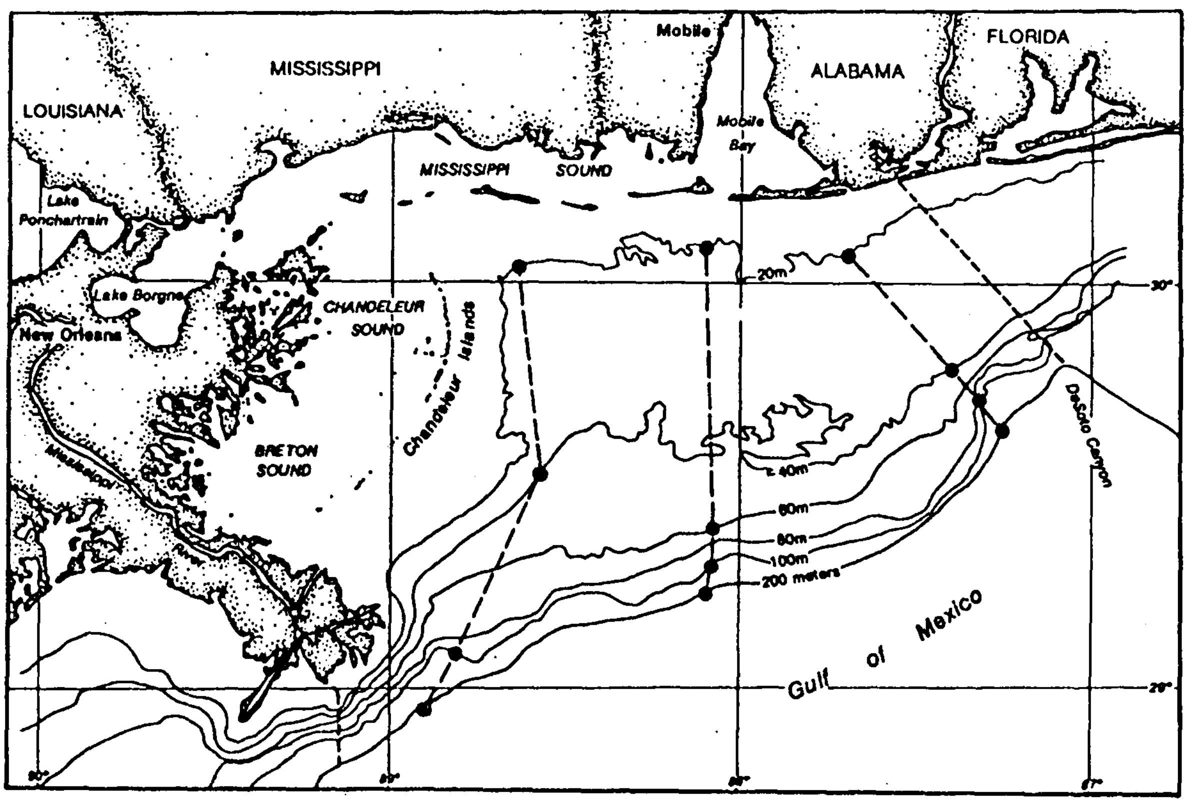
OCS Study
MMS 88-0071

Mississippi-Alabama Marine Ecosystem Study Annual Report Year 1

Volume I: Technical Narrative



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U.S. Department of the Interior
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OCS Study
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Mississippi-Alabama Marine Ecosystem Study Annual Report Year 1

Volume I: Technical Narrative

Editors

James M. Brooks
Charles P. Giammona

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ABSTRACT

Biological, physical, chemical, and geological characteristics were studied in a series of four cruises between March 1987 and March 1988 along three north-south transects across the continental shelf of Mississippi and Alabama. Four stations in depths of approximately 50, 100, 150 and 200 m were sampled along each of these transects. Side scan, Remotely Operated Vehicle (ROV), underwater color photographs, and video data were collected around topographic features in the study area. Subbottom profiler records indicate that the shelf edge is built upon delta-front forset beds that were truncated by erosion during the last low stand of sea level in the Pleistocene. Holocene sediments thickest (15 m), in the central part of the survey area cap the erosional surface and the topographic features were constructed on top of these sediments. Topographic features were, generally, of three classes: (1) pinnacles,with heights of about 2-15 m and widths of 2-200 m, probably formed by coral-algal assemblages; (2) linear ridges, perhaps lithified coastal dunes; and (3) enigmatic features. Sediments contained a mixture of biological and petroleum hydrocarbons. Biological hydrocarbons were predominantly plant biowaxes (n-C_{23} - n-C_{33}) with a possible minor planktonic input (n-C_{15} - n-C_{19}). Petroleum hydrocarbons were present as polynuclear aromatic compounds (PAH), a complete suite of n-alkanes, and an unresolved complex mixture. Sediment PAHs on the shelf are on average six times lower than PAHs analyzed in sediments in adjacent bays. High hydrocarbon concentrations were generally at the seaward end of the transects between the 100 and 200 m isobaths with the stations closest to the delta containing the highest concentration of hydrocarbons. Observed variations in sediment chemistry between samplings is possibly explained by a large episodic influx of riverine material followed by slow biological mixing by bioturbation or active currents on the shelf scouring the organic matter out of the sediments and depositing the organic rich material in a band along the shelf break. Sediments varied greatly in iron and trace metal content, but the variations seem to be largely the result of natural variability in grain size and mineralogy. Deep water sediments were enriched in Fe and trace metals compared to shallow water ones, but all were typical of unpolluted Gulf of Mexico shelf sediment. Manganese (Mn) concentration was only about half of that expected based on iron concentration for many of the samples. This shows the sediments of the area to be biochemically active and capable of solubilizing Mn and perhaps other metals. Physical oceanography studies initially showed surface temperature increased monotonically seaward from 15°C in shallow water to 18°C over the shelf slope. Isotherms followed the trend of the isobaths. A tongue of water with lower salinity and higher dissolved oxygen values extended southward from Mobile Bay across the shelf. In the southeastern portion of the study area, i.e., on the west side of De Soto Canyon, surface waters had higher salinity and lower oxygen values. Near the bottom, values of dissolved oxygen decreased monotonically from about 7.5 mg/l in shallow water to 4.5 mg/l at the 100 m isobath. A filament from a Loop Current eddy entered the study area at the end of the sampling period between Stations C4 and M4 and wrapped clockwise to the northeast. The filament contained water with higher temperature, salinity, and dissolved oxygen values both near the surface and bottom. A southwestward return flow, with opposite water mass characteristics, occurred in the southeast part of the study area. Satellite data positioned fronts associated with the Loop Current, warm core eddy, warm intrusions reaching into the region from the top of the Loop, warm intrusions from the Loop, and a cold ridge extending southward from the study area. Polychaetes were the dominant benthic macroinfauna taxon, both in terms of numbers of species and numbers of individuals. However, unlike many assemblages in the western Gulf of Mexico, no single species appeared to dominate the community. Nor were there any discernible patterns of diversity or abundance that could be attributed to inshore-offshore or east-west gradients. The macroepifauna data indicates the largest numbers of species were collected at stations in 100 m depths and the largest numbers of individuals were collected at the 150 and 200 m depth stations. A total of 2,839 demersal fish specimens representing 98 species and 37 families of fishes from the 11 samples were collected initially. Fishes were not caught at two stations (M4 and D3).

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ACKNOWLEDGEMENTS

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The work of the project field staff and the crew of the research vessels, R/V EXCELLENCE II and R/V TOMMY MUNRO is acknowledged. Dr. Roger Fay is the field coordinator and his assistance in the implementation of field sampling procedures has been very valuable and is greatly appreciated.

1.0 EXECUTIVE SUMMARY

James M. Brooks
Charles P. Giammona

The primary goal of the "Mississippi-Alabama Marine Ecosystem Program" is to describe the existing ecosystem and interrelate dominant, natural processes in a way that can be used to understand the impact of human activities in the area. This small area is important to the adjacent states because of the multiple use of the natural resources by a variety of groups. The first year of the "Mississippi-Alabama Marine Ecosystem Program" (known as the Tuscaloosa Trend Regional Data Search and Synthesis Study) was completed in the summer of 1985 and consisted of identifying all information sources that made reference to this area.

The program phase following the literature search involves a field effort to fill data gaps identified by the Minerals Management Service that builds on the information base required by MMS. The field effort will be followed by a comprehensive synthesis effort that will integrate both the results of the literature study and field sampling phases of the program. Field sampling has been designed to characterize dominant physical and chemical processes on the Outer Continental Shelf (OCS) and provide a basis for further investigations of spatial and temporal variations in biologic populations. Included in this study phase are analyses of trophic relationships among dominant biologic components of the ecosystem, descriptions of current movements, and descriptions of geologic features such as hard bottom areas that may be biologically sensitive or unique compared to surrounding habitats.

The survey area includes the edge of the continental shelf south of Mississippi and Alabama. Subbottom profiler records indicate that the shelf edge is built upon delta-front forset beds that were truncated by erosion during the last low stand of sea level in the Pleistocene. Holocene sediments up to 15 m thick cap the erosional surface and the topographic features of primary interest to this study were constructed on top of these sediments. The Holocene sediments are thickest in the central part of the survey area, indicating a small delta lobe was deposited in that area.

Interesting geologic features were found throughout the survey area. Generally, the sediment reflectivity displayed complex variations. High and low reflectivity was found and the variations between high and low reflectivity occurred in waves and patches of varying size and complexity. Topographic features were of three types: (1) pinnacles, (2) linear ridges, and (3) enigmatic features (features that could not be immediately interpreted). The first two categories account for most of the observed features, and many of these are located along an isobath approximately 73 m deep. This line is believed to be related to a stillstand in the recent post-glacial rise in sea level.

Following the acquisition of side scan and subbottom data from two cruises, the data were analyzed in a preliminary manner to determine which areas should be visited using the Remotely Operated Vehicle (ROV) during the scheduled ROV cruise of September 1988. This preliminary analysis was done prior to the compilation of the mosaic that is being constructed using the records.

The results of the preliminary side scan and subbottom data analysis indicated a surprisingly diverse habitat. The features in this area included:

- wave fields (closely spaced, low relief waves on bottom)
- spaced ridges (spaced approximately 100 m apart, if troughs exist, most seem to be in-filled with fine sediments)
- "pox" fields (areas of patchy hard bottom)
- ridges
- shorelines? (these may be previous stillstand erosional features)
- "boulder fields"
- extensive hard bottom areas (black side scan records)
- low topographic features (including "footprint" features which may be depressions in the bottom)
- moderate topographic features
- major topographic features (some with over 15 m relief)
- wrecks/sunken oil platforms
- oil platform (standing)

The primary objectives of the physical oceanography component are to characterize the circulation of the outer shelf, to identify exchange processes of the shelf with the deep ocean, and to synthesize existing data and new data to develop a coherent description of the hydrography and circulation of the study area. The measurement program for Year I includes three mooring arrays (30, 60, and 430 m) collecting information on current speed and direction, temperature, conductivity, and pressure, CTD/transmissivity vertical profiles at designated stations, and satellite imagery. The measurement program for Year II will be the same with the exception that two additional mooring arrays will be added. The mooring arrays for Year I were deployed in late December 1987. The two shelf moorings were changed out on 17-19 March 1988. All instruments were functioning properly except for the near surface current meter at the 60 m shelf mooring which had approximately a two week data loss at the end of the record. All three moorings were changed-out in August 1988. The Year I summary report will include all CTD/transmissivity data collected through 19 March 1988 (four cruises) and all data retrieved from the two shelf mooring arrays on 17-19 March 1988.

The satellite component of the physical oceanography investigation is responsible for monitoring and surveying the surface temperature expressions of the major physical features in the eastern Gulf of Mexico. The NOAA-9 and NOAA-10 Satellite Advanced Very High Resolution Radiometers were used to obtain infrared sensings of upwelling radiance from the sea surface in the channel four or 11 micron band. Eighty-three scenes have been purchased from National Oceanic Atmospheric Administration (NOAA), National Environmental and Satellite Data Information Service (NESDIS), and Satellite Data Services Division (SDSD) between 30 September 1987 and 29 May 1988.

The purpose of the satellite survey is to monitor the position of the Loop Current and mesoscale features in the Gulf. Accordingly, the positions of fronts associated with the Loop Current, warm core eddy, warm intrusions reaching into the region from the top of the Loop, warm intrusions from the Loop, and a cold ridge extending southward from the study area were observed. Frontal analyses that cover the entire eastern Gulf region have been prepared to show their development.

Sediments in the study area contain a mixture of biological and petroleum hydrocarbons. Biological hydrocarbons are predominantly plant biowaxes (n-C_{23} - n-C_{33}) with a minor planktonic input (n-C_{15} - n-C_{19})

possible. Petroleum hydrocarbons are present as polynuclear aromatic compounds (PAH), a complete suite of n-alkanes, and an unresolved complex mixture. Sediment PAHs on the shelf are on average six times lower than PAHs analyzed in sediments in adjacent bays. High hydrocarbon concentrations are generally at the seaward ends of the transects between the 100 and 200 m isobaths with the stations closest to the delta containing the highest concentration of hydrocarbons. Variations in sediment chemistry were observed between samplings and may relate to the influx of riverine material after further analyses are conducted. One possible scenario is a large episodic influx of riverine material followed by slow biological mixing by bioturbation to dilute the input. It is also possible that active currents on the shelf scour the organic matter out of the sediments, transport it offshore, and deposit the organic rich material in a band along the shelf break. Shelf sediment PAHs are typical of unprocessed petroleum as contrasted to adjacent bay sediment PAHs predominantly of a pyrogenic origin. Pyrogenic sources include fossil fuel combustion, carbonization of coal, and forest fires. The bay sediments were intentionally sampled away from point sources of pollution such as large urban areas and industrial complexes as part of the NOAA Status and Trends Program. Generally, higher hydrocarbon concentrations are associated with finer grained, organic rich sediments, but the association is weak.

The elements silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), thallium (Tl) and zinc (Zn) have been determined on all samples collected on the first three cruises. Twelve stations were sampled and sediment from the upper 5 cm of three different box cores was combined to produce a composite sample for each station.

All elements showed considerable variability from station to station and, for the shallow water stations, from cruise to cruise. The values were with few exceptions, about what would be expected for uncontaminated Gulf of Mexico sediment. This is best illustrated by looking at metal to iron ratios because, like iron, most metals are high in clay-rich samples and low in sand and carbonate rich samples. As expected, the outer (deeper water) samples were more iron and trace metal rich.

Assemblages of benthic organisms are, in part determined by composition of the substrate in which or on which the organisms live. Field observations indicate the study area has a great diversity of substrate types.

Macroinfauna - Polychaetes were the dominant taxon, both in terms of numbers of species and numbers of individuals. However, unlike many assemblages in the western Gulf of Mexico, no single species appeared to dominate the community. Nor were there any discernible patterns of diversity or abundance that could be attributed to inshore-offshore or east-west gradients. This lack of dominance and patterns is expected to change as data from more recent cruises are analyzed.

Macroepifauna - Data on composition and abundance of organisms collected by trawl indicates that the largest numbers of species were collected at stations in 100 m depths, and the largest numbers of individuals were collected at the 150 and 200 m depth stations. The data gathered and analyzed thus far are not adequate to construct even a rough estimation of infaunal and epifaunal community structure and distributional patterns. It is possible, in light of the varied nature of the substrates being sampled, that even with multiple data sets, it may only be possible to describe the community structure in general terms. Judgement on this must be deferred pending completion of more recent collections.

Results from the demersal fish study indicate the two most abundant species were the demersal outer shelf fish *Halieutichthys aculeatus* (Pancake batfish) (51 specimens), the demersal mid-shelf fish *Syacium gunteri* (Shoal flounder) (14 specimens), and the demersal outer shelf fish *Synodus poeyi* (Offshore lizardfish) (96 specimens), and *Syacium papillosum* (Dusky flounder) (44 specimens). Variation in species composition between the two outer shelf stations with fishes was similar to the midshelf stations.

There was considerable variation in species composition between the two upper slope stations. The most abundant species were the demersal outer shelf fish *Pontinus longispinus* (Longspine scorpionfish) (45 specimens) and the slope fish *Bathygadus macrops* (Rattail) (16 specimens), the demersal outer shelf fish *Macrorhamphosus gracilus* (Snipefish) (25 specimens) and the demersal outer shelf fish *Zalieutes mcgintyi* (Tricorn batfish) (17 specimens).

The results of preliminary fish food habit analysis of one species are given in this first report. Eighty-four specimens of the longspine porgy (*Stenotomus caprinus*) have been examined and 52 contained food. These represent 10 habitat/size-class groups. Polychaetes were the dominant food groups followed by small crustaceans. Trace amounts of nematodes, mollusks, and echinoderms were present. Organic detritus, the major category by volume, apparently consisted of mucous from polychaetes mixed with small amounts of organic material from other sources. Trace amounts of silt and sand were encountered. The number of specimens examined within each habitat/size-class is too small for discussion of habitat or size class implications.

2.0 INTRODUCTION

James M. Brooks
Charles P. Giammona

2.1 Program Relevance and Direction

The primary goal of the "Mississippi-Alabama Marine Ecosystem Study" is to describe the existing ecosystem and interrelate dominant natural processes in a way that can be used to understand the impact of human activities in the area, especially as it relates to petroleum exploration and development.

This relatively small area is important to the adjacent states because of the multiple use of the natural resources by a variety of groups including marine transportation, dredged material disposal, commercial fishing, recreational fishing, and energy-related industries. Competition for the space and resources and its effect on other resource uses requires an understanding of this system for effective management. Petroleum activities represent one of the more important resource uses in terms of positive and negative economic and environmental impact in this central Gulf states' region. This dual role has formed the basis for the design of the "Mississippi-Alabama Marine Ecosystem Study."

The first year of the "Mississippi-Alabama Marine Ecosystem Study" (known as the Tuscaloosa Trend Regional Data Search and Synthesis Study) was completed in the summer of 1985 and consisted of identifying all information sources that made reference to this area. The study compiled available data in the literature and produced a summary report that made an initial attempt to describe the regional biological and geological environment and some associated physical and chemical features. This information related to basic coastal process concepts and began to provide an integrated understanding of potential impacts on nearshore and offshore activities. A conceptual model was presented, again as a first attempt to interrelate processes and identify data gaps. Since the model was based on ecosystems in the northeast U.S., its major contribution was limited to illustrating the lack of information and the need for better models.

The phase following the literature search involves a field effort to fill data gaps identified by the Minerals Management Service and builds on the information base required by MMS to make petroleum development management decisions. The field effort will be followed by a comprehensive synthesis effort that will integrate both the results of the literature study and field sampling phases of the program. The final outcome of this program will produce the basis for a regional management plan for the central Gulf states Outer Continental Shelf (OCS) area.

Field sampling is designed to characterize dominant physical and chemical processes on the OCS and provide a basis for further investigations of spatial and temporal variations in biologic populations. Included in this study phase are analyses of trophic relationships among dominant biologic components of the ecosystems, descriptions of current movements, and descriptions of geologic features such as hard bottom areas that may be biologically sensitive or unique compared to surrounding habitats.

The second year of this field effort consists of field sampling cruises to further characterize the biology and chemistry of the OCS, continued current measurements on the OCS, and biological reconnaissance of continental slope topographic features. Second year sampling strategies will be based on information obtained during the first year field effort with an overall emphasis on special biotic or abiotic features.

The third year of this effort consists of final field work to gather environmental data that may be needed to fill information gaps. More importantly, it will be a time of synthesis and integration of information compiled during the previous years of field effort and literature review.

The complexity of the Mississippi-Alabama Marine Ecosystem Study has required a multidisciplinary research effort which is coordinated by a management team headed by Dr. James M. Brooks, program manager, and Dr. Charles P. Giammona and Dr. Rezneat M. Darnell, deputy program managers. The objectives of the management team are to oversee the fiscal aspects of the project, to act as liaison between principal investigators and the sponsor, to coordinate program output such as reports and data transmittal, and to coordinate field operations. The field personnel are responsible for coordinating the use of the Texas Engineering Experiment Station's research vessel R/V EXCELLENCE II, Gulf Coast Research Lab's R/V

TOMMY MUNRO, and other contract vessels. In addition, the field personnel assist the principal investigators in the collection of field data. The contractual matters of the project are the responsibility of the Texas A&M Research Foundation.

2.2 Study Objectives

The general objectives of this study area are:

1. TO BIOLOGICALLY CHARACTERIZE THE TOPOGRAPHIC FEATURES LOCATED ON THE OUTER SHELF OF THE STUDY AREA (Figure 2-1). A biological reconnaissance of topographic features on the outer continental shelf was conducted to characterize them with respect to habitat, biological community composition, structure and zonation; to define similarities and differences between hard-bottom communities in the study area and those associated with other oceanic topographic prominences in the Gulf of Mexico; to categorize the banks based on biological factors and zonation; and to correlate, as feasible, biological community composition and condition with environmental factors, particularly the nepheloid layer.

2. TO DESCRIBE THE SEDIMENTS AND TRANSITION AREAS OF THE REGION. The current field work corroborates data in the literature; provides integrated environmental information with simultaneously collected biological, chemical, and physical data; and helps our understanding of how biotic and abiotic factors relate in this study area.

3. TO DETERMINE THE SEAFLOOR TOPOGRAPHY AND HOW IT AFFECTS SEDIMENT DISTRIBUTION. Four cruises help corroborate information regarding seafloor topography given on existing charts.

4. TO EVALUATE THE PRESENCE OR ABSENCE OF BIOLOGICALLY PRODUCTIVE AREAS ON HARD BOTTOMS IN THE MOBILE AND NORTHERN VIOSCA KNOLL LEASING AREA. The data for this

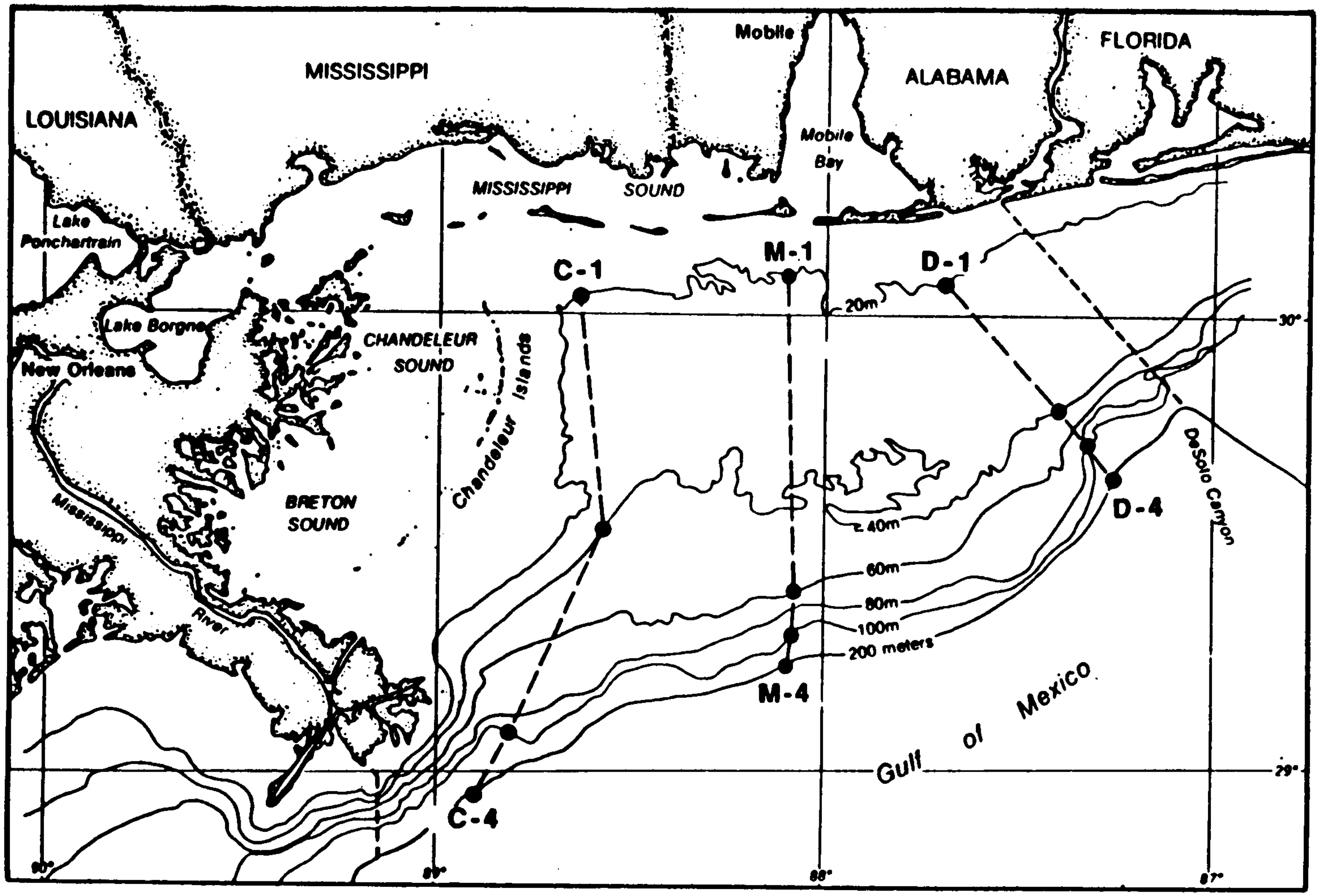

Figure 2-1. Twelve stations sampled on Cruises 0, 1, and 2 of the Mississippi-Alabama Marine Ecosystem Study.

objective were collected during biological and geological reconnaissance cruises in this study effort and help characterize and determine the extent of live bottom areas. It provides a stronger understanding of these poorly-known areas than any current information.

5. TO STUDY CIRCULATION PATTERNS AND DRIVING FORCES, ESPECIALLY DUE TO THE LOOP CURRENT, AROUND THE DE SOTO CANYON, INCLUDING METEOROLOGY, HYDROGRAPHY, CURRENTS, SEA STATE, AND FRESHWATER DISCHARGE. State-of-the-art satellite and physical oceanographic spectral analysis techniques were used to increase the understanding of physical processes in the area.

6. TO STUDY THE OCCURRENCE AND EXTENT OF THE NEPHELOID LAYER. Information on the nepheloid layer was collected by integrating data from physical, chemical, biological, geological, and reconnaissance sampling tasks.

7. TO INVESTIGATE THE EXTENT AND SIGNIFICANCE OF HYPOXIA ON THE SHELF. Information from chemical and physical measurements were collected to identify potential hypoxic conditions on the OCS.

8. TO STUDY THE FATES OF POLLUTANTS ASSOCIATED WITH SHELF ACTIVITIES, ESPECIALLY PETROLEUM EXPLORATION/PRODUCTION. The sampling scheme produces data that can corroborate information from existing data bases.

9. TO DEFINE SHELF BENTHIC COMMUNITIES WITH EMPHASIS ON HABITATS NOT PREVIOUSLY DESCRIBED AND NEAR-SLOPE ENVIRONMENTS. Data from the Strategic Petroleum Reserve Program of the Department of Energy, in conjunction with submersible observations on the outer shelf, provide insight to the benthic community structure in the study region.

10. TO ANALYZE TROPHIC RELATIONSHIPS AMONG BIOTIC COMPONENTS OF THE SHELF ECOSYSTEM WITH EMPHASIS ON ENERGY TRANSFER WITHIN AND BETWEEN PELAGIC AND BENTHIC COMPONENTS. The basis for the trophic relationships is being synthesized by integrating information from the above tasks.

2.3 Overview of the Study Area

The study area occupies the continental shelf from the Chandeleur Islands and Mississippi River delta, on the west, to a line extending from the Alabama-Florida border southeastward and intersecting the head of De Soto Canyon. It extends from the shoreline or barrier islands across the shelf to the 200 m isobath. Coastwise, the area extends about 140 miles from east to west, and the width of the shelf varies from around 40 miles in the east to about 80 miles in the west. For convenience the Mississippi-Alabama shelf is referred to herein as the Western Mississippi Bight (although technically it might better be termed the East Mississippi Bight).

As noted by Darnell and Kleypas (1987), the average annual stream discharge for the entire eastern Gulf of Mexico is slightly less than 10,000 m^3/sec, but about 85 percent of this total is received by the Mississippi Bight, primarily from the Mississippi River distributaries and the Pearl River (through Lake Borgne and Mississippi Sound). The actual quantity of freshwater received varies greatly from year to year, and the outflow also exhibits an extreme seasonal profile, with the heaviest outflow in late winter and spring and very low flow in summer and fall.

The Western Mississippi Bight is bordered on the northern and western sides by low salinity sounds, bays, and estuaries which are fringed with extensive coastal marshlands characterized by fine sediments and extremely high organic production rates. The Western Mississippi Bight receives annually, in addition to the large input of low salinity water, a considerable load of fine particulate inorganic and organic material which is subject to redistribution by water currents of the shelf. Thus, the western sector of the shelf contains fine-grained, organic-rich clays and silts of terrestrial origin, variously mixed with quartz sand. The clay and sand spread eastward and, east of Mobile Bay, sand predominates. Areas immediately off the barrier islands are subject to heavy wave action and strong alongshore currents which remove and transport finer particles, so that these islands are fronted by a band of coarse quartz sand which may extend to a depth of 40 m. In deep water along the edges of De Soto Canyon and likely along the outer shelf of much of the Mississippi Bight at depths of 150 m and more, are deposits of finer carbonates characteristic of the upper slope.

Directly south of Mobile Bay at a depth of about 36 m there are extensive areas of low relief calcareous outcrops of unknown origin, known locally as "broken bottoms" or "ragged bottoms." Mr. Elmer Gutherz and Mr. Bennie Rohr of the National Marine Fisheries Service have stated that these areas are major spawning grounds for the Atlantic croaker, spot, and other estuary related species, and extremely heavy species concentrations were demonstrated in this area by Darnell (1985). Because of its ecological importance, this area represents one of the study sites selected for the present project. Additional rocky outcrops have been reported to occur in depths of 146 m to 366 m in the area from south of Mobile Bay and eastward toward De Soto Canyon. Another outcrop has been noted at depths of 73 to 91 m directly south of Biloxi, MS, and others undoubtedly occur in deeper waters of the Mississippi Bight area. From submersible observations, Shipp and Hopkins (1978) reported that the deepwater outcrops around the edges of De Soto Canyon are flat limestone slabs lying on the surface. This is probably true for many of the other deepwater hard bottoms, but the possibility of fossil reefs and other hard structures cannot be precluded (Ballard and Uchupi 1970).

Circulation patterns in the Mississippi Bight area have recently been discussed by Darnell and Kleypas (1987). These patterns are complex and only partly understood. Waters of this area represent a coherent hydrographic unit which is primarily wind-driven although the Loop Current may sometimes reach this shelf area. During the fall and winter months, primarily in response to northerly winds, surface currents exhibit a cyclonic or counterclockwise gyre. During the summer, due to southerly winds, the rotation is reversed, and circulation becomes anticyclonic. Late spring and early fall are transitional periods in which the direction of flow is not predictable from wind data. Throughout the year in nearshore areas where the depth is less than about 20 m, the water column tends to be well mixed, and circulation of bottom water follows the patterns of the surface circulation. At depths greater than about 20 m, due to the Coriolis effect, bottom water moves at an angle somewhat to the right of the direction of flow of the surface water, the actual angle of deflection depending upon the depth. However, movement of the subsurface water is constrained by the configuration of the bottom contours, and when surface circulation is counterclockwise, the bottom waters must be in close accord.

The De Soto Canyon area is subject to the intrusion of deep Gulf water which may funnel up the canyon and spill onto the shallower shelves producing local upwelling conditions. Current patterns in this area are quite variable. Gulf loop current water has been recorded to transgress the shelf to within eight kilometers of shore between Pensacola and Panama City, FL (Huh, 1981). Cooler slope water may intrude upon the outer shelf anywhere in the eastern Gulf, but this phenomenon is particularly prominent around the head of De Soto Canyon.

From data presented in Darnell and Kleypas (1987) and in Franks *et al.* (1972) it is evident that the surface water temperature of the Mississippi Bight may vary from a winter low of 11.7°C to a summer high of 31.0°C for a seasonal change of about 19.0°C. During the warmer months, the water becomes stratified at a depth of about 18 m and vertical temperature differences of almost 13.0°C have been observed. Salinities may vary from 16.0 °/oo in winter and spring to 38.8 °/oo in the summer and fall. Generally speaking, the lower temperatures occur nearshore, and the lower salinities occur toward the west where the area is most influenced by stream runoff. Around the rim of De Soto Canyon, bottom temperatures during the summer range 1.0 - 4.0°C cooler during the summer than during the winter, and the summer temperature depression appears to be due to the intrusion of colder slope water during the summer months. No areas of anoxic bottom water have been reported for the continental shelf of the Mississippi Bight area, although late summer hypoxia does occur in Mobile Bay (R. Darnell, personal communication). Highest turbidity values tend to occur in the shallower nearshore waters, but a near-bottom nepheloid layer has been reported to persist over the outer shelf throughout the year.

Biological features of the Mississippi Bight area have been discussed by numerous authors, most prominently by Defenbaugh (1976), Barry A. Vittor and Associates (1985), and Darnell and Kleypas (1987). The invertebrate and demersal fish fauna are generally typical of the widespread species of the northern Gulf coast. However, detailed analysis shows that there is a considerable admixture of species more typical of the calcareous bottoms of the shelf of the Florida peninsula. Additional faunal elements include slope species which intrude onto the shelf around the Mississippi River delta and around De Soto Canyon and tropical elements which are apparently brought in by the Gulf loop current. Many of these are not permanent residents, but Humm and Darnell (1959) reported resident populations of many tropical species of marine algae in the lee of the Chandeleur Islands. Parker (1960) and Defenbaugh (1976) referred to a unique pro-delta environment and fauna near the Mississippi River delta. Reviewing the available faunal information, Darnell and Kleypas (1987) concluded that the fauna of the Mississippi delta is a transitional fauna, representing elements of both the northwestern and eastern Gulf shelf areas. However, it is more than a transition area. It is a unique mix of species, some of which are not found elsewhere along the U.S. Gulf coast, and it is characterized by extremely high biological productivity and fisheries yield (Roithmayr 1965). For these reasons it is considered biologically and ecologically unique and a major faunal area in its own right.

3.0 FIELD SAMPLING AND LOGISTICS

Roger Fay

3.1 General Sampling Overview

The first year field effort was directed toward characterizing biological, chemical, and physical processes which dominate the Mississippi-Alabama Florida (MAFLA) continental shelf. To this end two biological/chemical cruises were conducted in the summer and winter seasons, current meters were deployed along a transect to provide continuous yearly measurement, and a geological characterization of topographic features was conducted using shallow subbottom profiling, side scan sonar, bathymetry, and a Remotely Operated Vehicle (ROV).

In addition to this first year's sampling requirements, additional field data were utilized from the R/V GYRE cruise conducted in the winter of 1987. These samples were taken prior to contract award, and not as a part of this effort, but were included since stations and sample types were the same as for this study. These data are designated as having been collected on Cruise B-0.

Also in the first contractural year, the second summer sampling for biological/chemical characterization (Cruise B-3) was completed in conjunction with the third current meter servicing (Cruise P-3).

The biological/chemical sampling array was comprised of three onshore/offshore transects, each with four sampling stations (20, 50, 100, and 200 m). The geological characterization studies were located in the center of the study region between the 55 and 180 m isobaths. Three current meter arrays were placed near the eastern transect in water depths of 30, 50 and 500 m.

3.2 Vessels

Except for the initial effort on the geological characterization cruise (G-1), all the field work was conducted from the R/V TOMMY MUNRO. Cruise G-1 was begun in October 1987 on the R/V EXCELLENCE II, and was completed in April 1988 on the R/V TOMMY MUNRO. The R/V TOMMY MUNRO is owned by the Gulf Coast Research Lab and operated from the port of Biloxi, Mississippi. The vessel is 29.87 m long, accommodates 12 scientists, and is fully equipped with sampling gear and laboratory space to accommodate the project requirements.

3.3 Navigation

Navigation for all aspects of the study except for the geological mapping was by LORAN C. On the geological mapping Cruise G-1, precision navigation was contracted from John Chance and Associates (JCA) utilizing their STARFIX system. On the continuation of that geological characterization (Cruise G-1A), precision navigation was again contracted from JCA using ARGO.

3.4 Sampling

3.4.1 Water Column

Water column characterization was accomplished with a CTD/transmissivity profile and six bottle water casts at each of the 12 stations on every biological/chemical cruise. This basic data set was augmented with CTD/transmissivity profiles during current meter servicing and at selected stations as the vessel transited the study area.

The CTD was a Sea-Bird Electronics Model SEACAT SBE 19, interfaced with a Sea Tech, Inc. 25 cm transmissometer. Water samples for salinity, dissolved oxygen, and nutrient determinations were collected from 1.7 l Niskin samplers. Temperatures on the CTD were confirmed with reversing thermometers on the top and bottom bottles.

Light penetration in the upper water column was measured with a Secchi disc at those stations sampled in the daylight hours.

3.4.2 Sediments

Sediments were sampled using a 20 cm box corer or Smith-McIntyre grab depending on the sediment type. Six box cores were taken at each of the 12 stations for infaunal and grain size analysis. Additionally, three box cores were taken at each station and subsamples were composited from these three for analysis of sediment hydrocarbons, trace metals, and grain size.

3.4.3 Epifauna/Nekton

Duplicate 15 minute trawls were made at each station for epifauna and nekton collections. The trawl was a semi-balloon otter trawl with 1/2" stretch mesh, made by Marinovitch Trawl in Biloxi, Mississippi. Steel V doors and 100' bridles were used.

3.4.4 Sample Inventories

From each of the biological/chemical cruises inventory of samples and/or observations were collected (Table 3-1).

3.5 Cruise Summaries

3.5.1 Biological/Chemical Characterizations and Current Meter Deployments

Summer 1987, Cruise B-1 - Cruise B-1 was conducted on board the R/V TOMMY MUNRO. Rigging of the vessel was conducted on 28 September 1987 in Biloxi and the cruise departed that evening. Sampling was completed and the ship returned to Biloxi on 5 October.

Sampling consisted of nine box cores (or Smith-McIntyre grabs where the sediments were sandy), two trawls, and one CTD/water cast at each of 12 stations (three transects of four stations each). Additional CTD profiles were made along the transects to provide closer spacing between the shoreward most stations.

Table 3-1. Inventory of samples collected on each biological/chemical cruise.

	SEDIMENT						WATER COLUMN				
	BIOLOGICAL		REPLICATES	COMPOSITE			PROFILE		DISCRETE		
STATION	INFAUNA	TRAWL	GRAIN SIZE	GR SZ	TR MET	HC'S	CTD	TRANSMISS	DIS OX	NUTRIENTS	SAL
C-1	6	2	6	1	1	1	1	1	5	4	4
C-2	6	2	6	1	1	1	1	1	5	4	2
C-3	6	2	6	1	1	1	1	1	5	4	2
C-4	6	2	6	1	1	1	1	1	6	6	2
M-1	6	2	6	1	1	1	1	1	5	5	5
M-2	6	2	6	1	1	1	1	1	6	6	2
M-3	6	2	6	1	1	1	1	1	6	6	2
M-4	6	2	6	1	1	1	1	1	6	6	2
D-1	6	2	6	1	1	1	1	1	5	5	5
D-2	6	2	6	1	1	1	1	1	6	6	6
D-3	6	2	6	1	1	1	1	1	6	6	6
D-4	6	2	6	1	1	1	1	1	6	6	6

All samples were collected at the same locations which were occupied on the R/V GYRE cruise in January 1987, with the exception of Station C-2 which was moved to the west on this cruise in an effort to bring the location in closer proximity to oil production activities. After initial stations were sampled while adrift on station, it was determined and subsequently followed, that all shallow stations were sampled better while on anchor.

Participants - The scientific party consisted of the chief scientist (Roger Fay), the principal investigators for physical oceanography (Frank Kelly), infauna (Don Harper), and nekton (John McEachran), MMS representative (Bob Rogers), and six graduate students/technicians (Rusty Barnett, Andy Tirpac, Steve Mayfield, Janet Thomas, Matt Ellis, and Jim Simons).

Problems - The only sampling difficulty occurred at Stations D-2 and M-4. Three trawls were required at Station D-2 in order to get two good replicates. A similar difficulty was encountered during the January R/V GYRE cruise. Both trawls at Station M-4 produced little in the way of expected sample. Only a few traces of bottom contact indicators (rocks, corals) and a few small fish (no large fish or invertebrates) were recovered. The difficulty in sampling M-4 and the net tearing experienced on the "D" transect prompted use of additional sampling gear on the next cruise in order to better discern bottom type and fauna. A small dredge and a roller rigged otter trawl are suggested as a means to effect better sampling. Although the samples will not be directly comparable to those from the trawl, they will be better than none.

Sampling was interrupted on the morning of September 9 due to weather, and the vessel returned to Biloxi. The cruise resumed on the morning of 2 October. Weather also caused another 24 hour delay from 3-4 October as the boat was forced to seek shelter in the Mississippi River from a storm. Sampling was completed and the boat returned to Biloxi on 5 October.

Gear loss included one 5 l Niskin bottle from the rosette sampler during deployment at Station C-1, and a large tear in the trawl on the eastern stations (D transect).

Initial Current Meter Deployment P-1 - The current meter moorings were deployed in December 1987. Two cruises were required due to weather and the holiday schedule of the R/V TOMMY MUNRO. The first cruise departed Gulf Coast Research Lab dock, Biloxi, MS at 2010 hours on 20 December 1987. It arrived at mooring Site A at 0740 hours, 21 December 1987. The surface witness buoy was deployed about 9 m from the current meter array. The instruments were attached by divers and then the current meter mooring was deployed and the moorings were inspected. A CTD cast was then performed, and then departed Site A at 1135 hours. Arrival at Site B was at 1430 hours and began deploying the witness buoy. At about 1500 hours the operation was canceled by Chief Scientist Frank Kelly because of safety considerations due to deteriorating sea state. The boat arrived in Biloxi at about 0600 hours, 22 December 1987.

The second cruise aboard the R/V TOMMY MUNRO departed Biloxi at 1600 hours, 29 December 1987 and arrived at Site B at 0830 hours, 30 December 1987. Deployment of the witness buoy and the current meter mooring was completed at 1100 hours. A CTD cast was performed before departing for Site C at 1135 hours. Four additional CTD casts were performed on the return leg to Biloxi. The ship arrived Biloxi at 0600 hours, 31 December 1987.

The moorings were designed for specific water depths. Since actual water depths differed slightly from depths indicated by the nautical charts, the final location of each site differs slightly from that originally proposed.

No problems were encountered during the two cruises other than weather and sea state. All instruments and mooring systems appeared to be functioning properly. The U.S. Coast Guard, Private-Aids-To-Navigation Section, New Orleans was notified after each cruise about the deployment of the buoys, per the requirements of our permit to operate private aids to navigation.

Winter 1988, Cruise B-2 and Current Meter Servicing P-2 - Cruise B-2 was conducted onboard the R/V TOMMY MUNRO. Rigging of the vessel was conducted on 9 March 1988 in Biloxi and the cruise departed 10 March at 1230 hrs. Sampling was partially completed and the ship returned to Biloxi on 13 March due to weather and the need to change the scientific party.

During Cruise P-2, which departed Biloxi 15 March, biological sampling was completed and the current meter records and batteries were changed out. The vessel returned to Biloxi 18 March, unable to complete sampling at Station M2. This was accomplished during the completion of the geological characterization Cruise G-1A.

Biological/chemical sampling consisted of nine box cores (or Smith-McIntyre grabs where the sediments were sandy), two trawls, and one CTD/water cast at each of 12 stations (three transects of four stations each). Samples were collected at the same locations which were occupied on the R/V TOMMY MUNRO cruise in September 1987. Additional CTD profiles were made along the transects during Cruise P-2 to provide closer spacing between the shoreward most stations.

The two current meters and the tide meter at Site A were replaced with freshly serviced ones. The current meter from the top location at Site A was then serviced on board while enroute to Site B, in preparation for its use at that site. The two current meters and the tide meter at Site B were replaced with diver assistance. Because of calm seas, it was possible to raise Mooring B without having to trigger the acoustic release, thus saving the anchor. The surface witness buoys and their lights were functioning properly at both sites. An attempt was made by the divers to replace the top current meter at Site C, but visibility was surprisingly low in the water and this effort was aborted. However, the acoustic transponders at the top and bottom of the mooring verified its location and existence.

We also deployed Coast Guard experimental current drifter buoys in the vicinity of Station M4 during the major portion of the biological cruise. The buoys determine their position from LORAN, record the data internally, and transmit their positions to receivers/computers on the research vessel which tracks their progress and predicts their movement.

Participants - The scientific party on Cruise B-2 consisted of the chief scientist (Roger Fay), the principal investigators for infauna (Don Harper), and nekton (John McEachran), Coast Guard representatives Art Allen and Lew Lewandowski, electronics technician Eddie Webb and graduate students/technicians (Jim Simons, Maggie Edwards, Steve Mayfield, Joe Chazar, Mike Cook, and Warren Brasher).

The scientific party on Cruise P-2 consisted of chief scientists Frank Kelly and John McEachran, dive master Ervan Garrison, divers Mike Harrelson and Paul Fitzgerald, and graduate students Mike Cook, Jim Simons, Maggie Edwards, Steve Mayfield, and Joe Chazar.

Problems - On Cruise B-2, weather began to slow the operations early into the cruise on the afternoon of the second day. By 0130 of day three the seas had increased to the point that over the side sampling was discontinued except for trawling, and the boat began a return toward Biloxi. By noon on the third day all sampling at the nearshore stations was continued by anchoring in the more sheltered water. The weather worsened on day four to the point where sampling was extremely inefficient (28 grab attempts were required to get six good samples). With an unfavorable forecast, the boat returned to Biloxi in order to continue biological sampling on Cruise P-2 after some repairs to the Smith-MacIntyre.

Near the end of Cruise P-2 the wind and seas built quickly and prevented completion of the last two box cores at Station M2. A complete set of six replicates for infaunal analysis was collected on Cruise G-1A in April.

Summer 1988, Cruise B-3 and Current Meter Servicing P-3 - Cruise B-3 was conducted on board the R/V TOMMY MUNRO. Rigging of the vessel was conducted during the evening of 18 August and the early morning of 19 August 1988 in Biloxi, Mississippi. The cruise departed at 0930 hrs 19 August 1988 and returned to Biloxi at 1420 hrs 25 August 1988. All objectives for sampling and instrument servicing were completed. The weather for the duration of the cruise was very typical for this time of year -- very hot, occasional thunder showers, seas up to one meter.

Twelve primary stations were occupied. Their locations were the same as the ones occupied during Cruise B-2.

Additional CTD/Transmissivity profiles were made at nine supplemental stations along the cruise transects to provide better resolution of the distribution of hydrographic variables and at the current meter sites. Dissolved oxygen samples were collected at some of the supplemental stations. The locations of supplemental stations vary from cruise to cruise.

The mooring at Site A was retrieved in its entirety, including the anchor. The Sea Data Corp., TDR Micrologger (SN240) was found to be completely flooded; all data were lost, and the instrument was destroyed by corrosion. Bio-fouling was extensive on all surfaces without anti-fouling paint. The steel flotation buoys were scraped, cleaned and painted with anti-fouling paint. The mooring was re-deployed with new wire rope, new hardware, and instruments that had been prepared in the laboratory. The surface witness buoy at Site A was in good condition and its light was functioning.

An attempt was made to retrieve the mooring at Site B in its entirety, but the anchor broke loose from the mooring and was just prior to being brought on board. Bio-fouling on unpainted surfaces was not as severe as at Site A. The steel flotation buoys were scraped, cleaned, and painted with anti-fouling paint, and the instruments were serviced while sampling was conducted at Stations M2 through M4. The mooring was re-deployed with new wire rope and mooring hardware.

The two Data Sonics acoustic releases on the mooring at Site C failed to respond to both interrogation signals and release commands. The releases were new and had just been received from the manufacturer prior to being deployed in December 1987. They have a rated deployment life of more than one year. The cause of the failure is being investigated in cooperation with the manufacturer. Fortunately, the mooring also had a small acoustic transponder attached near the top. Instead of having to drag for the mooring, which can damage the instruments, divers searched for the top of the mooring with the aid of a hand-held, underwater acoustic interrogation unit. They were eventually able to locate the top of the mooring and attach a cable from the ship. The entire mooring was then lifted aboard. Two dive teams had to make several dives each because of a swift current and the limited bottom time at 21 to 27 m. The search and recovery efforts, including the time divers had to wait between dives to eliminate residual nitrogen, added about 18 hours of additional ship time to the cruise.

Participants - The scientific party on Cruise B-3 consisted of the chief scientist (Frank Kelly), the principal investigators for infauna (Don Harper) and nekton (John McEachran), MMS observer Ann Bull, electronics technician Eddie Webb, and graduate students/technicians (Jim Simons, Maggie Edwards, Mike Cook, Andy Terpak, Janet Thompson, Bob Huntington, and Jim Jobling).

Problems - The only major problem was the failure of the acoustic releases on Mooring C, as described above. Some minor problems occurred that required a total of a few hours of ship time to troubleshoot and fix, such as a twisted trawl cable and a short in the CTD cable.

3.5.2 Geological Characterizations

Geological Sampling Overview - Year 1 geologic mapping was carried out on two legs: 87-MMS-G1 and 88-MMS-G1A. The former was run in October-November 1987 aboard the R/V EXCELLENCE II, and the latter during April 1988 aboard the R/V TOMMY MUNRO. The purpose of the cruises was to map, with 100 percent bathymetric and side scan sonar coverage, the topographic and hard bottom features within the study area. The survey area is a rectangle whose corners are:

Northwest corner	29° 25' 44" N	88° 01' 48" W
Southwest corner	29° 14' 24" N	87° 56' 54" W
Southeast corner	29° 26' 06" N	87° 23' 36" W
Northeast corner	29° 36' 40" N	87° 28' 30" W

The survey consisted of 34 lines, oriented southwest-northeast, and six tie-lines run nearly perpendicular to the other lines (Figure 3-1). Lines 1-20 were completed on Cruise 87-MMS-G1 before inclement weather caused its cancellation. On the second leg, 88-MMS-G1A, Lines 21-34 and tie lines A-F were completed. Line 20 was resurveyed to assure the compatibility of the navigation of the two cruises. In all, approximately 1,166 NM of track-line data were collected.

Side Scan Sonar and Subbottom Profiler - The geological characterization study utilized a digital side scan sonar, analog subbottom

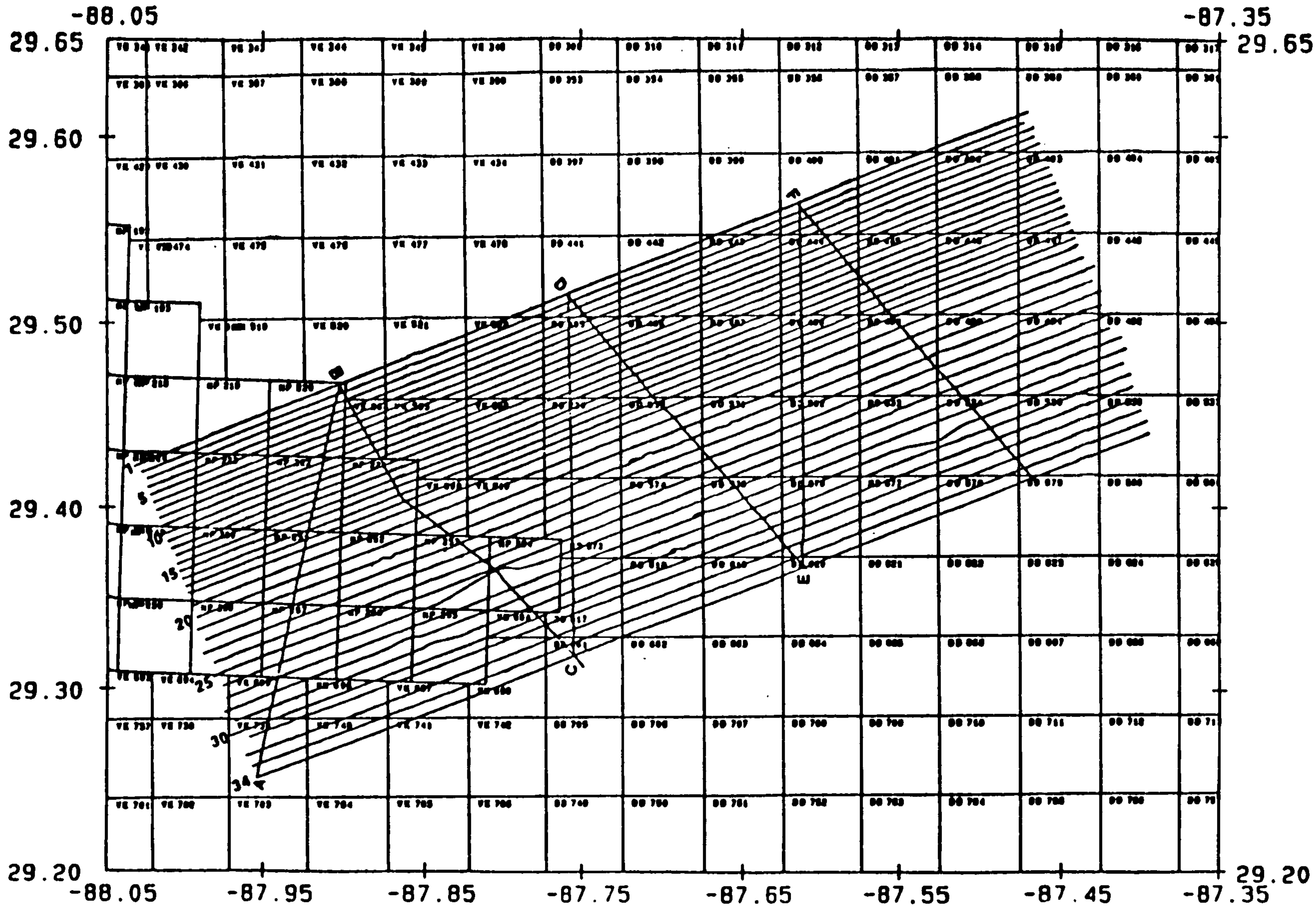

Figure 3-1. MMS survey -- Mississippi-Alabama ship tracks.

profiler, and a mini-sparker. The latter was used only on a few lines as it was found to interfere with the side scan sonar (see Section 12). The side scan sonar was an EG&G model 260 digital system which operates at a frequency of 100 kHz. Replay capability was provided by recording the raw side scan data on a PERTEC series 6000 tape drive. The subbottom profiler was an EDO-Western model 515A with a dual frequency (four and seven kHz) capability. In order to provide the maximum acoustic penetration, the lower frequency was used. The mini-sparker was a 700 Joule model manufactured by Del Norte Technology.

Geophysical data were collected continuously along all survey lines. Side scan and subbottom profiler records were obtained along lines 1-34 and subbottom and mini-sparker profiles were collected along lines A-F. For lines 1-34, the line trend and spacing was determined by the side scan sonar coverage. The trend follows the seafloor isobaths, minimizing both the number of ship turns and changes in tow fish depth. In the shallower parts of the survey area (less than about 55 m, lines 1-18) lines were spaced approximately 500 m apart and the sonograms were collected with a 300 m range setting (600 m total swath width). Originally, a 1,000 m spacing was planned for the lines in deeper water, however, this did not provide adequate coverage and a 750 m spacing was used. The side scan sonar was set on a range of 400 m (800 m total swath width). Tie-lines (A-F) were run to be approximately perpendicular to the other survey lines. As it is also nearly perpendicular to the structural trends that underlie the shelf edge, this trend yields the maximum amount of geologic information about the subsurface.

On the southwest and southeast corners of the survey, steep seafloor slopes and water deeper than 200 m were encountered. Under these conditions, the side scan sonar system did not yield a good image of the seafloor. The main problem was that it was difficult to get the side scan sonar tow fish close enough to the seafloor to receive a sufficiently strong acoustic return to allow the side scan range correcting electronics to work properly. Thus, in the deepest areas of the survey, good quality sonograms were not obtained. However, this problem was minor because this affected only the extreme ends of lines 32-34.

Navigation - Navigation on the first geologic cruise was accomplished using a STARFIX satellite positioning system. This system operates in the microwave frequency band (4.06 GHz) and yields an accuracy of approximately five m. On the second geologic cruise, a Cubic Western ARGO DM-54 radio navigation system was used because of the unavailability of STARFIX systems at cruise time. The ARGO device computes position by triangulation using a series of three to five shore-based radio transmitters using the 1.6-1.7 MHz frequency range. This system's accuracy is only slightly less than that of STARFIX (about five to seven meters) within about 150 miles of shore.

During Cruise 88-MMS-G1A, one line run on the first cruise was repeated as a check on the consistency of the two types of navigation. No significant differences were found. All navigation data were logged on nine-track tapes for plotting and merging with the side scan and subbottom data.

Geological Mapping Cruise G-1 - The objective of the cruise was to collect bathymetric and side scan sonar mapping data of the topographic features study area. Cruise 87-MMS-G-1 was conducted on board the R/V EXCELLENCE II. Rigging of the vessel was conducted on 4 October 1987 at Dauphine Island, Alabama. The cruise began with calibration of the navigation system at Pascagoula, Mississippi, 5 October 1987. Cruise activities continued until 8 November 1987 when the vessel returned to its home port of Surfside, Texas.

Digital side scan sonar and analog subbottom profiler systems were deployed from the vessel on a 14-18 hour watch schedule. Geographic position, depth bottom, and subbottom features were recorded. Time marks were recorded at intervals of two minutes for the side scan sonar and 20 minutes for the subbottom profiler. Transects were made on east-west headings across the area with a maximum line offset of 750 m and a minimum line offset of 500 m. A minimum of 20 transects of just over 61 km length were planned. Transects were to be continued until 100 percent coverage of the area was accomplished.

Good records were obtained on 20 of 34 survey lines. A total of 21 lines were run with only one line re-shot due to loss of data (line 1). These results represent 60 percent completion of all survey lines, over 50 percent of area coverage. Pre-survey planning had considered between 22 (1,000 m line spacing) and 44 (500 m line spacing) survey lines with the actual number necessary to provide 100 percent coverage dependent on field conditions, e.g., topographic, water depth, and instrumental (signal/noise, return strength, etc.).

In shallower portions of the survey area, such as 36.57 to 54.86 m, the 500 m offset with a side scan sonar range of 300 m (600 m total swath) gave excellent coverage with overlap on adjacent lines such as to allow mosaic construction for geological analyses. In deeper areas, beyond 73.15 m water depths, the 1000 m offset did not prove mosaic coverage, but a 750 m line spacing together with a 400 m range setting (800 m total swath) provided the required coverage. The conjunction of the 500 m and 750 m line spacings (lines 1-18 at 500 m line spacing: lines 19-34 at 750 m line spacing) resulted in the final survey line total of 34 lines. This total excludes any tie lines or partial lines that were resurveyed.

Activities Uncompleted - Contingent on good weather and minimal equipment delays, fourteen survey lines representing four and one-half to seven sea days, remained uncompleted at the end of Cruise G-1.

Participants - The scientific party consisted of Ervan Garrison, R. Rezak, R. Barnet, E. DeFriest, B. Trimm, B. Berglund, S. Singleton, MMS representative (J. Hunt), technicians (M. Muecke, A. Kos, and S. Montgomery), G. Locke, and crew (D. Peavy, captain; R. Carraway; and E. Cooper).

Problems - The major problem encountered was weather. Winds associated with fronts and two tropical systems that passed through or near the survey area kept seas marginal or unacceptable for high resolution-type mapping activities for a total of 27 of 35 days of the cruise.

Equipment problems were nominal and were generally associated with poor sea conditions. Typical of these weather-related equipment problems were two failures of the subbottom profiler tow assembly due to high seas. Summarizing the equipment problems:

05 October 1987	Repair of HP100 computer on navigation system, board replaced during weather lay day
06 October 1987	Back-up generator repaired on R/V EXCELLENCE II during weather stand-down
07 October 1987	Navigation system required re-set
08 October 1987	Power supply replaced on EDO 248E transceiver for subbottom profiler
16 October 1987	Subbottom tow assembly repaired due to failed shackle
24 October 1987	Subbottom tow cable failure
25 October 1987	Repair of subbottom tow scale
28 October 1987	Fuel pump failed on vessel
29 October 1987	Digital tape deck drive motor failure, replaced.

Geological Mapping Cruise G-1A - Cruise 88-MMS-G1A was conducted on board the R/V TOMMY MUNRO. The purpose of the cruise was mainly to complete the acquisition of bathymetric and side scan sonar data begun in October 1987 but terminated due to weather problems. Additionally, six grab samples were taken at one station, M2, that was missed by previous biological cruises. The geophysical data were obtained with three systems: a 100 kHz EG&G model 272 side scan sonar, a 4 kHz EDO subbottom profiler, and a 700 joule Del Norte mini-sparker. Fifteen lines, paralleling the shelf-edge and the previous geophysical tracks, were shot with the first two systems (lines 20A-34). Six tie-lines (lines A-F), crossing the previous lines at high angles, were shot with the latter two systems. Line 20A was a repeat of the last line surveyed in 1987. It was redone to insure that the navigation for the old and new surveys are consistent. A total of 558 NM of geophysical data were collected, 480 NM with side scan and subbottom profiler and 78 NM with sparker and subbottom profiler. It proved impossible to operate all three systems simultaneously as the sparker interfered with the side scan records. The six grabs were acquired as planned.

The crew left College Station on 5 April but did not put to sea until 8 April because of bad weather and delays in setting up the geophysical and navigational equipment. The cruise was broken into two parts by a weather delay caused by the passage of a front through the survey area. Lines 20A-26 were obtained during the first part whereas lines 27-34 and A-F were run during the second. A total of eight days were spent at sea with only one of those days being lost to weather. Four days were spent in port either setting up equipment (two days, 6-7 April) or waiting for bad weather to subside (two days, 12-13 April). The cruise ended on 17 April. Additionally, two days were spent transiting to and from Biloxi on land.

