using the depositional rate for the control area (Figure 26), these ages indicate that in cores 15, 152, and 1800 m east of Platform 288A, 1 m, 24 cm, and 7 cm, respectively, have been eroded. Observations of the depth of the Beaumont Formation in cores suggest that somewhat more erosion - up to 1 1/2 m - occurs locally (Behrens, 1977).

The locations of cores taken for Pb-210 dating are shown in Figure 27. The relatively low, and uniform, surface sediment Pb-210 activity among the six stations (see Figures 28 and 29) indicates a similarly uniform sedimentary composition and origin. The bulk of the materials are terrigenous and are moderately coarse-grained. Although Stations 2 and 3 have slightly higher surface values, the probable cause is an apparently greater degree of mixing in the top one or two cm at Stations 1, 5 and 6.

There is a definite trend in apparent sedimentation rates among the six stations. Stations 2, 3 and 4 on the northern (shoreward) side of the platform are characterized by lower (1.5 to 2.1 mm/yr) effective sedimentation rates than are Station 5 and 6 (3.5 and 3.7 mm/yr, respectively) on the seaward side of the platform. Station 1 sediments were apparently mixed to a degree that Pb-210 chronology was not possible. However, based on radiocarbon and particle size measurements, these Pb-210 sedimentation rates do not appear real. The absence of a surface mixed layer resulting from bioturbation may support other data which indicate the sediments are scoured and not deposited in BGOF. The lower apparent sedimentation rates in the upper part of the field may indicate greater erosion of sediment.

Available evidence indicates the BGOF is not affecting sedimentation rates. The erosion observed in the field results from coastal geologic processes not affected by BGOF.

6.3 BRINE AND OIL

6.3.1 Particulate and Dissolved Characterization

Table 15 shows particulate and dissolved measurements on four brine samples collected from Platform 296B directly from the brine outfall and processed in the field. There was considerable variability in all measured parameters, both daily and monthly. TSM levels ranged from 76 to 529 mg/L, a level about three orders of magnitude above seawater levels. However, because of the small volume of brine discharged compared against the transport of water through the field, elevated TSM levels are not observed in the water column. The higher organic carbon levels observed in the brine are typical of oil-related produced brine (Collins, 1975). ATP levels were negligible in the brine samples indicating little bacterial biomass. Nutrient levels were elevated for silicate and nitrate and about seawater levels for phosphate and nitrite.

6.3.2 Light Hydrocarbons in Oil and Discharge Brine

Tables 16 and 17 show data for gaseous and volatile hydrocarbon concentrations in brine discharge from Platform 296B. These hydrocarbons are found in high concentrations in the brine since it is in contact with petroleum both in the reservoir and as it rises in the well stem. Since C_1-C_{14} hydrocarbons, and particularly the light aromatics, are the most soluble components of petroleum, they are found in very much larger concentrations in the brine than are heavy hydrocarbons. For example, benzene is at least 5 or 6 orders of magnitutude more soluble in brine than the heavy hydrocarbon octadecane (C_{18}). The decreasing concentrations with increasing molecular weight for methane through pentane in the brine (Table 16) can be attributed to decreasing solubilities. The opposite trend observed for C_1-C_5 hydrocarbons in the oil is a result of increasing C_1-C_5 solubilities in oil with increasing molecular weight. Tables 16 to 18 indicate, as did the particulate characterization of the brine (Table 15), that there is much variation, both daily and seasonally, in the concentration of all components in both brine and oil.

The data in Table 17 and Figures 30 and 31 indicate that one-ring aromatics (e.g., benzene, toluene, ethylbenzene, xylenes) are the major components in the brine discharge. Benzene, the most soluble VLH, comprised from 40 to 50 % of the volatile hydrocarbons. Toluene concentrations were about half the benzene values, with decreasing amounts of the higher molecular weight, one-ring aromatics. The one-ring aromatics comprised 70 to 90 % of the VLH in the brine. VLH n-alkanes comprised only 2 to 10 % of the VLH in the brine. Although the concentrations of total VLH in the brine varied considerably, one-ring aromatics were always the major fraction. Higher amounts of VLH in the 8 January 1980 brine sample were probably the result of more dispersed oil in the sample. The average aromatic VLH concentration in the brine using our four samples was 16,600 μg/L. Assuming a mean rate of discharge of brine at 95,400 liters per day (Middleditch et al., 1978), the mean rate of discharge of VLH aromatic compounds is 1580 g per day. This compares to 191 g of high-molecular-weight n-alkanes discharged (Middleditch et al., 1978). This input rate should be noted well, since benzene and toluene are priority pollutants.

An examination of the data in Table 18 and Figure 32 indicates that the VLH in oil are dominated by n-alkanes. Relative to the n-alkanes, few light aromatic compounds are present in the oil. This is typical of most oils. The n-alkanes comprised 30 to 40 % of the VLH fraction in oil while the aromatics only comprised a few percent. These values are not unusual for Gulf of Mexico oils. The percentages of alkanes and aromatic compounds in oils results from selectivity during the maturation process which produces petroleum (see, for example, Hunt, 1978).

6.4 GASEOUS AND VOLATILE HYDROCARBONS IN THE WATER AND SEDIMENTS

6.4.1 Gaseous Hydrocarbons

Gaseous (C_1-C_4) hydrocarbons found in Gulf of Mexico waters and sediments originate from natural and anthropogenic sources (i.e., man-derived). Natural sources include *in situ* production (probably limited to anaerobic environments either within the sedimentary column or inside large suspended particles), oil and gas seepage, air-sea exchange, and terrestrial runoff. Anthropogenic sources include offshore petroleum production, transportation activities, and coastal refineries (Brooks et al., 1977). Brooks et al. (1977) have shown that light hydrocarbons are excellent tracers of man-derived hydrocarbon inputs along the Gulf coast. Gaseous and volatile hydrocarbon inputs from offshore platforms result from the underwater venting of waste gas, brine discharge, and oil spillage. The underwater venting of gas and brine discharges have increased gaseous hydrocarbon levels by several orders of magnitude across the entire Louisiana Shelf (Brooks et al., 1977). Oil spillage is a minor source of gaseous hydrocarbons to Gulf waters. The Texas coast is relatively 'clean' with respect to gaseous hydrocarbons. In these uncontaminated areas, gaseous hydrocarbon levels are controlled by air-sea exchange and *in situ* production.

Gaseous hydrocarbons measured in the water column in the Buccaneer field were typical of unpolluted waters along the Texas coast. Since no underwater venting of gas is occurring in Buccaneer field, the only major source of anthropogenic gaseous hydrocarbons is from the discharge of oil field brine. Although methane concentrations in the brine were 3-4 orders of magnitude greater than in the water column, only a few surface samples taken in a grid around Platform 296B showed elevated levels of C_1-C_4 hydrocarbons. Ethane and propane levels showed trends similar to methane. The highest concentrations observed were 302 nl/L, 23 nl/L, and 5 nl/L for methane, ethane, and propane, respectively. Normal surface values around the platforms varied from approximately 150-200 nl/L, 1-3 nl/L, and <1 to 1 nl/L for methane, ethane, and propane, respectively, which are typical of Texas coastal waters. Gaseous hydrocarbon levels in Buccaneer Field were generally indicative of a relatively 'clean' hydrocarbon environment. Brine discharges were apparently diluted rapidly by the large volume of water moving through the BGOF area, such that elevated gaseous hydrocarbon levels were not observed.

Surficial sediment methane levels are controlled by the level of organic carbon, proximity of the aerobic/anaerobic boundary, and seepage from subsurface hydrocarbon accumulations (Bernard, 1978). Methane levels in Buccaneer field ranged from 0.01 to 9.5 ml/L. No discernable pattern was observed in transects north, east, south, and west of Platforms 288A and 296B. The levels were controlled mainly by particle size. Highest levels were found in sediment with a high clay content, with lowest levels in sandy and shelly sediments. Ethane and propane showed patterns similar to methane. No discernable difference was observed between platforms.

6.4.2 Water Column Volatile Hydrocarbons

Since the volatile liquid hydrocarbon (VLH) fraction contains the most immediately toxic components of petroleum, the light aromatic compounds (e.g., benzene, toluene, xylene, ethylbenzene, trimethylbenzene), the high toxicity of VLH could have special importance for organisms and might have an influence on the biological effects observed beneath the Platform 296B brine discharge legs. By the fourth year of this project, we had developed the capability to measure the volatile hydrocarbon fraction of petroleum and, being considered important, it was added to our program during that final year. It was shown in the previous section that an average of 1580 g of VLH are introduced into the surface waters from the production platforms each day and that 70 to 90 % of the VLH is aromatics. Thus, in our VLH study, special attention was given to the light aromatic fraction.

The effect that a 1580 g/day input of VLH with the brine will have on the BGOF site depends on the dispersion of the VLH after input. To examine the distribution patterns of VLH in the water column, surface water samples were taken in a grid around Platform 296B, from which brine is discharged. A comparison control grid was sampled around Platform 288A, where no brine is discharged (see Table 19). The grid study around Platform 296B was performed twice, with no obvious seasonal variation. The data for the 25 meter and 50 meter sampling stations are given in Tables 20 and 21. An additional attempt was made to estimate the dispersion and dilution of the VLH introduced with the brine by examining the downcurrent plume associated with the brine input at Platform 296B. The results of this one day plume study are shown in Table 22.

The control grid sampled around Platform 288A (Table 19) showed very few trends which could be related to the presence of the platform. Benzene levels were fairly constant throughout the grid while toluene and xylene levels were slightly elevated to the north, relative to the other directions. Total volatile levels were actually higher to the north of Platform 288A, with the majority of the VLH being aromatic compounds. The percent aromatics ranged from 68 % to the south to 91 % to the north. These high percentages of organics compare favorably with the 70 to 90 % aromatics found in the VLH from the brine discharged at Platform 296B and are typical of aromatic percentages reported by Sauer (1978) for several near shore Gulf stations in 1977. Also, the total volatile levels around this platform fall in the same range for levels of VLH measured in those near coastal stations (Sauer, 1978).

The VLH levels at this control site were generally an order of magnitude lower than at production Platform 296B, where brine is being actively discharged (Tables 20 and 21). At Platform 296B, the total volatile concentration under the brine discharge was 65,000 ng/L, about 20 times the highest levels recorded at 25 meters from the discharge. The grid stations taken at 25 and 50 meter distances indicate that the input brine probably has a complicated flow pattern away from the platform. At the 25 meter stations the highest concentrations found were to the north and west, while at the 50 meter stations the highest values were to the south and west. The prevailing current of the sampling day was to the north or northwest, which probably accounts for the higher values recorded there. Also, the brine discharge pipe is on the west side of the platform and its location probably influences the lower values of the east side, due both to the increased distance from the input source and the inhibitory effect of the platform on advective current flow.

In an attempt to evaluate the advective, current-related mixing processes on the VLH input, a set of samples was taken at 5 meter intervals for 30 meters down current from the brine discharge. Since the predominant current flow was to the north and west, and since the brine discharge pipe is on the west side of the platform, this transect extended under the platform itself. The results of this plume study (Table 22) were not conclusive. The samples taken 20 and 25 meters from the discharge actually have higher VLH levels than the samples taken 5 to 15 meters from the discharge. It is possible that, since the 5 to 15 meter samples were taken under the platform, some of the discharge flow is diverted around the platform or, more likely, that the presence of the platform legs inhibited our ability to sample exactly in the discharge plume during this sampling effort. Once free of the platform, however, the plume was found again and the higher concentration samples were obtained.

From the data in Tables 19 to 22, it can be seen that there is very rapid dilution of the VLH in the outfall brine as it enters the surface waters of the Buccaneer Field. The concentrations of VLH in the surface waters below the platform are four orders of magnitude lower than the VLH levels in the discharge brine itself. The VLH levels are diluted another twenty times within a distance of 25 meters from the discharge, and more with increasing distance from the platform. A comparison of the control platform with the brine discharge platform indicates that the VLH levels at Platform 288A are an order of magnitude lower. The VLH observed at Platform 288A may have come from the discharge at Platform 296B. If this is the case, then the VLH introduced with the brine probably have no significant effects outside of the field itself, since the VLH levels found at Platform 288A are not significantly higher than in other coastal waters along the Gulf.

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TABLE 1. WATER COLUMN AND SURFICIAL SEDIMENT SAMPLING PERIODS

Season	Dates
Water Column	
Summer	17-19 August 1978
Fall	29-31 October 1978
Winter	18-20 February 1979
Spring	28-30 May 1979
Summer	21-22 August 1979
Winter	7-8 January 1980
Sediments	
Summer	31 August 1978
Fall	1 September 1978
Winter	18-19 December 1978
Spring	May 1979
Summer	14 August 1979
Winter	8 December 1979

TABLE 2. SUMMARY OF TOTAL SUSPENDED PARTICULATE DISTRIBUTIONS

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Summer 1978[1]	321 ± 159	1266 ± 1006	288 ± 138	-	530 ± 366
Fall 1978[1]	781 ± 281	1015 ± 394	388 ± 119	-	661 ± 231
Winter 1979[1]	929 ± 267	865 ± 131	1008 ± 221	-	1075 ± 239
Spring 1979[1]	874 ± 310	1790 ± 738	814 ± 187	-	1554 ± 260
Summer 1979[2]	-	-	233 ± 61	219 ± 61	323 ± 275
Winter 1980[2]	-	-	481 ± 128	396 ± 129	1529 ± 3214

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Each number represents mean or standard deviation of 20 stations near each platform.

Concentrations in μg/L.

TABLE 3. SUMMARY OF DISSOLVED ORGANIC CARBON CONCENTRATIONS

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Summer 1978[1]	1.33 ± 0.24	1.23 ± 0.16	1.38 ± 0.11	-	1.34 ± 0.14
Fall 1978[1]	1.20 ± 0.17	1.14 ± 0.20	1.14 ± 0.11	-	1.15 ± 0.08
Winter 1979[1]	1.71 ± 0.09	1.84 ± 0.19	1.80 ± 0.31	-	1.82 ± 0.23
Spring 1979[1]	1.15 ± 0.12	0.97 ± 0.10	1.30 ± 0.16	-	1.01 ± 0.09
Summer 1979[2]	-	-	1.94 ± 0.58	1.65 ± 0.20	1.78 ± 0.18
Winter 1980[2]	-	-	1.61 ± 0.37	1.38 ± 0.15	1.31 ± 0.15

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Each number represents mean or standard deviation of 20 stations near each platform.

Concentrations in mgC/L.

TABLE 4. SUMMARY OF PARTICULATE ORGANIC CARBON CONCENTRATIONS

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Summer 1978[1]	65 ± 8	86 ± 21	63 ± 14	-	75 ± 9
Fall 1978[1]	66 ± 8	72 ± 11	65 ± 10	-	67 ± 11
Winter 1979[1]	187 ± 17	191 ± 11	156 ± 32	-	161 ± 25
Spring 1979[1]	166 ± 42	106 ± 44	150 ± 24	-	96 ± 11
Summer 1979[2]	-	-	80 ± 12	78 ± 14	94 ± 20
Winter 1980[2]	-	-	92 ± 24	79 ± 17	92 ± 21

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Each number represents mean or standard deviation of 20 stations near each platform.

Concentrations in μgC/L.

TABLE 5. SUMMARY OF CHLOROPHYLL *A* DISTIBUTIONS

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Summer 1978[1]	0.068 ± 0.022	0.195 ± 0.189	0.059 ± 0.016	-	0.125 ± 0.038
Fall 1978[1]	0.114 ± 0.028	0.129 ± 0.026	0.097 ± 0.026	-	0.119 ± 0.022
Winter 1979[1]	1.729 ± 0.208	1.872 ± 0.307	1.883 ± 0.469	-	1.883 ± 0.469
Spring 1979[1]	0.491 ± 0.214	0.557 ± 0.068	0.389 ± 0.152	-	0.499 ± 0.131
Summer 1979[2]	-	-	0.498 ± 0.186	0.36 ± 0.105	0.358 ± 0.125
Winter 1980[2]	-	-	0.573 ± 0.092	0.413± 0.138	0.449 ± 0.104

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Each number represents mean or standard deviation of 20 stations near each platform.

Concentrations in mg/m^3.

TABLE 6. SUMMARY OF ADENOSINE TRIPHOSPHATE DISTRIBUTIONS

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Summer 1978[1]	349 ± 201	493 ± 239	552 ± 336	–	806 ± 368
Fall 1978[1]	288 ± 126	339 ± 154	302 ± 151	–	301 ± 122
Winter 1979[1]	644 ± 212	791 ± 263	749 ± 196	–	793 ± 194
Spring 1979[1]	537 ± 155	553 ± 238	532 ± 363	–	380 ± 224
Summer 1979[2]	–	–	301 ± 140	375 ± 185	416 ± 248
Winter 1980[2]	–	–	487 ± 473	334 ± 216	354 ± 203

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Each number represents mean or standard deviation of 20 stations near each platform.

Concentrations in ng/L.

TABLE 7. PARTICULATE ORGANIC COMPOSITION AT PLATFORM 288A

Season	Depth	TSM[2] (μg/L)	POM[3] (μg/L)	Biomass[3,4] (μg/L)	Phytoplankton[3,5] (μg/L)
Summer[1]	SFC	321	146	196	14
	BT	1266	194	277	43
Fall[1]	SFC	781	148	162	25
	BT	1015	162	189	27
Winter[1]	SFC	929	420	373	387
	BT	865	429	445	420
Spring[1]	SFC	874	373	301	110
	BT	1790	238	310	126

[1] Compositions represent averages of 13 stations near Platform A.

[2] See Table 1.

[3] Carbon concentrations (Table 2) multiplied by 2.25 to convert to particulate organic matter.

[4] ATP concentrations (Table 5) times 250 to convert to biomass C.

[5] Chlorophyll concentrations (Table 3) times 100 to convert to phytoplankton C.

TABLE 8. PARTICULATE ORGANIC COMPOSITION AT PLATFORM 296B

Season	Depth	TSM[3] (µg/L)	POM[4] (µg/L)	Biomass [4,5] (µg/L)	Phytoplankton [4,6] (µg/L)
Summer 1978[1]	SFC	288	141	310	14
	BT	530	168	454	27
Fall 1978[1]	SFC	338	146	171	23
	BT	661	150	169	27
Winter 1979[1]	SFC	1008	351	421	423
	BT	1075	362	445	423
Spring 1979[1]	SFC	814	447	299	90
	BT	1554	216	214	113
Summer 1979[2]	SFC	233	180	169	112
	MID	219	175	211	81
	BT	323	210	234	81
Winter 1980[2]	SFC	481	207	274	129
	MID	396	178	188	93
	BT	1529	207	199	101

[1] Compositions represent averages of 13 stations near Platform B.

[2] Compositions represent averages of 20 stations near Platform B.

[3] See Table 1.

[4] Carbon concentrations (Table 3) multiplied by 2.25 to convert to particulate organic matter.

[5] ATP concentrations (Table 5) times 250 to convert to biomass C.

[6] Chlorophyll concentrations (Table 4) times 100 to convert to phytoplankton C.

TABLE 9. SUMMARY OF NUTRIENT CONCENTRATIONS[1]

Season	Platform A		Platform B		
	Surface	Bottom	Surface	Mid	Bottom
Phosphate[2]					
Summer 1978	0.31 ± 0.03	0.32 ± 0.05	0.29 ± 0.12	-	0.32 ± 0.10
Fall 1978	0.52 ± 0.05	0.55 ± 0.05	0.59 ± 0.06	-	0.55 ± 0.42
Winter 1979	0.39 ± 0.02	0.40 ± 0.02	0.39 ± 0.02	-	0.38 ± 0.02
Spring 1979	0.30 ± 0.05	0.36 ± 0.04	0.38 ± 0.04	-	0.39 ± 0.04
Summer 1979	-	-	0.19 ± 0.04	0.19 ± 0.03	0.29 ± 0.06
Winter 1980	-	-	0.28 ± 0.04	0.27 ± 0.04	0.34 ± 0.07
Nitrate[2]					
Summer 1978	0.31 ± 0.05	0.31 ± 0.05	0.23 ± 0.03	-	0.25 ± 0.02
Fall 1978	0.38 ± 0.06	0.40 ± 0.09	0.36 ± 0.11	-	0.34 ± 0.04
Winter 1979	0.34 ± 0.03	0.34 ± 0.03	0.32 ± 0.03	-	0.32 ± 0.03
Spring 1979	2.73 ± 0.32	1.74 ± 0.05	3.03 ± 0.85	-	1.59 ± 0.20
Summer 1979	-	-	0.79 ± 0.14	0.68 ± 0.13	1.44 ± 0.43
Winter 1980	-	-	1.40 ± 0.07	1.48 ± 0.09	2.20 ± 0.53
Silicate[2]					
Summer 1978	2.53 ± 0.07	3.26 ± 0.52	2.00 ± 0.31	-	2.58 ± 0.41
Fall 1978	5.23 ± 0.20	5.35 ± 0.16	5.04 ± 0.32	-	4.94 ± 0.55
Winter 1979	1.25 ± 0.05	1.25 ± 0.05	1.15 ± 0.05	-	1.15 ± 0.05
Spring 1979	4.75 ± 2.54	13.06 ± 0.35	4.57 ± 0.45	-	11.99 ± 2.98
Summer 1979	-	-	1.91 ± 0.29	1.91 ± 0.31	4.62 ± 2.14
Winter 1980	-	-	0.92 ± 0.14	1.60 ± 0.33	3.76 ± 2.08

[1] Each number represents mean or standard deviation of 13 stations near each platform.

