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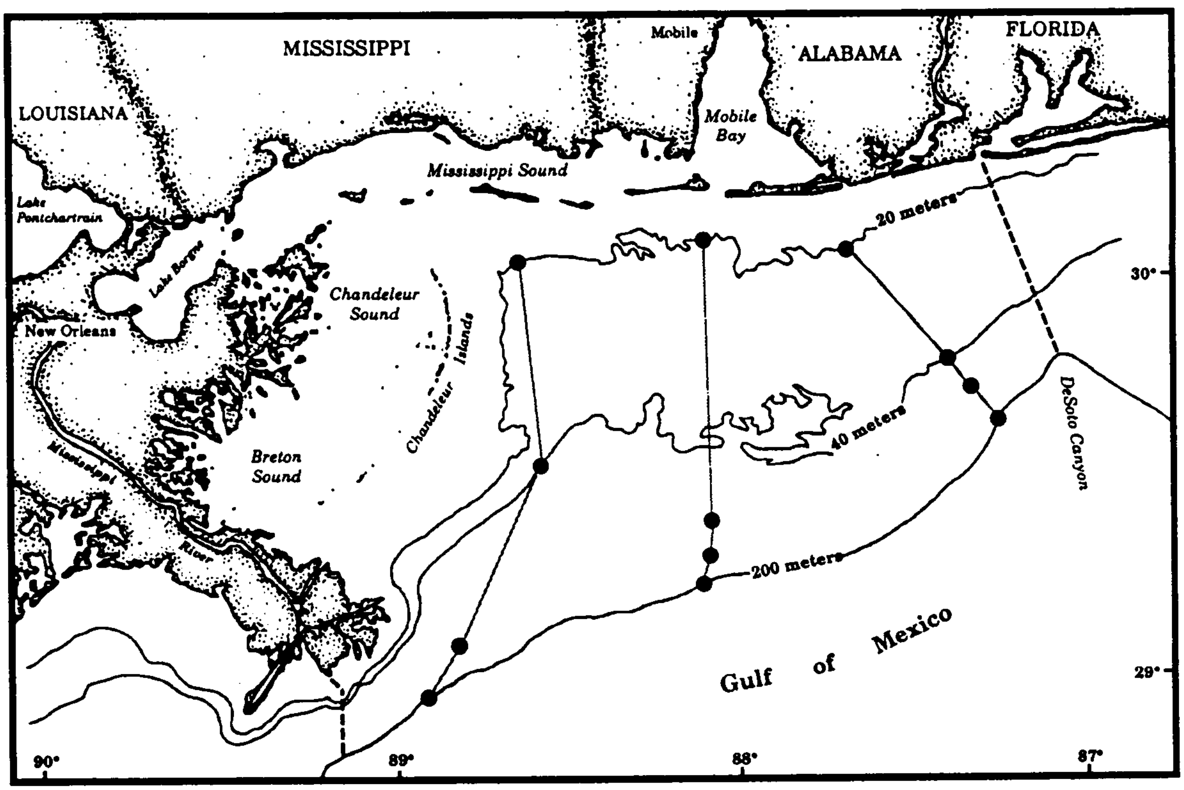
MMS 89-0095

Mississippi-Alabama Marine Ecosystem Study Annual Report: Year 2

Volume I: Technical Narrative



U.S. Department of the Interior
Minerals Management Service
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Mississippi-Alabama Marine Ecosystem Study Annual Report: Year 2

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 five cruises between March 1987 and February 1989 along three north-south transects across the continental shelf of Mississippi and Alabama. Four stations in depths of approximately 20, 40, 100, 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 ($n\text{-}C_{23}$ - $n\text{-}C_{33}$) with a possible minor planktonic input ($n\text{-}C_{15}$ - $n\text{-}C_{19}$). 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 concentrations of hydrocarbons. Observed variations in sediment chemistry between samplings is possible 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. Fish food analyses have been completed for 2,500 specimens representing 42 fish species. Adequate depth, transect, and size class representation is being attempted. Types of results being obtained are illustrated for the longspine porgy, *Stenotomus caprinus*. The food of this species is primarily polychaetes and small crustaceans, with significant amounts of organic detritus (mainly polychaete mucous mixed with sedimentary materials). The percentage of polychaetes is highest in young fish, nearshore areas, and on muddy/sandy bottoms off Mobile Bay and near the Mississippi River Delta. The percentage of crustaceans increases with age, distance from shore, and proximity to De Soto Canyon.

An organizational plan of the Summary/Synthesis chapter is presented and discussed. The four major headings include: The Natural System, Human Effects, Sensitive Biological Areas, and Knowledge Gaps. Heavy emphasis will be placed upon understanding the composition and process of the natural system in relation to the external driving mechanisms. Historical data suggest that there are two basic scenarios for control of the shelf ecological systems: those which operate in regular cyclic fashion versus those which involve massive episodic intrusive events. Efforts will be made to examine the ecological systems from both perspectives.

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ACKNOWLEDGEMENTS

The assistance of the research staff, secretaries, clerks, student technicians, draftspersons, and other numerous support staff needed to complete the many tasks associated with this study is appreciated.

The assistance of the Texas A&M Research Foundation personnel and the Minerals Management Service is most appreciated. Ms. Joanna Fritz and Ms. Debbie Paul organized, typed, and edited the manuscripts for this project and their work is greatly appreciated.

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 and 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 impacts of man's activities in the area. This relatively 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 involved a field effort to fill data gaps identified by the Minerals Management Service (MMS) that built on the information base required by MMS. The field effort will be followed by a comprehensive synthesis effort that integrates the results of the literature study and the results of the field sampling phase of the program.

Field sampling was 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 the field phase were 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.

Year 2 geologic mapping was conducted on two cruises aboard the R/V TOMMY MUNRO, 88-MMS-G2 and 88-MMS-G2A, the former during 2-5 August 1988 and the latter 30 August - 7 September 1988. Side-scan sonar and subbottom profiler data were collected on these cruises for two main purposes: (1) to obtain detailed side-scan sonograms of interesting features mapped during the Year 1 surveys, and (2) to obtain reconnaissance data from areas to the east and west of the Year 1 survey block thought likely to contain additional hard bottom and topographic feature sites. Six sites were surveyed in Years 1 and 2. Four detailed surveys were conducted of features within Year 1: (1) the drowned patch reef ("boulder field") area, (2) a section of the 40 fathom reef trend, (3) a linear ridge feature, and (4) a cluster of flat-topped reefs. The other two survey areas in Year 2 were designed to follow the 40 fathom (73 m) isobath to the east and west of the Year 1 survey block because many of the reefs mapped in that block were found near this depth.

Weather continued to be a problem during Year 2. One cruise was affected by a tropical storm and the other by Hurricane Florence. Nevertheless, most of the proposed areas were surveyed. All of the detailed surveys and most of the west addition survey were completed, but there was sufficient time only for three lines in the east addition area. In all, 19 nautical miles of detailed survey lines were obtained, with a side-scan half-swath-width of 100-200 m, in addition to 335 nautical miles of reconnaissance data using a 300 m half-swath-width.

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. 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. 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.

The temporal variations in sediment properties in the study area can be explained by various scenarios. Individual sediment components vary independently and are subject to a variety of different processes.

Sediments on the Mississippi-Alabama shelf are very dynamic and change on time scales varying from less than six months to more than two years. Inputs are complex and often independently driven. Removal processes are complex, constituent dependent and vary independently. Sediment properties vary by an order of magnitude or more over the two years of the study. Many of these variations can be directly related to variations in land derived inputs that are mediated by river outflow from the Mississippi River/Delta system as well as other rivers in the area. Hydrocarbon pollutant loading to sediments is primarily derived from fresh, unrefined petroleum closely associated with fine particulates derived from riverine transport. Aeolian transport and outflow from coastal bays appear to be minor influences.

In contrast to the view of sediments as relatively stable repositories of particulate matter, very dynamic interactions are apparent. Clearly if sediments are to be characterized temporal as well as spatial variations need to be considered. As an intimate part of the benthos as well as an interface with the overlying water column, these dramatic variations in sediment composition and character need to be assessed in light of ecological assessments of man's potential impact on these areas.

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 most 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.

Repeated sampling at the twelve transect stations reveals differences in sediment texture that in some instances are quite large. No single cause for these differences has been discovered as yet, but the relict nature of the shelf sediments in combination with one or more of the items listed above are most probably the reasons for the differences.

Polychaetous annelids were the dominant macroinfaunal taxon and constituted 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. There was a marked increase in numbers of species and individuals, and in biomass between the winter and summer cruises

Macroepifauna appeared to display a trend of increasing diversity across the shelf to the 150 m depth stations, then decreased in abundance seaward. There does not appear to be an abundance pattern; this may be more a function of sampling error than actual distributional differences. The numerically dominant macroepifaunal taxon (excluding heart urchins) at most stations was 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. As with the macroinfauna, the numbers of species and individuals increased between winter and summer in 1987.

During the second year of the contract the final two nekton sampling cruises (88-B-3 and 89-B-4) were completed. All of the specimens collected on cruises 87-B-1 and 88-B-2 were sorted, identified, measured, and weighed, and all of these data were entered onto a computer file, and the file was proofed to remove transcription errors. Nearly 4,000 specimens, representing 128 species and 49 families of fishes, were identified from the samples of Cruise 87-B-1. The third station along each transect yielded the highest number of individuals and species, and the fourth station along each transect yielded the lowest number of individuals and species. Transect C yielded the most individuals while Transect M yielded the most species of the three transects. About 3,500 specimens, representing 128 species and 52 families, were identified from samples of Cruise 88-B-2. The first station of each transect yielded the highest number of individuals and the third station of each transect yielded the highest number of species. Transect C yielded the most individual and Transect M yielded the highest number of species of the three transects. There was considerable variation is size of the catch and species composition both within stations (between replicates) and among the same stations (across the three transects) on both cruises (87-B-1 and 88-B-2).

Trophic studies have resulted in the explanation of over 2,500 specimens representing 42 species. The totals reveal that 24 species represent nearshore stations, 23 species represent the deepest stations. Four species occur at all four depths, six species appear at three depths, and 15 species occur at two depths.

Types of results expected from this study are illustrated by data from the longspine porgy, *Stenotomus caprinus*. The primary food of this species is polychaetes and small crustaceans. The percentage of crustaceans is highest among older individuals, at greater depths, and in the vicinity of DeSoto Canyon. Such information will be available from many species and will be interpreted in relation to food availability, sediment type, and other variables. From such information the trophic relations of the marine ecosystem will be reconstructed.

During the second year, the NOAA-09, 10, and 11 satellites were used to gather infrared sensing of upwelling sea surface radiance in the channel four or eleven micro band. Sixty-three pertinent scenes were selected between 26 September 1988 and 07 May 1989.

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° latitude and 10° longitude.

Analysis of the Year 1 survey data for the geological tasks is nearly complete. Mosaics were made of the side-scan sonar data, breaking the Year 1 survey block into 11 smaller blocks for presentation. The mosaics are overlain on a coordinate grid with 10 m bathymetry contours and lease block boundaries. An interpretation map of each of the 11 blocks were prepared, containing coordinates, lease block boundaries, geological sample stations, and a generalization of the reflectivity characteristics. The mosaics and interpretation maps are being assembled into an atlas.

The acoustic reflection characteristics of the seafloor in the survey area are complex. Twelve different types of reflection signals have been recognized and divided into three broad categories: (1) topographic features, which are primarily drowned reefs and ridges, (2) homogeneous seafloor with low to high acoustic backscatter, and (3) seafloor with patchy reflections that are irregularly shaped or are linear trends.

The areas of high reflectivity are mostly related to topographic features; e.g. most drowned reefs and ridges are associated with such areas. However, just as often the distribution of high reflectivity areas appears to be unrelated to topography. Ground truthing studies suggest that the reflectivity variations relate to sediment composition, perhaps the concentration of shell fragments. Furthermore, the restriction of wave-like linear trend patterns to the shallowest part of the survey suggests that large storm waves may play a role in sorting and distributing the sediments.

Drowned reef features and associated high reflectivity areas are found mainly at 105 m, 60-70 m and shallower depths. This distribution implies that reefs at each depth formed at a different stage of the Holocene rise in sea level. Each perhaps represents a still stand in the transgression.

The analysis of Year 2 data is proceeding as follows: (1) bathymetry points were digitized and merged with navigation; and (2) side-scan sonograms will be rephotographed and made into mosaics this coming year. A preliminary study of the records from the east and west additions shows a distinct difference between these and the Year 1 survey data. Whereas the same type of topographic features and reflectivity variations were noted, the concentration of drowned reefs, ridges, and hard-bottom zones were less. Both survey areas from Year 2 studies are characterized by relatively featureless stretches of seafloor.