Participants - The scientific party on Cruise 88-MMS-G1A consisted of six watch-standers and two navigation technicians. An electronics technician sailed on the first half of the cruise, but was recalled to College Station while the crew was in port because of bad weather. Additionally, watch-stander Robert Barros was replaced by Eri Wienstein (at the same time).

Scientific Crew:

April 5-12, 1988

- William Sager - TAMU OCNG - Chief Scientist
- William Crow - TAMU CE
- Scott Singleton - TAMU OCNG
- Scott Laswell - TAMU OCNG
- Steven Gittings - TAMU OCNG
- Robert Barros - TAMU CE
- R. V. Pittman - TAMU OCNG - Electronics Tech.
- Merle Goehring - LORAC - Navigator
- Blair Yeager - TAMU GERG - Navigator

April 13-18, 1988

- William Sager - TAMU OCNG - Chief Scientist
- William Crow - TAMU CE
- Scott Singleton - TAMU OCNG
- Scott Laswell - TAMU OCNG
- Steven Gittings - TAMU OCNG
- Eri Wienstein - TAMU CE
- Merle Goehring - LORAC - Navigator
- Blair Yeager - TAMU GERG - Navigator

Problems - Originally, Cruise 88-MMS-G1A was scheduled to last only three days rather than eight. The problems that led to its being lengthened by 160 percent fell into several categories: navigation, equipment problems, weather delays, and miscalculation of time needed for the lines crossing the deepest water.

At the last minute, the navigation was changed by LORAC from STARFIX to ARGO. The latter needs a network of radio stations to operate and must be calibrated at landmarks in and near the survey area. Station problems with the ARGO net contributed to the delay in putting to sea. Calibration and navigation equipment malfunction delays amounted to approximately 10 hours. Additionally, the use of ARGO cost an additional 10 hours in lengthened transit time because of the necessity to steam to calibration points rather than directly to and from the survey.

4.0 HIGH MOLECULAR WEIGHT HYDROCARBONS

Mahlon C. Kennicutt II

4.1 Introduction (including historical background)

Previous studies of sediment hydrocarbons in or near the present study area are primarily restricted to three reports (Gearing *et al.* 1976; Boehm 1979; and Brooks *et al.* 1988). Quantitative data are difficult if not impossible to directly compare with the present study due to the widely varying analytical methods utilized. One exception is the National Oceanographic and Atmospheric Administration (NOAA) Status and Trends data recently generated by the Geochemical and Environmental Research Group. The types of data collected are also highly variable with no study collecting the same sets of data as the present study.

Gearing *et al.* (1976) reported the analysis of sixty sediments from the northeastern Gulf of Mexico continental shelf. Total extractable organic matter (EOM) averaged 133 ppm $\pm$ 80 percent and 232 ppm $\pm$ 53 percent for sediments off Florida and the Mississippi River, respectively. Aliphatic hydrocarbons were determined gravimetrically and accounted for only a small percentage of the EOM. The aliphatic hydrocarbons were dominated by a series of branched or cyclic unsaturated C_{25} isomers, n-C_{17}, high molecular weight odd carbon number n-alkanes, and an unresolved complex mixture (UCM). The relative abundances of these compounds varied regionally and represent a mixture of biological (marine and terrestrial) and petroleum hydrocarbons (UCM). Aromatic fractions exhibited sharp peaks on top of a moderate envelope of unresolved compounds (GC/FID). The large number of peaks in the aromatic fractions did not correspond to the available aromatic standards (no GC/MS confirmation was available). It was concluded that a western zone, which encompasses the present study area, extending eastward to the Alabama shelf, was dominated by terrigenous and petroleum hydrocarbon inputs from the Mississippi River and delta area.

A similar conclusion was reached by Boehm (1979) based on the analysis of sediments from the Mississippi, Alabama, Florida Outer Continental Shelf (BLM/MAFLA) baseline environmental study. A region on the Mississippi-Alabama Shelf and the more offshore areas of the Florida OCS showed strong petrogenic, anthropogenic, and terrigenous biogenic influences. Petrogenic sources were inferred from chromatograms with a double "hump" of unresolved compounds and a regular series of n-alkanes. Total hydrocarbons as estimated by gas chromatography averaged 1.6 ppm on the Mississippi-Alabama Shelf.

The most extensive sediment aromatic hydrocarbon (PAH) database in bays shoreward of the study area has recently been generated by GERG as part of NOAA's Status and Trends program. Sediments were collected at multiple sites within Gulf coast estuaries and bays and analyzed over a two year period. The data summarized here include samples in bays from Terrebonne Bay on the western side of the delta to Pensacola Bay in Florida on the east. Total PAHs in sediments of these bays varied from undetected to 4252 ppb and 44 to 5591 ppb during 1986 and 1987 sampling, respectively. Based on molecular compositions (i.e., the abundance of anthracene relative to phenanthrene) it was determined that the PAHs were predominantly pyrogenic in origin. Pyrogenic sources include fossil fuel burning, carbonization of coal, and forest fires. Unrefined petroleum did not appear to be a major source of PAHs though the sampling locations were intentionally selected away from known point sources of pollutants such as large urban areas and industrial complexes.

4.2 Methods

Sediments samples from six replicate box cores were combined and analyzed for the compounds listed in Table 4-1. The following analytical procedures provide quantitative hydrocarbon concentrations in sediments from the study area. The Quality Assurance protocol as described in GERG's manual for "Analytical and Quality Assurance Procedures for the Measurement of Trace Organic Compounds" are strictly adhered to and provide data that meet the precision, accuracy, and completeness objectives outlined in Table 4-2.

Table 4-1. Hydrocarbons determined by the analytical methodologies.

Aliphatic Compounds	Aromatic Compounds
n-C_{11} to n-C_{32}	Naphthalene
pristane	Methylnaphthalenes
phytane	Dimethylnaphthalenes
	Trimethylnaphthalenes
	Fluorene
	Fluoranthene
	Acenaphthene
	Acenaphthylene
	Phenanthrene
	Anthracene
	Methyl phenanthrenes
	Pyrene
	Benzanthracene
	Chrysene
	Benzo(b) fluoranthene*
	Benzo(k) fluoranthene*
	Benzo(e) pyrene
	Benzo(a) pyrene
	Dibenzanthracene
	Benzo (g,h,i)perylene
	Indenoperylene

* These two isomers are resolved under the given conditions but other more complex mixtures of benzofluoranthenes may not be fully resolved.

Table 4-2. Summary of precision, accuracy and completeness objectives.

Measurement Parameter (method)*	Reference	Precision Std. Dev.	Accuracy	Completeness
Aliphatic Hydrocarbons[1] (AH)	-	$\leq$ % 20%	$\leq$ % 30%	90%
Polynuclear Aromatic[2] Hydrocarbons (PAH)	EPA Method 625	$\leq$ % 20%	$\leq$ % 30%	90%

[1]List of A.H. analyzed is given in Table 1.
[2]List of PAH analyzed is given in Table 1.

4.2.1 Cleaning Procedures

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

4.2.2 "System" and "Spiked Blanks"

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

4.2.3 Internal Standards

Internal standards (ISs) are added to all samples immediately before extraction. The aliphatic IS contains d_{26}-dodecane, d_{42}-n-eicosane, d_{50}-tetracosane and d_{62}-triacontane. The aromatic IS contains d_4-1,4-dichlorobenzene, d_8-naphthalene, d_{10}-acenaphthene, d_{10}-phenanthrene, d_{12}-chrysene, and d_{12}-perylene. ISs are added at a concentration similar to that expected for the analytes of interest. It has been verified that all ISs are fully resolved from, and do not interfere with, naturally occurring substances under the described analytical conditions. All data is corrected for IS recoveries.

4.2.4 Sediment Extraction Procedure

Approximately 25 g of freeze-dried sediment is ground, internal standards added, and Soxhlet extracted for 12 hours with 250 ml of methylene chloride. The organic phase is concentrated to ~ 10-15 ml in a round bottom flask equipped with a three-ball Snyder condenser. Activated copper is added to the extract during the extraction and concentration steps to remove elemental sulfur. The extract is concentrated further in a 25 ml Kuderna-Danish (KD) receiver in a water bath (60^oC). Extracts are stored refrigerated (-4^oC)

Extractable organic matter (EOM) content is determined by weighing an aliquot of the solvent extract. Ten µl of the extract is transferred to a preweighed filter pad on a Cahn Electrobalance and the solvent is allowed to evaporate. The lipid content is determined from the residual weight and reported as a percent of the total dry weight of sediment.

4.2.5 Aliphatic Hydrocarbon Quantitation - GC/FID

Component separation of the aliphatic fraction (f_1) is accomplished using 25 m fused silica capillary columns coated with DB-5 (J&W Scientific Inc.). Interior diameter of the column is 0.25 mm, film thickness 0.32 µ, and flow (He) through the column is 2-3 ml/min. Dilutions and injection sizes are appropriately adjusted to be within the detectors linear range. Two HP 5880A and two HP 5790A gas chromatographs equipped with HP 7571A autosamplers and flame ionization detectors are used for the analyses. Samples are injected on the capillary column at 60^oC, the GC oven is then temperature programmed to 300^oC (12^oC/min) and held at 300^oC for 10 minutes. Total analysis time is 30 minutes. Baseline separation on n-C_{17} and pristane and n-C_{18} and phytane is maintained or the capillary column is replaced.

A quantitative alkane standard (including pristane and phytane) from n-C_{11} to n-C_{34} containing all of the internal standards is prepared twice yearly (Alltech Assoc. and MSD Isotopes). The new standard is calibrated against the previous standard.

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

A calibration check is run twice daily (per ~10 sample analyses) and calculated values must predict the known value by ±20 percent on average for all analytes and ±30 percent for any single analyte or remedial action is taken. No further samples are analyzed until the instrument is in calibration. A "blank" and "spiked blank" are included in each set (~10) of samples. "Spiked blanks" and/or SRMs must calculate within ±30 percent of the known concentration on average for all analytes and within ±35 percent for individual analytes or analyses are halted. Duplicate samples are analyzed at a frequency of five percent. At least ten percent of the aliphatic hydrocarbon fractions are analyzed by GC/MS to confirm peak identity and to investigate unidentified peaks.

4.2.6 Polynuclear Aromatic Hydrocarbon Quantitation - GC/MS/SIM

PAHs are quantitatively analyzed by GC/MS in a selected ion mode (SIM) utilizing molecular and secondary analyte ions. Typical operating conditions are summarized in Table 4-3. Total analysis time is 36 minutes.

Table 4-3. GC/MS/SIM operating conditions for PAH analysis.

INSTRUMENTS:
- GC/MS HP 5996 linked with an HP 1000 (RPN) data system
- GC/MSD HP 5970 Mass Selectie Detector interfaced to an HP 5890 gas chromatograph linked with an HP 1000 (RPN) data system

One HP 5996 GC/MS and two HP 5970 GC/MSD's are available

TYPICAL MS SETTINGS:

Ion Source: 250°C	Multiplier Voltage: 1600V
Transfer Line: 290°C	Entrance Lens: 50 mV/AMU
Analyzer: 250°C	Repeller: 9.8V
Run Time: 36 min.	Ion Focus: 0
Scan Start Time: 5 min.	Axis Gain: -63
Electron Energy: 70 ev	Axis Offset: -6
X-Ray: 44V	AMU Gain: 149

SELECTED ION MONITORING:

GROUP I IONS Start Time: 5 min Stop time: 14 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
128	50	127	50	naphthalene
136	50	-----	----	*-$d_8$naphthalene
142	50	141	50	methyl-naphthalene
152	50	151	50	acenaphthylene
154	50	153	50	diphenyl, acenaphthene
156	50	141	50	dimethyl-naphthalenes
162	50	-----	----	**hexamethyl-benzene
164	50	-----	----	*d_{10}-acenaphthene
166	50	165	50	fluorene
170	50	155	50	trimethyl naphthalenes

Total Dwell time : 600 m sec

Table 4-3. Continued

GROUP II IONS Start time: 14 min Stop time: 22 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
178	100	179	100	phenanthrene, anthracene
188	100	-----	100	d_{10} plenanthrenes
192	100	191	100	methylphenanthrene methyl anthracene
202	100	226	100	benzanthracene, chrysene
240	100	-----	-----	*d_{12}-chrysene

Total dwell time: 800 msec

GROUP III IONS Start time: 22 min Stop time: 36 min.

Quantitation Ion (m/z)	Dwell Time (msec)	Secondary Ion (m/z)	Dwell Time (msec)	Compounds Detected
252	150	253	150	benzopyrenes, perylene, benzofluoranthenes
264	150	-----	-----	*d_{12}-perylene
276	150	138	150	indenopyrenes, benzoperylenes
278	150	139	150	dibenzanthracenes

Total dwell time 1050 msec

Table 4-3. Continued

GAS CHROMATOGRAPHY:

Injector: 300°C, splitless mode
Total Run Time: 36 min.
Column: 25m, DB-5

Temp 1	40°C	Temp 2	300°C
Time 1	0 min.	Time 2	10 min.
Rate	10°C/min.		

* - internal standards (IS)
** - gas chromatography internal standards (GCIS)

Mass	Ion Abundance Criteria
50	15 to 40% of Mass 95
75	30 to 60% of Mass 95
95	bass peak, 100% rel abund.
96	5 to 9% of Mass 95
173	<2% of Mass 174
174	>50% of Mass 95
175	5 to 9% of Mass 174
176	>95% but <101% of Mass 174
177	5 to 9% of Mass 176

* EPA Method 624
NOTE: BFB Key Ion Abundance Criteria (background corrected).*

The mass spectrometer is calibrated daily to the standard Hewlett-Packard autotune parameters using perfluorotributylamine (PFTBA). The GC/MS is initially calibrated and detector linearity is determined by duplicate injection of standards (including all internal standards) at three concentrations (usually 0.5 ng/μl, 2.5 ng/μl, and 5.0 ng/μl). A linear relationship between concentration and response is assumed and an R of better than 0.99 for a first degree fit of the data must be obtained before analysis of samples is initiated. Sample components are quantified from the average response of the standard injections. Peak identity is confirmed by their molecular ion, the ratio of the primary (base) ion to the secondary ion, and retention time. At a minimum, calibration checks are analyzed daily. "Spiked blanks" and "system blanks" are analyzed with each set of samples. Calibration checks are routinely analyzed twice daily (per ~10 sample analyses). The GC/MS is considered to be in calibration if the average percent difference between the calculated value and the known value for the calibration check is on average less than ±20 percent for all analytes and less than ±30 percent for individual analytes. Duplicate samples are run at a frequency of 5 percent. The "spiked blank" and/or SRM is considered acceptable if the percent difference between the calculated and the known value is less than ±30 percent on average for all analytes and individual analytes are than less than ±35 percent. Typical calibration parameters for GC/MS/SIM analysis of aromatic hydrocarbons is shown in Table 4-4. A gas chromatographic internal standard (GCIS) (hexamethylbenzene or d-fluorene) is added just prior to the GC/MS/SIM analysis. The sample analyte concentrations are calculated using the appropriate internal standard area and the average response factor from the six standard injections. The GCIS recoveries are used to estimate absolute recoveries in order to evaluate analyte losses during the analytical procedure. Data are <u>not</u> corrected for GCIS recoveries.

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

Calibration Report

Title: MUSSEL WATCH YEAR II CAL FILE (NBS STDS-USE WITH MSD2 & DB5)

Calibrated 880504 22:30

COMPOUND	FILES: >W7828 RF 0.40	>W7829 RF 0.40	>W7830 RF 2.15	>W7831 RF 2.15	>W7832 RF 4.00	>W7833 RF 4.00	$\overline{RRT}$	$\overline{RF}$	% RSD	CORR1
Naphthalene	1.40599	1.25886	1.02443	1.03017	1.07617	1.06576	1.005	1.14356	13.536	0.998876
2-Methylnaphthalene	1.08556	0.94215	0.74830	0.75174	0.72992	0.72666	1.214	0.83072	17.967	0.999823
1-Methylnaphthalene	0.86663	0.81246	0.76899	0.77805	0.75853	0.75609	1.245	0.79012	5.400	0.999951
Biphenyl	1.71039	1.56026	1.37383	1.37292	1.36168	1.36615	0.889	1.45762	10.010	0.999907
"2,6-Dimethylnaphthalene"	1.22269	1.16206	1.02352	1.02507	1.01238	1.01682	0.917	1.07709	8.490	0.999963
Acenaphthylene	1.95418	1.88053	1.71573	1.73635	1.86161	1.88503	0.967	1.83891	5.064	0.998380
Acenaphthene	1.37957	1.24510	1.10837	1.09077	1.17854	1.18908	1.006	1.19857	8.765	0.998302
"2,3,5-trimethylnaphthalene"	1.11422	1.08100	1.03365	1.04829	1.02086	1.03297	1.090	1.05516	3.374	0.999930
Fluorene	1.33407	1.33552	1.26195	1.28007	1.35726	1.36713	1.109	1.32267	3.202	0.998971
Phenanthrene	1.55165	1.51733	1.03528	1.05864	1.09736	1.09158	1.003	1.22531	19.652	0.998206
Anthracene	1.02457	1.02787	0.92852	0.98250	1.06214	1.07378	1.010	1.01657	5.289	0.997325
1-Methylphenanthrene	0.82816	0.85790	0.81855	0.82790	0.83182	0.82694	1.104	0.83188	1.621	0.999958
Fluoranthene	1.31845	1.30608	1.16077	1.19727	1.27917	1.28995	1.192	1.25861	5.097	0.998220
Pyrene	1.39450	1.31259	1.21713	1.23832	1.35511	1.37298	1.225	1.31511	5.562	0.997594
Benz(a)anthracene	1.23386	1.16764	1.00583	1.06728	1.06882	1.10028	0.998	1.10729	7.347	0.998710
Chrysene	1.41170	1.29278	1.13303	1.22398	1.07862	1.08861	1.003	1.20479	10.853	0.998246
Benzo(b)fluoranthene	1.19458	1.14656	1.26226	1.28822	1.63691	1.51744	0.969	1.34100	14.418	0.992174
Benzo(k)fluoranthene	1.59886	1.45395	1.36877	1.42872	1.47868	1.58012	0.971	1.48485	6.001	0.996774
Benzo(e)pyrene	1.38903	1.33414	1.36912	1.42655	1.44399	1.49720	0.991	1.41001	4.123	0.999144
Benzo(a)pyrene	1.33809	1.29220	1.28458	1.32089	1.53498	1.49788	0.995	1.37811	7.946	0.996008
Perylene	1.71459	1.67226	1.59969	1.61319	1.70257	1.68817	1.002	1.66508	2.869	0.999413
"Indeno[1,2,3-c,d]pyrene"	1.02399	0.97435	1.03533	1.05118	1.14588	1.16304	1.092	1.06563	6.911	0.998312
"Dibenz(a,h)anthracene"	1.01828	0.99717	1.02197	1.03820	1.16806	1.13864	1.092	1.06372	6.699	0.997722
"Benzo(g,h,i)perylene"	1.36351	1.24483	1.21530	1.27152	1.39872	1.35422	1.116	1.30802	5.656	0.997553

RF - Response Factor (Subscript is amount in ppb)

$\overline{RRT}$ - Average Relative Rentention Time (RT Std/RT Istd)

$\overline{RT}$ - Average Response Factor

%RSD - Percent Relative Standard Deviation

4.2.7 Laboratory Automation/Data Reduction

All GC/FID and GC/MS/SIM analyses are fully automated. The Hewlett-Packard 3357 Laboratory Automation System (LAS) acquires, integrates, calibrates, reports and stores information generated by chromatographic detectors, in this case the GC/FID. The HP 3357 LAS system consists of a central processing unit (CPU), memory, disc storage, terminals (CRT), and 3357 software. GC/MS/SIM data is acquired, integrated, calibrated, reported, and stored by the Hewlett Packard RPN/Aquarius system. A/D (analog-to-digital) modules, sampler/event control modules, line printing devices, and analytical instruments make up the complete system. The HP 1000 processes, stores, and retrieves analytical data. Situated within the loop (cable) are various modules, all of which are interfaced to the CPU: i.e., A/D modules convert analog signals from a detector to digital signals and transmit them to the CPU and Sampler Control Modules (SCM) control Automatic Samplers. Directly connected to the CPU are various input/output (I/O) devices: HP 2623 and HP 2648 terminals allow users to communicate with the system and receive data from the system. Terminals include display screens and/or tape cartridges. A HP 2631B line printer and a HP 9872C (eight pen X-Y plotter) supplies hardcopy reports. The system and the analytical instruments are interfaced by a communications loop connected to a loop controller board in the CPU.

Due to the potential for artifacts created by the high degree of automation in today's analytical systems, visual and manual calculation checks are essential. Every GC pattern is visually inspected to verify proper selection of peaks for quantitative calculations based on retention times. Analyte retention times are verified versus the standard run most closely in time. After establishment of calibration curves all standards are recalculated to verify the calibration file. Calculations are checked every third day manually. Tabulations of daily response factor are maintained in order to assure stability with time and to highlight any unusual shifts in sensitivity or possible misidentification of peaks.

4.2.8 Limits of Quantitation

Limits of quantitation (LOQ) are summarized in Table 4-5. These limits are determined by serial dilution of authentic standards and set at the level where the error in replicate injections of a standard is greater than ±30 percent.

4.3 Results

The complete hydrocarbon results are presented in Appendix A. The following results include all samples from Cruises 0, 1, and 2. Extractable organic matter (EOM) values ranged from 7 to 262 ppm and averaged 63.6 ppm. EOM has a source in both biological materials and petroleum. In general the EOM was highly variable between locations within a single sampling and between samplings at a single location (Figure 4-1). The unresolved complex mixture varied from 1 to 32 ppm, averaged 11 ppm and generally parallel the EOM distributions (Figure 4-2). The UCM is believed to be primarily due to petroleum though in non-purified extracts a portion of the UCM may be biological in origin. Total alkane concentrations (Σ n-C_{15} to n-C_{32}) varied from 144 to 2091 ppb and averaged 1088 ppb (Figure 4-3). The dominant alkanes were the odd carbon number alkanes with 23 to 31 carbons presumably due to terrigenous plant biowaxes (Figure 4-4). Significant amounts of n-alkanes with 15 to 21 carbons were also present and have a dual source in petroleum and marine plankton. Marine planktonic inputs were difficult to identify. Total polynuclear aromatic hydrocarbons (PAH) ranged in concentration from below the method limit of quantitation to 514 ppb (Figure 4-5) and averaged 129.1 ppb (assuming all < LOQ values equal to zero). PAHs are a major constituent of petroleum and have little or no source in biological materials. The aromatic compounds were evenly distributed among 2, 3, 4 and 5 ring aromatics typical of unprocessed petroleum as compared to bay samples with predominantly pyrogenic PAHs (Figure 4-6). This interpretation is confirmed by the absence of anthracene at most sites, a constituent of pyrogenic hydrocarbons (Figure 4-7). Unprocessed petroleum can result from natural seepage, urban runoff, industrial complexes, offshore oil production, and shipping or tanker activities.

Table 4-5. Limits of quantitation for aliphatic and aromatic hydrocarbons.

COMPOUND	LIMITS OF QUANTITATION[1] Sediments[2] ppb (ng/g)
Petroleum Hydrocarbons	
$n\text{-}C_{12}$ to $n\text{-}C_{32}$	10
pristane	10
phytane	10
acenapthene	10
acenaphthylene	10
anthracenes	10
1,2-benzanthracene	10
benzo(b)fluorathene	10
benzo(k)fluoranthene	10
benzo(a)pyrene	10
benzo(e)pyrene	10
benzo(g,h,i)perylene	10
chrysene	10
1,2,5,6-dibenzanthracene	10
fluoranthene	10
fluorene	10
naphthalenes	10
phenanthrenes	10
pyrene	10

1 Limits of quantitation are based on 25g wet weight, 1 ml final extract volume, and a 2 µl (microliter) injection

2 Limits of quantitation can be improved by increasing sample size or reducing final extract volume.

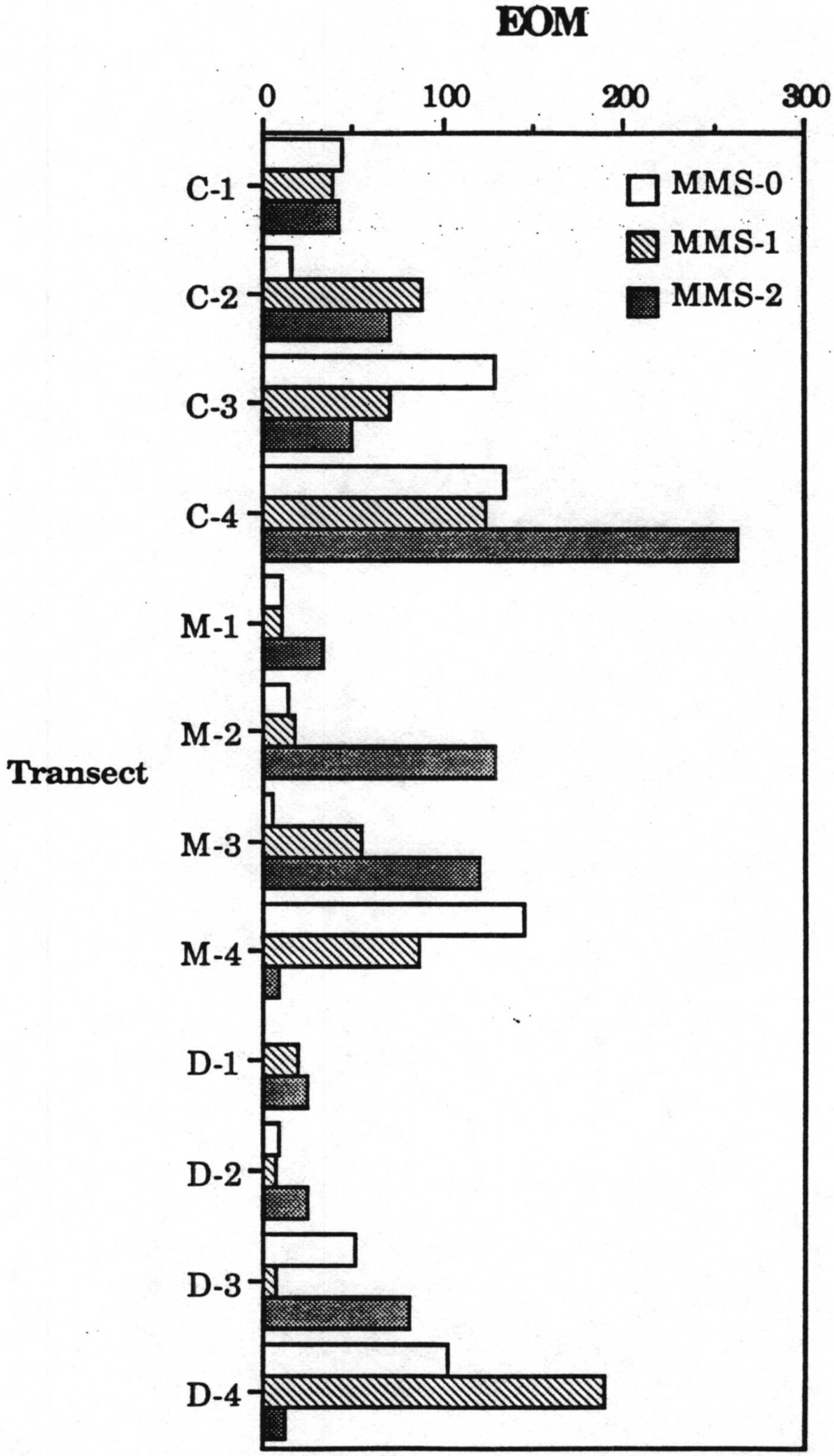

Figure 4-1. Sediment extractable organic matter (EOM) concentrations (ppm) from Cruises 0, 1, and 2.

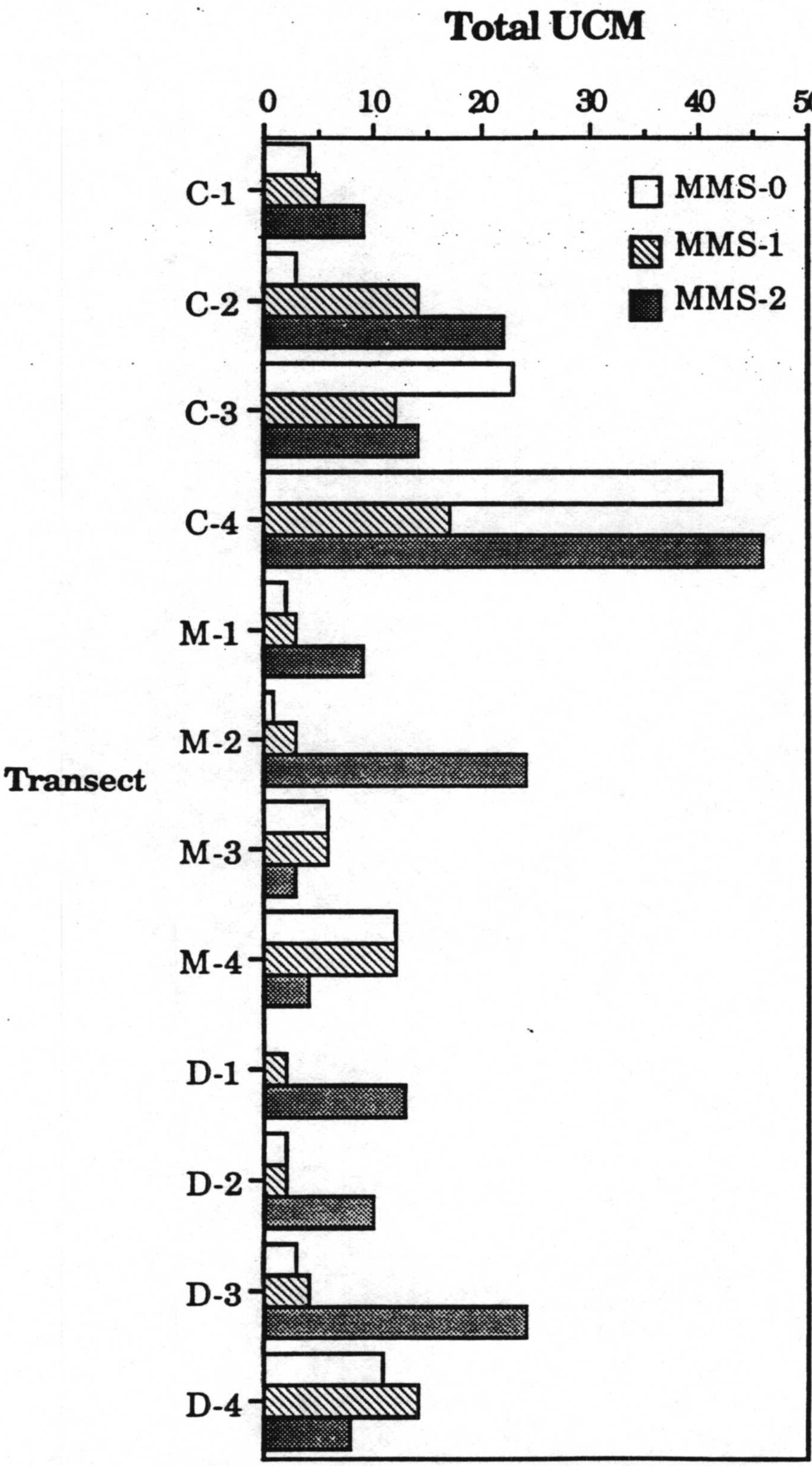

Figure 4-2. Sediment unresolved complex mixture (UCM) concentrations (ppm) for Cruises 0, 1, and 2.

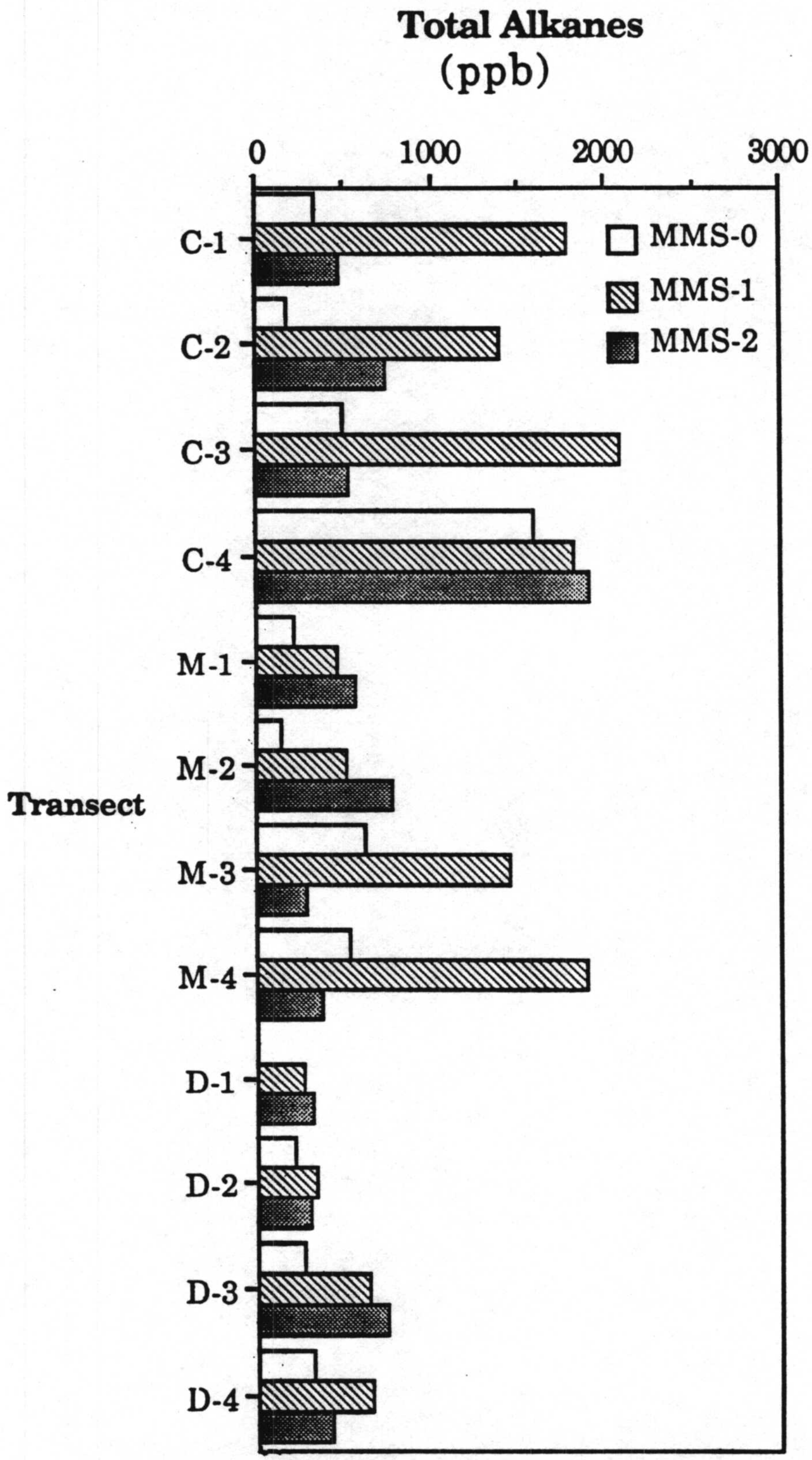

Figure 4-3. Sediment total alkane (Σn-C_{15} to n-C_{32}) concentrations (ppb) for Cruises 0, 1, and 2.

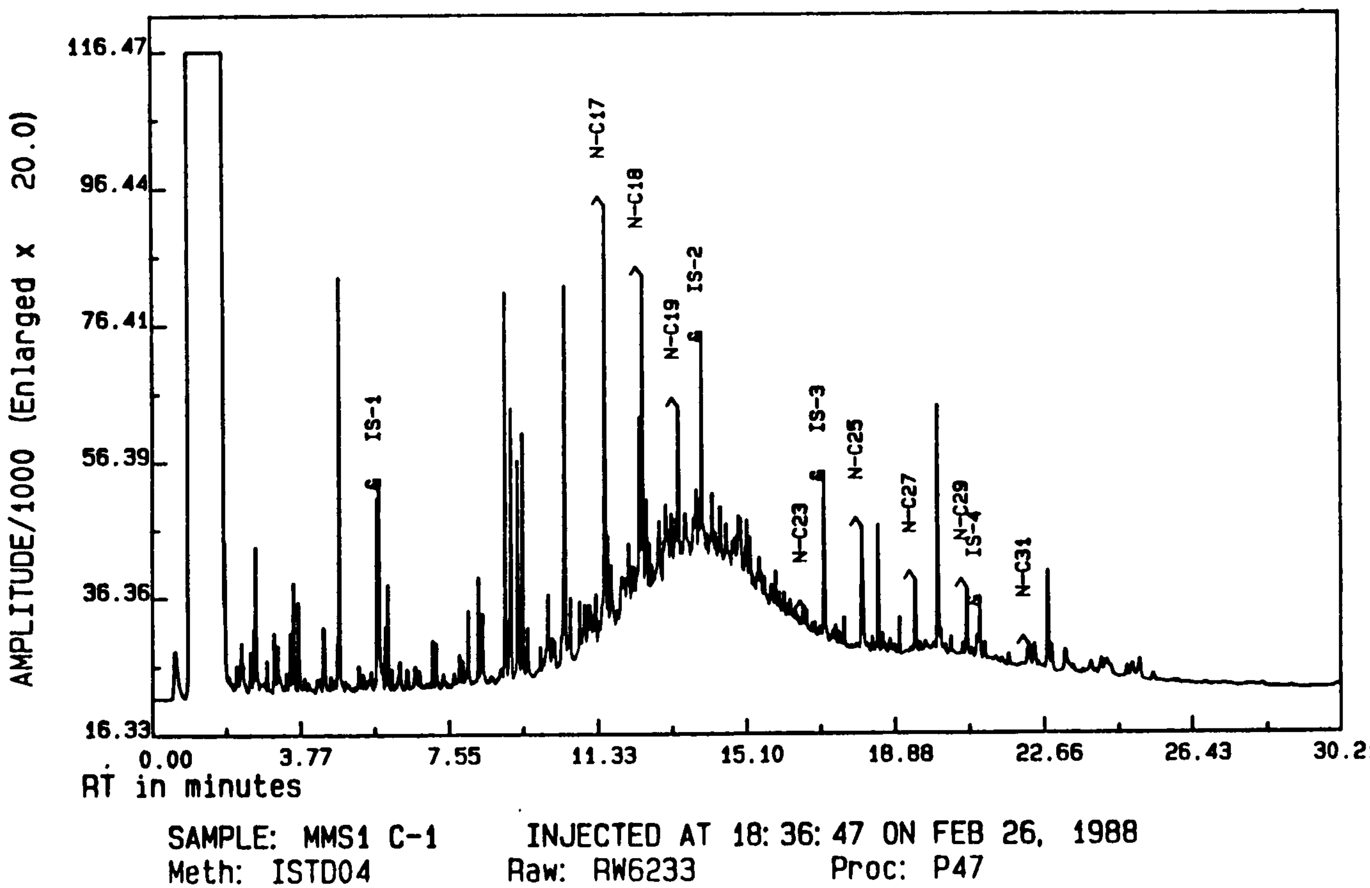

Figure 4-4. A gas chromatogram of a typical sediment extract.

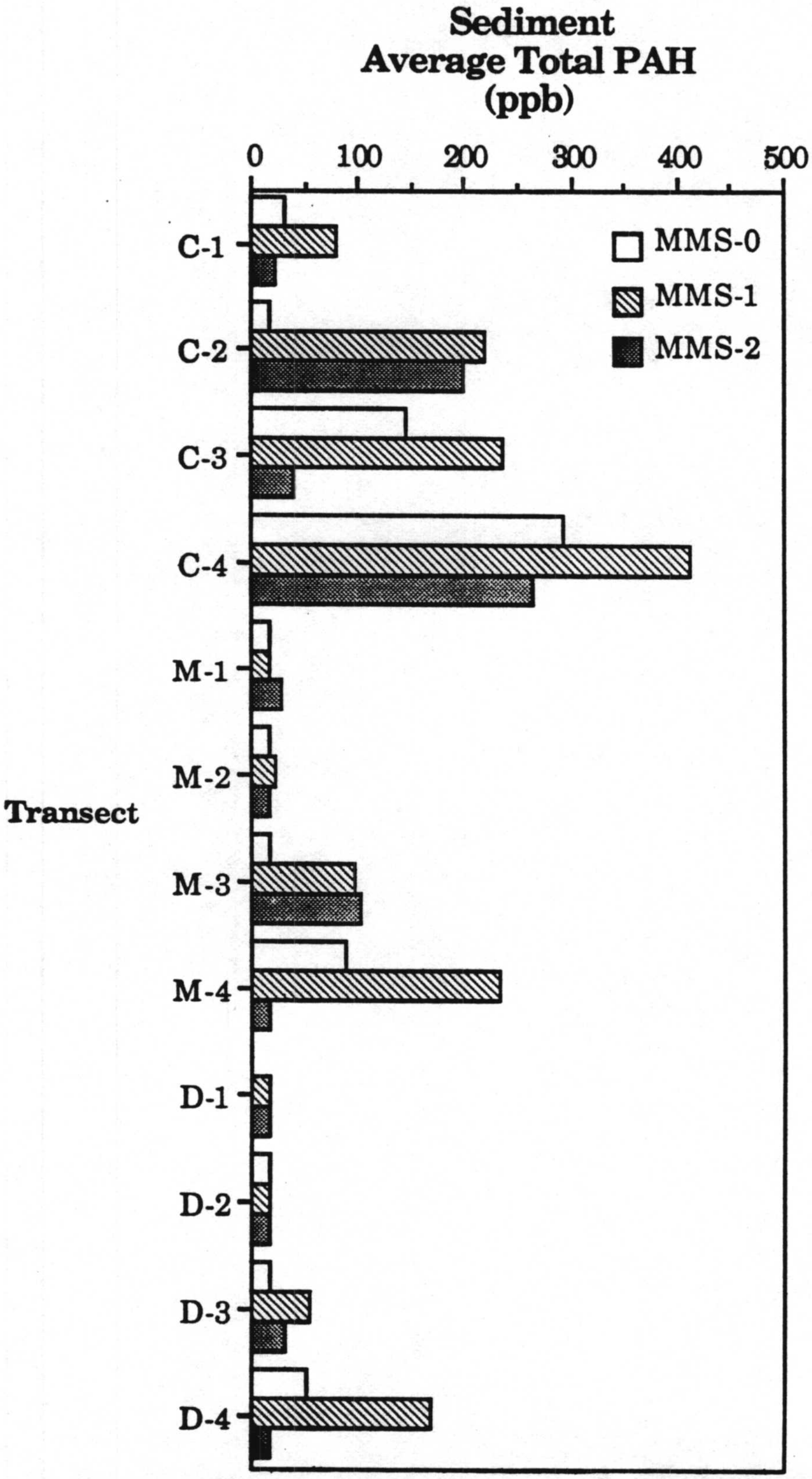

Figure 4-5. Sediment total polynuclear aromatic hydrocarbons (PAH) concentrations (ppb) for Cruises 0, 1, and 2.

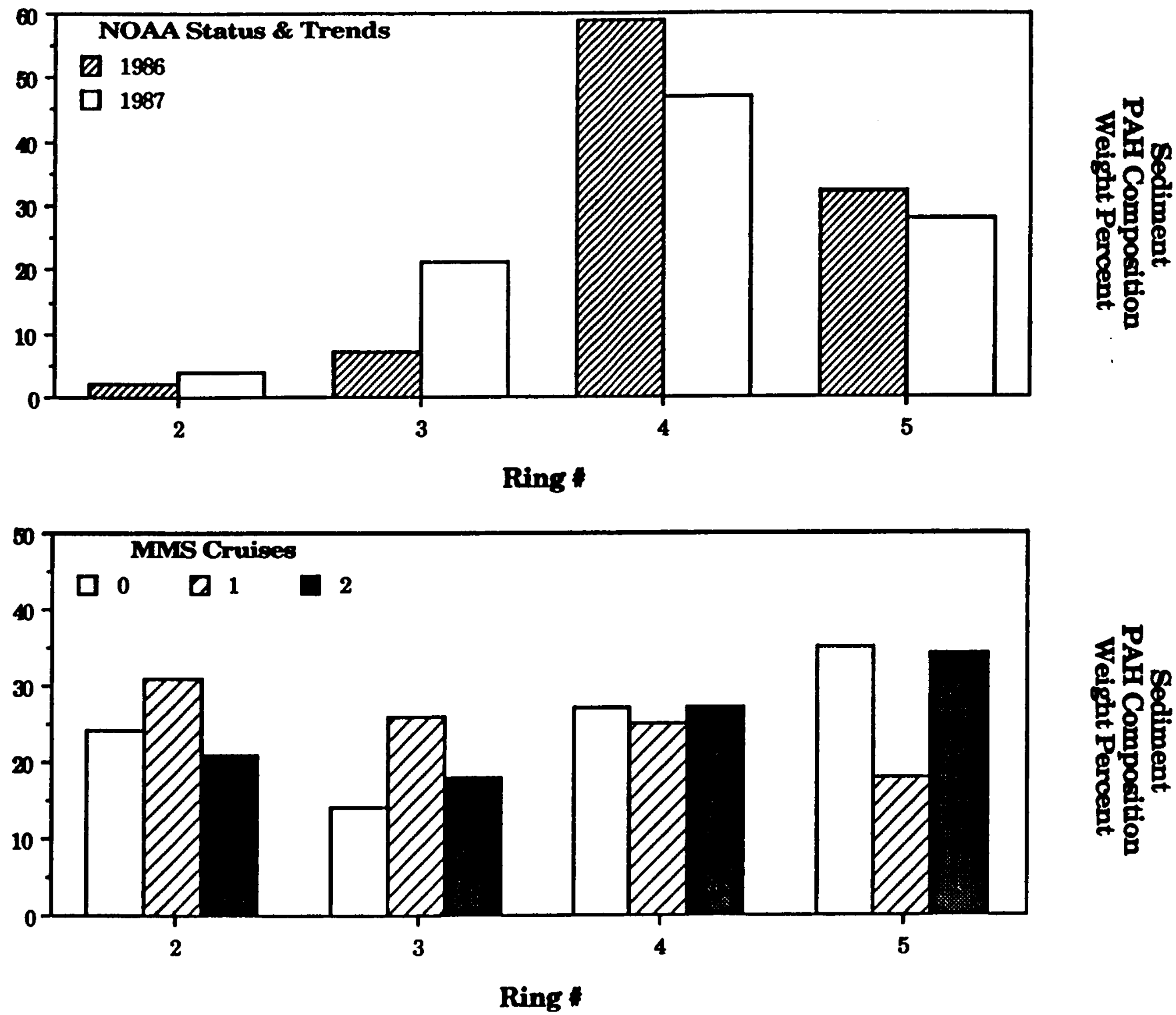

Figure 4-6. Sediment PAH distributions by number of rings for Cruises 0, 1, and 2 and NOAA Status and Trends adjacent bays.

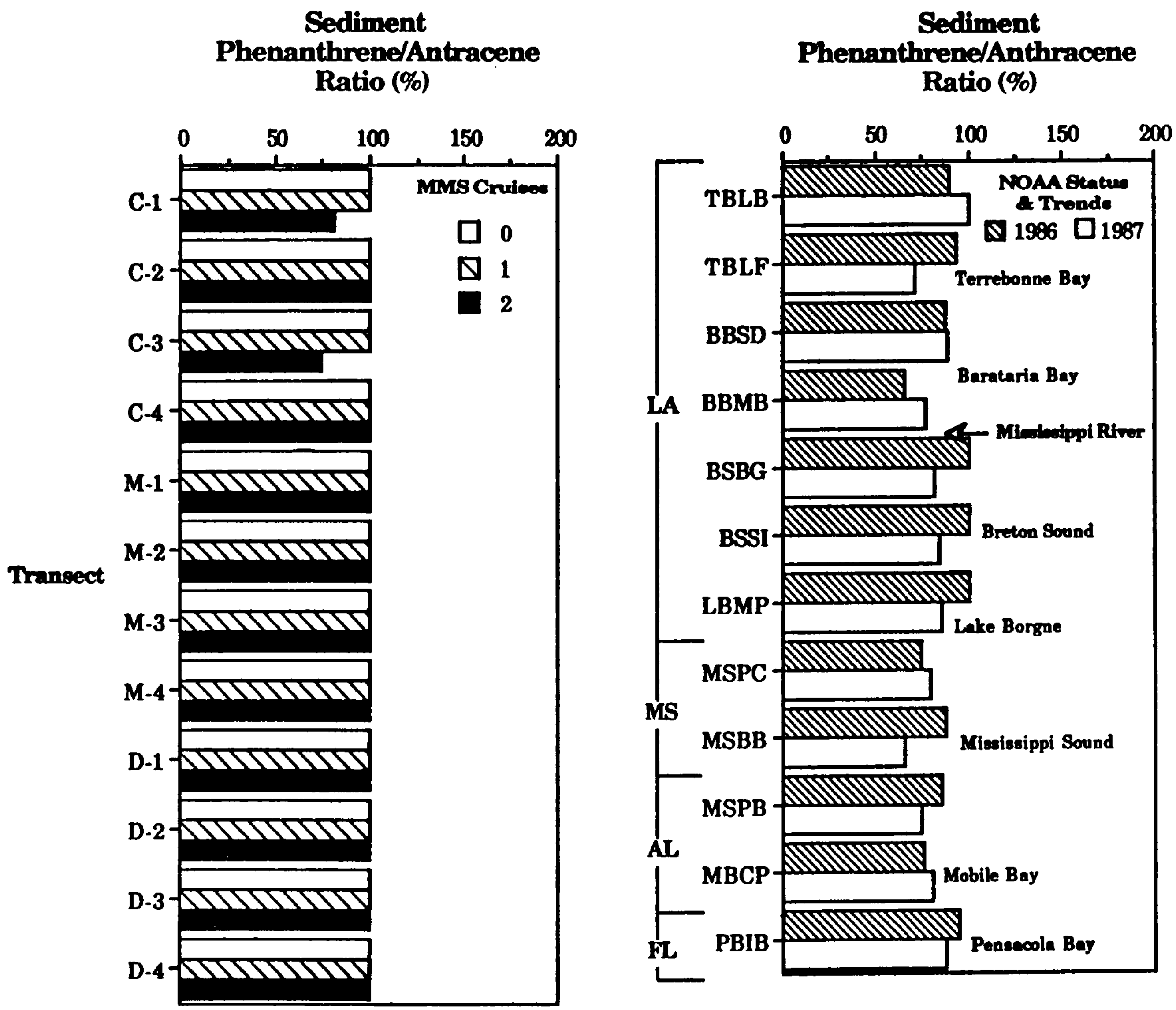

Figure 4-7. The ratio of phenanthrene/(phenanthrene + anthracene) x 100 for sediments from Cruises 0, 1, and 2.

The geographic distributions of the various hydrocarbon parameters are presented in Figures 4-8 to 4-11. Large variations in concentrations were observed between sampling. In general the highest hydrocarbon concentrations were in sediments from the deeper water stations and those closest to the Mississippi River delta system.

4.4 Summary/Conclusions

Sediments in the study area contain a mixture of biological and petroleum hydrocarbons. Biological hydrocarbons are predominantly plant biowaxes (n-C_{23} - n-C_{33}) with a minor planktonic input (n-C_{15} - n-C_{19}) possible. Petroleum hydrocarbons are present as polynuclear aromatic compounds (PAH), a complete suite of n-alkanes, and an unresolved complex mixture. Sediment PAHs on the shelf average six times lower than PAHs analyzed in sediments in adjacent bays (Figure 4-12). High hydrocarbon concentrations are generally at the seaward ends of the transects between the 100 and 200 m isobaths with the stations closest to the delta containing the highest concentration of hydrocarbons. Large variations in sediment chemistry were observed between samplings, apparently related to the influx of riverine material. One possible scenario is a large episodic influx of riverine material followed by slow biological mixing (bioturbation) diluting the input. It is also possible that active currents on the shelf scour the organic matter out of the sediments, transport it offshore, and deposit the organic rich material in a band along the shelf break. Shelf sediment PAHs are typical of unprocessed petroleum as contrasted to adjacent bay sediment PAHs which are predominantly of a pyrogenic origin. Pyrogenic sources include fossil fuel combustion, carbonization of coal, and forest fires. The bay sediments were intentionally sampled away from point sources of pollution such as large urban areas and industrial complexes as part of the NOAA Status and Trends Program. In general, higher hydrocarbon concentrations are associated with finer grained, organic rich sediments, but the association was weak. Normalization of hydrocarbon data to grain size or organic matter content did not significantly reduce data variability.

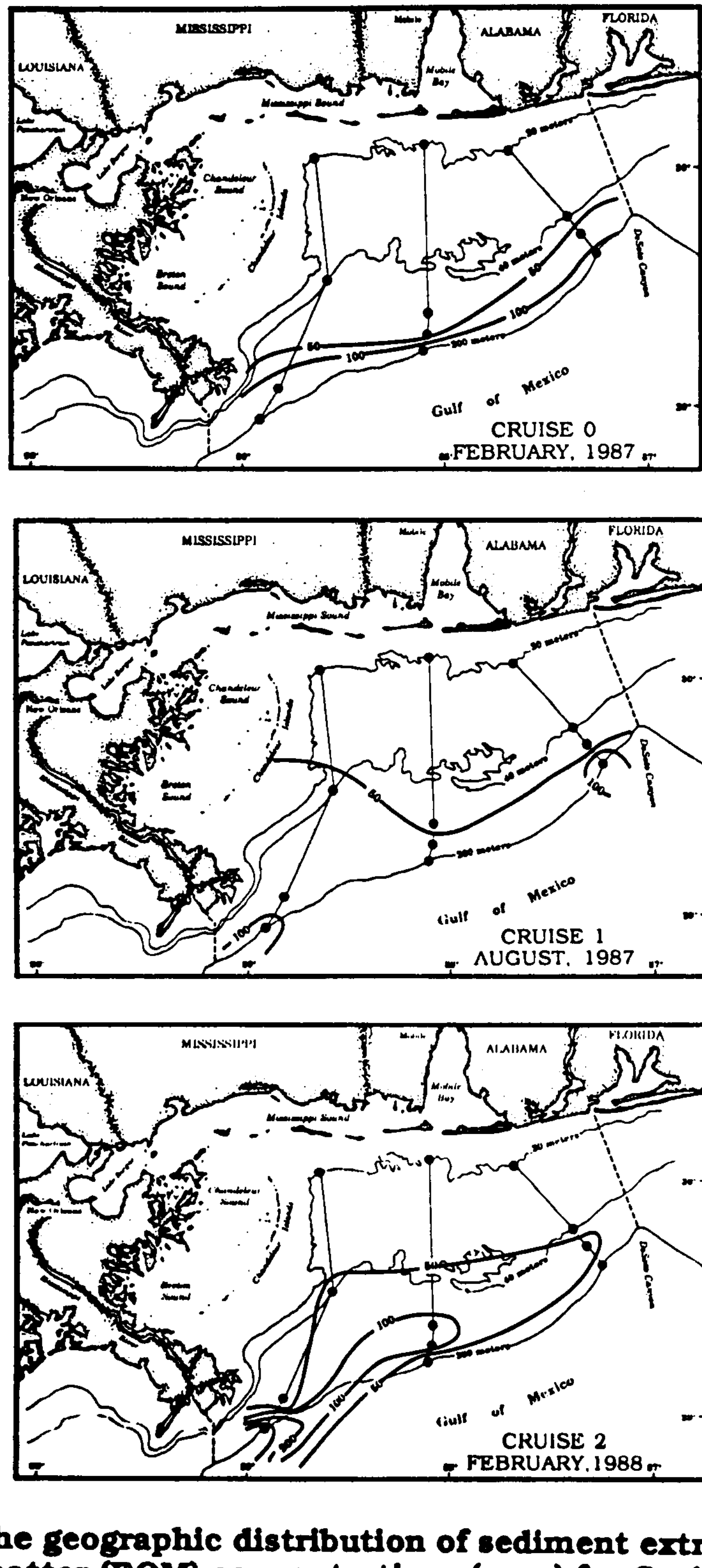

Figure 4-8. The geographic distribution of sediment extractable organic matter (EOM) concentrations (ppm) for Cruises 0, 1, and 2.

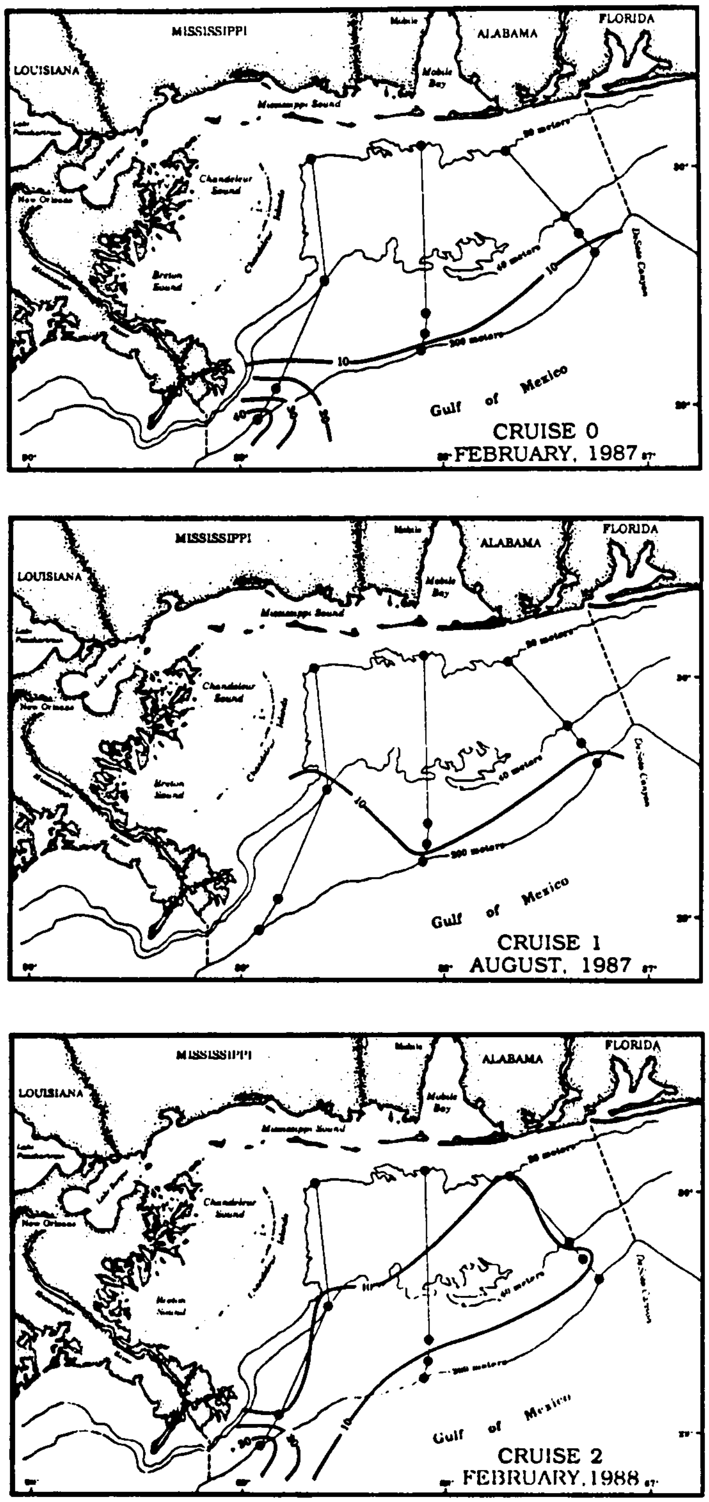

Figure 4-9. The geographic distribution of sediment unresolved complex mixture (UCM) concentrations (ppm) for Cruises 0, 1, and 2.

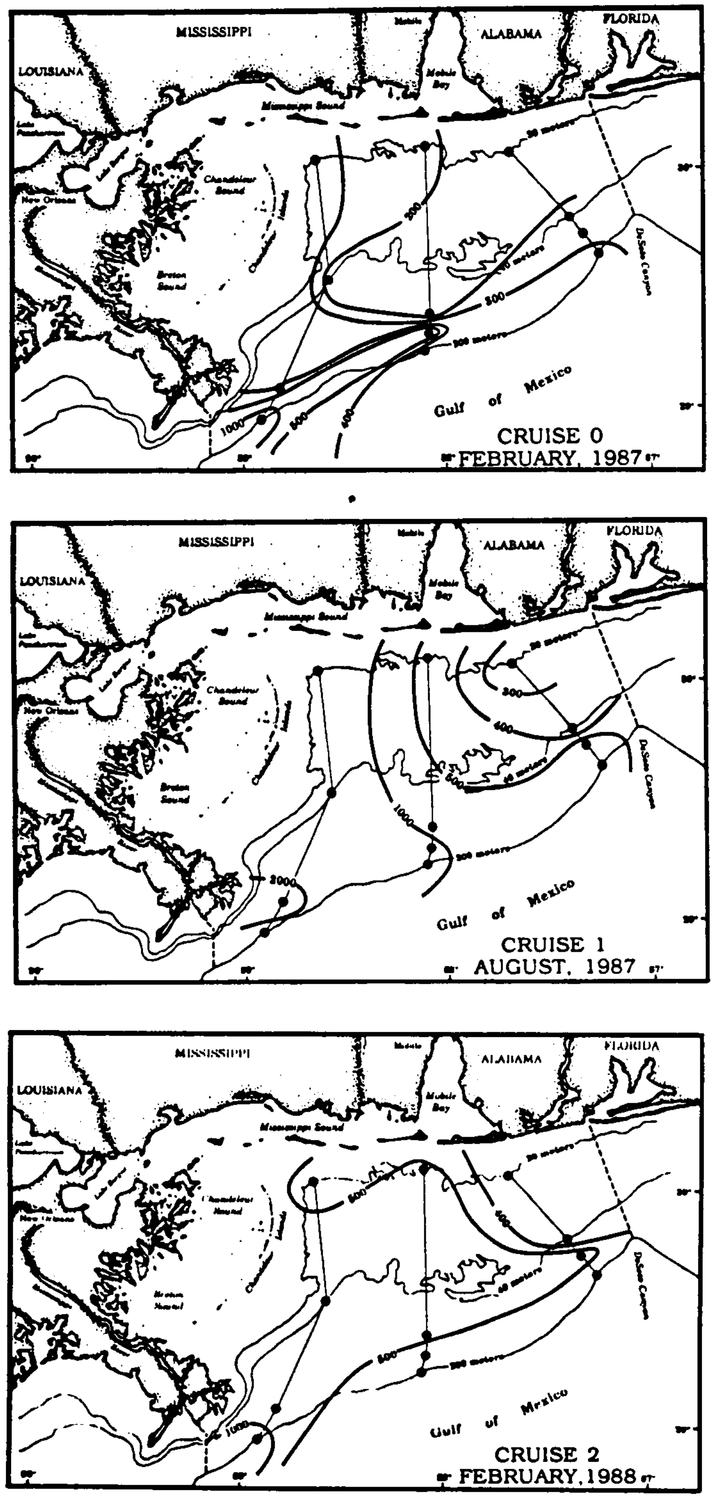

Figure 4-10. The geographic distribution of sediment n-alkane (Σn-C_{15} - n-C_{32}) concentrations for Cruises 0, 1, and 2.