[2] Concentrations in μM.

TABLE 10. CLAY MINERAL COMPOSITION IN WATER COLUMN[1]

Season	Smectite (%)	Illite (%)	Kaolinite (%)	Quartz (%)
Summer 1978	62	4	7	27
Fall 1978	36	5	10	49
Winter 1979	3	39	38	20
Spring 1979	16	55	7	21

[1] Numbers represent average of at least 16 samples from each season taken at surface and near-bottom depths near Platforms 288A and 296B. Values are percent of total clay.

TABLE 11. SUMMARY OF SUSPENDED SEDIMENTS--SILICICLASTIC FRACTION

Season		Median	Mean	St. Dev.	Skewness	Kurtosis
PLATFORM 288A						
Fall, 1978	Surf.	8.21±2.76	8.05±2.70	0.76±0.30	-0.34±0.24	0.89±0.32
	Bottom	6.70±4.31	6.52±4.19	0.63±0.44	-0.33±0.28	0.74±0.49
Winter, 1978	Surf.	8.58±0.28	8.61±0.23	0.81±0.19	0.00±0.16	0.99±0.27
	Bottom	8.67±0.36	8.69±0.20	0.77±0.08	-0.03±0.26	0.95±0.18
Spring, 1979	Surf.	9.26±0.16	9.09±0.13	0.66±0.09	-0.21±0.13	0.84±0.14
	Bottom	8.64±0.29	8.69±0.21	0.68±0.04	-0.05±0.10	0.97±0.20
PLATFORM 296B						
Fall, 1978	Surf.	6.31±4.15	6.30±4.14	0.59±0.39	-0.09±0.19	0.58±0.39
	Bottom	3.46±4.40	3.41±4.33	0.36±0.50	-0.09±0.15	0.38±0.50
Winter, 1978	Surf.	8.27±2.64	8.16±2.59	0.73±0.27	-0.29±0.26	1.00±0.60
	Bottom	8.84±0.56	8.73±0.47	0.83±0.15	-026±0.27	1.23±0.46
Spring, 1979	Surf.	9.01±0.21	8.93±0.13	0.72±0.07	-0.21±0.18	0.91±0.20
	Bottom	8.46±0.19	8.56±0.17	0.75±0.12	-0.10±0.12	1.09±0.24
Summer, 1979	Surf.	9.29±0.22	9.09±0.14	0.72±0.08	-0.04±0.18	0.91±0.16
	Mid.	9.20±0.24	9.05±0.16	0.73±0.07	-0.36±0.18	0.96±0.18
	Bottom	9.13±0.33	9.00±0.24	0.73±0.08	-0.32±0.17	0.89±0.15
Winter, 1980	Surf.	8.82±2.03	8.67±1.99	0.58±0.17	-0.42±0.15	0.95±0.36
	Mid.	8.71±2.12	8.55±2.07	0.63±0.17	-0.36±0.26	0.94±0.32
	Bottom	9.04±0.38	8.92±0.24	0.68±0.29	-0.31±0.25	0.88±0.14

MEDIAN--Median particle size, in Phi
MEAN--Graphic mean particle size, in Phi units
ST. DEV.--Inclusive graphic standard deviation, in Phi units (Sorting)
SKEWNESS--Inclusive graphic skewness
KURTOSIS--Inclusive graphic kurtosis

TABLE 12. SURFICIAL SEDIMENT VARIATIONS THROUGH TIME AT PLATFORMS 288A AND 296B

Platform 288A	
Summer to Fall 1978	Active current activity - winnowing effect
Fall to Winter 1978	Mild winnowing by currents
Winter to Spring 1979	Deposition of fine-grained material
Spring to Summer 1979	Winnowing of sediments by currents
Summer to Winter 1979	No data collected
Platform 296B	
Summer to Fall 1978	Winnowing to east; deposition to west
Fall to Winter 1978	Deposition of fine-grained material
Winter to Spring 1979	Deposition to south and east, winnowing beneath platform
Spring to Summer 1979	Deposition beneath platform and to north and south; Erosion occurring to east
Summer to Winter 1979	Extreme winnowing beneath platform, deposition of fine-grained material to northeast

TABLE 13. BULK MINERALOGY IN SEDIMENTS, SUMMER, 1978

Platform	Location	Halite (%)	Quartz (%)	Feldspars (%)	Plagioclase (%)	Calcite (%)	Dolomite (%)	Total of Clay Minerals (%)	Barite (%)
288A	10 M.N.	3.0	38.0	3.0	5.0	19.0	0.0	32.0	0.0
288A	25 M.N.	2.0	50.0	5.0	7.0	2.0	2.0	39.0	0.0
288A	50 M.N.	2.0	38.0	4.0	10.0	4.0	1.0	41.0	0.0
288A	10 M.E.	1.0	42.0	8.0	9.0	3.0	1.0	36.0	0.0
288A	25 M.E.	3.0	41.0	7.0	7.0	4.0	2.0	36.0	0.0
288A	50 M.E.	2.0	43.0	13.0	10.0	3.0	1.0	28.0	0.0
288A	10 M.S.	2.0	39.0	30.0	6.0	1.0	1.0	21.0	0.0
288A	25 M.S.	2.0	47.0	4.0	6.0	2.0	0.0	39.0	0.0
288A	50 M.S.	2.0	40.0	4.0	19.0	2.0	1.0	32.0	0.0
288A	10 M.W.	3.0	41.0	8.0	5.0	4.0	1.0	38.0	0.0
288A	25 M.W.	2.0	56.0	8.0	9.0	2.0	1.0	22.0	0.0
288A	50 M.W.	2.0	56.0	4.0	8.0	3.0	1.0	26.0	0.0
288A	288WJ[1]	3.0	41.0	3.0	6.0	7.0	0.0	37.0	0.0
288A	0	2.0	65.0	1.0	6.0	3.0	0.0	23.0	0.0
296B	10 M.N.	9.0	14.0	6.0	3.0	24.0	0.0	44.0	0.0
296B	25 M.N.	1.0	48.0	7.0	6.0	2.0	1.0	35.0	0.0
296B	50 M.N.	1.0	64.0	6.0	9.0	1.0	1.0	18.0	0.0
296B	10 M.E.	3.0	58.0	16.0	8.0	3.0	0.0	12.0	0.0
296B	25 M.E.	5.0	57.0	6.0	3.0	4.0	0.0	20.0	5.0
296B	50 M.E.	2.0	48.0	8.0	14.0	2.0	1.0	27.0	0.0
296B	10 M.S.	3.0	47.0	11.0	7.0	4.0	2.0	26.0	0.0
296B	25 M.S.	1.0	44.0	18.0	10.0	1.0	1.0	25.0	0.0
296B	50 M.S.	1.0	53.0	11.0	9.0	1.0	0.0	25.0	0.0
296B	10 M.W.	3.0	41.0	10.0	6.0	1.0	1.0	38.0	0.0
296B	25 M.W.	3.0	66.0	4.0	7.0	1.0	0.0	19.0	0.0
296B	50 M.W.	1.0	40.0	5.0	6.0	1.0	0.0	47.0	0.0
296B	0	0.0	64.0	10.0	8.0	4.0	2.0	12.0	0.0
296B	296-FS[2]	0.0	69.0	5.0	2.0	2.0	0.0	22.0	0.0

---

[1] Well jacket

[2] Flare stack

TABLE 14. CLAY MINERALOGY IN SEDIMENTS, SUMMER 1978

Platform	Location	Smectite (%)	Illite (%)	Kaolinite (%)
288A	10 M.N.	45.0	35.0	20.0
288A	25 M.N.	37.0	25.0	38.0
288A	50 M.N.	37.0	28.0	35.0
288A	10 M.E.	50.0	23.0	27.0
288A	25 M.E.	55.0	21.0	24.0
288A	50 M.E.	39.0	29.0	32.0
288A	10 M.S.	69.0	17.0	14.0
288A	25 M.S.	48.0	24.0	28.0
288A	50 M.S.	66.0	16.0	18.0
288A	10 M.W.	51.0	23.0	26.0
288A	25 M.W.	57.0	17.0	26.0
288A	50 M.W.	46.0	36.0	18.0
288A	288WJ[1]	54.0	26.0	20.0
288A	0	61.0	23.0	16.0
296B	10 M.N.	52.0	26.0	22.0
296B	25 M.N.	46.0	36.0	18.0
296B	50 M.N.	51.0	22.0	27.0
296B	10 M.E.	67.0	15.0	18.0
296B	25 M.E.	53.0	27.0	20.0
296B	50 M.E.	72.0	14.0	14.0
296B	10 M.S.	61.0	16.0	23.0
296B	25 M.S.	71.0	15.0	14.0
296B	50 M.S.	57.0	21.0	22.0
296B	10 M.W.	78.0	11.0	11.0
296B	25 M.W.	62.0	25.0	13.0
296B	50 M.W.	65.0	19.0	17.0
296B	0	49.0	30.0	21.0
296B	296-FS[2]	56.0	27.0	17.0

[1] Well Jackett; [2] Flare Stack

TABLE 15. CONCENTRATIONS OF SELECTED PARAMETERS IN BUCCANEER GAS AND OIL FIELD PLATFORM 296B BRINE

	Brine #1[1]	Brine #2[2]	Brine #3[3]	Brine #4[4]
TSM (mg/L)	130	529	158	76
DOC (mgC/L)	41.4	34.4	29.4	32.9
POC (mgC/L)	7.44	1.20	1.37	1.65
ATP (ng/L)	4	9	6	6
$CaCO_3$ (μg/L)	92	86	97	74
SiO_2 (μM)	972	890	657	324
Phosphate (μM)	0.42	0.68	0.76	0.85
Nitrate (μM)	3.93	5.00	1.8	3.6
Nitrite (μM)	0.19	0.55	0.13	0.32

[1] Brine sampled 21 August 1979.

[2] Brine sampled 22 August 1979.

[3] Brine sampled 7 January 1980.

[4] Brine sampled 8 January 1980.

TABLE 16. LIGHT HYDROCARBONS IN BUCCANEER GAS AND OIL FIELD OIL AND BRINE

Sample	Date	Methane	Ethane	Propane	Iso-butane	Butane	Iso-pentane	Pentane
				Brine				
1	21 Sept. 79	0.96 ml/L	0.14 ml/L	0.069 ml/L	23 µl/L	19 µl/L	39 µl/L	41 µl/L
2	22 Sept. 79	1.23 ml/L	0.30 ml/L	0.16 ml/L	48 µl/L	48 µl/L	57 µl/L	38 µl/L
3	7 Jan. 80	2.55 ml/L	0.51 ml/L	0.32 ml/L	130 µl/L	121 µl/L	137 µl/L	109 µl/L
4	8 Jan. 80	4.91 ml/L	0.68 ml/L	0.40 ml/L	190 µl/L	197 µl/L	219 µl/L	203 µl/L
				Oil				
1	5 Jan. 80	13.5 ml/L	6.9 ml/L	33 ml/L	33 ml/L	49 ml/L	219 ml/L	224 ml/L
2	9 Jan. 80	206 ml/L	224 ml/L	837 ml/L	536 ml/L	609 ml/L	1,300 ml/L	1,000 ml/L
3	4 Feb. 80	215 ml/L	138 ml/L	438 ml/L	283 ml/L	333 ml/L	834 ml/L	695 ml/L
4	8 April 80	192 ml/L	286 ml/L	1,020 ml/L	645 ml/L	711 ml/L	1,750 ml/L	1,400 ml/L

TABLE 17. VOLATILE HYDROCARBONS IN BUCCANEER GAS AND OIL FIELD OIL AND BRINE IN µg/L.

	Sample[1]			
Compound	1	2	3	4
n-Hexane	20	30	80	30
n-Heptane	21	32	110	39
n-Octane	19	66	80	130
n-Nonone	16	75	66	200
n-Decane	39	68	110	400
n-Undecane	18	64	78	880
n-Dodecane	35	52	74	1000
n-Tridecane	77	48	120	1050
n-Tetradecane	180	64	250	1410
Benzene	6,200	5,600	8,500	17,700
Cyclohexane	110	82	290	400
Methylcyclohexane	62	67	290	340
Toluene	2,600	3,100	4,100	8,500
Dimenthylcyclohexane	48	78	86	140
Ethylbenzene	220	260	550	1,100
m, p-Xylene	500	670	1,100	1,900
o-Xylene	480	700	980	1,800
Total n-C_5-C_{14}	420	500	1,100	5,100
Total aromatic	10,000	10,300	15,300	31,100
Total VLH	11,300	11,900	18,800	44,400

[1] Samples 1,2,3, and 4 taken on 21 August 1979, 22 August 1979, 7 January 1980 and 8 January 1980, respectively.

TABLE 18. VOLATILE HYDROCARBONS IN BUCCANEER FIELD OIL IN μg/g.

Compound	Sample[1] 1	2	3	4
n-Pentane	580	3,600	1,900	4,600
n-Hexane	1,700	3,700	2,800	6,100
n-Heptane	3,900	5,600	4,800	10,000
n-Octane	3,700	8,400	7,600	14,000
n-Nonane	10,000	11,000	10,000	16,000
n-Decane	17,000	18,000	17,000	18,000
n-Undecane	20,000	21,000	19,000	19,000
n-Dodecane	22,000	23,000	21,000	17,000
n-Tridecane	26,000	26,000	24,000	19,000
n-Tetradecane	36,000	37,000	35,000	25,000
Benzene	2,200	3,900	3,200	6,000
Methylcyclohexane	6,800	9,500	8,300	15,000
Toluene	2,700	3,200	2,800	6,800
Ethylbenzene	3,500	3,800	3,500	5,500
m, p-Xylene	7,200	7,900	7,200	12,000
o-Xylene	7,060	7,700	7,000	11,000
Total n-C_5-C_{14}	140,000	190,000	140,000	150,000
Total Aromatic	23,000	26,000	24,000	41,000
Total VLH	420,000	470,000	420,000	490,000

[1] Samples 1, 2, 3, and 4 taken on 5 January 1980, 9 January 1980, 4 February 1980, and 8 April 1980, respectively.

TABLE 19. VOLATILE HYDROCARBONS (ng/L) AROUND PLATFORM A AT BUCCANEER FIELD 8 AUGUST 1979.

C_5-C_{14} Hydrocarbons	Below Discharge	North 10m	South 10m	East 10m	West 10m
n-Hexane	51.9	-	-	-	-
Benzene	21.5	38.3	20.6	20.1	39.2
Cyclohexane	-	-	-	-	-
Iso-octane	-	-	-	1.5	-
Heptane	-	-	-	-	-
Methylcyclohexane	-	-	-	-	-
Toluene	1.3	265	17.4	23.8	2.6
Dimethylcyclohexane	88.2	20.2	2.5	25.0	5.4
Octane	69.7	14.4	-	-	14.0
Ethylbenzene	-	112	4.0	8.5	23.7
m,p-Xylene	13.5	403	28.4	52.9	57.8
o-Xylene	-	120	8.3	16.3	15.6
Nonane	-	-	-	-	-
Cumene	-	3.7	-	-	-
n-Propylbenzene	-	133	-	-	-
Mesitylene	-	66.3	4.8	3.3	6.2
Butylbenzene/1.2.4 trimethylbenzene	1.0	60.9	1.8	3.5	2.7
n-Decane/Butylbenzene	8.1	37.7	33.3	11.2	17.7
p-Cymene	34.1	11.5	3.8	53.1	-
n-Butylbenzene	59.8	41.2	-	6.0	6.9
Undecane	8.5	40.9	-	-	3.8
1;2;4;5-Tetramethylbenzene	-				
Naphthalene	-	31.7	26.6	5.1	118
Diisopropylbenzene	12	5.8	-	13.1	1.1
Dodecane	4.8	-	-	-	4.9
n-Hexylbenzene	-	1.6	-	-	-
Tridecane	-	-	-	-	-
Tetradecane	-	8.5	17.5	-	2.1
Total Volatiles	374	1420	169	243	321
Total Aromatics	143	1300	116	206	274
% Aromatics	38.2	91.4	68.2	84.5	85.1
Total n-alkanes	143	102	50.8	11.2	42.5
% n-alkanes	38.2	7.2	30.1	4.6	13.2
Alkanes odd/even Ratio	15.8	1.5	-	-	10.2

TABLE 20. VOLATILE HYDROCARBONS (ng/L) 25m FROM AND BELOW DISCHARGE, PLATFORM B AT BUCCANEER FIELD, 8 AUGUST 1979.

C_5-C_{14} Hydrocarbons	Below Discharge	North 25m	South 25m	East 25m	West 25m
n-Hexane	16.6	-	79	-	-
Benzene	64.9	2.5	26.1	3.5	3.9
Cyclohexane	114	-	-	-	18.8
Iso-octane	370	-	-	-	135
Heptane	743	-	-	-	155
Methylcyclohexane	531	-	-	-	42.1
Toluene	27400	535	9.1	5.8	435
Dimethylcyclohexane	973	2.8	-	15.4	24.1
Octane	299	4.5	-	12.1	63.8
Ethylbenzene	3390	323	8.8	4.3	322
m,p-Xylene	7960	41.7	55.2	33	211
o-Xylene	7320	597	12.2	4.1	669
Nonane	262	7.7	4.1	3.5	15.6
Cumene	494	35.5	-	-	42.9
n-Propylbenzene	595	92	-	-	61.2
Mesitylene	1730	196	12.2	-	168
Butylbenzene/1.2.4 trimethylbenzene	1750	226	25	4.0	116
n-Decane/Butylbenzene	668	54.7	24.7	11.7	36.8
p-Cymene	2330	396	16.6	7.5	238
n-Butylbenzene	927	224	4.2	3.7	168
Undecane	923	109	4.1	8.9	116
1;2;4;5-Tetramethylbenzene	641	157	8.5	7.8	109
Naphthalene	697	8.1	-	1.6	27
Diisopropylbenzene	1520	271	2.0	1.0	119
Dodecane	1250	5.6	6.7	-	52
n-Hexylbenzene	343	25.1	-	-	6.2
Tridecane	1300	26.7	5.9	-	40.8
Tetradecane	235	25.4	-	-	85.2
Total Volatiles	64900	3370	304	128	3480
Total Aromatics	57200	3130	180	76.3	2700
% Aromatics	88.1	92.9	59.1	59.7	77.5
Total n-alkanes	6060	329	125	36.2	700
% n-alkanes	0.9	9.7	40.9	28.3	20.1
Alkanes odd/even Ratio	1.5	0.63	7.8	1.9	1.1

TABLE 21. VOLATILE HYDROCARBONS (ng/L) 50m FROM PLATFORM B AT BUCCANEER FIELD 8 AUGUST 1979.

C_5-C_{14} Hydrocarbons	North 50m	South 50m	East 50m	West 50m
n-Hexane	-	192	-	-
Benzene	16.8	132	13.6	-
Cyclohexane	-	1.7	-	-
Iso-octane	-	283	-	-
Heptane	-	68.9	2.6	-
Methylcyclohexane	-	-	-	0.8
Toluene	25.9	134	23.1	5.8
Dimethylcyclohexane	1.4	-	57.6	1.3
Octane	-	-	-	-
Ethylbenzene	3.9	538	11.0	48.8
m,p-Xylene	37.5	2620	47.8	103
o-Xylene	12.5	859	6.3	138
Nonane	2.5	289	29	4.8
Cumene	-	202	-	6.5
n-Propylbenzene	-	21.9	1.6	23
Mesitylene	11.6	559	10.3	93
Butylbenzene/1.2.4 trimethylbenzene	-	19.5	-	71.1
n-Decane/Butylbenzene	13.2	175	54.9	60.9
p-Cymene	4.0	186	77.6	80.1
n-Butylbenzene	97.2	-	-	90.9
Undecane	-	8.2	7.3	105
1;2;4;5-Tetramethylbenzene	-	61.1	-	98.6
Naphthalene	-	-	4.2	4.8
Diisopropylbenzene	-	12.6	-	28.0
Dodecane	22.6	8.5	31	5.3
n-Hexylbenzene	-	2.2	-	1.5
Tridecane	12.5	21.2	-	2.4
Tetradecane	12.7	-	13.5	56.5
Total Volatiles	274	6400	391	1030
Total Aromatics	209	5350	196	786
% Aromatics	76.3	83.6	49.9	76.3
Total	63.5	1050	138	235
%	23.1	16.3	35.3	22.8
Alkanes odd/even Ratio	3.4	1.7	1.3	1.1

TABLE 22. VOLATILE HYDROCARBONS (ng/L) DOWN CURRENT FROM PLATFORM B AT BUCCANEER FIELD, 8 AUGUST 1979.