Biological assemblages dominated by tropical hard bottom organisms and reef fishes occupy a variety of topographic features that exist between 60 and 110 m in the north eastern Gulf of Mexico between the Mississippi River Delta and the DeSoto Canyon. The origins of the carbonate features vary. Some are small, isolated, low to moderate drowned reefal features or outcrops of unknown origin. Some appear to be hard substrates exposed by erosion during sea level still-stands along late Pleistocene-early Holocene shorelines. Others appear to be small reefs that existed near these shorelines. The largest features appear to have been offshore reefs. Formation of the largest features probably occurred prior to the Holocene Transgression. Some additional growth of these features and growth of other smaller reefs on exposed substrates may have taken place during the early transgressional period. The structure of the summits of some reefs may also have been modified by Holocene erosional events following their initial period of growth (namely, the flat-topped reefs). Most currently appear to be deteriorating under the influence of bioerosional processes.

The hermatypes that contributed to the development of these structures probably included coralline algae, reef-building corals, bryozoans, foraminiferans, and molluscs, among others. Present-day production of calcium carbonate is probably limited to an impoverished calcareous algae population on features above 70-75 meters. Features below this depth can most likely be considered completely drowned reefs.

The topographic features in the northeastern Gulf may be of similar age and origin to those that exist in a number areas along the outer continental shelf of the Gulf of Mexico and the east coast of the United States. The depth ranges of many of these features are similar, and most are non-growing reefs inhabited by tropical to warm temperate, hard bottom organisms most commonly found below the depths of living coral reefs.

Present-day biological assemblages on features in the northeastern Gulf are dominated by suspension feeding invertebrates. Populations are depauperate on features of low topography, those in habitats laden with fine sediments, and at the base of larger features (where resuspension of sediments limits community development). On larger features, the diversity and development of communities appears to depend on habitat complexity, that is, the number of habitat types available to hard bottom organisms. On reefs containing extensive reef flats on their summits, there are rich assemblages distinguished by a high relative abundance of sponges, gorgonian corals (especially sea fans), crinoids, and bryozoans. Due to the generally accordant depth of flat-topped reefs (62-63 m), coralline algae are also in abundance. Other organisms on reef flats include holothurians, basket stars, and myriads of fish (mostly the roughtongue bass, *Holanthias martinicensis*). On reefs lacking this reef flat habitat, as well as on reef faces of flat-topped features, the benthic community is characterized by a high relative abundance of ahermatypic corals (both solitary and colonial scleractinians). Other frequently observed organisms on these rugged, often vertical reef faces include crinoids, gorgonians, sea urchins, and basket stars.

Human impact in these environments appears to be minimal at present. Discarded debris, though present at many sites, was not abundant, and therefore poses little threat to the environment. Cables and ropes can affect shallower reef communities, but probably have little impact at these depths once they become tangled on or lodged against reefal structures. Fishing pressure on these relatively small features may reduce the population of the larger, commercially important species, and may explain the abundance of smaller individuals of unprofitable species on heavily fished reefs.

In analyzing the composition and dynamics of the Mississippi-Alabama shelf marine ecosystem as part of the summary/synthesis task of this study, special attention is being given to natural variation of two types: normal, regular seasonal changes and dramatic episodic changes due to major physical intrusions (especially due to storms, heavy river outflow, and loop current intrusions) for which there is already some evidence. Attention is being given to the ecological setting, cyclic and episodic events, ecosystem dynamics, estuary/shelf/slope relationships, and influence of the Mississippi River. Attention is also being given to human effects including effects of engineering activities, commercial and recreational fishing, ship traffic, and oil and gas activities, as well as changes in the chemical environment. Sensitive biological areas are being identified. Historical literature is being reviewed as background for interpretation of newly acquired knowledge. The concern here is to produce a sophisticated overview of the whole system with special attention to composition, variation, and dynamics.

2.0 INTRODUCTION

James M. Brooks, Charles P. Giammona, and Rezneat M. Darnell

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 man's 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, dredge dumping, 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 its 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 literature data and produced a summary report that made a good 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 this two year field effort to fill data gaps identified by the Minerals Management Service and that builds on the information base required by MMS to make petroleum development management decisions. The field is followed by a comprehensive synthesis effort that integrates 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 of coastal zone resources for the Central Gulf states area.

Field sampling is designed to characterize dominant physical and chemical processes on the Outer Continental Shelf 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.

This second year of the field effort consisted of field sampling cruises to further characterize the biology and chemistry of the OCS, continued current measurements, and biological reconnaissance of continental slope topographic features. Second year sampling strategies were 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 but 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, 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 research vessels used on this project. 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.

The principal investigator for High Molecular Weight Hydrocarbons is Dr. Mahlon C. Kennicutt II. Dr. Kennicutt is also in charge of Sediment Texture, Total Carbonate, and Carbon Isotope Ratios. Dr. Bobby J. Presley is the principal investigator for the Trace Metals. The principal investigator for Sediment Analysis is Dr. Richard Rezak. Dr. Donald E. Harper is the principal investigator for Macroinfauna and Macroepifauna. The principal investigator for Demersal Fish Taxonomy is Dr. John McEachran. Dr. Rezneat M. Darnell is responsible for the Demersal Fish Food Habit Analysis as well as the overall program Summary/Synthesis effort. The principal investigator for Physical Oceanography/Water Column Characterization is Mr. Francis J. Kelly, Jr. Dr. Andrew Vastano is the principal investigator for Satellite Imagery. The principal investigators in charge of Geological Topographic Features Characterization are Dr. William Sager, Dr. Ervan G. Garrison, and Dr. Richard Rezak. Drs. Tom Bright and Stephen Gittings are the principal investigators for Biological Topographic Features Characterization. The principal investigator for Data Management is Dr. Gary Wolff. Dr. William W. Schroeder is serving as a consultant on the project.

2.2 Study Objectives

The general objectives of this study are:

1. TO BIOLOGICALLY CHARACTERIZE THE HARD BANKS LOCATED ON THE OUTER SHELF OF THE STUDY AREA. Biological reconnaissance of hard bottom features on the outer continental shelf characterized the hard bottom with respect to habitat, biological community composition, structure and zonation. The hard bottom communities were differentiated from those of other oceanic topographic prominences in the Gulf of Mexico. Topographic features were described based on biological factors and zonation and correlated with environmental factors such as 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. As noted above, cruises over two years within the study area corroborate information regarding seafloor topography and have extended our knowledge on hard bottoms and topographic high areas in the region. The extended 200 m sampling scheme is providing new information on the shelf break region.

4. TO EVALUATE THE PRESENCE OR ABSENCE OF LIVE BOTTOM AREAS IN THE MOBILE AND NORTHERN VIOSCA KNOLL LEASING AREA. The data for this objective were collected during biological and geological reconnaissance cruises in this study effort and is resulting in habitat characterization and the determination of the extent of live bottom areas. It is providing a stronger understanding than any current information for these poorly known areas.

5. TO STUDY CIRCULATION PATTERNS AND DRIVING FORCES, ESPECIALLY DUE TO THE LOOP CURRENT AND AROUND THE DESOTO CANYON, INCLUDING METEOROLOGY, HYDROGRAPHY, CURRENTS, SEA STATE, AND FRESHWATER DISCHARGE. State-of-the-art satellite imagery and physical oceanographic spectral analysis techniques are being merged to increase the understanding of physical processes in the area as part of the Year 3 synthesis effort.

6. TO STUDY THE OCCURRENCE AND EXTENT OF THE NEPHELOID LAYER. Information on the nepheloid layer is being integrated from physical, chemical, biological, geological, and reconnaissance sampling tasks.

7. TO INVESTIGATE THE EXTENT AND SIGNIFICANCE OF HYPOXIA ON THE SHELF. Information on hypoxia has been collected and is being integrated with our own experiences in the surrounding study area.

8. TO STUDY THE FATES OF POLLUTANTS ASSOCIATED WITH SHELF ACTIVITIES, ESPECIALLY PETROLEUM EXPLORATION AND PRODUCTION. The sampling scheme produces data that is being integrated with existing data bases as part of the summary/synthesis task. In addition, our own experiences will allow us to provide better insights to these processes.

9. TO DEFINE SHELF BENTHIC COMMUNITIES WITH EMPHASIS ON HABITATS NOT PREVIOUSLY DESCRIBED AND NEAR SLOPE ENVIRONMENTS. Special attention is being given to two types of natural variation: normal seasonal changes and episodic changes. An attempt is being make to integrate this with anthropogenically-induced changes.

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 data collected from cruises will help construct trophic relationships of the marine ecosystem within the study area.

2.3 Overview of the Study Area

The east Mississippi Bight, extending from the Chandeleur Islands and Mississippi River Delta eastward to the Alabama/Florida border and seaward to a depth of 200 m, occupies an area of approximately 20,000 km^2. It is floored by an extensive sand sheet which gives way to the west and in deeper water to silts and clays. Carbonate deposits are known from the De Soto Canyon area in the east and locally around outcrops and other topographic features of the outer shelf. In depths of less than 60 m, the bottom is flat and largely devoid of outcrops except for a limited area at a depth of about 40 m off Mobile Bay (M/V OREGON report for cruise No. 72, 7 December 1960). Beyond a depth of 60 m, however, outcrops and other topographic features appear in some abundance. Submarine observations by Shipp and Hopkins (1978) have revealed large flat limestone slabs lying on the surface around the head and sides of De Soto Canyon. Ludwick and Walton (1957) described a complex zone of topographic prominences in the depth range of 76-104 m south of Mobile Bay. Of particular interest was a series of sharp pinnacles with average relief of about 9 m (30 ft.). Detailed study revealed these to be remnants of drowned coralline algal reef formations which are now colonized by a diverse fauna dominated by polychaetes, mollusks, echinoderms, sponges, hydrozoans, and other invertebrates. Sediments of the adjacent seafloor were found to be high in carbonate content and rich in foraminiferal species. The photosynthetically active reef was apparently developed in the Pleistocene during periods of lower sea stands and possibly warmer waters.

Water circulation and sediment dispersal have recently been discussed in detail by Dinnell (1988). On the basis of historical hydrographic information and more recent current meter data, he concluded that the persistent westerly flow along the inner shelf during all seasons represents the northern portion of cyclonic circulation cells. This flow is interrupted, particularly during the winter, by aperiodic reversals in relation to cold fronts passing through the area. Peak current speeds were found to exceed 0.3 m/s in either alongshore direction. Wave-induced sediment resuspension and advection by subtidal bottom currents transport fine sediments along the inner shelf. Dinnell (1988) further concluded that during high wave conditions sediment resuspension can occur in depths out to 40 m and that highest wave conditions (particularly those associated with hurricanes) may resuspend sediments in depths up to 80 m. Outer shelf and upper slope sediments may be resuspended by indirect influence or by direct intrusions of the Gulf Loop Current. Huh et al. (1981) demonstrated intrusion of Loop Current water onto the West Florida shelf and measured current speeds of 0.2 m/s. Using mathematical models, Pickett and Burns (1987) estimated that nearshore current speeds (8-10 miles off Pensacola Bay) during hurricane Frederick reached 1.0 m/s.

Using satellite imagery, Russell (1977) studied the influence of Mississippi River water on the area during flood periods. With the Bonnet Carré Spillway closed, Mississippi River water extended eastward from the Delta distributaries to De Soto Canyon, but it remained largely south of the lower level of the Chandeleur Islands. However, when the Bonnet Carré Spillway was opened, turbid water from the Mississippi River passed through Lakes Pontchartrain and Borgne and extended out from Cat Island Channel to De Soto Canyon, covering the entire southwest half of the continental shelf. Clearly, major episodic events including the passage of cold fronts, floods, hurricanes, and intrusions by the Gulf Loop Current exert major influences on the shelf environment, interrupting the normal seasonal progressions of events.

Biological features of the Mississippi Bight area have been discussed by numerous authors, most prominently by Defenbaugh (1976), 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 (Roitmayr 1965). For these reasons it is considered biologically and ecologically unique and a major faunal area in its own right.

Little has been published on the effects of episodic events upon the biota of the shelf area, but some insight may be gained from the study of Russell (1977). He found that during periods of flooding the inshore bottomfishes appear to disperse into deeper offshore waters. For example, under normal conditions, Atlantic croakers are seldom caught in depths exceeding 76 m, but during heavy spring floods when much freshwater entered the nearshore shelf, croakers were taken to depths of 171 m, and highest concentrations occurred in the depth range of 76-151 m. Whether this dispersal resulted from increased suspended silt, decreased salinity and temperature, or a combination of these factors could not be determined.

The discovery by Ludwick and Walton (1957) of deepwater pinnacles and the accompanying pinnacle fauna carries interesting zoogeographic implications. The outer shelf off Alabama may now be viewed as providing habitat for both transient and permanent hardbottom-related fauna. This habitat may be colonized by West Indian species brought in by the Loop Current or by outer shelf reef fauna from Texas and Louisiana to the west or from Florida to the east and south. Thus, the pinnacles may have served as a source of live bottom and reef fauna for the rest of the northern Gulf outer shelf or as a stepping stone for along-shelf colonization.