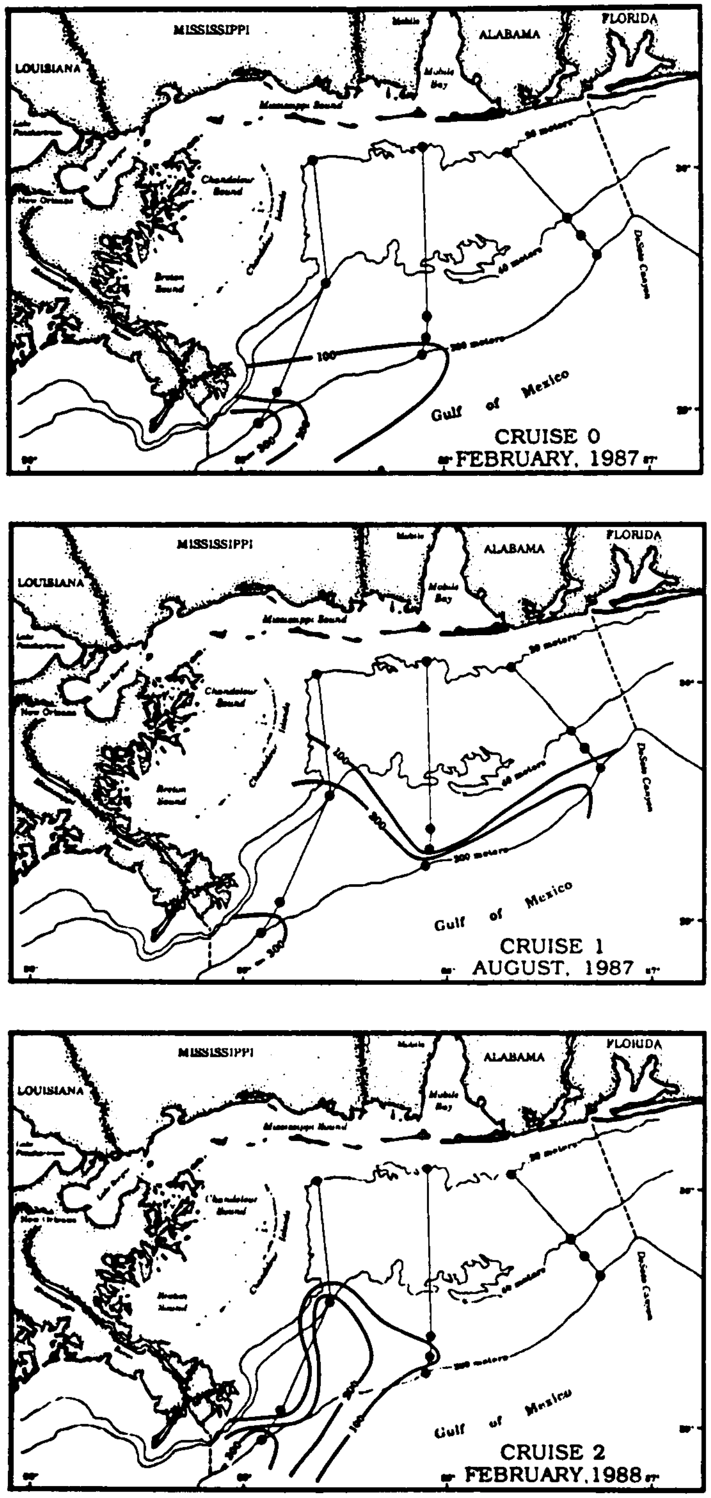

Figure 4-11. The geographic distribution of sediment polynuclear aromatic hydrocarbon (PAH) concentrations (ppb) for Cruises 0, 1, and 2.

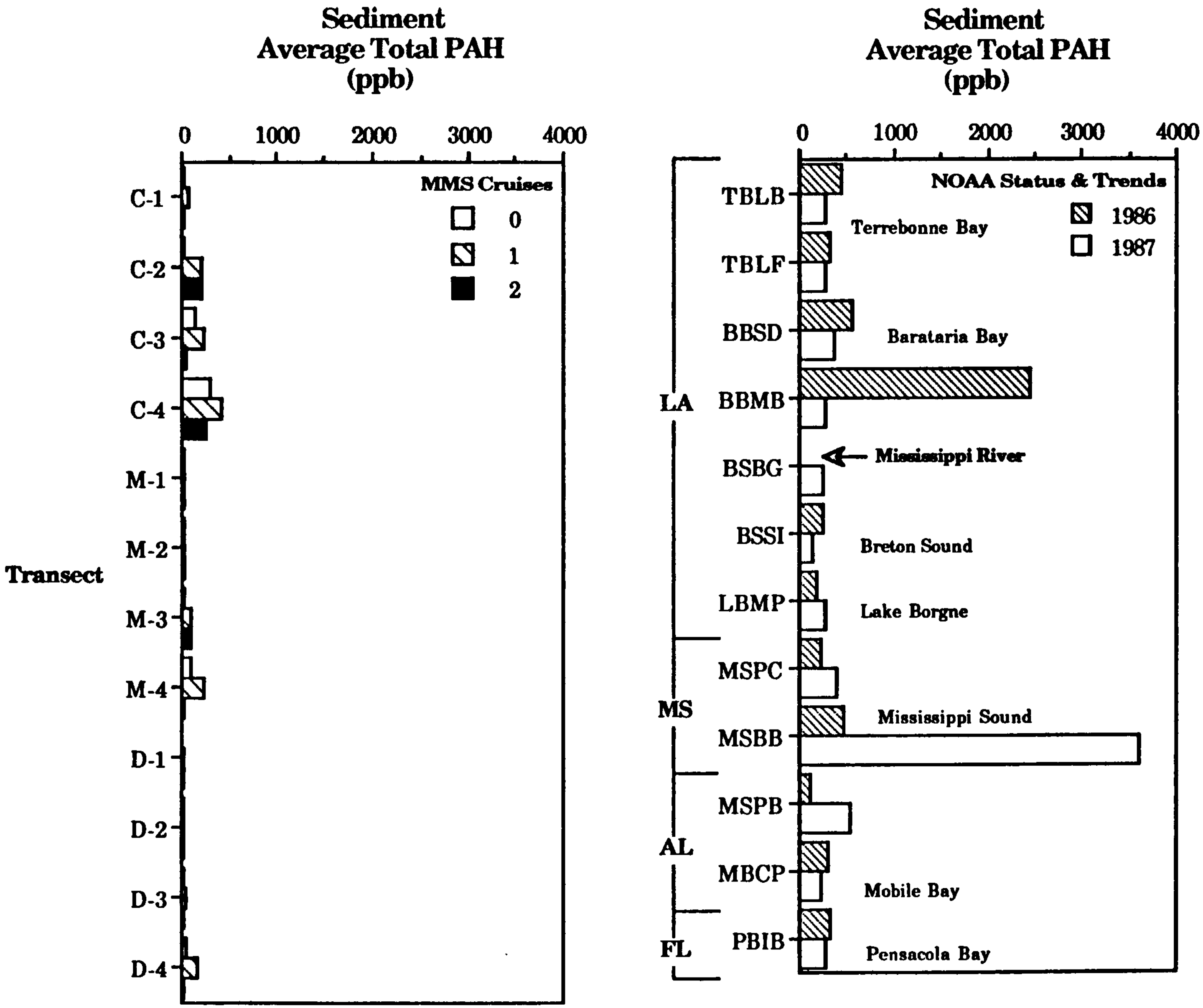

Figure 4-12. Comparison of sediment PAH concentrations from Cruises 0, 1, and 2 and NOAA Status and Trends data from adjacent bays.

5.0 TRACE METALS

Bobby J. Presley

5.1 Introduction (including historical background)

Trace metal concentrations in the environment can be increased as a result of petroleum exploration and production, and this can potentially have harmful effects on marine organisms. In order to assess present day background levels of trace metals in the offshore Mississippi-Alabama area sediment samples collected on each of the three cruises completed to date have been analyzed. The twelve stations shown in Figure 5-1 were sampled on each cruise, except no sample was obtained at Station D-1 on the first cruise. At each station three different box cores were taken and the upper 5 cm of all three were used to make a composite sample for analysis.

The composite samples were analyzed for the 16 elements currently being determined on the NOAA Status and Trends Program using the methods employed on that program (Brooks *et al.* 1988). This method has been shown to produce high quality data through a series of intercalibration exercises and its use here will allow the MMS data to be compared to the large data set on northwest Gulf of Mexico sediments produced by Status and Trends.

A summary of much of the previous work that has been done in the Mississippi-Alabama area is included in this report for comparative purposes.

5.1.1 Sources of Trace Metals to the Study Area

Trace metals, unlike pesticides and other synthetic organic compounds, have both natural and anthropogenic sources. Continental rocks, soils and organisms have variable contents of trace metals, some of which are released during weathering, decomposition, and destruction of the parent materials. The released trace metals are transported from continents to the sea largely associated with particles of various sizes. In addition to these natural sources of trace metals from the continents,

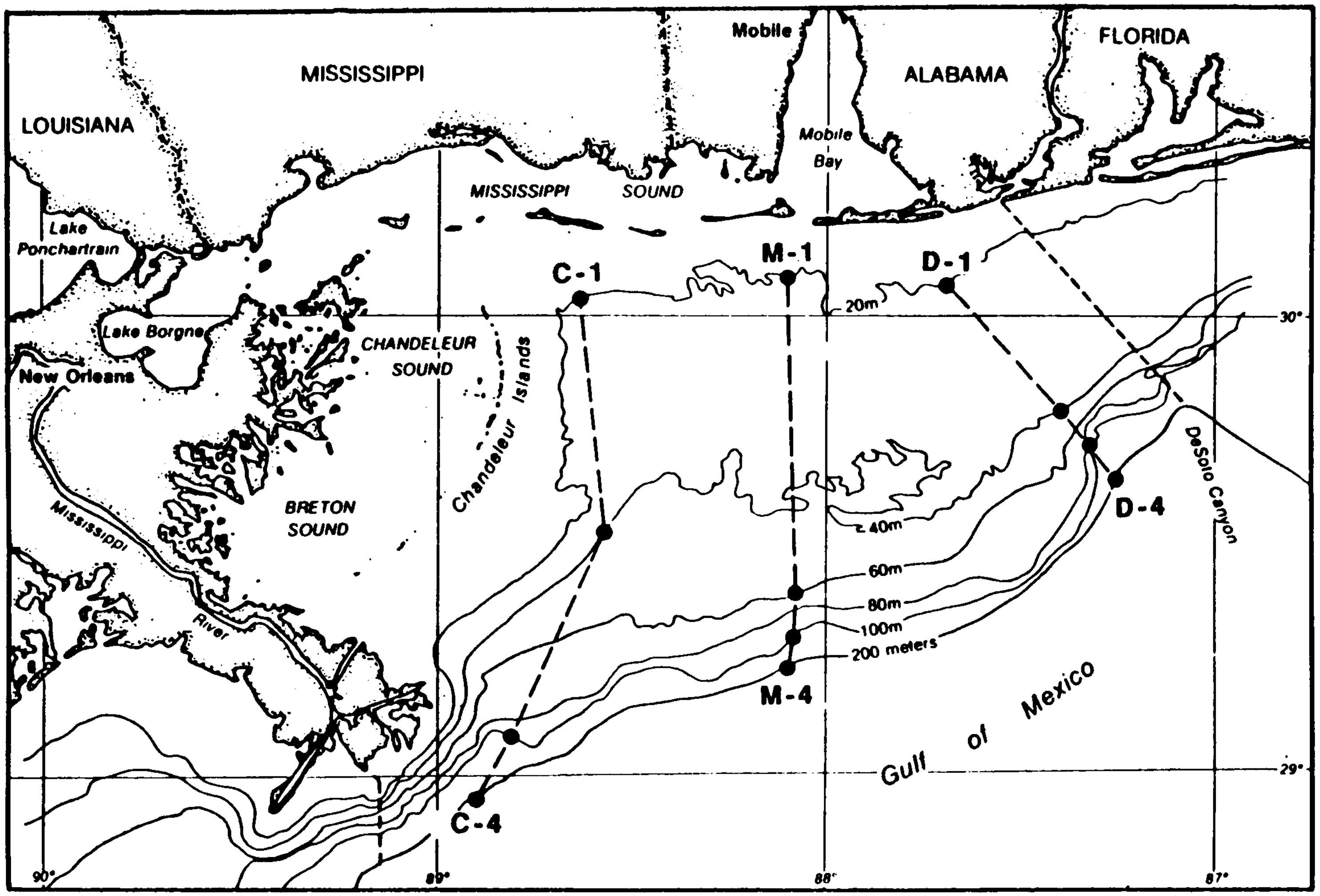

Figure 5-1. Twelve stations sampled on Cruises 0, 1, and 2 of the Mississippi-Alabama Marine Ecosystem Study.

natural sources within the sea itself might, in some cases, supply significant amounts of trace metals to near-shore areas. Man, through his many activities, both on the continent and in the sea, can significantly influence the flux of trace metals to the nearshore marine environment.

For most nearshore areas, such as the area offshore Mississippi and Alabama being considered here, most trace metals will come from the nearby land. Such marine processes as undersea volcanos and hydrothermal vents, authigenic mineral formation, manganese nodules, etc. can be neglected. The activities of man in the marine environment must be considered, of course, whether it be direct dumping of wastes, oil exploration and production, dredging, construction, shipping or whatever. In considering land sources for marine trace metals, a first consideration is their transport to the ocean. This can be by rivers, the air or through the activities of man (e.g., pipelines, barges, etc.).

River Inputs - Rivers are the main pathway by which both natural and pollutant trace metals reach the coastal ocean. Garrels and Mackenzie (1971) estimate that rivers account for 90 percent of the total seaward transport of dissolved and suspended material. The Gulf of Mexico (GOM) receives about 60 percent of the total dissolved material (Leifeste 1974) and 66 percent of the total suspended solids (Curtis *et al.* 1973) transported to the ocean from the continental United States. The Mississippi-Atchafalaya River, in turn, accounts for about 86 percent of all U.S. riverine transport to the GOM. To characterize the Mississippi River input is, therefore, sufficient to describe a large percentage of the input of continental material to the Gulf.

Table 5-1 lists recent data on both the dissolved trace metal concentrations in Mississippi River water and concentrations of trace metals carried by particulates in the river. Also given, for comparative purposes, are recent estimates of world average dissolved and particulate riverine trace metals. It can be seen that trace metal concentrations in the Mississippi River are generally less than, or equal to, those in world average rivers, in spite of the large and highly industrialized drainage basin of the Mississippi. The Mississippi data given are thought to be typical of the river in that the Trefry and Presley (1976b) data are weighted averages of four

Table 5-1. Mississippi River dissolved and particulate trace metal concentrations.

	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	V	Zn
Dissolved metal concentrations in µg/l water											
Mississippi River (Trefry and Presley, 1976)	0.1	--	0.5	2	5	10	-	1	0.2	--	-
(Trefry et al., 1986)	0.013	--	0.28	1.9	--	--	--	1.4	0.11	--	--
(Shiller and Boyle, 1987)	0.013	--	0.07	1.5	1.7	--	1.1	1.4	--	1.2	0.2
Average River Water (Martin and Whitfield, 1983)	0.002	0.2	1	1.5	40	8	0.5	0.5	0.1	1	30
Particulate metal concentrations in µg metal/g suspended matter											
Miss. Suspended Matter (Trefry and Presley, 1976)	1.3	20	80	46	46,000	1300	--	55	46	150	180
(Trefry et al., 1986)	0.68	--	74	32	42,000	1220	--	46	32	--	--
Average River Suspended Matter (Martin and Whitfield, 1983)	1	20	100	100	48,000	1050	3	90	100	170	250
Average continental soil (Martin and Whitfield, 1983)	0.35	8	70	30	40,000	1000	1.2	50	35	90	90

sampling periods seasonally spaced through 1974 and 1975 and the Shiller and Boyle, 1987 data are weighted averages of six sampling times during 1982-84. Dissolved trace metal concentrations in both of these studies were relatively constant with time, with copper (Cu) and nickel (Ni) showing only about a 25 percent variation, but molybdenum (Mo) and chromium (Cr) showing larger variations with time. It should be noted that other reported dissolved trace metal data for the Mississippi River are probably in error, due to sampling and analytical artifacts. The U.S. Geological Survey (USGS) data as published each year in the USGS Water Data Reports, generally gives much higher concentrations of trace metals which are judged to be unreliable based on the agreement between the data of Trefry and Shiller and the reputations of these two investigators.

It is generally recognized that dissolved trace metals are much more available to organisms than are particulate metals, and furthermore that certain forms of the dissolved metal fraction are more bioavailable than others. For example, the ionic form of a dissolved metal is generally more available than a complexed form. Unfortunately, little work has been done on the form of metals dissolved in Mississippi River water, although Andren and Harriss (1975) were able to show that about 65 percent of the total 40 ng/l dissolved mercury (Hg) was associated with a less than 500 molecular weight fraction and that less than two percent was present as methylmercury.

More work on the forms of dissolved metals in Mississippi River water are needed, including metal-organic complexing and related studies, because the chemical form of the metal determines its behavior and biological effect. Despite the acknowledged importance of the dissolved trace metal load of the Mississippi River, it should be noted that the suspended trace metal load is much greater for essentially all potentially toxic trace metals. Trefry and Presley (1976b) point out that 90 percent or more of the trace metals they studied were carried by particles. The behavior of these river-borne particulates as they mix with seawater is critically important to the ultimate fate of the trace metals, yet this is a subject that is not well understood. Metals can stay with the particles or become separated (desorbed) from them during river water-seawater mixing. Trefry and Presley (1976b) found little evidence of desorption of the trace metals they studied at the river mouth but Hanor and Chan (1977) present evidence for desorption of Ba. This is a subject needing more study.

Table 5-1 shows that many of the particulate trace metal concentrations in the Mississippi are similar to those of world average river particulates and world average soils. Thus, neither the dissolved nor the suspended load of the Mississippi gives any clear indication of large scale pollutant influences although cadmium (Cd), lead (Pb) and zinc (Zn) seem to be somewhat elevated relative to continental soils in both world average and the Mississippi River. As will be discussed later, Mississippi River Delta sediments also seem to be somewhat enriched in Cd and Pb. The pollutant (man-derived) nature of part of the Pb carried by the Mississippi River is also shown in a study by Trefry *et al.* (1985) which shows a decrease in the Pb load of the river between 1975 and 1985 which is attributed to the decreased usage of leaded gasoline during this period.

Atmospheric Inputs - Numerous studies of transfer of trace metals from continents to oceans through the atmosphere have been conducted in recent years (e.g., Buat-Menard 1986). It is generally recognized that atmospheric transport dominates over riverine transport for open ocean areas far from land. For some metals, such as Pb, which have been common in automobile exhaust, atmospheric transport dominates even in coastal regions especially near population centers. Other processes, such as cement manufacture and coal burning, can also add large amounts of some trace metals to the atmosphere and for these metals the atmosphere can be a significant transport pathway to the coastal ocean, especially in areas remote from large rivers. Church *et al.* (1982) suggest that atmospheric sources of several trace metals are as great as riverine sources for the middle Atlantic coast (Delaware area) and Windom (1981) reaches similar conclusions about the Georgia area. Unfortunately, no data are available on atmospheric inputs of trace metals to the northern Gulf of Mexico shelf. Such inputs might be high, due to extensive industrial activity in this area, but may still be insignificant compared to the large riverine inputs to the area.

Activities of Man - A number of activities by man could be suggested as potential sources of direct addition of trace metals to the study area. For example, ocean dumping of industrial wastes from ships or barges has been a major concern in some places. It is estimated that in 1973 more than 300 industrial facilities in the U.S. were ocean dumping their wastes and that about 5 million tons of wastes were so dumped. At that time, two sites in the GOM were designated as dumpsites by the U.S. Environmental Protection Agency (EPA), one about 50 nautical miles from the entrance to Southwest Pass of the Mississippi River in water depths of about 1000 m and another about 120 NM south of Galveston, Texas. About 10 different kinds of industrial wastes were dumped at these sites between 1973 and 1978 when dumping was halted. It is unlikely that residues from this dumping are still affecting the area of concern in this report but these dumpsites should be remembered and it should be recognized that industries could request resumption of ocean dumping in the future as land disposal becomes more expensive.

Closely related to ocean dumping are industrial outfalls. Some pipeline discharges of industrial wastes directly enter estuarine or marine waters. These are regulated by EPA but can, nevertheless, degrade the marine environment, especially in view of the difficulty of monitoring compliance with EPA permits.

A listing of industrial outfalls in the GOM should be available through the EPA permitting procedure, but no such summary was available to the authors of this report. Therefore, we can only speculate that trace metal additions to the study area from industrial outfalls is likely to be significant. It is essential that data be obtained on industrial and municipal outfalls in the study area so that their influence not be confused with inputs from other sources.

In addition to ocean dumping and pipeline discharges of wastes, two other activities by man potentially affect trace metal distributions in the study area. These are petroleum exploration and production and dredging to create and maintain navigational channels. Both of these are large scale activities and they are related in that much of the dredging is done in conjunction with petroleum production.

More than 26,000 oil wells have been drilled in federal offshore waters through 1986 and more than 20,000 of these were located offshore Louisiana (Minerals Management Service 1988). If offshore oil well drilling has an effect on the marine environment anywhere, it has an effect in the area of concern in this report. A number of activities conducted during offshore drilling and production could affect trace metal levels in the area, for example, transporting and constructing drilling platforms, building pipelines, etc. However, the two activities which have received the most criticism are disposal of drilling muds and disposal of water (brine) produced with petroleum.

Drilling fluid (mud) is essential to oil well drilling. Circulating the drilling fluid through the well cools the drill bit, removes cuttings, coats the borehole to prevent fluid loss, controls downhole pressure, and performs other functions. The drilling fluid is essentially a mud made from fresh or seawater and bentonite (montmorillonite) clay. However, many chemicals are added to the mud to perform specific functions, as a result over 1000 brand name drill mud additives are on the market. By far the most common additive is barite ($BaSO_4$) which is added to increase the weight of the mud. This compound can amount to 90 percent or more of the dry weight of a typical drill mud. Other common additives include chrome lignosulfonate, lignite and sodium hydroxide. All of these additives contain finite amounts of trace metals, therefore depending on the amounts and nature of additives, drill muds contain variable amounts of trace metals.

The concern that drill mud disposal might pollute the environment with trace metals stems not from the fact that drill muds contain high concentrations of trace metals (except for Ba and possibly Cr) but from the fact that very large amounts of drill muds are used. A typical GOM oil well requires drill mud containing about 600 metric tons of dry solids according to data on 49 wells given by Boothe and Presley (1985). Almost all of the used drill mud is dumped into the sea during or at the conclusion of drilling. Multiplying the 600 tons per well released by the 22,000 wells that have been drilled offshore Texas and Louisiana gives a very large number compared to the input of most other substances to the area. For example, the Ba contained in the drill mud which is dumped from the approximately 1000 new wells that are drilled each year is slightly greater than the Ba which is carried down the Mississippi River each year. In the case of Ba, then, man, through offshore oil well drilling is drastically changing the entire geochemical balance of the area. Other trace metals are in much lower concentrations in drill mud, but may in some cases be significant additives to local areas of the Texas-Louisiana Shelf.

As has been discussed, large volumes of drill mud are dumped into the sea during offshore well drilling. Another substance dumped in large amounts is the formation water (brine) which is produced with petroleum and which must be separated from it on offshore production platforms. Over the lifetime of a typical well in the GOM the amount of brine discharged is greater than the amount of oil produced. The Minerals Management Service reports that more than 5 billion barrels of oil were produced on offshore federal lands in the northwestern GOM during the period 1954-1980. Production from state lands and production since 1980 could almost double this volume. This enormous volume of brine could have added significant amounts of some trace metals to the Gulf of Mexico, but the chemical composition of the brines is not well known. Most oil well brines are enriched in lithium, boron, strontium, bromine, florine, barium, iron, and manganese (Collins 1975) but the concentrations of rarer and more toxic trace metals such as Cd and Pb are not well known. If the produced brines mix rapidly with the large volume of water, then even toxic metals would be rapidly diluted to harmless concentrations unless they are initially in very high concentrations, which seems unlikely. Nevertheless, it seems that more study of the nature and fate of oil well brines is needed.

Like oil well drilling, dredging of navigational channels and dredging to recover sand, gravel, and shell is a major operation in nearshore marine environments. In terms of volume, dredging is the largest single source of material that is dumped into the sea. A recent estimate says about 465 million cubic yards of material are dredged annually of which 60 percent is coastal and estuarine dredging and 64 percent of that is along the Gulf Coast (Pequegnat 1987). In many cases the dredged material contains no harmful pollutants, especially if it is largely sand. In other cases, however, the dredged material can be quite polluted, especially when it is removed from harbors in industrialized areas. The dredged material is likely to be highly reducing and organic rich and this can result in both high concentrations and more readily available trace metals. Failure to consider nearby dredging operations could seriously complicate interpretation of trace metal data for nearshore areas.

5.1.2 Trace Metals in the Water and Sediment of the Study Area

Dissolved in Water - Essentially all data more than 10 years old and much recent data on concentrations of trace elements dissolved in seawater are too high by factors of 10 to 1000 or more. Bruland (1983) gives a good review of recent dissolved trace metal data and discusses problems with earlier data. He points out that only within the past 10 years have sets of dissolved trace metal data for seawater been obtained which conform to known physical and biological oceanographic parameters. For example, a number of metals have now been shown to have "nutrient-like" behavior, whereas in older literature no correlations between trace metals and other oceanographic parameters could be found. It should also be noted that only a few investigators in the world have produced these "oceanographic consistent" dissolved trace metal data sets and even recent data from most investigators should be viewed with extreme skepticism.

Unfortunately, few seawater samples from the northern Gulf of Mexico have been analyzed for dissolved trace metals with the care required to lend confidence to the data. Data that are almost certainly of high quality have, however, been reported by Edward Boyle and his co-workers. Boyle is one of the most respected seawater analysts in the world and one of the most experienced. Boyle *et al.* (1984) report on two sets of samples that apply to the area of concern in this report.

The first set of approximately 50 surface samples was collected along a cruise track extending from Miami, around the tip of Florida and across the Gulf of Mexico (GOM) to near Bay St. Louis, Mississippi. The cruise track crossed the Loop Current and a warm core ring. In spite of these different water masses and the long cruise track, there was almost no difference in concentrations of cadmium (Cd), copper (Cu) and nickel (Ni), the only metals determined. The open GOM surface samples gave concentrations of 0.082 parts per billion (ppb) for Cu, 0.11 ppb for Ni and 0.0005 ppb for Cd, values much lower than those reported by previous investigators (for example, Slowey and Hood 1971). However, the half dozen surface samples collected a few miles off the Mississippi coastline gave higher values, averaging 0.5 ppb for Cu and Ni and 0.02 ppb for Cd. These coastal concentrations, obtained on samples collected in April 1981, are similar to values obtained by Shiller and Boyle (1983) on samples collected farther west, in the Mississippi River plume. It seems that for these three metals, concentrations are fairly constant in surface coastal GOM water and while considerably higher than open GOM values, are nevertheless much lower than values which have been reported by other investigators. Boyle *et al.* (1984) report Cd, Cu and Ni data for a second set of samples collected in the northwestern GOM in December 1982. About 20 surface samples were taken off Texas and Louisiana, mostly in water depths of 100 to 1000 meters. Concentrations of Cu, Cd and Ni in these samples were very similar to those of the eastern Gulf samples, with an indication of higher values towards shore but because no samples were taken nearshore the increase was not as dramatic as that seen off Mississippi. Boyle *et al.* (1984) analyzed samples from a few hydrocasts and found increases in concentration of Ni, Cd and Cu with depth, in response to organic matter degradation and nutrient release. For Cu and Ni, however, the increases were irregular and at most a factor of two. Cadmium increased more sharply with depth and some deep samples were ten times richer in Cd than average surface samples.

The role of diffusion from sediment pore water in controlling trace metal concentrations in overlying coastal seawater has been much discussed but not enough work has been done to verify its importance for most metals. It seems clear that the phenomenon is important for Mn, which exists in the sediment as an oxide which is easily reduced to the soluble Mn^{+2} form. Trefry and Presley (1982) calculated that Mn was diffusing from Mississippi River Delta sediments at a rate of 200-1000 $ug/cm^2/year$. This diffusion depletes the delta sediments in Mn by about 50 percent and should affect bottom water Mn concentrations. Iron too is reduced and mobilized in the sediments and high Fe values are found in nearshore sediment pore water. However, Fe flux out of the sediment is less than that of Mn and fluxes of Cd, Ni, Pb, etc., are no doubt less yet, but this has not been well documented. More work is needed on this subject because benthic organisms would be exposed to sediment pore water and might be affected by high trace metal concentrations or high levels of such chemicals as ammonia and sulfide which also build up in pore water.

Suspended in Water - Most of the particulate matter brought to the sea by rivers settles out very near the river mouth, even the very fine grained clay material. Thus a river plume, such as that of the Mississippi, is highly visible, with a sharp transition from muddy to clear water. Several factors contribute to this rapid settling of river particulates, including the lower current speeds in the ocean and the higher salinity in the ocean which destabilizes and flocculates clay particles. Plankton in the ocean can also aid in sinking of clay particles by packaging them into fecal pellets which sink rapidly.

Total suspended matter (TSM) in the Mississippi, the most important river to our study area, varies considerably from season to season as a function of river flow. At normal and high flow rates the river water usually has 100-500 mg/l of TSM, but can have as little as 10 mg/l at very low flow stages. In contrast to river TSM values, coastal seawater values are low and can vary due to variations in both inorganic and biological particles. Nelsen and Trefry (1986) found 6-7 mg/l TSM at a station very near the Mississippi River mouth when concentrations in the river were 180 mg/l. A few miles away, at mid-shelf, TSM had dropped to 2-3 mg/l and at the shelf break to 0.3-0.5 mg/l. Open Gulf of Mexico (GOM) TSM values are typically 10-100 µg/l, that is 5 to 50 times lower than the shelf break values.

Most TSM values are obtained by filtering a discrete water sample of 100-1000 ml. A problem with this procedure is that it can miss large particles which sink rapidly and may carry most of the mass that is sinking towards the seafloor. A second problem arises when the chemistry of the particulate matter is to be determined. If, as is usually the case, this is done by analyzing material caught on filters, the material may not be typical of what is sinking and the filter is likely to hold so little material that great skill is needed to analyze it properly. For these reasons there is relatively little data on the chemistry of suspended matter on the northwest Gulf of Mexico shelf and some of the data that are available are of questionable quality. The most reliable and representative data set is probably that of Trefry and Presley (1976b).

Sediments - Marine sediments are usually considered to be the "ultimate sink" for trace metals added to the ocean and that is certainly true after the trace metals have been buried a meter or so deep in the sediment column. As has been noted above, however, trace metals can be returned to the water column from a few centimeters deep in the sediment column by mobilization processes which solubilize them. Either molecular diffusion or physical disturbance within the sediment can transfer the soluble metals to the water column. In spite of processes which can return trace metals to the water column, or make them available to organisms living in the sediment, the sediment column represents, in general, a record of past and present trace metal inputs to the marine environment. As such, sediment data provides valuable information to environmental monitoring studies. An example of using sediment for a historical perspective on pollutant inputs to GOM sediments is given by Presley *et al.* (1980).

One of the first large scale studies of the trace metal chemistry of coastal GOM sediments was that of Holmes (1973). He found highly variable concentrations of a number of trace metals, with high values in the clay-rich sediments off the Mississippi River Delta and low values in sandy and/or carbonate rich sediments from Texas and Florida. Trefry and Presley (1976a) analyzed 51 samples from San Antonio Bay and 72 samples from the Texas-Louisiana Shelf for Fe, Mn, Pb, Zn, Cd, Cu and Ni. These samples also varied in trace metal content depending on clay, sand and carbonate contents. In order to compare the sediment in a simple way, and to uncover possible areas of pollutant input, Trefry and Presley constructed scatter plots of trace metals versus Fe content. These plots gave generally good positive correlations for both bay and shelf sediments. Some metals in some samples deviated from the linear relationship, as, for example, did some Pb samples. Trefry and Presley (1976a) attributed these deviations to pollutant input of Pb in the Mississippi River Delta. Much greater deviations were found for obviously polluted areas such as the Houston Ship Channel.

In addition to generalized survey work along the northwestern Gulf of Mexico, several studies have concentrated on areas immediately around offshore oil drilling platforms. Examples of these studies include Gettleson and Laird (1980), Tillery and Thomas (1980), Middleditch (1981) and Boothe and Presley (1985, 1987). Sediment Ba concentrations were determined in all of these studies as it is the most abundant metal in drilling muds and therefore provides the most sensitive indicator of the presence of drill mud in the sediments. Most of the sediment studies included Cr as it too can be in higher concentration in drill mud than in normal shelf sediment. Some studies included Ni and V, two metals common in petroleum and trace metals generally recognized to be highly toxic, such as Cd, Hg and Pb.

The sediment sampling and analysis program conducted by Boothe and Presley (1985) on six drilling sites in the northwestern GOM was the most intensive such study yet conducted and included several novel features not included in other drilling site monitoring studies. Sediment cores were collected at 40 stations around each site, 36 of them in a regular circular pattern within 500 m of the site, and four stations on a circle 3000 m from the site. Sediment type at each station was described in terms of sediment texture and concentration of organic carbon, calcium carbonate, aluminum and iron. The influence of drilling activities was characterized by determining sediment concentrations of elements known to be major constituents of drilling fluids (e.g., barium) and of trace elements of environmental concern (i.e., cadmium, chromium, copper, mercury, lead, zinc). Exploration, development, and production sites in both shallow and deep water were studied to determine how the amount of drilling, water depth, and elapsed time between cessation of drilling and sampling influence the characteristics of surrounding sediments ($\leq$500 m).

This is evidently the first study in which an accurate, three-dimensional mass balance of discharged (excess) barium has been determined. This three-dimensional approach estimates all excess barium present in the top 21-31 cm of the sediment column sampled within 500 m of each study site. This barium mass balance data clearly shows that only a small fraction of the total barium used (i.e., <1.5 percent nearshore, <12.0 percent offshore), and presumably similarly behaving drilling mud components, are present in near-site sediments. The length of time between cessation of drilling and sampling had little effect on the percentage of the total barium used in drilling activities which was present in near-site sediments. Multiple regression analysis suggests that the distribution of excess sediment barium observed among the six drilling sites is largely controlled by water depth (as an indicator of the magnitude of sediment resuspension and transport) and the total amount of Ba used in the drilling activities. In terms of total excess barium, the effect of multiple wells on near-site sediments is directly additive. Discriminant analysis suggested that statistically significant ($p < 0.01$) barium enrichment ($\geq$twice background levels of 200-700 ppm dry weight) existed in surface sediments even at 25 of the 30 control stations at 3000 m.

Despite the large amounts of drilling mud components used at the six drill sites, the more pervasive sediment perturbations attributable to drilling activities are largely restricted to deep water development and production sites. These two sites had by far the largest total excess (discharged) barium values among the six study sites.

Statistically significant elevations in surficial sediment mercury concentrations (i.e., within 125 m of the site, 4-7 times mean control levels of 43 ppb dry weight at V321 and 24 ppb at HI) were observed at the Vermilion 321 and High Island sites. Barite containing a trace amount of natural Hg contamination is the most likely explanation for these observations. The concentration of Hg in the barite required to cause the elevated sediment Hg levels observed is only 1-3 micrograms Hg/g of barite. Little or no significant elevations in other trace metal concentrations were observed. Trends in chromium levels in near-site sediments were largely controlled by the clay content of the sediment and elevations above control levels were infrequent (patchy) and generally less than twice expected concentrations.

Another platform monitoring study was the "Central Gulf Platform Study" funded by the Minerals Management Service and conducted by Southwest Research Institute in 1978 (Tillery and Thomas 1980). In this study 20 platforms and four control sites were examined offshore Louisiana in water depths of 20 to 100 m. Four of the platforms were "primary sites" and 16 "secondary sites." At the primary sites, samples were taken at 100, 500, 1000 and 2000 m in two directions from the platform whereas at the secondary sites samples were only taken in one direction from the platform.

This restricted sampling scheme makes it much more difficult to document influences by the platforms than in, for example, the study by Boothe and Presley (1985). Suspected analytical problems in this study also limit the usefullness of the data. Concentrations of trace metals were found to be similar to those reported by Trefry and Presley (1976a) and to decrease with distance from platforms, at least for some metals (Ba, Cd, Cr, Cu, Pb and Zn) and at some platforms.

One of the largest, most systematic and highest quality trace metal data sets for the northwestern GOM shelf and upper slope is unpublished data of Boothe and Presley. Nearly 100 stations were sampled during the period 1976-1984 and at more than 50 of those, both surface and sub-surface sediment samples were taken. All samples have been analyzed by neutron activation analysis for Ba and Fe as well as other trace elements (e.g., Cr, Co, rare earth elements, etc.). Table 5-2 summarizes mean sediment Ba levels as a function of Fe concentrations (indicative of sediment texture) in various regions of the Texas-Louisiana shelf and slope.

As discussed previously, the northern GOM is the most heavily explored and developed offshore petroleum hydrocarbon region in the world. The majority of the more than 21,000 petroleum wells drilled in this region are on the eastern Texas-Louisiana continental shelf (<200 m water depth) between the Mississippi River Delta (89.25°W longitude) and Morgan City, LA (91.5°W). Prevailing currents in this area are westerly tending to disperse any barite discharged from this intensive drilling activity longshore to the western TX-LA shelf and cross-shelf over the shelf-slope break (200 m) to the deeper Gulf.

An estimated 250 metric tons of Ba are discharged from each well drilled on the TX-LA shelf. This means that >5 million metric tons of Ba have been discharged into the area since 1947 when offshore petroleum development began. If this Ba was retained in the discharge area then the mean surficial sediment Ba concentration ($\leq$4 cm sediment depth) on the TX-LA shelf should be elevated >2500 ppm above background levels (<700 ppm). The general lack of a direct correlation between Ba and Fe on the eastern shelf is most likely due to discharged drill mud Ba retained in the sediments. Comparison of surface and sub-surface (circa 1940) data suggests that elevated surface Ba is a generalized phenomenon over the

Table 5-2. Sediment Ba concentrations in various regions of the Texas-Louisiana (TX-LA) continental shelf and slope as a function of sediment iron levels.

Area of TX-LA Shelf/ Slope (2)	Water Depth (m)	Depth Interval Range (cm) (3)	Mean barium concentrations ± 1 standard deviation (ppm dry wt.) for samples with range of iron concentrations (ppm dry wt.) indicated (4)				
			< 1.5	1.5-2.5	2.5-3.5	3.5-4.5	> 4.5
Miss. River Susp. Matter	-----	------	-----	307 (1)	394 (1)	460 ± 12 (4)	475 (1)
Eastern Shelf (Delta-91.5°W)	< 200	0-2	620 ± 122 (3)	645 ± 95 (10)	600 ± 141 (16)	615 ± 179 (55)	555 ± 42 (13)
		8-29	-----	-----	420 ± 5 (2)	505 ± 13 (2)	495 (1)
Barataria Bay (89.75°W)	3	0-2	-----	725 ± 48 (5)	----	-----	-----
		20-21	635 (1)	680 (1)	-----	-----	-----
Western Shelf (91.5-94°W)	< 200	0-2	20 ± 130 (9)	410 ± 94 (26)	545 ± 85 (30)	511 ± 74 (11)	520 ± 28 (3)
		11-15	-----	390 (1)	512 (1)	-----	-----
Eastern Slope (Delta-91.5°W)	> 200	0-2	-----	-----	470 ± 28 (12)	590 ± 111 (32)	565 ± 68 (13)
		5-20	-----	-----	415 ± 54 (2)	480 ± 69 (24)	483 (1)
Western Slope (91.5-93.6°W)	> 200	0-2	-----	535 ± 5 (2)	565 ± 199 (18)	1000 ± 156 (4)	-----
		5-21	-----	245 ± 17 (5)	335 ± 29 (5)	445 ± 42 (9)	-----
Abyssal Plain	3350	0-4	-----	-----	290 ± 25 (5)	-----	-----

1. From Boothe and James (1985). All samples 500 mg, irradiated 14 hrs and counted 4000 secs with dead time < 10%. Decay time was 10-24 days and sample to detector distances ranged from 4.3 to 9.3 cm. Total number of samples = 329.
2. Only unfractionated (whole) Mississippi River suspended matter data are reported here.
3. Deeper sediment intervals (> 4 cm) were deposited about 1940. This year predates the onset of offshore petroleum drilling on the TX-LA continental shelf by at least 5 years. This sediment dating is based on sedimentation rates calculated from lead-210 measurements made in this area. This sediment dating does not apply to the Barataria Bay subsurface sample.
4. Number of samples in each barium/iron group is given in parentheses.

entire shelf and slope. This situation is consistent with the wide-spread drilling and potential for sediment transport in this area. However, the surface elevations observed are generally much smaller (i.e., averaging <160 ppm) than could be expected. A combination of large-scale, off-shelf fine-grain sediment transport and dissolution of discharged barite is the most likely explanation for the low retention of discharged Ba in shelf sediments.

5.1.3 Transport and Transfer of Trace Metals in the Study Area

Processes which transport trace metals into the study area have been discussed in Section 5.1.1 and transfer of trace metals has been discussed briefly in Section 5.1.2. A separate section on transport and transfer seems warranted, however, to emphasize the importance of the processes and to again emphasize that the study area cannot be considered in isolation where trace metals are concerned.

High concentrations of trace metals in some component of the environment within the study area might well be the result of some activity (e.g., oil well drilling, dredging, etc.) within the area. On the other hand, some activity outside the area may be releasing metals which are then transported into the study area. The importance of the Mississippi River as a transporter of trace metals was discussed earlier in this report and other rivers are also important. It should also be noted, however, that the amount of water transported into the Gulf of Mexico (GOM) from the Caribbean is more than 800 times greater than the Mississippi River inflow. Of course, an almost equal volume of water exits the Gulf, but if some process removes trace metals from the water while it is in the Gulf, concentrations in the GOM would be increased.

Several mechanisms can remove dissolved trace metals from seawater and transfer them to other reservoirs. For example, plankton can extract dissolved trace metals, which could then be transferred up the food chain or to the seafloor. Similarly, dissolved trace metals can be absorbed on clay particles and therefore transferred to the seafloor. The reverse transfer, from particles to water (desorption) is also well documented. No attempt will be made here to explain, or even to list, all the possible transfer pathways by which metals could move into, within, and out of the study area.

It is sufficient to note here that such transfers do occur and that they must be considered in evaluating trace metal distributions within the study area.

5.2 Methods

5.2.1 Sample Preparation and Digestion

Sediment samples were frozen in plastic containers in the field. In the laboratory, the sediment samples were freeze-dried and finely ground before analysis. The major analytical technique used was atomic absorption spectrometry (AAS), flame for those elements in high enough concentration and flameless or cold vapor when necessary. This technique made it necessary to dissolve the samples before analysis. To prepare samples for AAS, digestions were carried out in closed all-teflon "bombs" (Savillex Corp.) of 50 ml capacity. Accurately weighed aliquots of about 200 mg of sediment was digested at 130°C for eight hours in a mixture of nitric, perchloric and hydrofluoric acids. A saturated boric acid solution was then added to complete dissolution of the sediment and the digest was brought to a known volume. Various dilution were made on the clear digest solutions to bring them into the working range for AAS. Standard reference materials and blanks were digested with every batch of samples. A more complete outline of the preparation methods is given in Table 5-3 and Table 5-4 gives details on cleaning the digestion equipment to avoid contamination of the samples.

5.2.2 Instrumental Analysis

As mentioned above, the primary analytical method used in our laboratory was atomic absorption spectrometry. This technique has good sensitivity but requires the sample to be in solution for analysis. Dissolving the sample can, if not done correctly, result in either losses or gains in the trace metal content. When possible, therefore, we also analyzed the samples by neutron activation analysis, a method which uses the untreated solid sample. Unfortunately, only a few of the elements were in high enough concentration in the sediment to be determined by neutron activation, but

Table 5-3. Outline of sediment digestion methods for trace metal analysis.

Reagents:

4:1 mixture of nitric:perchloric, both vycor distilled and stored in teflon bottles.

Baker reagent grade Hydrofluoric Acid.

2.5% solution of Baker Ultrex Boric Acid - 50 g boric acid in 2L of distilled-deionized water.

1. Weight out 200 mg ground, dry sediment and add to a preweighed, acid cleaned teflon bomb. Be as careful as possible to pour the sediment to the bottom of the bomb. Static electricity will cause the sediment particles to adhere to the inside walls of the bomb.

2. Add 1 ml of 4:1 HNO_3NClO_4. Try to carefully wash the inside walls of the bomb with acid. Tighten the bombs with wrenches and place in 130°C oven for 4 hours.

3. Remove bombs and let cool. Add 3 ml HF, retighten bombs and return to oven ~8 to 12 hours (overnight).

4. Remove bombs and let cool. Add 20 ml of 2.5% H_3BO_3, tighten bombs and return to oven ~8 hours.

5. Let bombs cool and weigh. Calculate the solution volume using a density of 1.05 g/ml.

6. Transfer the solutions to 30 ml acid cleaned polybottles.

7. Remove 0.5 ml of solution and dilute it to 20:1 with dilute HNO3 (the exact composition of the diluting solution changes). This can be done in a new 5-dram snap cap vial. This dilution is used for Fe, Al, and Si analyses.

8. Reagent blanks - run 2 for each batch. Follow steps 2-7.

Each batch of sediments and oysters digested included two to four of the reference standards listed below.

Sediments:

NOAA Intercalibration Standards, A,B,C,&D
NBS River Sediment Standard #1645
USGS Geochemical Exploration Sample #5
NBS Estuarine Sediment Standard
TAMU House Standard #1
TAMU House Standard #2

Table 5-4. Bomb cleaning procedures for trace metals after sediment digestion.

Bomb Cleaning After Sediment Digestions:

1. Wipe inside of bombs with a paper towel and diluted Micro™ cleaning solution, then place bombs in a dilute Micro™ bath* for 24 hours.

2. Rinse with house distilled water and then with deionized water. Place rinsed bombs into nitric bath** for 24 hours.

3. Rinse with deionized water and set the bombs out to dry in the clean room.

*Change these baths after each batch.
**Change the nitric bath one a week.

where an element was determined by both methods (e.g., Fe) agreement was good, indicating good recovery by the digestion method used.

5.2.3 Atomic Absorption Spectrometry (AAS)

Three different AAS techniques were used on the sample digests. Flame AAS was used when concentrations were high enough due to the great speed and relative freedom from matrix interference of this technique. For sediment samples, only Al, Fe, Mn and Zn were consistently in high enough concentrations to be determined by flame AAS. Other elements, for example Cr, Cu, and Pb, were high enough to be determined by flame AAS on the clay-rich samples, but many of the samples were sandy and thereby low in trace metals. The flame AA Fe and Al values were judged to be less reliable than INAA values for these elements, therefore the INAA values are given in the data tables. Most of the other elements were determined by graphite furnace AAS.

The flame AAS work was conducted on a Perkin-Elmer Corp. Model 306 instrument, essentially following the manufacturer's recommendations. An air-acetylene flame was used, except for Al where a N_2O-acetylene flame was employed. Working curves were constructed from commercial standards and resulting concentrations were verified by analyzing NBS and other standard materials with every batch of samples (see Table 5-3).

Graphite furnace AAS is much more of an "art" than is flame AAS. The Perkin-Elmer Zeeman 3030 we used was equipped with a HGA 600 furnace and ASA-60 autosampler. The furnace is capable of an almost infinite number of temperatures, holding times and ramp times and, in addition, samples can be placed either on a platform or directly on the furnace tube wall. A number of different matrix modifiers can also be used. Therefore, in the early stages of this program, a great deal of time was spent in working out the best combination of conditions for analyzing each element. The conditions are stored in the computer memory of the instrument and can be recalled and printed out on command. The conditions we are currently using will be supplied on request, but it should be noted that the conditions must be changed slightly from time to time, especially as a graphite tube ages, in order to maximize sensitivity and minimize interferences.

5.2.4 Instrumental Neutron Activation Analysis (INAA)

A dozen or more metals can be determined on coastal sediments by instrumental neutron activation analysis using a single irradiation and a single counting. The element Ba can be determined following an 8- to 16-hr irradiation and a 10- to 15-day "cooling" period. Ba is an element of interest to us because of the widespread use of $BaSO_4$ in oil well drilling mud. We therefore analyzed many of the sediment samples under conditions optimized for determining Ba. Under these conditions several of the rare earth elements, Cr, Co, Fe, Sb and Th are also detected. We have included the INAA data (except for the rare earths) in the data tables. We also analyzed some of the samples by INAA after a short (1 min) irradiation, which gives good data for Al and Mn.

Irradiations for INAA were done at the one megawatt TRIGA reactor at Texas A&M, which produces a flux of about 10^{13} neutrons/cm^2/sec. After a cooling period (usually 10 days), to allow Na, Cl and other interfering isotopes to decay to non-interfering levels, the samples were counted. Counting was done using a Ge (Li) detector coupled to a Nuclear Data Corp. Model 66 pulse height analyzer and computer data acquisition system. Concentrations were obtained by comparing counts for each sample with counts for standard rock powders of accurately known concentration which were irridiated and counted under conditions identical to those used for samples. The INAA technique we used is described in detail by Boothe and James (1985) who also discuss analysis of standard reference materials and other aspects of the technique.

5.2.5 Procedure for Mercury

Mercury was determined by cold vapor AAS on a aliquot of the same digest used to determine other trace elements. The method used was a "head space" sampling procedure in contrast to the more common "stripping" procedure so it will be described here. One ml of sample or standard (more if needed) was put into a 25-ml Erlenmeyer flask and the flask was closed with a rubber serum stopper. The flask was injected with

0.5 ml of a 10 percent $SnCl_2$ solution from a syringe. The sample and $SnCl_2$ was shaken for 30 seconds to reduce Hg to the metal and allow it to transfer into the air space in the flask. A syringe needle connected to the mercury analyzer by a short piece of tygon tubing was next pushed through the serum stopper. Finally, a syringe needle connected to a water reservoir by tygon tubing was pushed through the serum stopper. Water was allowed to flow into the flask at a rate that filled it in about 10 seconds. The water forced air from the flask, with its Hg, into the Hg analyzer where it was measured. A Laboratory Data Control Corp. UV monitor with a 30 cm path length cell was used for Hg detection.

5.3 Results

Samples were collected for trace metal analysis at the 12 stations shown in Figure 5-1 on each of the first three cruises, except no sample was collected at Station D-1 on the first cruise. A composite sample made by combining aliquots from the upper 5 cm of three box cores taken at each station was analyzed for silver (Ag), arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), tin (Sn), thallium (Tl) and zinc (Zn). The data are given in Table 5-5 where the cruises are designated as Cruise 0, 1, and 2, respectively. No data is given for Ba and Sb in Cruise 2 samples as this data, which is produced by neutron activation analysis, was not available when this report was written. Sample D-4 on Cruise 2 appeared to be 10 times higher in Hg than any other sample and this data has been omitted from the data table until the value can be confirmed by analyzing another aliquot of the archived sample.

As the data show, there was considerable station to station variation in the trace metal concentrations in the samples. There was also considerable variation from cruise to cruise, especially at the shallow water stations. This latter observation results from the heterogeneous nature of shallow water sediments and the difficulty of sampling in exactly the same place on each cruise. It is also possible that the surface-most sediments in this shallow water area are somewhat mobile and shift with changing currents. The most drastic change from cruise to cruise was the result of deliberately slightly

Table 5-5. Trace metals in sediments from MMS Cruises 0, 1, and 2.

Cruise - 0

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Sn (ppm)	Tl (ppm)	Zn (ppm)
I-C-1	49	12	333	49	47	8	2.20	66	346	8	15	0.58	<0.5	1.9	0.34	55
I-C-2	18	1	150	19	15	2	0.66	15	141	3	5	0.40	<0.5	0.4	0.10	20
I-C-3	92	15	895	130	84	22	4.20	83	1239	27	33	1.20	<0.5	3.3	0.60	126
I-C-4	118	14	890	204	84	23	4.20	96	664	31	34	1.30	0.6	2.9	0.55	124
I-D-2	22	7	<18	90	13	1	1.13	28	202	4	2	0.38	<0.5	0.1	0.06	10
I-D-3	12	5	125	83	35	8	2.47	22	264	14	5	0.34	0.9	0.1	0.21	42
I-D-4	49	4	195	148	52	17	1.79	41	371	23	11	0.65	1.2	1.3	0.32	56
I-M-1	11	3	70	13	7.2	1	0.32	8	65	1	2	0.17	<0.5	0.4	0.06	11
I-M-2	11	2	44	4	5.7	1	0.26	8	40	1	2	0.18	<0.5	<0.1	0.03	8
I-M-3	39	6	170	50	30	6	2.34	24	367	10	10	0.43	<0.5	1.4	0.13	55
I-M-4	56	8	525	143	76	23	3.58	70	329	31	33	1.10	0.6	4.4	0.52	71

Cruise - 1

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Se (ppm)	Sn (ppm)	Tl (ppm)	Zn (ppm)
II-C-1	47	12	310	52	45	8	2.02	27	334	15	15	0.45	<0.5	1.0	0.09	48
II-C-2	53	10	510	70	62	11	2.80	47	481	18	24	0.55	<0.5	1.4	0.22	90
II-C-3	76	9	910	140	79	23	3.80	63	433	28	30	0.80	<0.5	2.2	0.20	137
II-C-4	112	10	770	179	86	22	4.10	81	148	39	40	0.90	0.6	2.2	0.17	154
II-D 1	<10	2	55	4	16	1	0.20	7	12	4	2	< 0.10	<0.5	<0.1	0.08	<2
II-D-2	<10	1	10	4	5	1	0.13	7	20	1	< 1	< 0.10	<0.5	0.3	0.06	<2
II-D-3	<10	10	50	59	23	15	2.39	16	484	9	9	0.45	1.2	0.4	0.16	25
II-D-4	21	3	140	162	48	19	1.64	44	302	20	9	0.55	1.1	0.8	0.16	55
II-M-1	19	1	75	4	15	1	0.35	<5	47	1	< 1	0.18	<0.5	0.1	0.10	2
II-M-2	<10	2	95	11	14	1	0.49	8	74	1	1	0.20	<0.5	0.1	0.13	7
II-M-3	<10	5	180	54	36	12	2.40	22	271	15	11	0.45	<0.5	0.9	0.15	59
II-M-4	99	8	510	126	72	19	3.38	85	200	43	32	0.90	0.8	1.6	0.17	79

Cruise - 2

Sample	Ag (ppb)	As (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
III-C-1	12	15	23	36	5	1.75	66.	201	11	14	<0.5	0.3	50
III-C-2	35	17	64	60	13	3.21	43.	495	22	21	<0.5	1.5	97
III-C-3	23	6	50	41	10	2.27	39.	168	13	18	<0.5	1.2	73
III-C-4	157	15	99	79	23	4.32	113.	324	24	38	0.8	2.0	134
III-D-1	11	5	8	1	1	0.04	30.	17	<1	1	<0.5	<0.1	6
III-D-2	< 10	3	11	1	1	0.14	<5.	23	<1	2	<0.5	<0.1	7
III-D-3	< 10	12	31	14	2	1.52	44.	349	11	8	1.6	0.2	27
III-D-4	48	5	105	42	15	1.52		312	22	16	0.8	0.4	59
III-M-1	< 10	4	21	2	1	0.17	<5.	52	5	2	<0.5	<0.1	8
III-M-2	45	2	11	7	1	0.30	49.	38	7	3	<0.5	0.7	11
III-M-3	36	4	48	36	6	2.51	21.	325	14	12	<0.5	1.8	58
III-M-4	90	8	101	75	18	3.57	93.	480	27	29	0.7	2.6	97

changing the location of Station C-2 after Cruise 0. This was done in order to sample sediment more characteristic of the station location. The Cruise 1 and 2 samples from Station C-2 are generally two to five times richer in trace metals than the Cruise 0 sample which shows the strong effect of moving a station even slightly if it is moved into an area with more clay rich sediments.

Sediment from all 12 stations are characterized as to grain size, calcium carbonate content and organic carbon concentration elsewhere in this report, but it should be noted here that these parameters have a strong influence on trace metal concentration. A fine-grained sediment in this, and most other, areas implies a more clay mineral rich sediment and these are enriched in trace metals compared to quartz sand rich and calcium carbonate rich sediment. Organic carbon usually associates with clay rich sediment and may enhance the clay minerals ability to adsorb trace metals.

The Mississippi River is a prominent source of clay rich sediment for the Gulf of Mexico and its influence can be clearly seen at Stations C-3 and C-4. Clay rich sediment is also supplied by other rivers and some of this material no doubt adds to that from the Mississippi to make up the sediment found at Stations M-3, M-4, D-3 and D-4. Sediment from the shallow water Stations (1 and 2) on each transect has less clay because it is winnowed away by bottom currents. These samples are therefore less trace metal rich. In all cases, the iron content of the sediment reflects the grain size, with the deep water, more clay rich sediment being high in iron and the shallow water stations being iron poor.

This correlation between iron, grain size and trace metal concentration has been pointed out by Trefry and Presley (1976b) and many other authors and is an expected relationship for unpolluted sediment. The sediment from the study area gives little indication of pollutant influence although subtle influences would be hard to recognize, especially in the samples with low trace metal levels where the precision of the data is not as good. There is, however, a definite indication of drill mud influence in the Ba concentrations of samples from transect C, where some samples seem to be enriched by about a factor of two over what would be expected for Mississippi River derived sediment. These same samples seem to be enriched in As by about 25 percent but this is less definite. In any case, neither the Ba nor As concentrations are likely to cause biological effects.

Other trace metal concentrations are about as expected from sediment of a given iron content and there is no indication of trace metal pollution from Mobile Bay or the Mississippi River. Manganese concentrations are generally less than expected for the observed Fe concentrations, in many cases by a factor of two. This shows that biological activity is intense in the sediments, leading to oxygen depletion and Mn oxide reduction. This is further indicated by a few Mn-enriched sediment samples, where the Mn mobilized at one place has precipitated in another. The Mn and other trace elements show somewhat more variability from station to station and from cruise to cruise than does iron (Figures 5-2 to 5-7), but generally they show the same pattern in almost all cases. In those few cases where a trace metal (Cd for example) is higher in a low Fe sample than a high Fe sample, subtle pollution is suspected but natural variability cannot be ruled out. With multiple sources of sediment to the area, some natural variation in metal to iron ratios is likely.

5.4 Summary and Conclusions

Sediment from the 12 stations sampled in the Mississippi-Alabama offshore area varied greatly in iron and trace metal content, but the variations seem to be largely the result of natural variability in grain size and mineralogy. Deep water sediments were enriched in Fe and trace metals compared to shallow water ones, but all were typical of unpolluted Gulf of Mexico shelf sediment. A few samples from transect C (near the Mississippi River) seem to be enriched in Ba by about a factor of two over what would be expected but there were few other indications of trace metal pollution in the area. Manganese concentration was only about half of that expected based on iron concentration for many of the samples. This shows the sediments of the area to be biochemically active and capable of solubilizing Mn and perhaps other metals.