C_5-C_{14} Hydrocarbons	DISTANCE DOWN CURRENT					
	5m	10m	15m	20m	25m	30m
n-Hexane	1.2	-	2.3	-	35.2	-
Benzene	13.6	11	6.6	3.2	-	-
Cyclohexane	11.6	2.6	11.1	-	148	-
Iso-octane	36.1	2.0	23.8	-	-	-
Heptane	72.3	54.1	7.7	5.3	-	-
Methylcyclohexane	1.6	15.5	4.0	3.8	-	-
Toluene	9.0	6.2	75.7	52.8	-	48
Dimethylcyclohexane	24.8	61.7	31.1	1.6	-	-
Octane	42.6	26.0	22.5	7.4	19.0	-
Ethylbenzene	52.2	24.2	-	113	47.0	6.8
m,p-Xylene	235	94.4	35.2	218	168	38.8
o-Xylene	90.3	81.6	4.4	2.1	106	18.4
Nonane	18.9	7.9	2.8	19.3	22.5	-
Cumene	2.0	2.7	30.4	-	64.5	-
n-Propylbenzene	30.0	20.3	-	110	101	10.2
Mesitylene	38.8	43.6	-	136	133	9.7
Butylbenzene/1.2.4 trimethylbenzene	56.8	31.3	18.2	-	165	-
n-Decane/Butylbenzene	81.1	38.4	-	147	114	3.8
p-Cymene	10.2	19	22.8	53.6	42.7	6.7
n-Butylbenzene	3.7	6	-	20.0	7.2	10.6
Undecane	-	-	-	2.0	121	4.4
1;2;4;5-Tetramethylbenzene	-	-	-	78.5	-	-
Naphthalene	35.2	3.8	121	88.3	12.6	6.0
Diisopropylbenzene	-	-	-	-	-	-
Dodecane	2.4	-	15.6	3.1	4.4	-
n-Hexylbenzene	-	11.3	47.0	3.5	-	-
Tridecane	-	-	17.0	-	-	-
Tetradecane	47.2	36.4	4.4	53.2	34.4	22.2
Total Volatiles	916	600	504	1120	1340	186
Total Aromatics	576	355	361	878	842	155
% Aromatics	62.9	59.2	71.7	78.4	62.8	83.6
Total n-alkanes	255	165	88.4	237	350	30.4
% n-alkanes	27.8	27.5	17.6	21.1	26.1	16.4
Alkanes odd/even Ratio	1.9	1.7	2.5	7.9	1.6	5.9

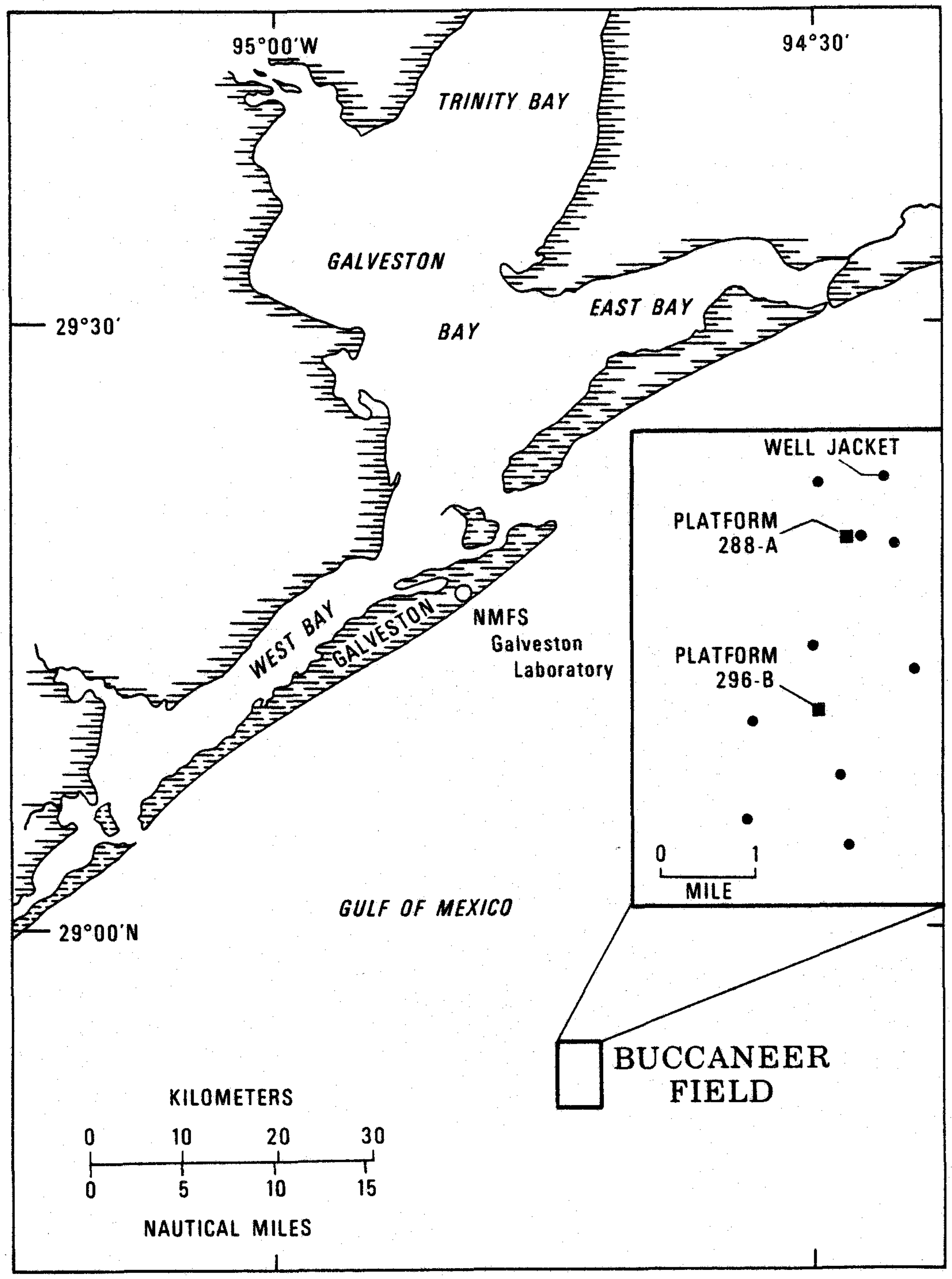


Figure 1. Location of Buccaneer Gas and Oil Field.

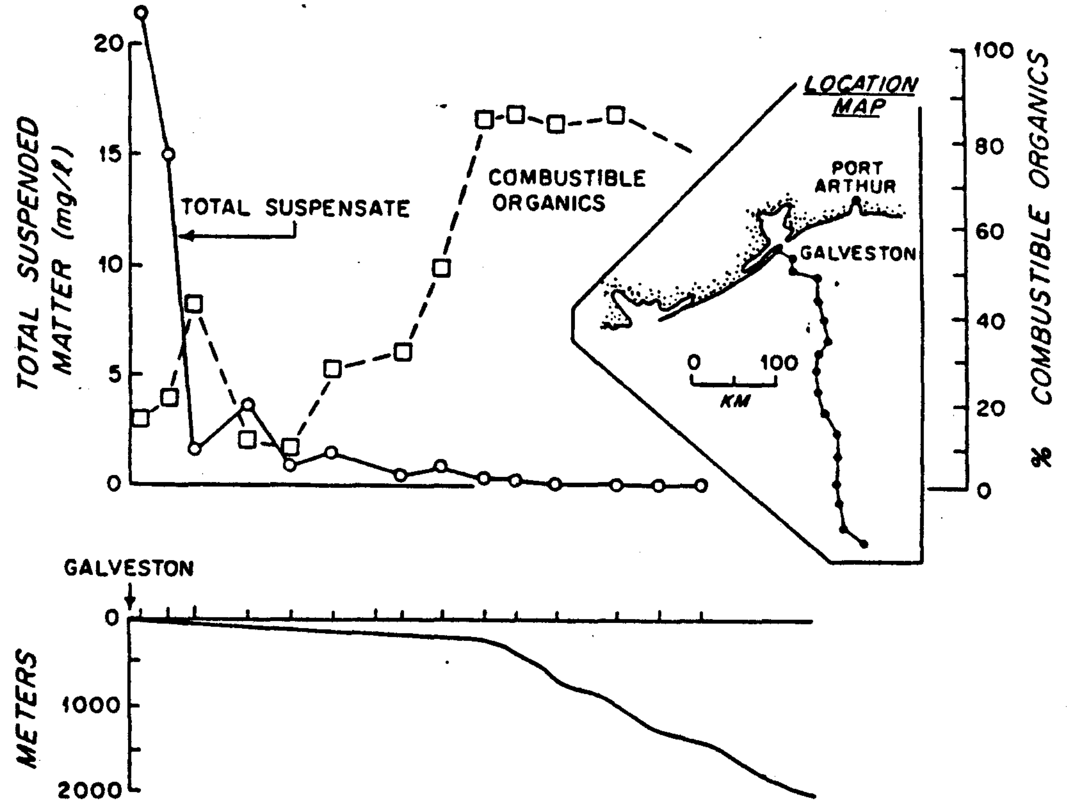
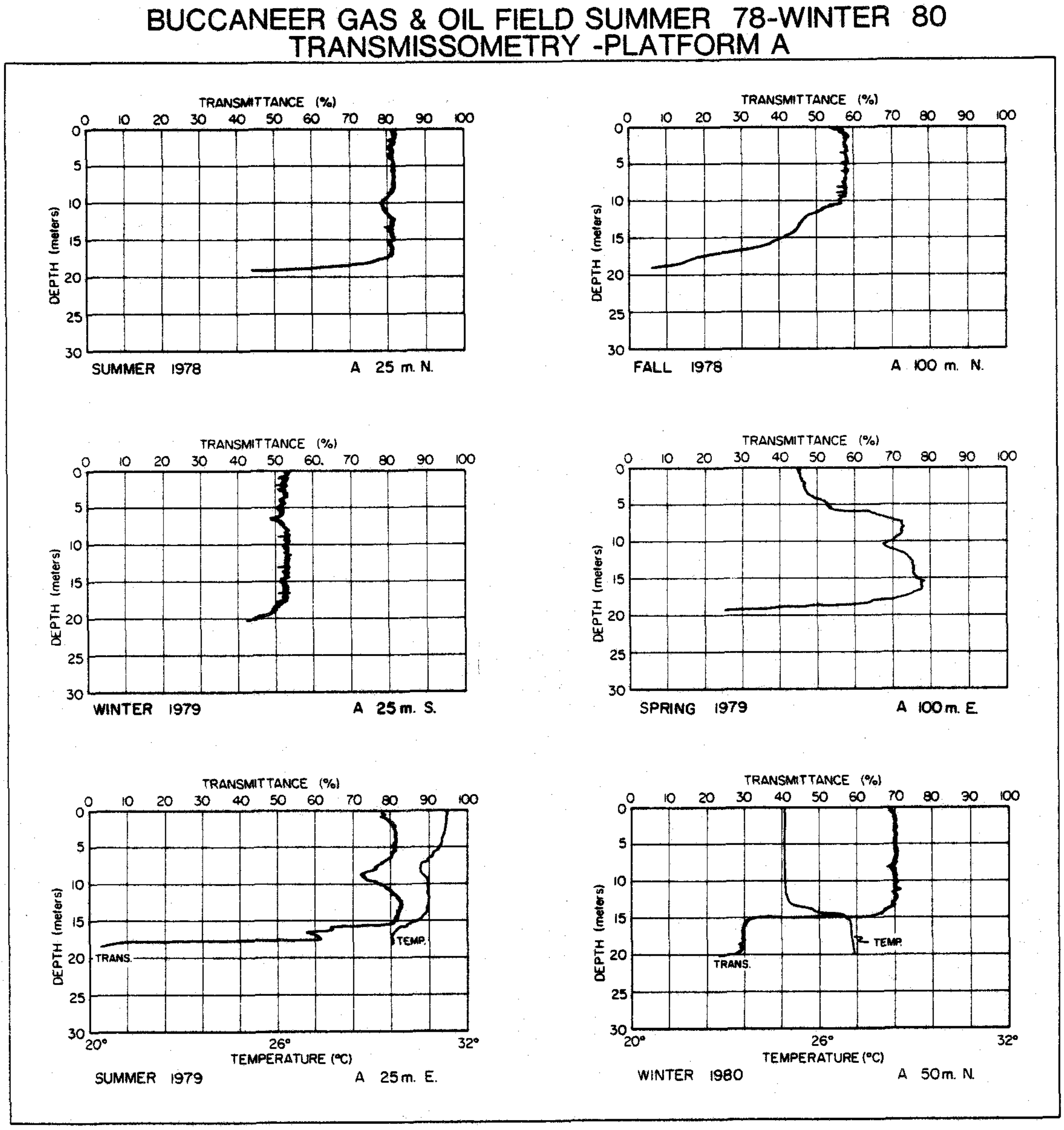
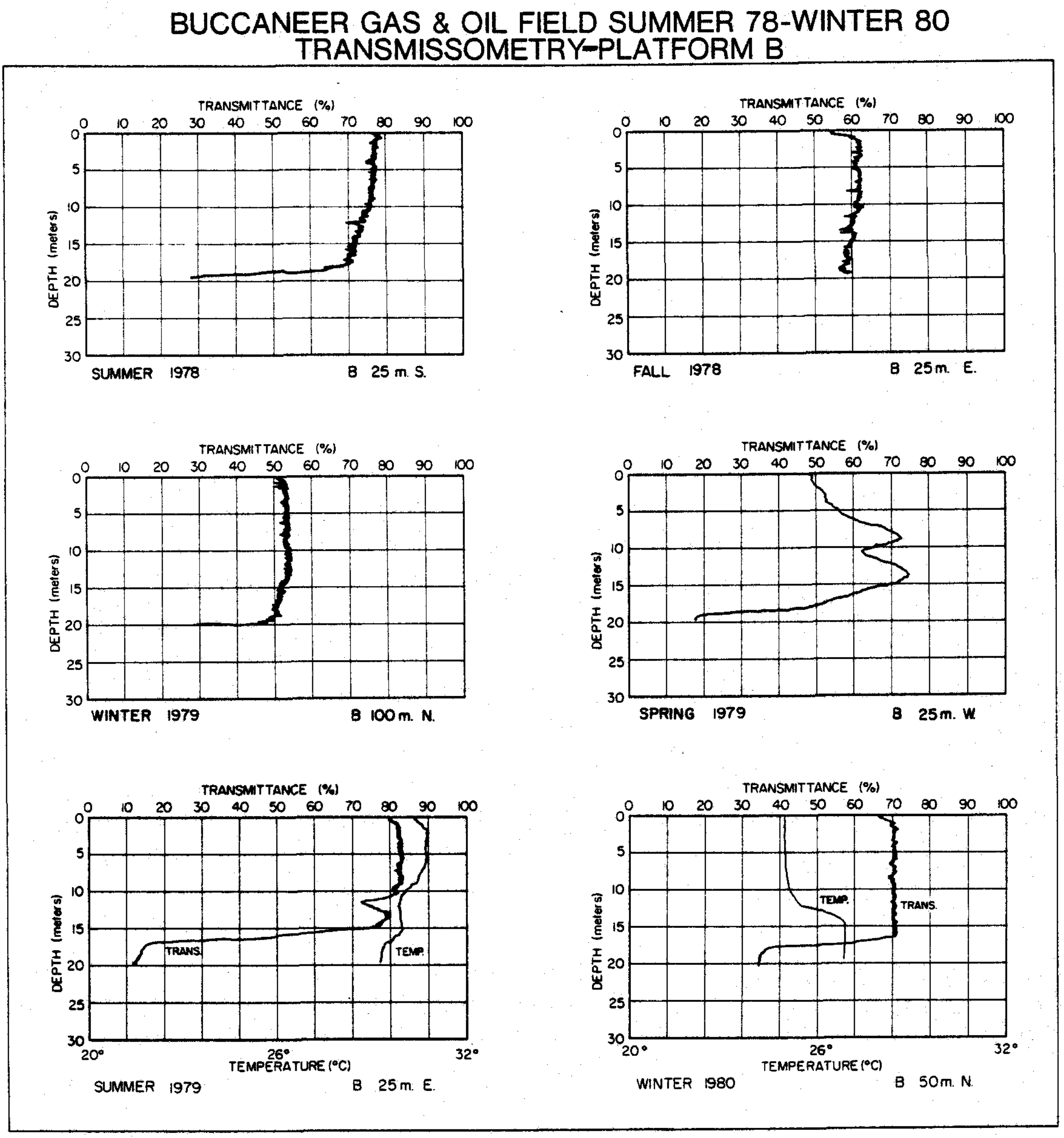


Figure 2. Suspended sediment sample profile from Galveston Bay through the BGOF area showing the boundary between sediment-rich Galveston Bay waters and offshore waters (after Manheim et al., 1972).



BUCCANEER GAS & OIL FIELD SUMMER 78-WINTER 80
TRANSMISSOMETRY -PLATFORM A

Figure 3. Representative transmissometry profiles obtained during six seasonal samplings at Platform 288A. Temperature profiles also displayed in summer 1979 and winter 1980.


BUCCANEER GAS & OIL FIELD SUMMER 78-WINTER 80
TRANSMISSOMETRY-PLATFORM B

SUMMER 1978 B 25 m. S.

FALL 1978 B 25m. E.

WINTER 1979 B 100m. N.

SPRING 1979 B 25m. W.

SUMMER 1979 B 25m. E.

WINTER 1980 B 50m. N.

Figure 4. Representative transmissometry profiles obtained during six seasonal samplings at Platform 296B. Temperature profiles also displayed in summer 1979 and winter 1980.

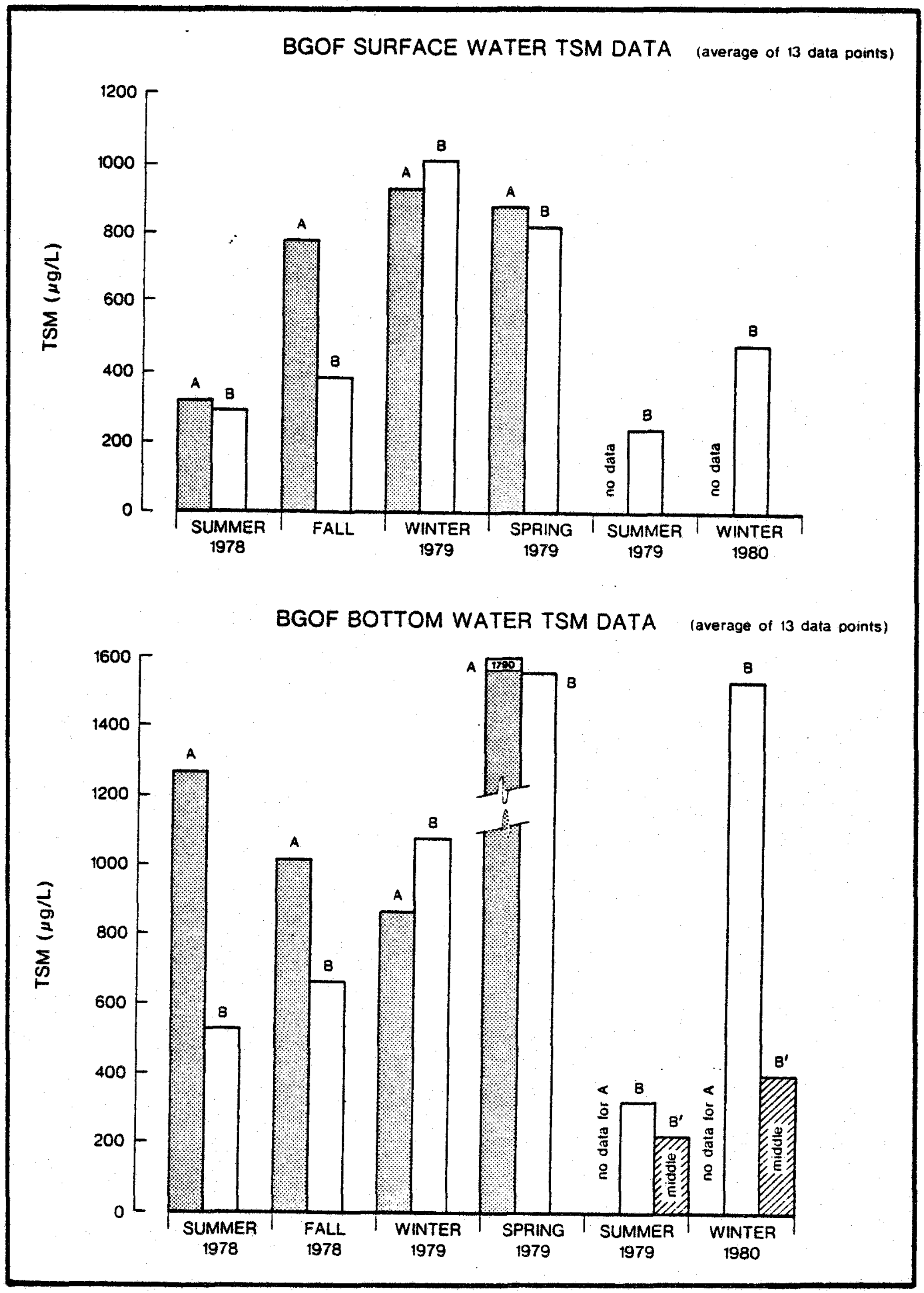


Figure 5. Histogram of total suspended matter concentrations during six seasonal samplings at Platform 288A (A) and 296B (B) in surface and near-bottom waters. Concentrations represent an average of 13 or more stations around each platform.