3.0 FIELD SAMPLING AND LOGISTICS

Roger Fay, William Sager, and William W. Schroeder

3.1 Overview

During the second year of the project all biological/chemical characterization cruises were completed, as well as the second geological characterization cruise. In addition to completing the first topographic features study utilizing the ROV, the second topographic features study also using the ROV (originally planned for the final contract year) was completed during Year 2. Current meters deployed during Year 1 were serviced so as to provide continuous data records at the mooring sites, and an additional two moorings were deployed during the second year. The complete suite of biological and chemical samples collected during the first year's study were again obtained in Year 2.

The study area, vessel, navigation, etc. were unchanged from Year 1, and the reader is referred to the Year 1 Annual Report for detail on those aspects of the field program. Refer to Figure 3-1 and Table 3-1 for the locations of the sampling sites.

3.2 Cruise Summaries

3.2.1 ROV Cruises 1 and 2

The first topographic features study utilizing the ROV to investigate geologic features identified during the first year's study was divided into two cruises, ROV 1 and ROV 2. The two cruises, separated by a period of approximately two months, were necessary in order to accommodate the second year geological study in between these two cruises (allowing for scheduling conflicts with the ship and cruise personnel to be resolved) and to permit repair and debugging of the ROV systems.

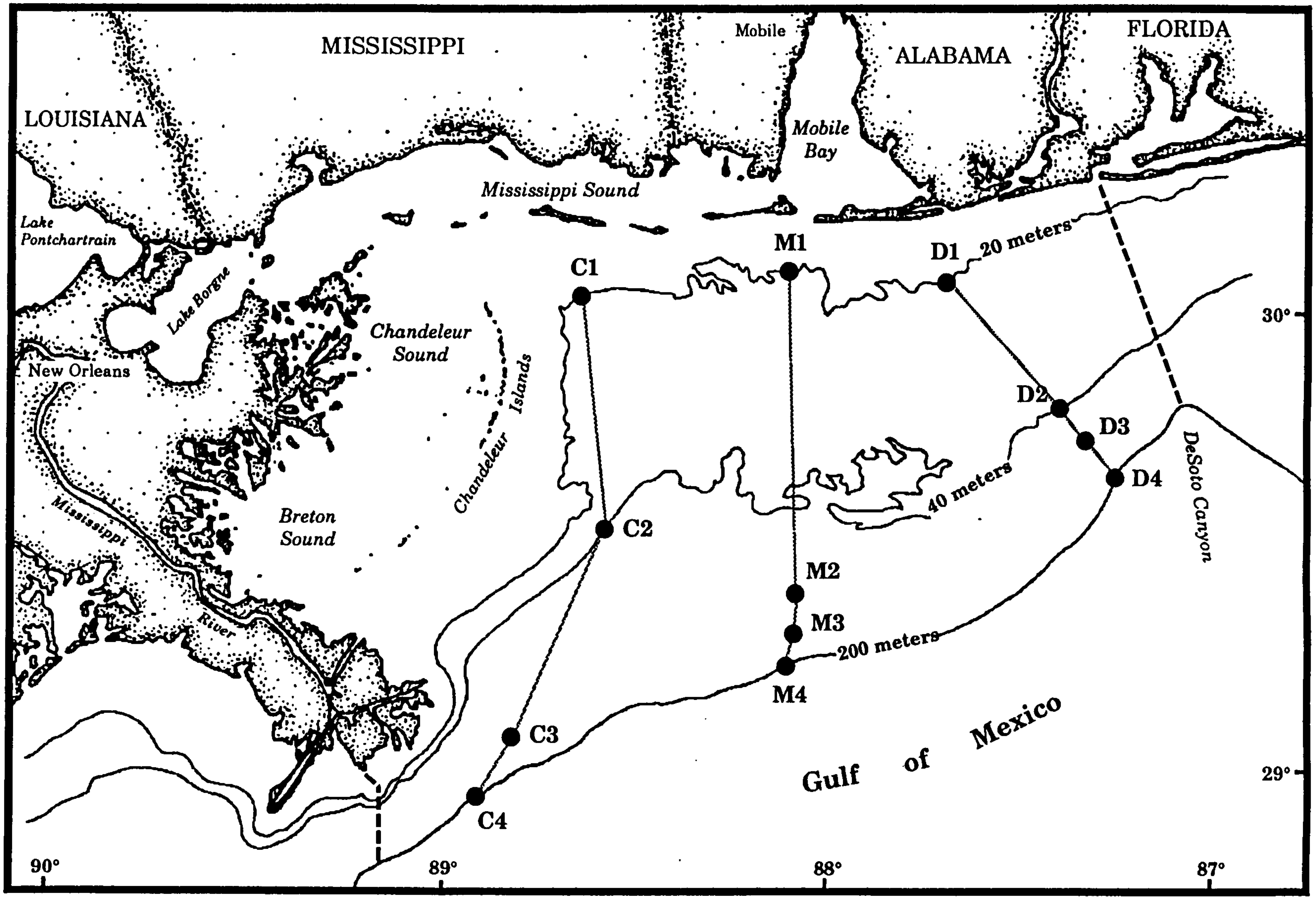


Figure 3-1. Sampling station locations (map).

Table 3-1. Sampling station locations (latitude/longitude).

OCTOBER 87, CRUISE 1

STATION	DATE	TIME (GMT)	COORDINATE 1	COORDINATE 2	BOTTLE DATA COLLECTED?
C-1	9/29/87	3:40	30 02.11 N	88 38.08 W	YES
C-2	10/5/87	5:05	29 26.85 N	88 34.95 W	YES
C-3	10/4/87		29 04.94 N	88 45.51 W	YES
C-4	10/4/87	15:00	28 56.60 N	88 54.11 W	YES
C-1-2	10/5/87	10:15	30 00.80 N	88 37.21 W	NO
M-1	9/29/87	10:15	30 03.42 N	88 07.10 W	YES
M-2	10/2/87	20:15	29 24.00 N	88 07.00 W	YES
M-3	10/3/87	6:00	29 16.30 N	88 06.50 W	YES
M-4	10/3/87	2:20	29 14.90 N	88 07.28 W	YES
D-1	9/29/87	15:50	30 04.05 N	87 41.67 W	YES
D-1A	9/29/87	19:40	29 55.78 N	87 31.04 W	NO
D-2	9/29/87	21:15	29 48.00 N	87 22.80 W	YES
D-2A	10/2/87	14:30	29 50.00 N	88 30.00 W	YES
D-2B	10/2/87	18:25	29 37.00 N	88 18.60 W	YES
D-3	9/30/87	2:00	29 42.08 N	87 20.16 W	YES
D-4	9/30/87	5:10	29 40.50 N	87 16.00 W	YES

3.2.1.1 Overview ROV-1

Cruise 88-MMS-ROV-1 was conducted aboard the R/V TOMMY MUNRO (chartered from the Gulf Coast Research Laboratory). The cruise was scheduled from 14-28 July 1988. The objective was to visit as many of the different types of features observed on side scan sonar records (collected on cruises 87-MMS-G1 and 88-MMS G1A) as possible. ROV surveys were to be carried out on these features in an attempt to determine biotic assemblages, habitat characteristics, zonation, community condition, and environmental controls. Other sampling at the sites was to include bottom grabs, rock dredges, light transmissivity, and hook-and-line fishing (light transmissivity measurements could not be carried out due to equipment problems).

3.2.1.2 Personnel ROV1

The scientific crew consisted of four scientists from TAMU Oceanography, two electronics technicians from TAMU, a visiting scientist from Dauphin Island Sea Lab and one MMS Observer. All performed admirably. Special note should be made of the untiring efforts of Mike Cooke and Dave Murphy, who often worked back-to-back watches in order to keep the ROV operational. Their expertise and dedication is not only essential, but much appreciated.

Name	Affiliation
Steve Gittings	TAMU-OCNG/Chief Scientist
Ian MacDonald	TAMU-OCNG
Roger Fay	TAMU-GERG
Dan Wilkinson	TAMU-GERG
Will Schroeder	University of Alabama
Mike Cooke	TAMU-OCNG/Electronics Tech.
Dave Murphy	TAMU-OCNG/Electronics Tech.
Bob Rogers	MMS Observer

3.2.1.3 Cruise Detail ROV1

S. Gittings, I. MacDonald, M. Cooke, and D. Murphy left College Station on 14 July 1988 and began to mobilize for two days of test operations on 15 July. R. Fay and D. Wilkinson flew to Biloxi on 15 July. Mobilization was completed on the morning of 17 July. The ROV was tested in 8 m of water about 0.5 km inside Horn Island on 17 July. A number of problems were encountered. One flood light leaked, one thruster was lost, one electronics cannister flooded, and the ROV tracking system failed to operate correctly. We also found it difficult to operate into currents that would be expected to be typical for this area.

On 18 July, we had a debriefing to discuss problems and solutions, and then headed offshore to 29°50.54'N, 88°32.96'W (88 feet deep) to test the system offshore. We anchored with the ship heading down current with a 1-2 kt. current. It proved difficult to navigate the ROV away from the ship in the current. It was even more difficult to recover the system, which drifted helplessly across the bow on surfacing from the dive. We finally were forced to pull the ROV in by its tether. We found that this tether is sufficient for pulling the system to the point of recovery and that it is preferable to sending a swimmer overboard to attach a lifting cable. If it ever becomes necessary to send a swimmer overboard, he/she should wear a tethered live vest, flippers, mask, and snorkel.

Problems on the second test dive included losing the focus on the video camera and the strobe for the stereo camera, and the failure of the tracking system to operate. We found that a two-point anchoring operation is preferable to drift surveys in rugged areas and to singly or three-point anchoring. The optimal ship orientation is cross-current with the current coming from the starboard if operating from the port side. If operating from the stern, the best ship orientation would be into the current.

Parts were purchased on 19 July to repair the camera and strobe. Another debriefing was held to discuss ROV problems, ship operations, ROV deployment and recovery operations, and other sampling protocol. We put to sea at 1330 on 19 July. A summary of the activities at each site is given in Appendix D.

At 1644 on 22 July, the ROV developed video problems, making underwater navigation of the unit impossible. The electronics technicians began working on the problem immediately. At approximately 2400 hours, they were told to get some sleep before continuing. During the ROV downtime, rock dredges and Smith-Mac grabs were made on future ROV sites. We also fished a shoreline feature that previous subbottom records suggested might have a large population of bottom fishes. In fact, large numbers did exist, but pelagic fished (king mackerel) consistently appropriated the catch before it could be landed. Fortunately, some paid for it with their lives.

At 1400 on 23 July, it became apparent that we did not have the parts required to repair the ROV at sea. We decided to interrupt the cruise. On land we could make repairs to the ROV, order or fabricate more spare parts, send a faulty laser in to Deep Sea Power and Light for repair, process film, and adjust camera exposure settings, if necessary.

3.2.1.4 Overview ROV2

Cruise 88-MMS-ROV-2 was conducted aboard the R/V TOMMY MUNRO (chartered from the Gulf Coast Research Laboratory). The cruise was scheduled from 21-27 September 1988. The objective was to visit various types of hard bottom features observed on side-scan records collected during cruises 87-MMS-G1 and 88-MMS-G1A. We finished the reconnaissance sequence proposed for cruise 88-MMS-ROV-1 (14-23 July 1988), which was terminated due to equipment problems. ROV surveys were conducted on these features in an attempt to determine biotic assemblages, habitat characteristics, zonation, community condition, and environmental controls. Sampling included bottom grabs and rock dredges. These ancillary samples were limited on this cruise because samples of these types were taken at most of the planned reconnaissance sites during the first ROV cruise.

3.2.1.5 Personnel ROV2

The scientific crew consisted of four scientists from Texas A&M University, Department of Oceanography (TAMU-OCNG), two electronics technicians from TAMU, and two Minerals Management Service (MMS) observers. The scientific personnel gratefully acknowledge the efforts of Mike Cooke and Dave Murphy, whose efforts made the ROV surveys successful, and the crew members of the R/V TOMMY MUNRO, who helped in nearly all phases of the operation. Following is a list of the crew and their respective institution affiliation:

Name	Affiliation
Steve Gittings	TAMU-OCNG/Chief Scientist
Ian MacDonald	TAMU-OCNG
Roger Fay	TAMU-GERG
Ed Baxter	TAMU-GERG
Mike Cooke	TAMU-OCNG/Electronics Tech.
Dave Murphy	TAMU-OCNG/Electronics Tech.
Gary Goeke	MMS Observer
Richard Bennett	MMS Observer

3.2.1.6 Cruise Detail ROV2

All scientific and technical personnel travelled to Biloxi, Mississippi on 21 September 1988, arriving at approximately 2200. On 22 September, the ship was mobilized and all systems were tested and found to be operational. We departed Biloxi at 2245 on 22 September, arriving at our first ROV station (ROV-8) at 0700 23 September.