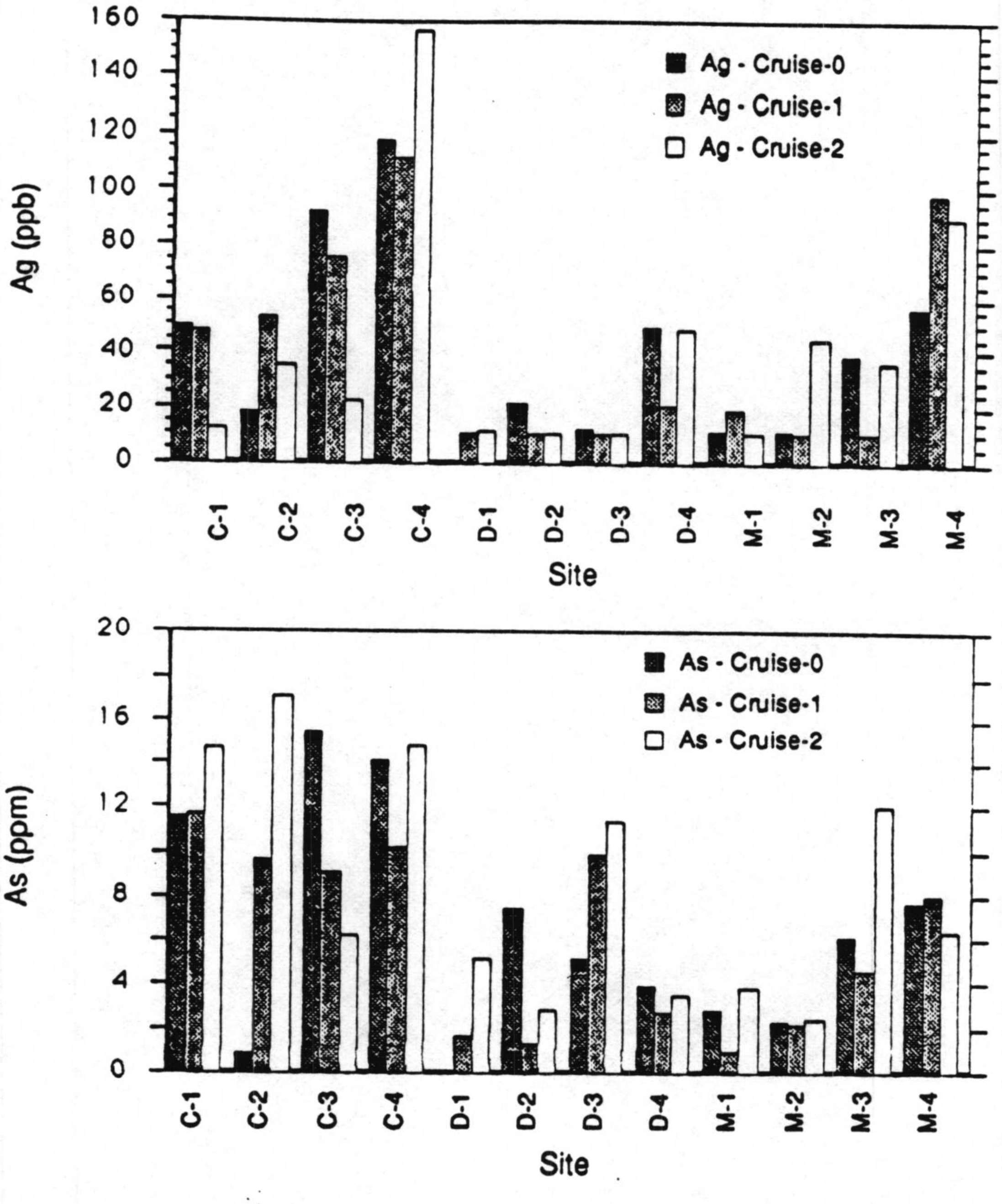

Figure 5-2. Silver and arsenic concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

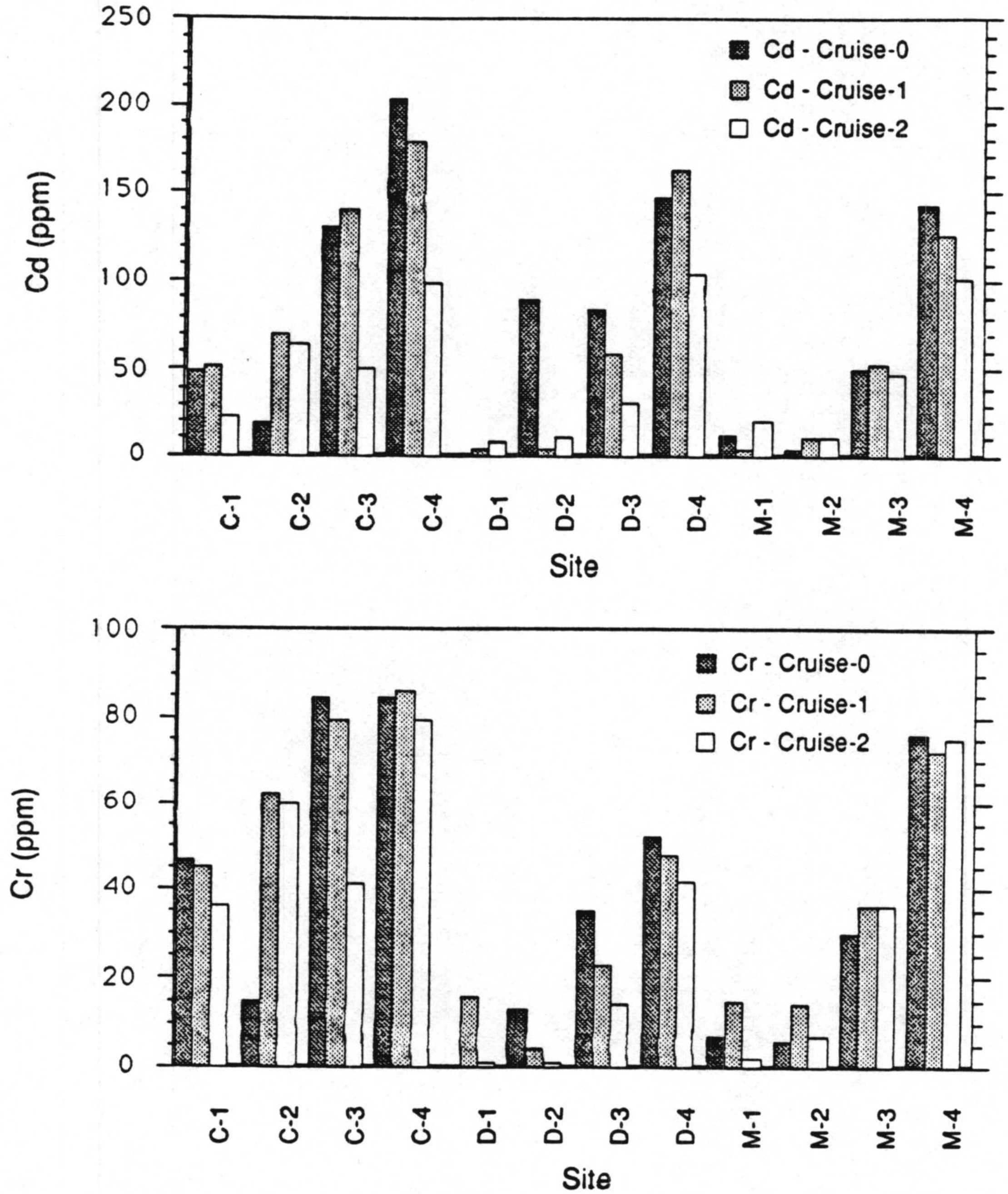

Figure 5-3. Cadmium and chromium concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

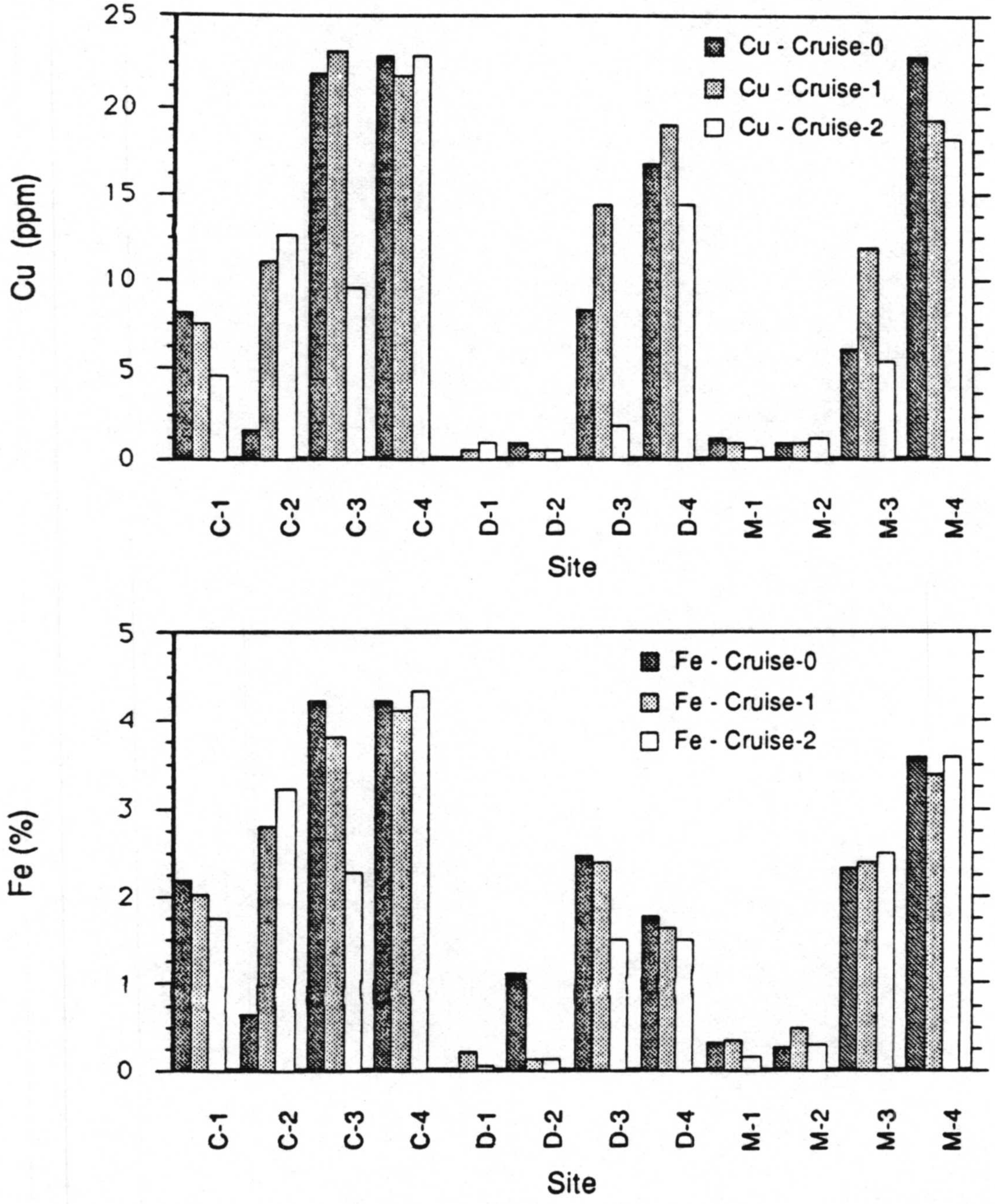

Figure 5-4. Copper and iron concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

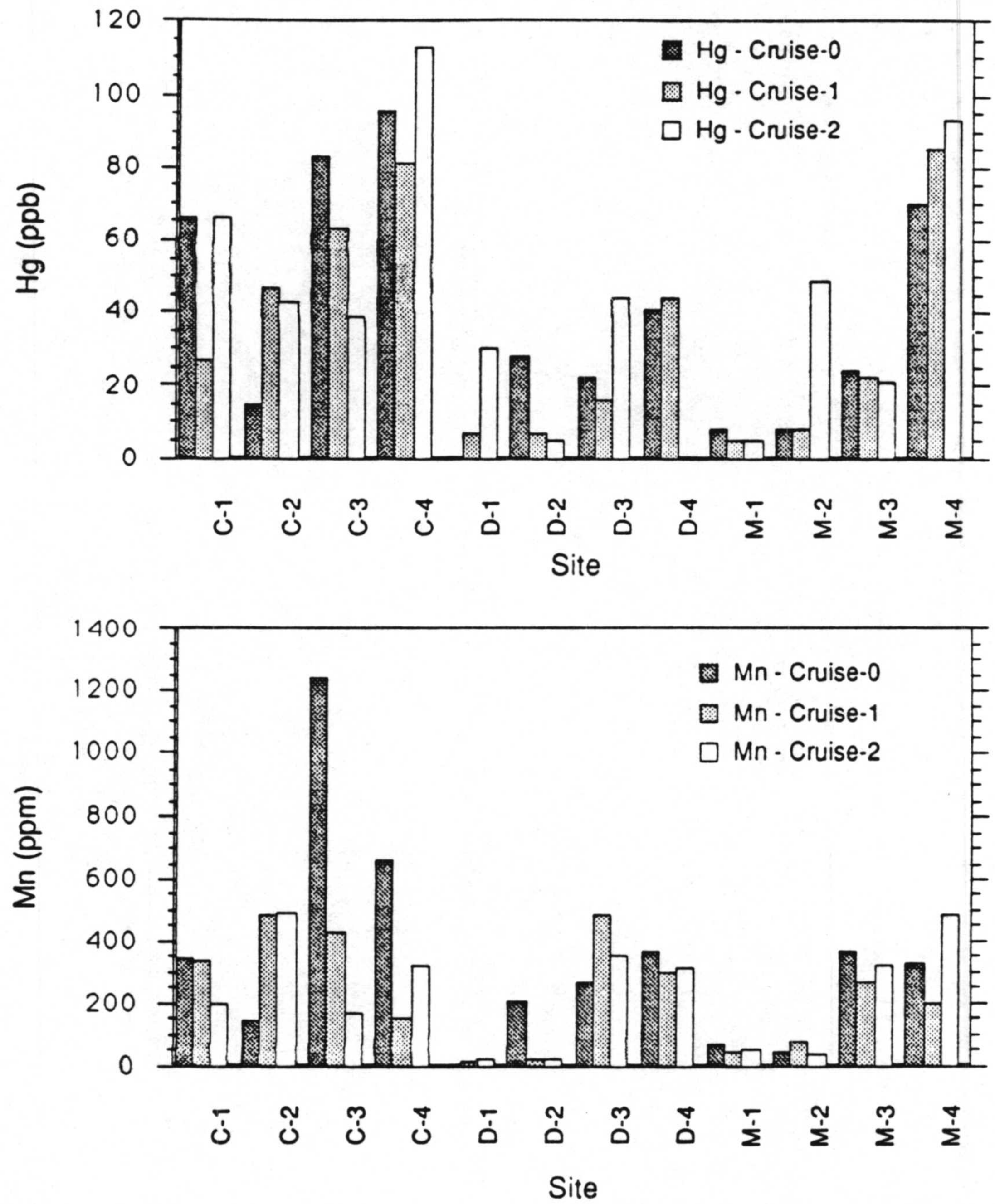

Figure 5-5. Mercury and manganese concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

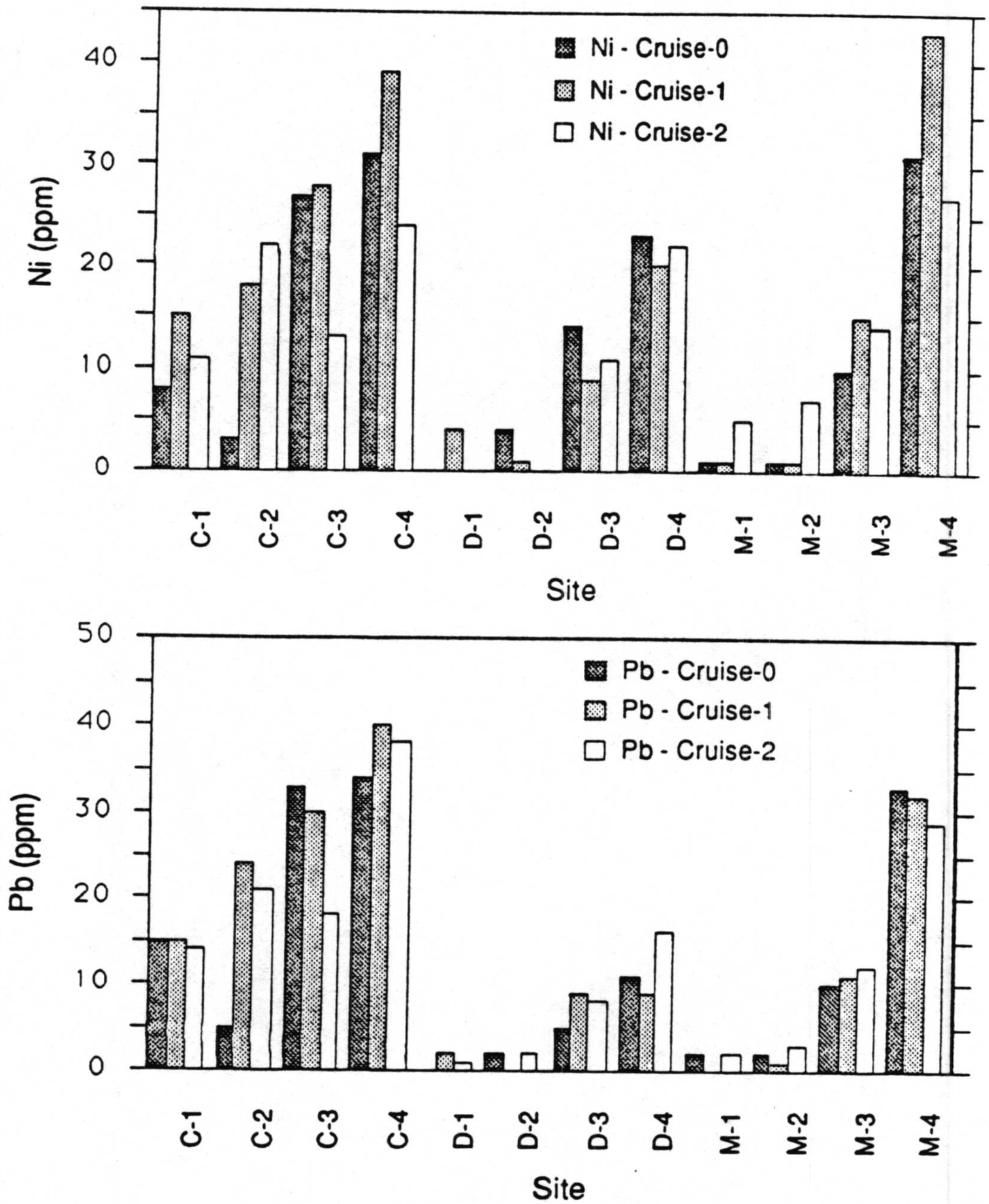

Figure 5-6. Nickel and lead concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

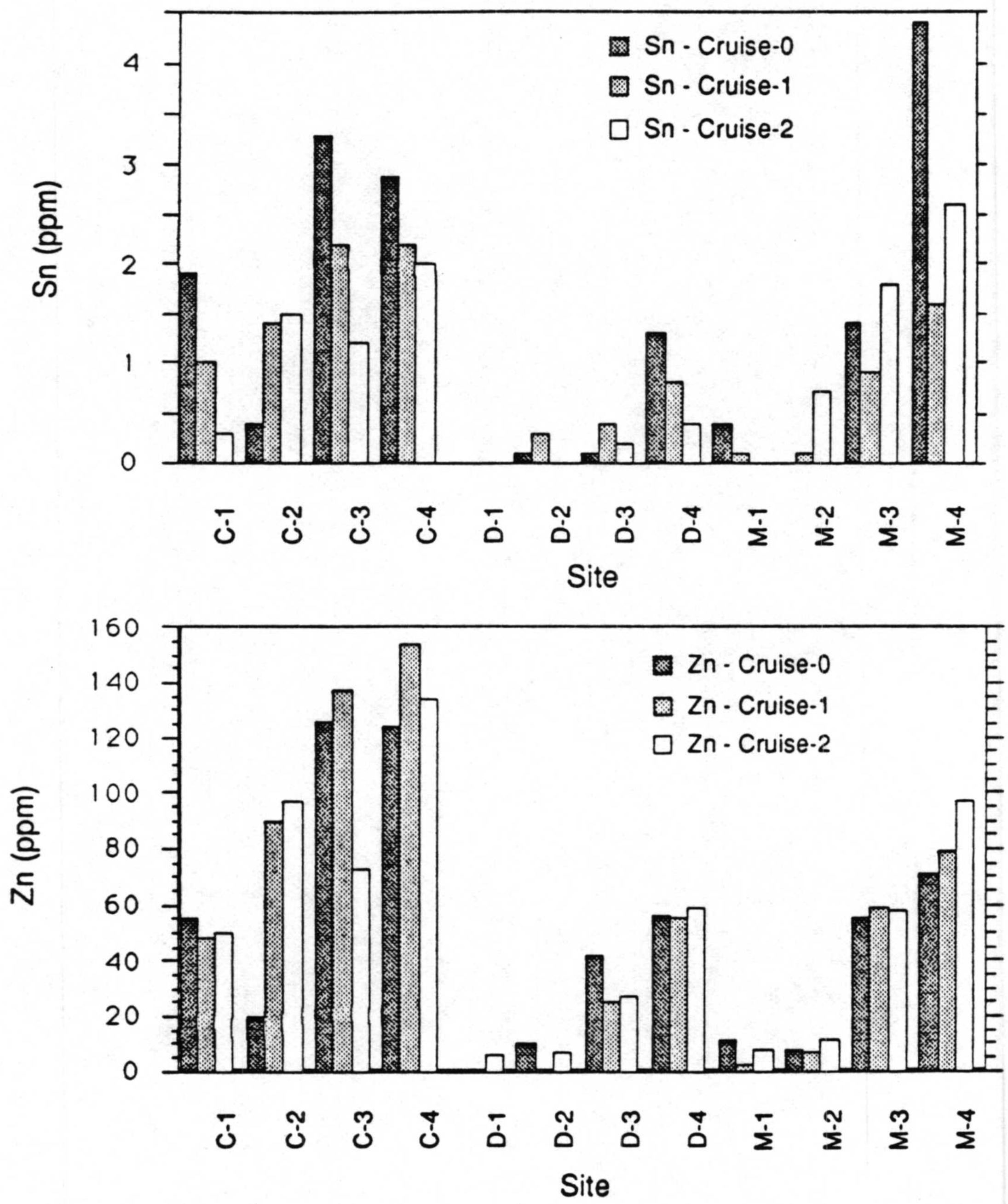

Figure 5-7. Tin and zinc concentrations in sediment samples from three cruises in Year 1 of the MMS Mississippi-Alabama Study.

5.5 Recommendations for Further Study

The variability from station to station and cruise to cruise makes it difficult to exactly characterize sediment from a given station, even when the data is normalized to Fe content. More analyses are required if subtle pollution effects are to be recognized. Analyzing 10 samples collected within a 200 m circle at one middle shelf station would help determine if the metal to Fe ratio variations from cruise to cruise at a given station are due to sediment heterogeneity or to sediment transport between cruises. Large benthic organisms collected as part of the program should be analyzed for trace metals for background information.

6.0 SEDIMENT ANALYSES

Richard Rezak

6.1 Introduction (including historical background)

The most comprehensive study of sediment facies on the Mississippi-Alabama Outer Continental Shelf was published by Ludwick (1964). Grady's (1970) map of sediment types in the northern Gulf of Mexico is a compilation of published studies and Grady does not cite his sources. However, it is evident when comparing the Grady (1970) map with those in Ludwick (1964) that the major source was the Ludwick paper. Other references to sediments in the published record deal with the heavy mineral suites and their provenance (Van Andel 1960; Van Andel and Poole 1960; Fairbank 1979; Doyle and Sparks 1980), the paleogeomorphology of the study area (Ballard and Uchupi 1970), or part of a larger study (Dames and Moore 1979; Pyle *et al.* 1975; Swift *et al.* 1971; Gould and Stewart 1955; Ludwick and Walton 1957). Boone (1973), is a rehash of Ludwick (1964) and later contributions.

6.1.1 Sediment Facies

Ludwick (1964) described the following five sediment facies on the Mississippi-Alabama Outer Continental Shelf:

1. Chandeleur Facies
2. St. Bernard Prodelta Facies
3. Mississippi-Alabama Sand Facies
4. Mississippi-Alabama Reef and Interreef Facies
5. Mississippi Prodelta Facies

Figures 6-1 and 6-2 illustrate the sediment types and the distribution of these facies. Figure 6-1 also shows the locations of the soft-bottom transect stations sampled during the present study.

The Chandeleur Facies is a fine grained, well sorted, quartz sand. The Chandeleur Islands have resulted from the redistribution of St. Bernard Sub-delta sands (Otvos 1985). After abandonment of a delta lobe, bay fill sedimentation stops, subsidence and coastal retreat become the principal

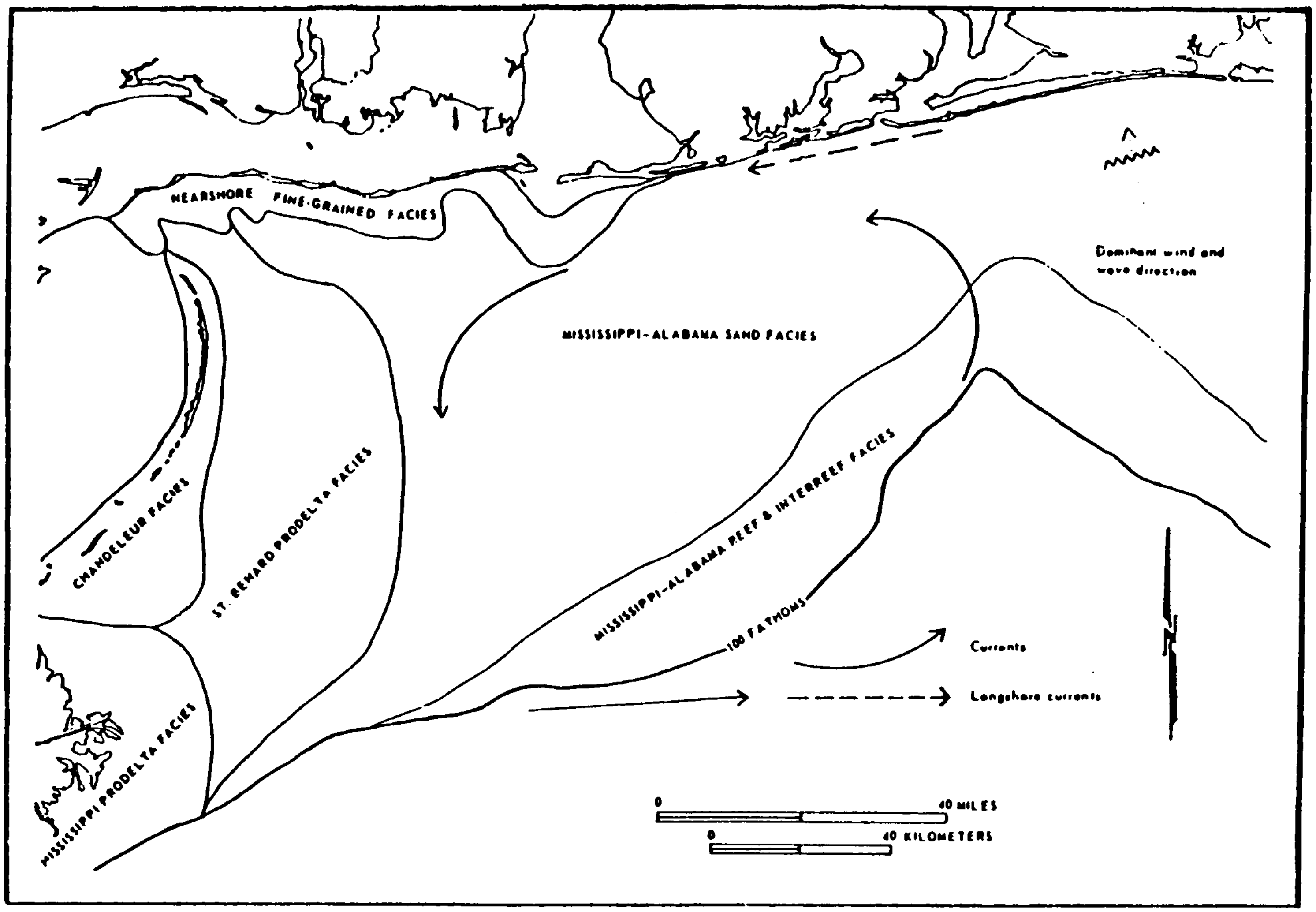

Figure 6-1. Sediment distribution map, Mississippi-Alabama OCS (after Barry Vittor and Assoc. 1985).

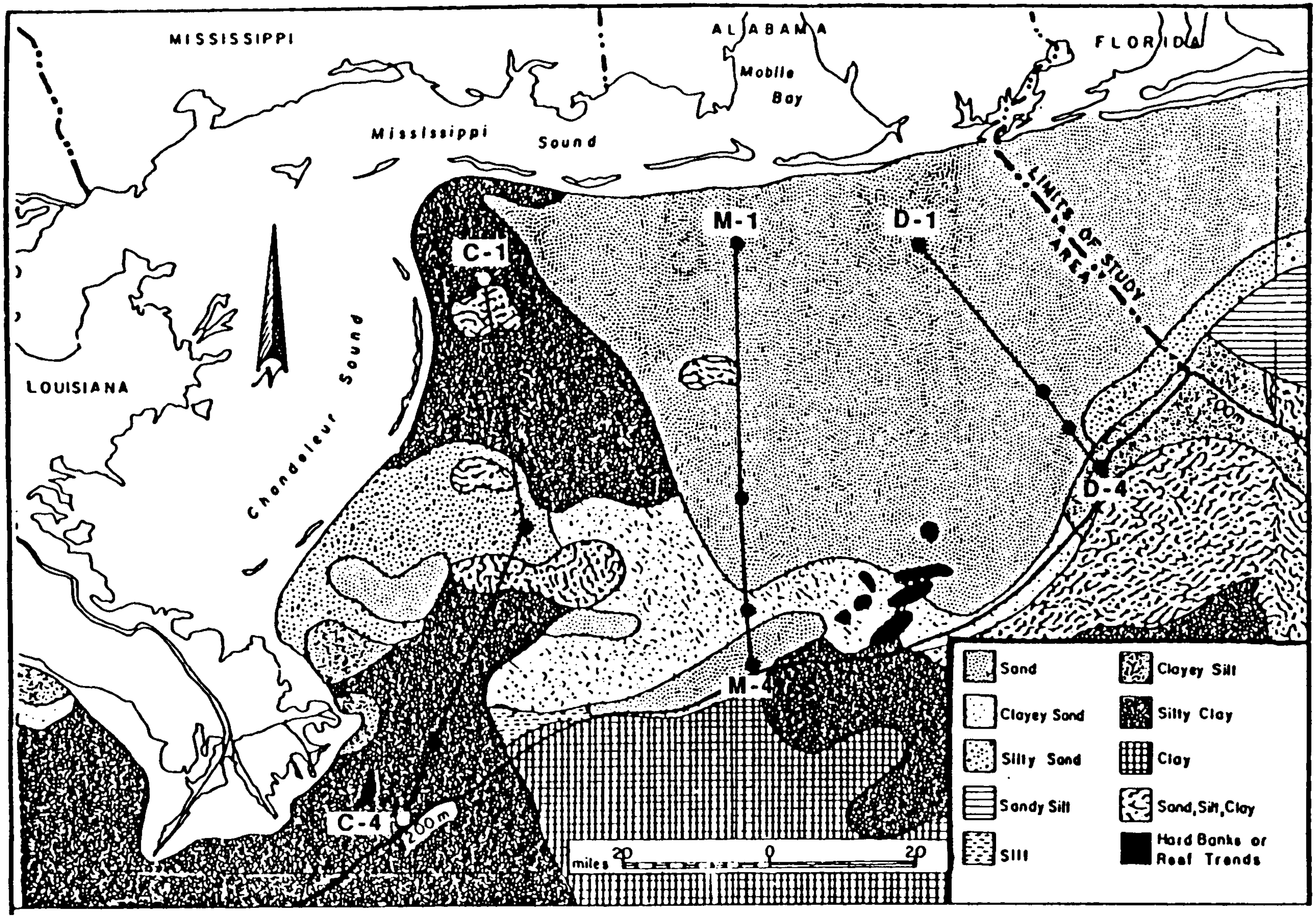

Figure 6-2. Ludwick (1964) sediment facies (after Boone 1973).

natural process. Coarse sediments become reworked by wave action and barrier islands and bars may develop near the fringes of the once active delta lobe (Penland and Boyd 1981).

The St. Bernard Prodelta Facies lies as a broad arc on the western part of the shelf. The sediment consists of a homogeneous silty clay that is overlain to the west by the Chandeleur Facies and other remnants of the abandoned St. Bernard delta lobe. To the east, the prodelta sediments overlie the Mississippi-Alabama Sand Facies. Between the two facies, there is a transition zone varying in width from a few to about 10 miles.

The Mississippi-Alabama Sand Facies consists predominantly of a well sorted, fine grained, clean, quartz sand. Shelly sands occur locally that usually consist of black to brown stained molluscs. In many places, these include disarticulated oysters that must have grown in protected brackish water environments.

The Mississippi-Alabama Reef and Interreef Facies lie to the southeast of the relict quartz sand facies. Beginning adjacent to De Soto Canyon and running to the west along the shelf break, the reefs, described by Ludwick and Walton (1957) appear to have developed due to the growth of coralline algae. Sediments in the areas of reef growth are composed of a mixture of about 70 percent carbonate skeletal material and the remainder terrigenous sediment primarily in the silt and clay size range. No samples have been received from this facies during the present study.

Sediments in the Mississippi Prodelta Facies are clay and silt size material that is either deposited very rapidly at the shelf edge or carried westward by the prevailing surface currents. The sediment that is not transported seaward or westward is deposited on the older sediments of the Chandeleur and St. Bernard Prodelta Facies as a clastic wedge.

6.2 Methods

6.2.1 Grain Size

Sample analyses followed the procedures described by Folk (1974). Samples were homogenized, treated with an aliquot of 30 percent hydrogen peroxide (H_2O_2) to oxidize organic matter, and washed with distilled water to remove soluble salts. Sodium hexametaphosphate was added to deflocculate each sample. The samples were wet-sieved using a 62.5 micron (4 phi) sieve to separate the sand and gravel from the mud fraction.

The total gravel and sand fraction was then oven dried, weighed, and sieved at 1/2 phi intervals (-1.5, -1.0, -0.5, 0.0, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0). Each fraction was examined for aggregates, and aggregates, when found, were disaggregated. Fractions were weighed to three significant figures. The mud fraction was analyzed for particle size distribution by the pipette method at 4.5, 5.0 5.5, 6.0, 7.0, 8.0, 9.0, and 10.0 phi intervals.

6.2.2 Organic Carbon, Calcium Carbonate, and Carbon Isotope Composition

Organic carbon concentrations (OC) varied from < 0.1% to 2.6% over the three samplings. Organic carbon (Figure 6-3) varied by as much as a factor of ten between samplings and by more than a factor of ten along a transect. Highest OC was at the ends of the transects. Calcium carbonate ($CaCO_3$) (Figure 6-4) content varied inversely with organic carbon with highest values at the end of the eastern transects. Calcium carbonate content varied from <1% to >90% and was highly variable between samplings and along transects. The end of the western transect nearest the Mississippi River had the lowest $CaCO_3$ content, most likely reflecting the impact of clay rich riverine sediments. Low carbonate sediments were present during all three samplings as a large tongue trending northeast from Station C-1. The carbon isotopic composition ($\partial\ ^{13}C_{org}$) of the sediment organic matter reflected a mixed terrigenous and planktonic input. The carbon isotopic composition (Figure 6-5) also varied widely along a transect and between samplings at a single location. A strong terrestrial influence across the central area of the survey was observed during all three samplings. Overall the terrestrial influence was much more widespread during Cruise 1 and 2 than Cruise 3.

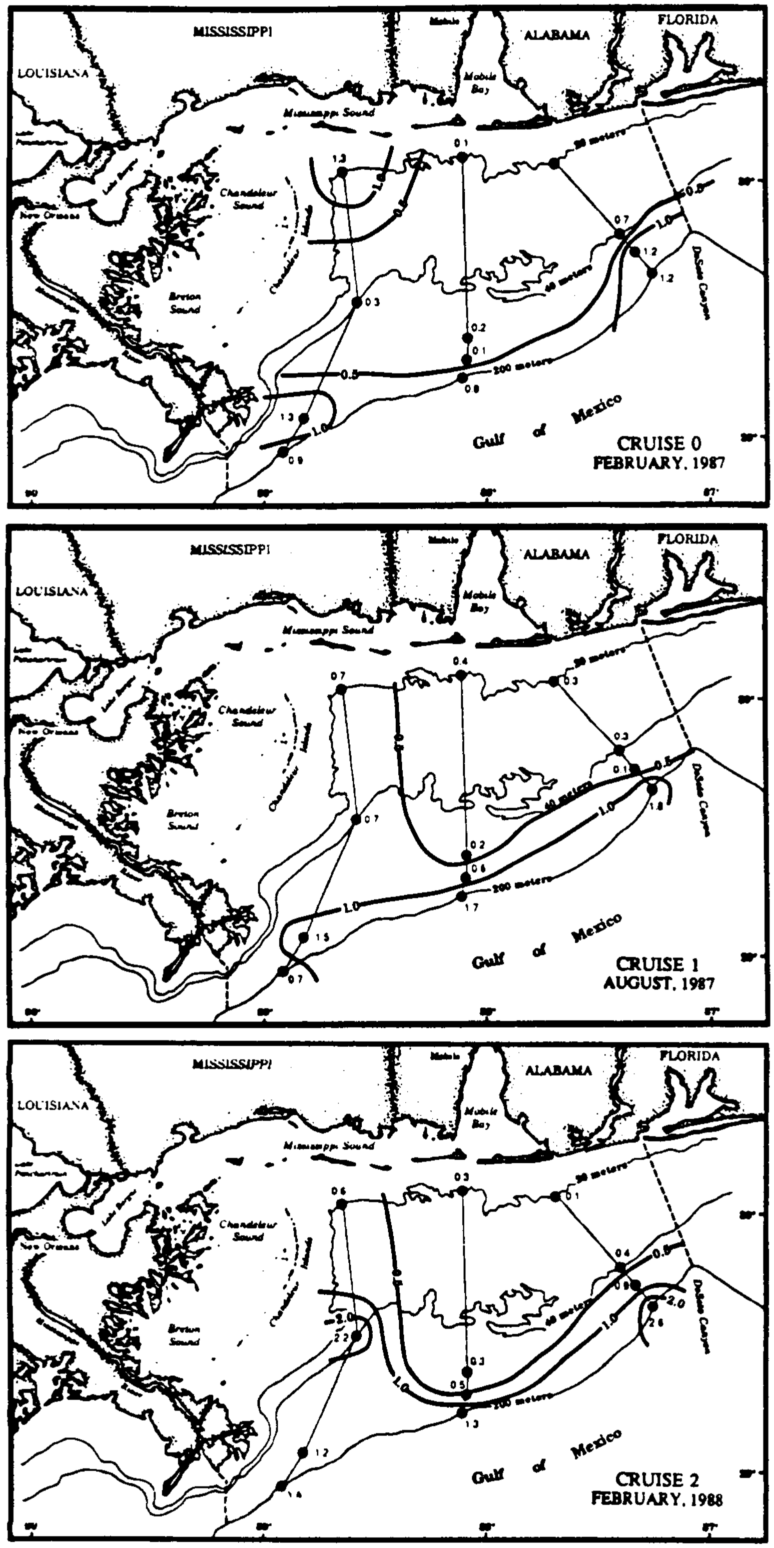

Figure 6-3. The geographic distribution of organic carbon concentrations from Cruises 0, 1, and 2.

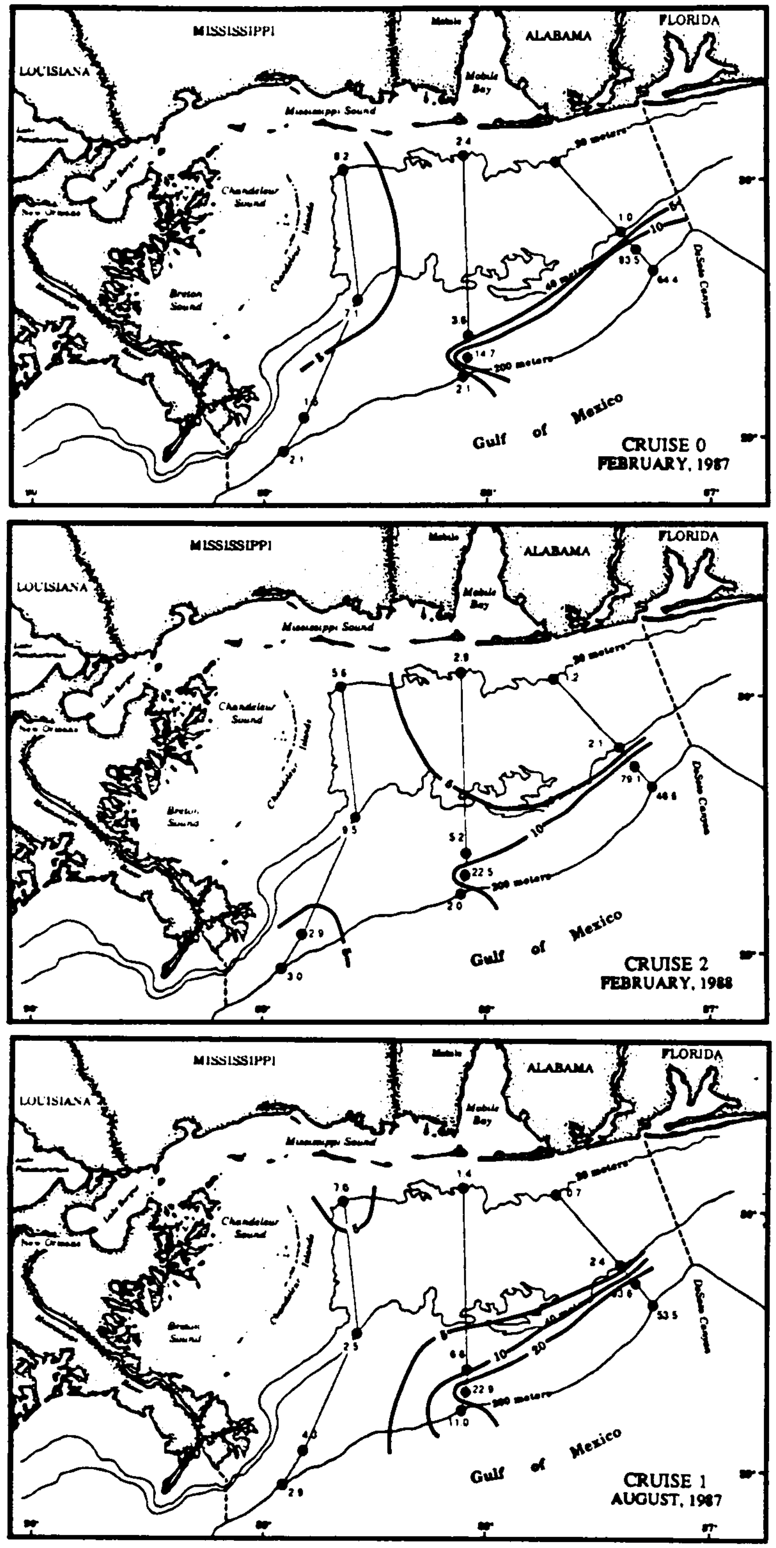

Figure 6-4. The geographic distribution of calcium carbonate concentrations from Cruises 0, 1, and 2.

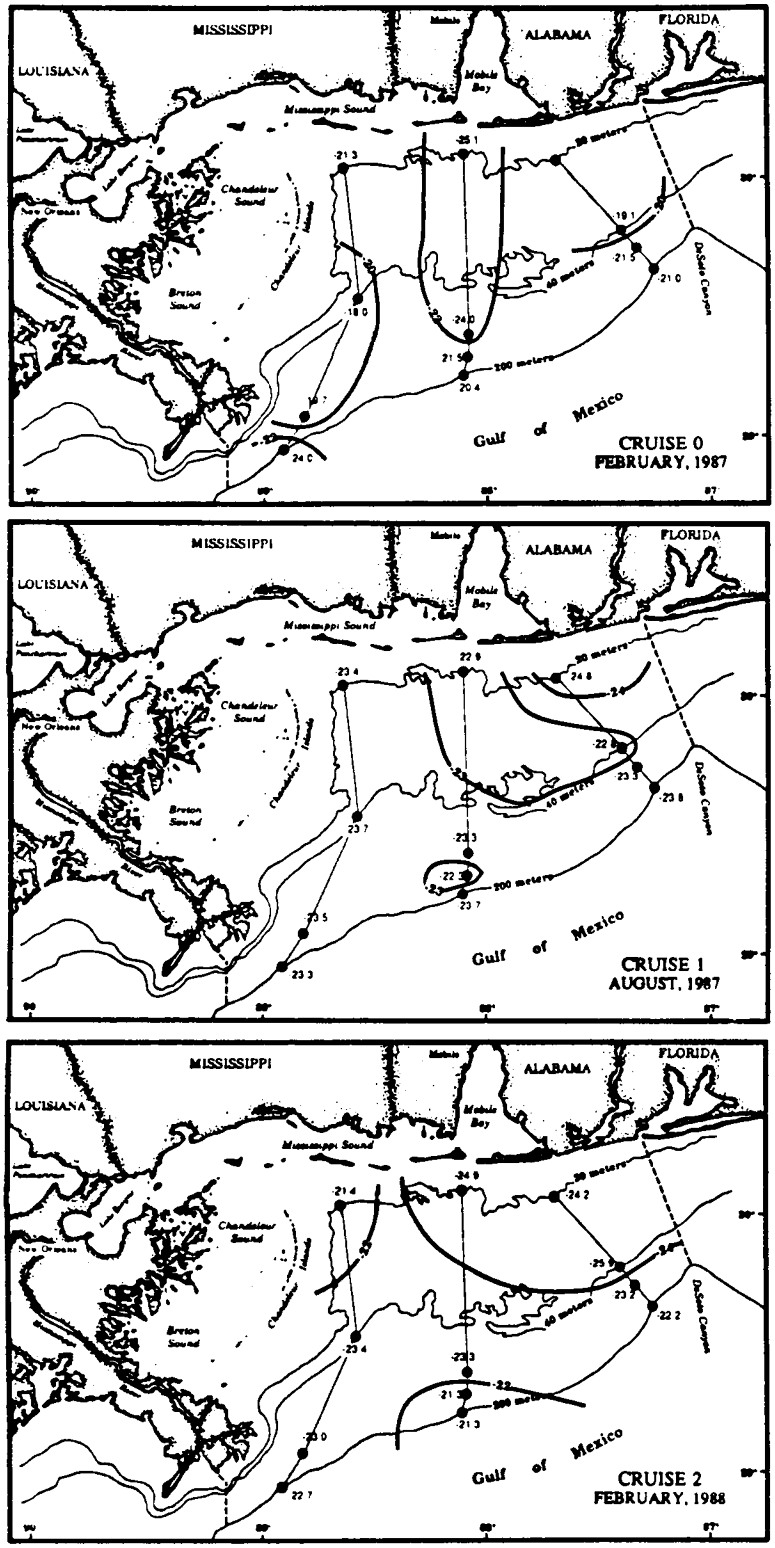

Figure 6-5. The geographic distribution of carbon isotopic composition from Cruises 0, 1, and 2.

6.3 Results

One hundred sixty-six sediment textural analyses were conducted, on samples collected during Cruises 1 and 2. Samples from Cruise 0 have been located and are currently being analyzed. The sediment samples taken on transects "C", "M", and "D" have not yielded any great surprises. The only departures from the published sediment distribution (Barry A. Vittor & Associates 1985) was found at Station C-1 and D-3. Station C-1 is located close to the boundary between the St. Bernard Prodelta Facies and the Mississippi-Alabama Sand Facies but within the sand facies. Boone (1973) states that the transition (mixing) zone between these two facies averages about seven miles in width but may be as much as 10 miles wide. This would explain the apparent anomolous presence of mud in the samples from this station. Station D-3 lies in an area reported to have a silty sand bottom. Our textural analyses show the sediment to be a gravelly sand. Examination of the coarse fraction under a microscope using reflected light reveals that the clasts are derived from a nearby pinnacle. The coarse fraction consists of weathered lithoclasts, and weathered and stained skeletal fragments consisting of coralline algae, coral, worm tubes, and large foraminifers. Admixed with that material are relatively fresh bryozoans, coralline algae, and foraminifers. Many of the samples from both of the sandy facies contained black shell fragments and many black sand grains of unknown origin. No large mollusc shells were present in the samples; most of the whole clam shells were less than a centimeter in long dimension.

6.4 Summary/Conclusions

Ludwick's (1964) description of the ocurrence of corroded and coated disarticulated oyster shells close to the southern margin of the Mississippi-Alabama Sand Facies, together with our own sediment analyses, our mapping and side-scan data, the direct observations of the seafloor by W.W. Schroeder (personal communication), and my own observations of the sediments in the vicinity of Southwest Rock off the mouth of Mobile Bay are convincing evidence that the sediments on the Mississippi-Alabama OCS are relict Holocene to recent deposits that have been modified in varying degrees by sea level rise since they were originally deposited. The presence of stained mollusc shells, including blackened and brownish oysters and the occurrences of calcite cemented and siderite cemented quartz sands found at several different water depths in this facies suggests, according to W.W. Schroeder (personal communication), that the post-Pleistocene history of this shelf is punctuated by a series of sea level stillstands that created barrier islands and protected brackish water lagoonal areas similar to the modern day Mississippi Sound. The variation of sediment texture in this facies reported by Pyle *et al.* (1975), is most probably due to the fact that it is a relict deposit representing several different environments. The lagoonal deposits, being typically muddy as are the modern Mississippi Sound sediments, were easily eroded as sea level rose leaving a lag deposit of blackened shell hash with more resistant, exhumed, blackened oyster reefs standing as shoals on the otherwise featureless seafloor. The sands of the old barrier islands were then smeared out over the seafloor covering the old lagoon with a thin veneer of sand as new barrier islands were formed by some of the same older sands plus newly arrived quartz sands from the east. However, not enough sand was available to completely bury the high relief oyster reefs leaving them as low relief pinnacles or flat areas of high reflectance as seen on the side scan records.

6.5 Recommendations for Further Study

The hypothesis presented above can be tested by taking rock dredges on some of the low relief pinnacles that have been identified in the Sand Facies and vibracoring in their vicinity. The rock dredges should bring up large, blackened oyster shells. The vibracores should show a clean quartz sand overlying a lag of small shell hash that in turn overlies a muddy lagoonal deposit.

7.0 MACROINFAUNA AND MACROEPIFAUNA

Donald E. Harper

7.1 Introduction (including historical background)

Benthic infaunal organisms make ideal subjects for studying not only the general ecology of an area, but also acute and chronic effects associated with discharges of organic and toxic substances into the environment. The benthic infauna are primarily non-motile or slow moving, small organisms. The larvae tend to be induced to metamorphose by specific sediment types, and the adults tend to remain associated with that type of sediment. Infaunal organisms that cannot easily escape an environmental stress (i.e., a discharge) and those that cannot tolerate the stress perish. If the stress persists, larvae of these organisms may be unable to settle and metamorphose, and the stressed area will remain devoid of intolerant species.

The macroepifaunal category of organisms has both slow moving (i.e., bivalves, snails, most echinoderms) and fast moving (i.e., portunid crabs) representatives. Slow moving species can also be used to study specific ecological habitats, and the effects of a stress on the slow moving organisms may be identical to that of the infauna. Motile macroepifauna, however, tend to cover a broader range of habitat types, and generally remove themselves from a stressed area. Also, motile macroepifaunal organisms may be able to repopulate an acutely affected area much more quickly than the other forms.

Major (either area-wide or long term) studies of assemblages of benthic organisms inhabiting soft bottoms have been conducted at one time or another along much of the northern Gulf of Mexico. Defenbaugh (1976) compiled information on distributions of macroepifaunal organisms in the northern Gulf of Mexico; his specimens were trawled from the continental shelf between Mexico and Tampa Bay, Florida. The present study area is included in that study area. One transect of the Mississippi-Alabama Florida (MAFLA) study (Dames and Moore 1979) was located in the present study area also.

In the western Gulf of Mexico, research efforts which have encompassed broad areas of the continental shelf include macrofaunal studies by Hildebrand (1954), and Parker (1960). Studies of a more regional nature on the Louisiana shelf west of the delta which included infauna and macroepifauna are the Central Gulf Platform Study (Southwest Research Institue 1981; Fitzhugh 1984) and the West Hackberry Study (McKinney *et al.* 1984, Landry *et al.* 1985). Other macroinfaunal studies on the Texas shelf include the Buccaneer Oil/Gas Field study (Harper *et al.* 1984), the SEADOCK study (Harper and Case 1975), and the Bryan Mound study (Harper *et al.* 1985). The South Texas Outer Continental Shelf study (Berryhill 1977) was a shelf-wide study in the western Gulf of Mexico.

Several trends are evident from these data that are probably applicable to the present study. Distribution of infaunal and non-motile macroepifaunal organisms appear primarily governed by sediment type and water depth, the latter simply being a manifestation of increasing stability of other abiotic factors; i.e., the temperature tends to remain cold and the salinity tends to remain at about 36 ^{0}/oo. Shallower water, in contrast, is much less stable, being subjected to seasonal variations in temperature and salinity. Researchers have classified the shelf inhabitants into assemblages based on depth distributions. These are: the inner shelf assemblage (= "white shrimp grounds" in the western Gulf; the pro-delta sound assemblage of Defenbaugh 1976, ca. 4 - 20 m depth), the intermediate shelf assemblage (= "brown shrimp grounds" in the western Gulf, ca. 20 - 60 m depth), an outer shelf assemblage (ca. 60 - 120 m depth), and an upper slope assemblage (Chittenden and McEachran 1976, Defenbaugh 1976, Moore *et al.* 1970, Parker 1960, ca. 120 - 200 m depth). In general, as one proceeds across the shelf, abundances of organisms decrease with increasing depth and seasonal variability in species composition decreases with increasing depth. Infaunal assemblages are generally dominated by polychaetous annelids if the substrate is soft mud. Mollusks or crustaceans may dominate in sandy to shelly bottoms. Further, evaluation of infaunal data from the western Gulf of Mexico has indicated that both the northern Gulf and the southwestern Gulf have similar species, but the abundances of species appears to decrease considerably south of Matagorda Bay (Harper and Nance 1985).

7.2 Methods

7.2.1 Field Methods

Stations were located on three transects which originated off Chandeleur Sound (C-transect), Mobile Bay (M-transect) and Pensacola (D-transect; so named because this transect terminated at the edge of De Soto Canyon) (Figure 7-1). Stations on each transect were located in 50, 100, 150 and 200 m depths. Sampling, where practical, was conducted across shelf so cross-shelf temperature, salinity and D.O. measurements could be made. In actuality, the sampling pattern was dictated, at least in part, by predicted weather patterns.

Field activities were recorded in a log book as events occurred. The time of arrival on station and LORAN coordinates were noted, and general comments regarding the sea state, weather, etc. were noted. The LORAN coordinates were used to determine if the vessel had drifted off station during the course of sample collection. If this occurred, sampling was suspended while the vessel returned to station.

Macroinfauna - Macroinfaunal samples were collected using either a 0.1 m^2 box core or a 0.1 m^2 Smith-McIntyre (SM) grab. It was determined during the preliminary cruise that sediments at several stations consisted of hard sand or coral rubble; complete sets of samples were not collected at two stations (D1 and D2) because the box core would not penetrate. Therefore, both machines were used during subsequent cruises. If we determined that a good sample could not be obtained with the box corer because the substrate composition impeded penetration of the box, the SM grab was used.

The time of each drop was recorded when the instrument hit bottom. In some cases it was necessary to make in excess of 15 drops to obtain the requisite nine samples. Of these nine samples, six were used for macroinfaunal analysis and three for sediment analyses. When each grab was brought aboard, supernatant water was drained into a sieve using a hose, and a meter stick was pushed into the sediment to determine depth of penetration. If the sample was to be used for macroinfauna, a syringe was

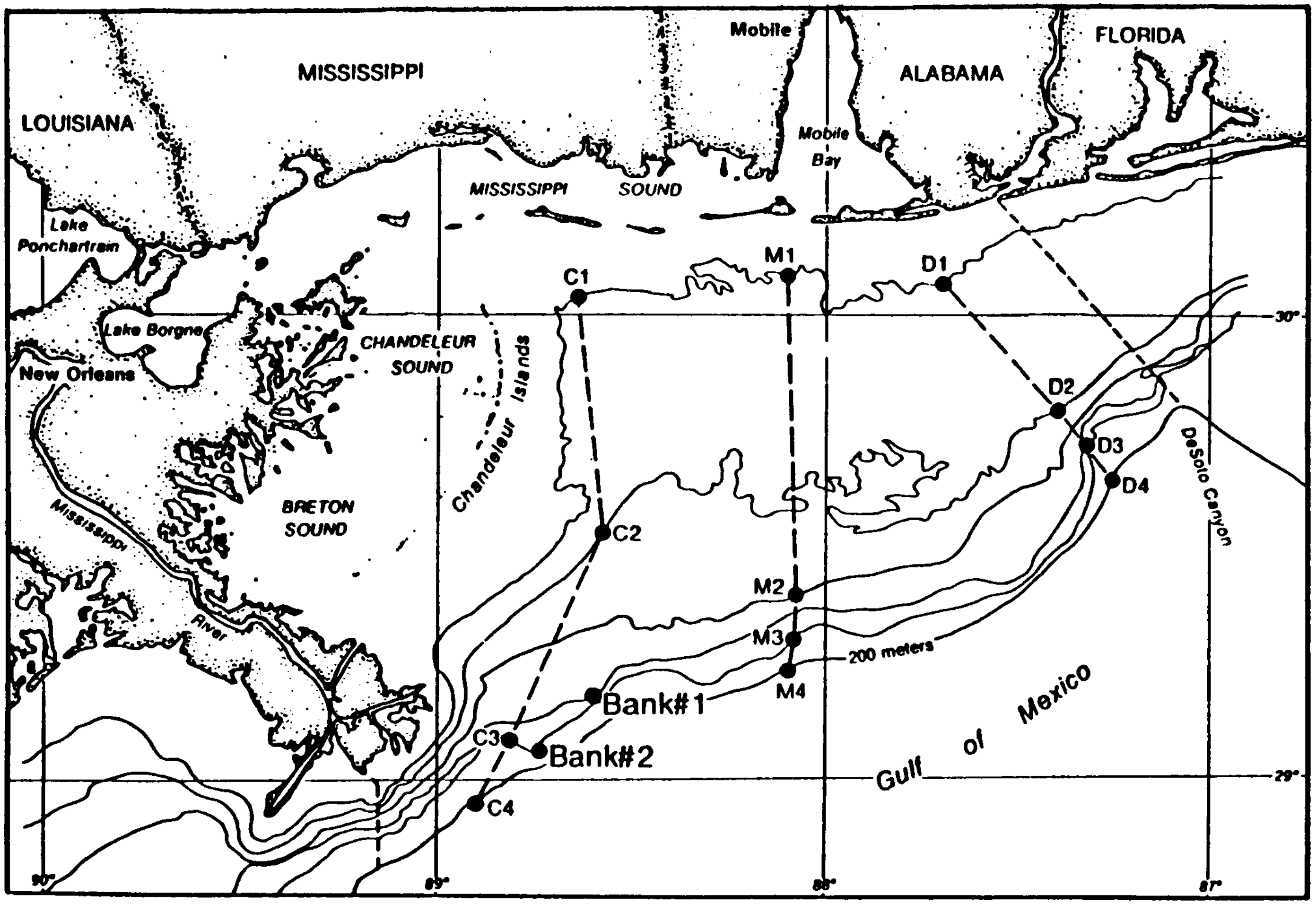

Figure 7-1. Map of the Mississippi-Alabama continental shelf showing locations of sampling stations.

used to remove a sediment subsample. This subsample was placed in a plastic bag.

Sediments were removed from the sampler using a scoop or by hand and placed in a large numbered bucket. Water was added to the bucket. If sediments were soft, the stream of water was directed down the inside of the bucket. This created an upwelling pressure and brought small organisms to the surface. The supernatant water was then poured onto a 0.5 mm mesh sieve. This was done at least twice to remove soft bodied invertebrates and then the sieve contents were then emptied into a prelabeled jar. The firmer sediments were then hand stirred and poured onto the sieve in batches. These sediments were washed away using a spray attachment on a hose.

When all sediments were gone, the sieve contents were added to the jar and Epsom salts ($MgSO_4$) and a plastic Dymolabel were placed in the jar. About 30 minutes after the sixth bucket had been processed, the jar contents were fixed in five percent seawater-formalin.

Macroepifauna - Macroepifaunal samples were collected using a 40' otter trawl having solid iron doors and a net having 1.25" stretch mesh and a 0.25 inch liner in the cod end. When the vessel was brought on station (using LORAN coordinates), the trawl was dropped in the water and line was payed out until a scope of about 3-4:1 was attained. Trawl durations were 15 minutes each and were timed from the time the winch was dogged until started again. Two replicate trawls were attempted on all cruises except the preliminary cruise during which single trawls were made. When the trawl was brought aboard, the contents were dumped on deck or on a sorting table, separated into vertebrates and invertebrates and placed in separate buckets. The contents of the invertebrate buckets were weighed, narcotized with $MgSO_4$ (30 minutes) and fixed in 10 percent seawater formalin. Each bucket was identified with both an external grease pencil label and an internal Dymolabel.

At two stations near the Mississippi Delta (C3 and C4) enormous numbers of heart urchins (Echinodermata: Echinoidea) were collected. Representatives of these were retained. The remainder were measured, weighed and discarded.

7.2.2 Laboratory Methods

Macroinfauna - Upon return to the laboratory, macroinfaunal samples were washed on a 0.5 mm mesh sieve with fresh water to remove formalin and any remaining sediments. The samples were then preserved in rose bengal stained 70 percent ethanol. After at least 24 hours had elapsed the samples were examined using a dissecting microscope and all organisms were removed (picked) and placed in vials of unstained 70 percent ethanol. The vial contents were separated to major taxa (Polychaeta, Crustacea, Mollusca, etc.) and these were weighed. Because the Polychaeta constituted the dominant taxon, both in terms of numbers of species and individuals, they were separated to family after being weighed *en masse*. When the entire cruise collection had been sorted in this manner, all vials containing a particular polychaete family were identified and counted as a unit before identification of the next family was begun. The other taxa were not nearly so numerous and were not split to smaller taxonomic units prior to being identified. All members of each species were placed in a separate labeled vial. These were assembled in taxonomic units and stored.