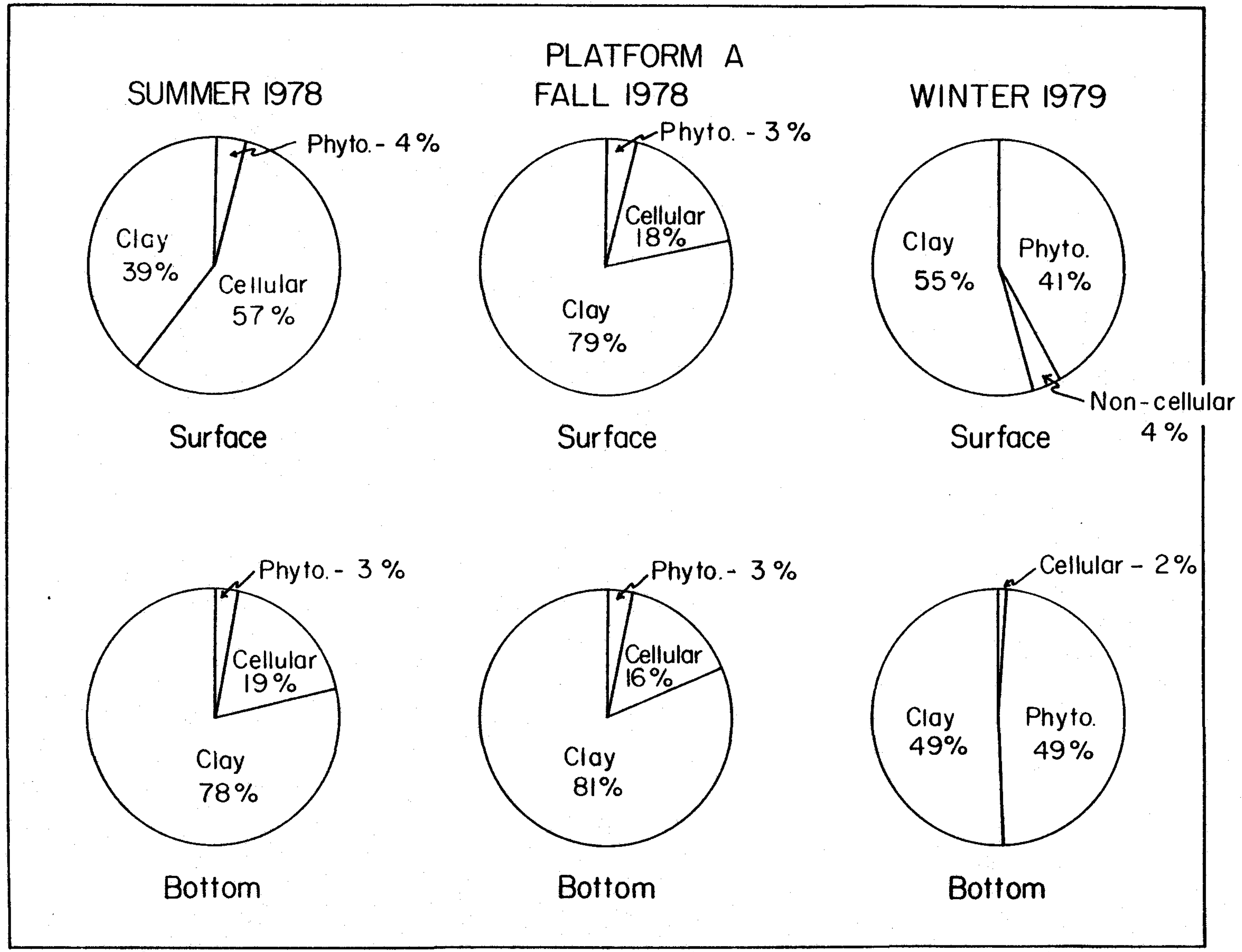


Figure 6. Composition of suspended particulates at stations near Platform 288A during seasonal samplings. Phyto. = phytoplankton biomass estimated from chlorophyll a. Cellular = cellular biomass estimated from ATP minus phytoplankton biomass.

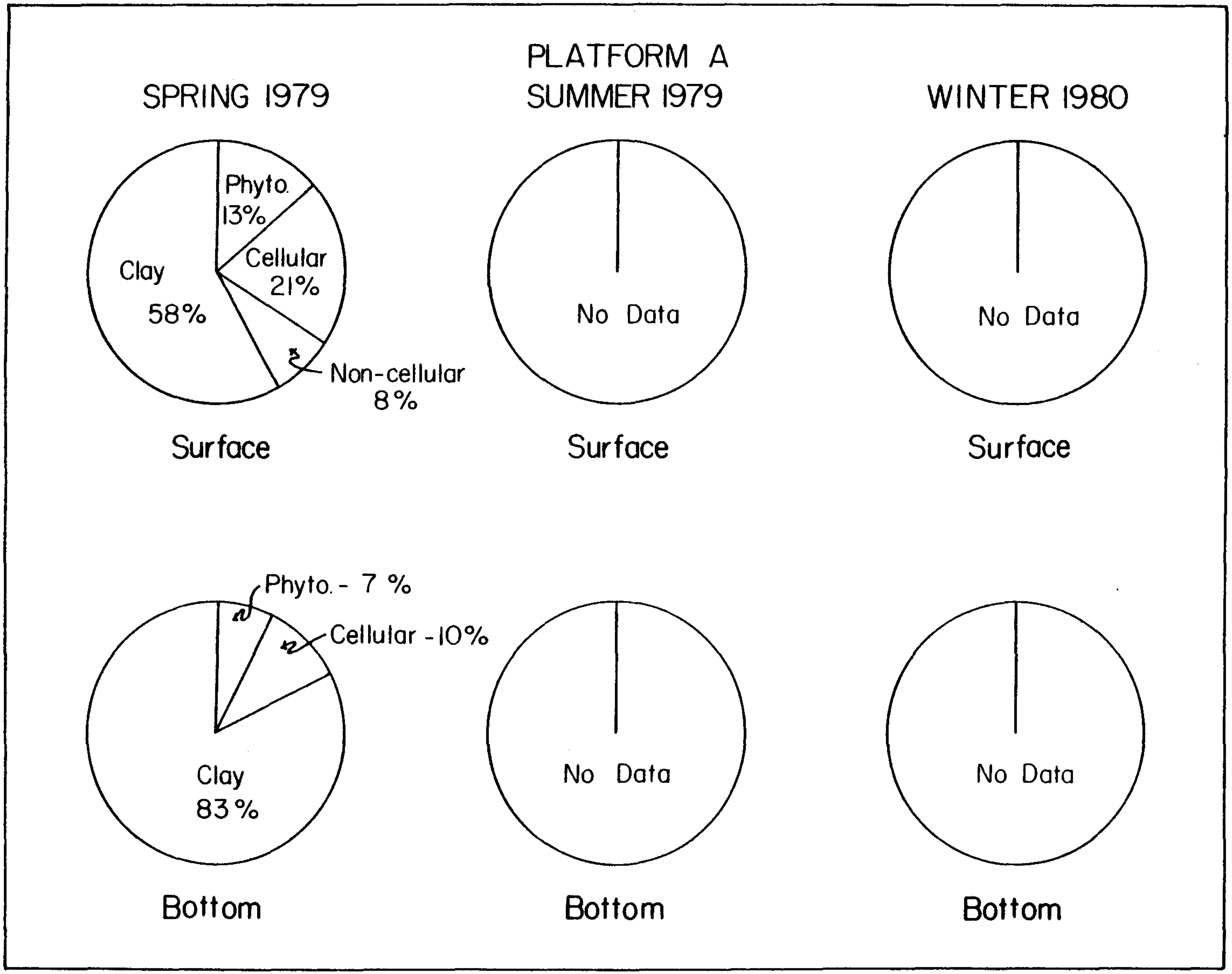


Figure 7. Composition of suspended particulates at stations near Platform 288A during seasonal samplings. Phyto. = phytoplankton biomass estimated form chlorophyll a. Cellular = cellular biomass estimated from ATP minus phytoplankton biomass.

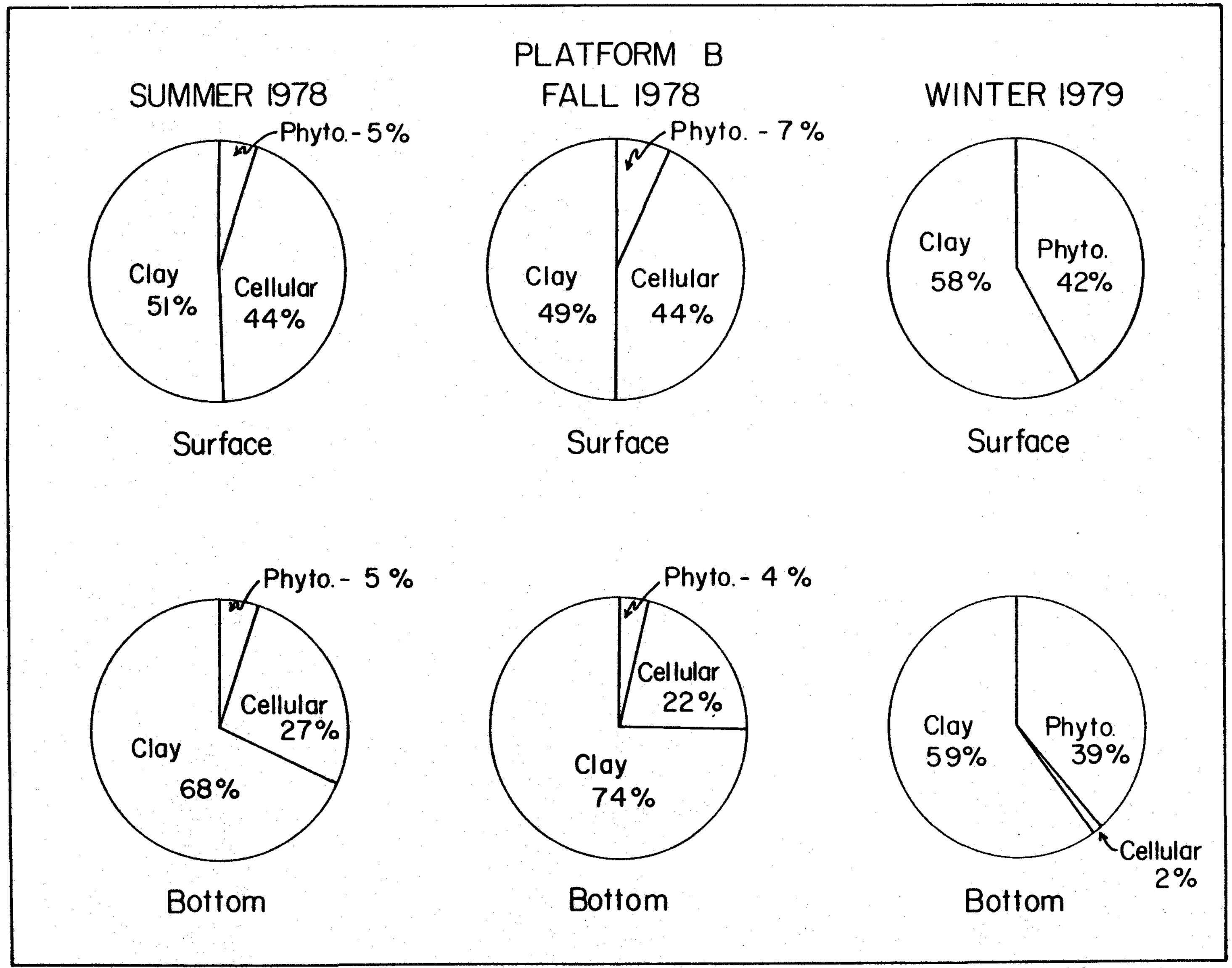


Figure 8. Composition of suspended particulates at stations near Platform 296B during seasonal samplings. Phyto. = phytoplankton biomass estimated from chlorophyll a. Cellular = cellular biomass estimated from ATP minus phytoplankton biomass.

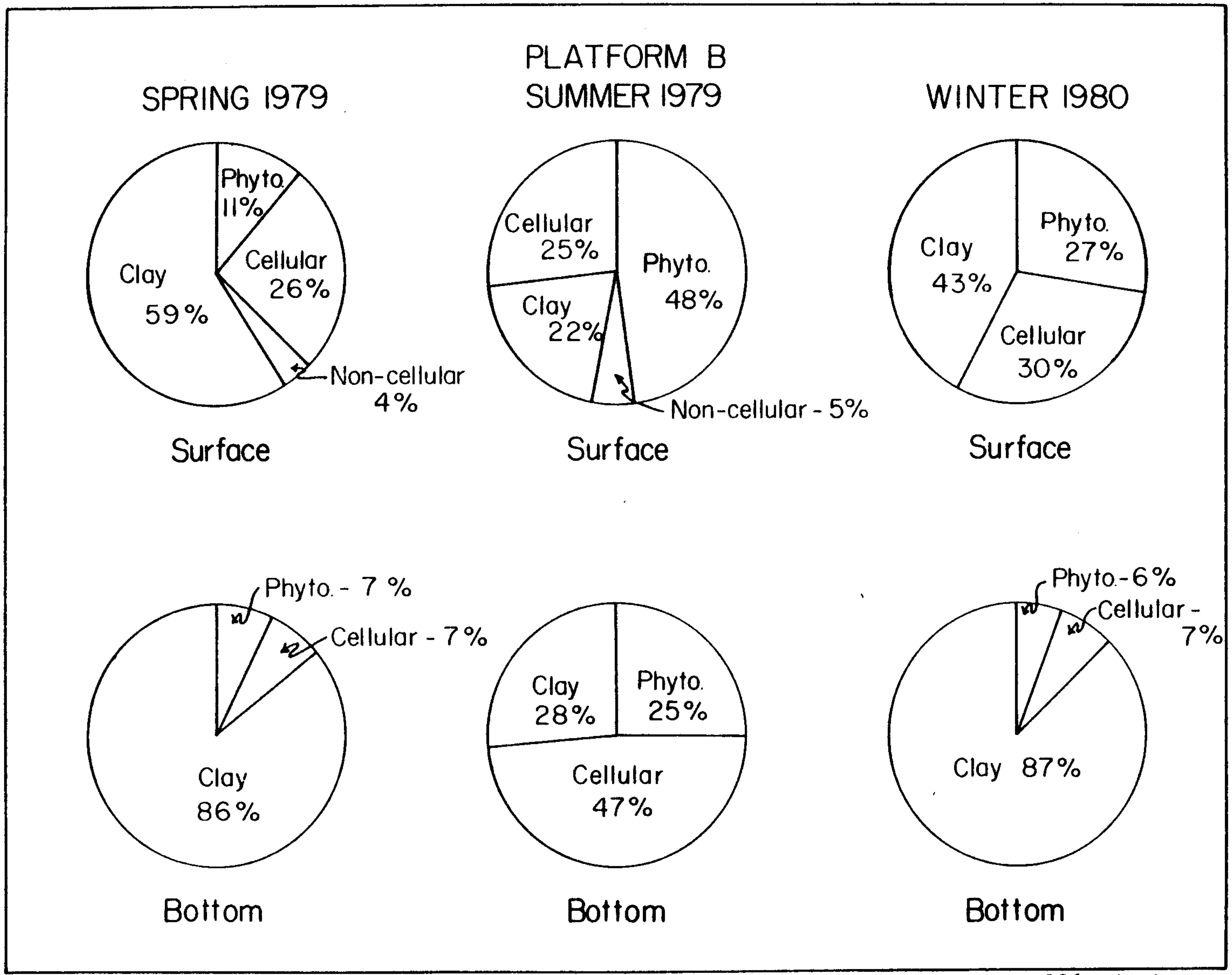
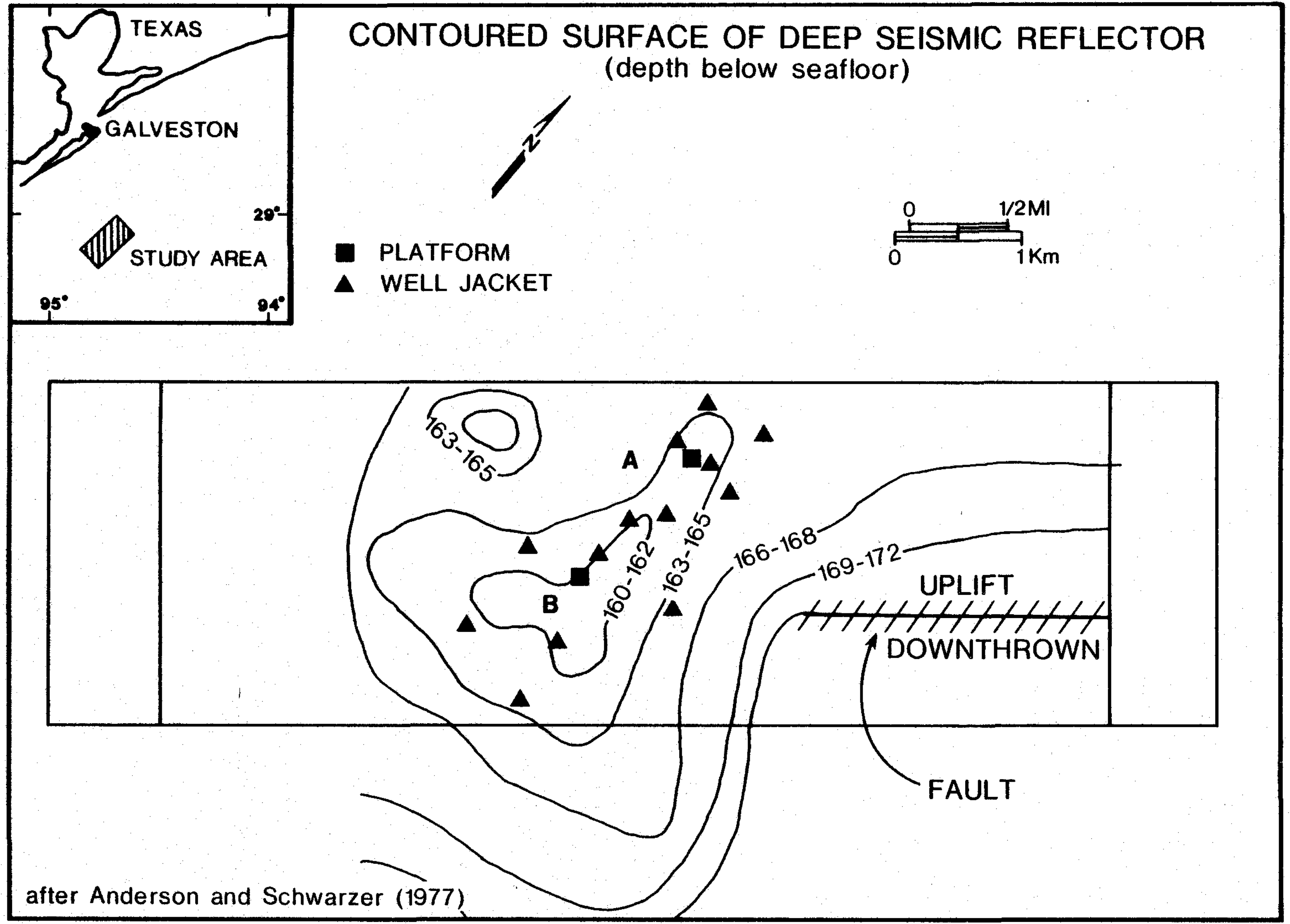


Figure 9. Composition of suspended particulates at stations near Platform 296B during seasonal samplings. Phyto. = phytoplankton biomass estimated from chlorophyll a. Cellular = cellular biomass estimated from ATP minus phytoplankton biomass



after Anderson and Schwarzer (1977)

Figure 10. Contoured surface of deep seismic reflector beneath BGOF.