A cruise meeting was held at the first station. Watches were set up 12 hours on, 12 hours off. Noon to midnight watches were drawn by I. MacDonand, R. Fay, M. Cooke, and R. Bennett. Midnight to noon watches were drawn by S. Gittings, E. Baxter, D. Murphy, and G. Goeke. Other topics covered during the meeting were deck safety and ROV operations.

Our plans were to survey sites using a two anchor mooring system, a crossing current from starboard, and deployment of the ROV from the port side of the ship. At ROV site 8, the stern anchor had to be sacrificed after it snagged a reef on the bottom. A spare anchor was rigged and we surveyed site ROV-9 using a two-anchor mooring. The stern anchor again had to be sacrificed after a snag, forcing us to rerig the ROV to operate from the stern and mooring by use of the bow anchor only. All other sites were surveyed in this manner. Fortunately, we did not experience sufficient ship drift on anchor during any ROV dives to endanger the operation by snagging the ROV on submerged reefs.

We had limited trouble with the ROV functions. The camera tilt and lasers malfunctioned at ROV-8. We set the cameras in a fixed position that was optimal for stereo photography and surveyed sites ROV-8 through ROV-12 in this manner. The problem was repaired at site ROV-13. Sites ROV-13 through ROV-18 were surveyed with laser and tilt capabilities. One of the two strobes on the ROV flooded during the cruise, but on-board processing of test strips of film allowed us to adjust the camera settings to accommodate the use of one strobe rather than two for the rest of the cruise.

Underwater photographs of the ROV were taken at the surface at ROV-12. These slides will be used for presentations relating to this project.

In general, both weather and visibility were far superior on this cruise to that on the first ROV cruise. Visibility was poor only at the "footprints" (ROV-11, 95 m deep, visibility 1 m). The only other time visibility was poor was on the first of two visits to site ROV-17 ("boulder field) when a bonita lodged between the video camera and the ROV frame and constantly fanned sediments in front of the lens. We were unable to detect the problem until the ROV was brought on deck. A summary of the activities at each site is given in Appendix D.

Operations were halted at approximately 1200 hours on 27 September and we headed to port. Both of Frank Kelly's buoys were checked and seemed to be in proper order. The ship arrived in Biloxi at 2300 hours on 27 September. All gear was removed by 0100 on 28 September.

3.2.2 Geological Cruise G2 and G2A

3.2.2.1 General Sampling Overview

Year 2 geologic mapping was carried out on two cruises, 88-MMS-G2 and 88-MMS-G2A. Both cruises were accomplished aboard the R/V TOMMY MUNRO, the former during August 2-5, 1988 and the latter during August 30-September 7, 1988, totaling 13 days at sea. Side-scan sonar and subbottom profiler data were collected on these cruises for two purposes: (1) to obtain detailed side-scan sonograms of features noted in the Year 1 survey area; and (2) to obtain reconnaissance side-scan and subbottom records from areas to the east and west of the Year 1 survey thought likely to contain additional topographic features and hard bottom sites.

The Year 1 survey covered a rectangle with the following corners:

NW corner	29° 25' 19.8" N	88° 02' 00.8" W
SW corner	29° 15' 02.6" N	87° 57' 14.3" W
SE corner	29° 26' 23.2" N	87° 23' 41.6" W
NE corner	29° 36' 45.5" N	87° 28' 14.5" W

Unlike the Year 1 geologic mapping cruises, in which surveying was continued until the entire target area was covered, the Year 2 surveys were limited to about 10 working days at sea. The Year 2 target areas were designed to occupy all of this time assuming perfect weather and operations. In all, there were six survey sites. Four were detailed surveys of features within the Year 1 work area: (1) the "boulder field" patch reef area; (2) a section of the 40 fm (73 m) reef trend; (3) a linear ridge feature; and (4) a cluster of flat-topped reefs (Figure 3-2). The other two survey areas were larger and designed to follow the 40 fm (73 m) isobath to the east and west of the Year 1 survey rectangle. This depth was considered important because many large topographic features and hard bottoms were found at this depth on previous surveys. The West Addition survey was laid out to cover a rectangle with the following corners:

NW corner	29° 18' 16.7" N	88° 21' 57.4" W
SW corner	29° 12' 30.8" N	88° 19' 16.3" W
SE corner	29° 20' 11.0" N	87° 59' 26.7" W
NE corner	29° 25' 57.3" N	88° 02' 06.9" W

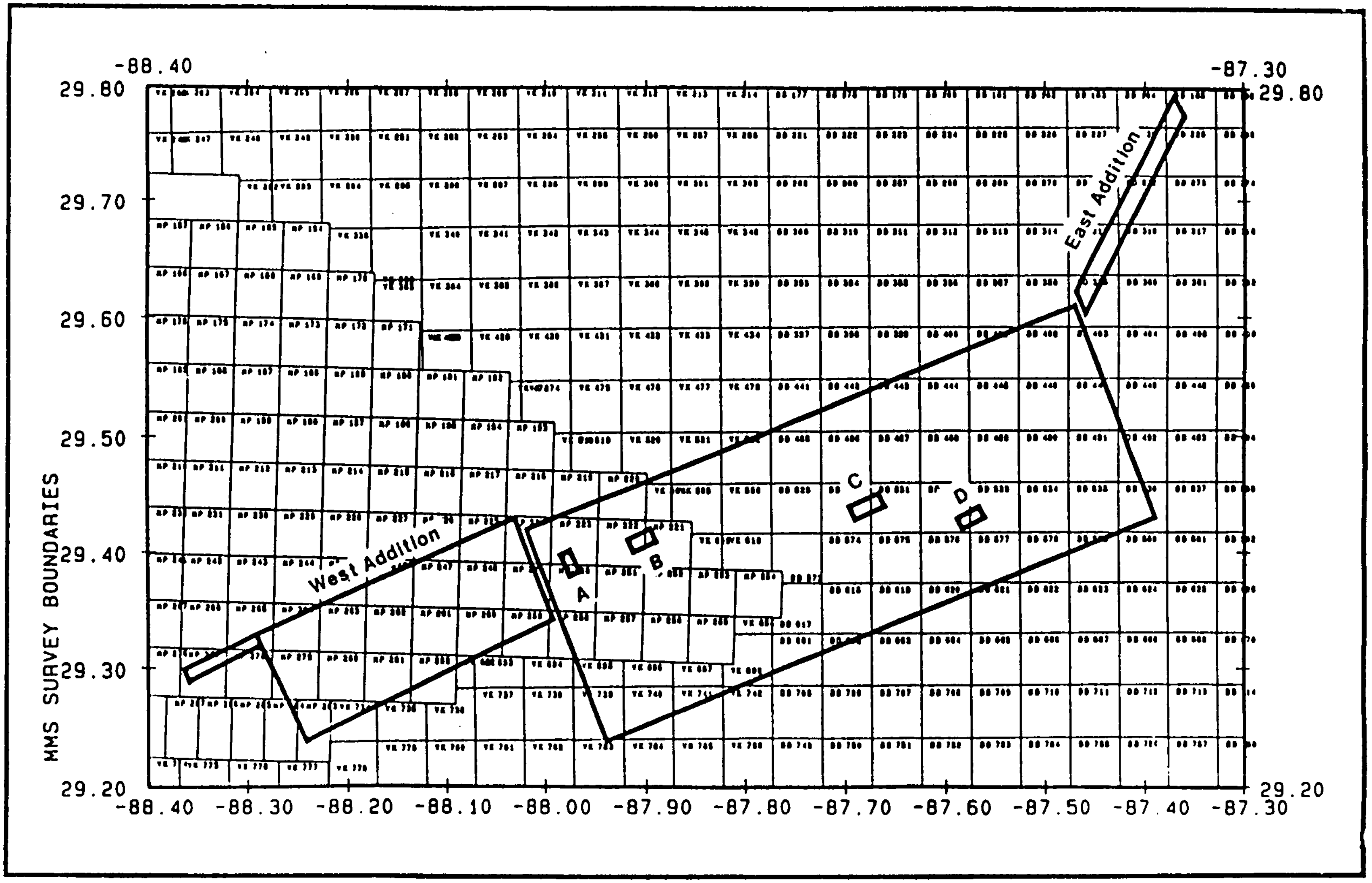


Figure 3-2. Locations of geological characterization surveys. Heavy lines denote the boundaries of the MMS Mississippi/Alabama Ecosystems Study project surveys. East Addition, West Addition, and small rectangles labelled A, B, C, D are the year 2 survey areas; large rectangle in center outlines borders of year 1 survey for comparison. Detailed surveys labelled as follows: (A) flat-topped reef survey; (B) linear ridge survey; (C) patch reefs "boulder field" survey; and (D) 40 fathom reefs survey. Light lines show lease block boundaries.

Whereas the East Addition survey was designed as a parallelogram with the following corners:

NW corner	29° 37' 56.5" N	87° 28' 57.3" W
SW corner	29° 29' 14.8" N	87° 25' 02.2" W
SE corner	29° 40' 07.9' N	87° 18' 35.0" W
NE corner	29° 48' 49.8" N	87° 22' 30.0" W

Both cruises were terminated because of rough seas. The subbottom profiler transducer was lost during a squall spawned by a tropical storm during Cruise 88-MMS-62. The conductive cable of the side-scan sonar transducer malfunctioned during mounting seas ahead of hurricane Florence during Cruise 88-MMS-62A.

Despite these problems, most objectives were met. All of the detailed surveys were completed with 100 percent coverage at a side-scan sonar half-swath-width of 100 or 200 meters. A 300 m reconnaissance half-swath-width was used for the East and West Addition surveys. In the West Addition, 66 percent of the planned survey was carried out (Figure 3-3). Initially, 24 lines were laid out; however, lines 2, 4, 6, and 8 were skipped and lines 5-24 were shortened. The line skipping was done because no reflectivity features were noted in the northern part of the survey area. To save time, the odd numbered lines were first run to define the areas of interesting bottom reflectors, and then the even numbers were filled in where warranted. The lines were shortened for two reasons. First, the records at the west end of the survey area were virtually featureless, so shortening the lines saved ship time to be used elsewhere. Second, there were a number of active oil rigs located at the west end of the survey and these represented survey hazards. Consequently, 100 percent side-scan coverage was obtained from line 9 to line 24, whereas 55 percent coverage was achieved on the remainder survey area.

Three lines (Figure 3-4), representing 11 percent of the planned survey, were run in the East Addition because of weather problems. The areas of the West Addition and East Addition surveys completed and line numbers are shown in Figures 3-3 and 3-4. The surveyed area of the West Addition can be described by two rectangles with the following corners:

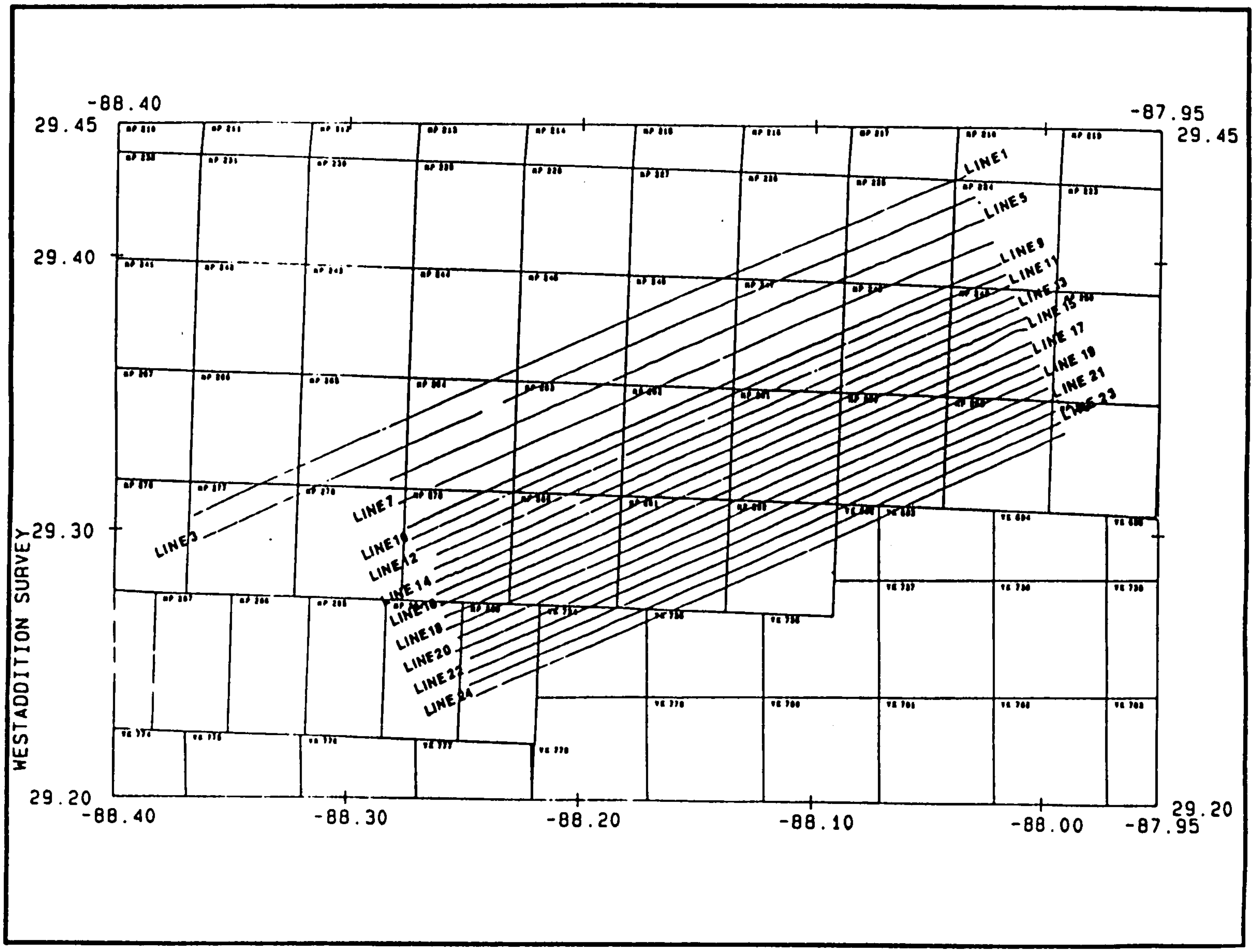


Figure 3-3. Geological characterization survey track lines in West Addition survey area. Continuous side-scan sonar and subbottom profiler records were obtained along these 20 ENE-WSW oriented lines. Lines 2, 4, 6, and 8 were not surveyed (see text for explanation). Lease blocks shown for reference.