Raw data were recorded in lab notebooks. These data were transferred to formatting sheets. When all samples from a cruise had been completed, the sheets were sent to the data manager for entry into a computer file. A verification printout was generated and this was checked against the raw data. When all data were correct, the data manager was notified that the data set was ready to be transmitted to NESDIS.

Macroepifauna - Upon return to the laboratory, macroepifaunal samples were washed with fresh water to remove formalin and were then preserved in 70 percent ethanol. The contents of each bucket were then sorted to major taxa or species and placed in separate containers. The contents of these containers were identified, measured, counted and weighed. Data were recorded in laboratory data books. When a collection had been completed, the data were recorded on formatting sheets. The sheets were sent to the data manager for entry into a computer file. Verification followed the procedure described for macroinfauna.

7.3 Results and Discussion

7.3.1 Substrate Composition

Assemblages of benthic organisms are, in part, determined by composition of the substrate in which or on which the organisms live. Field observations indicate the study area has a great diversity of substrate types (Figure 7-2) Stations on the C-transect, adjacent to the Mississippi Delta and the deep (200 m) stations, had muddy sand (C1) to soft mud (C2-C4, M4, D4) sediments that could be sampled easily by box core; sediments at C3 and C4 consisted of deep layers of very soft mud containing large numbers of heart urchins. Stations D2 and D3, adjacent to De Soto Canyon, had bottoms of coarse sand and coral rubble that could be sampled only by Smith McIntyre grab. Stations M1, M2, and D1 had bottoms of sand to shelly sand and were sampled using the Smith-McIntyre grab. Station M3 had a muddy sand substrate which was soft enough to be sampled using a box core.

Macroinfauna - Polychaetes were the dominant taxon, both in terms of numbers of species (Figure 7-3) and numbers of individuals (Figure 7-4). However, unlike many assemblages in the western Gulf of Mexico, no single species appeared to dominate the community. Nor were there any discernable patterns of diversity or abundance that could be attributed to inshore-offshore or east-west gradients. This lack of dominance and patterns is expected to change as data from more recent cruises are analyzed.

Biomass data from the preliminary cruise (Figure 7-5) indicates two stations (D4 and M3) had average biomasses in excess of 5 g/m^2 and three stations (D1, M2, and C4) with less than 1 g/m^2. Again, there does not appear to be any pattern to the data. The low biomass at Stations C3 and C4 is misleading -- large numbers of heart urchins (Echinodermata: Echinoidea), which are infaunal organisms, were collected by trawl at these two stations (see macroepifaunal section).

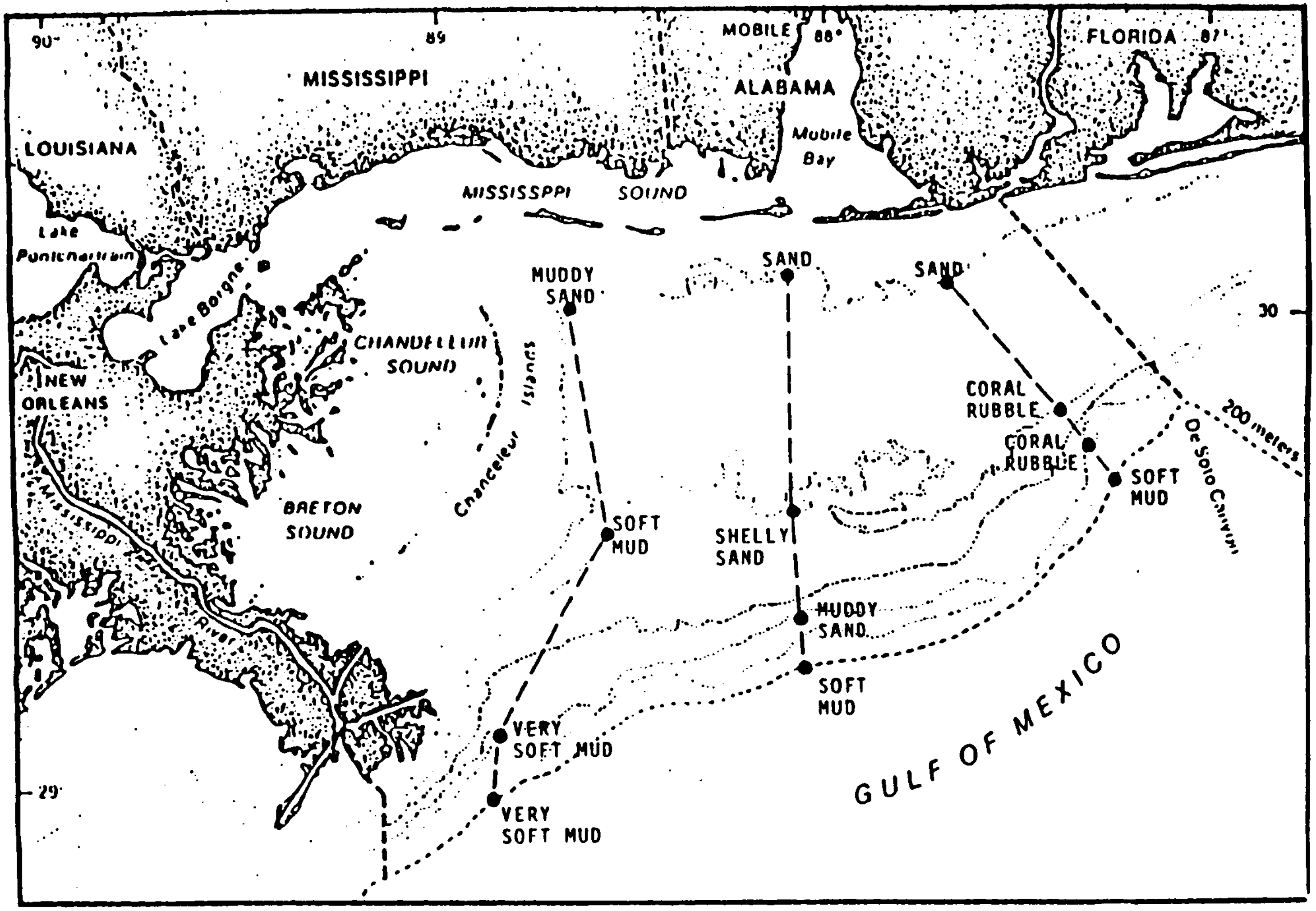

Figure 7-2. Map of the Mississippi-Alabama continental shelf showing the general substrate type, as determined by visual assessment during the preliminary cruise, at each station.

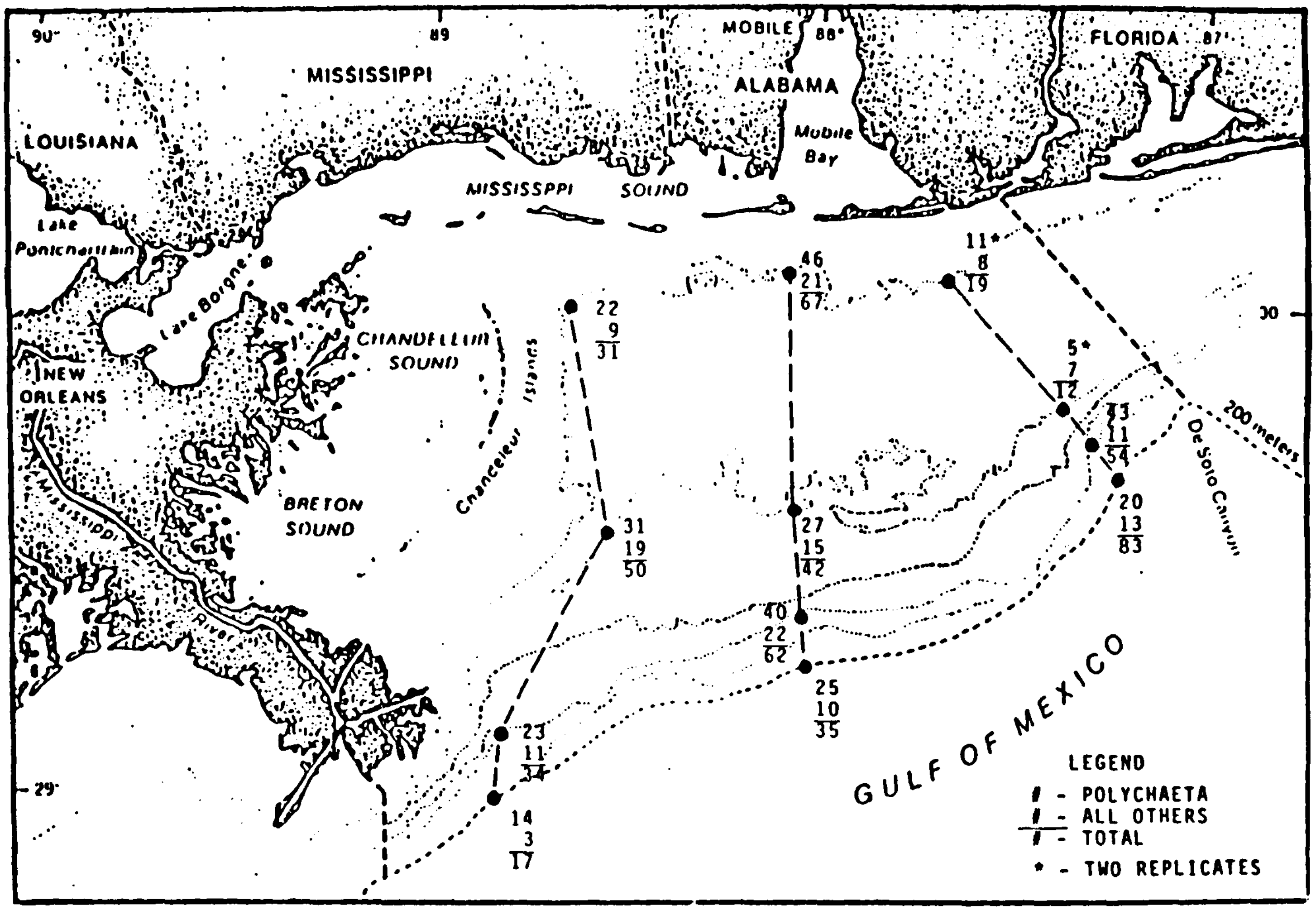

Figure 7-3. Map of the Mississippi-Alabama continental shelf showing the numbers of species of polychaetous annelids and of total other macroinfaunal taxa collected at each station during the preliminary cruise.

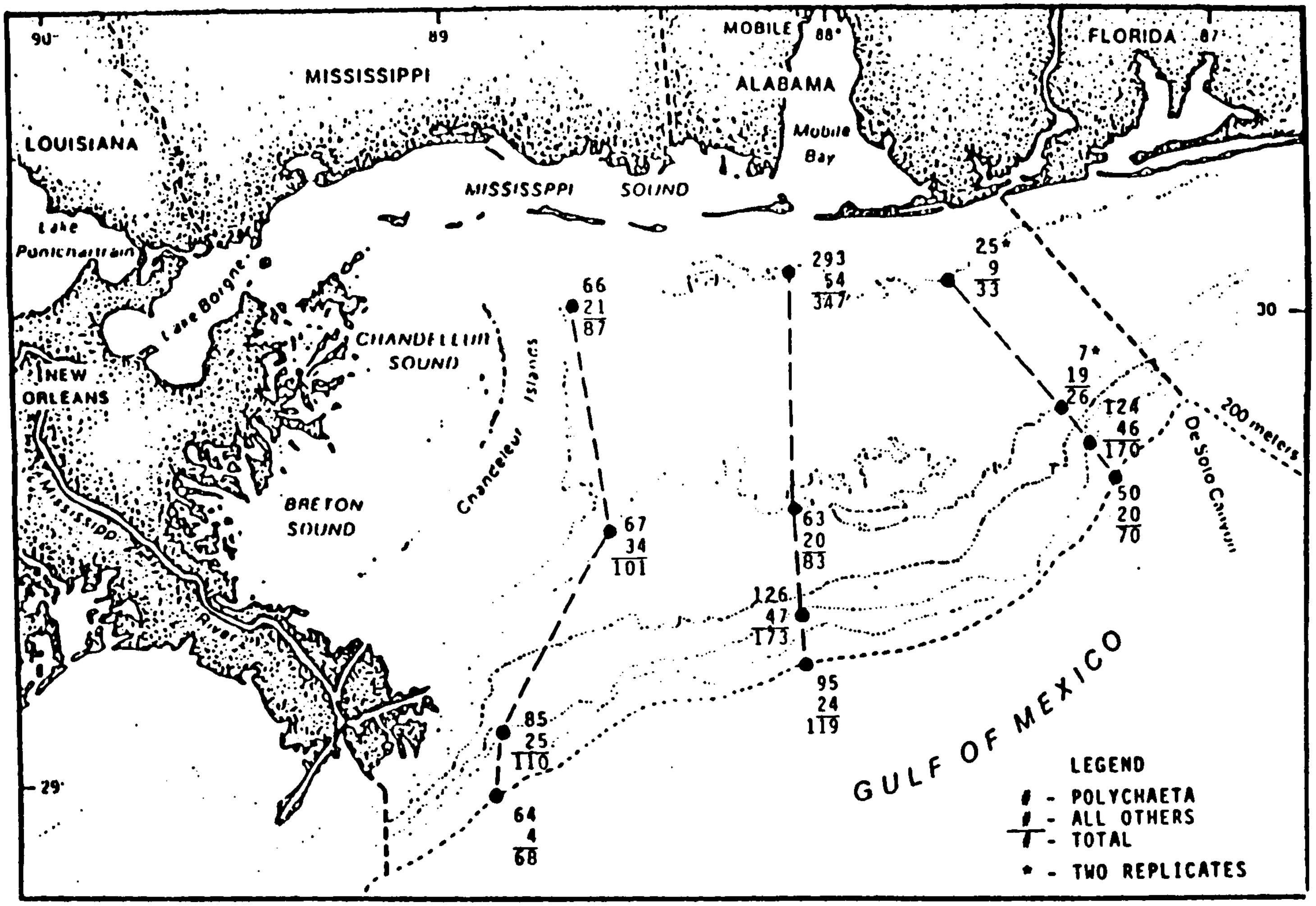

Figure 7-4. Map of the Mississippi-Alabama continental shelf showing the numbers of individuals of polychaetous annelids and of total other macroinfaunal taxa collected at each station during the preliminary cruise.

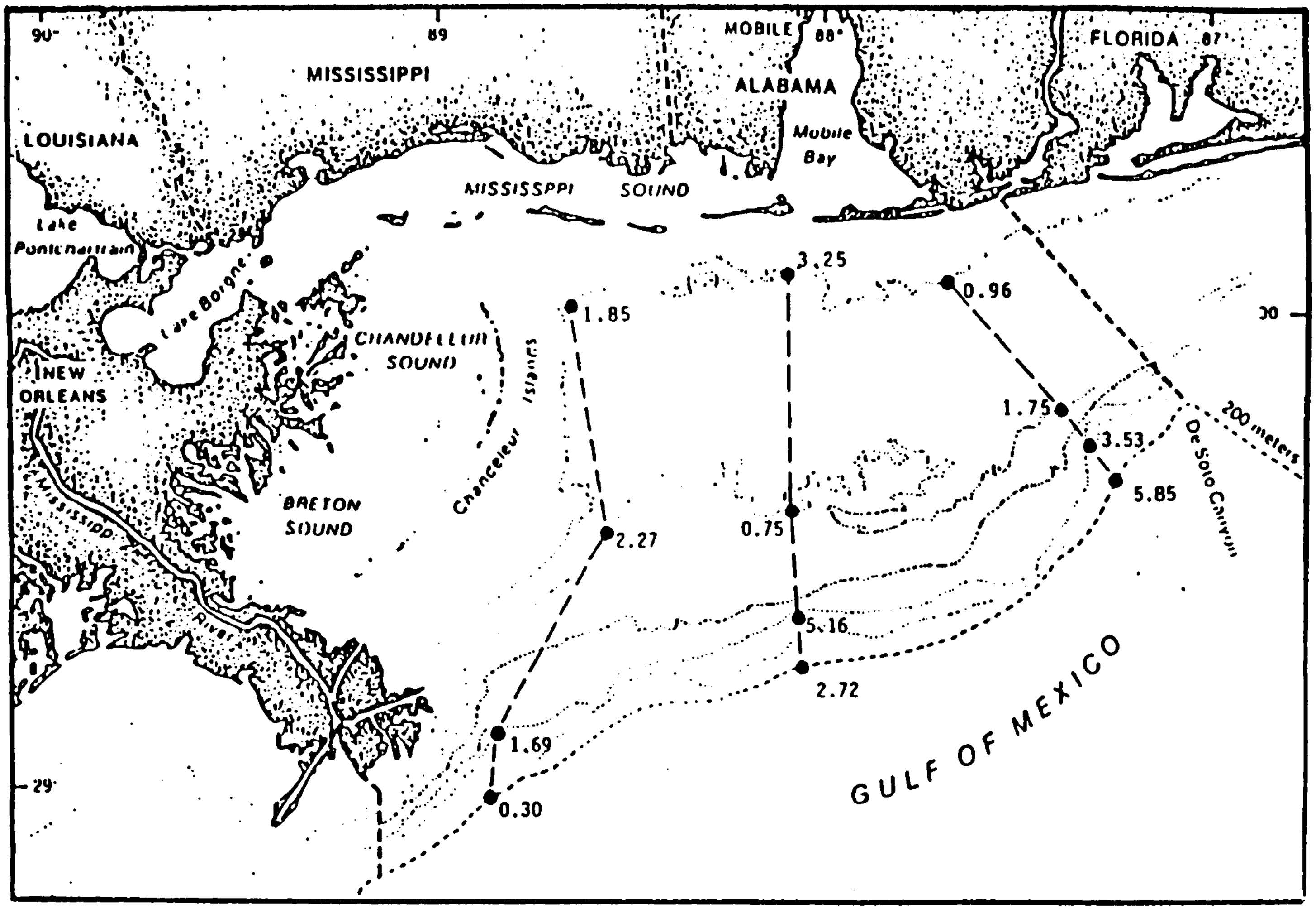

Figure 7-5. **Map of the Mississippi-Alabama continental shelf showing the mean macroinfaunal biomass/m² collected at each station during the preliminary cruise.**

Macroepifauna - Data on composition and abundance of organisms collected by trawl indicates that the largest numbers of species were collected at stations in 100 m depths and the largest numbers of individuals were collected at the 150 and 200 m depth stations (Figure 7-6). The greatest biomass collected by trawl occurred at Stations C3 and C4 off the Mississippi Delta. Box core samples indicated the bottom consisted of very soft mud, and the heavy trawl apparently was digging deeply into this mud and collecting enormous quantities of infaunal heart urchins.

Biomass data for macroepifauna (exclusive of heart urchins) are shown in Figure 7-7. The data show no discernable pattern. This may reflect a lack of sufficient information or be an artifact due to sampling error. Of the stations with biomass amounts in excess of 1000 g, portunid crabs (*Callinectes similis* and *Portunus gibbesii*) and squills (*Squilla empusa*) comprised the majority of biomass at Station C1, *Portunus spinicarpus* was the numerical and biomass dominant at Station M3, and the sea star, *Luidia clathrata*, and a majid crab, *Stenocionops spinimana*, comprised most of the biomass at Station D4. Excluded from the biomass for two reasons were heart urchins. First, they are infaunal organisms, and second, 14 "full garbage cans" of urchins were thrown overboard without being counted or weighed, and an accurate assessment of their biomass cannot be obtained.

The data gathered and analyzed thus far are not adequate to construct even a rough estimation of infaunal and epifaunal community structure and distributional patterns. In fact it is possible, in light of the varied nature of the substrates being sampled, that even with multiple data sets, it may only be possible to describe the community structure in general terms. Judgement on this must be deferred pending completion of more recent collections.

Polychaetous annelids are the dominant infaunal taxon and constitute the majority of biomass at most stations. However, the lack of dominance by any one species within a given depth zone is unusual for the northern Gulf of Mexico. It remains to be seen if this pattern will persist in other collections.

Unlike the macroinfauna, macroepifauna appeared to display an increasing abundance trend across the shelf to the 150-m depth stations, then decreased in abundance seaward. The numerically dominant

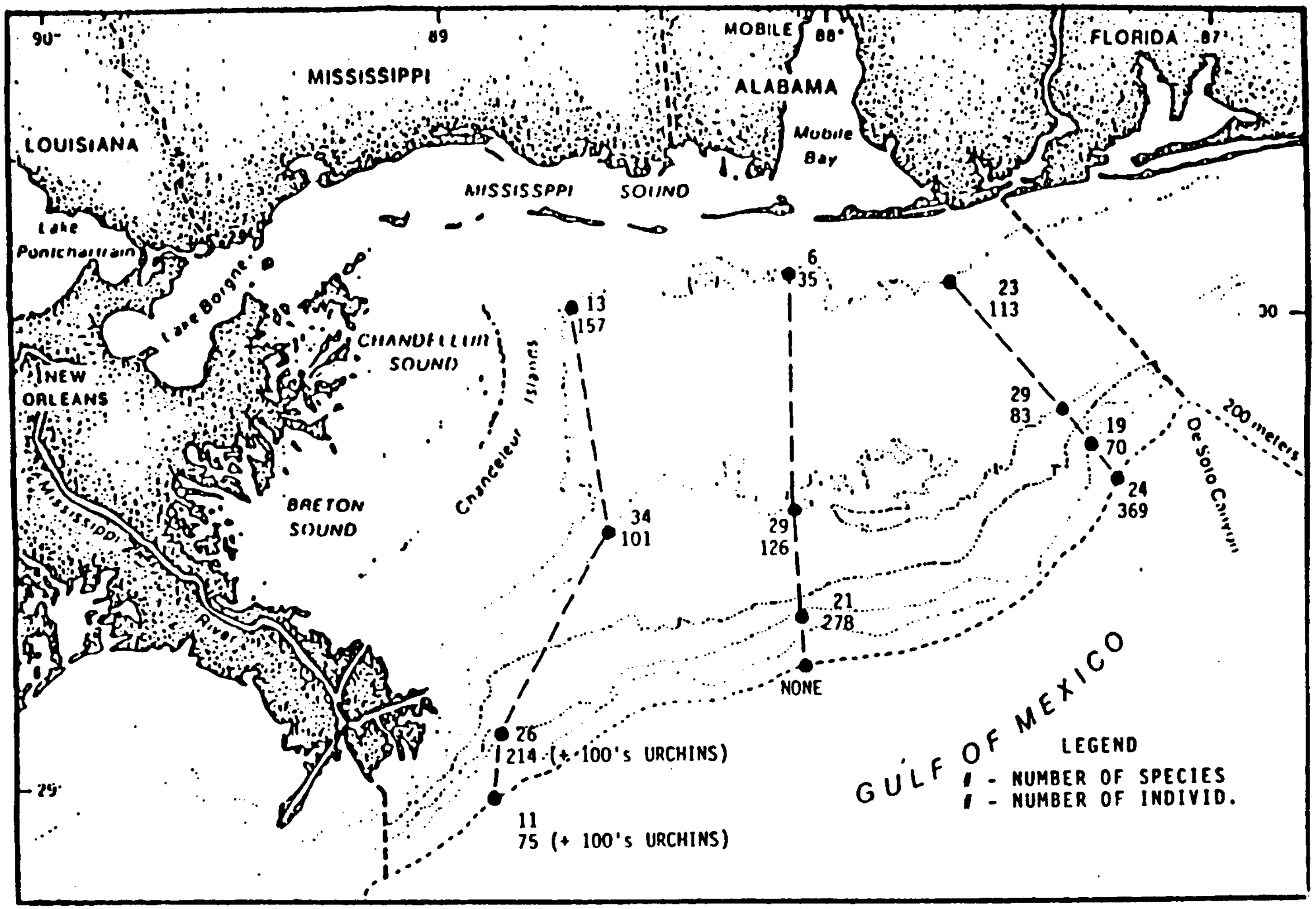

Figure 7-6. Map of the Mississippi-Alabama continental shelf showing total numbers of macroepifaunal species and individuals collected at each station during the preliminary cruise.

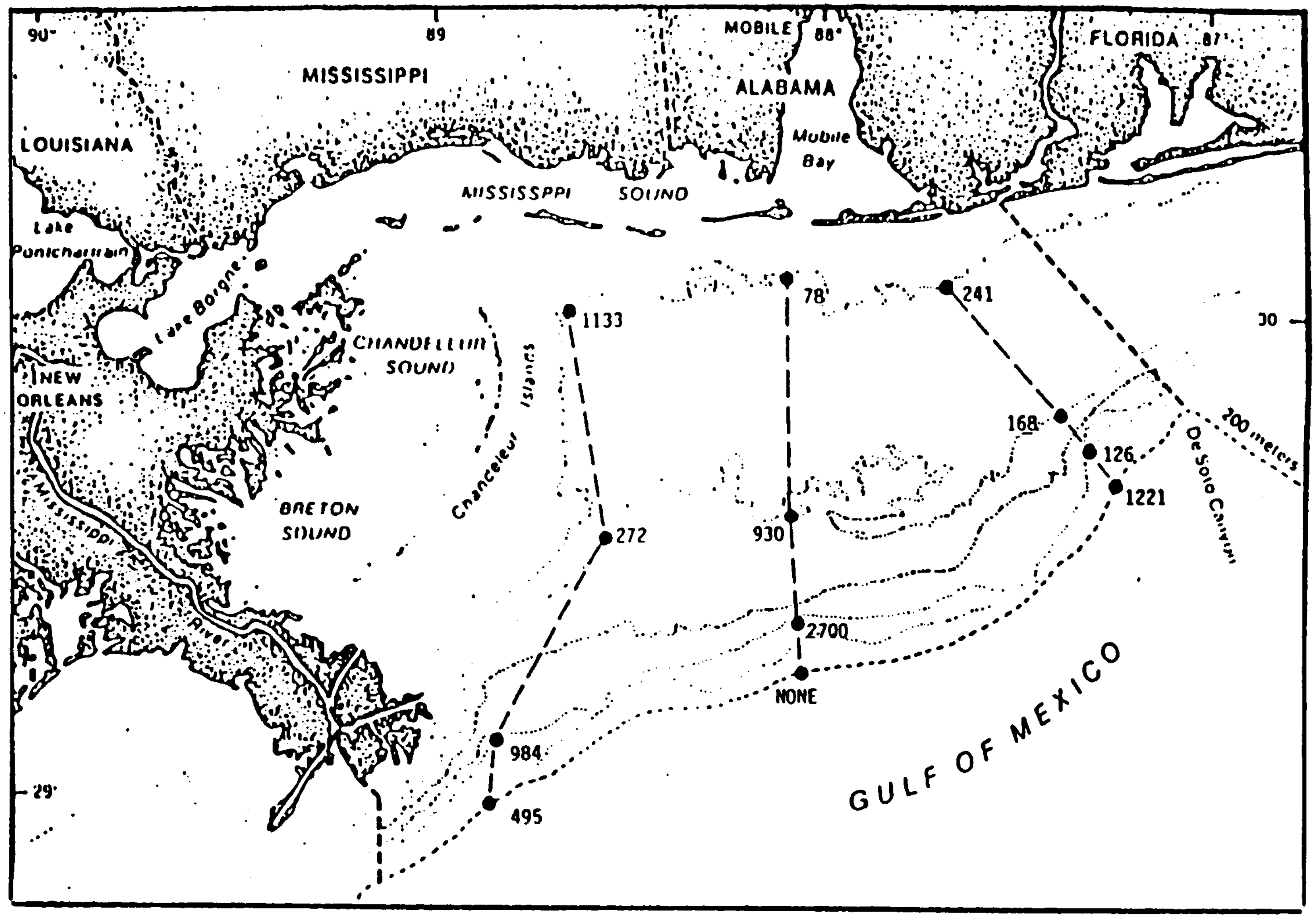

Figure 7-7. Map of the Mississippi-Alabama continental shelf showing total macroepifaunal biomass collected at each station during the preliminary cruise.

macroepifaunal taxon (excluding heart urchins) at most stations is the Crustacea. Echinoderms were also occasionally present in large numbers. In many cases, one or two large crabs (i.e., *Calappa sulcata* or *Stenocionops spinimana*) may have weighed several times more than all other species combined, and thus "inflated" the biomass value.

8.0 DEMERSAL FISH TAXONOMY

John D. McEachran

8.1 Introduction (including historical background)

The fish fauna of the Mississippi-Alabama continental shelf have been well investigated and the numerous publications and reports concerning this fauna have recently been summarized (Darnell 1985; Darnell and Kleypas 1987). Springer and Bullis (1956) and Bullis and Thompson (1965) listed the fishes and benthic invertebrates captured in this area by the National Marine Fisheries Service research vessels from 1950 through 1955 and 1956 through 1960, respectively. Franks *et al.* (1972) and Christmas *et al.* (1973) reported on the nekton and benthic faunas of the inner continental shelf of Mississippi. McCaffrey (1981) described the demersal fish fauna of the continental shelf from the Mississippi River Delta to Apalachicola Bay, Florida. Shipp and Hopkins (1978) reported on some of the fishes occurring on the rim of De Soto Canyon in the northeastern Gulf of Mexico. Williams and Shipp (1980) described fishes not previously recorded or rarely recorded from the northeastern Gulf of Mexico. Benson (1982) discussed aspects of the life history of fishes and crustaceans in the Mississippi Sound.

These studies, in addition to a number of unpublished reports and data sources, were summarized by Darnell (1985) and Darnell and Kleypas (1987). Sources of data for these summaries included various studies: 1) monthly trawl transects across the continental shelf off Mississippi conducted by the Gulf Coast Marine Laboratory, Ocean Springs, Mississippi; 2) monthly trawl transects across the continental shelf off Mississippi and Alabama conducted by Darnell; 4) seasonal trawl collections made at scattered locations by the Bureau of Land Management's Mississippi, Alabama, Florida study (MAFLA); and 5) trawl collections on the continental shelf off Mississippi and Alabama made from 1978 through 1982 by the National Marine Fisheries Service Laboratory in Pascagoula, Mississippi.

This combined data base consisted of records of 201,585 fishes representing 250 taxa. Darnell (1985) and Darnell and Kleypas (1987) used this data base exclusively or along with extralimital data to estimate the species composition and relative abundance of the fishes of the continental shelf off Mississippi and Alabama. They classified the fauna into four ecological assemblages: 1) estuarine related fishes, 2) reef and structure related fishes, 3) nektonic and fast swimming fishes, and 4) demersal shelf fishes.

The estuarine related fishes use the low salinity estuaries as nursery grounds and spawn in and occupy the near shore continental shelf as adolescents and adults. This assemblage appears to be most concentrated off the Mississippi Sound in 60 m or deeper and off Mobile Bay in 20 to 40 m. Common species were noted in this assemblage: *Arius felis* (sea catfish), *Archosargus probatocephalus* (sheepshead), *Menticirrhus americanus* (southern kingfish), *Lagodon rhomboides* (pinfish), *Bairdiella chrysura* (silver perch), *Cynoscion arenarius* (sand seatrout) *Micropogonias undulatus*, and *Leiostomus xanthurus* (spot).

The reef and structure related assemblage is found over hard substrate exposures such as fossil and living reefs, blocks of limestone, rocky outcrops and artificial structures (oil rigs, ship wrecks, and artificial reefs). Darnell and Kleypas (1987), based on Smith (1976), subdivided this assemblage into primary and secondary components in reference to the fishes' affiliation with the hard substrates. Primary components were those fishes which were considered to be obligatory hard substrate dwellers: *Apogon pseudomaculatus* (twospot cardinalfish) *Lutjanus campechanus* (red snapper), *Haemulon aurolineatum* (tomtate) and *H. plumieri* (white grunt). Secondary components were considered to be facultative hard substrate dwellers: *Synodus intermedius* (lizardfish), *Trachinocephalus myops* (snakefish), *Centropristis ocyura* (bank seabass), *Diplectrum formosum* (sand perch) and *Pristipomoides aquilonaris* (wenchman).

The demersal shelf assemblage is independent of estuaries as nursery grounds and occurs on or over the soft substrate of the continental shelf. These fishes are dependent to some degree on the soft substrate for feeding and other aspects of their life histories. Eggs and larvae generally occur in the water column. Darnell and Kleypas (1987) further divided this assemblage into three groups based on bathymetry: mid-shelf species, outer shelf species and trans-shelf species.

The mid-shelf species range from 20 to 80 m and include: *Diplectrum bivittatum* (dwarf sand perch), *Rypticus bistrispinus* (Soapfish), *Pristigenys alta* (Short bigeye), *Rhomboplites aurorubens* (vermillion snapper), *Prionotus ophryas* (bandtail searobin), *P. roseus* (bluespotted searobin) and *P. salmonicolor* (blackwing searobin). The outer shelf species range from 80 to 120 m and include: *Gymnothorax nigromarginatus* (West ocellated moray), *G. saxicola*, (East ocellated moray) *Synodus poeyi* (offshore lizard fish), *Halieutichthys aculeatus* (Pancake batfish), *Centropristis philadelphica* (rock seabass), *Scorpaena calcarata* (smoothhead scorpionfish) and *Cyclopsetta chittendeni* (Mexican flounder). The trans-shelf species extend over the entire continental shelf.

The syntheses of Darnell (1985) and Darnell and Kleypas (1987) were the first attempts to summarize and standardize the fish species composition and abundances of the continental shelf off Mississippi and Alabama. Although these syntheses were based on large data bases, the data were collected independent of the analyses and were therefore difficult to compare quantitatively. Sampling gear and strategies varied both among and within the various studies. These circumstances thus limited the quantitative analyses of the syntheses. The present study was designed to further quantitatively define the shelf demersal fish communities. The same sampling gear is used to sample designated stations along three transects. Replicates are taken at each station to estimate in-sample variability. The transects are designed to estimate changes in species composition and abundance with changes in substrate (across transects). The substrate changes from fine to coarse from west (off the Mississippi) to east (off Alabama).

8.2 Methods

During the first year of the field effort of the Mississippi-Alabama Marine Ecosystems Study, three sampling cruises were completed. The first cruise (Cruise 0) was conducted before the contract was awarded.

Within the study area three transects were established along environmental gradients. On each transect four stations were defined. Two 15 minute trawl samples were taken at each station on the second and the third cruises. Only one replicate sample was taken on the first cruise. The contents of each trawl sample were dumped on a sorting table and the invertebrates and vertebrates were preserved separately in 10 percent buffered formalin. Large fishes and those to be used for food habit analysis were first injected with 10 percent formalin.

After the fish specimens were preserved for several weeks the samples were briefly soaked in water and stored in 70 percent ethanol. Each sample was then sorted to species. The complement of each species was weighed and individuals were measured to the nearest millimeter of total length.

8.3 Results

During the first year of the field effort all of the samples collected on the first cruise (Cruise 0) and 20 of the 23 samples collected on the second cruise (Cruise 1) were processed. All of the data sheets containing identifications, numbers, and lengths of specimens captured on the first cruise, and for 15 of the samples on the second cruise, were entered in computer files and were proofed for transcription errors.

8.3.1 Cruise 0

A total of 2,839 specimens representing 98 species and 37 families of fishes were identified from the 11 samples collected on Cruise 0. Fishes were not caught at two stations (M4 and D3) and a replicate was made at only one station (C2).

The third station along each transect yielded the highest number of individuals while the first station along each transect yielded the highest number of species. An average of 374 individuals representing an average of 17 species were captured at the third station along each transect and an average of 288 individuals representing 21 species were captured at the first station along each transect. The fourth station along each transect yielded the fewest number of individuals and species of fishes. An average of 83 individuals representing an average of 10 species were captured at the fourth station along each transect.

Transect M yielded the most individuals while transect C yielded the most species. An average of 270 individuals representing 17 species were captured at the four stations along transect M and an average of 228 individuals representing 18 species were captured at the four stations along transect C. Transect D yielded an average of 191 specimens representing 13 species at the four stations.

There was considerable variation in the species composition among the three shallowest stations (C1, M1, D1). The two most abundant species at Station C1 were the pelagic fish *Bregmaceros atlanticus* (Antenna codlet) (97 specimens) and the demersal mid-shelf fish *Sphoeroides parvus* (Puffer) (49 specimens); at Station M1, the estuarine related fish *Micropogonias undulatus* (Atlantic croaker) (28 specimens) and the reef and structure related fish *Haemulon aurolineatum* (Tomtate) (26 specimens); and at Station D1, the pelagic fish *Anchoa cubana* (Cuban anchovy) (311 specimens) and the demersal mid-shelf fish *Diplectrum bivittatum* (Dwarf sand perch) (47 specimens).

There was less variation in the species composition among the three mid-shelf stations (C2, M2, D2). The two most abundant species at Station C2 were the demersal outer shelf fish *Halieutichthys aculeatus* (Pancake batfish) (51 specimens) and the demersal mid-shelf fish *Syacium gunteri* (Shoal flounder) (14 specimens); at Station M2, *Halieutichthys aculeatus* (Pancake batfish) (51 specimens); and at Station D2, the demersal outer shelf fish *Synodus poeyi* (Offshore lizardfish) (96 specimens) and *Syacium papillosum* (Dusky flounder) (44 specimens).

Variation in species composition between the two outer shelf stations with fishes (C3, M3) was similar to that of the midshelf stations. The two most abundant species at Station C3 were *Halieutichthys aculeatus* (Pancake batfish) (240 specimens) and the secondary reef and structure related fish *Serranus atrobranchus* (Blackear bass) (69 specimens); and at Station M3, the demersal outer shelf fish *Prionotus paralatus* (Mexican searobin) (225 specimens) and *Halieutichthys aculeatus* (Pancake batfish) (135 specimens).

There was considerable variation in species composition between the two upper slope stations with samples of fishes (C4, D4). The two most abundant species at Station C4 were the demersal outer shelf fish *Pontinus longispinis* (Longspine scorpionfish) (45 specimens) and the slope fish

Bathygadus macrops (Rattail) (16 specimens); and at Station D4, the demersal outer shelf fish *Macrorhamphosus gracilis* (Snipefish) (25 specimens) and the demersal outer shelf fish *Zalieutes mcgintyi* (Tricorn batfish) (17 specimens).

Variation in species composition is also evident within stations. At Station C2, the only station at which a replicate was taken, only nine of the total 26 species captured were present in both of the samples.

8.3.2 Cruise 1

Comparisons within and among stations, within and among transects, and among cruises will be included in the next annual report after all of the samples of Cruise 1 have been processed.

9. 0 DEMERSAL FISH FOOD HABIT ANALYSIS

Rezneat M. Darnell

9.1 Introduction (including historical background)

The continental shelf of the northern Gulf of Mexico is one of the most productive fishery areas of the United States, and these fisheries are concentrated in the "fertile fisheries crescent" which extends essentially from Mobile Bay to near the Louisiana-Texas border. Two primary sets of environmental factors appear to be responsible for the high production of fisheries in the area: the presence of extensive low salinity bays and *Spartina* marshes along the coast and the distribution onto the continental shelf of nutrient-rich river waters and soft sediments brought down by the Mississippi River, but also by the Mobile, Pearl, and Atchafalaya Rivers. The environment of the continental shelf is seaward thus, an extension of the estuarine environments seaward of the barrier islands. A high percentage of the local catch of fishes and shellfishes is made up of estuary dependent species of which penaeid shrimp, portunid crabs, and sciaenid fishes constitute a large proportion.

Due to the presence of organic rich waters and soft sediments, there is an extensive bottom fauna which, together with the seasonal estuary related migrants, supports a large and diverse population of true shelf residents which are also of some commercial interest. To these are added deeper water and oceanic species which invade the outer shelf and a group of migratory predators which is resident during the summer months.

Despite the obvious importance of the Mississippi-Alabama continental shelf as a fishery resource and as an area of ecological interest in terms of faunal mixing and interaction, little effort has been made to understand the trophic interactions of this dynamic area. Numerous studies have been carried out on the food relations of fishes in the adjacent marshes, bays, and estuaries, as well as Mississippi Sound. However, aside from the limited investigations of Henwood, Johnson, and Heard (1978), Mercias (1981), and Overstreet and Heard (1978) which treated only one or a few species, only the extensive study of Rogers (1977) attempts to address the trophic structure of the shelf ecosystem through analysis of the food habits of a large percentage of the major consumer species. Additional investigations which have some relevance to the local trophic interactions are those conducted elsewhere on the northern Gulf which treat food relations of species which also inhabit the Mississippi-Alabama continental shelf.

As a background for fish food analysis in the present investigation a thorough survey of the existing northern Gulf fish food literature has been conducted (Simons 1988). About fifty relevant studies have so far been located and examined, and in a later report a summary of the historical literature will be presented. In view of the obvious importance of the study by Rogers (1977), insofar as possible analytical methods employed in the present study are identical with his methodology so that detailed comparisons will be possible.

9.2 Methods

An overview of the steps involved in the fish food analysis program is presented in Figure 9-1. These steps include field collection, taxonomic identification, lab processing, preliminary food analysis (to major taxonomic group), final food analysis (with food items identified to the lowest level of taxonomic certainty), interpretation, and write-up. In this process there are two points of delay. Laboratory work on the stomaches cannot begin until the specimens from a cruise have all been identified, and final food analysis cannot be completed until the detailed taxonomy of the food items can be checked out. This builds into the study an initial lag which shows up in the progress made during the first year. Since that has been the case, much time this first year has been devoted to locating and synthesizing the existing literature which will be needed for the interpretation process.

In the laboratory, specimens are identified, weighed, and measured (total length as well as standard body length). For each cruise tabular information on size class availability of each species by station and transect permits selection of species and size classes for food analysis. For each species and size class the stomachs are removed and their contents amassed as a group. The quantity of this food is determined by volume displacement. The contents are then sorted by major food categories, and the percentage

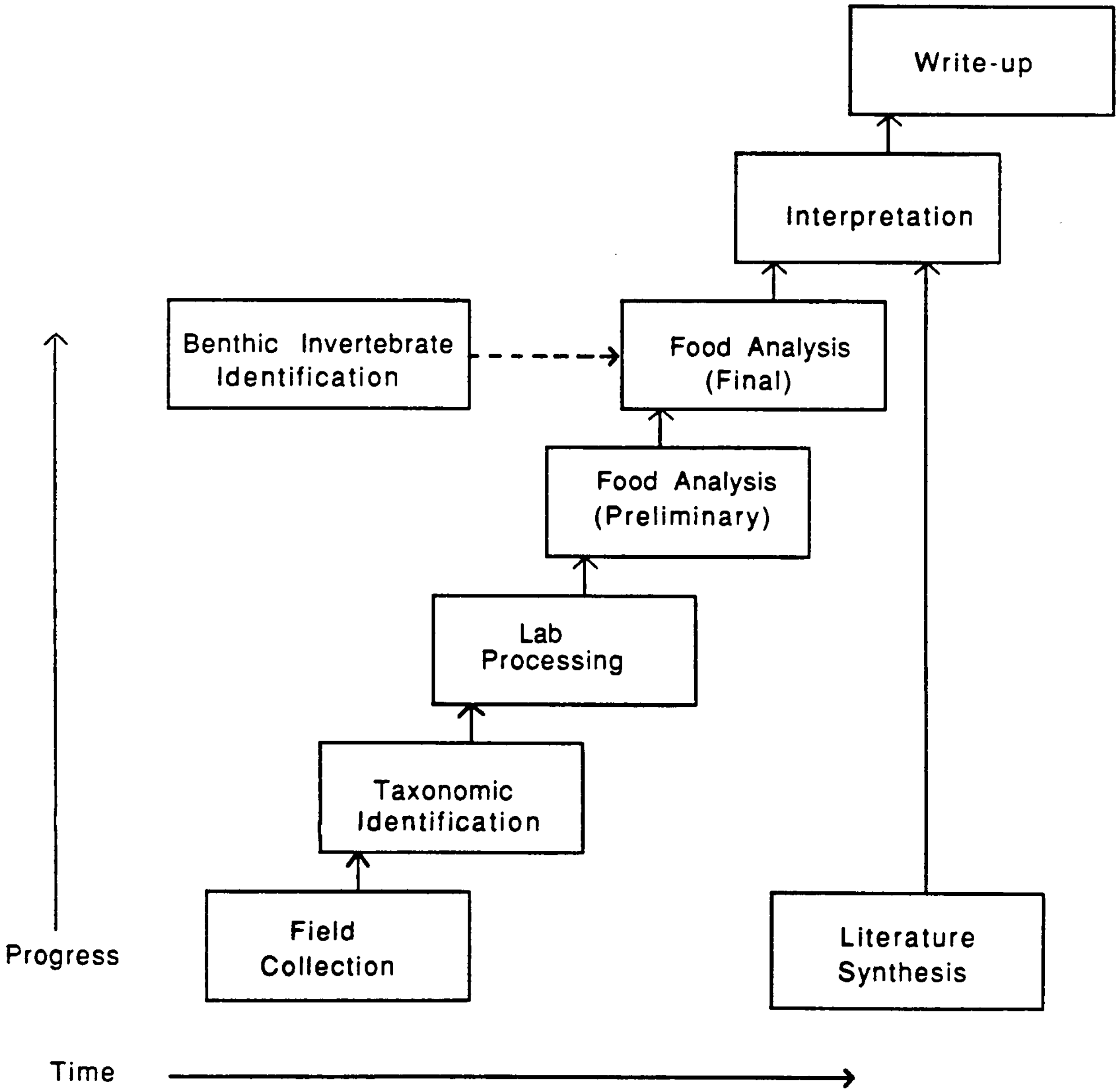

Figure 9-1. Steps involved in demersal fish food habit analyses.

of each food group is estimated visually using bottom-gridded petri dishes. Specific food items are then withdrawn and separately preserved for later detailed identification. The items are selected on the basis of their representativeness and state of preservation. Subsequent comparisons are made with voucher specimens isolated in the benthic invertebrate study. The final process involves interpretation of the food analysis data in relation to the historic literature and other information obtained in the present investigation dealing with bottom sediments and benthic invertebrates.

9.3 Results

As of the present writing, the following field collections have been made: Cruise 0 (February 1987), Cruise 1 (September 1987), and Cruise 2 (March 1988). Taxonomic identifications have been completed only for Cruise 0. For these fishes, weights, body length, and measurements have been completed, and a table has been prepared showing the numbers of individuals of each size class of each species by station which have been selected for possible food analysis (Table 9-1). Included are 29 species representing 15 families. A final decision on whether to include certain species will be made after reviewing availability of additional size classes and habitat representation from subsequent cruises.

Food analyses are already underway, and the results of preliminary analysis of one species is provided as an example of the types of results to be expected (Table 9-2). Eighty-four specimens of the longspine porgy (*Stenomotomus caprinus*) have been examined, of which 52 contained food. These represent 10 habitat/size-class groups. Polychaetes were the dominant food groups followed by small crustaceans. Trace amounts of nematodes, mollusks, and echinoderms were present. Organic detritus, which was the major category by volume, apparently consisted of mucous from polychaetes mixed with small amounts of organic material from other sources. Trace amounts of silt and sand were encountered. The number of specimens examined within each habitat/size-class is too small for discussion of habitat or size-class implications.

Table 9-1. Species and size classes of fishes from Cruise 87-G-0 selected for possible food analysis. C, M, and D refer to the transects (Chandeleur, Mobile, and DeSoto Canyon). Species with some everted stomachs are indicated with by an asterisk (*).

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Engraulidae													
Anchoa cubana	26-50			20									
	51-75			20									
Synodontidae													
Saurida brasiliensis	51-75					14							
Synodus poeyi								22					
	51-75							20					
	76-100												
Batrachoididae													
Porichthys plectrodon									9				
	76-100					9							
Ogcocephalidae													
Halieutichthys aculeatus								10	16				
	26-50				2			20	22				
	51-76				23	21							
Ogcocephalus nasutus									20				
	76-100												
Gadidae													
Bathygadus macrops											7		
	101-150								1				
	151-200												
Serranidae													
Diplectrum formosum	26-50			13									
	51-75			20									
	76-100	10											
Serranus atrobranchus	76-100							19					

Table 9-1. Continued.

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Lutjanidae													
Rhomboplites aurorubens	76-100		13										
Haemulidae													
Haemulon aurolineatum	76-100		12										
Sparidae													
Stenotomus caprinus	76-100		14	20	12	5		9	20				
	101-125			2		8							
Sciaenidae									4				
Cynoscion arenarius	151-200								6				
	201-300												
Leiostomus xanthurus	151-175			14					20				
Micropogonias undulatus	126-150		20	21									
Scorpaenidae													
Pontinus longispinis	76-100										16		
	101-125										11		
Scorpaena calcarata	51-75					20							

Table 9-1. Continued.

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Triglidae													
Bellator militaris	26-50					20							
	51-75					17							
Prionotus alatus	76-100								10				
	101-125								20				
	126-150								8				
Prionotus roseus	101-125						7						
	126-150						9						
Prionotus rubio	101-125								11				
	126-150								7				
Prionotus salmonicolor	126-175					6							
Prionotus scitulus	126-175					8							
Prionotus stearnsi	76-100								8				
Bothidae													
Syacium gunteri	51-75				12								
	76-100				7								
Syacium papillosum	26-50			10									
	51-75			13		23							
	101-150					15	13						
	151-250					8	20						

Table 9-1. Continued.

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Trichopsetta ventralis	76-100							16					
	101-150							14					
Cynoglossidae													
Symphurus plagiusa	101-125	20											
Tetraodontidae													
Sphoeroides parvus	26-50	20											

Table 9-2. **Food of the Longspine Porgy (*Stenotomus caprinus*) based upon specimens collected on Cruise 87-G-0 (t = trace amount).**

Station	C-1	C-2	C-2	C-3	M-1	M-2	M-2	M-3	D-1	D-1
Size class (mm)	51-75	76-100	101-125	76-100	76-100	76-100	101-125	76-100	76-100	101-125
No. of stomachs examined	1	12	2	6	12	5	6	20	18	2
No. of stomachs with food	1	12	2	4	7	2	3	20	1	0
FOOD ITEMS (% of total)										
Nematodes		t	t		1		t	3		
Polychaetes	5	35	7	40	40	25	40	10		
Mollusks		1	t				t	t		
Crustaceans	40	5	1			10	9	6	85	
Echinoderms		t	t							
Organic detritus *	55	55	90	60	58	65	50	80	15	
Silt and Sand		3	1	t	1	t	t	t		

*Mostly polychaete mucous with inclusions

All techniques are well in hand, and stomachs have been removed for all specimens listed in Table 9-1. During the coming year analyses will be completed for all specimens selected from the first several cruises. By the second annual report, considerable information should be available concerning food habits by habitat and size-class for at least 30 of the common species.

10.0 PHYSICAL OCEANOGRAPHY/WATER MASS CHARACTERIZATION

F. J. Kelly

10.1 Introduction (including historical background)

The major objective of the physical oceanography component of the project is to characterize the circulation on the outer shelf, with emphasis on influence of exchange processes between the outer shelf and the deep ocean. An additional objective is to develop a coherent description of the circulation and hydrography of the entire area during the period of interdisciplinary field sampling. The objectives will be achieved by synthesizing the results of previous studies and the new data obtained during this study from CTD surveys, moored instruments, satellite imagery, meteorology, river input, and tide gauges. Efforts during Years I and II of this study are focused on the collection of hydrographic and time-series data in regions where there is little historical data. In this report we present the basic results of three hydrographic surveys and describe the moored instruments that were deployed in December 1987 and retrieved in March 1988. Results from the moored instruments are not included in this report because it is statistically better to analyze long time-series whenever possible. The time-series from the first deployment period will be joined to those from the next one before we run them through the suite of computer programs that do the various analyses.

10.2 Moored Instruments

10.2.1 Mooring Locations

For the Year I deployment period a cross-shelf array of three moorings was installed as shown by the triangles in Figure 10-1. They are designated Sites A, B and C. Table 10-1 gives the coordinates of the sites. They differ slightly from the positions originally proposed because the moorings were designed and pre-cut for specific water depths, and actual water depths differed slightly from the depths indicated by nautical charts. Table 10-1 also lists the locations proposed originally. The array is located

Table 10-1. Mooring locations, Year I.

Site	Planned	Actual
A	29°53.0'N, 87°40.0'W	29°54.0'N, 87°40.2'W
B	29°37.0'N, 87°31.0'W	29°37.2'N, 87°40.2'W
C	29°24.0'N, 87°21.0'W	29°23.9'N, 87°20.7'W

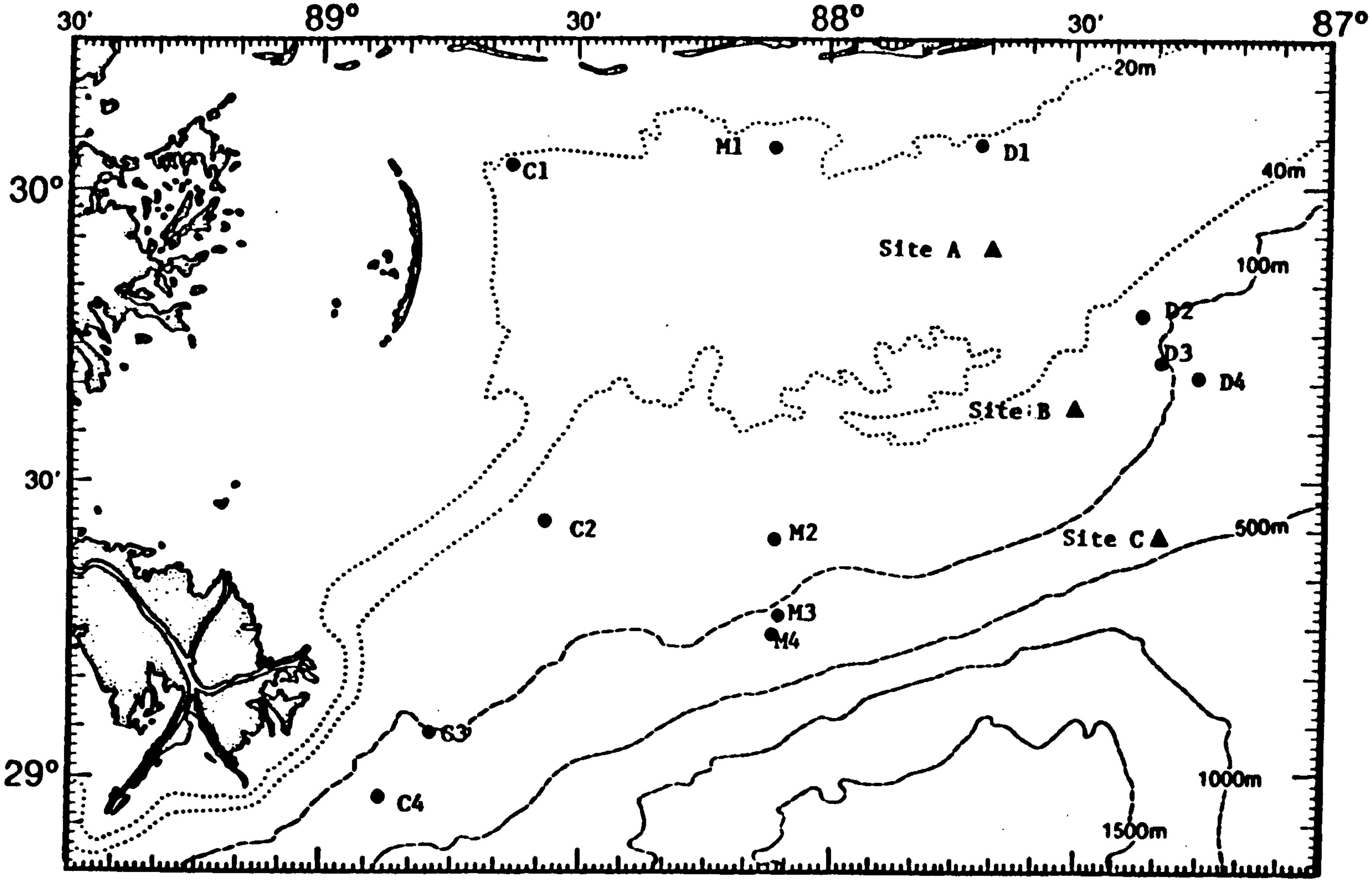

Figure 10-1. Map showing locations of moored instrument Sites A, B, and C (triangles) and the twelve primary stations for interdisciplinary sampling (circles).

between the middle and eastern lines of stations (circles in Figure 10-1) that are occupied during the semi-annual surveys by ship. Site C is located on the 430 m isobath west of the deeper head of De Soto Canyon. (De Soto Canyon has, in effect, a shallow and a deep head because the 200 and 400 m isobaths begin to spread apart near 87° 20'W). Site B is located near the shelf break in 60 m of water, and Site A is in 30 m of water. The mooring sites are separated by about 30 km.

10.2.2 Instruments and Mooring Configurations

Figure 10-2 shows schematically the configuration of the moorings at Sites A and B. Each has an ENDECO Type 174SSM current meter located about 10 m below the surface, an ENDECO Type 174DMT current meter located about 4 m above the bottom and a Sea Data Corp TDR Micrologger located 2-3 m above the bottom. The configuration of the mooring at Site C is shown in Figure 10-3. It has an ENDECO Type 174SSM current meter located 20 m below the surface and Aanderaa RCM-8 current meters at depths of 150 m and 425 m (4.5 m above the bottom). Table 10-2 lists the design depths of the instruments and other components for each mooring. Analysis of the long-term pressure records from the instruments that record pressure will give the most accurate estimate of the water depth at each site. After sufficiently long records are available, the actual depths of the instruments may be revised according to the pressure data.

Both types of ENDECO instruments are axial-flow, ducted impeller current meters that are ballasted for neutral buoyancy and level trim, and are connected to the mooring wire by a slack tether assembly that minimizes the effects of mooring motion and orbital wave motion. The DMT version records on magnetic tape, and the SSM version version averages vectorially and records into solid state memory. The Aanderaa RCM-8 is a Savonious-rotor and vane type of current meter that averages vectorially and records into solid state memory. All current meters have temperature and conductivity sensors; the Aanderaa RCM-8's also have pressure sensors. The TDR Micrologger uses a Sensometrics strain gauge and a YSI precision thermistor to measure pressure and temperature and records into solid

Table 10-2. Design depths of the instruments and other major components for each mooring.

Depth (m)	Component
	Mooring A
6.1	28" Ore Steel Flotation Buoy
10.1	ENDECO 174SSM Current Meter
21.3	24.5" InterOcean Steel Flotation Buoy
25.3	ENDECO 174DMT Current Meter
26.8	Data Sonics UAT-377 Acoustic Transponder
27.4	Sea Data TDR Micrologger
30.0	Sea Bottom
	Mooring B
5.5	28" Ore Steel Flotation Buoy
7.3	Data Sonics UAT-377 Acoustic Transponder
10.1	ENDECO 174SSM Current Meter
51.5	24.5" InterOcean Steel Flotation Buoy
55.5	ENDECO 174DMT Current Meter
56.7	Sea Data TDR Micrologger
57.3	Data Sonics ATR-397/30 Acoustic Release
60.0	Sea Bottom
	Mooring C
15.2	30" Ore Steel Flotation Buoy
17.1	Data Sonics UAT-377 Acoustic Transponder
19.8	ENDECO 174SSM Current Meter
146.0	28" Ore Steel Flotation Buoy
150.3	Aanderaa RCM8 Current Meter
421.2	24.5" InterOcean Steel Flotation Buoy
425.3	Aanderaa RCM8 Current Meter
426.7	Data Sonics Twin ATR-397/30 Acoustic Releases
430.0	Sea Bottom

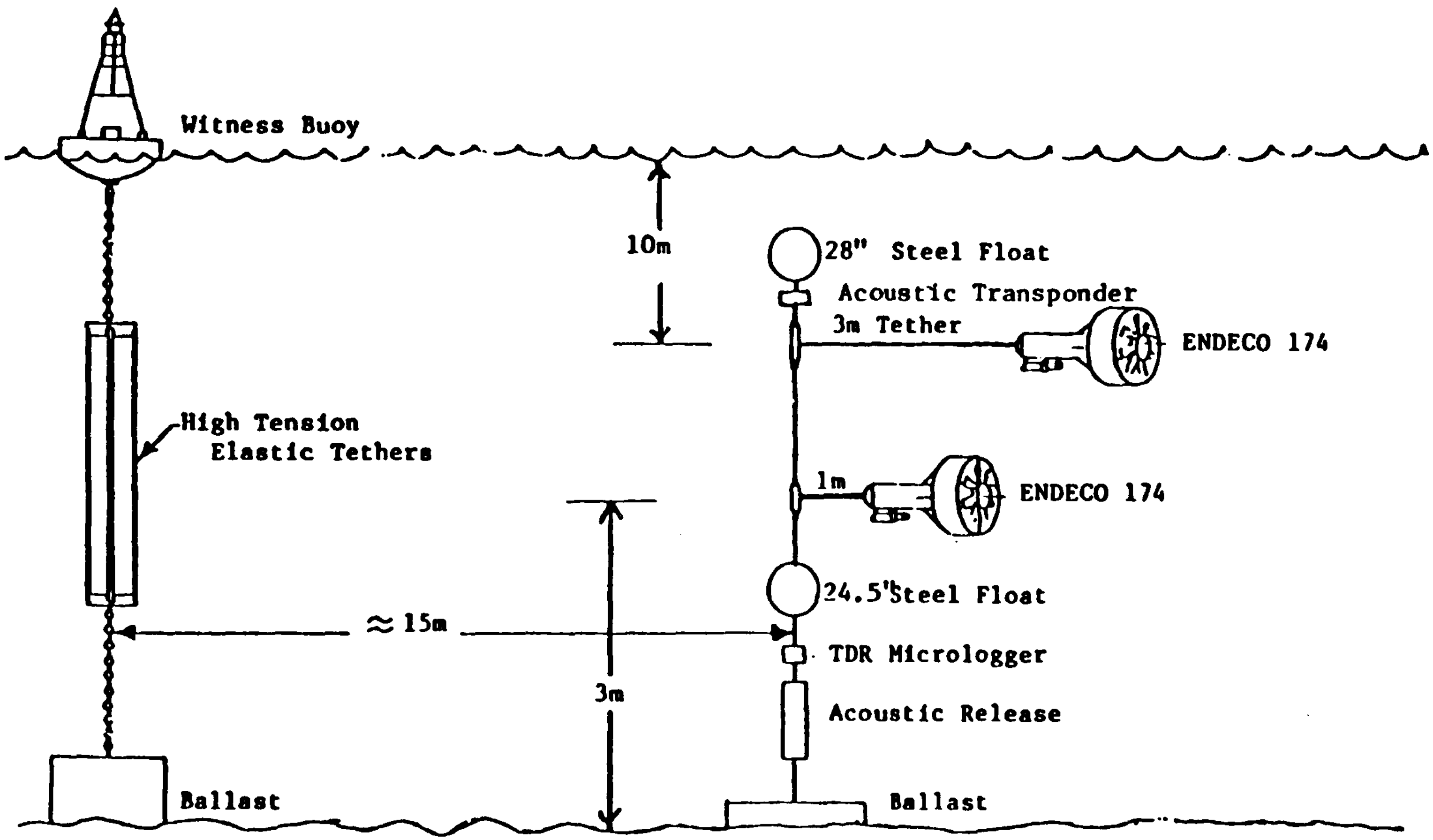

Figure 10-2. Schematic diagram of the mooring configuration at Sites A and B. The two sites have the same configuration except that Site A does not have an acoustic release.