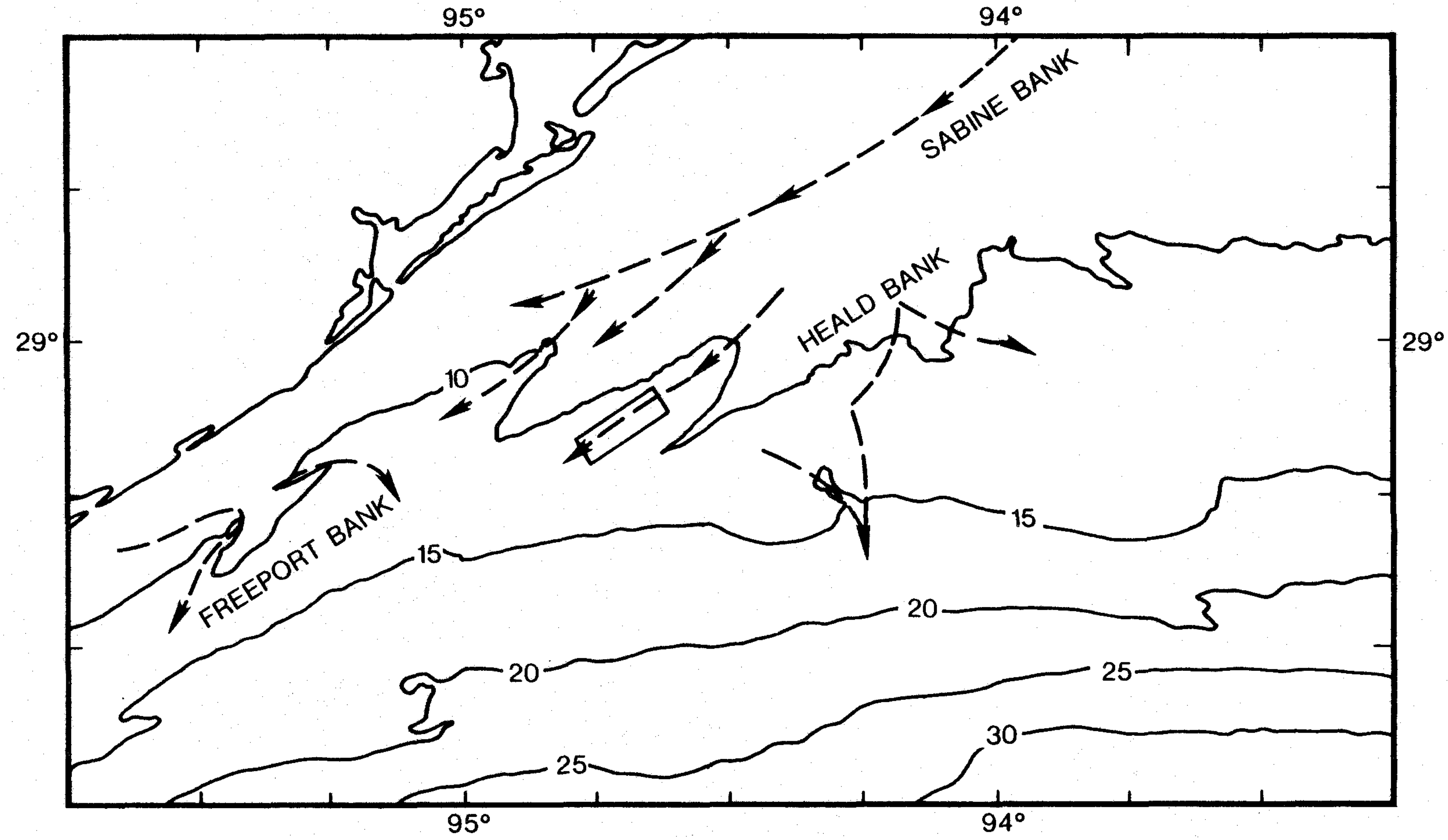


Figure 11. Physiographic map of the northwestern Gulf of Mexico showing relict channels and depositional redges (after Curray, 1959). Contour interval = 5 fathoms.

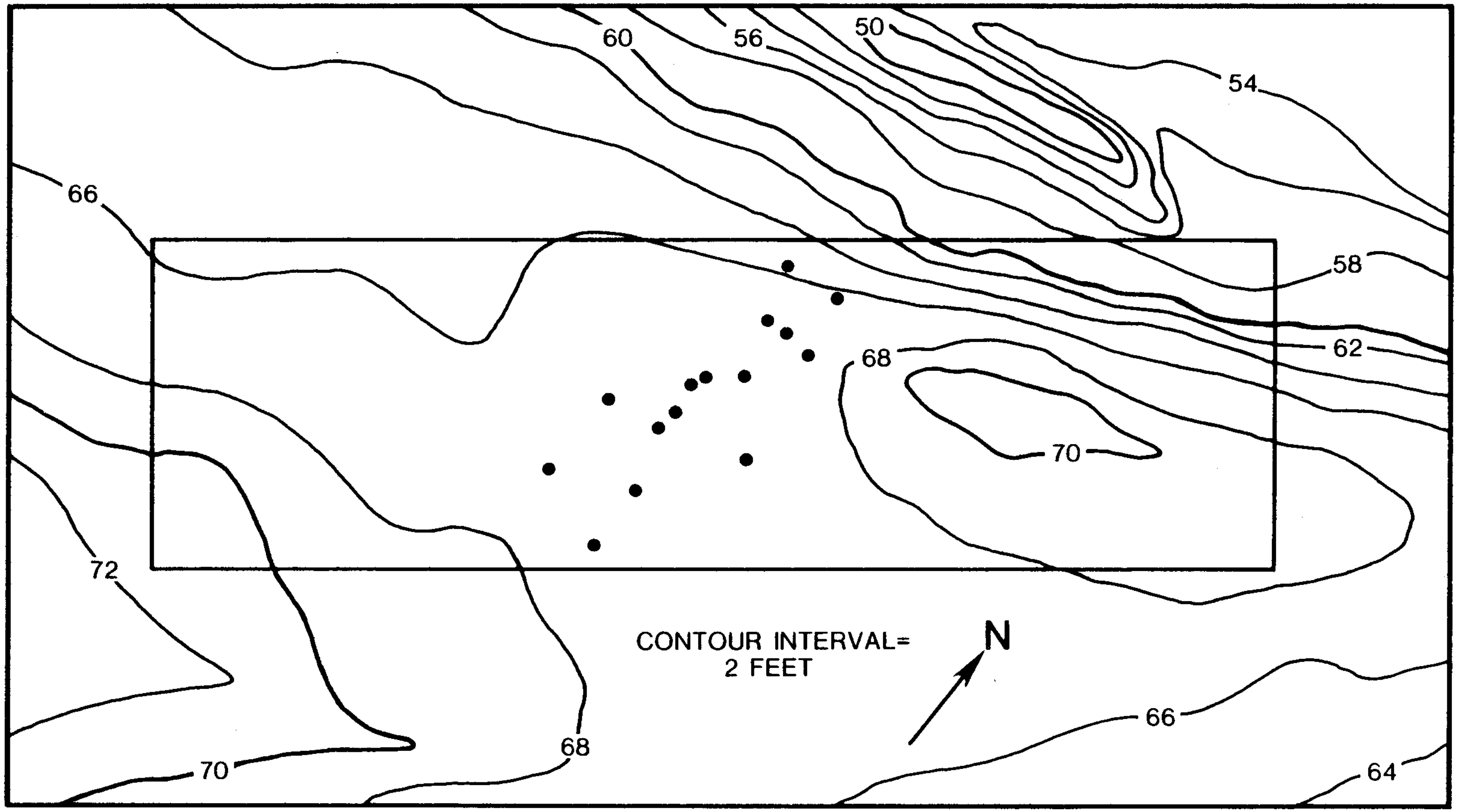
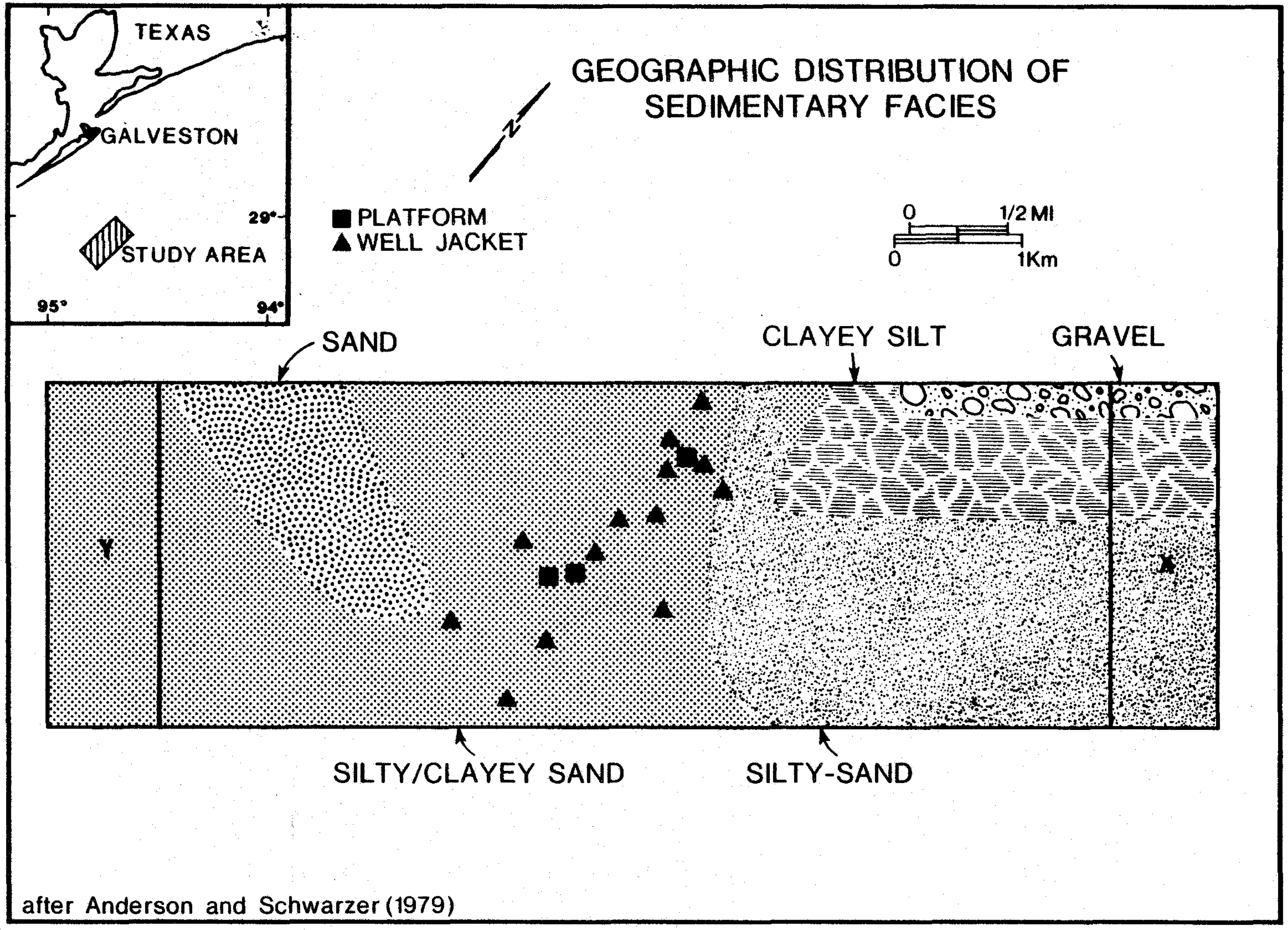
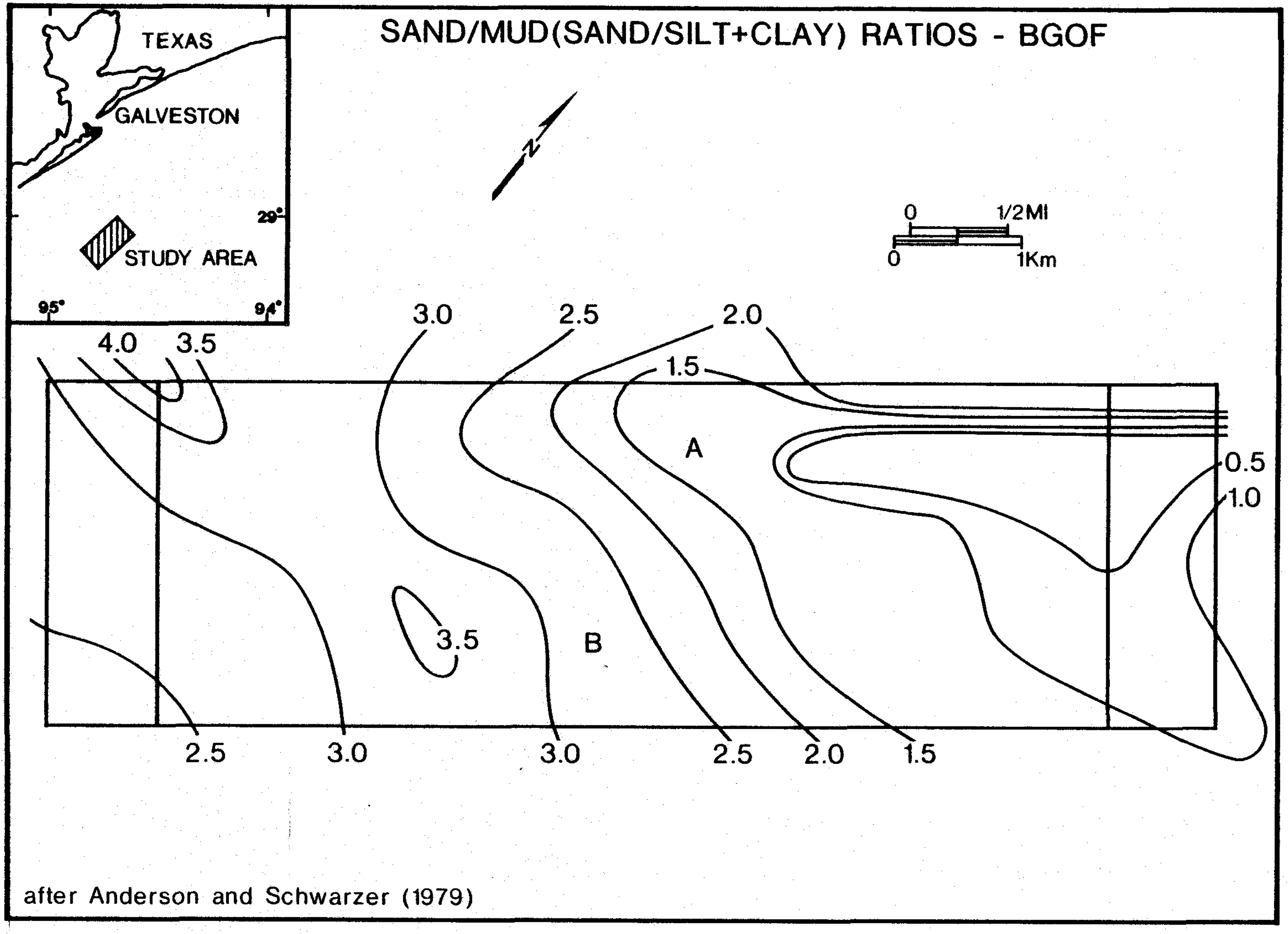


Figure 12. Bathymetry of the Buccaneer Gas and Oil Field (after Wheeler, 1979).



after Anderson and Schwarzer (1979)

Figure 13. Geographic distribution of sedimentary facies at BGOF study area.



after Anderson and Schwarzer (1979)

Figure 14. Sand/mud (silt + clay) ratios in the BGOF study area.

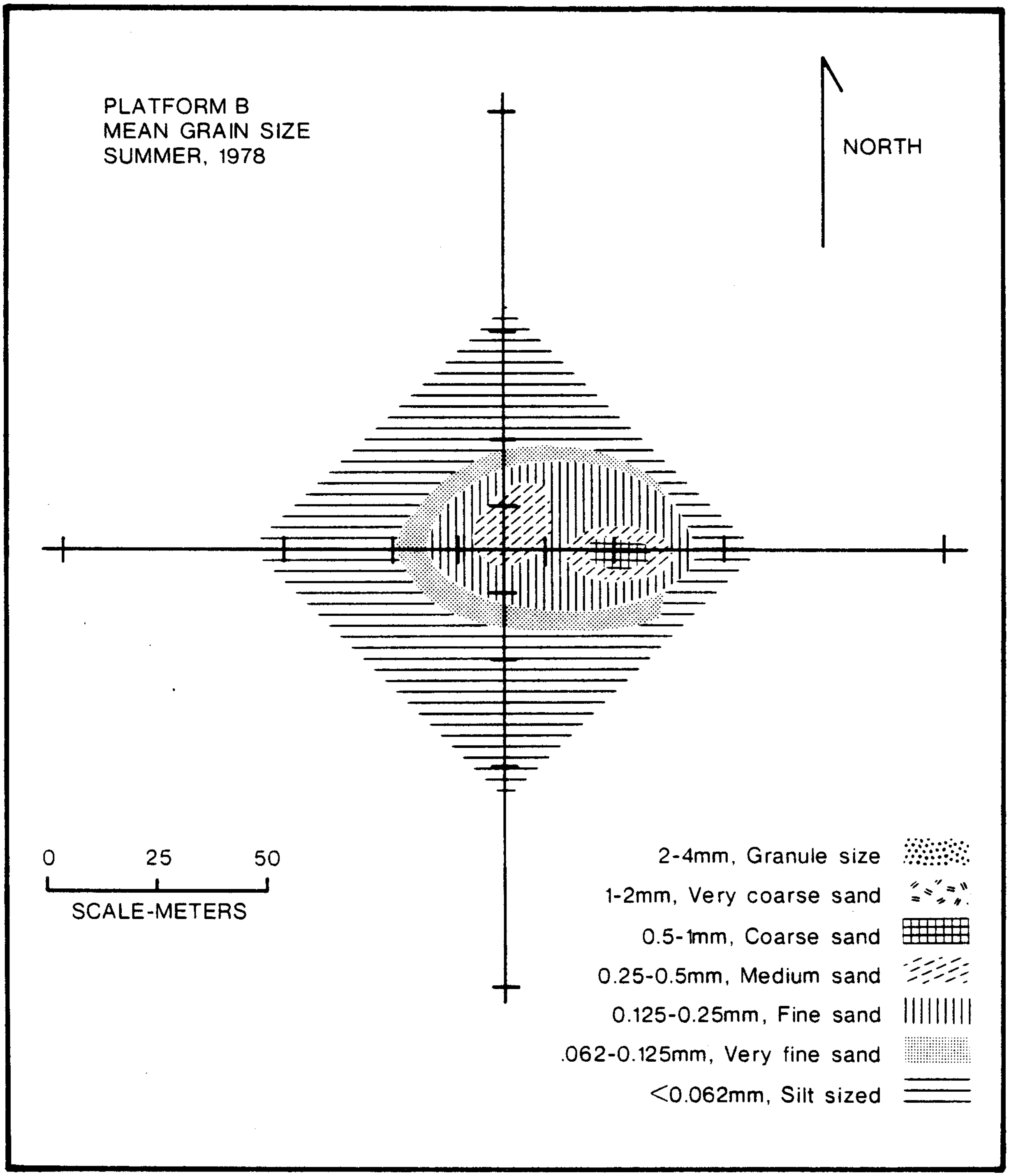


Figure 15. Mean grain size distribution at Platform 296B during summer 1978.