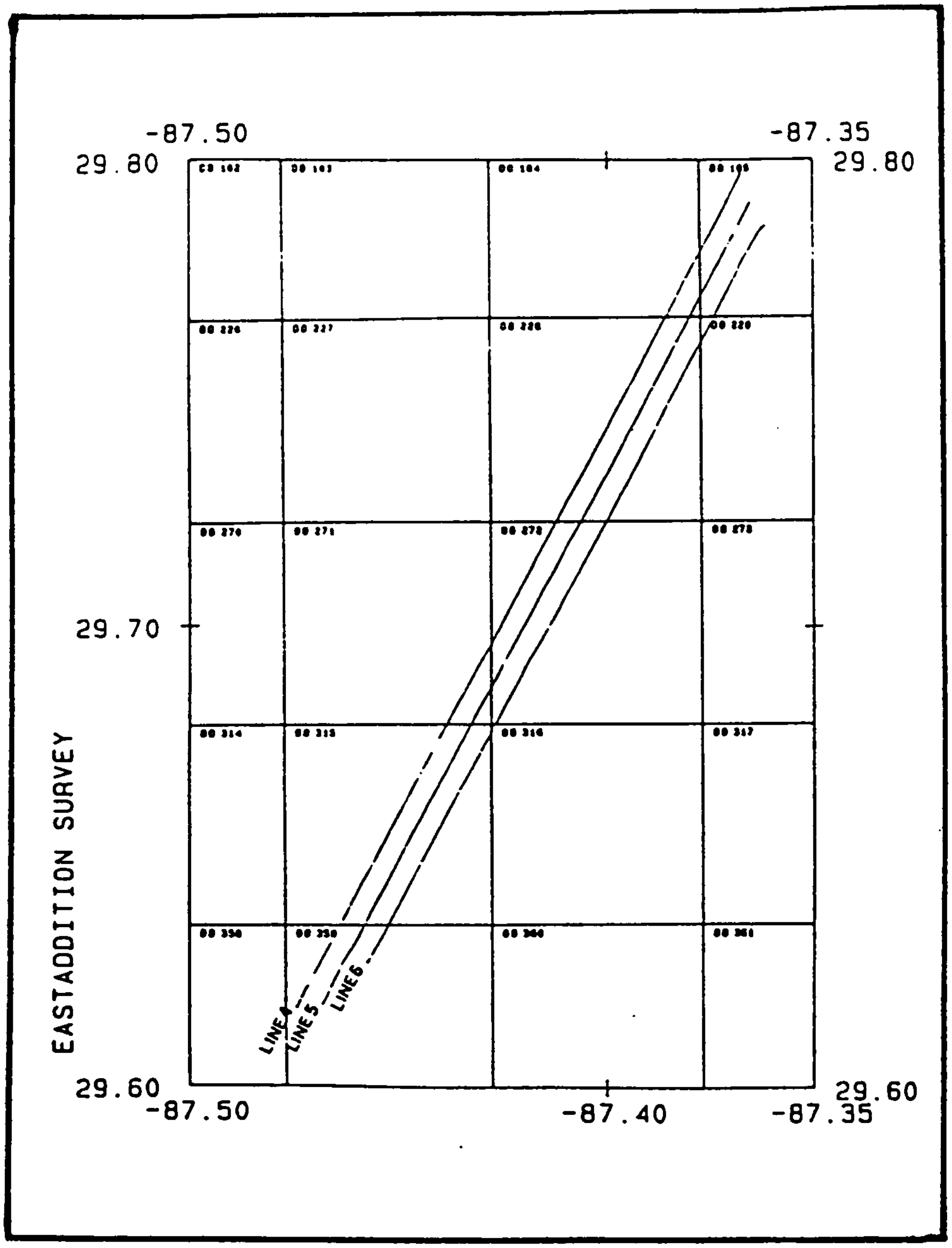


Figure 3-4. Geological characterization survey track lines in East Addition survey area. Continuous side-scan sonar and subbottom profiler records were obtained along these 3 NNE-SSW oriented lines. Lease blocks shown for reference.

Main area

NW corner	29° 20' 01.6" N	88° 17' 28.2" W
SW corner	29° 14' 16.3" N	88° 14' 41.5" W
SE corner	29° 20' 11.0" N	87° 59' 26.7" W
NE corner	29° 25' 55.9" N	88° 02' 06.3" W

Northwest extension

NW corner	29° 18' 16.8" N	88° 21' 57.4" W
SW corner	29° 17' 47.6" N	88° 21' 43.7" W
SE corner	29° 19' 31.1" N	88° 17' 13.7" W
NE corner	29° 20' 01.6" N	88° 17' 28.2" W

The area of the East Addition survey completed is delimited by a parallelogram with the following corners:

NW corner	29° 37' 00.5" N	87° 28' 27.6" W
SW corner	29° 36' 17.9" N	87° 28' 10.2" W
SE corner	29° 47' 08.5" N	87° 21' 42.8" W
NE corner	29° 47' 49.8" N	87° 22' 03.5" W

In all, approximately 19 nautical miles of detailed records were obtained along with 335 nautical miles of reconnaissance data collected in the East and West Addition survey areas.

3.2.2.2 Sampling Procedures

3.2.2.2.1 Side-Scan Sonar and Subbottom Profiler

With one exception, the equipment used for the Year 2 surveys was the same as that used in the first year geological characterization studies. Reflection data were collected with a digital side-scan sonar and an analog subbottom profiler. The side-scan sonar used was a EG&G model 260 operating at a frequency of 100 kHz. Replay capability was provided by recording the raw side-scan data on a PERTEC series 6000 tape drive using 3600 foot long nine track tapes. The surveying was begun with the same subbottom profiler used during the previous year, an EDO-Western model

515A operating at a frequency of 4 kHz. However, during cruise 88-MMS-G2, the transducer for this system parted its tow cable in rough seas and was lost. It was replaced on cruise 88-MMS-G2A by a Raytheon model PTR-105 using a frequency of 3.5 kHz. This unit was used with a Raytheon CESP correlator to improve the signal-to-noise ratio.

Geophysical data were continuously collected along all survey lines. In the East and West Addition survey areas, track lines were spaced 550 m apart. The side-scan sonar was used in a 300 m swath mode in these surveys, providing 50 m overlap of adjacent line records. For the detailed imaging, track lines were spaced 150 m apart and the side-scan was used either in the 100 m swath mode for the patch reef, shoreline, and flat-top reef surveys or 200 m mode for the 40 fathom reefs survey. The former yielded 50 percent overlap and the latter 100 percent.

3.2.2.2.2 Navigation

As on the first year cruises, the STARFIX satellite positioning system was used for navigation. This system operates in the microwave frequency band (4.06 GHz) and yields an lateral positional accuracy of approximately five meters. All navigation data were logged on nine track tapes for plotting and merging with the side-scan and subbottom data.

3.2.3 Biological Chemical Cruise B4 and Physical Cruise P4

A cruise on 13-14 January retrieved the moorings at Site A, B, and C. The instruments were returned to the laboratory for detailed servicing in preparation for the second year's deployment. These three moorings and two new moorings (sites D and E) were redeployed during cruise B-4.

3.2.3.1 Cruise Overview

Cruise B-4 (the final biological/chemical characterization) and Cruise P-4 (a routine servicing of the current meter arrays) was conducted from the R/V TOMMY MUNRO, on 11-18 February 1989. As in the previous cruises, box cores, trawls, and CTDs were performed at each of the 12 stations. Three current meters arrays were serviced (A, B, C) and two arrays were deployed (D and E). Additional CTD casts were made while enroute across the continental shelf. All work was accomplished as planned with the exception of the trawl calibration, which was postponed until the next cruise.

3.2.3.2 Participants

The scientific party on Cruise B-4/P-4 consisted of the Chief Scientist and Principal Investigator for hydrography (Frank Kelly), the Principal Investigators for infauna (Don Harper) and nekton (John McEachran), MMS observer (Dr. Ann Bull), electronics technician (Eddie Webb), and seven students/Technicians (Simons, Broach, Jacob, Huntington, Hyde, Vasek, Jobling).

3.2.3.3 Problems

At the first use of the CTD in the profiling mode (not utilizing the internal recording) at Station D, the CTD failed to operate properly. However, it had worked satisfactorily on previous profiles using the internal recorder. Conductivity measurements continued to be a problem despite trouble shooting efforts by the electronics technician. On the second day at sea, winds and seas built to the point where continued work was impossible. The vessel sought shelter at Venice for 38 hours and a replacement CTD was sent to the ship. Work resumed on the fourth day, without the replacement CTD eliminating the conductivity problem. The CTD problem was traced to a faulty cable on the fifth day and was fixed by disconnecting the cable completely from the CTD (not normally required) for operation in the internally recording mode.

A problem noted by the biologists for which no explanation could be offered was the paucity of organisms in all the trawl samples. Even the numerous sea urchins off the Mississippi delta were absent. Indications from the trawl and boards were that the net was fishing and on the bottom, yet the catches were markedly reduced.

Day light time limitations and weather considerations at the end of the cruise prevented our accomplishing the trawl opening calibration that had been planned. This activity will be conducted on the June ROV cruise.

3.2.3.4 Sample Inventory

A complete suite of samples at each of the 12 stations were collected on this cruise. The number and type of replicate samples at each station is the same as for all previous cruises (see Table 3-2).

3.2.4 ROV Cruise 3 and Physical Cruise P5

3.2.4.1 Overview

Cruise 89-MMS-ROV-3 and the interim current meter servicing was conducted aboard the R/V TOMMY MUNRO (chartered from the Gulf Coast Research Laboratory). The cruise was scheduled from 18 June to 3 July with two of those days allotted for weather delays. The objectives were to visit hard bottom features observed on side scan records collected during the most recent geological cruises, visit pinnacle reefs and features on salt domes nearer the Mississippi River, conduct video surveys at MMS study stations C2, M2, M3, D1, D2, and D3, change out current meters at five mooring sites, and determine the spread of a trawl used for sampling during Years 1 and 2 of this study.

Weather delays were limited during the cruise. Operations were halted for only 3.5 hours and slowed for 13.25 hours. Most of these delays were limited to the first leg of the cruise. During the second leg, seas never rose above one to 1.5 meters, and the only factor affecting ROV operations was a strong tidal current at one study site. Within two hours, the current subsided and normal operations were continued. With the exception of a bottom survey at Station M3, which could not be conducted due to its depth, all objectives were achieved. In addition to the proposed objectives, one additional pinnacle reef, one moderate sized ridge somewhat larger than the other pinnacle reefs, and one additional diapiric bank, all between the original hard bottom study area and the Mississippi Delta were surveyed. In

Table 3-2. 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

addition, all ROV sites at pinnacles and banks were surveyed acoustically to produce bathymetric charts. Furthermore, phytoplankton and filtered water samples were taken at many stations and turned over to investigators studying fish food webs in the region.

3.2.4.2 Personnel

The cruise was conducted in two legs. Personnel are listed below along with the cruise leg on which each participated.