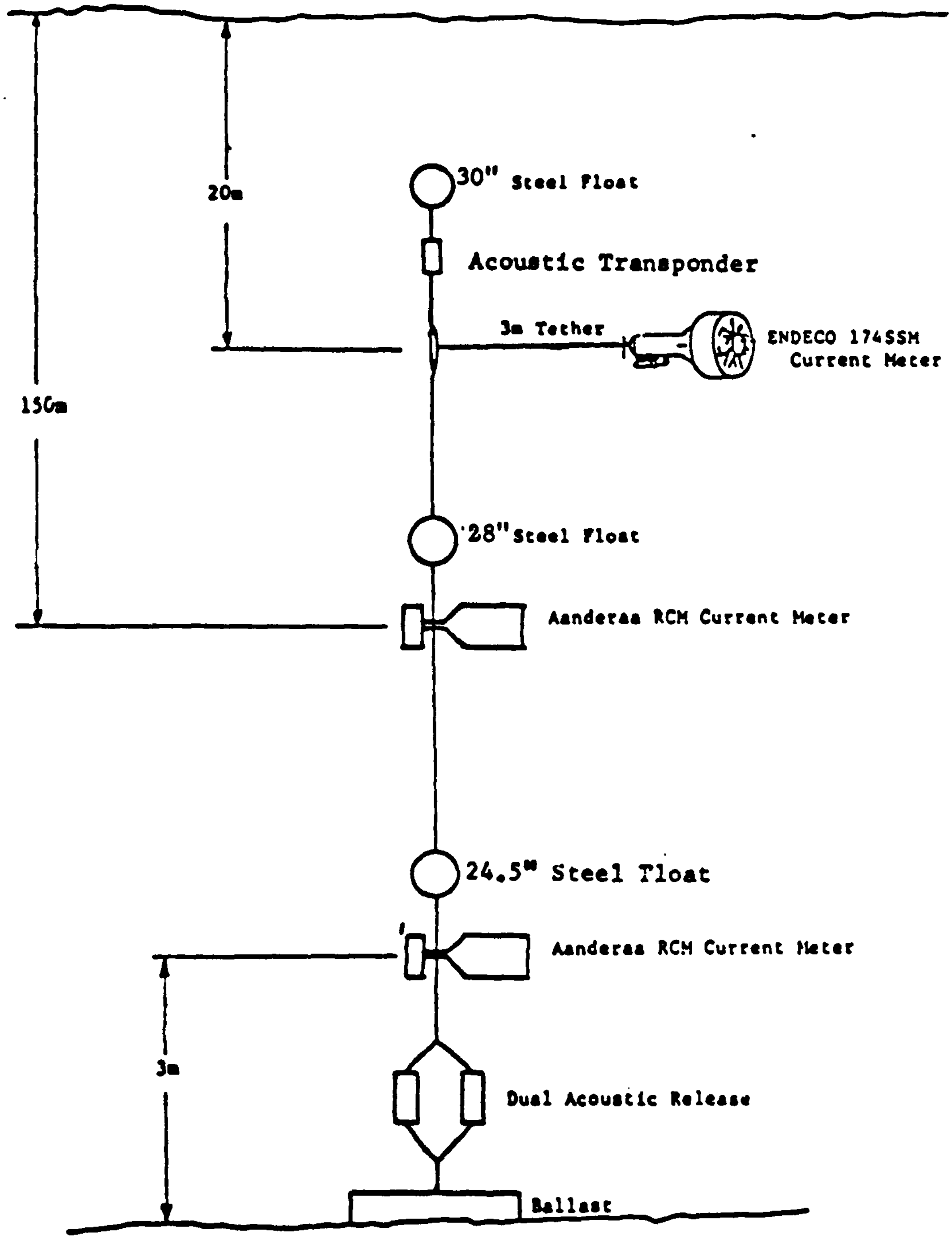

Figure 10-3. Schematic diagram of the mooring configuration at Site C.

state memory. Tables 10-3 through 10-6 give the specifications for each of the four types of instruments.

The moorings at Sites A and B are protected by surface witness buoys that are independent of the subsurface instrument moorings but located less than 10 m away. Each witness buoy is a 2 m diameter, steel-dish type of buoy that has a superstructure with a daymark, radar reflector, and marine lantern. It is anchored by a high-tension elastic mooring that has virtually no watch circle (less than 5 percent of depth). The witness buoy is registered with the U.S. Coast Guard and is an authorized Private-Aid-to-Navigation.

10.2.3 Deployment Period and Data Return

The current meter moorings and witness buoys were deployed in December 1987. Two cruises were required because of weather. Site A was installed 21 December 1987 and Sites B and C were installed 30 December 1987. The instruments at Sites A and B were serviced during 16-17 March 1988. All three sites were serviced again in August 1988.

During the first deployment period two instruments partially malfunctioned. The top current meter at Site A did not record any conductivity data because of a broken wire in a connector. The break was intermittent. During checkout procedures, because of the position of the connector, the break would make contact and appear normal, but would separate when the instrument was closed prior to deployment. The top current meter at Site B stopped recording on 5 March 1987 because of low battery voltage. The cause of this malfunction is unknown. During all subsequent tests the instrument has operated properly. Table 10-7 summarizes the data return for the first deployment period. Overall data return for Sites A and B during the first deployment period exceeds 93 percent.

Table 10-3. Specifications of the ENDECO type 174 SSM current meter.

CURRENT SPEED
SENSOR TYPE: Ducted Impeller
SENSITIVITY: 111.9 rpm/m/sec. (57.58 rpm/knot)
SPEED RANGE: 0 to 2.57 m/sec. (0 to 5 knots)
Programmable to 10 knots
IMPELLER THRESHOLD: 1.54 cm/sec (0.03 knots)
ACCURACY: 1.6% of full scale (99% confidence limit)
RESOLUTION: 0.1% of Speed Range

CURRENT DIRECTION
SENSOR TYPE: Gimballed, 2 axis, flux gate compass
MAGNETIC DIRECTION: 0 to 360°
GIMBALLED RANGE: ±30° (2 axis)
ACCURACY: ±5.0° above speed threshold
RESOLUTION: 1.4°
INTERNAL HEADING CORRECTION: 32 Point EPROM Stored Correction Curve
VECTOR AVERAGING: Fixed Displacement, Sine/Cosine Summation

TEMPERATURE
SENSOR TYPE: Thermilinear Thermistor
RANGE: −5° to +45°C (23°F to 113°F)
ACCURACY: ±0.2°C (±0.36°F)
RESOLUTION: 9 Bits Binary, 0.098°C (0.176°F)
OPTIONAL RESOLUTION: Up to 12 Bits Binary (0.012°C)
TIME CONSTANT: 3.4 seconds

CONDUCTIVITY
SENSOR TYPE: Inductive Probe
RANGE: 5 to 55 millisiemens/cm
ACCURACY: ±0.55 millisiemens/cm when referenced to calibration
RESOLUTION: 9 Bits Binary, 0.098 millisiemens/cm
OPTIONAL RESOLUTION: Up to 12 Bits Binary, (0.012 millisiemens/cm)
OPTIONAL RANGE: 30 to 80 millisiemens/cm

OPTIONAL PARAMETERS
PRESSURE (Depth)
SENSOR TYPE: Potentiometric Transducer
RANGE: 0 to 152 meters (500 feet)
ACCURACY: ±1%
RESOLUTION: 0.39%
OPTIONAL RESOLUTION: Up to 12 Bits Binary (0.02%)
SPARE
Many sensors available.
Contact ENDECO, INC. for details.

PROGRAMMABLE PARAMETERS AND INTERNAL FUNCTIONS
- Real-Time Clock
- Sample/Average Interval
- Mode (Active Parameters)
- Real-Time Output (for profiling applications)
- Self Diagnostics (memory test)
- Individual Parameter Test Function
- Self-aligning compass

SAMPLE INTERVAL
Current Speed and Current Direction are sampled once per second. All other parameters are sampled at the end of desired averaging interval.

AVERAGING INTERVAL
PROGRAMMABLE INTERVALS: 1, 10, 20, 30, 40 seconds,
1, 2, 3, 5, 10, 15, 20, 30, 40 minutes
1, and 2 hours
DEFAULT VALUE: Internally Selectable

MEMORY CHARACTERISTICS
TYPE: CMOS RAM, Battery back-up (1 year life)
CAPACITY: 1.05 Mega Bit, 29,166 Samples of 4 Parameters
OFFLOAD: RS-232 format at 19,200 Baud (sail interface available)
I/O: MS DOS and CP/M compatible

DEPLOYABLE LIFE
Average Interval x 29,166, 8.1 hours to 1 year

INSTRUMENT IDENTIFICATION
Instrument serial number permanently stored in EPROM

POWER
Eight "D" size batteries

OPERATING ENVIRONMENT
OPERATING MEDIUM: Salt, Fresh or Polluted Water
OPERATING TEMPERATURE RANGE: −5°C to +45°C (23°F to 113°F)
STORAGE TEMPERATURE RANGE: −34°C to +65°C (−29°F to 149°F)
MAXIMUM DEPTH: 152 meters (500 feet)

INSTRUMENT HOUSING
TYPE: Neutrally Buoyant, Tethered, Self-Aligning
MATERIAL: PVC and Abs Plastics, Urethane and Glass Reinforced Epoxy
FINISH: All surfaces painted for resistance to marine growth
HARDWARE: 300 Series Stainless Steel and Nylon

PHYSICAL SIZE
WEIGHT: 14 kg (31 pounds) in air
BUOYANCY: Neutrally Buoyant, adjustable for fluid medium
DIMENSIONS: 88.9 cm (35.0 inches) long X 40.6 cm (16 inches) in diameter
SHIPPING WEIGHT: 25.7 kg (57 pounds)
SHIPPING CONTAINER: Barrel 102 cm (40 inches) long X 56 cm (22 inches) in diameter

Table 10-4. Specifications of the ENDECO type 174 digital current meter.*

1. Current Velocity

Sensor Type:	Ducted Impeller
Range:**	0 to 257.2 cm/sec (0 to 5.0 knots) at 2-min interval
	0 to 171.5 cm/sec (0 to 3.33 knots) at 3-min interval
	0 to 102.9 cm/sec (0 to 2.0 knots) at 5-min interval
	0 to 51.4 cm/sec (0 to 1.0 knots) at 10-min interval
Threshold:	Less than 2.57 cm/sec (0.05 knots)
Resolution:	0.4% of speed range
Accuracy:`	± 3.0% of full scale

2. Current Direction

Sensor:	Digicourse Model 218
Range:	0 to 360°
Resolution:	1.4°
Accuracy:	± 7.2° above 2.57 cm/sec (0.05 knots)

3. Temperature

Sensor:	Thermolinear thermistor
Range:	-5°C to +45°C
Resolution:	0.098°C
Accuracy:	± 0.2°C

4. Conductivity

Sensor:	Electrodeless probe (inductive)
Range:	5 TO 55 millimhos/cm
Resolution:	0.098 millimhos/cm
Accuracy:	± 0.55 millimhos/cm

*TAMU's meters are modified slightly to permit deployments in excess of three months.
**Note: TAMU software can handle speeds which exeed the given ranges so that there is not data loss when over-range speeds occur.

Table 10-5. Specifications of the Sea Data Model TDR Micrologger

PRESSURE	
Sensor:	Sensometrics Strain Gauge
Conversion:	12 bits
Range:	60 m
Accuracy:	0.2%
Resolution:	1 part in 4096 or 0.02%
TEMPERATURE	
Sensor:	YSI 44032 Precision Thermistor
Conversion:	12 bits
Range:	-5° to 35°C
Accuracy:	± 0.1°C
Resolution:	1 part in 4096 or 0.02%

Table 10-6. The specifications of the Aanderaa Recording Vector Averaging Current Meter, RCM 7.

Measuring system:
Self balancing bridge with sequential measuring of 6 channels and solid state memory. 10-bit binary word for each channel. The channels are:

1. Reference:
A fixed reading to check RCM's performance and identify individual instruments.

2. Temperature:
Standard is Low Range (-2.46 to 21.4°C). Also available are: Wide Range (-0.34 to 32.17°C); High Range (to 36°C) and Arctic Range (-2.64 to 5.62°C in channel 4). Sensor type is Thermistor (Fenwall GB32JM19) and accuracy is ±0.05°C. Resolution is 0.1% of range selected and response time is 12 seconds (63%).

3. Conductivity: (optional)

Sensor Type:	Inductive Cell 2994
Ranges:	0-74 mmho/cm (standard)
	24-68 mmho/cm (on request)
	24-36 mmho/cm (on request)
Resolution:	0.1% of range
Calibration Accuracy:	±0.025 mmho/cm

4. Pressure: (optional)

Sensor Type:	Bourdon tube driving potentiometer
Ranges:	100, 200, 500, 1000, 3000 and 9000 PSI
	0-3000 PSI is standard
	0-9000 PSI is only available for RCM 8
Accuracy:	±1% of range
Resolution:	0.1% of range

5. and 6. Current speed and direction:
Vector Averaging: No. of rotor revolutions and direction is sampled every 12 seconds and broken up into North and East Components. Successive components are added and recorded as speed and direction. For longer recording intervals than 10 minutes, speed and direction is sampled 1/50 of recording interval.

Direction:

Sensor Type:	Magnectic compass with needle campled onto potentiometer ring.
Resolution:	0.35°
Accuracy:	±5° for speeds from 5 to 100 cm/sec
	±7.5° for current speeds 2.5 to 5 and 100 to 200 cm/sec

Speed:

Sensor Type:	Rotor with magnetic coupling
Range:	2 to 250 cm/sec
Accuracy:	±1 cm/sec or ±2% of actual speed whichever is greater
Starting Velocity:	2 cm/sec

Clock:

Type:	Quartz Crystal
Accuracy:	Better than ±2 sec/day within 0 to 20°C
Recording Intervals:	0.5, 1, 2, 5, 10, 20, 30, 60 or 120 min.
External Triggering:	A 6V pulse to terminal activates instrument.

Recording system:

Type:	Data Storing Unit 2990
Coding:	PDC-4
Storage Capacity:	Maximum 10,900 records of all channels (i.e. 75 days with 10 min. interval).

Telemetry:

Acoustically:	Acoustic carrier keyed on and off
Frequency:	16.384KHz ±5Hz
Detection Range:	Up to 2000m with unit 3079

Power:

Battery	9V, non-magnetic: 63x50x80 mm
Capacity:	4Ah (sufficient for 10,900 records)

External Materials

Pressure Case:	Cu Ni Si alloy (OSNISIL) and stainless acid proof steel. Epoxy coated
Other meal Parts	Nickel plated bronze and stainless acid proof steal, Epoxy coated

Mooring:
Spindle for 15 mm max, diameter rope. Gimbal mounting permits 27° deviation between spindle and instrument
Spindle: breaking load 4.000 kg.

	RCM 7		RCM 8	
Depth Capability:	2000m		6000m	
Net Weight (kg) in:	air	water	air	water
Recording Unit:	13.6	8.8	15.2	10.9
Vans Assembly:	12.2	9.5	14.1	11.8
Dimensions (mm):				
Recording Unit:	495 x 128		520 x 128	
Vans Assembly:	485 x 500			
Overall Size:	540 height x 865 length			
Gross Weight (kg):				
Recording Unit:	18.5		20.5	
Vans Assembly:	20.0		22.0	

Packing:

	Plywood cases
Recording Unit:	190 x 250 x 600mm
Vans Assembly:	140 x 520 x 770mm

Spares:
A set of recommended spares is delivered free of charge with each instrument (rotor, bearings, O-rings, etc.)

Table 10-7. Summary of the data return for the instruments at Sites A and B during the first deployment period, December 1987-March 1988.

Site	Instrument Depth	Instrument Period	Deployment	Parameter Period	Record	% Return
A	10.1	174SSM	21Dec87-16Mar88	Spd	21Dec87-16Mar88	100
				Dir	21Dec87-16Mar88	100
				Temp	21Dec87-16Mar88	100
				Cond	no data	0
A	25.3	174DMT	21Dec87-16Mar88	Spd	21Dec87-16Mar88	100
				Dir	21Dec87-16Mar88	100
				Temp	21Dec87-16Mar88	100
				Cond	21Dec87-16Mar88	100
A	27.4	TDR Micrologger	21Dec87-16Mar88	Pres	21Dec87-16Mar88	100
				Temp	21Dec87-16Mar88	100
B	10.1	174SSM	30Dec87-16Mar88	Spd	30Dec87-4Mar88	84
				Dir	30Dec87-4Mar88	84
				Temp	30Dec87-4Mar88	84
				Cond	30Dec87-4Mar88	84
B	55.5	174DMT	30Dec87-16Mar88	Spd	30Dec87-16Mar88	100
				Dir	30Dec87-16Mar88	100
				Temp	30Dec87-16Mar88	100
				Cond	30Dec87-16Mar88	100
B	56.7	TDR Micrologger	30Dec87-16Mar88	Pres	30Dec87-16Mar88	100
				Temp	30Dec87-16Mar88	100

10.2.4 Quality Control

The various quality control procedures for the time-series data will be described in detail in the next report in conjunction with the presentation and analyses of the time series data. TAMU developed quality control and assurance procedures for the instruments used in this study during its long term studies for the Department of Energy's Strategic Petroleum Reserve Brine Disposal Operations. The Field and Laboratory Procedures Manual (Kelly *et al.* 1983) for that project also describes the quality control for time-series data. For moored instruments, the chain-of-custody is relatively simple because uniquely identifying information is recorded automatically along with the data onto magnetic tape or into solid state memory. Logs are kept for each instrument. In addition to standard servicing procedures, the calibration of each instrument is checked every time it is returned to the laboratory.

10.3 Hydrographic Sampling

10.3.1 Station Locations

During the major interdisciplinary cruises, March 1987, October 1987, and March 1988, both CTD/Transmissivity profiles and discrete bottle samples were obtained at each of the 12 primary stations (Figure 10-1). Dissolved oxygen and nutrient values were determined from the bottle samples. Some CTD/Transmissivity profiles, without bottle samples, were also obtained at supplemental stations of opportunity during the October 1987 and March 1988 cruises (indicated by crosses in the maps in the next section). Profiles, by CTD only, were obtained at each of the current meter sites during deployment or recovery operations. Because of ship drift and small LORAN C variations, the exact location of each station varies a little among cruises. The exact locations are listed together with the data in Appendix C.

10.3.2 Instruments and Methods.

The CTD is a Sea-Bird Electronics, Inc., Model SEACAT SBE19 Conductivity, Temperature, Depth Recorder. Its specifications are listed in Table 10-8. The SEACAT PROFILER is customized to interface with a Sea Tech, Inc., 25 cm transmissometer. Table 10-9 lists the transmissometer's specifications. The CTD/Transmissometer system is coupled to a General Oceanics Rosette Sampler with six 1.7 liter Niskin bottles. The CTD records data internally into solid state memory, and, at the same time, can also transmit the data via cable to an IBM PC compatible computer.

Continuous CTD profiles are made during the downcast. It is lowered at a rate of about 0.5 to 1.0 m/sec. The SEACAT samples twice per second. Bottle samples are obtained by the Rosette Sampler during the upcast. The instrument package is stopped at each depth selected for a bottle sample. If a bottle also has reversing thermometers attached, several minutes are allowed for equilibration.

After the instrument package is brought aboard dissolved oxygen samples are drawn and chemically fixed in 150 ml Erlenmeyer flasks for laboratory analysis. Nutrient samples are drawn into plastic Whirl-Pak bags and frozen. Salinity samples are drawn and thermometers are read for use in checking the calibration of the CTD.

10.3.3 Quality Control

The accuracy of the CTD is checked by linear regression with data obtained from bottle samples and paired reversing thermometers. Salinity values from bottle samples are determined using a Grundy Laboratory Salinometer with Standard Seawater as a reference. Values of temperature and salinity are obtained from the upcast portion of the CTD record by averaging over a 15 second period about the time the bottle was tripped. Outlier points are discarded in selecting pairs for linear regression. For salinity, an outlier is defined as a pair for which the CTD value differed from the bottle value by more than 0.400. Strong vertical gradients and the roll and heave of the ship are the probable causes of the outliers.

Table 10-8. Specifications of Sea-Bird Electronics, Inc., SEACAT SBE19 Conductivity, Temperature, Depth (CTD) profiling recorder.

Measurement Range:	Temperature	-5 to +35 °C
	Conductivity	0 to 7 S/m (0 to 70 mmho/cm)
	Pressure	50, 100, 150, 200, 300, 500, 1000, 2000, 3000, 5000, or 10,000 psia
Accuracy:	Temperature	0.01 °C/6 months
	Conductivity	0.001 S/m/month
	Pressure	0.5% of full scale range
Resolution:	Temperature	0.001 °C
	Conductivity	0.0001 S/m
	Pressure	0.05% of full scale range
Sensor Calibration:	Temperature	-1 to +31 °C (measurements outside this range may be at slightly reduced accuracy due to extrapolation errors)
	Conductivity	0 to 7 S/m. Physical calibration over the range 1.4 to 6 S/m. Measurements outside this range may be at slightly reduced accuracy due to extrapolation errors.
	Pressure	0 to full scale
Counter time-base	Quartz TCXO, +/- 2 ppm per year aging; +/- 2 ppm vs. temperature (- 5 to + 30 °C).	
Memory	CMOS static RAM, 64K or (optional) 256K byte; battery backed for minimum 2 years data retention.	
Real-time clock	Watch-crystal type 32,768 Hz; battery backed for minimum of 1 year operation irrespective of condition of main battery. Corrected for drift and aging by comparison to SEACAT counter time-base	
Batteries:	6 alkaline 'D'-cells provide 48 hours continuous operation and 2 year data retention reserve	
Materials:	600 Meter Pressure Case, acetal copolymer (plastic) 3400 Meter Pressure Case, 6061-T6 anodized aluminum 6800 Meter Pressure Case, 7075-T6 anodized aluminum	

Table 10-9. Specifications of Sea Tech, Inc., 25 cm transmissometer.

TRANSMISSOMETER SPECIFICATIONS

Water Path Length		25 cm
Beam Diameter		15 mm
Transmitted Beam Collimation		< 5 milliradians
Receiver Acceptance Angle (in water)		< 18 milliradians
Light Source, Wavelength		LED, 660 nm
Transmission:	Range (in water)	0 - 100% (0-5 VDC)
	Accuracy	+/- 0.5%
	Linearity	+/- 0.1%
	Temperature Stability	+/- 0.3% (0-25 °C)
Power Supply:	Voltage	+8 to +15 VDC
	Current	< 10 mA
Dimensions:	Length	78.13 cm
	Diameter (max)	10.16 cm
Weight:	In Air	kgm
	In Water	kgm
Depth Capability:		5000 meters

For temperature, points are discarded if:

1) the equilibration time was less two minutes;
2) difference between values from pairs of reversing thermometers exceeds 0.100°C;
3) the difference between the mean CTD value and the reversing thermometers values exceeds 0.400 °C.

Figure 10-4 shows the results of the linear regression for salinity for the October 1987 cruise. There is no corresponding linear regression for temperature because the equilibration times during the October cruise were too short, i.e., about one minute. Figure 10-5 shows the linear regressions for salinity and temperature for the March 1988 cruise. Salinity is a function of both conductivity and temperature. Therefore, the accuracy of salinity values determined from the CTD data is also a function of these two parameters. Table 10-8 indicates that over a seven month period (the SEACAT was last calibrated 4 September 1987), the combined accuracies of conductivity and temperature should yield a salinity accuracy better than (smaller) about 0.015 $^{o}/oo$. The results of the linear regression analyses confirm that the CTD is operating within manufacturer's specifications.

The Sea Tech transmissometer was calibrated by the manufacturer on 14 July 1983 and on 21 February 1988. Because of the interval between factory calibration and the October 1987 cruise, the quality of the transmissometry data for that cruise is unknown; the data will be compared with transmissometry data from subsequent cruises before a final determination is made as to the quality of the October 1987 data. In addition to the manufacturer's calibration, air calibration and blocked light-path calibration values are obtained during each cruise, per the operating instructions for the instrument.

Duplicate samples of dissolved oxygen, nutrients, and salinity are randomly drawn from the Niskin bottles as a check on consistency of the analysis procedures for these parameters.

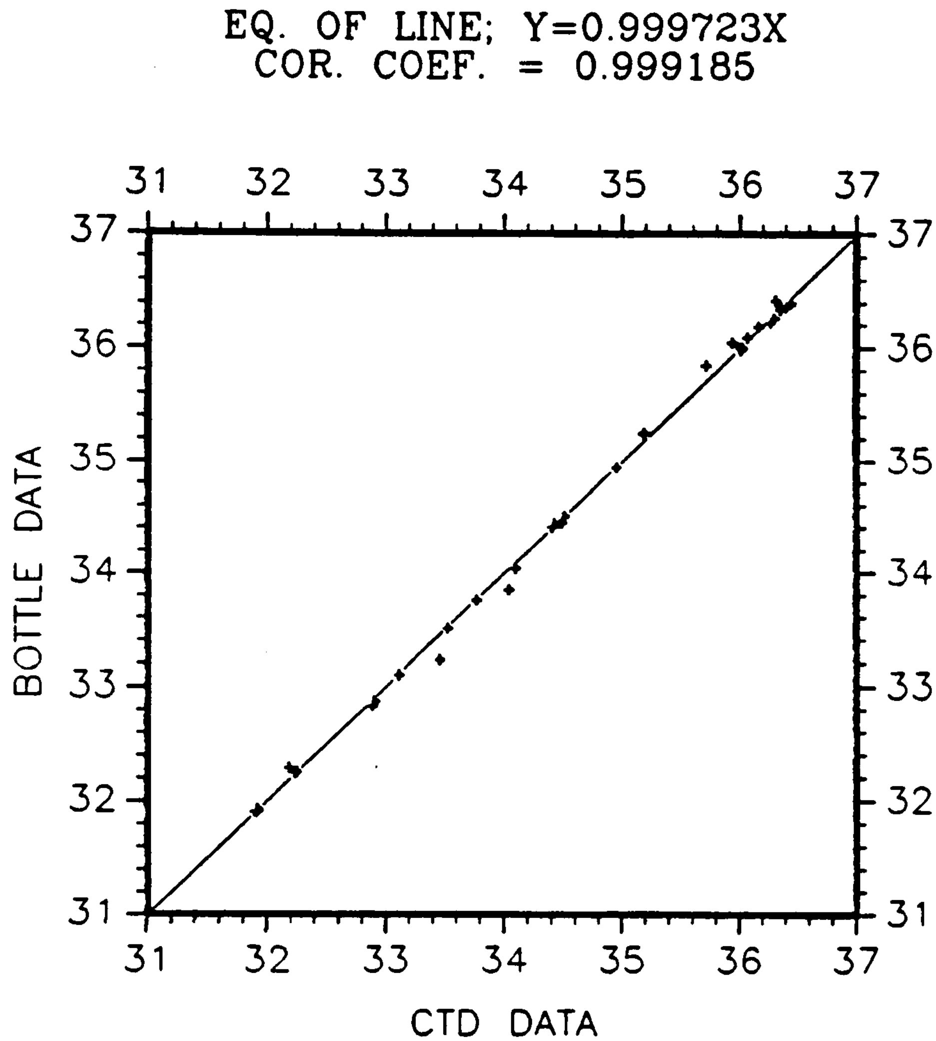

Figure 10-4. **Cruise 1 salinity calibration check. Linear regression between salinity measured by CTD and salinity determined by laboratory salinometer analysis of bottle samples.**

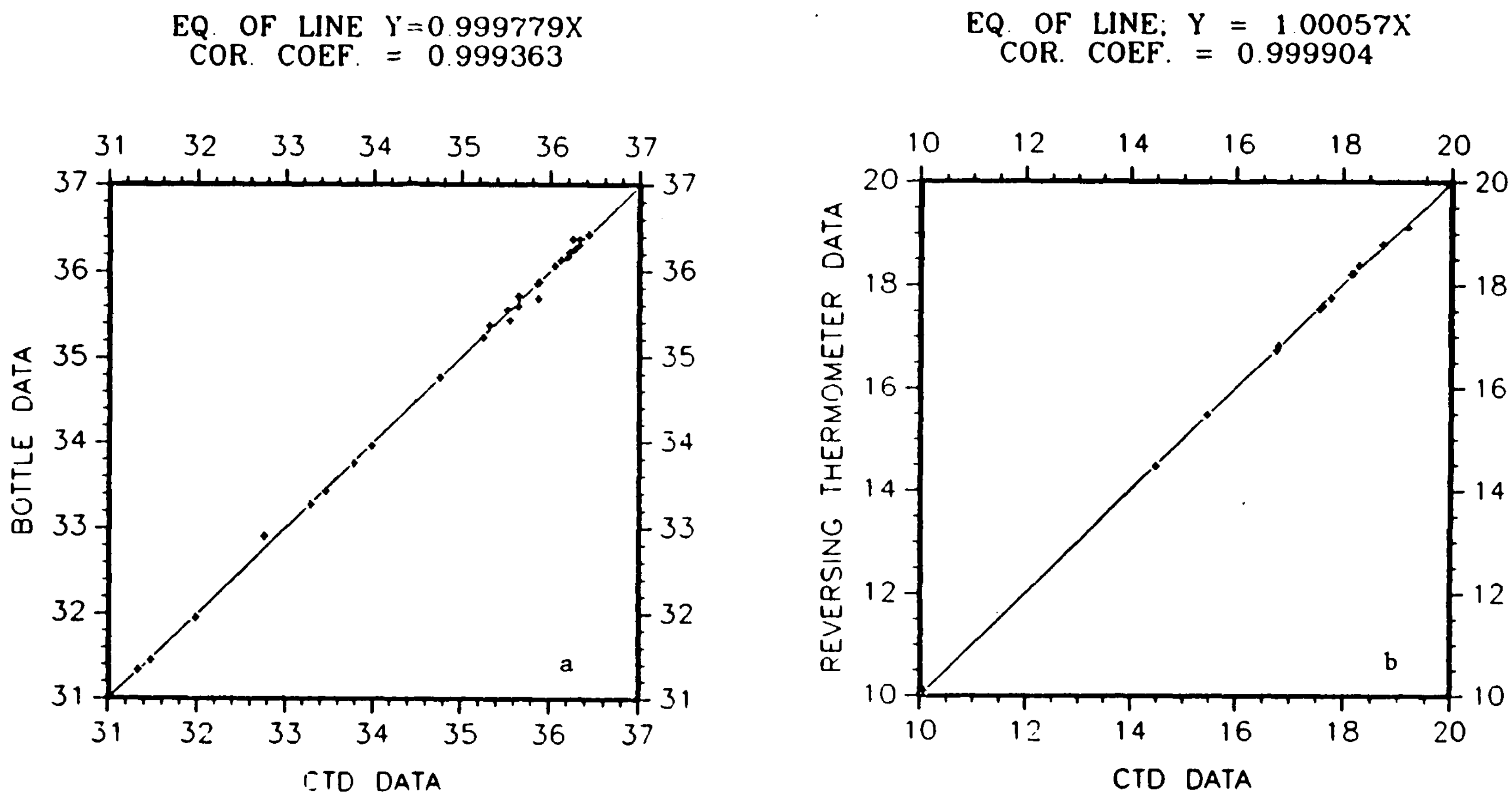

Figure 10-5. Cruise 2 salinity and temperature calibration check. (a) linear regression between salinity measured by CTD and salinity determined by laboratory salinometer analysis of bottle samples. (b) linear regression between temperature measured by CTD and temperature measured by reversing thermometers.

10.4 Basic Analysis

10.4.1 Data Processing Methods

Data processing methods for the time-series data will be described in the next report, by which time the full set of time-series for the first year of deployment will be available for processing and analysis.

The processing of the CTD/Transmissometry data utilizes a computer software package provided by the manufacturer, Sea Bird, Inc. The raw data from each cast are separated into downcast and upcast parts. Only the downcast data are used to construct a vertical profile. Scans (sets of samples of the parameters) are then removed if the pressure value is non-increasing or decreasing. The deleted scans are replaced by values interpolated between good scans. Spiking in the computed salinity record may occur because of the mismatch between the response times of the conductivity and salinity sensors. The severity of spiking depends on the strength of vertical gradients and the descent rate of the sensors. The effects of this phenomena can be considerably ameliorated by numerical filters that correct the mismatch and also by averaging over depth segments. For each CTD record, a variety of filters and averaging intervals are tried in order to maximize the structure and minimize spiking and density instabilities in the record.

10.4.2 Basic Analysis Products

Tabular listings and plots of the CTD/Transmissometry data for each station are in the appendix.

Figures 10-6 through 10-23 present horizontal distributions of temperature, salinity, and dissolved oxygen near the surface (about 2 m below the surface) and near the bottom (1-4 m above the bottom) for each of the three cruises. The temperature and salinity data are from the CTD casts, and the dissolved oxygen data are from bottle samples.

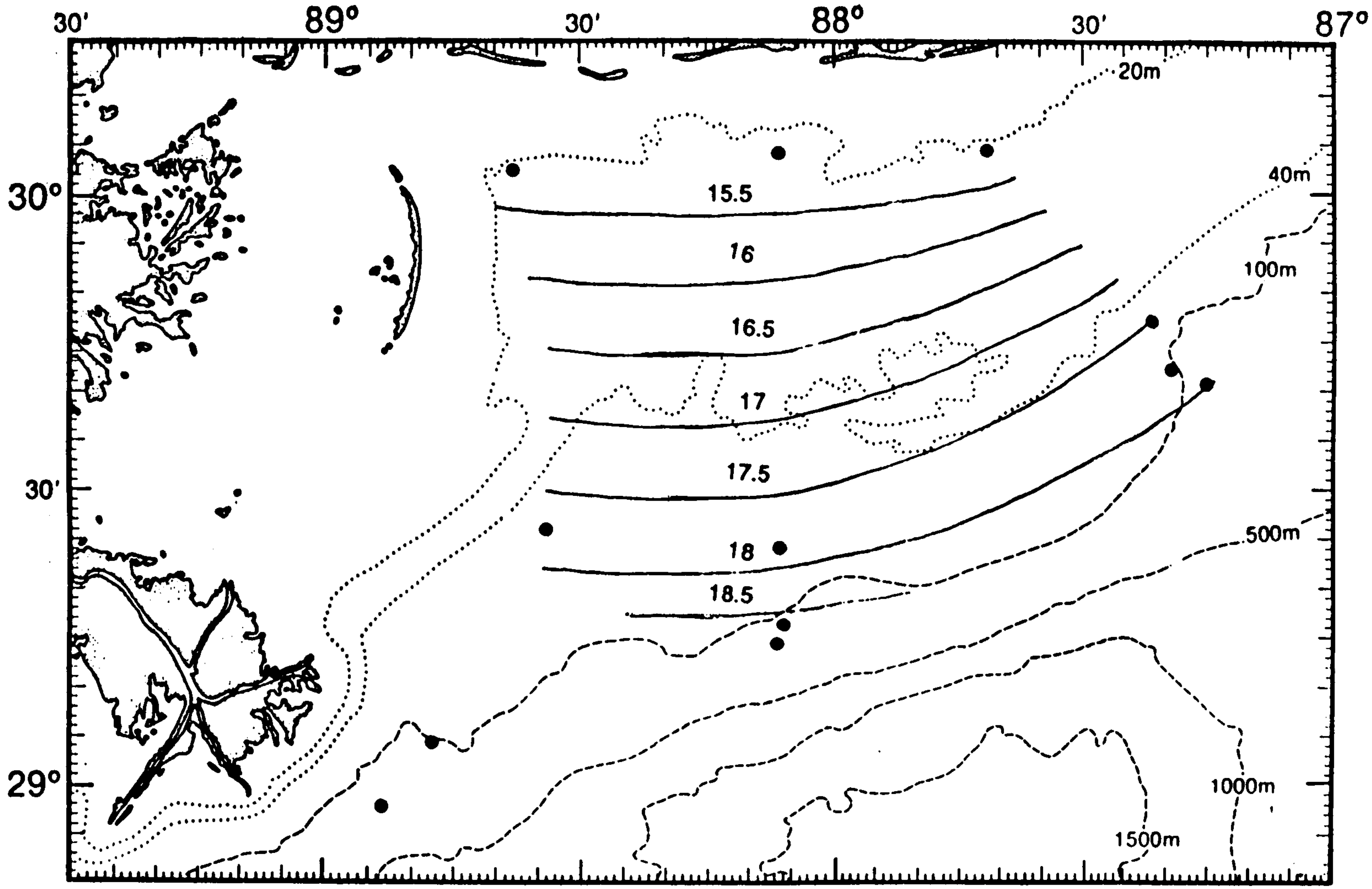

Figure 10-6. March 1987 (Cruise 0) distribution of near-surface temperature (°C).

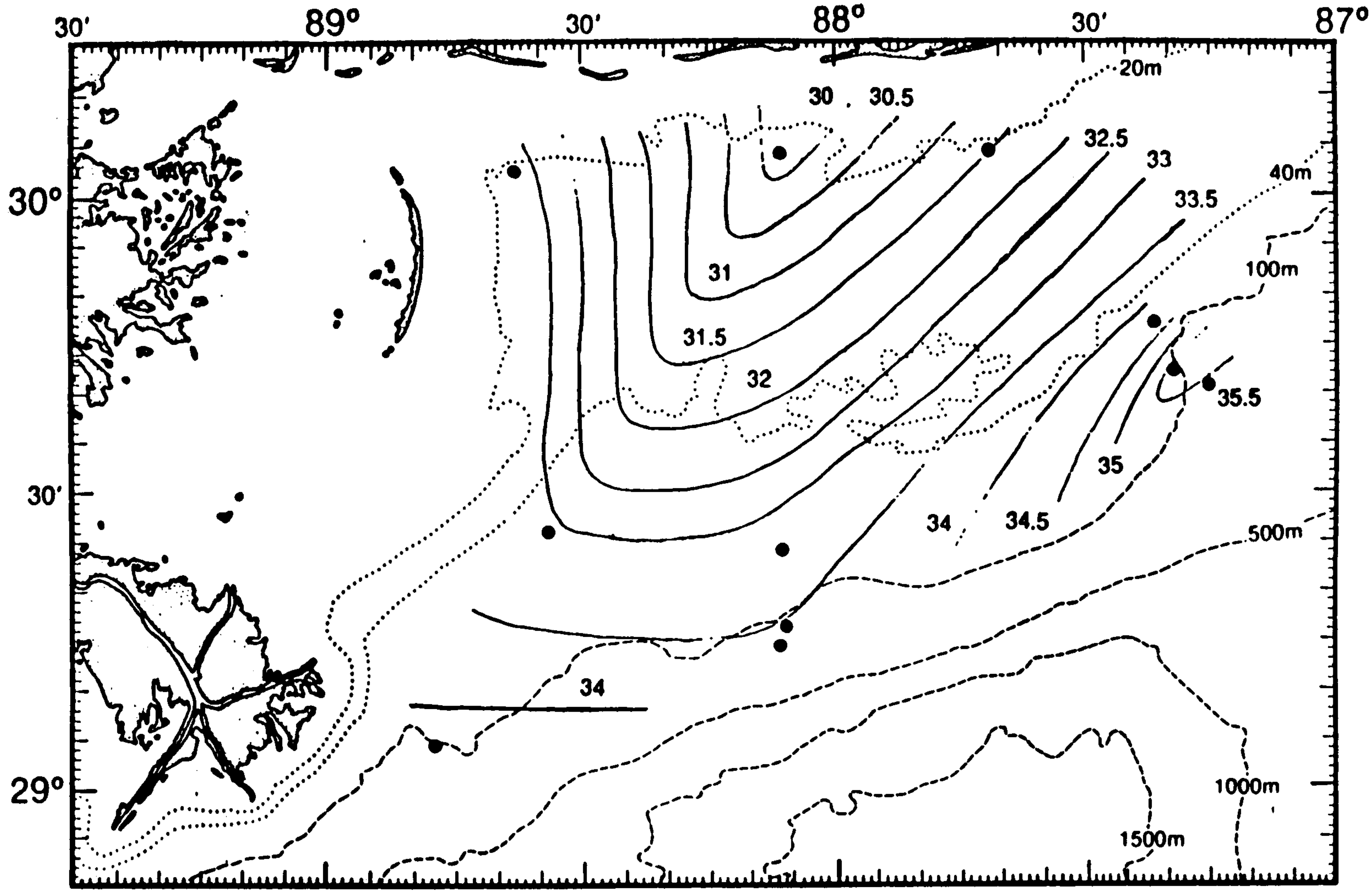

Figure 10-7. March 1987 (Cruise 0) distribution of near-surface salinity (°/oo).

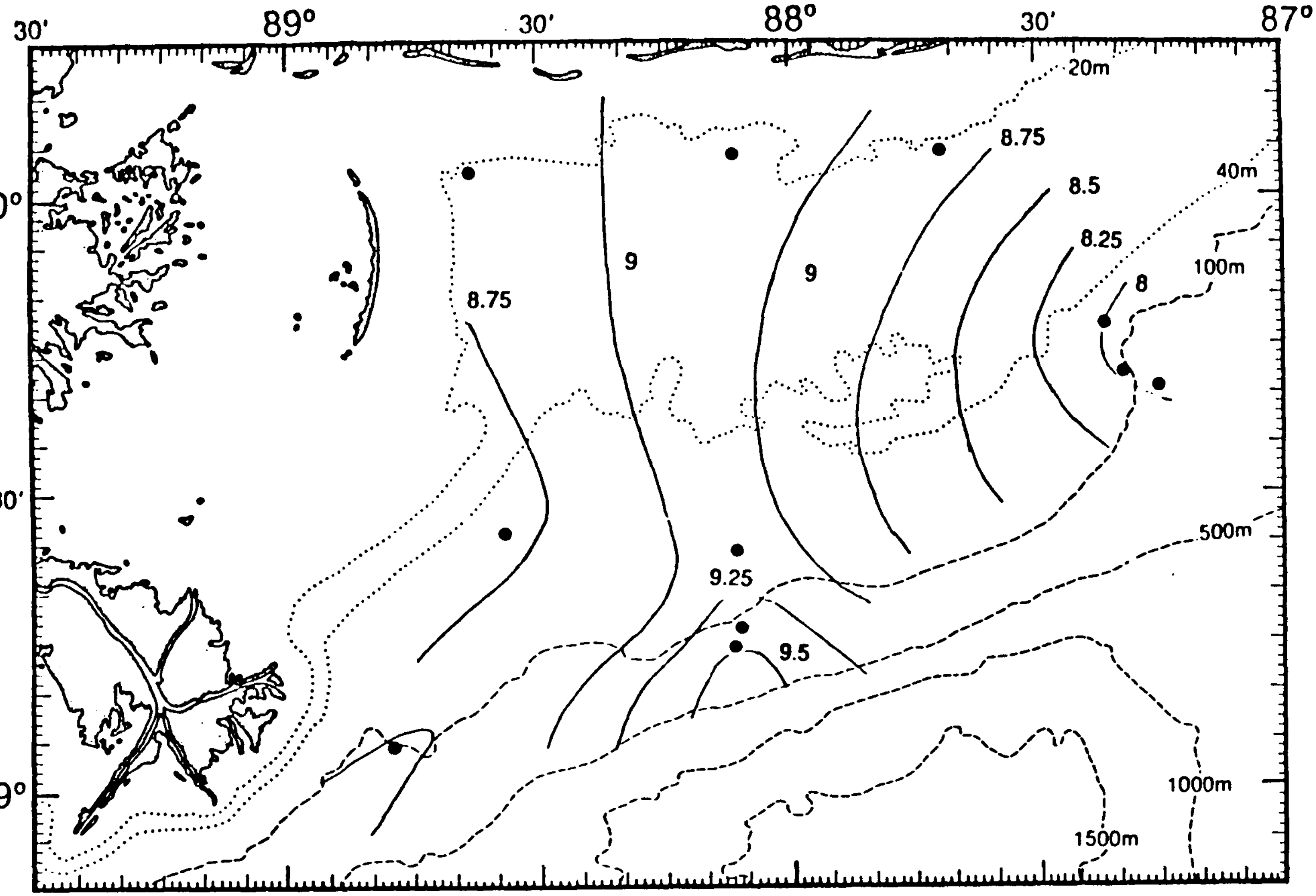

Figure 10-8. March 1987 (Cruise 0) distribution of near-surface dissolved oxygen (mg/l).

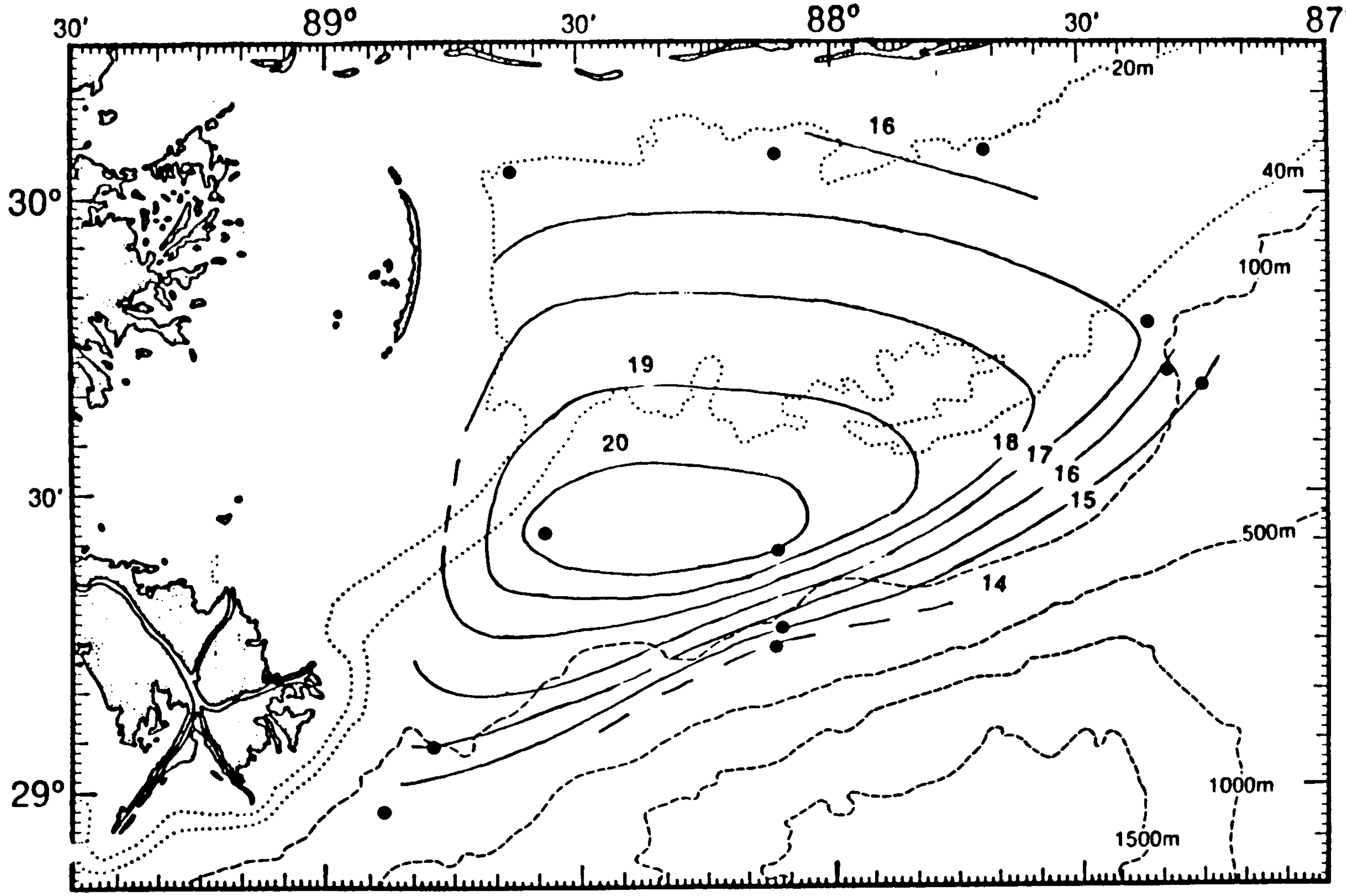

Figure 10-9. March 1987 (Cruise 0) distribution of near-bottom temperature (°C).

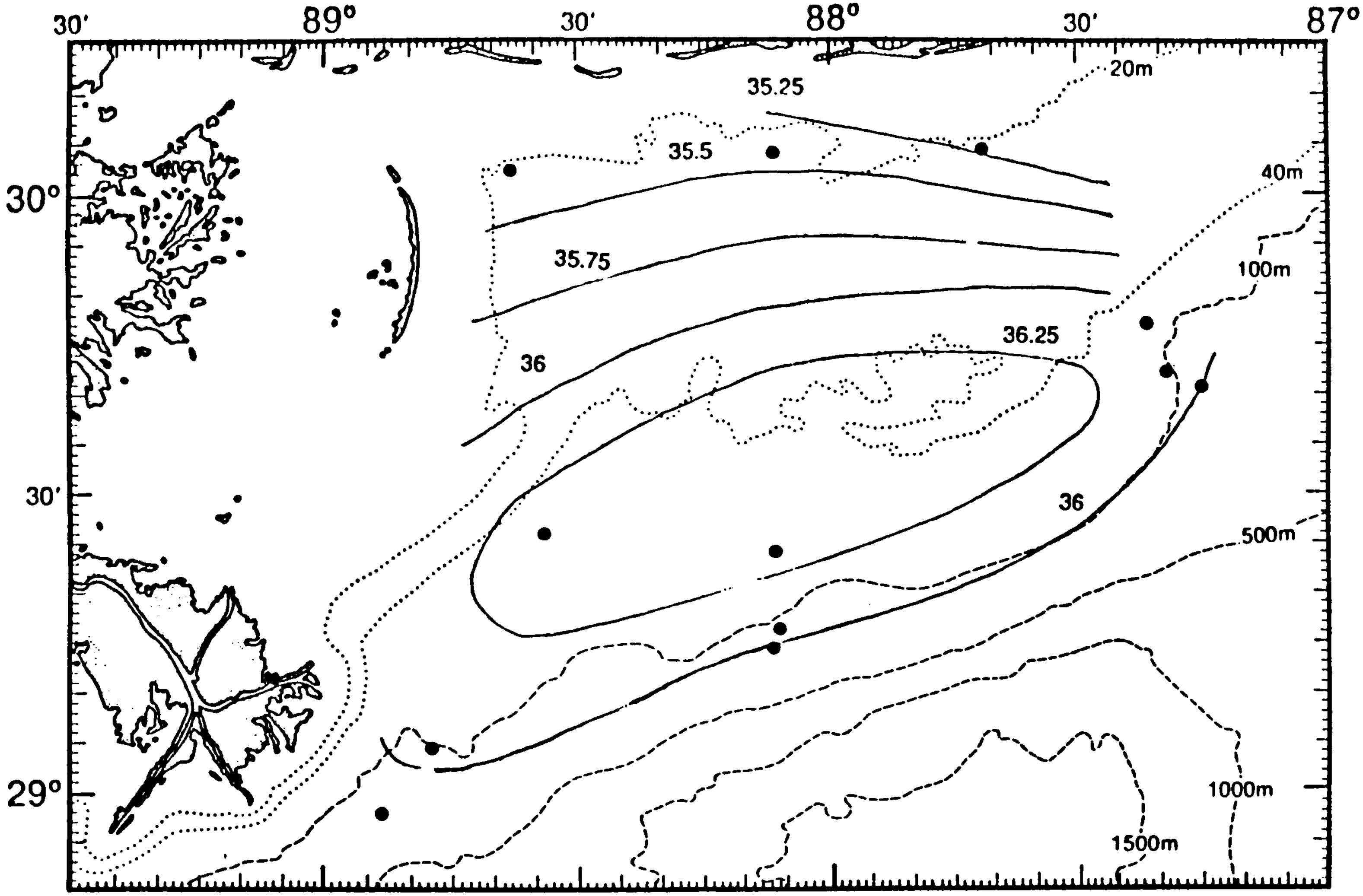

Figure 10-10. March 1987 (Cruise 0) distribution of near-bottom salinity (°/oo).

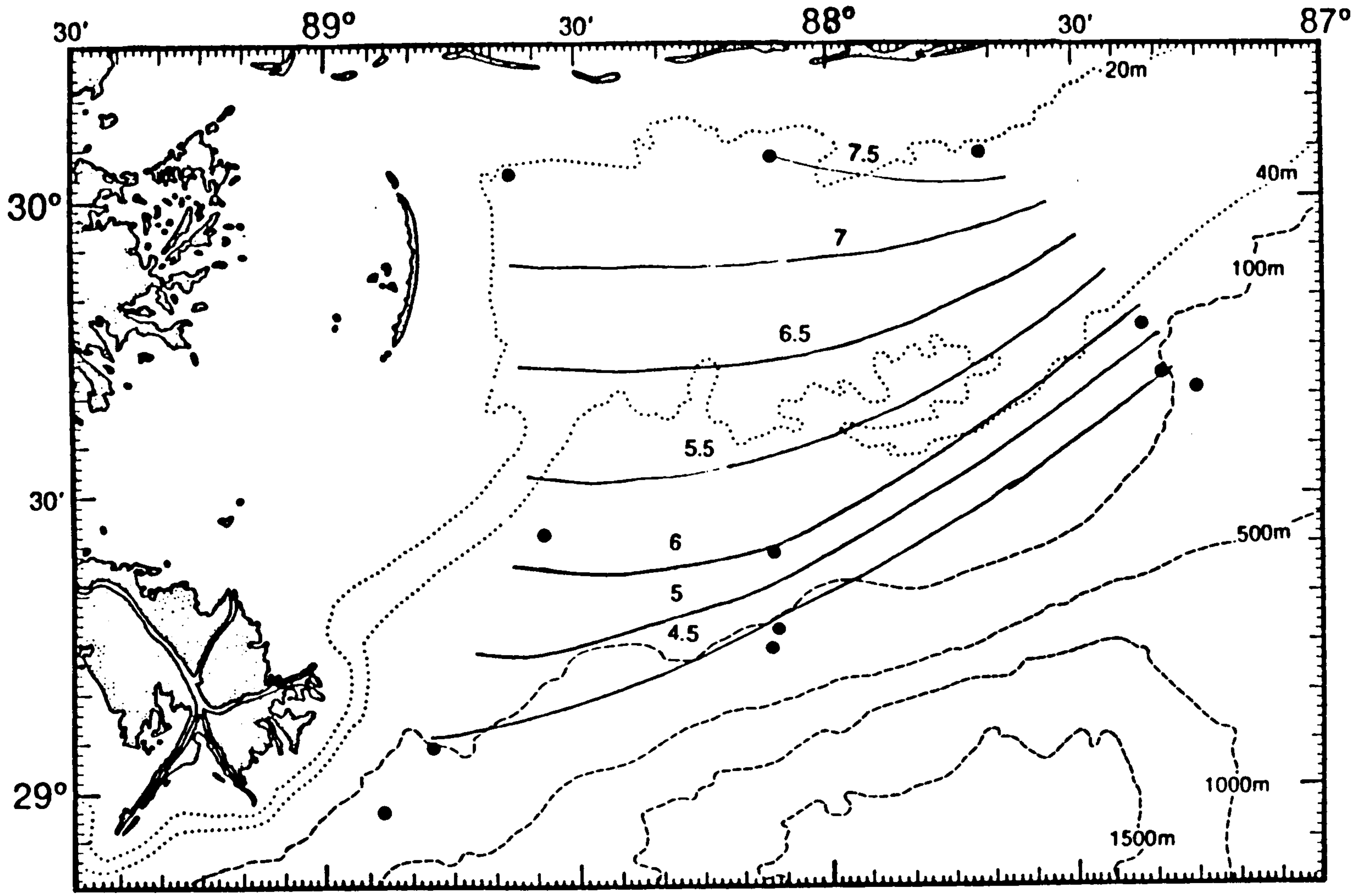

Figure 10-11. March 1987 (Cruise 0) distribution of near-bottom dissolved oxygen (mg/l).

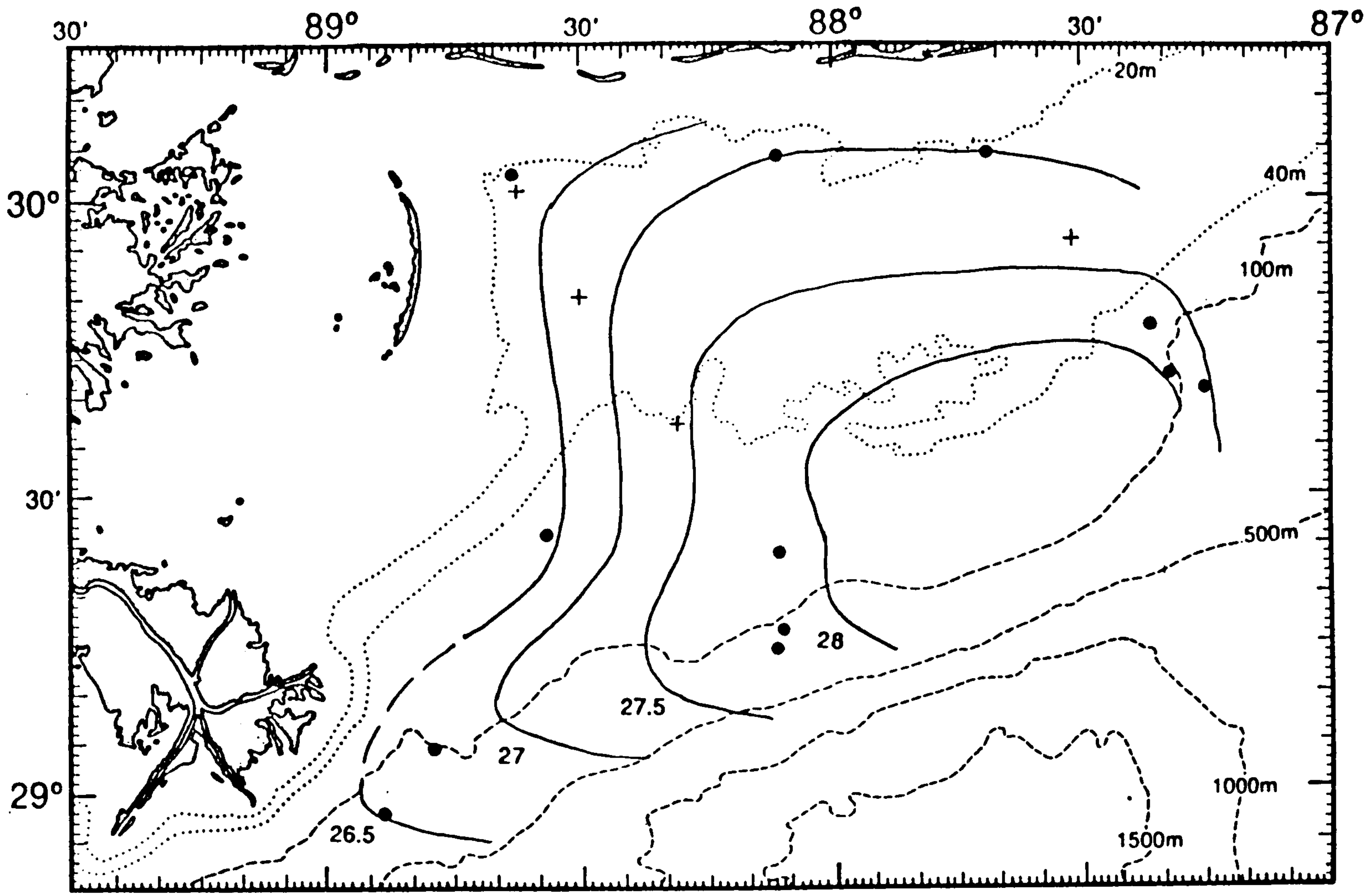

Figure 10-12. October 1987 (Cruise 1) distribution of near-surface temperature (°C). Supplemental stations are indicated by a cross.