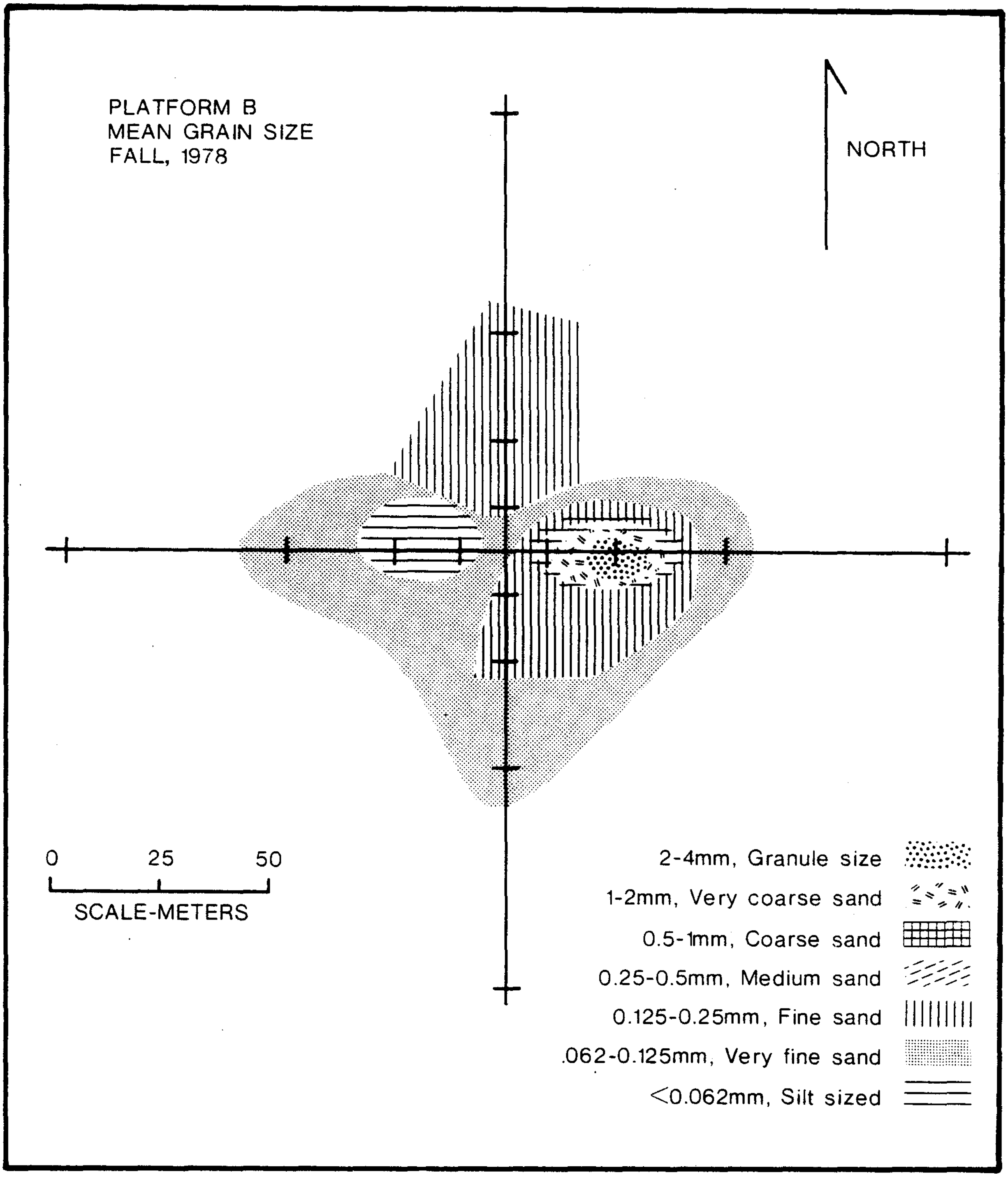


Figure 16. Mean grain size distribution at Platform 296B during fall 1978.

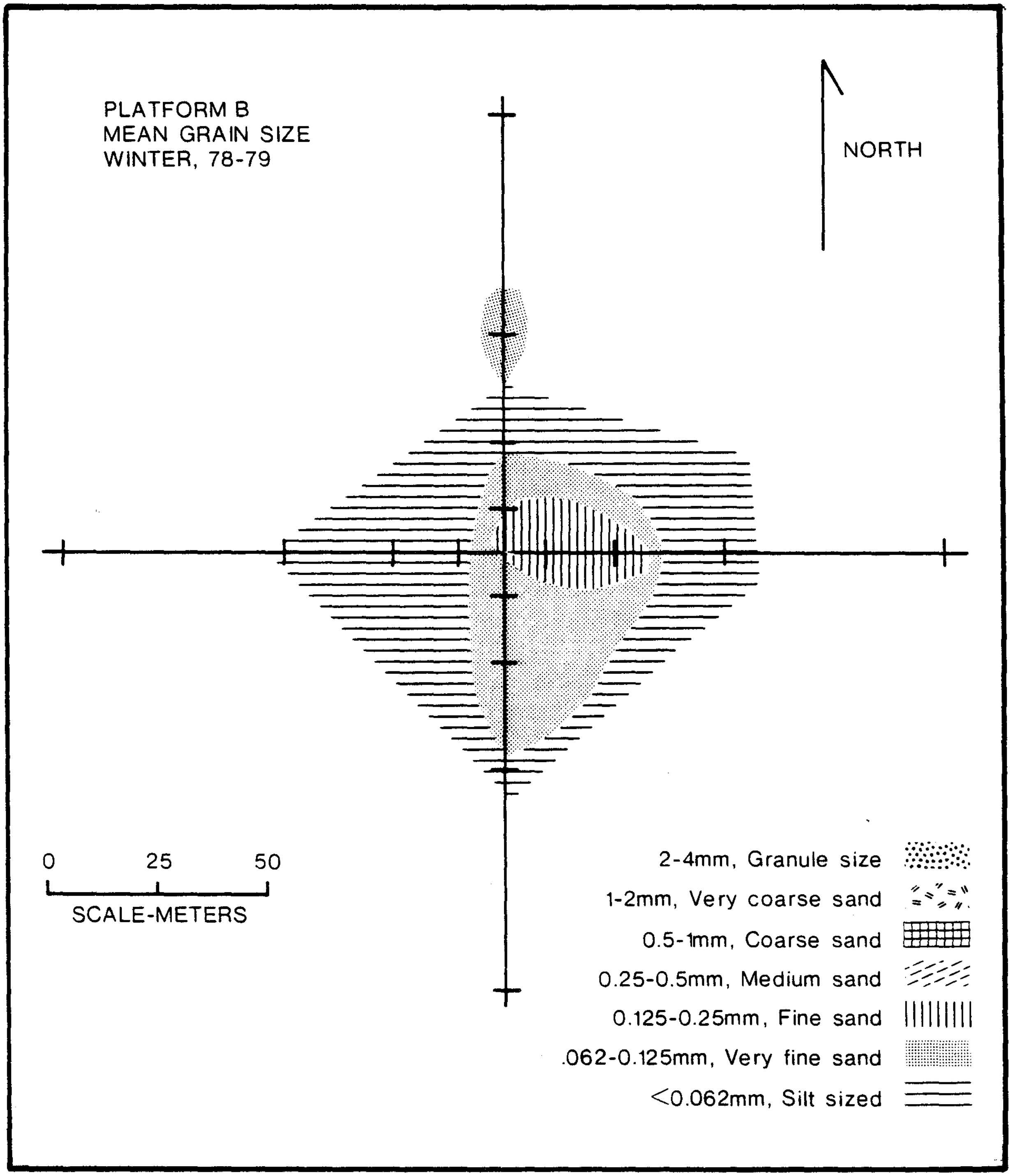


Figure 17. Mean grain size distribution at Platform 296B during winter 1979.

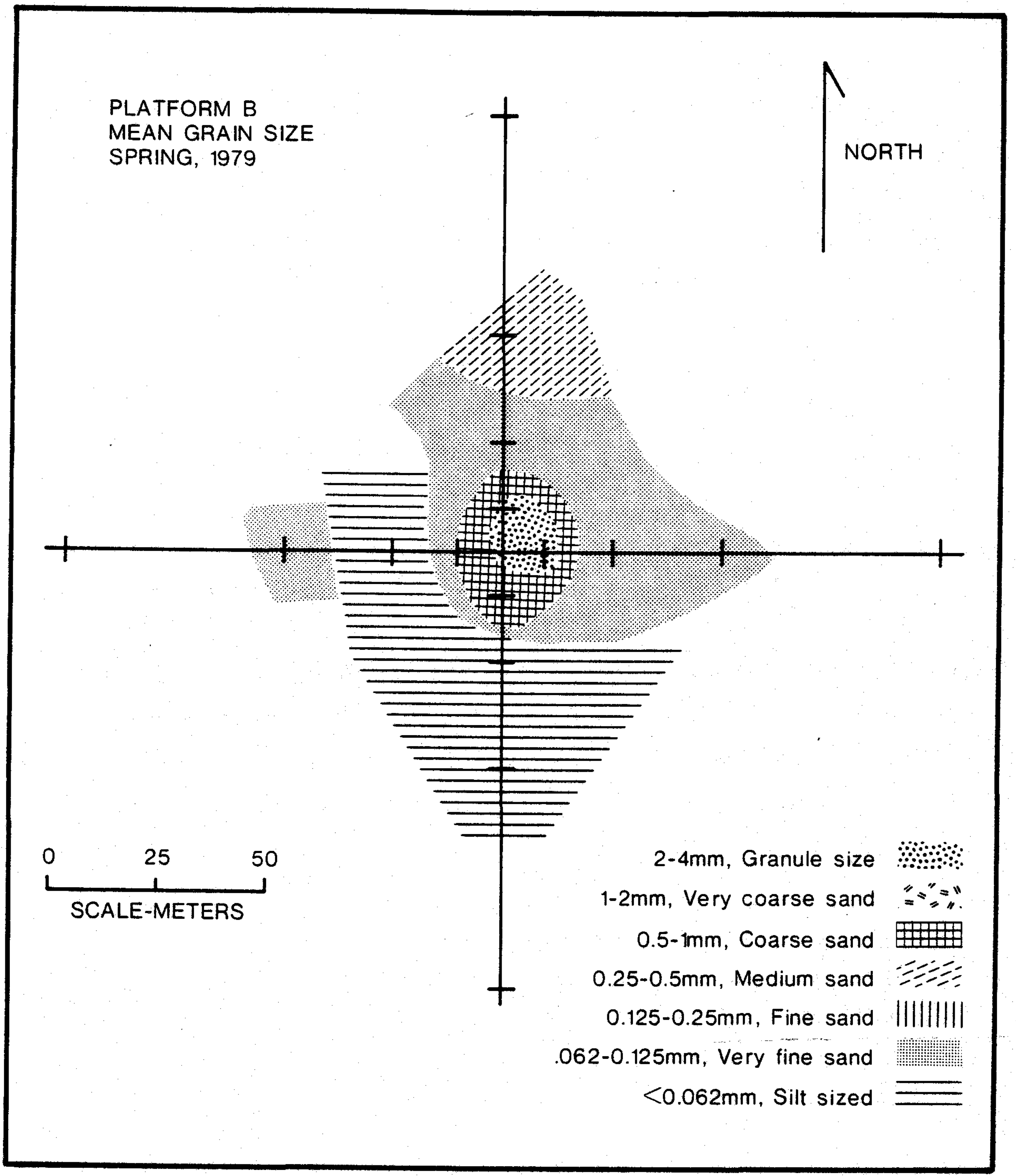


Figure 18. Mean grain size distribution at Platform 296B during spring 1979.

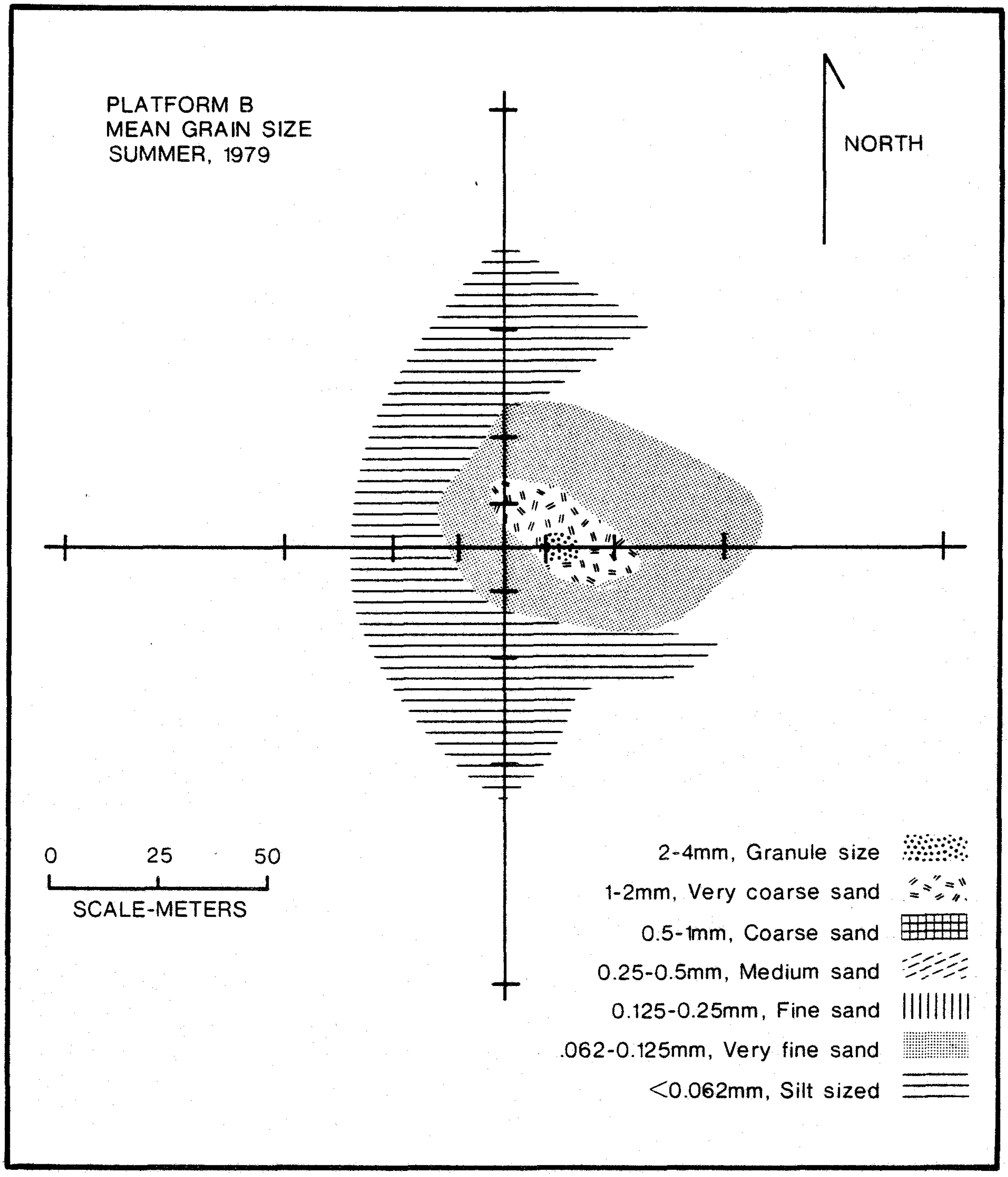


Figure 19. Mean grain size distribution at Platform 296B during summer 1979.

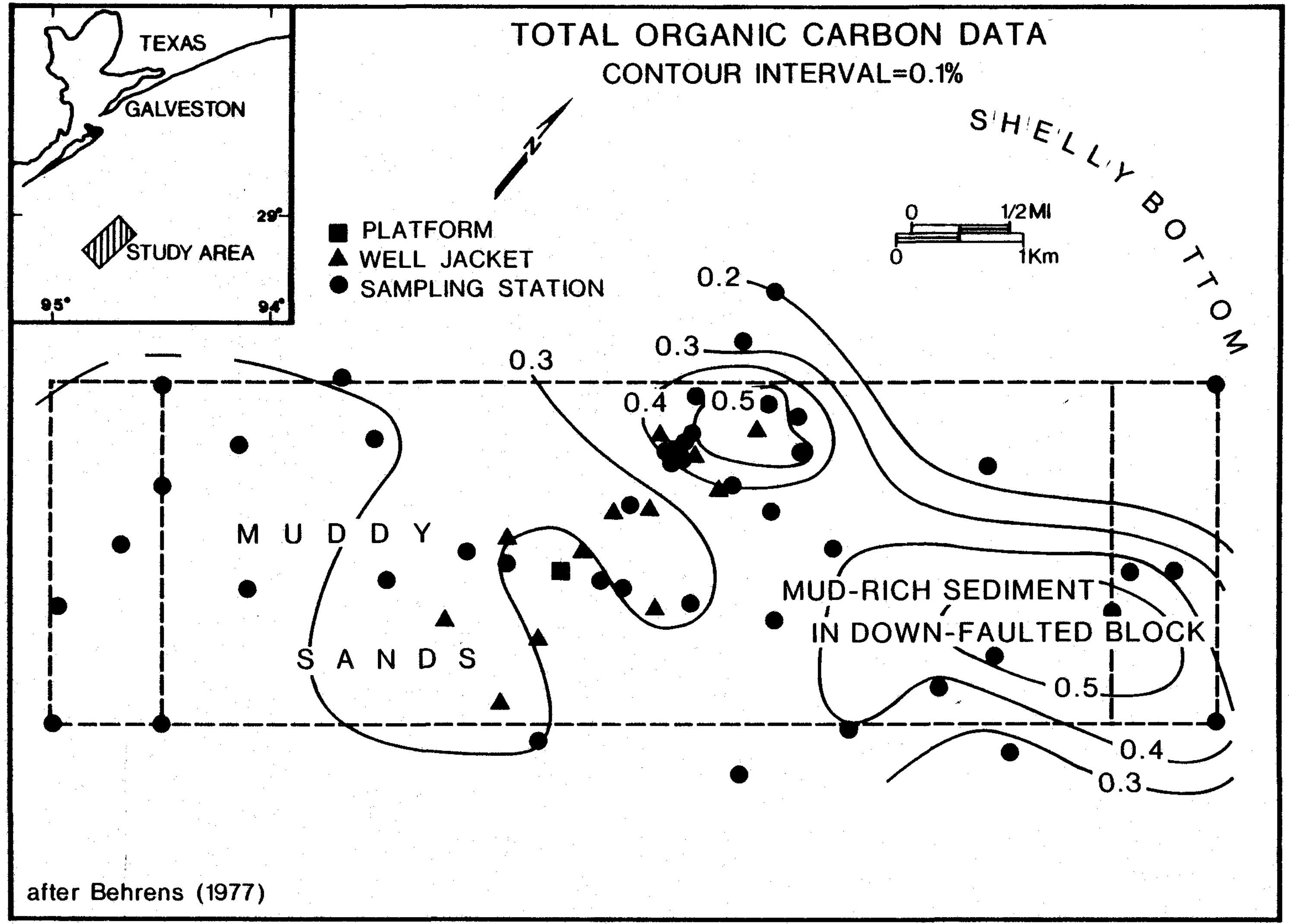


Figure 20. Total organic carbon in surficial sediment (upper 2 cm) in the BGOF area.

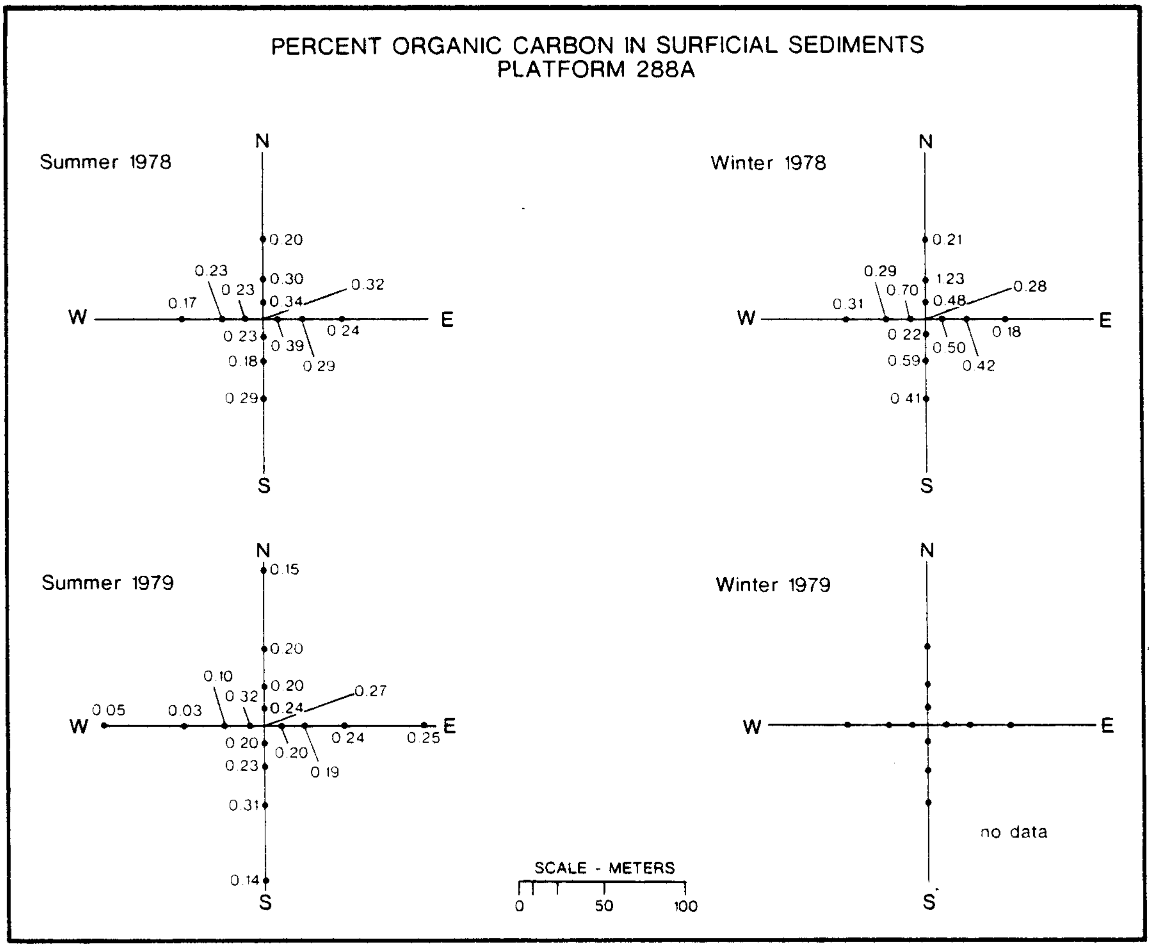


Figure 21. Percent organic carbon around Platform 288A.