Name	Affiliation	Leg
Roger Fay	TAMU-GERG/Chief Scientist	1
Steve Gittings	TAMU-OCNG/Chief Scientist	2
Ian MacDonald	TAMU-OCNG	1,2
Dan Wilkinson	TAMU-GERG	1,2
Frank Kelly	TAMU-OCNG	1
Jim Jobling	TAMU-Naut. Arch.	1
David Bishop	TAMU-GERG	2
R.J. Wilson	TAMU-GERG	2
David Murphy	TAMU-OCNG/Electronics Tech.	1
Eddie Webb	TAMU-OCNG/Electronics Tech.	1,2
R.V. Pittman	TAMU-OCNG/Electronics Tech.	2
Will Schroeder	Univ. of Alabama-Dauphin Is.	1
Ken Graham	MMS Observer	1
Dennis Chew	MMS Observer	2

3.2.4.3 Cruise Detail

Scientific and technical personnel traveled to Biloxi, MS on 16 July 1989. On 17 and 18 July, the ship was mobilized and departed Biloxi at 0100 on 19 July.

Current meters were changed at each of the five arrays during the daylight hours and ROV dives were made at the biological stations and topgraphic features at night. CTD casts were also made at the locations of each current meter array. Dredge samples were obtained from an area near the "West Addition Pinnacles" and at areas between sites in an effort to collect relict riverbed sediments.

All current meters were successfully exchanged and ROV dives 22 through 28 were completed during the first leg. An exchange of personnel was effected at Biloxi on 24 June and the cruise resumed with the second leg. Personnel departing included Roger Fay, Frank Kelly, Jim Jobling, Dave Murphy, and Ken Graham (MMS). Personnel coming aboard for the second leg included Steve Gittings, David Bishop, R.J. Wilson, and Dennis Chew (MMS).

The second leg of the cruise accomplished ROV dives 29 through 39, but resulted in extensive damage and wear to the ROV.

Two interesting discoveries were made during the second leg. On the top of Bank 3, locally referred to as "Mountain Top", an area with extensive gas seepage and bacterial growth (*Beggiatoa* mats) was found. Bacterial growth proliferated around gas seeps and fissures in the reef plate and may affect local reef epifauna. Dive 37 was made on Bank 3 near the previously surveyed area that contained bacterial mats. Similar bacterial communities were also observed during this dive.

During transit, another reef apparently similar to the pinnacles, but taller was passed over. This feature could not be detected on navigation charts. Therefore, we returned to the feature to do an acoustic survey and found the structure to be a ridge rising from approximately 91 m to 66 m, over 1.5 km long (north to south) and less than 0.7 km wide. Thus, the feature is taller than any pinnacles surveyed and intermediate in size between the pinnacle-type reefs and the diapiric banks to the west of this area. ROV Dive 39 was made on the crest of this ridge.

ROV Damage summary

Minor damage to the black and white camera and compass occurred during an encounter with the bow anchor. A board controlling the ROV motors blew during ascent and was repaired in transit. The wire in the video coaxial cable on ROV has deteriorated due to water intrusion. The camera tilt motor failed on the ROV, which forced completion of the survey with the cameras in a fixed position. One of the two lasers required for scale calibration failed. The Trackpoint transponder mounted on the ROV was lost in a heavy current when the ROV bumped the hull of the ship and was replaced with the only spare. Though none were taken below their rated depth of 300 feet, all four Ikelite 225 strobes leaked around their MTS switches and need to be repaired.

Trawl calibration

The trawl calibration study, which had proved unsuccessful during the first leg due to wind, seas and turbidity was conducted again in the vicinity of current meter Mooring "A". We cleared the intended track using the ship's chromoscope and rigged the trawl with measured lines ranging from 6 to 9 m in length in front of the mouth. After trawling past the current meter buoy at three knots using a scope of 3:1, the lines across the mouth were inspected. The 6 m lines broke but all others were intact. This seemed to confirm the intended mouth opening of 7 m for this net. However, divers were sent in to measure trawl door scars near the buoy. They made measurements at several locations over a 30 meter distance and found the average distance between the doors to be 4 m. The trawl was then moved to shallower water to do another measurement. A similar methodology was used, but the depth was only 12 m, the ship speed was approximately 2.5 kts, and approximately 46 m of cable was used. This time the trawl spread measurements averaged approximately 3 m.

Sled surveys

With the functional damage to the ROV high, and desiring to develop a more efficient method for broader bottom survey, Station D1 was resurveyed to develop a more extensive bottom survey than had been done previously. This time a towed sled equipped with video and still cameras was deployed. The sled was "flown" approximately 1 m above the bottom over a predetermined grid surrounding the station. The grid covered 1.8 km by 1.5 km and survey lines were spaced 200 m apart. The ship speed averaged two knots and the survey took place from 1153 to 1648 hours.

One stop was made in approximately 18 m of water at 2100 hours to test the sled in turbid conditions at night.

3.3 Results

Some features surveyed during this cruise are very similar in structure and community composition to those in the previous survey area in which reconnaissance work was conducted during two 1988 ROV cruises. That is, they are pinnacle-type foundations covered by large populations of ahermatypic scleractinian corals, crinoids, sponges, etc., and having large fish populations. The largest features in the region are of a different origin, being surface expressions of salt diapirism. They are broader in surface area. The hard-bottom areas of these banks contain a similar suite of organisms. Due to their location, however, the banks are more heavily influenced by the Mississippi River discharge and are bathed in water that is generally more turbid. Consequently, on banks closer to the River, reefal populations are depauperate. On the bank closest to the River (Bank 2), no hard bottoms were found. Beyond approximately 6 km east of the delta, the influence on the communities on high relief features appears to be minimal. Whether the data fully support this observation awaits detailed analysis of video tapes and photographs.

The most interesting observation on the cruise was the discovery of extensive bacterial mats near the top of one bank over a salt dome. Such mats have been observed in the past around brine seeps, oil seeps and other discharges containing sulfides. Most observations, however, have been made in deeper water. Our observations were at less than 70 m. The bacteria on this bank seemed to be concentrated around and within crevices, cracks, and holes in the rock. Gas seeps were frequently observed in the area, but not in areas on the bank without bacterial mats. There may be some influence of the local environment on reef populations. In areas containing mats, typical reef populations were low compared to those elsewhere on the bank at similar depths. Such an area could provide a shallow study site in which to further investigate the dynamics and effects of these unique communities on surrounding ecosystems.

3.4 Field Work Remaining

Two field efforts remain to be accomplished in the last year of the contract: (1) the last interim current meter servicing cruise, was completed October 1989; and (2) the final current meter servicing and current meter removal, scheduled for early February 1990.

4.0 SEDIMENT HYDROCARBON AND BULK ORGANIC MATTER DISTRIBUTIONS

Mahlon C. Kennicutt II

4.1 Introduction (including historical background)

Previous studies of sediment hydrocarbons in or near the 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. 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 ±80 percent and 232 ppm ±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 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 base includes 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 below the detection limit to 4252 ppb and 44 to 5591 ppb during 1986 and 1987 samplings, 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 and the target compounds do not detect highly weathered petroleum residues, since most target compounds are removed due to microbial degredation and solution in water.

4.2 Analytical Methods

4.2.1 Bulk Parameters

Sediment (0.2-0.5 g) is weighed into disposable 5 ml polystyrene beakers and treated with concentrated HCl to remove inorganic carbon (carbonate). Acid is added dropwise until no degassing is observed. The treated samples are then dried at 50°C in a recirculating oven for 24-36 hours to remove excess acid and moisture. After drying, the sample is quantitatively transferred to a sintered crucible. Iron accelerator and tin coated copper catalyst are added and analyzed by total combustion on the Leco instrument. Organic carbon is converted to CO_2 and analyzed with a non-dispersive infrared spectrophotometer (Leco WR-12 Total Carbon System). Blanks and standards are run on a daily basis. Leco steel ring carbon standards are commercially available. All samples are analyzed in duplicate and averaged. Periodically samples are combusted at > 800°C in a high vacuum Craig-type combustion system as a check on the combustion efficiency of the Leco System. Calcium carbonate is determined as the difference between a treated (acidified) and untreated carbon determination.

Sediment grain size analyses follows the laboratory procedure of Folk (1974). Samples are homogenized, treated with an aliquot of 30% 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 then wet-sieved using a 62.5 micron (4.0 phi) sieve to separate gravel and sand from the silt-clay fraction.

The total gravel and sand fraction was then oven dried (40°C). Each fraction collected was examined for aggregates, disaggregated if necessary, and weighed to three significant figures.

The silt-clay fraction was analyzed for particle size distribution by the pipette (settling rate) method.

Sediment samples for carbon isotope analysis are prepared by a closed tube method. The carbon dioxide samples are anazlyed on a Finnigan MAT 251 isotope ratio mass spectrometer with triple collector. Measurements are made relative to several working standards. All values are reported versus PDB (Pee Dee Belemnite).

4.2.2 Hydrocarbons

Sediment 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. The lower limit of reporting is 10 ppb for all analytes and exceeds the method detection limit by at least a factor of five.

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

Aliphatic Compounds	Aromatic Compounds	
n-C_{11} to n-C_{32}	Naphthalene	Methyl phenanthrenes
pristane	Methylnaphthalenes	Pyrene
phytane	Dimethylnaphthalenes	Benzanthracene
	Trimethylnaphthalenes	Chrysene
	Fluorene	Benzo(b) fluoranthene*
	Fluoranthene	Benzo(k) fluoranthene*
	Acenaphthene	Benzo(e) pyrene
	Acenaphthylene	Benzo(a) pyrene
	Phenanthrene	Dibenzanthracene
	Anthracene	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	Precision Std. Dev.	Accuracy	Completeness
Aliphatic Hydrocarbons (AHs)	≤ 20%	≤ 30%	90%
Polynuclear Aromatic Hydrocarbons (PAHs)	≤ 20%	≤ 30%	90%

Sample Preparation

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 Laboratories, Inc.). 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.

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.

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

Approximately 25 g of freeze-dried sediment is ground, surrogates 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°C). Extracts are stored refrigerated (-4°C).

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.

Aliphatic Hydrocarbons (AHs) - 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°C, the GC oven is then temperature programmed to 300°C (12°C/min) and held at 300°C 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.

Polynuclear Aromatic Hydrocarbon (PAHs) - 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.

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

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
Transfer Line: 290°C
Analyzer: 250°C
Run Time: 36 min.
Scan Start Time: 5 min.
Electron Energy: 70 ev
X-Ray: 44V

Multiplier Voltage: 1600V
Entrance Lens: 50 mV/AMU
Repeller: 9.8V
Ion Focus: 0
Axis Gain: -63
Axis Offset: -6
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	-----	----	*-d8naphthalene
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	-----	----	*d10-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) 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. An internal standard (IS) (hexamethylbenzene or d_{10}-fluoranthene) 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 corrected for surrogate recoveries.

4.3 Results

4.3.1 Sediment Bulk Parameters

Sediment total organic carbon content (TOC) varied from < 0.1% to 3.1% and averaged 0.8% (Table 4-4). The highest TOC concentrations were along the Chandeleur Sound transect (C) and at the deepest stations of the Mobile (M) and Desoto Canyon (D) transects in water depths of 100-200 meters. The central portion of the study area was consistently low in TOC. Organic carbon content was highly variable between samplings with certain locations increasing (Station D-3 after Cruise 0) and others decreasing (Stations C-1, D-1, D-2) with time (Figure 4-1). Other locations contained relatively constant organic carbon contents (transect M) while a few varied regularly, exhibiting maximum values at various sampling times (i.e. Stations C-2, C-3, and C-4).

Sediment calcium carbonate content varied from less than 1% to greater than 80% and averaged 17.4% (Table 4-4). The greatest variability in carbonate content, as well as the highest values, was observed at Stations D-3 and D-4 (Figure 4-2). Carbonate content was relatively constant and low along transects C and M and Station D-1 during the study period.

Table 4-4. Summary of sediment bulk parameters on three transects during five sampling times. (C-Chandeleur, M-Mobile, D-Destin Dome).