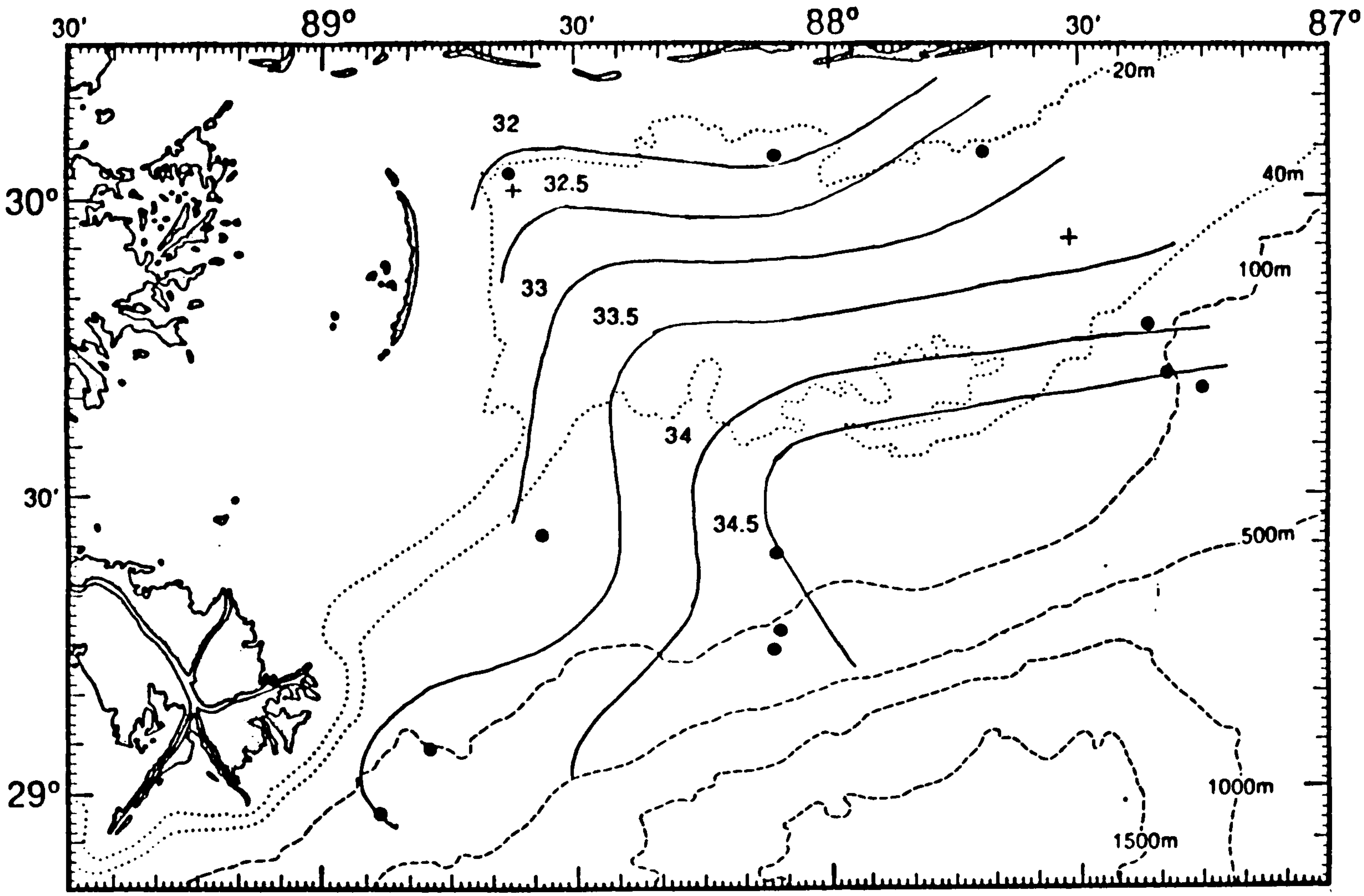

Figure 10-13. October 1987 (Cruise 1) distribution of near-surface salinity ($^{o}/_{oo}$). Supplemental stations are indicated by a cross.

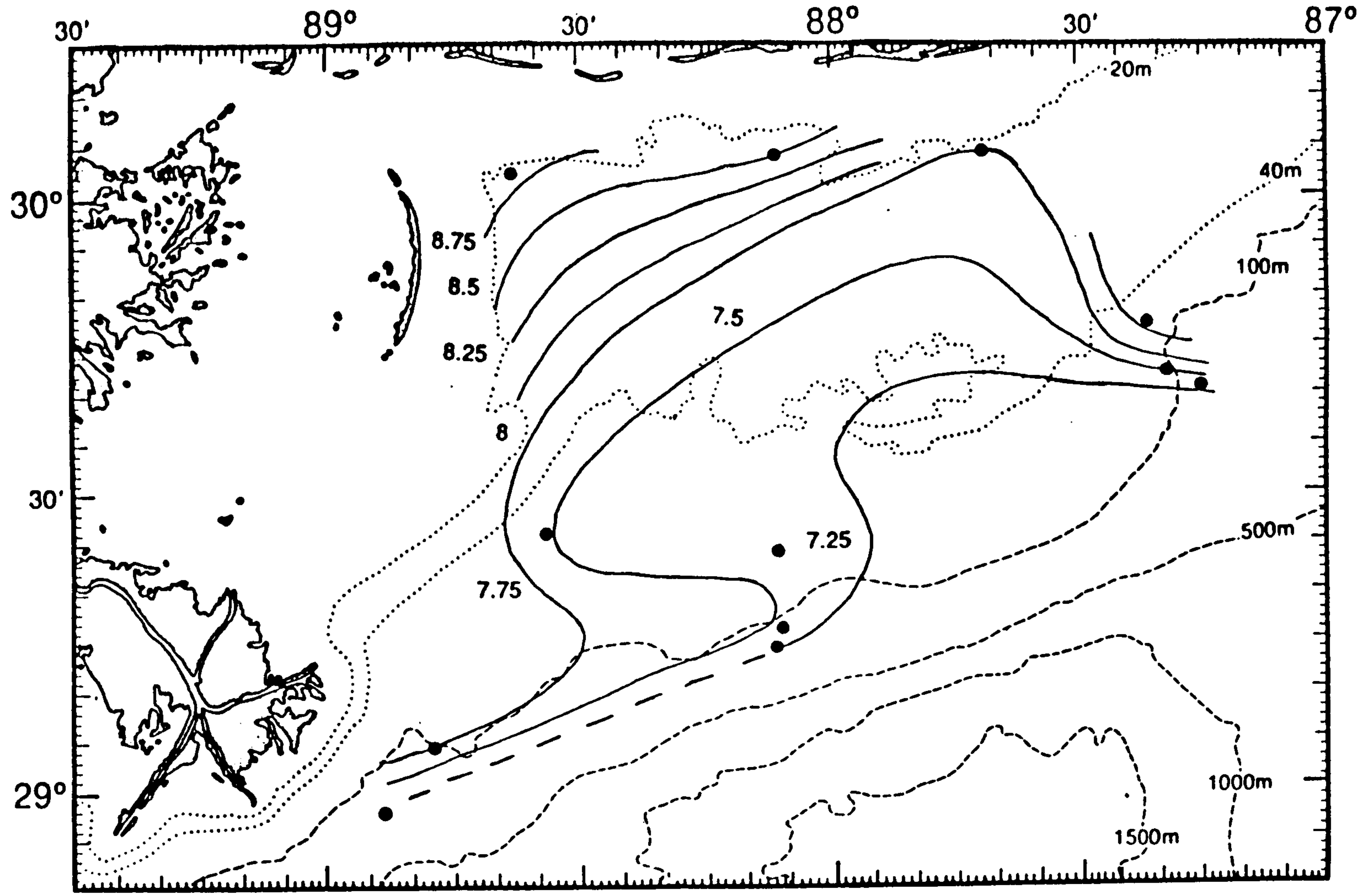

Figure 10-14. October 1987 (Cruise 1) distribution of near-surface dissolved oxygen (mg/l). Supplemental stations are indicated by a cross.

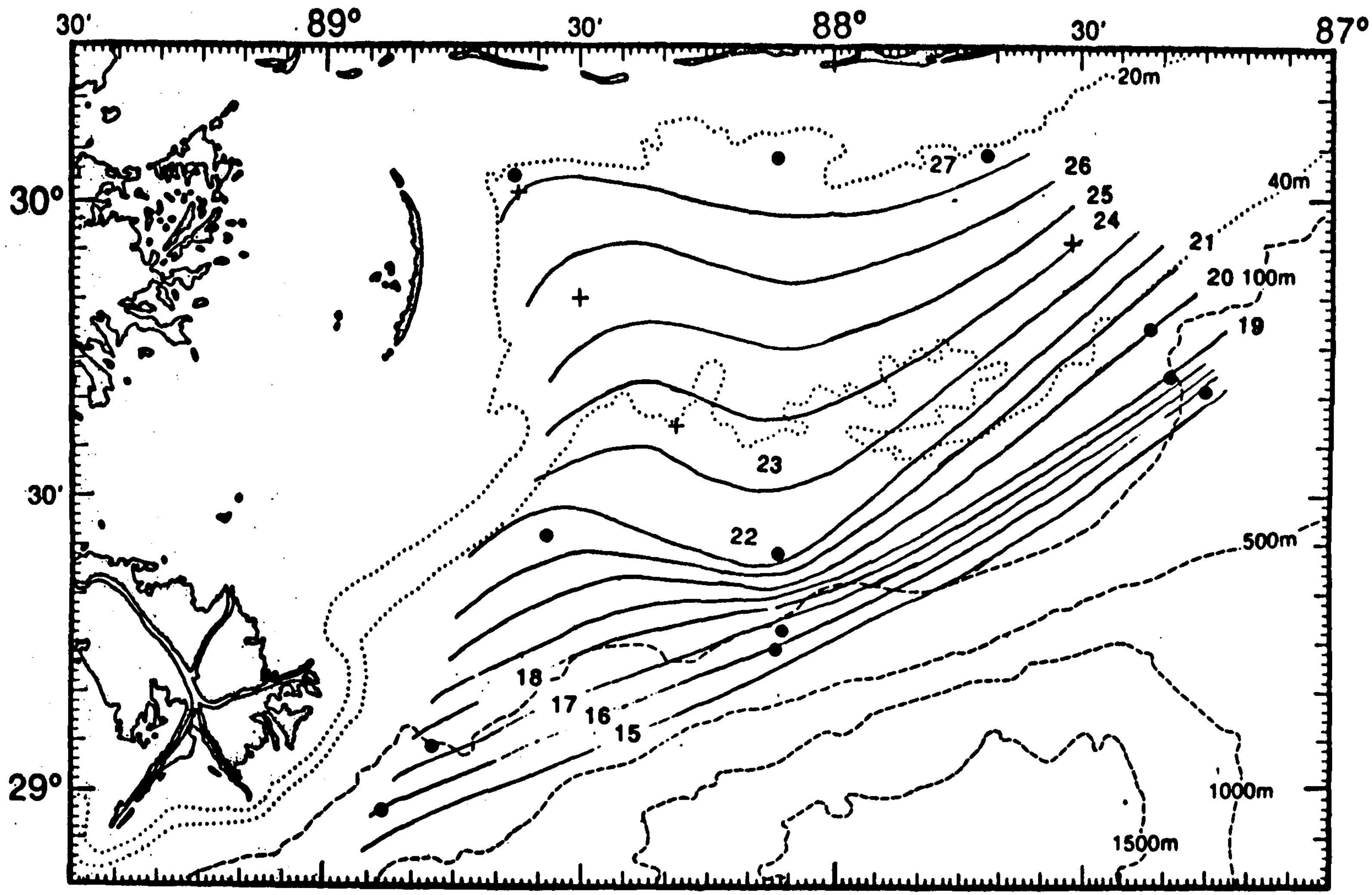

Figure 10-15. October 1987 (Cruise 1) distribution of near-bottom temperature (°C). Supplemental stations are indicated by a cross.

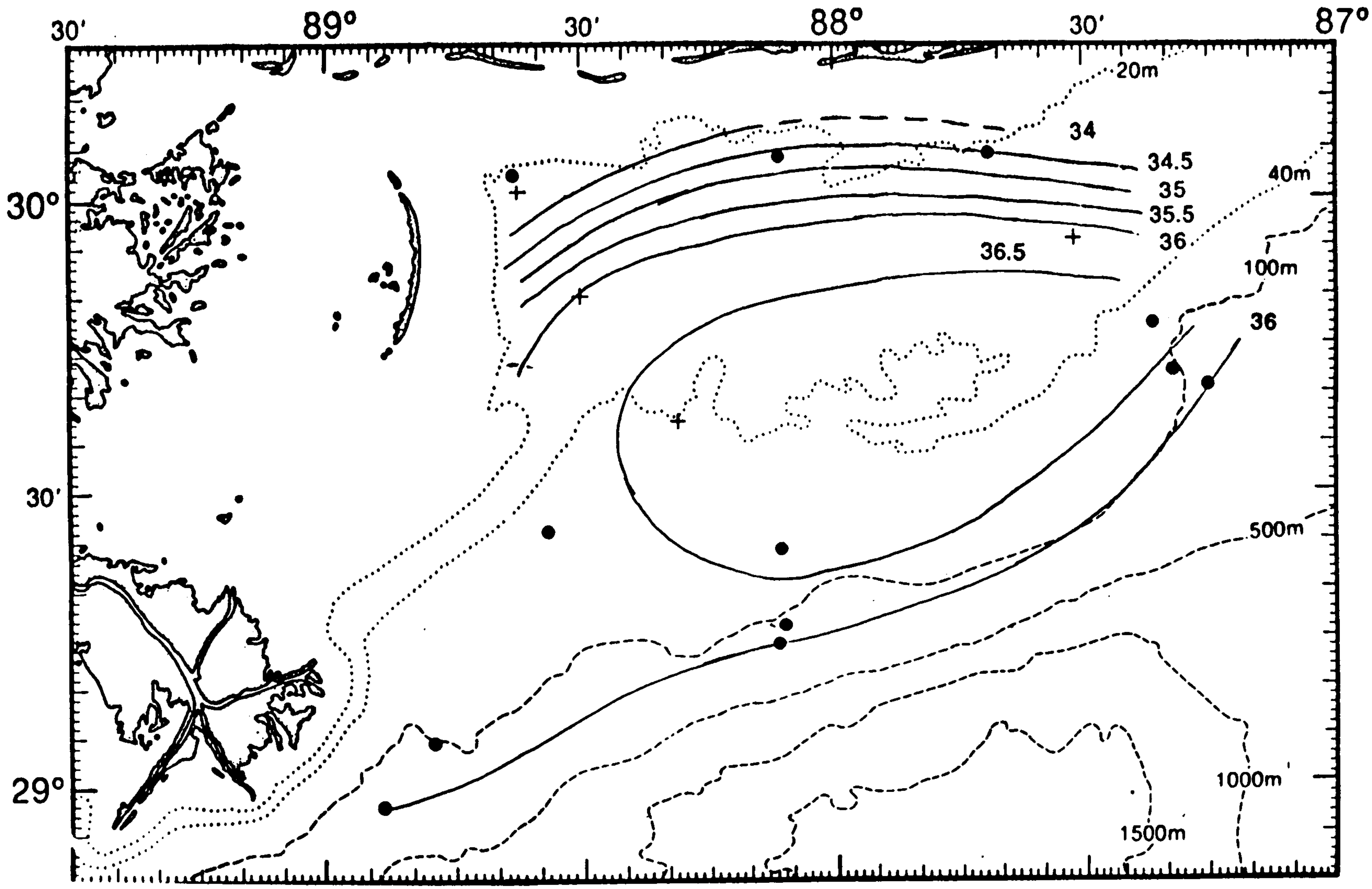

Figure 10-16. October 1987 (Cruise 1) distribution of near-bottom salinity (°/oo). Supplemental stations are indicated by a cross.

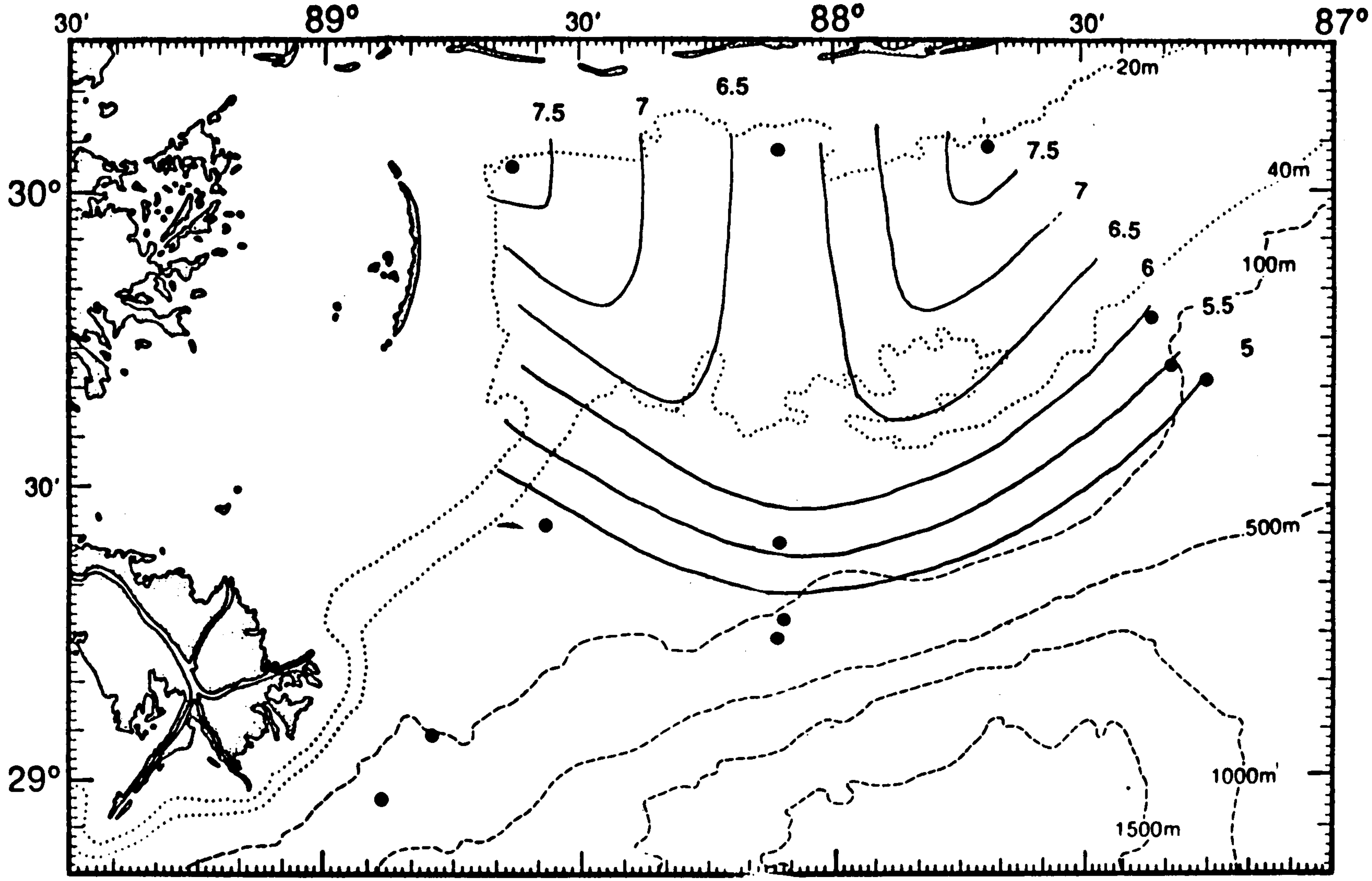

Figure 10-17. October 1987 (Cruise 1) distribution of near-bottom dissolved oxygen (mg/l). Supplemental stations are indicated by a cross.

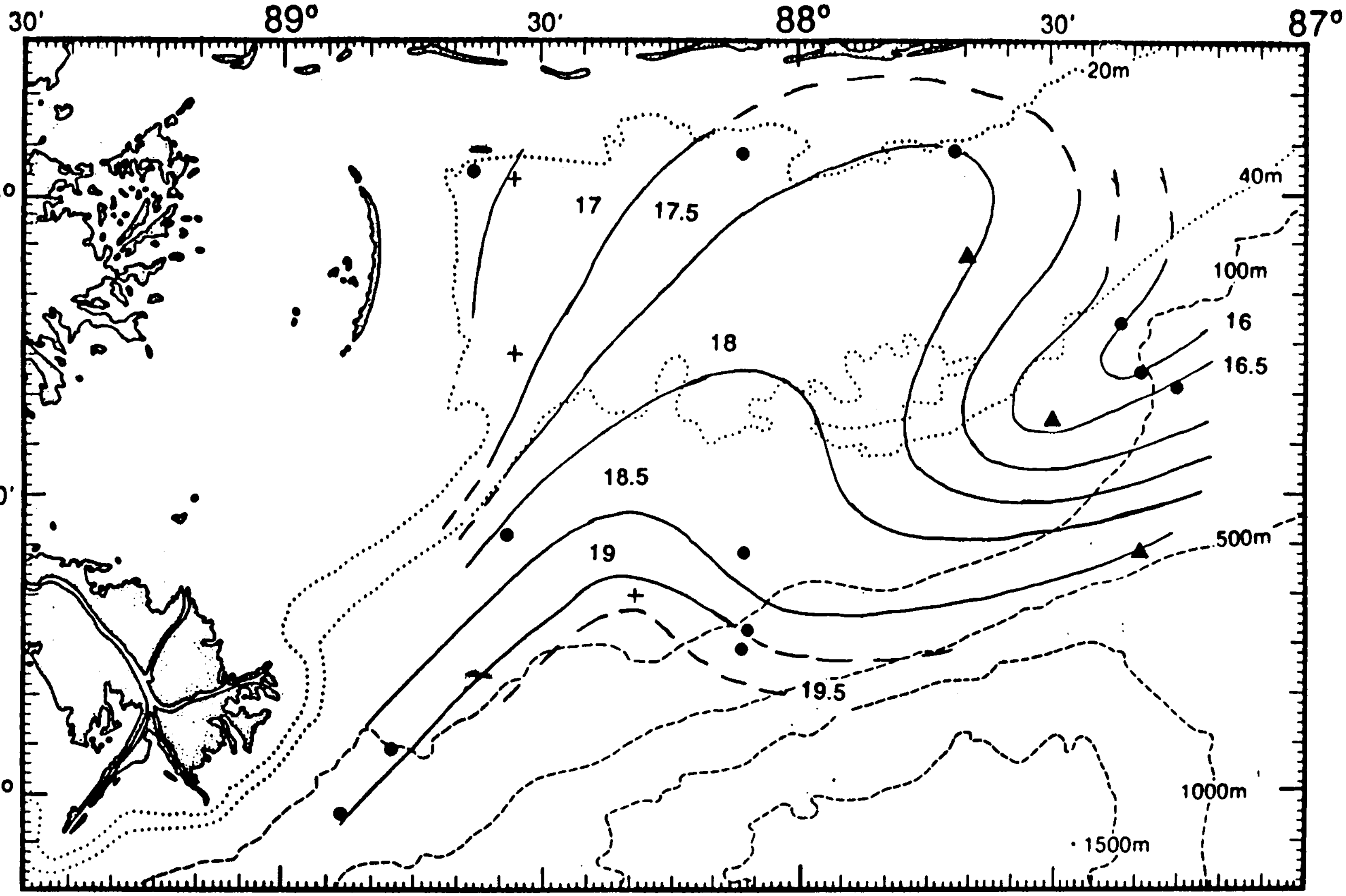

Figure 10-18. March 1988 (Cruise 2) distribution of near-surface temperature (°C).

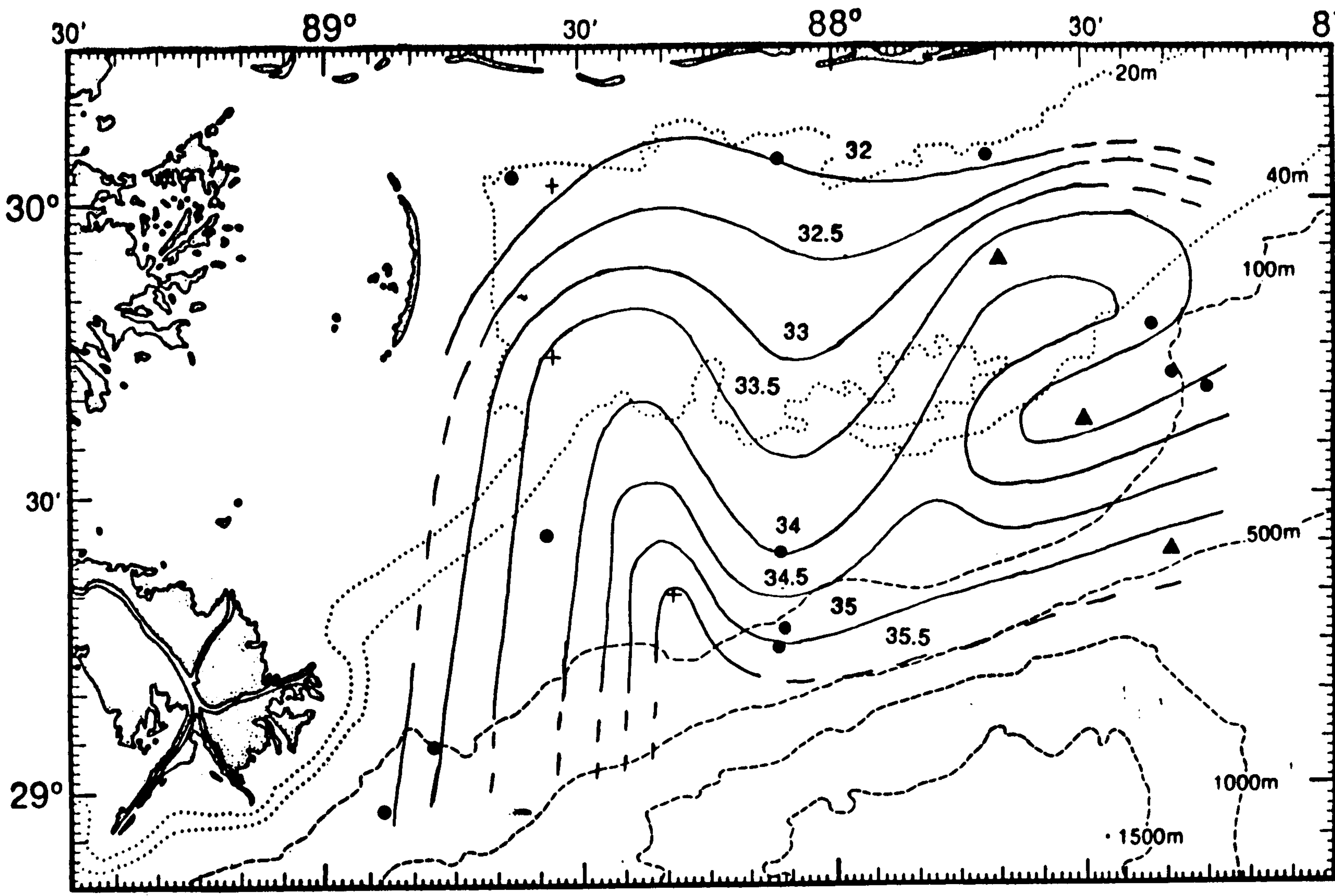

Figure 10-19. March 1988 (Cruise 2) distribution of near-surface salinity (°/oo).

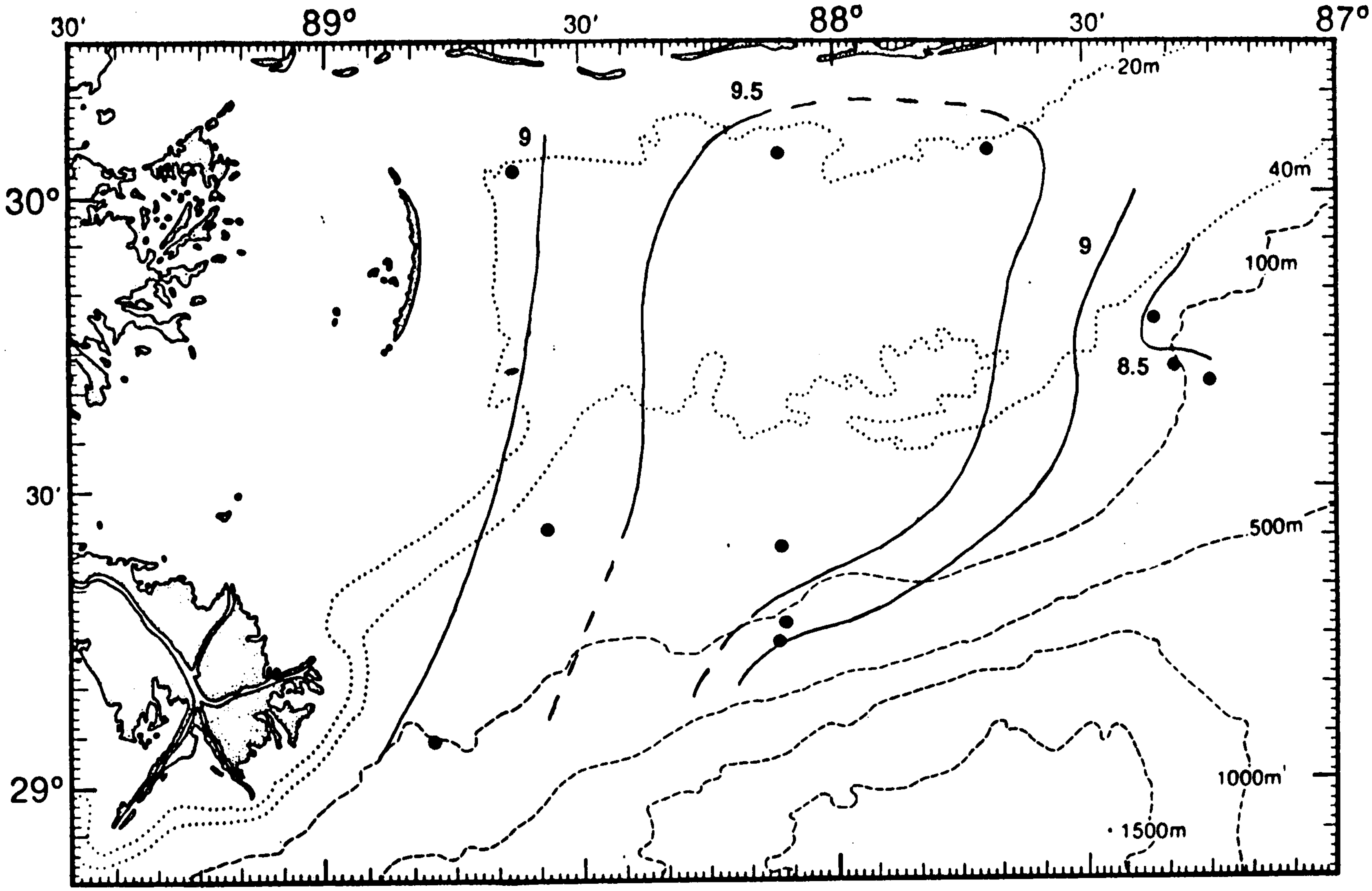

Figure 10-20. March 1988 (Cruise 2) distribution of near-surface dissolved oxygen (mg/l).

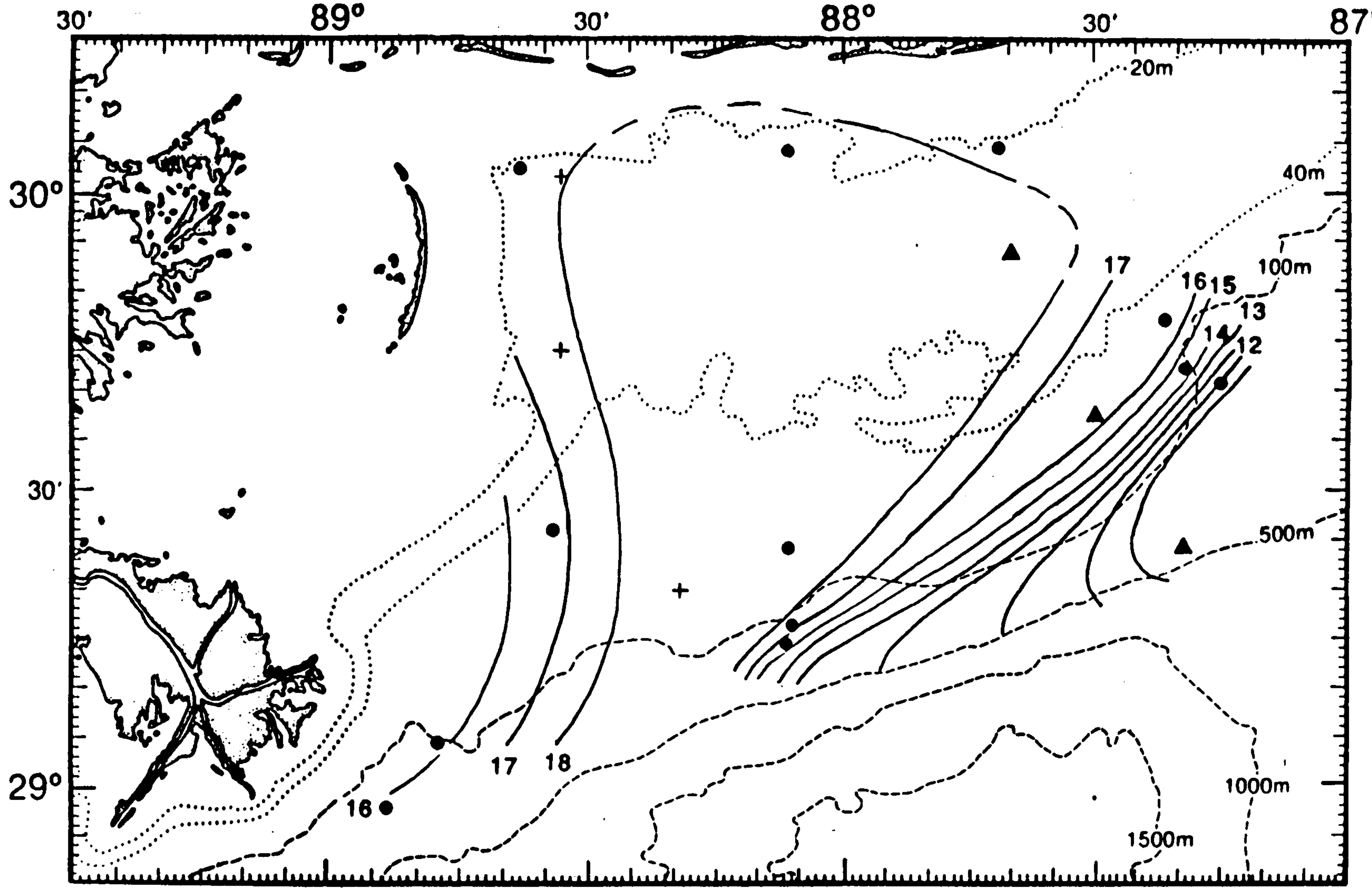

Figure 10-21. March 1988 (Cruise 2) distribution of near-bottom temperature (°C).

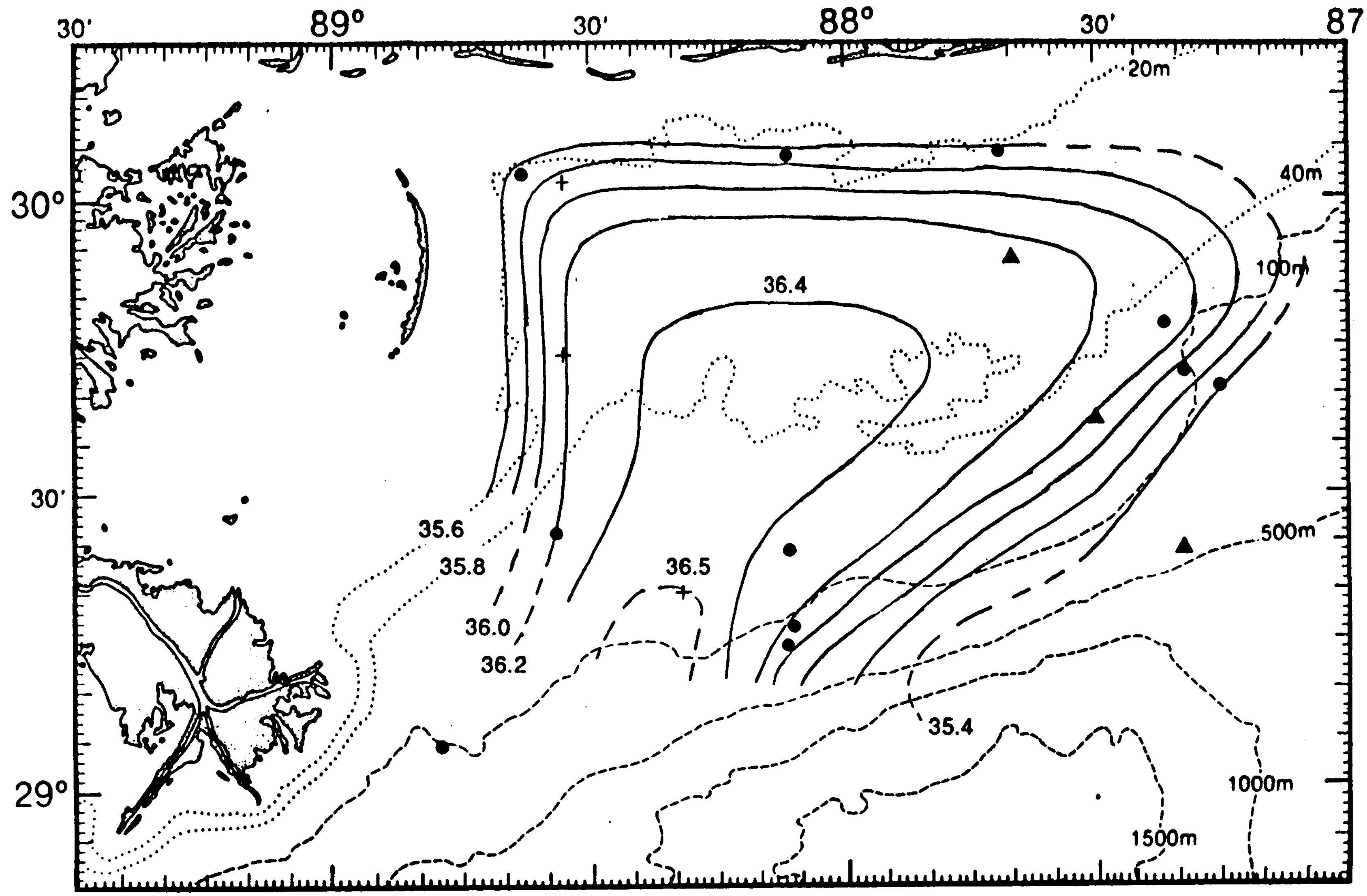

Figure 10-22. March 1988 (Cruise 2) distribution of near-bottom salinity (°/oo).

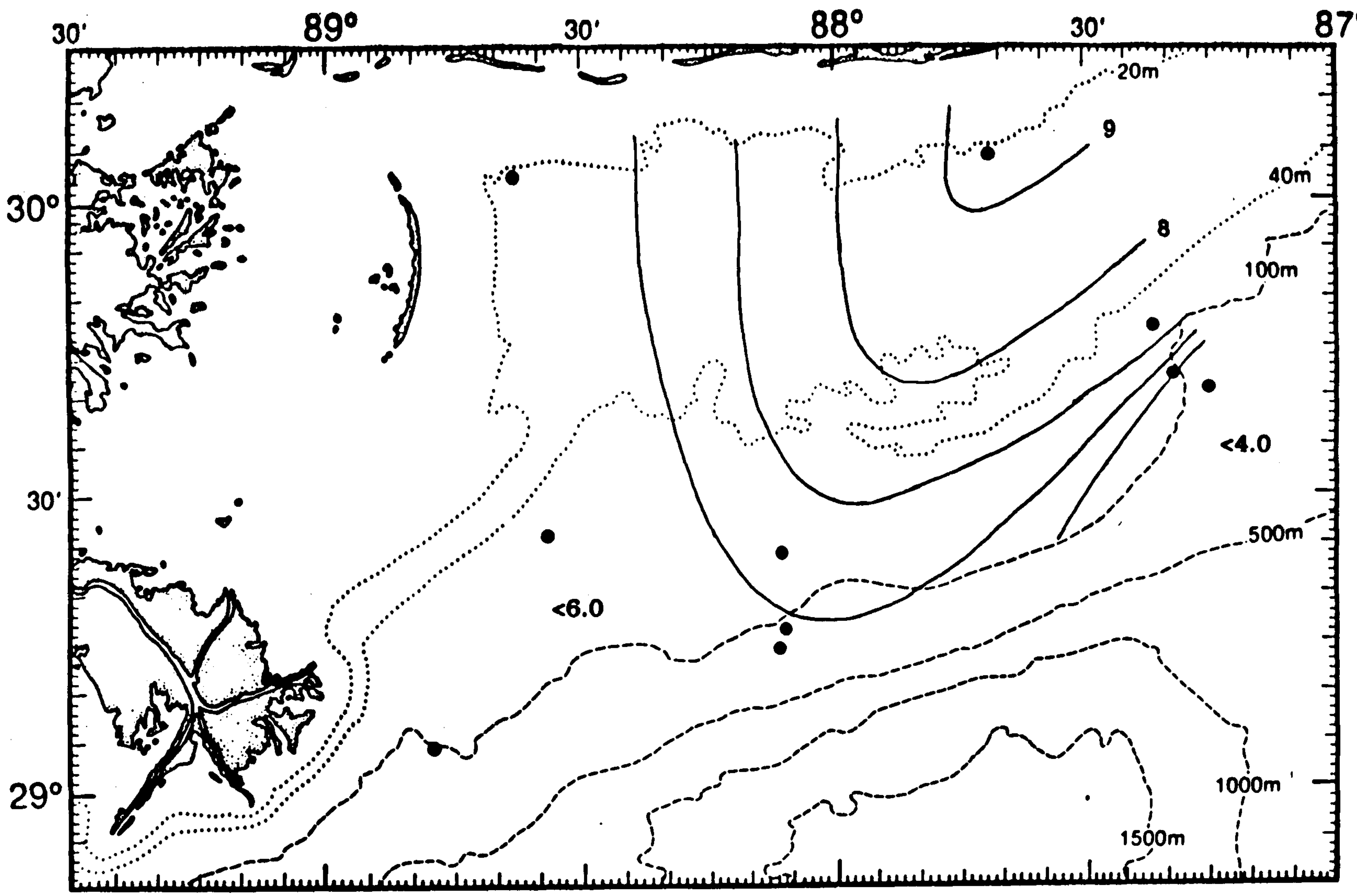

Figure 10-23. March 1988 (Cruise 2) distribution of near-bottom dissolved oxygen (mg/l).

10.5 Results

A detailed discussion and interpretations of the hydrographic data and the time-series data from Sites A and B are not attempted because a number of other data sets are not yet available at the time of this report, including the data from the instruments at Site C, river runoff data, and meteorological data. However, the following are some general observations.

During the March 1987 cruise, surface temperature increased monotonically seaward from 15°C in shallow water to 18°C over the shelf slope. Isotherms followed the trend of the isobaths. A tongue of water with lower salinity and higher dissolved oxygen values extended southward from Mobile Bay across the shelf. In the southeastern portion of the study area, i.e., on the west side of De Soto Canyon, surface waters had higher salinity and lower oxygen values. Near the bottom, values of dissolved oxygen decreased monotonically from about 7.5 mg/l in shallow water to 4.5 mg/l at the 100 m isobath. The distributions of temperature and salinity near the bottom exhibited relative maxima between the 40 and 100 m isobaths.

During the October 1987 cruise, a surface water mass with higher temperature and salinity and lower dissolved oxygen entered the study region from the southeast and spread northwestward over the shelf. Bottom temperatures decreased seaward from the shallow inshore waters. The distribution of bottom salinity suggests a high salinity tongue extending westward across the shelf. The highest value was 36.8 $^{o}/oo$ at Station D2. The distribution of dissolved oxygen generally decreases seaward, except for the value at M1.

The hydrographic data from the March 1988 cruise (Section 11, Figure 11-5) indicates that a filament from a Loop Current eddy entered the study area between Stations C4 and M4 and wrapped clockwise to the northeast. The filament contained water with higher temperature, salinity and dissolved oxygen values both near the surface and bottom. A southwestward return flow, with opposite water mass characteristics, occurred in the southeast part of the study area.

11.0 SATELLITE OCEANOGRAPHY

Andrew Vastano

11.1 Project Scope

The satellite portion of the physical oceanography investigation is responsible for surveying surface temperature expressions of major physical features in the northeastern Gulf of Mexico. The purpose is to monitor the position of the Loop Current and the mesoscale features in the MMS study region. Accordingly, the positions of Loop Current fronts, warm core eddies, warm intrusions reaching into the study region, and cold plumes extending seaward from the study region are observed. Frontal analyses are prepared to show the development of these features.

11.2 First Year Summary

During the initial year, the NOAA-9 and NOAA-10 Satellite Advanced Very High Resolution Radiometers (AVHRR) were used to obtain infrared sensings of upwelling sea surface radiance in the channel four or eleven micron band. Eighty-three pertinent scenes were selected and purchased from the NOAA Satellite Data Services Division between 30 September 1987 and 29 May 1988. Table 11-1 lists each of these scenes in terms of satellite, date, time, orbit, and number of scan lines.

Each satellite scene is processed to extract an atmospherically corrected, sea surface temperature image, and each is mapped to a Mercator projection. The images cover a region of 8 degrees in latitude and 10 degrees in longitude. Figure 11-1 is an example of the 83 extracted images that were taken on 5 December 1987. The convention of cold/white and warm/black governs the image grey scale distribution. A warm core eddy is northwest of, and still connected to, the Loop Current. Eighty-three enlargements were made showing details of the surface temperature distribution (Figure 11-2) in the study region. An example taken from 6 November 1987, is shown in Figure 11-2.

Table 11-1. Satellite Imagery: 1987-1988

SATELLITE	YEAR	DATE	JULIAN DAY	HOUR	MIN	DAY	ORBIT	SCANS
09	87	Sep 30	273	20	45	27	14423	1319
10	87	Oct 05	278	14	08	31	5444	1308
10	87	Oct 06	279	13	46	52	5458	1256
09	87	Oct 06	279	21	21	29	14508	1225
09	87	Oct 07	280	21	10	35	14522	1258
09	87	Oct 08	281	09	41	13	14529	1283
09	87	Oct 08	281	21	00	16	14536	1084
09	87	Oct 16	289	21	13	59	14649	1244
09	87	Oct 17	290	21	03	05	14663	1283
09	87	Oct 27	300	09	37	37	14797	1213
09	87	Oct 28	301	09	26	17	14811	1243
09	87	Oct 29	302	09	15	27	14825	1218
10	87	Oct 29	302	13	47	56	5785	1200
09	87	Nov 06	310	09	29	33	14938	1247
09	87	Nov 12	316	10	05	50	15023	1247
09	87	Nov 13	317	09	54	27	15037	1305
09	87	Nov 15	319	09	53	19	15433	1247
10	87	Nov 21	325	01	23	01	6105	1236
09	87	Nov 21	325	10	09	04	15151	1096
10	87	Nov 21	325	13	47	46	6113	1264
10	87	Nov 22	326	01	01	12	6119	1290
10	87	Nov 22	326	13	26	04	6127	1208
09	87	Dec 03	337	09	39	19	15319	1266
09	87	Dec 04	338	20	48	20	15340	855
09	87	Dec 05	339	09	17	39	15348	1215
10	87	Dec 05	339	13	43	37	6312	1247
09	87	Dec 11	345	09	53	19	15433	1299
09	87	Dec 11	345	21	12	02	15439	1253
09	87	Dec 23	357	09	22	56	6569	976
09	87	Dec 29	363	21	20	52	15693	465
10	88	Jan 11	011	01	14	44	6830	1339
09	88	Jan 11	011	20	38	03	15876	1456
10	88	Jan 12	012	00	52	55	6844	1401
10	88	Jan 12	012	13	17	37	6852	1280
10	88	Jan 15	015	13	52	23	6894	1379
09	88	Jan 27	027	09	47	19	16095	1225
09	88	Jan 28	028	09	36	59	16109	1442
09	88	Jan 28	028	20	53	32	16116	1247
09	88	Jan 29	029	09	25	59	16123	1802
09	88	Feb 12	043	21	34	07	7292	1326
10	88	Feb 13	044	00	57	20	7299	1392
09	88	Feb 13	044	10	04	20	16335	1419
10	88	Feb 13	044	13	22	04	7306	124
09	88	Feb 13	044	21	23	11	16342	1358
10	88	Feb 14	045	00	35	32	7313	1414
10	88	Feb 16	047	01	32	16	7342	1311
10	88	Feb 16	047	13	56	49	7349	1376
10	88	Feb 17	048	01	10	26	7356	1359
10	88	Mar 10	070	13	56	55	7676	1285
09	88	Mar 10	070	21	43	24	16709	1219
10	88	Mar 11	071	01	10	22	7683	1266
09	88	Mar 11	071	10	13	42	16716	1339

Table 11-1. Continued.

SATELLITE	YEAR	DATE	JULIAN DAY	HOUR	MIN	DAY	ORBIT	SCANS
10	88	Mar 11	071	13	25	15	7690	1220
09	88	Mar 13	073	21	10	39	16751	1298
09	88	Mar 14	074	09	41	15	16758	1247
09	88	Mar 15	075	09	30	23	16772	1226
10	88	Mar 15	075	13	48	12	7747	1259
10	88	Mar 16	076	01	01	37	7754	1293
10	88	Mar 17	077	00	39	48	7768	1312
10	88	Mar 20	080	01	14	40	7811	1252
10	88	Mar 21	081	00	52	51	7825	1317
09	88	Mar 23	083	21	03	43	16892	969
09	88	Mar 24	084	09	25	52	16899	1230
10	88	Apr 07	098	13	49	09	8074	813
10	88	Apr 08	099	13	19	01	8088	1206
10	88	Apr 18	109	00	42	47	8223	1315
09	88	Apr 19	110	21	09	35	17273	1305
09	88	Apr 20	111	20	59	11	17287	1314
10	88	Apr 21	112	01	16	41	8266	1231
09	88	Apr 26	117	21	34	30	17372	1245
09	88	Apr 27	118	09	59	40	17379	1311
09	88	May 05	126	21	37	23	17499	1240
09	88	May 06	127	21	26	06	17513	1261
09	88	May 07	128	09	51	14	17520	1271
09	88	May 07	128	21	15	07	17527	1292
09	88	May 08	129	09	40	29	17534	1252
10	88	May 18	137	13	52	32	8657	1213
10	88	May 19	138	01	08	18	8664	1122
10	88	May 19	138	13	32	18	8671	1122
10	88	May 20	139	00	50	09	8678	1308
09	88	May 27	148	20	59	22	17805	1318
10	88	May 28	149	13	39	16	8799	1210
10	88	May 29	150	00	54	10	8806	1249

11.3 Relation to Sediment Hydrocarbons

Kennicutt [4.0 High Molecular Weight Hydrocarbons] has shown geographic concentration contours (Figures 4-8, 4-9, 4-10, 4-11) that indicate hydrocarbons in sediments with high values near the Mississippi River and Delta region that decrease eastward. In particular, such distributions are clear in the late winter of 1988 (during Cruise 2). Satellite image enlargements for January, February, March, April, and May 1988 offer a possible physical mechanism that would contribute to the development of these hydrocarbon distributions. The images suggest flow to the north and eastward immediately east of the Mississippi River and Delta passes.

The temperature pattern in the enlargement for 28 May 1988 (Figure 11-3) is representative of the patterns over this spring. Northward flow is implied from the Delta to the Chandeleur Islands, then eastward to 86°30'N where flow is seaward and eventually returns westward at the latitude of the southern tip of the Delta. Figures 11-4 (27 January), 11-5 (4 February), 11-6 (11 March) and 11-7 (27 April) also support such flow and illustrate its variability.

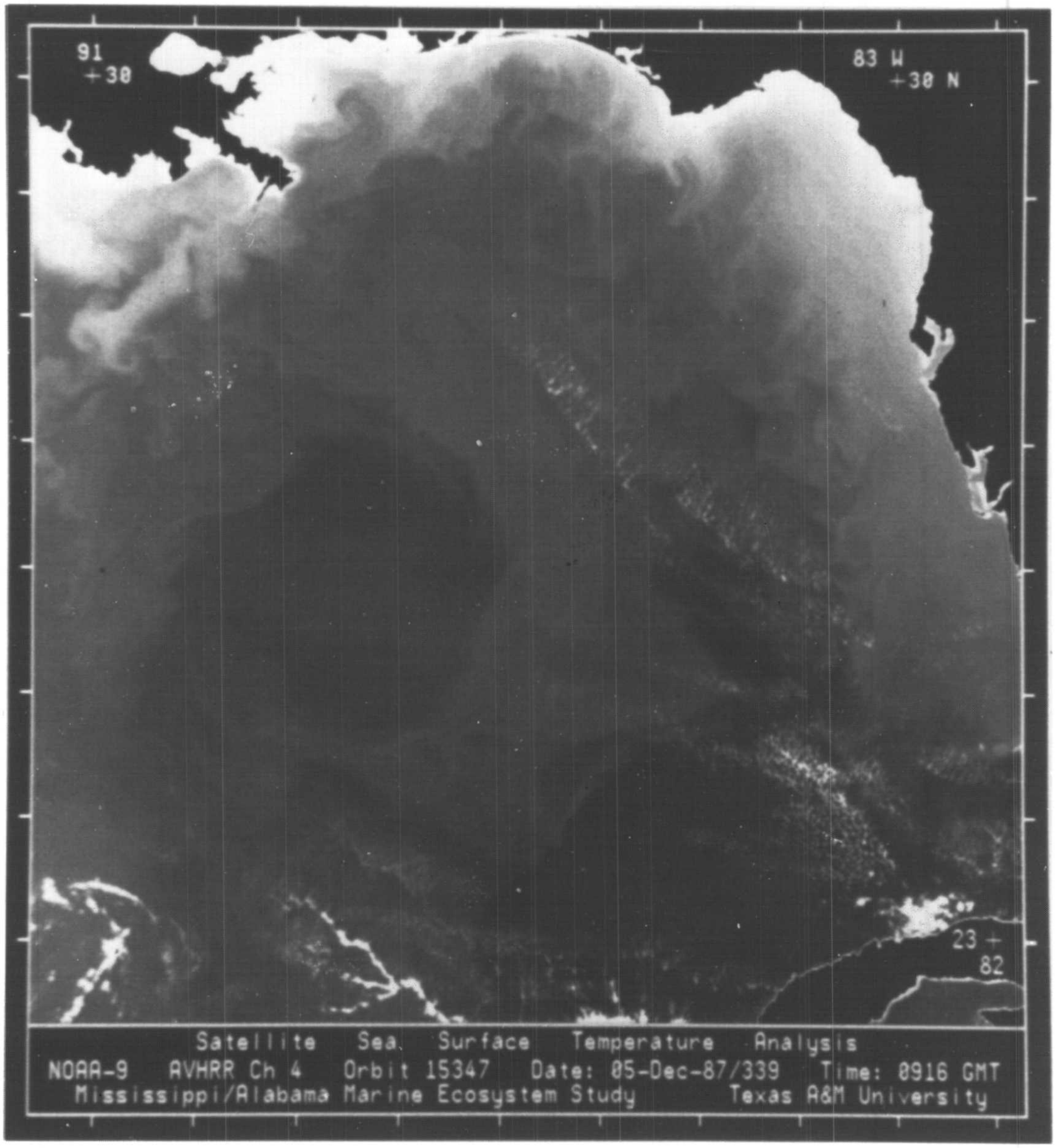

Figure 11-1. NOAA AVHRR satellite image for 5 December 1987/339; Time 0917Z; Orbit 15348.

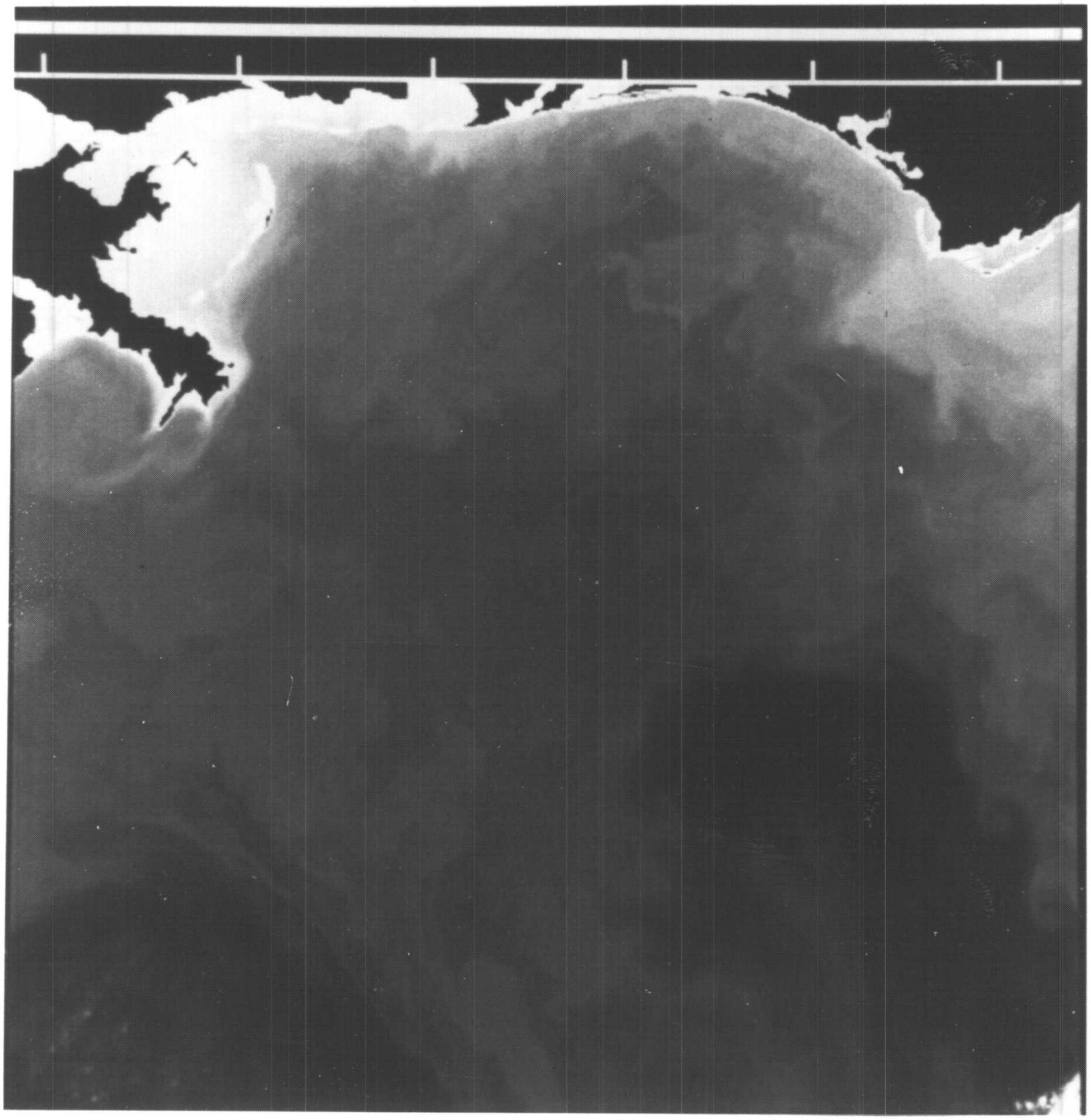

Figure 11-2. NOAA AVHRR satellite image for 6 November 1987/310; Time 0929Z; Orbit 14938

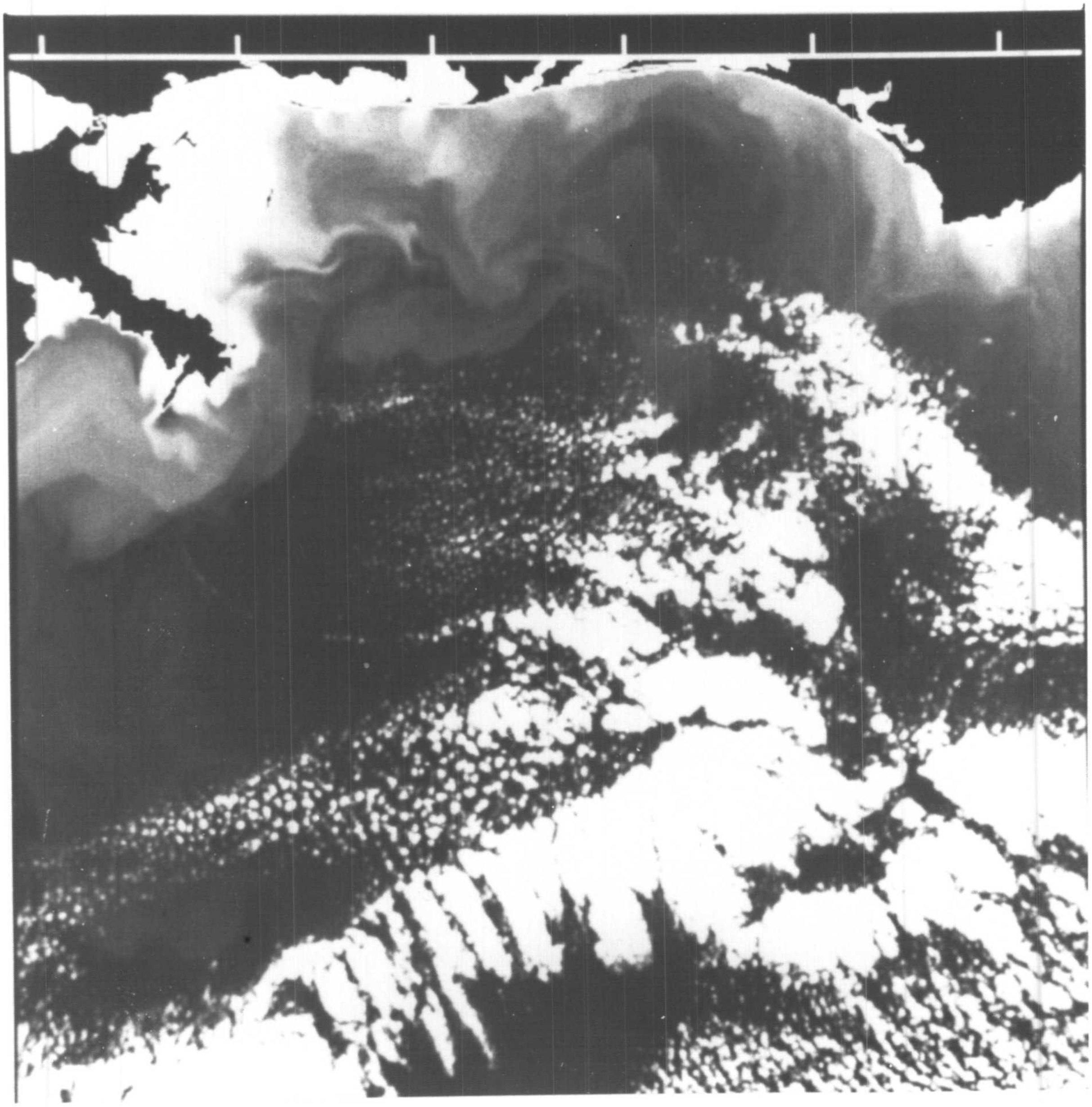

Figure 11-3. NOAA AVHRR satellite image for 27 January 1988/027; Time 0947Z; Orbit 16095.