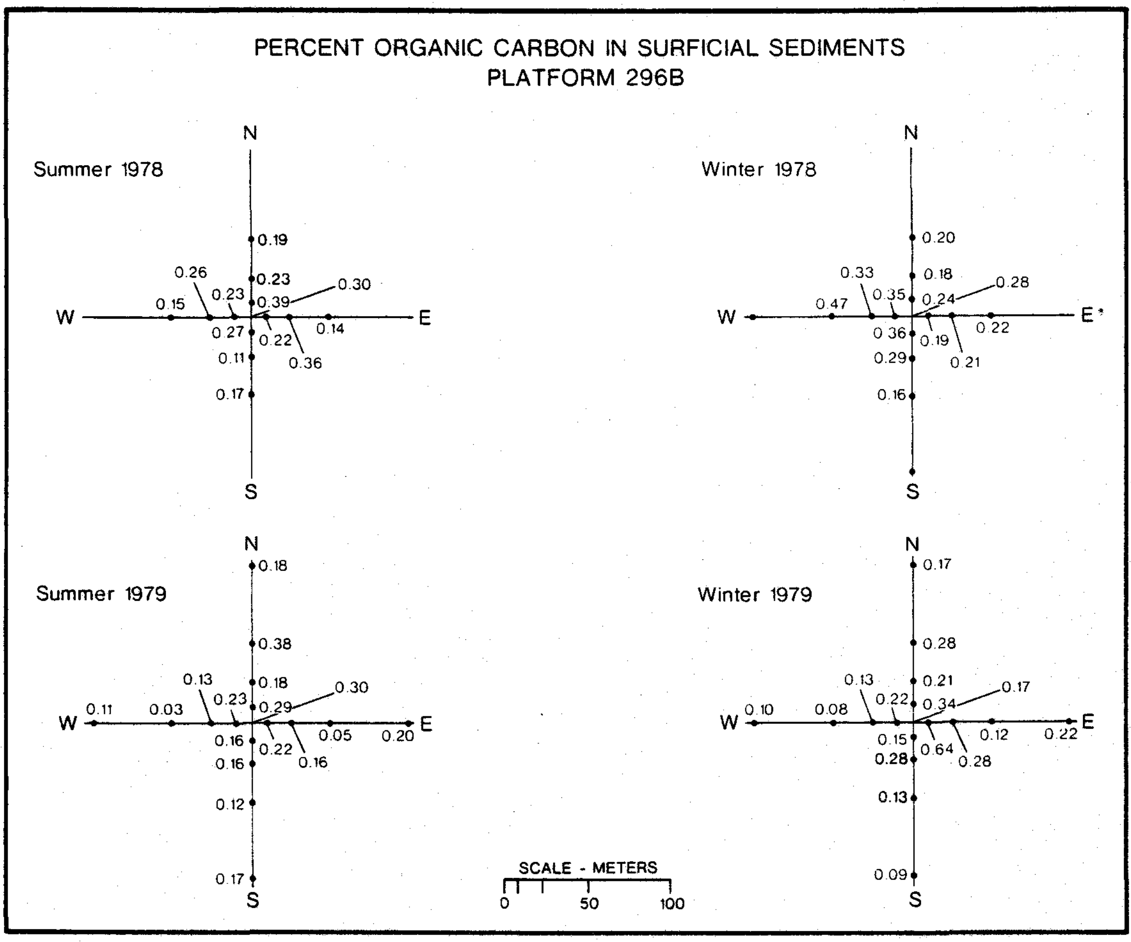


Figure 22. Percent organic carbon around Platform 296B.

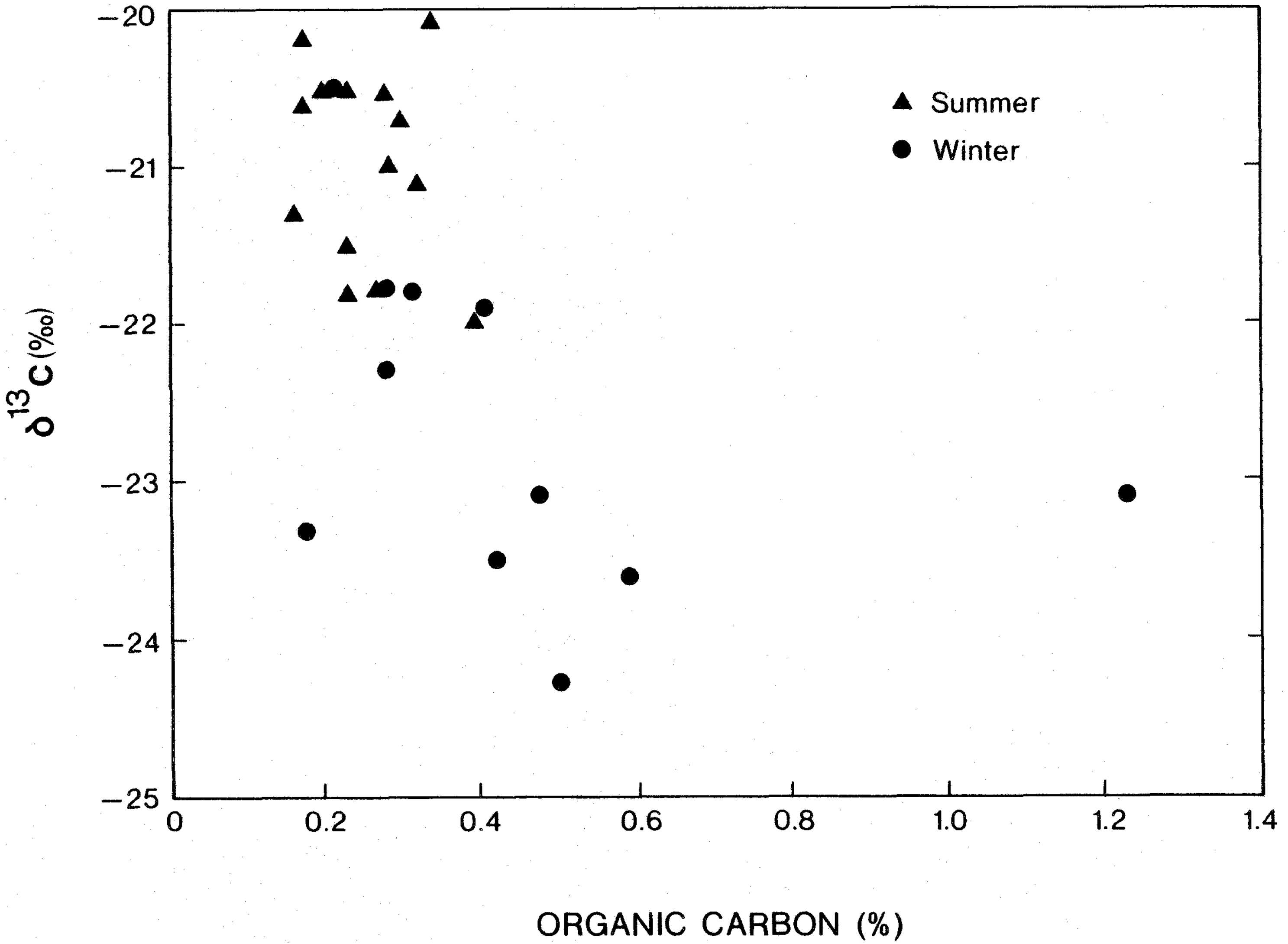


Figure 23. Percent organic carbon versus $\delta^{13}C$ from Platform 288A during both summer and winter samplings.

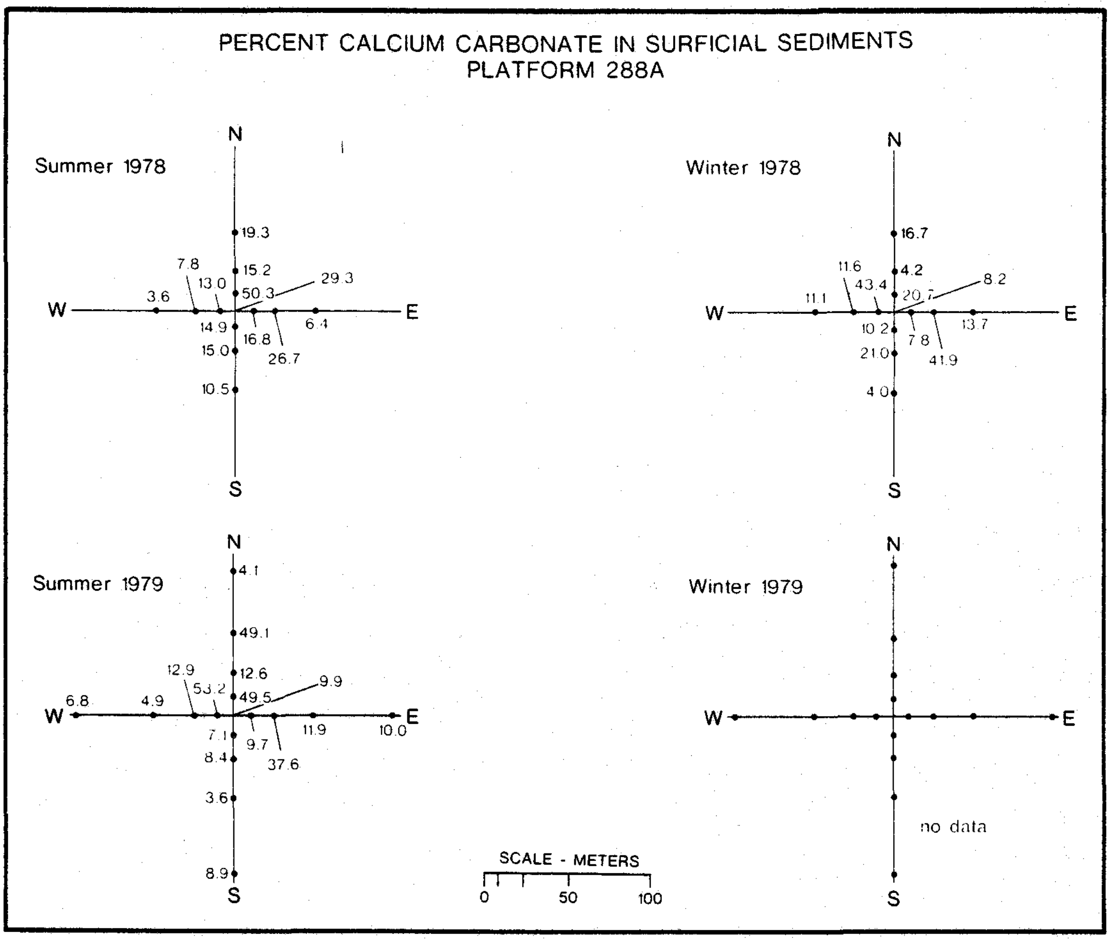


Figure 24. Percent calcium carbonate around Platform 288A.

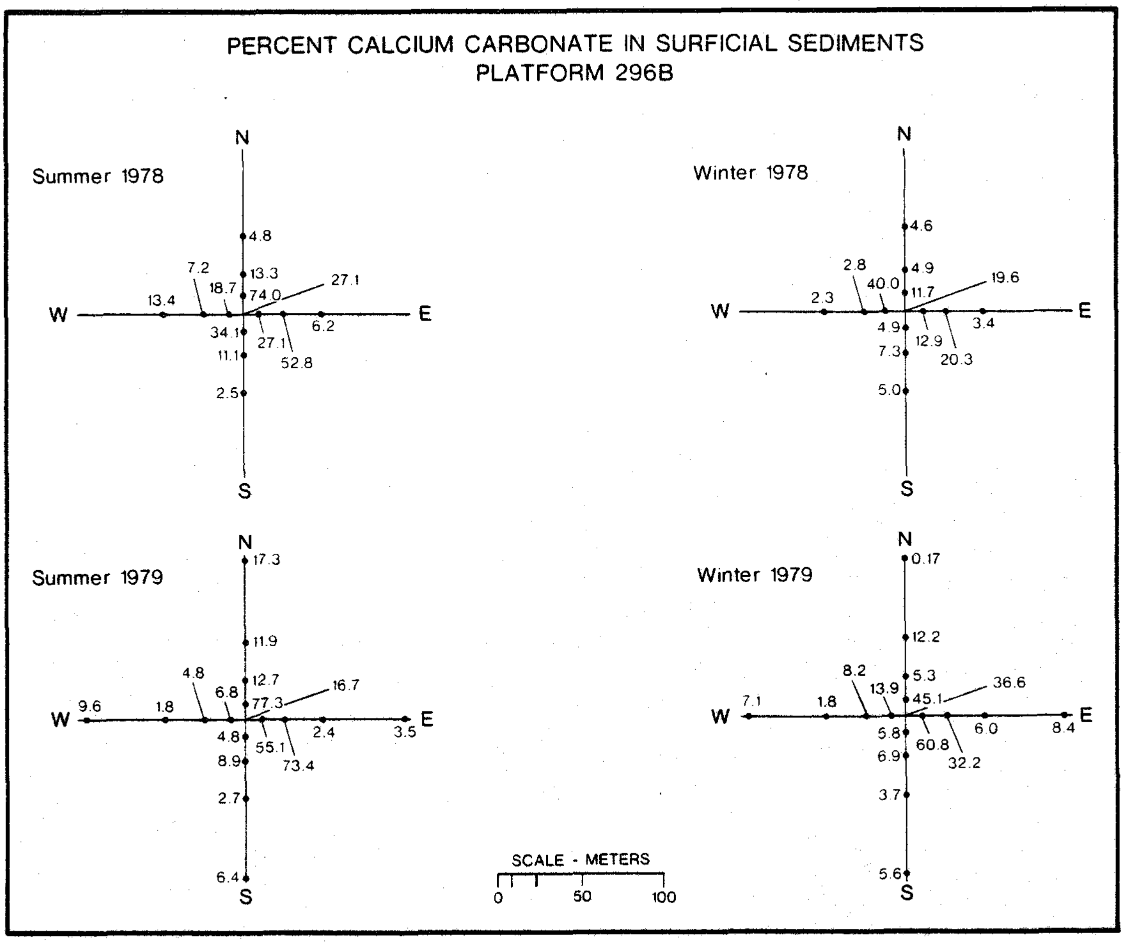


Figure 25. Percent calcium carbonate around Platform 296B.

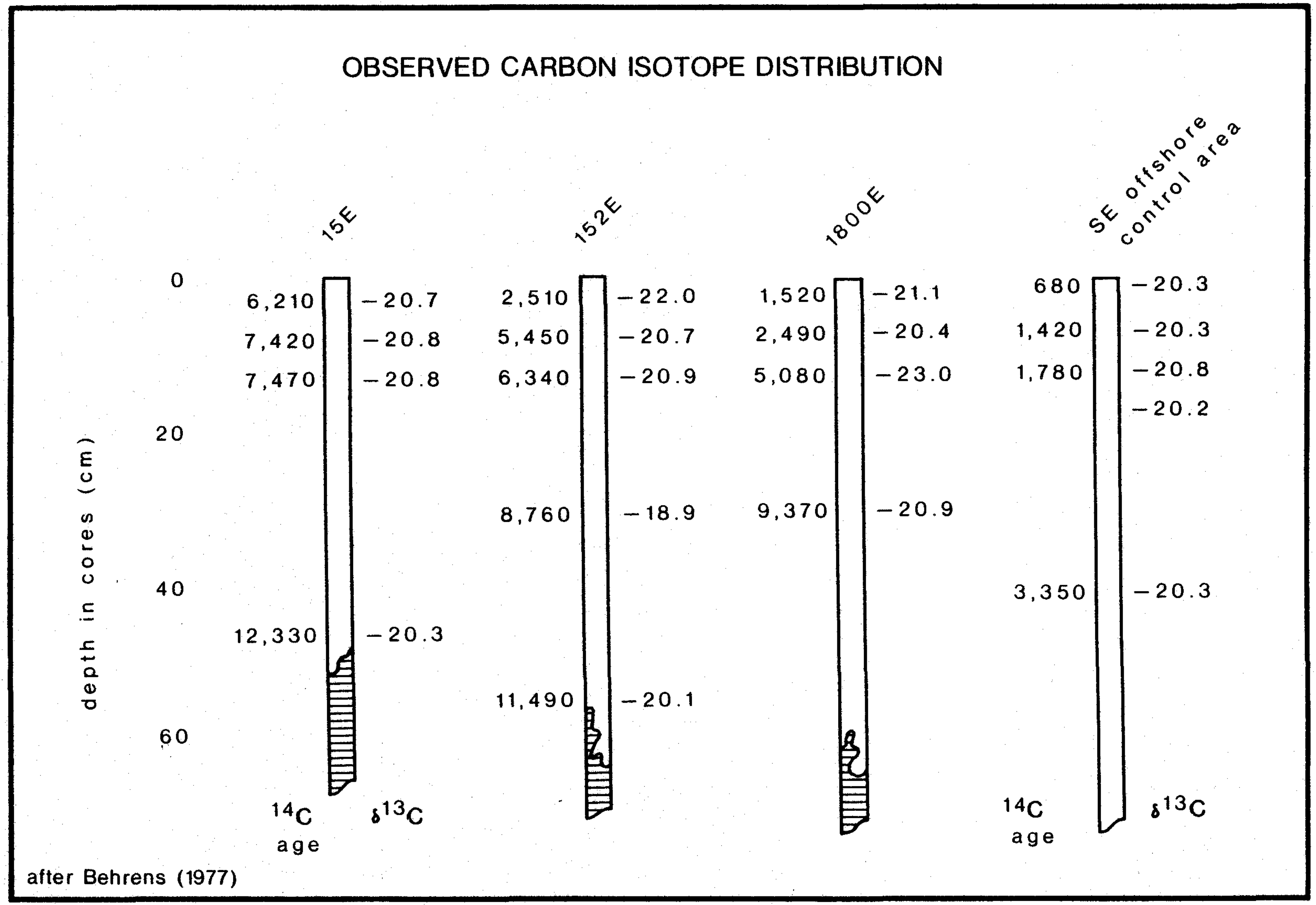


Figure 26. Observed carbon isotope distribution in cores. Lined parts are Pleistocene Beaumont Formation clays. Core designations ending in E indicate distance in meters East of Platform 288A. Control area is about 7 km southeast of the field.

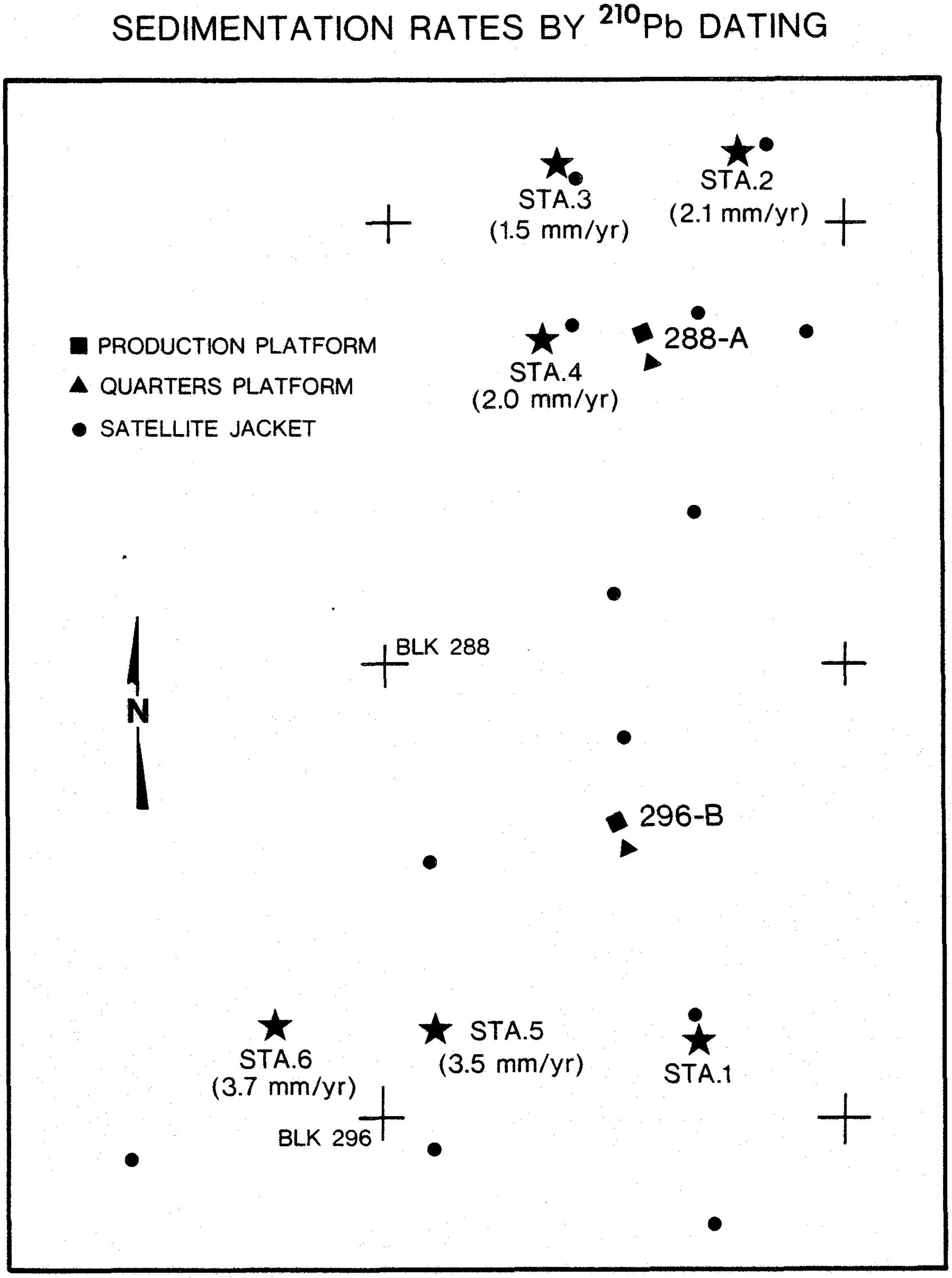


Figure 27. Locations of cores for Pb-210 dating. Sedimentation rates are in parenthesis.