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total Organic Carbon (%)												
Cruise MMS-0	1.3	0.3	1.3	0.1	0.1	0.2	0.1	0.8	**	0.1	0.9	1.7
Cruise MMS-1	0.7	0.7	1.7	0.8	0.4	0.2	0.6	1.7	0.3	0.3	0.2	2.0
Cruise MMS-2	0.6	1.5	1.2	1.4	0.3	0.3	0.5	1.3	0.1	0.4	0.9	3.1
Cruise MMS-3	0.3	0.9	1.3	1.9	0.1	< 0.1	0.6	1.5	<0.1	0.2	1.1	1.8
Cruise MMS-4	0.2	1.0	1.3	1.5	0.5	< 0.1	0.2	1.7	<0.1	< 0.4	2.6	2.9
Carbonate Content (%CaCO3)												
Cruise MMS-0	8.2	7.1	1.5	2.1	2.4	3.6	14.7	17.6	**	54.0	60.9	43.3
Cruise MMS-1	7.0	2.5	3.2	2.9	1.4	6.6	16.0	11.0	0.7	2.5	58.0	53.5
Cruise MMS-2	5.6	6.8	2.9	3.0	2.9	5.2	22.5	2.0	1.2	2.1	53.3	25.9
Cruise MMS-3	7.4	11.4	4.0	12.3	0.1	7.1	30.7	1.1	0.1	45.2	78.1	72.0
Cruise MMS-4	4.8	8.7	6.3	5.2	6.1	6.2	9.9	20.4	0.2	2.4	80.0	84.8
Total Extractable Matter (ppm)												
Cruise MMS-0	44.8	16.0	129.6	134.4	10.4	14.4	4.8	145.2	**	8.0	51.2	102.0
Cruise MMS-1	38.1	87.5	70.1	123.6	10.4	18.4	55.0	86.6	19.7	7.3	7.7	188.1
Cruise MMS-2	41.5	70.3	49.5	262.1	32.9	128.0	119.2	8.0	24.8	24.8	81.5	12.0
Cruise MMS-3	63.3	68.4	179.2	135.9	41.8	25.2	53.2	64.0	31.8	16.8	56.8	98.1
Cruise MMS-4	53.6	81.5	104.8	130.4	68.0	38.3	59.3	97.7	33.5	46.3	28.0	100.8
del 13C (per mil)												
Cruise MMS-0	-21.3	-20.4	-21.2	-20.4	-25.1	-24.0	-21.5	-20.4	**	-19.1	-21.5	-21.0
Cruise MMS-1	-23.4	-23.7	-23.4	-23.3	-24.8	-20.5	-23.3	-23.3	-22.9	-23.3	-22.3	-22.7
Cruise MMS-2	-21.4	-23.5	-23.0	-22.7	-24.9	-23.3	-21.3	-21.7	-24.2	-20.6	-23.2	-22.2
Cruise MMS-3	-22.6	-21.7	-21.2	-22.1	-21.5	-20.5	-21.3	-20.9	-20.5	-21.9	-20.7	-22.3
Cruise MMS-4	-21.3	-21.3	-21.1	-21.6	-21.5	-20.7	-20.8	-21.1	-19.0	-21.2	-20.4	-20.4

** = Samples not taken during first cruise

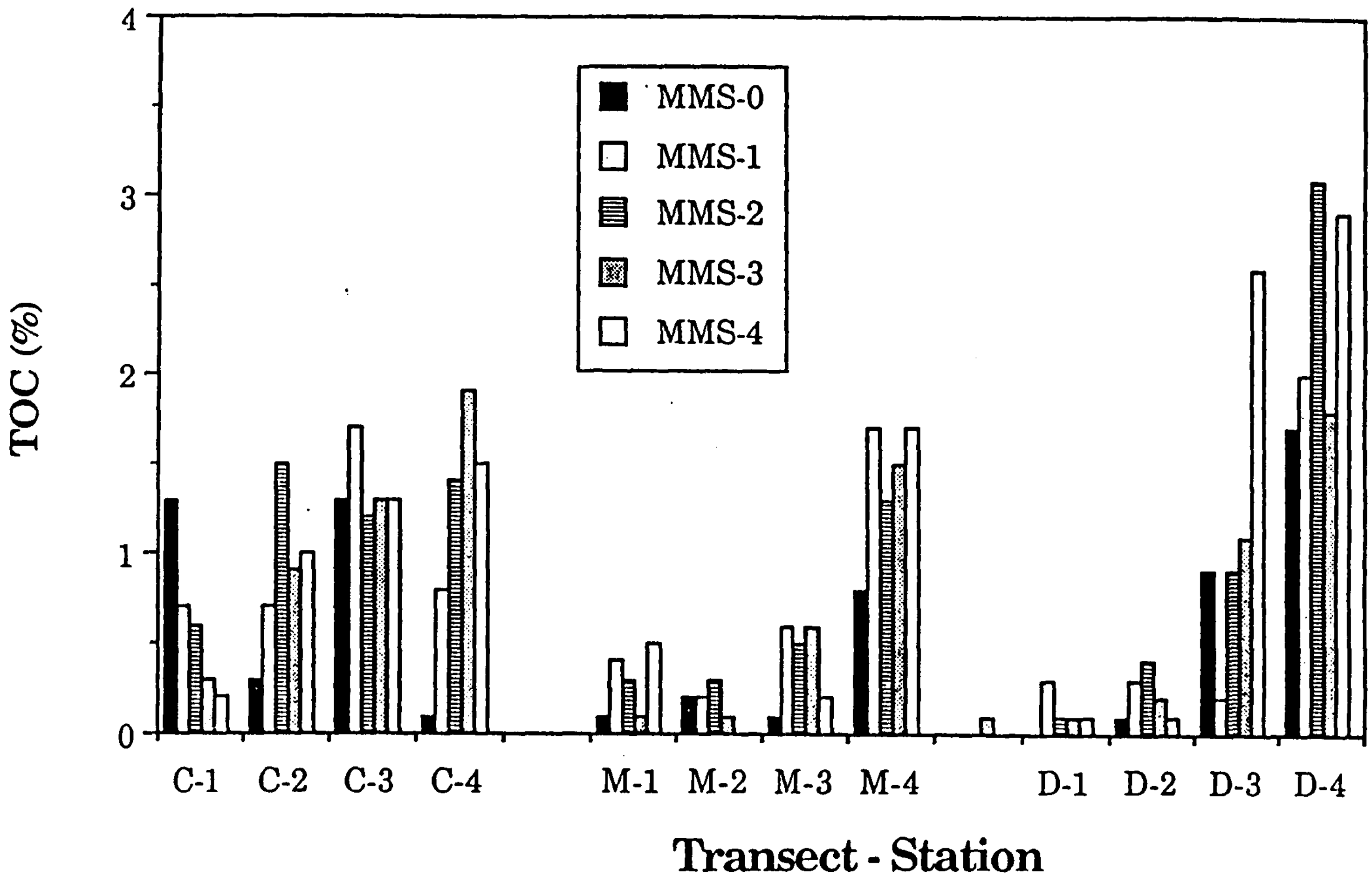


Figure 4-1. Summary of total organic carbon content (%) of sediment from the study area.

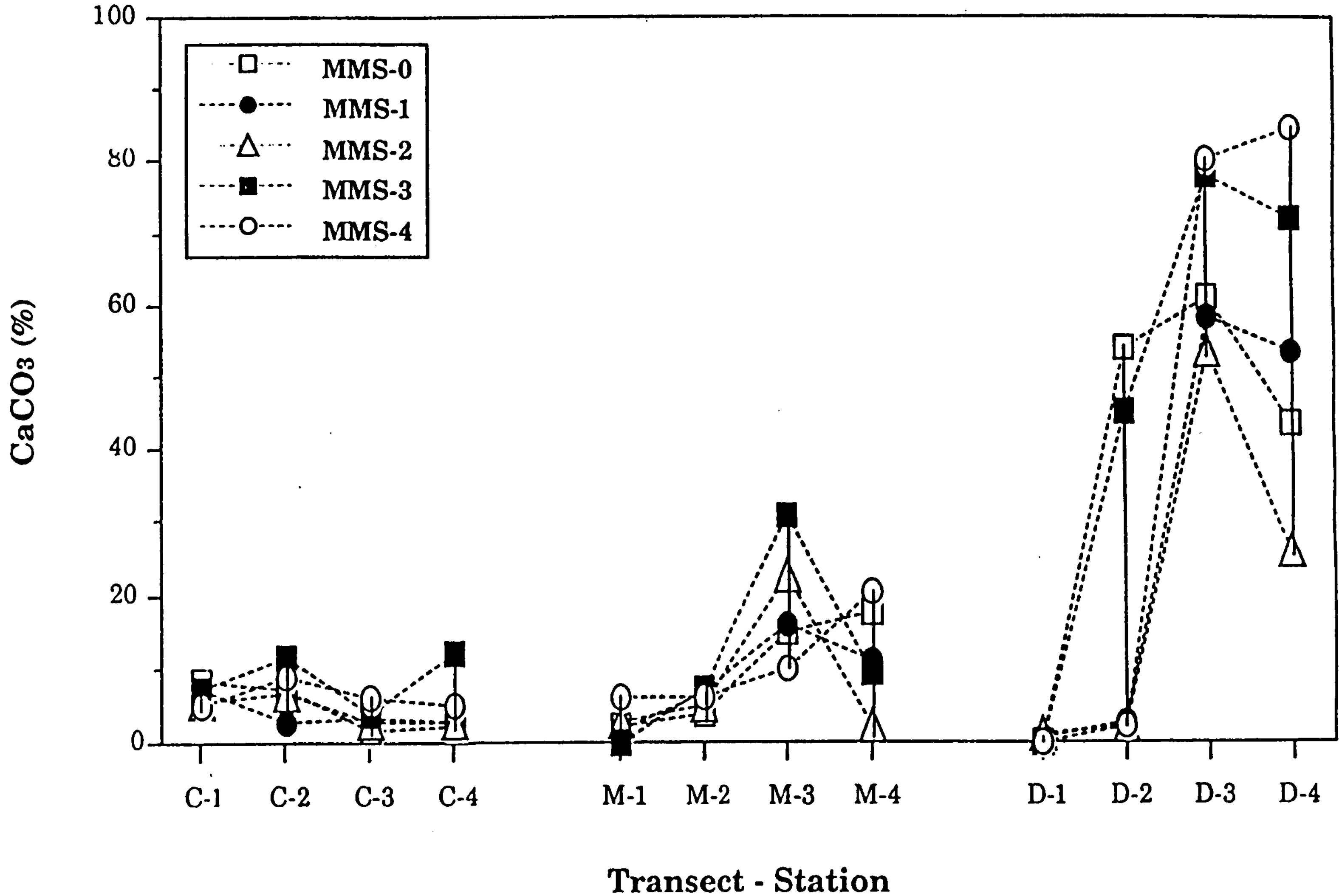


Figure 4-2. Summary of the calcium carbonate content (%) of sediments from the study area.

Extractable organic matter content varied from 4.8 to 262.1 ppm and averaged 66.2 ppm. As with TOC distributions the highest values were in sediments from transect C and at the deepest stations of transects M and D (Figure 4-3). At a few locations EOM appeared to vary in a cyclical fashion (C-3, D-3, D-4) whereas other locations had relatively constant EOM values or the concentrations varied randomly.

The stable carbon isotope composition of sedimentary organic matter ($d^{13}C_{om}$) varied widely within a sampling and between samplings at a given location (Table 4-4; Figure 4-4). In general the entire study area had more negative $d^{13}C_{om}$ values during the August 1987 sampling suggesting a significant influx of land-derived materials. Stations closest to Mobile Bay were consistently more negative than the deeper water stations during the first three cruises. During the fourth and fifth cruise all locations had stable isotope compositions more typical of planktonic debris.

Reflective of these trends, sediments in the central portion of the study area were predominantly sand (> 60%; stations M-1, M-2, M-3, D-1, D-2, D-3). Stations on deeper water were predominantly silt/clay (C-3, C-4, M-4, D-4). One notable event was a large influx of silt material before the August 1987 sampling that significantly changed grain size distributions at several stations (C-2, C-3, C-4, M-3, M-4 and D-4). This increased silt content was apparent at least through the third sampling.

4.3.2 Hydrocarbons

Aliphatic hydrocarbons were ubiquitous throughout the study area. Total n-alkanes varied from 100 to 3157 ppb and averaged 860 ppm (Table 4-5). Molecular compositions were highly variable and were found in highest concentrations along transect C and at the deepest stations of transects M and D (Figure 4-5a-e). Lowest values were found in the central portion of the study area corresponding to the low organic carbon, high sand content sites. On occasion the station directly offshore of Mobile Bay had elevated concentrations of aliphatic hydrocarbons (M-1). Odd n-alkanes appeared to continuously increase during the sampling period on transects C and M (Figure 4-6). The unresolved complex mixture varied from 1 to 32 ppm, averaged 11 ppm and generally parallels EOM distributions.