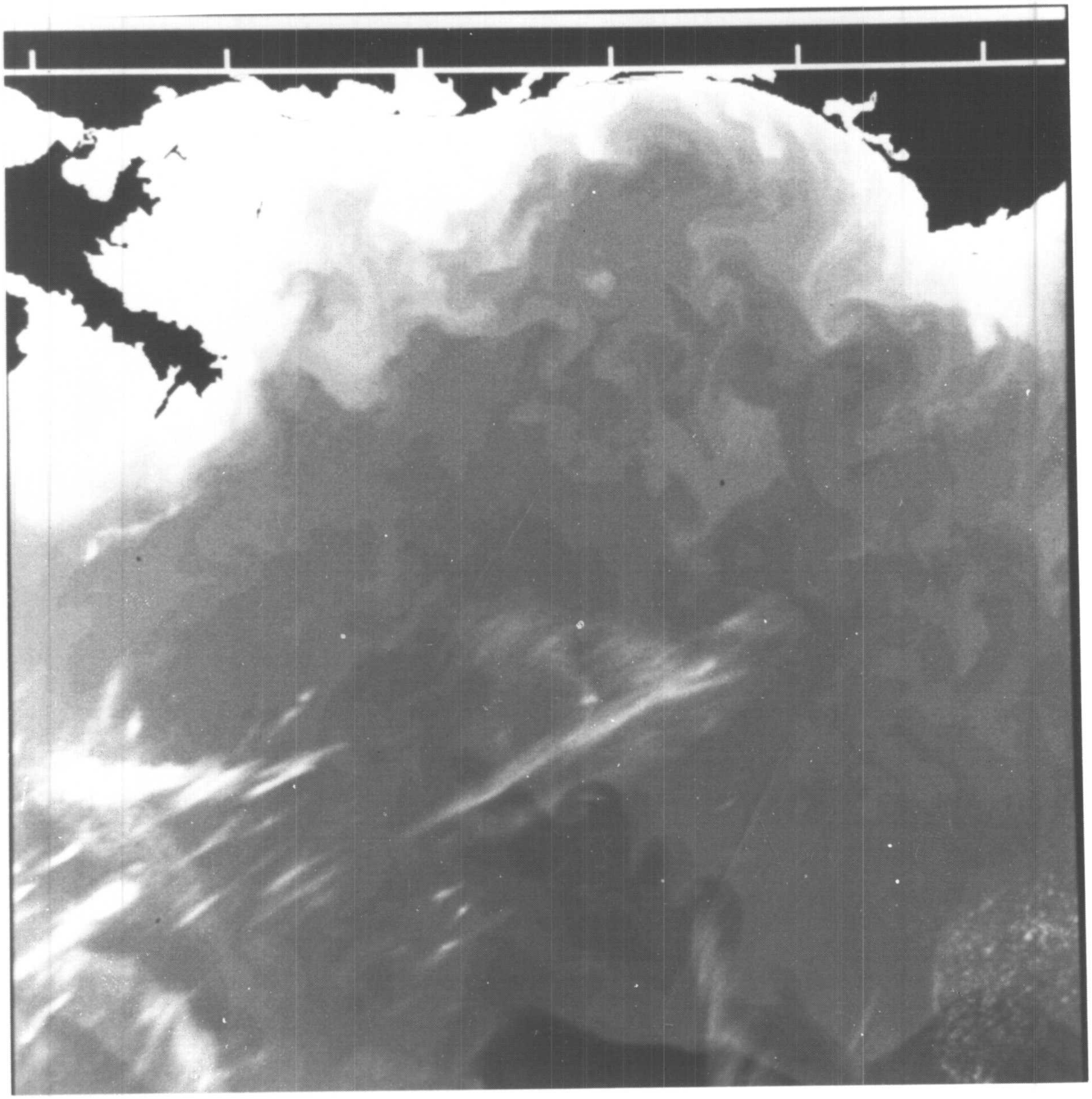

Figure 11-4. NOAA AVHRR satellite image for 14 February 1988/045; Time 0035Z; Orbit 7313.

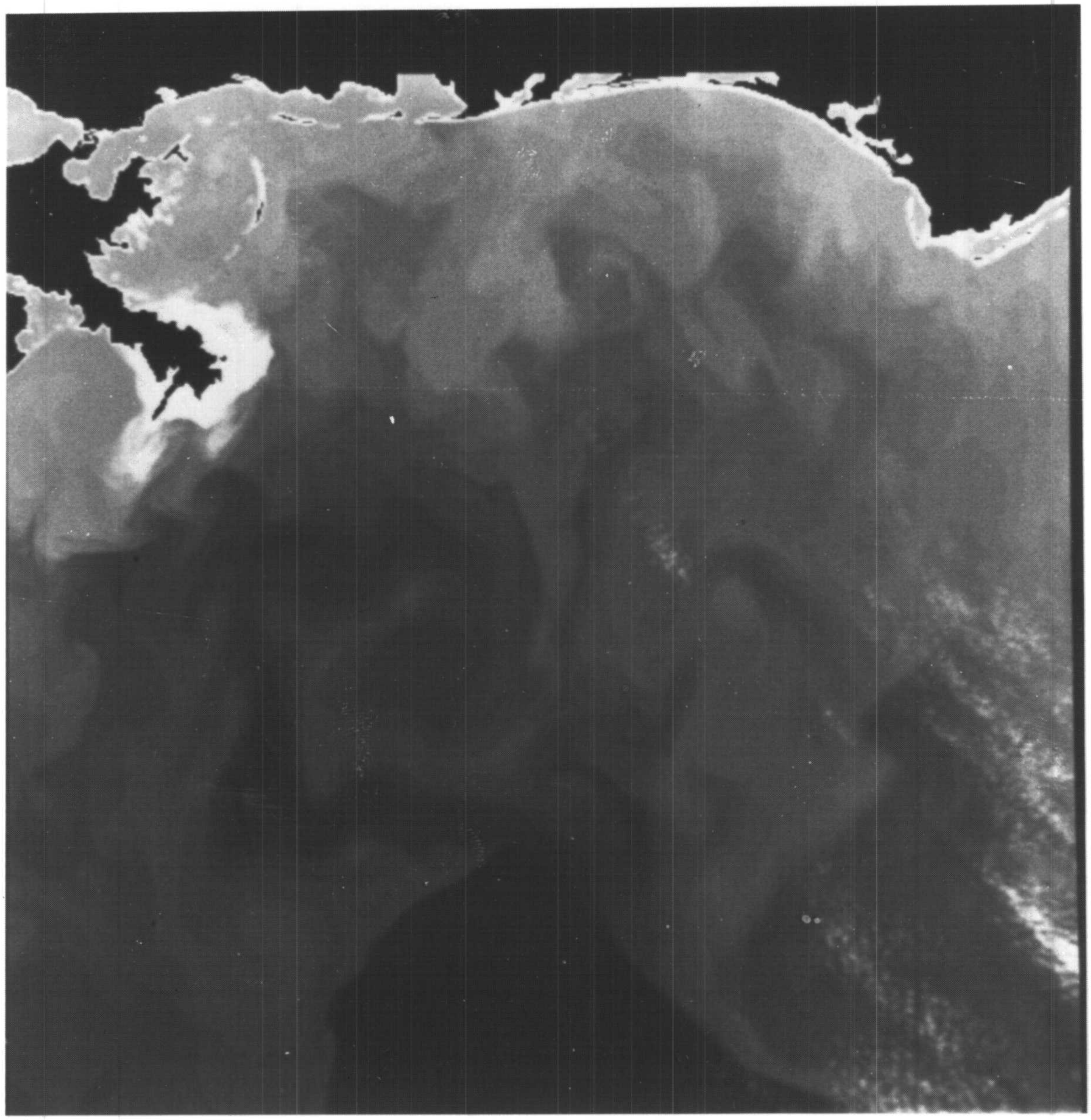

Figure 11-5. **NOAA AVHRR satellite image for 11 March 1988/071; Time 1325Z, Orbit 7690.**

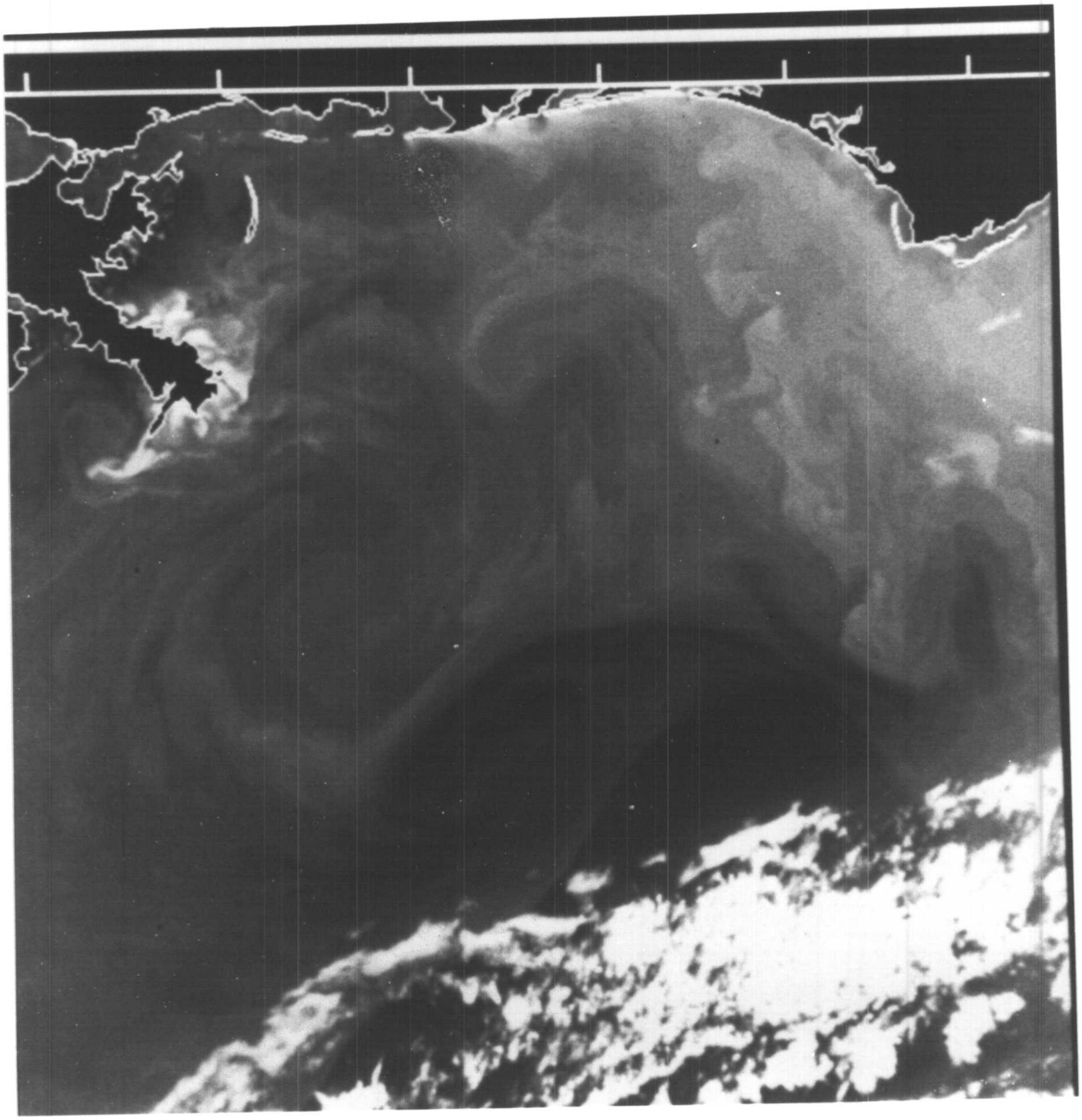

Figure 11-6. NOAA AVHRR satellite image for 27 April 1988/118; Time 1006Z; Orbit 17379.

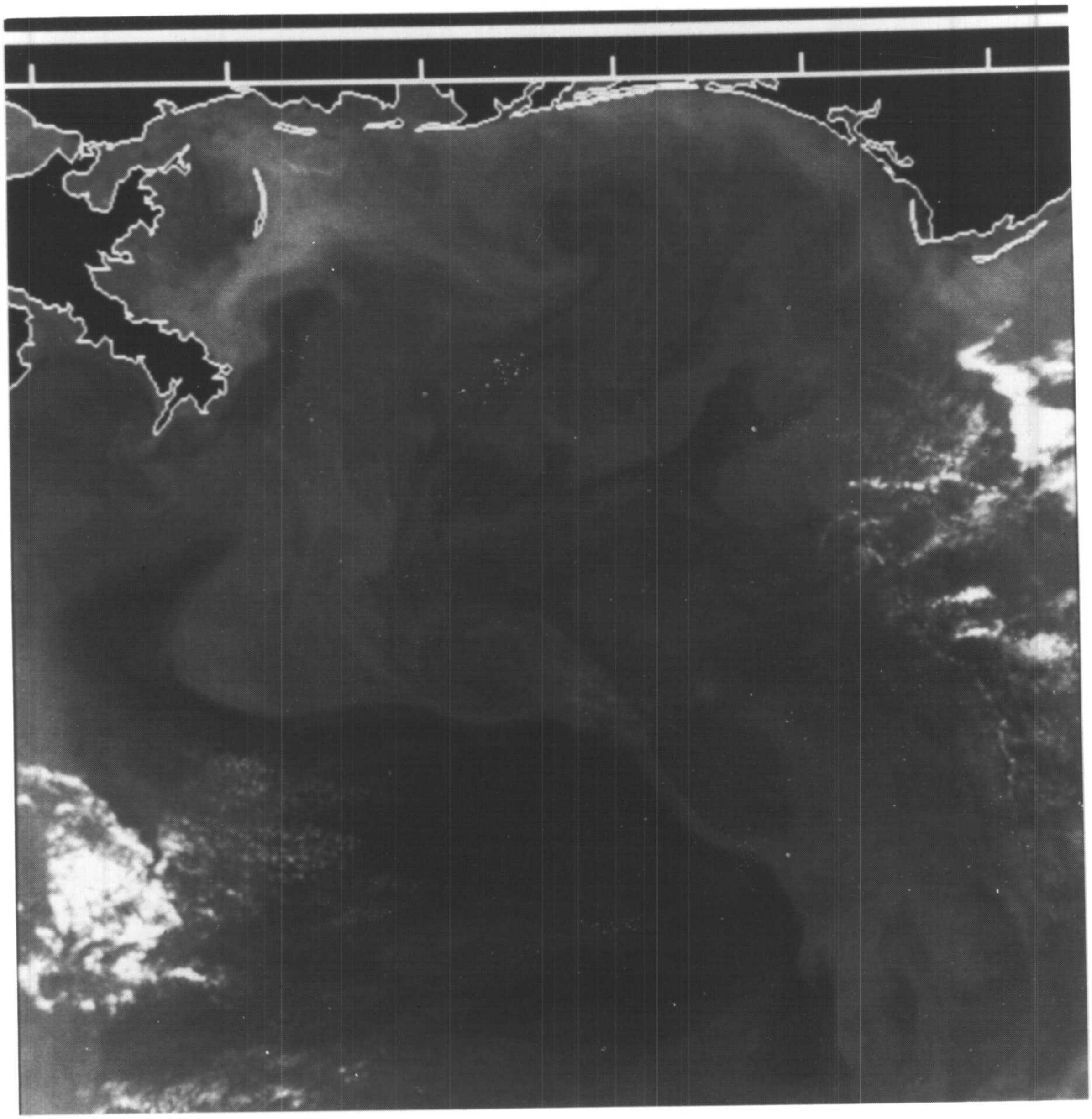

Figure 11-7. NOAA AVHRR satellite image for 28 May 1988/149; Time 1339; Orbit 8799.

12.0 TOPOGRAPHIC FEATURES CHARACTERIZATION - GEOLOGICAL

William W. Sager

12.1 Introduction (including historical background)

The middle and outer continental shelf between the Mississippi River and De Soto Canyon has received little attention from marine geologists. A few small scale studies of isolated features have been published (Moore and Bullis 1960; Shipp and Hopkins 1978) and apparently there exist a few reports in the "gray" literature produced by commercial studies (W. Schroeder, personal communication, 1988). However, there has been only one attempt to synthesize the geologic nature of the outer shelf in this area (Ludwick and Walton 1957). This study found that topographic features were common on the Mississippi-Alabama shelf, but noted that they are different from those found farther west in the Gulf of Mexico (e.g., Rezak *et al.* 1985). In the northwestern Gulf, topographic highs generally tend to be the result of uplift caused by salt or shale diapirs. They may have colonies of calcareous organisms at their tops. However, on the Mississippi-Alabama shelf, the topographic highs are apparently calcareous reefs constructed without the aid of geologic uplift. Ludwick and Walton (1957) concluded that these features were in an intermediate stage between active growth and fossilization. They also surmised that they were built at lower stands of the sea during the rise in sea level following the most recent ice age.

During the first year of geophysical surveying, approximately 1,166 NM of data were acquired. The survey consisted of 34 lines run with an east-northeast trend, following the shelf edge, and six lines approximately perpendicular to these (Chapter 3, Figure 3-1). Lines 1-18 were spaced approximately 500 m apart, whereas lines 19-34 were spaced about 750 m apart. This spacing difference made it possible to achieve a greater swath-width with the side scan sonar in deeper water. Side scan sonograms and 4 kHz subbottom profiles were obtained along lines 1-34; however, along cross-lines A-F the 4 kHz subbottom profiler and a 700 Joule mini-sparker were used.

From these data two main types of maps will be produced. The side scan sonographs will be made into composite mosaics. These are analogous to large scale photographs of the ocean bottom. The subbottom profiler records will be used to precisely determine the seafloor depth beneath the ship tracks. These bathymetric data will be contoured, using the side scan mosaics as a guide for interpolation between tracks, to produce topographic maps of the seafloor. From the sonogram and bathymetric data, other secondary data sets, such as seafloor reflection character or the distribution of pinnacle features, will be produced.

Progress on the sonograph mosaics and bathymetry maps was slowed by two factors. First, due to inclement weather, the geophysical surveying was not completed until mid-April of 1988. Second, the desire to achieve high positional accuracy for the maps has produced the need to develop and test new computer software for reducing and plotting the data. However, both data types are nearly at the stage required for production of the first working maps.

12.2 Methods

12.2.1 Bathymetry

Bathymetry and subbottom profiles were gathered with a 4 kHz EDO-Western subbottom profiler system. The raw subbottom data were displayed in analog fashion on an electrostatic plotter. Event marks were used to show the locations of navigational fixes (shotpoints). Bathymetry values were derived by digitizing the seafloor echo on the analog subbottom profiler records. The following process was used. The horizontal distance (in inches) of each shotpoint on a given subbottom record was measured with the digitizer. Similarly, the horizontal and vertical distances (also in inches) of selected bathymetric points on the same record were digitized. Comparison of the horizontal distance of each bathymetric point with the shotpoint list allowed its location to be expressed in shotpoint coordinates by linear interpolation. The seafloor depth was determined by computing the two-way travel time of the sound pulse and using 1500 m/sec as the speed of sound in water. A correction for the depth of the transducer below the sea surface was applied at this step. Finally, the bathymetric points were placed into geographic coordinates by merging the navigation (latitude and longitude pairs corresponding to shotpoints) with the shotpoint-depth files.

A rough analysis of the digitizing process suggests that it contributes an error of less than about three meters in the horizontal positioning of each depth value. This is less than the 5-7 m accuracy of the navigation. In the determination of the depth values, the digitizing should contribute an error of only about 1 cm. The major contributors to the uncertainty of bathymetric values are probably the variations in the depth of the transducer caused by changes in ship speed and by wave action, which result in an average error estimated at about 0.5 m.

The processing of the bathymetric data has recently been completed. The next stage of analysis is to plot the data and draw contour maps. A generalized bathymetric map with a contour interval of 10 m is planned as is a series of more detailed maps contoured at 2-5 m intervals. The latter will be compared with existing NOAA-NOS maps of the study area.

12.2.2 Side Scan Sonar

Side scan sonar data were collected with a 100 kHz EG&G model 260 system. These data were recorded in both digital and analog forms. The digital data were recorded aboard ship on 70 reels of nine-track magnetic tape, 2,400' in length. The digital data allow us to replay sections of lines at different gain settings as desired. The sonar data were also recorded in analog fashion using a 10" electrostatic plotter. The analog records were taken to the U. S. Geological Survey in Menlo Park, California, for microfilm reproduction using a flow camera. Prints three inches in width were made of each record for use in constructing sonogram mosaics. In its original form, each survey line is about 50' in length, but the reduced print is about 12' in length. This is still too large to allow the construction of a single mosaic, so the survey area was be divided into 11 subsections. In order to construct mosaics, plots of navigation points will be made at the appropriate scales. The sonograph prints will be attached to these plots followimg the ship tracks. The important details of these mosaics will be digitized for plotting at suitable scales.

12.2.3 High Resolution Subbottom Profiles

As stated, subbottom profiles were obtained using an EDO Western system with a 4 kHz transducer. The profiles were preserved in analog fashion on either an EDO or EPC 20" electrostatic recorder. These profiles will be analyzed using standard seismic stratigraphy techniques to examine the stratigraphy of the uppermost sediment layers. In the survey area the seafloor is unusually reflective and subbottom acoustic wave penetration is low, typically less than 10-15 m.

During the second geophysical cruise, 88-MMS-G1A, a 700 Joule mini-sparker was tested in an attempt to increase acoustic wave penetration by using a more powerful source. However, the sparker generated acoustic interference with the side scan sonar, and the high reflectivity of the seafloor prevented any significant increase of penetration. Consequently, further use of the sparker was abandoned.

12.2.4 Sediment Texture

None of the sediment analyses done during the first year were of samples specifically from topographic features; instead, they were all from the transects. Thus, all of the sediment study results are addressed in Section 6.

12.2.5 Rock Dredging

No hard rock dredges were taken during the first year of the study. However, now that the large scale survey effort is nearing completion, dredging will probably be done on several of the banks mapped during the first year effort.

12.3 Results

A preliminary examination of the side scan sonar data has revealed a number of interesting features. The reflectivity of the seafloor varies greatly.

High reflectivity bottom is often found in the vicinity of topographic highs. However, sometimes no topographic features are associated with this phenomenon. Furthermore, the variations in reflection character sometimes appear in regular "waves," sometimes in large random "splotches," and occasionally as a rash of small splotches that we nicknamed "pox." In many cases these variations in reflection character do not appear correlated with topography and are probably caused by differences in sediment composition.

Many topographic features were mapped by the survey. In general, these are of three classes: (1) pinnacles, probably formed by coral-algal assemblages; (2) linear ridges, perhaps lithified coastal dunes; and (3) enigmatic features. The pinnacles are features with heights of about 2-15 m and widths of 2-200 m. Some of the larger of these features have flat tops, but most large pinnacles have bumpy tops suggesting that they may have formed from many smaller reefs gravity together. Although pinnacle features were found scattered over all quadrants of the survey area, concentrations were found around the 73 m contour. This contour may represent a stillstand in the most recent rise in sea level (Poag 1973).

The linear ridges are also found primarily along the 40 fathom contour. They are distinguished from the pinnacles by the fact that they are decidedly linear and two-dimensional with large aspect ratios. By comparison, the pinnacles tend to be subcircular in plan. The ridges also generally, but not always, have lesser topographic relief than the pinnacles.

Two features were mapped whose origins were enigmatic. In several areas fields containing thousands of small topographic mounds were noted. These were nicknamed "boulders" because of their appearance on the side scan sonograms, but they are probably not boulders in the classical sense of the term. Their sizes are in the range of 1-2 m in height and 1-4 m in width. The fields in which they are found are typically several miles on a side. The second type of enigmatic feature consists of small (5-10 m in width) depressions found in several areas. These features were nicknamed "footprints" and their origin is unknown.

The subbottom records show a layer of recent sediments lying atop what appears to be an erosional surface. This surface was probably created during the low stand in sea level that corresponded to the last Pleistocene glacial period, approximately 15,000 to 20,000 years ago (Poag 1973). Bedding planes below the erosional surface were seen to be dipping steeply seaward indicating that the erosion truncated deltaic forset beds.

The sediments atop the erosional surface have been deposited during the Holocene. Their thickness is quite variable, ranging from virtually nil to about 15 m. These sediments are thinnest and mostly transparent at the east and west ends of the survey area. However, in the middle, they form a lobe of sediments that display internal reflections probably indicative of deltaic processes.

12.4 Summary/Conclusions

The survey area includes the edge of the continental shelf south of Mississippi and Alabama. Subbottom profiler records indicate that the shelf edge is built upon delta-front forset beds that were truncated by erosion during the last low stand of sea level in the Pleistocene. Holocene sediments 0-15 m thick cap the erosional surface and the topographic features of primary interest to this study were constructed on top of these sediments. The Holocene sediments are thickest in the central part of the survey area, perhaps indicating a small delta lobe that has been or was deposited in that area.

Interesting geologic features were found throughout the survey area. In general, the sediment reflectivity displayed complex variations. High and low reflectivity were found, and the variations between high and low reflectivity occurred in waves and patches of varying size and complexity. Topographic features were of three types: (1) pinnacles, (2) linear ridges, and (3) enigmatic features. The first two categories account for most of the observed features, and many of these are located along an isobath approximately 73 m deep. This line is believed to be related to a stillstand in the recent post-glacial rise in sea level.

12.5 Recommendations for Further Study

The geophysical study results suggested several avenues worth following. (1) The 73 m line showed a significant concentration of topographic features and should be explored to the east and west of the survey area. (2) Several features found in the survey area are worth examining in greater detail. In particular, several different representative types of pinnacles should be surveyed as should the enigmatic "boulder" features. (3) Because of the complexity of the geology of the shelf in this region, an effort should be made to obtain geologic characterization of as many as possible of the stations of the three transects. (4) The geophysical survey has revealed a great deal about the shelf edge, and W. Schroeder of the Dauphin Island Marine Laboratory has done extensive work on the shallow shelf (less than 36 m). Consequently, some effort should be made to characterize the mid-shelf region in between.

13.0 TOPOGRAPHIC FEATURES CHARACTERIZATION - BIOLOGICAL

Thomas J. Bright
Stephen R. Gittings

13.1 Introduction (including historical background)

Rocky, hard bottom outcrops have been reported to occur in several areas in waters off Mississippi, Alabama, and eastern Louisiana. The distribution of some of these was mapped in a report of the M/V OREGON (Cruise No. 72, 7 December 1960). Directly south of Mobile Bay, there are extensive areas of low relief calcareous outcrops of unknown origin, known locally as "broken bottoms" or "ragged bottoms" (Schroeder, personal communication). Additional rocky outcrops have been reported to occur in depths of 73 to 366 m in the area from south of Mobile Bay (Ludwick and Walton 1957; Ballard and Uchupi 1970) and eastward toward the De Soto Canyon (Shipp and Hopkins 1978). The rim of the De Soto Canyon is composed of flat limestone blocks encrusted with biota of various invertebrate groups (Shipp and Hopkins 1978). At least some hard bottoms off Mississippi and Alabama may represent "drowned reefs" or "paleo-reefs" (Ludwick and Walton 1957; Ballard and Uchupi 1970).

Within the boundaries of the Mississippi-Alabama Marine Ecosystems Study, MMS has requested complete side scan coverage and selective video reconnaissance of topographic features in the following area which consists of a number of sites of known or suspected hard bottoms:

	Latitude	Longitude
Northwest Corner	29°25'24"N	88°01'48"W
Southwest Corner	29°14'24"N	87°56'54"W
Southeast Corner	29°26'06"N	87°23'36"W
Northeast Corner	29°36'40"N	87°28'30"W

Many topographic features within the study area are of sufficient relief that they may support communities distinct from those of nearby habitats. Ludwick and Walton (1957) used echo sounding to survey the outer continental shelf between the Mississippi River and Cape San Blas, Florida.

They noted a zone of prominences they called "pinnacles" one mile wide and discontinuous with 10-25 mile gaps in depths from 73-100 m. The average relief of the pinnacles was 10 m, but some were found to be over 15 m tall. These pinnacles are thought to be calcareous biogenic structures that formed during the lower sea level stands of the Pleistocene. Biological sampling of some of the pinnacles surveyed in this study has been carried out using rock dredges (Ludwick and Walton 1957) and combinations of dredges and television and still cameras (Woodward-Clyde Consultants 1979; Continental Shelf Associates (CSA) 1985; Schroeder personal communication data). Biotic assemblages were found to be of tropical Atlantic origin and dominated by ahermatypic hard corals (e.g., *Oculina*), octocorals, crinoids, and hydroids. Other organisms included gorgonians, antipatharians, various crabs, asteroids, ophiuroids, and a number of fish commonly associated with hard bottom habitats in the Gulf of Mexico. The biotic assemblage was considered by CSA (1985) to be comparable to that of the "transitional antipatharian zone" described by Rezak *et al.* (1985) at depths below 82 m at the Flower Garden Banks off Texas. In fact, both the Flower Gardens and the pinnacles surveyed by CSA have a number of species in common, including the Bank butterfly fish, *Chaetodon aya*, the Roughtongue bass, *Holanthias martinicensis*, the antipatharians, *Antipathes furcata* and *Cirrhipathes* sp., a number of alcyonaceans and some ahermatypic corals, among other taxa.

13.2 Methods

13.2.1 Preliminary Analysis of Side Scan Sonar Records/Target Site Determinations

The results of hard bottom surveys carried out using the remotely operated underwater vehicle (ROV) are currently being analyzed. Reported results are from a preliminary analysis of side scan and subbottom surveys carried out in the fall of 1987 and spring of 1988. This analysis was done in order to determine which areas were to be visited on the ROV cruise in July and September 1988. This preliminary analysis was done prior to the compilation of the mosaic that is being constructed using the side scan records.

Side scan and subbottom records were reviewed individually and habitat information was transferred onto a copy of a cruise track chart which indicated the locations of shot points surveyed during the side scan cruises (all necessary corrections for cable lengths were made before transferring the data). It should be noted that side scan and subbottom records were interpreted primarily by biologists during this exercise and, therefore, these do not represent the final interpretations of geologists working on the project.

13.2.2 Remotely Operated Vehicle (ROV)

Texas A&M's Department of Oceanography purchased a Benthos RPV-2000, medium-sized, remotely operated underwater vehicle in 1987. The camera capability of the unit consisted of a Subsea Model CM-8 low light sensitive S.I.T. black-and-white video camera, a Benthos Model 378 35 mm camera, one strobe, and three banks of two flood lights each. The Geochemical and Environmental Research Group (GERG) upgraded the photographic capabilities of the ROV by installing a 3-CCD Photosea 3000 series color video camera and a Photosea 2000 Series 35 mm stereo camera. The video camera is a modified Sony DXC-3000 3-CCD video unit. GERG also had two underwater optical lasers fabricated. These lasers are installed adjacent to the video/stereo package and in a parallel configuration at a prescribed spread, allowing for size and scale determinations on video and stereo images. The ROV has a present depth capability of 600 meters. It is acoustically tracked with ultra-short baseline navigation using a Ferranti/ORE Trackpoint II system.

The majority of data used to assess the biological composition, zonation, and condition of the hard bottom areas within the study area boundaries are obtained using the ROV. Predetermined sites (Section 13.3) were surveyed using the ROV, providing continual footage and still photographs of the hard bottom surficial geology and topography and biological communities.

The height of the ROV above the bottom at each site is determined by factors controlling the resolution necessary to identify and classify the biotic communities and zones (e.g., water clarity, bottom topography and camera resolution). Generally, however, adequate coverage of the features requires a camera-to-subject distance of 2-5 meters (in relatively clear water). Closer approaches are necessary at frequent intervals to acquire high resolution video photographs. Ship time during Year III will be utilized as necessary for additional ROV surveys, including more video and still photographs, for dredge samples (Section 13.2.3), and for hook-and-line collections (Section 13.2.4).

Video tapes and photographs are reviewed on board the ship, when necessary, for making survey decisions and will be thoroughly reviewed during Years II and III. The objectives of the review are to identify benthic and nektonic organisms to the lowest feasible taxon, to describe habitat structure, biological communities, and biotic zonation, and to categorize the topographic features on the basis of biological and environmental factors and zonation (e.g., location on the continental shelf, depth range, vertical relief, habitat complexity, and the number and nature of benthic biotic zones).

13.2.3 Rock Dredge

Seventeen rock dredge transects and 17 sets of grab samples were made during the two ROV cruises. These provided small samples of the hard bottom fauna that inhabit the topographic features of the study area. These samples allowed for species collections and the identification of what may be the dominant occupants or substrate producers on the hard bottoms, especially where the habitats contain hard corals, sponges, or coralline algae. They will also be made available to the geological personnel on the project and may be used to augment the geological investigations.

The rock dredge has an opening which measures 0.70 by 0.32 m and a collection cage depth of 1.0 m. The mesh of the cage is 12.7 by 38.1 mm. The dredge is equipped with sharp, jagged edges around the mouth, so that collections can be made regardless of orientation. The grab samplers included one 0.25 m^2 Smith-McIntyre grab and one 0.25 m^2 box core.

13.2.4 Hook-and-Line

In order to acquire information on the species of some of the near-bottom nekton associated with the continental shelf hard bottoms in the study area, we collected fish using hook-and-line gear (and electric reels, where appropriate for deeper features). Some fish species may not be photographed during the ROV surveys, since they may avoid the noise or lights of the vehicle. Fishing was carried out during the evening or morning hours, and when other equipment could not be used.

Species identifications were made and recorded by experienced personnel using recent taxonomic literature. Fish stomachs will be made available to those involved in trophic studies. Stomachs were extracted and preserved for future examination.

13.2.5 Habitat and Community Characteristics

Biological Community Composition - Benthic communities on all surveyed topographic irregularities will be described based on a thorough examination of all color video footage, still photographs, rock dredge samples, and hook-and-line collections.

Video tapes will be thoroughly reviewed, documenting depth of sample footage, feature locations, species observed (or higher taxa, when necessary), apparent abundances, apparent bottom coverage (if applicable), associated organisms, and species interactions (when applicable). Data from rock dredge samples, and hook-and-line collections will also be included in community descriptions. It is expected that the latter techniques will provide samples of several of the dominant species of the features, allowing for positive identification of these species.

The resulting information will be synthesized into as complete a community description as possible. The presentation of results will include biotic zonation charts and cross sections, photographs of selected features, lists of observed taxa, and topographic feature community and zone descriptions.

Apparent and Relative Abundance - Though this is primarily a qualitative biological characterization, we will attempt to ascertain the apparent and relative abundance of conspicuous elements of the biological community.

Apparent abundances of nekton have, in the past, been evaluated on the basis of number of sightings of selected species per unit time of observation (e.g., Dennis 1985, for fish on the banks of the northwest Gulf of

Mexico). For hard banks and over hard bottom areas, as in this study, these data can also be obtained from ROV transect observations of coral colonies, alcyonacean and antipatharian corals, sponges, and other conspicuous epibenthic colonial and solitary species. The data can then readily be converted to measures of relative abundance (or relative density) of the species, if all other members of the group (e.g., hard corals as a whole) are also conspicuous:

$$\text{Relative abundance of species A} = \frac{\text{number of species A}}{\text{total number of all species of the group}}$$

In order to obtain these data, the investigators reviewing the video tapes of the ROV transects will score sightings of selected taxa and monitor video recording time on each transect. Abundances will then be reported as the number of sightings per unit time at each depth or hard bottom zone traversed by the ROV. For species which cannot be accurately counted, we will report abundances categorically (i.e., abundant, common, frequent, occasional, rare, or absent). These categories will be defined similar to Stark (1968). In this manner, not only can biotic communities and zones be more fully described, but comparisons can be made between topographic features of the region and study area as a whole as well as with locations elsewhere in the Gulf of Mexico.

13.2.6 Biotic Zonation

Biotic zone descriptions will require mainly ROV data. Video tapes will be reviewed, noting pertinent habitat characteristics of each feature, biotic composition of primary zones on the features, and the nature of transition zones between them. Included for each feature will be a description of crest depth, apparent zone extents, type and extent of vertical relief, bottom type, sessile benthic faunal assemblages, associated mobile epibenthos, associated nekton, species interactions, the presence and nature of algal nodules, the nature of outcrops, the presence of gas or other seepages, proximity and relation to the nepheloid layer, and any other characteristics pertinent to the description of biotic zonation.

Both the rock dredge and hook-and-line efforts will provide additional data that will be incorporated into the zonation descriptions. The rock dredge data are expected to help our characterization of the nature of the hard bottom (sediment and substratum type) and may provide specimens representing the primary space utilizers (especially corals, sponges and coralline algae). On the other hand, hook-and-line data may allow for a more complete description of the nektonic communities associated with the topographic features. While visual observations of nekton using the ROV will most likely provide the most information on populations associated with the features, fishing may result in the identification of species that are cryptic or that avoid the ROV noise or lights or remain outside the camera range (including some pelagic fish).

13.2.7 Associations with Environmental Parameters

It is likely that variations in the geologic structure of the topographic features and the physical and chemical regime of specific localities within the study area govern the nature of biotic assemblages present. Some of the factors likely to be of consequence in this study area are topographic feature crest depth (which is especially important to light penetration), surrounding depth, substratum type, amount of relief (which influences the number of hiding places for mobile organisms, light angle, etc.), temperature, salinity, particulate load of the water, proximity to the nepheloid layer, and seasonal variability of the four latter factors. We will correlate as many factors as possible with biotic composition and zonation patterns where they exist. The correlations will depend on the interaction of geologists and physical and chemical oceanographic personnel on the project and an integration of their characterization of the hard bottom study area with our own.

13.2.8 Comparison and Categorization of Features Within Study Area

For all topographic features described during Years II and III, qualitative comparisons will be made on the basis of habitat and community characteristics, biotic zonation and the factors most likely influencing biotic assemblages. Habitat differences may include the extent of outcrops, hard substratum type, sediment type, vertical relief, relative depth of the nepheloid layer, and crest depth. Community characteristics to be compared are species composition, apparent abundances, relative abundances, richness, and apparent diversity. Biotic zonation comparisons will be made with respect to the composition, number, extent, and depth distribution of zones, and the parameters that most affect the observed zonation. Where appropriate, quantitative comparisons will also be made.

The objective of the categorization effort is to provide a framework of feature characterization that will facilitate judgement by regulatory personnel as to the need for and the nature of protective regulations to be imposed on drilling and other activities around environmentally unique or sensitive habitats. Rezak and Bright (1983) developed a system of categorization for the submarine banks of the Texas-Louisiana continental shelf. The system is based upon both a geological characterization incorporating the structural expression of the banks (the nature of underlying structures, bedrock, and the caps of the banks) and biological characterization. The biological characterization involves recognition of the number of distinct biotic zones on each bank, the depth range of each zone and their biotic composition.

Using the above criteria, two geological bank categories were identified: mid-shelf bedrock banks and outer shelf bedrock banks with carbonate reef caps. Seven distinct benthic biotic zones were identified within four major categories:

A. Zones of major reef-building activity and primary production.

- I. *Diploria-Montastrea-Porites* Zone
- II. *Madracis* Zone and Leafy Algae Zone
- III. *Stephanocoenia-Millepora* Zone
- IV. Algal-Sponge Zone

B. Zone of minor reef-building activity.

- V. *Millepora*-Sponge Zone

C. Transition zones of minor to negligible reef-building activity.

VI. Antipatharian Zone

D. Zone of no reef-building activity.

VII. Nepheloid Zone

Based on previous work carried out on some of the features of the Tuscaloosa Trend region, their location on the continental shelf, preliminary analysis of side scan and subbottom data collected in this study, and impressions gained from our first two ROV cruises, we anticipate that some features may contain hard bottom communities comparable to those of the Antipatharian Zones and the Nepheloid Zones on outer shelf, midshelf and south Texas banks described by Rezak and Bright (1978, 1983). They apparently contain limited crusts of coralline algae, several species of hard corals, and sizeable populations of antipatharians. Some elements of Rezak and Bright's Algal-Sponge Zone may also be present (e.g. crustose coralline algae, algal nodules and encrusting sponges). Over areas covered by the nepheloid layer, where there is high turbidity, sedimentation, resuspension and resedimentation, there may exist rock outcrops or drowned reefs containing a depauperate and variable epifauna component. In the northwestern Gulf, these zones contained deep-water octocorals and hearty solitary stony corals.

Based on the above geological and biological criteria, Rezak and Bright (1983) divided the hard banks of the Texas-Louisiana outer continental shelf into five environmental groups:

1. South Texas midshelf relict Pleistocene carbonate reefs bearing turbidity-tolerant Antipatharian Zones and Nepheloid Zones (surrounding depths of 60 to 80 m; crests 56 to 70 m).

2. North Texas-Louisiana midshelf Tertiary outcrop banks bearing clear water, *Millepora*-Sponge Zones and turbid water-tolerant Nepheloid Zones (surrounding depths of 50 to 62 m; crests 18 to 40 m).

3. North Texas-Louisiana midshelf banks bearing turbidity-tolerant assemblages approximating the Antipatharian Zone (surrounding depths of 65 to 78 m; crests 52 to 66 m).

4. North Texas-Louisiana shelf-edge carbonate banks bearing clear-water coral reefs and Algal-Sponge Zones, transitional assemblages approximating the Antipatharian Zone, and Nepheloid Zones (surrounding depths of 84 to 200 m; crests 15 to 75 m).

5. Eastern Louisiana shelf-edge carbonate banks bearing poorly developed elements of the Algal-Sponge Zone, transitional Antipatharian Zone assemblages, and Nepheloid Zones (surrounding depths of 100 to 110 m; crests 67 to 73 m).

Like the scheme used by Rezak and Bright for the banks of the northwestern Gulf of Mexico, the categorization of the Tuscaloosa Trend topographic features will be based on the features' geological and biological characteristics, distribution, degree of development, and environmental controls.

13.2.9 Comparison of Features to Other Gulf of Mexico Topographic Prominences/Zoogeographic Affinities

The relationships between various hard bottom communities of the Gulf of Mexico and other western Atlantic hard bottom assemblages have been investigated by Bright *et al.* (1984) and Rezak *et al.* (1985). Though some offshore banks of the northwestern Gulf are decidedly tropical in nature (Rezak *et al.* 1985), near-shore benthos (both hard- and soft-bottom organisms) are subjected to relatively high seasonal variability, resulting in an affinity to the warm temperate, Carolinian Province of the east coast of the United States (Briggs 1974).

The extent of seasonal temperature and salinity variability, the influence of apparently aperiodic intrusions of the Loop Current (Barry A. Vittor and Associates 1985), and water turbidity may be found to significantly influence the biotic assemblages present on hard bottoms of the

Tuscaloosa Trend. These factors may especially influence the extent to which tropical epibenthos inhabit hard bottom features.

The objective of this portion of the study is to determine the biogeographic affinities of the outer continental shelf topographic features within the Tuscaloosa Trend region. Comparisons will be made primarily with the findings of other Gulf of Mexico benthic investigations, including those carried out in the northwestern Gulf of Mexico on salt-diapiric structures and on south Texas relict coralgal reefs (e.g., Rezak and Bright 1978; Rezak *et al.* 1983, 1985; Bright *et al.* 1984), in Mexico on reefs of the Yucatan and the southwestern Gulf of Mexico (Moore 1958; Logan *et al.* 1969; Rannefeld 1972), on shelf-edge prominences off eastern Florida (Avent *et al.* 1977), and on live bottom areas on the Florida shelf (for example, at the Florida Middle Ground; Hopkins *et al.* 1981).

Imperative to the understanding of biogeographic affinity is a knowledge of species composition of a community and seasonal variability with respect to both the community inhabitants and physical factors. We will acquire the majority of species composition data from ROV transect analyses. Furthermore, though we do not plan to acquire data on population variability, we expect to obtain physical and chemical data on seasonal variability near the topographic features from published literature and from other project investigators. These data will be used as indicators of biological seasonal variability and biogeographic affinity determinations will take them into account.

13.2.10 Community Health (Condition)

The evaluation of the health (or "condition") of hard bottom communities involves a diagnosis by experienced benthic ecologists and the subjective comparison of a given area to similar habitats that have been observed in the past. There are, however, several objective criteria that can be incorporated into this evaluation. These include the evidence of mass mortalities having occurred [e.g., sea grasses (Tutin 1938); sponges (Galtsoff 1940); sea urchins (Lessios *et al.* 1983, among others)], and consequently, abnormally high cover or abundances of atypical species (Hughes *et al.* 1987), the deterioration of individual organisms or colonies (e.g., zooxanthellae expulsion in corals under stress; Jaap 1979), storm impact

(Glynn *et al.* 1964, and many others), and human impact such as anchor damage (Davis 1977; Gittings and Bright 1986), other mechanical impact (Woodland and Hooper 1977), and pollution (e.g., solid wastes, hung and discarded fishing nets, etc.).

We documented all apparent abnormalities on sites surveyed using the ROV. This provides a record of both natural and human impacts on the hard bottom communities. We also took still photographs of apparent impacts. These data may be used as baseline data on community condition for future studies.

Ultimately, the overall condition of the communities will be assessed relative to hard bottom communities we have observed in the past. Emphasis will be placed on the criteria mentioned above and any other factors that may be determined as indicative of less than optimal growing conditions for the communities encountered.

13.3 Results

The results of the preliminary side scan and subbottom data analysis indicated a surprisingly diverse habitat. The features in this area included:

- wave fields (closely spaced, low relief waves on bottom)
- spaced ridges (spaced 100-200 m apart; if troughs exist, most seem to be in-filled with soft sediments)
- areas of patchy hard bottom returns
- ridges
- shorelines? (these may be previous still-stand erosional features)
- fields of large boulders or small "reefs"
- extensive high reflectivity, possibly hard bottom areas (black side scan records)
- fields of what appear to be small depressions in the bottom
- features of low topographic relief
- features of moderate topographic relief

- features of major topographic relief (some over 15 m tall; some are smooth topped, some knobby; some broad and some spire-like)
- wrecks and/or sunken oil platforms (two within study area, one of which is definitely a sunken platform)

We visited approximately half of the planned site locations in our July 1988 cruise, but had to delay completion of the cruise due to equipment problems. The survey was completed in September 1988. A prioritization scheme was developed to determine the order of visitation to the targets. This scheme took into account the target locations, relief of the targets, their depth, the nature of the features, and the apparent association between different features. Generally, we began with surveys of low targets such as wave fields and low topographic features and delayed the surveys of pinnacles and other high topographic features until several of the less heterogenous habitats had been surveyed.

Other activities planned for the ROV cruise were carried out during times when the ROV was not operating. These include:

- Sediment grabs in or across sediment aprons adjacent to moderate and major features and in areas of apparent hard bottoms and talus fields
- Rock dredges in sediment aprons and in areas of apparent hard bottoms and talus fields
- Hook-and-line fishing in areas of hard bottoms, pinnacles, and areas previously indicating abundances of fish over relatively level bottoms (i.e., on subbottom records).

13.4 Summary/Conclusions

Preliminary analyses of side scan and subbottom data that were done in order to develop a ROV cruise plan revealed a surprisingly diverse habitat within the study area. The ROV work was carried out in such a manner as to provide information on what may be a fairly large number of distinct biotic assemblages. Therefore, the ROV cruises included visits to locations that are thought to be representative of a number of sites within the study area exhibiting similar topographic characteristics. Results of these reconnaissance surveys will be presented in later reports.

13.5 Recommendations for Further Study

Because no biological data from hard bottom areas have yet been analyzed, we are not in a position to make recommendations for future work. Furthermore, we do not propose to make any changes to our initial proposal of work.

14.0 DATA MANAGEMENT AND DELIVERABLES

Gary A. Wolff

14.1 Introduction

The principal responsibilities of the data management group are the maintenance of a centralized data storage and retrieval system, the control and protection of the data system, the transmission of validated data to the National Environmental and Satellite Data Information Service (NESDIS) data bank in National Oceanic Data Center (NODC) format, National Geography Data Center (NGDC) or the format specified by NESDIS, and programming support for project scientists. In order to meet these requirements the data management section monitors and documents the flow of data from the initial sampling, analytical history, data entry, validation, and analysis to its final transmission and storage.

14.2 Methods

Data are received from components of the project on formatted data sheets, on-line data files or diskettes. As samples move through the processing procedure, a chain-of-custody is maintained so that the sample's location and status are continuously monitored. Table 14-1 shows the source and format of the data received from project tasks.

Several computer systems are used by data management in storing and processing the data, depending on the specific requirements. Diskette data are received in several micro formats (IBM Personal Computer, Macintosh) and transferred to VAX mainframe computers via a dedicated line with error checking data transmission software. Data are then transferred from the VAX to an AMDAHL computer through a BITNET line using system utilities. Data entry and processing are performed on all three systems (Macintosh, AMDAHL and VAX). Data sorting, merging, and statistical programming are primarily performed on the AMDAHL and Vax systems to use the speed and storage capabilities of the mainframes. The Macintosh is used primarily for graphics and table generation.

Table 14-1. Format and source of data received from project tasks.

TASK	FORMAT	SOURCE
SEDIMENTS		
HMW HC	Macintosh	Kennicutt
TRACE METALS	Macintosh	Presley
SEDIMENT ANALYSIS:		
Sediment Texture	Macintosh	Rezak
Total Organic Carbon	Macintosh	Kennicutt
Total Carbonate	Macintosh	Kennicutt
Carbon Isotope Ratios	Macintosh	Kennicutt
BIOLOGY		
MACROINFAUNA	Data Sheet	Harper
MACROEPIFAUNA	Data Sheet	Harper
DEMERSAL FISH TAXONOMY	Data Sheet	McEachran
FISH FOOD HABIT ANALYSIS	Data Sheet	Darnell
PHYSICAL OCEANOGRAPHY/ WATER COLUMN CHARACTERIZATION		
Currents	IBM Disk	Kelly
CTD	IBM Disk	Kelly
Dissolved Oxygen	IBM Disk	Kelly
Transmissivity	IBM Disk	Kelly
Nutrients	Data Sheet	Kelly
Meteorology	IBM Disk	Kelly
SATELLITE IMAGERY	Summary	Vastano
TOPOGRAPHIC FEATURES		
Geological	Summary	Sager/Rezak
Biological	Summary	Bright

After entering the data on-line, a cycle of validation is initiated through the appropriate principal investigator and the data management section to check for errors. With each cycle, the data are corrected by data management until they are error free. Validated data are then stored on computer files accessible to all project tasks.

Access to all data is provided each task with a centralized computer account. Components of the project are provided with a personal AMDAHL account which contains all the validated data files. The principal investigator is able to directly access and incorporate supporting data into his analysis as needed.

Validated on-line data are formatted and copied to magnetic tape and forwarded to the specified data bank. Included with the tapes are:

1. Letter of Transmittal - a form which briefly states the contents of the tapes which is signed by data bank staff personnel and returned to the data management group as verification that the tapes have been received.
2. Cover Letter and Copy of Letter of Transmittal - this is sent separately and informs the data bank that a tape is en route.
3. Tape Dump - a hard copy of the actual contents of the data contained on the tape.
4. Data Documentation/Data Format - a form which gives specific information on the sampling parameters (location, type of vessel, etc.) and describes the data's format and variables. These will follow the format specified by NESDIS/NGDC.
5. File List - identifies the sequential location of specific files contained on the tape.

Copies of these forms are kept by the data management section as well as the project manager for every data transmittal. The tapes are sent by certified mail in clearly marked mailing cartons which describe the contents. The certified mail receipt serves as verification that tapes were sent to the data bank and the returned certified postcard, as well as the letter of transmittal, verifies that the data bank received the tapes. A continuous monitoring of the data from validated data copied onto magnetic tapes to their arrival at the data bank is thus established.

The data management section generates and updates a monthly inventory listing of the status of each project investigator's samples and data files. This file contains information on the current status of each task's data and is used as a cross-reference among the data management section, the principal investigators and the data bank to ensure the project's data is completely transmitted and accurately identified.

A Report of Observations/Samples Collected by Oceanographic Programs (ROSCOP), which describes the data variables and collection parameters in an encodable form for the data base, is sent shortly after the conclusion of each sampling cruise to the COTR. An annotated chart showing the cruise trackline in the survey area accompanies the ROSCOP form. Appropriate abstract information is provided to the NEDRES office.

14.3 Results

Tables 14.2 - 14.4 summarize the status of all data collected during the first year (Cruise 1 and 2) and the pre-award cruise (Cruise 0). Some categories of data (satellite imagery, ROV) are received as a summary of the task's activities. Other data (meteorology) are not provided the first year.

Table 14-2. Data summary of Cruise 0.

TASK	CRUISE 0			
	Received	Validated	Formatted	Transmitted
SEDIMENTS				
HMW HC	X	X		
TRACE METALS	X	X		
SEDIMENT ANALYSIS:				
Sediment Texture				
Total Organic Carbon	X	X		
Total Carbonate	X	X		
Carbon Isotope Ratios	X	X		
BIOLOGY				
MACROINFAUNA	X	X		
MACROEPIFAUNA	X			
DEMERSAL FISH TAXONOMY	X	X		
FISH FOOD HABIT ANALYSIS				
PHYSICAL OCEANOGRAPHY/ WATER COLUMN CHARACTERIZATION				
Currents				
CTD	X	X		
Dissolved Oxygen, Salinity	X	X		
Transmissivity	X	X		
Nutrients	X	X		
Meteorology				
SATELLITE IMAGERY				
TOPOGRAPHIC FEATURES				
Geological				
Biological				

Table 14-3. Data summary of Cruise 1.

TASK	CRUISE 1			
	Received	Validated	Formatted	Transmitted
SEDIMENTS				
HMW HC	X	X		
TRACE METALS	X	X		
SEDIMENT ANALYSIS:				
Sediment Texture	X	X		
Total Organic Carbon	X	X		
Total Carbonate	X	X		
Carbon Isotope Ratios	X	X		
BIOLOGY				
MACROINFAUNA				
MACROEPIFAUNA				
DEMERSAL FISH TAXONOMY	X			
FISH FOOD HABIT ANALYSIS				
PHYSICAL OCEANOGRAPHY/ WATER COLUMN CHARACTERIZATION				
Currents				
CTD	X	X		
Dissolved Oxygen, Salinity	X	X		
Transmissivity				
Nutrients	X			
Meteorology				
SATELLITE IMAGERY				
TOPOGRAPHIC FEATURES				
Geological				
Biological				

Table 14-4. Data summary of Cruise 2.

TASK	CRUISE 2			
	Received	Validated	Formatted	Transmitted
SEDIMENTS				
HMW HC	X	X		
TRACE METALS	X	X		
SEDIMENT ANALYSIS:				
Sediment Texture	X	X		
Total Organic Carbon	X	X		
Total Carbonate	X	X		
Carbon Isotope Ratios	X	X		
BIOLOGY				
MACROINFAUNA				
MACROEPIFAUNA				
DEMERSAL FISH TAXONOMY				
FISH FOOD HABIT ANALYSIS				
PHYSICAL OCEANOGRAPHY/ WATER COLUMN CHARACTERIZATION				
Currents				
CTD	X	X		
Dissolved Oxygen, Salinity	X	X		
Transmissivity				
Nutrients	X	X		
Meteorology				
SATELLITE IMAGERY				
TOPOGRAPHIC FEATURES				
Geological				
Biological				

15.0 SUMMARY/SYNTHESIS

Rezneat M. Darnell

15.1 Background

The goal of the interpretation and synthesis effort is to reproduce a thorough ecological characterization of the study area in its spatial and temporal manifestations and toward further interpreting the system and its components in relation to major external controlling factors and influences. Of particular concern is the identification and possible quantification of key components and processes which constitute the primary structure of the entire system. This information should then be reduced, through a process of sophisticated simplification, so that it may be available in a format most useful for management purposes.

This effort will proceed through a series of logical sequential stages. The first step is to develop a thorough characterization of each individual study site including environmental parameters, biological composition, and dynamic relations, both physical and biological. The next step is to compare and contrast the different sites to determine similarities and differences with respect to the various descriptors. This permits the grouping of sites and characterization of communities. Interactions within and between community types must be analyzed in detail. Building further, it is necessary to consider interrelations between the regional ecosystem and external factors which influence the system. The final step involves identification of the primary components, processes, and external factors which determine the characteristics and dynamics of the functioning ecological system. The results will be displayed through models and other simplified visuals.

15.2 Approach

In order to achieve the goals of the synthesis effort, two approaches will be followed, and these will proceed simultaneously throughout the project. The first deals with data accumulation and information transfer among investigators; the second involves multidisciplinary problem solving. Each of these approaches will be addressed briefly.

15.2.1 Data Accumulation and Information Transfer

At an early date during the second year of the investigation the project synthesizer will request a meeting of all principal investigators on the project. Using data from the first annual report he will discuss goals and strategies of the synthesis effort. Specifically, he will distribute form sheets to each investigator for reporting information in a format most useful for preliminary synthesis efforts. For example, in relation to the macro-infaunal study, it would be extremely useful to obtain early information from each station concerning total density (number/m^2) and specific densities for each major group (gastropods, bivalves, polychaetes, amphipods, etc.). Such information could become available well in advance of final taxonomic identifications and before sophisticated statistical analyses have been completed. In like manner, early input of general sediment analyses would be desirable. On the other hand, the investigators studying demersal invertebrates and fishes need to know the area covered by each trawl in order to express their data in terms of absolute density. This information should flow from the project synthesizer back to the investigators. This two-way flow of information, initiated at the meeting, will be continued throughout the project by means of personal contact between the project synthesizer and the individual investigators during periodic meetings of the synthesizer with investigative subgroups. This will facilitate communication and permit the synthesis effort to develop a general picture of the ecological system which will come into progressively sharper focus with time.

15.2.2 Multidisciplinary Problem Solving

After careful reexamination of the RFP, the proposal, and some of the relevant literature, the project synthesizer has formulated a set of five major ecological questions which should be addressed by the project. These are listed as follows:

1. Ecosystem structure - What is the basic structure of the ecological system, and what major environmental factors determine this structure?
2. Pathways of flow - What are the primary pathways of flow of nutrients and energy, and can these be roughly quantified?
3. Seasonal events - How are the major seasonal events orchestrated, and to what extent can these be related to the physical forcing functions?
4. Estuary-shelf-slope relationships - Can the estuary-shelf-slope relationships be defined in greater detail?
5. Influences of the Mississippi River - Can the influences of the Mississippi River on the Mississippi-Alabama shelf be more thoroughly defined?

Each of these questions has been further factored into its components (Table 15-1). The list is not necessarily complete and is subject to revision during the life of the project.

In addition to the major ecological questions, the project synthesizer has formulated a list of major management-oriented questions which should be addressed:

1. Chemical pollutants - What are the background levels of the various chemical pollutants in the environment, and how do these relate to the living ecosystem components?
2. Sensitive biological areas - On a spatial and seasonal basis, can sensitive biological areas be identified and defined in terms of their sensitivities?
3. Human intrusion - Can actual or potential forms of human intrusion be defined in terms of their effects upon the biological and ecological resources?
4. Knowledge gaps - To what extent can we identify knowledge gaps or types of research which should be undertaken to provide a more thorough basis for environmental and resource management?

Table 15-1. Major ecological questions concerning the Mississippi-Alabama continental shelf area.

1. What is the basic structure of the ecological system, and what major environmental factors determine this structure?

   a. Definition and relationships of species assemblages.
   b. Composition and variation (spatial and temporal) within each species assemblage.
   c. Trophic structure of each species assemblage.
   d. Relationships of species assemblages to the physical, chemical, and geological factors.

2. What are the primary pathways of flow of nutrients and energy, and can these be roughly quantified?

   a. Development of simple transport and transfer models.
   b. Estimation of non-biological transport and transfers.
   c. Estimation of biological transport and transfers.
   d. Development of integrated budgets and models.

3. How are the major seasonal events orchestrated, and to what extent can these be related to the physical forcing functions?

   a. Definition of the seasonal physical events and their relationships.
      - Shelf circulation patterns
      - Wind patterns
      - Oceanic circulation patterns
      - River outflow
      - Storms
      - Sediment transport and turbidity
   b. Definition of the seasonal biological events and their relationships.
      - Spawning and larval transport
      - Migrations
      - Biomass density concentrations
   c. Determination of relationships of physical and biological events.
   d. Preparation of simple models demonstrating major seasonal linkages.

4. Can the estuary-shelf-slope relationships be defined in greater detail?

Table 15-1. Continued

a. Definition of estuary-shelf relationships.
b. Definition of shelf-slope relationships.
c. Preparation of simple models demonstrating the total pattern of relationships.

5. Can the influence of the Mississippi River on the Mississippi-Alabama shelf be more thoroughly defined?

a. Definition of water, sediment, and nutrient input to the area.
b. Definition of seasonal aspects of input and the controlling physical factors.
c. Relationships with the delta-built marshland and estuarine areas and their importance to the shelf system.
d. Development of simple models depicting the relationships of the Mississippi River with the shelf study area.

Again, this list is subject to revision. The point of this approach is to establish major targets early in the study so that historical and newly acquired information can be constantly focused upon answering the questions of interest. If some of the needed information is not being obtained, this should show up early enough for possible mid-course corrections. Furthermore, early in the project each investigator will understand how his data input fits into the broader picture, and feedback suggestions should enrich the quality and coverage of the final synthesis product.

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