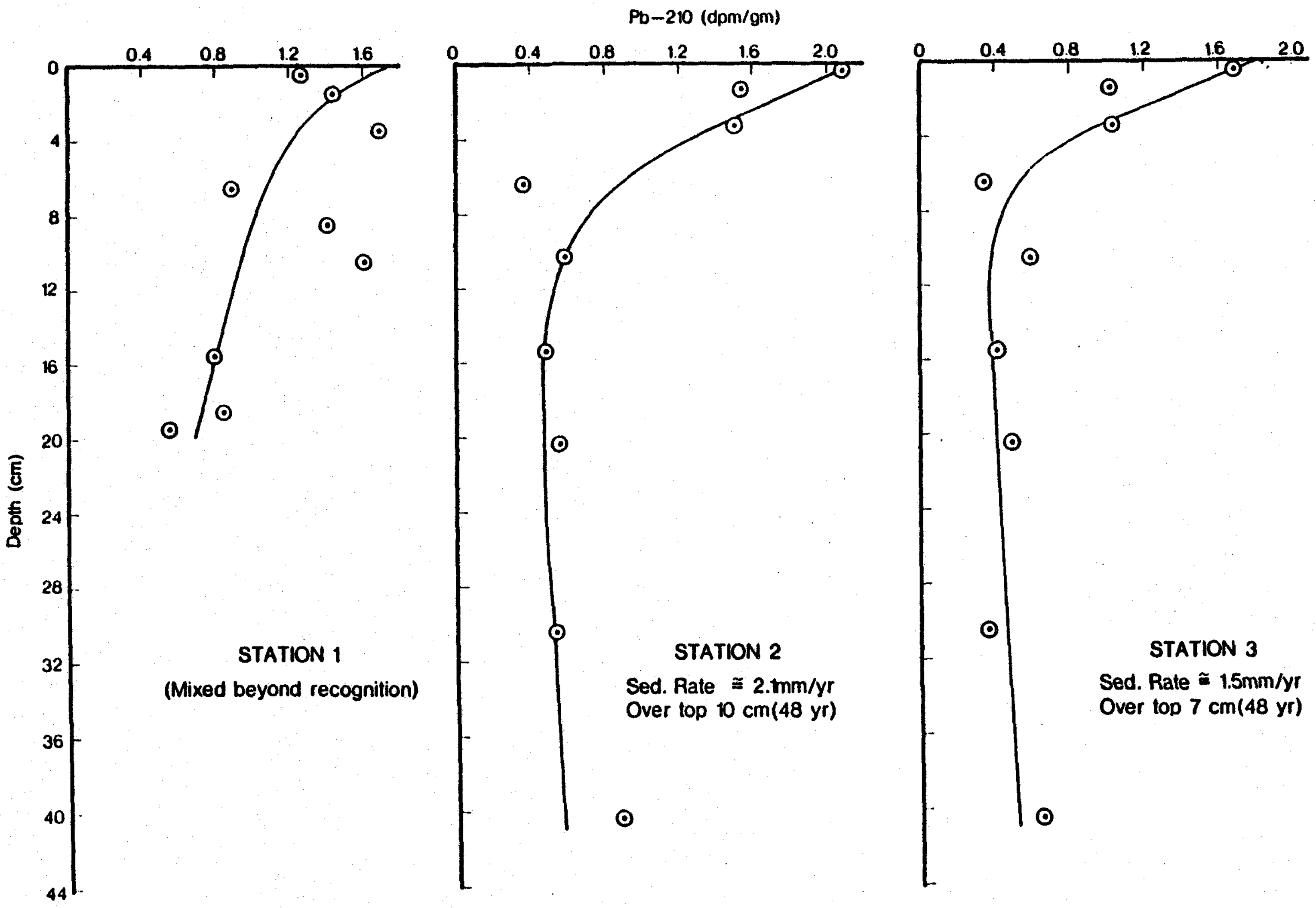


Figure 28. Pb-210 profiles in Buccaneer Field (see Figure 27 for location of stations).

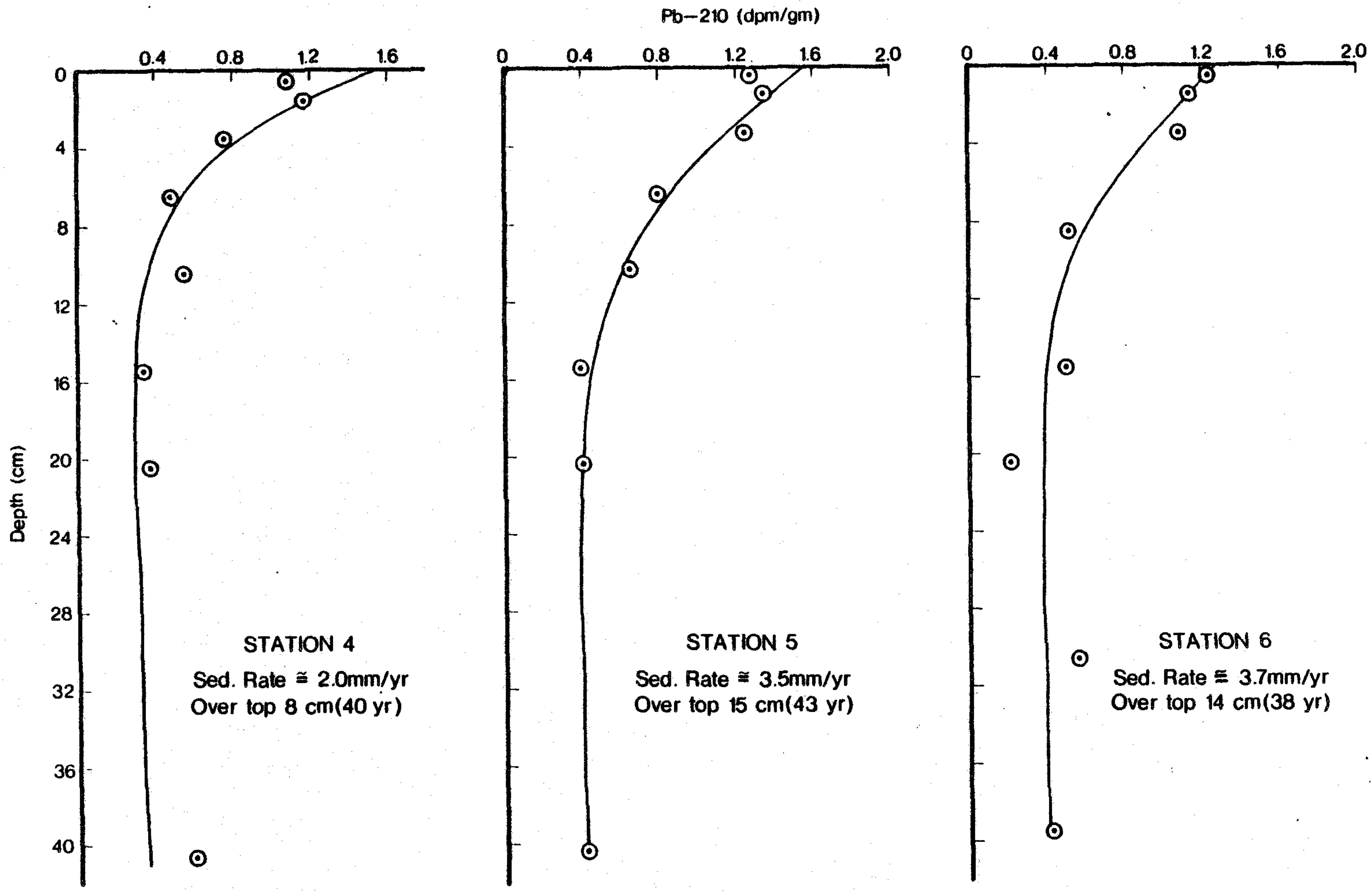


Figure 29. Pb-210 profiles in Buccaneer Field (see Figure 27 for location of stations).

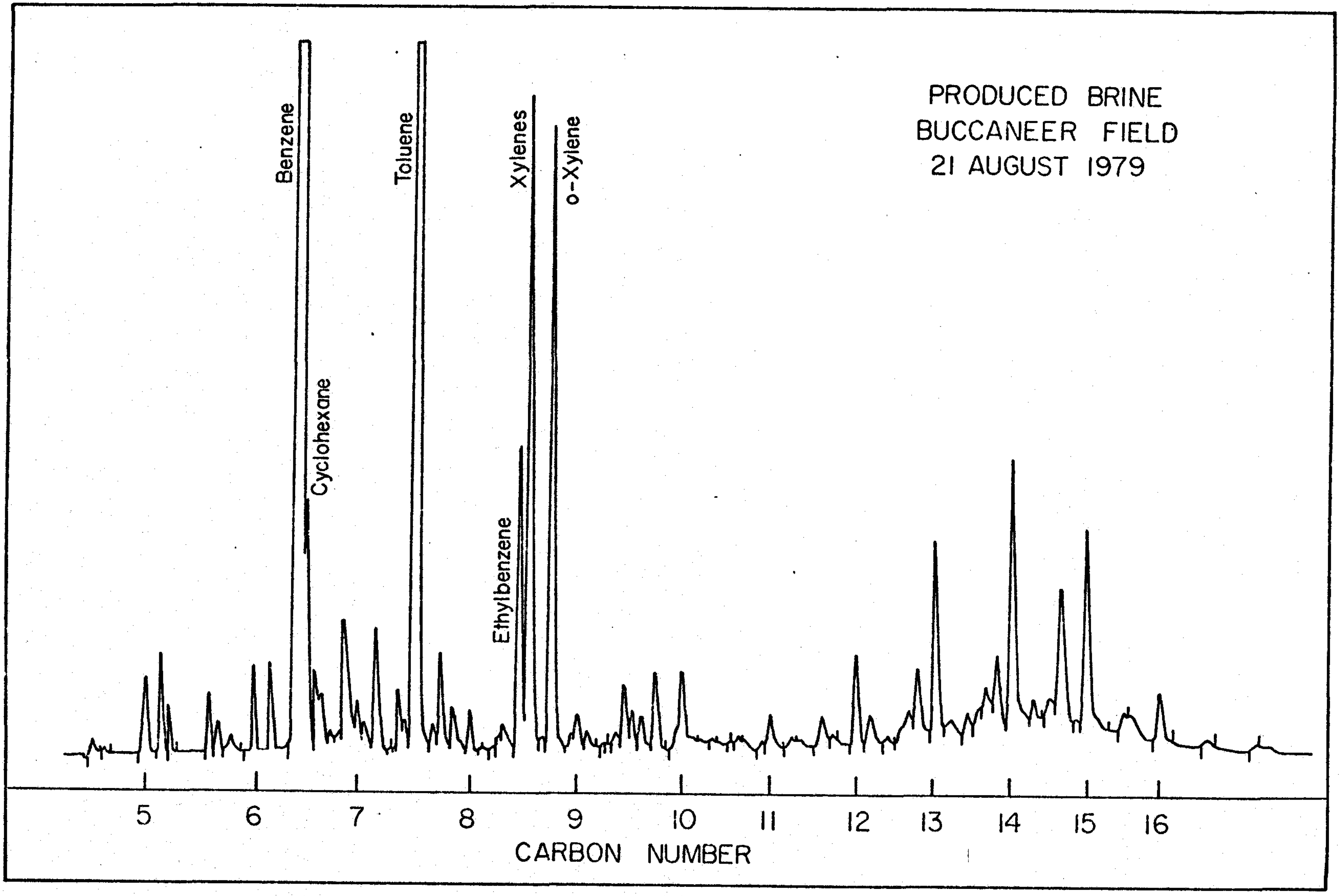


Figure 30. Chromatogram of volatile hydrocarbons in BGOF brine sampled on 21 August 1979.

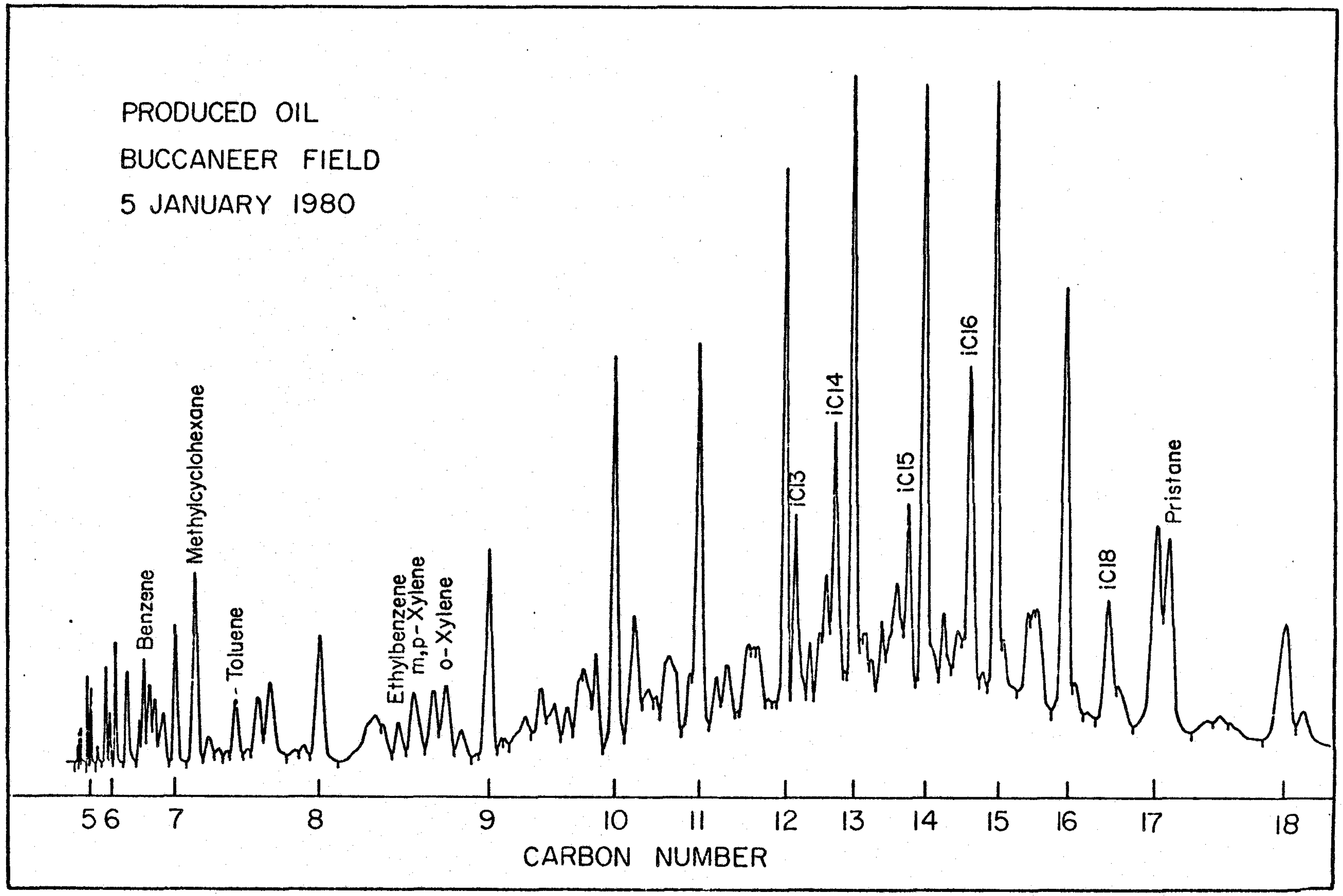


Figure 31. Chromatogram of volatile hydrocarbons in BGOF brine samples on 8 January 1980.

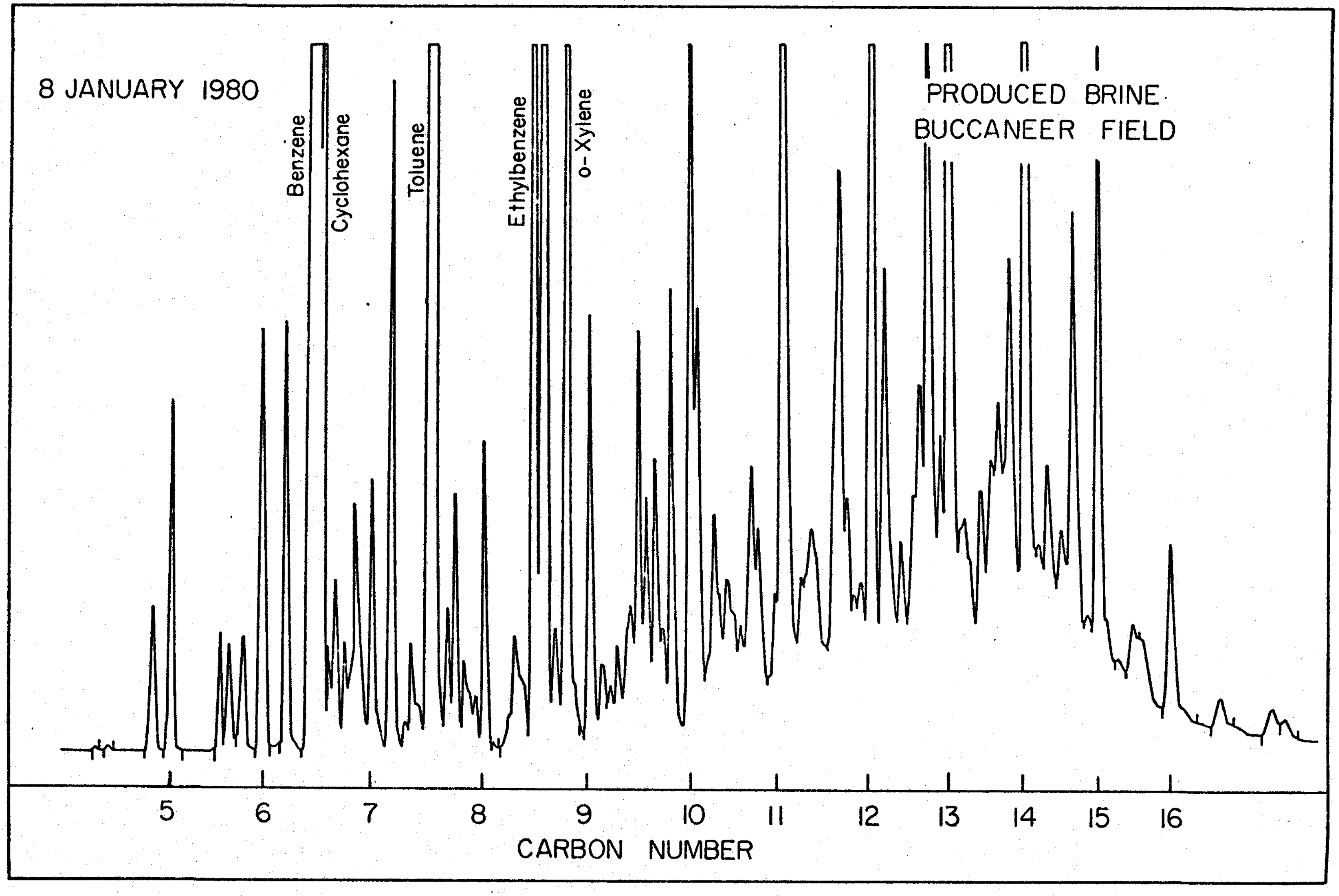


Figure 32. Chromatogram of volatile hydrocarbons in BGOF oil sampled on 5 January 1980.