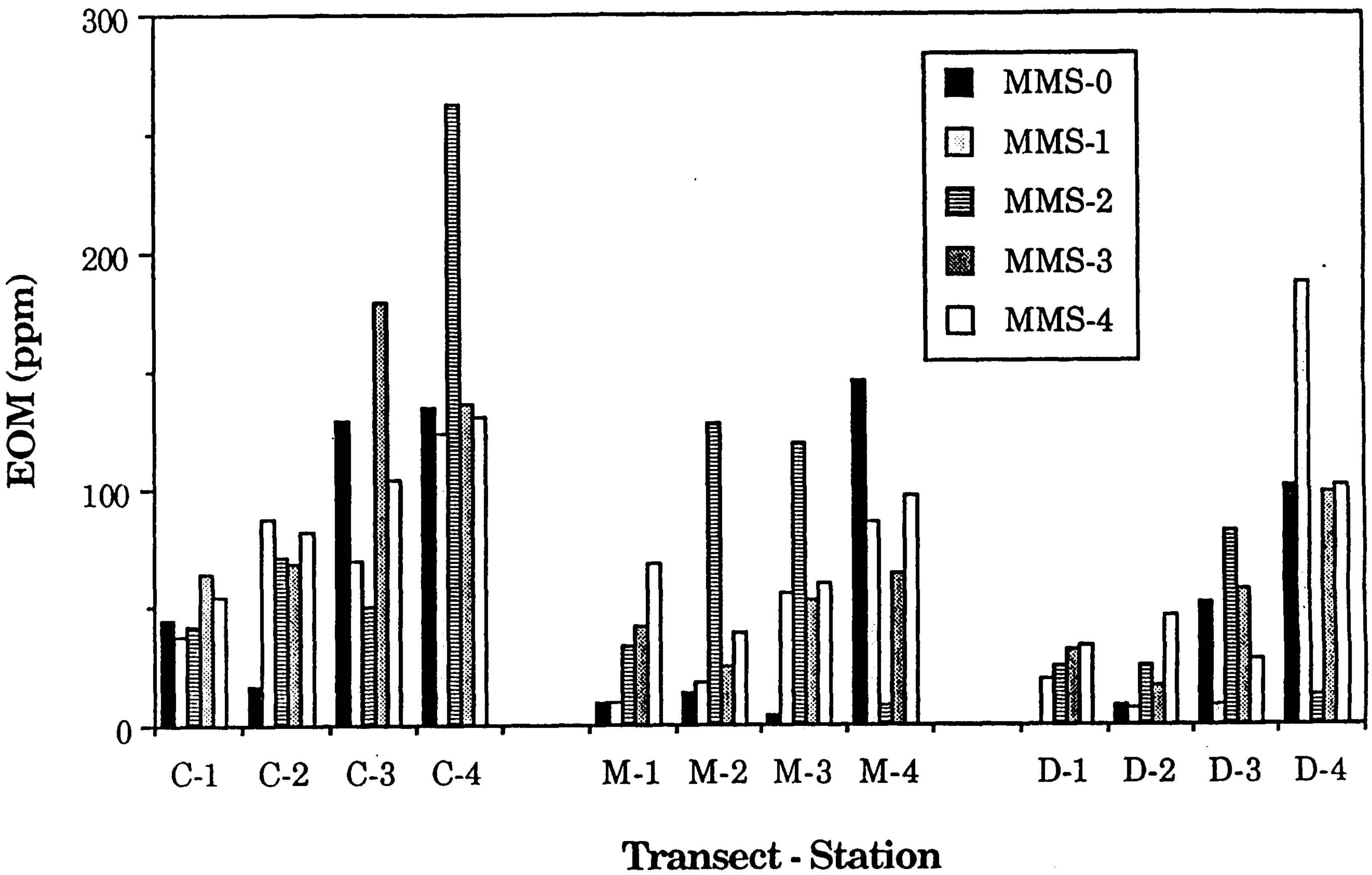


Figure 4-3. Summary of the extractable organic matter (EOM) content (ppm) of sediments from the study area.

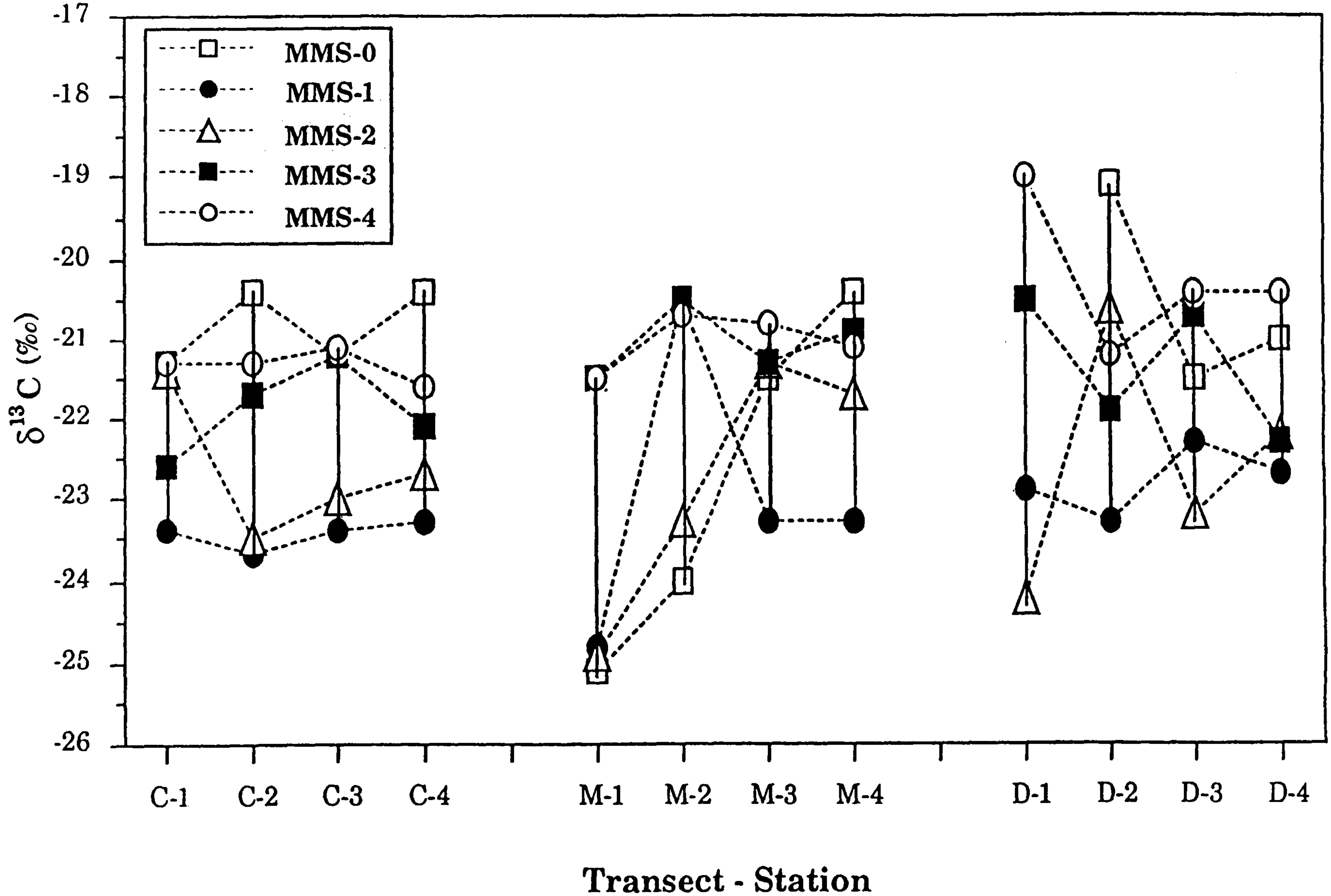


Figure 4-4. Summary of the stable carbon isotope compositions of organic matter in sediments from the study area.

Table 4-5. Summary of sediment aliphatic hydrocarbon data for the study period.

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total n-Alkanes (ppb)												
Cruise MMS-0	330	156	499	1592	184	128	626	525	**	215	254	312
Cruise MMS-1	1777	1402	2091	1810	461	511	1440	1893	271	343	635	656
Cruise MMS-2	482	738	528	1905	573	773	289	365	322	299	735	431
Cruise MMS-3	487	1397	1150	1946	517	244	1531	953	100	199	482	1294
Cruise MMS-4	857	2089	2411	3157	1724	633	420	1995	133	355	243	895
Total UCM (ppm)												
Cruise MMS-0	4	3	23	42	2	1	6	12	**	2	3	11
Cruise MMS-1	5	14	12	17	3	3	6	12	2	2	4	14
Cruise MMS-2	9	22	14	46	9	24	3	4	13	10	24	8
Cruise MMS-3	19	35	52	66	17	7	23	22	8	6	21	29
Cruise MMS-4	35	65	104	131	76	19	23	92	13	7	20	45
CPI > n-C23												
Cruise MMS-0	3.30	1.60	3.55	5.78	16.00	13.67	2.37	3.23	**	0.78	11.58	1.99
Cruise MMS-1	8.89	8.19	5.55	9.66	8.00	19.73	3.06	7.83	42.40	43.20	6.36	3.98
Cruise MMS-2	4.65	3.84	3.74	6.65	4.01	5.47	6.22	9.59	2.23	4.43	4.11	1.29
Cruise MMS-3	4.86	5.25	4.80	4.40	4.91	2.74	1.87	3.62	5.25	2.64	3.55	7.09
Cruise MMS-4	5.45	4.03	5.02	5.28	6.09	13.73	4.12	5.48	1.91	13.42	2.41	5.55
Pristane/Phytane												
Cruise MMS-0	*	2.20	1.67	3.24	*	*	1.10	2.00	**	0.73	1.56	2.00
Cruise MMS-1	0.77	0.59	0.65	0.73	0.83	0.81	0.90	0.82	*	0.55	1.00	3.38
Cruise MMS-2	0.50	0.70	0.80	0.96	1.14	1.70	*	1.40	2.80	1.00	1.63	1.00
Cruise MMS-3	*	3.14	1.39	2.13	*	*	1.36	1.67	*	*	*	*
Cruise MMS-4	2.03	0.23	1.56	1.60	2.02	*	1.23	*	0.74	*	*	*

* = Not determined due to one or more peaks less than the limit of quantification.

** = Samples not taken during first cruise

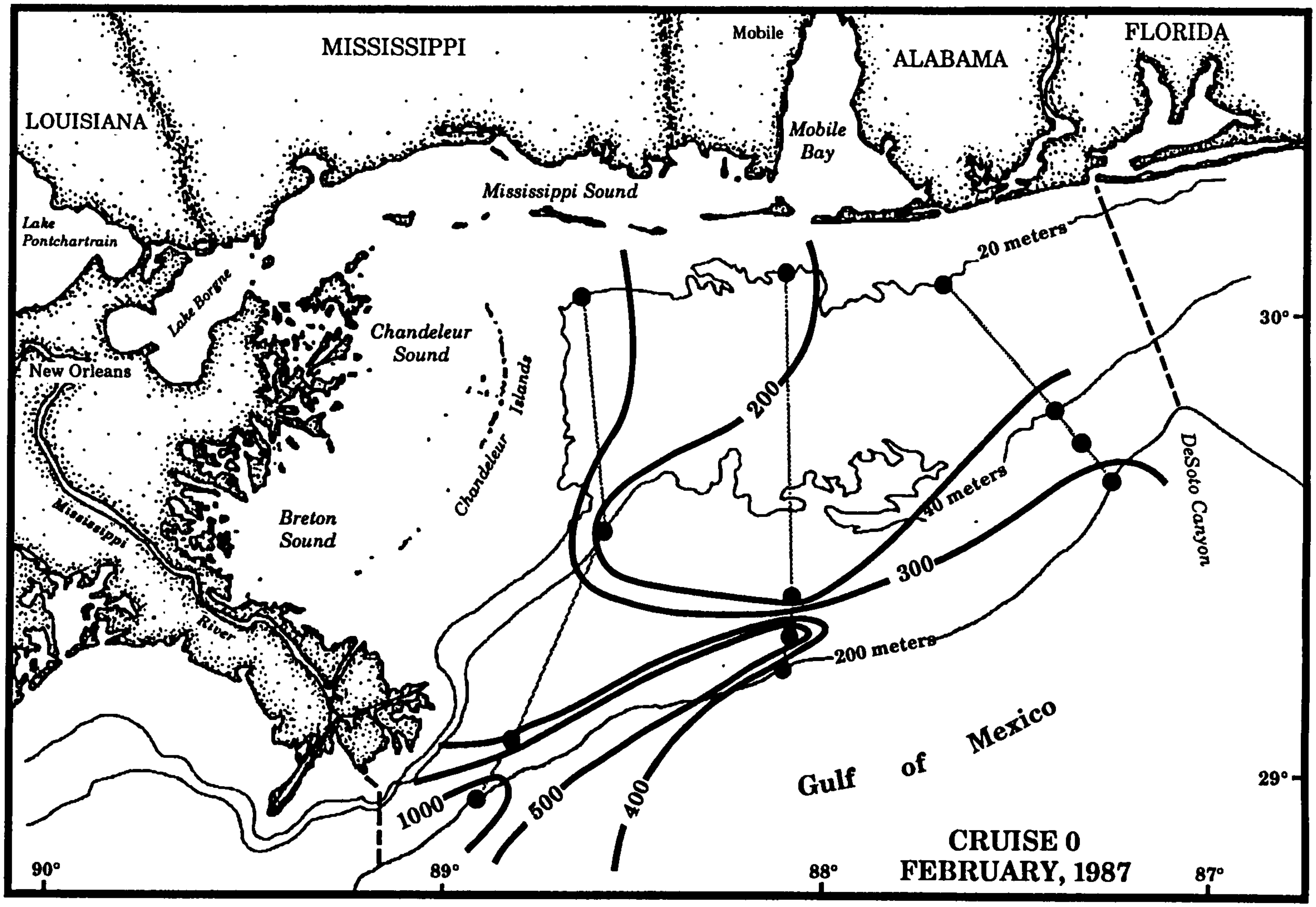


Figure 4-5a. Geographic distributions of total n-alkanes concentrations during five samplings.

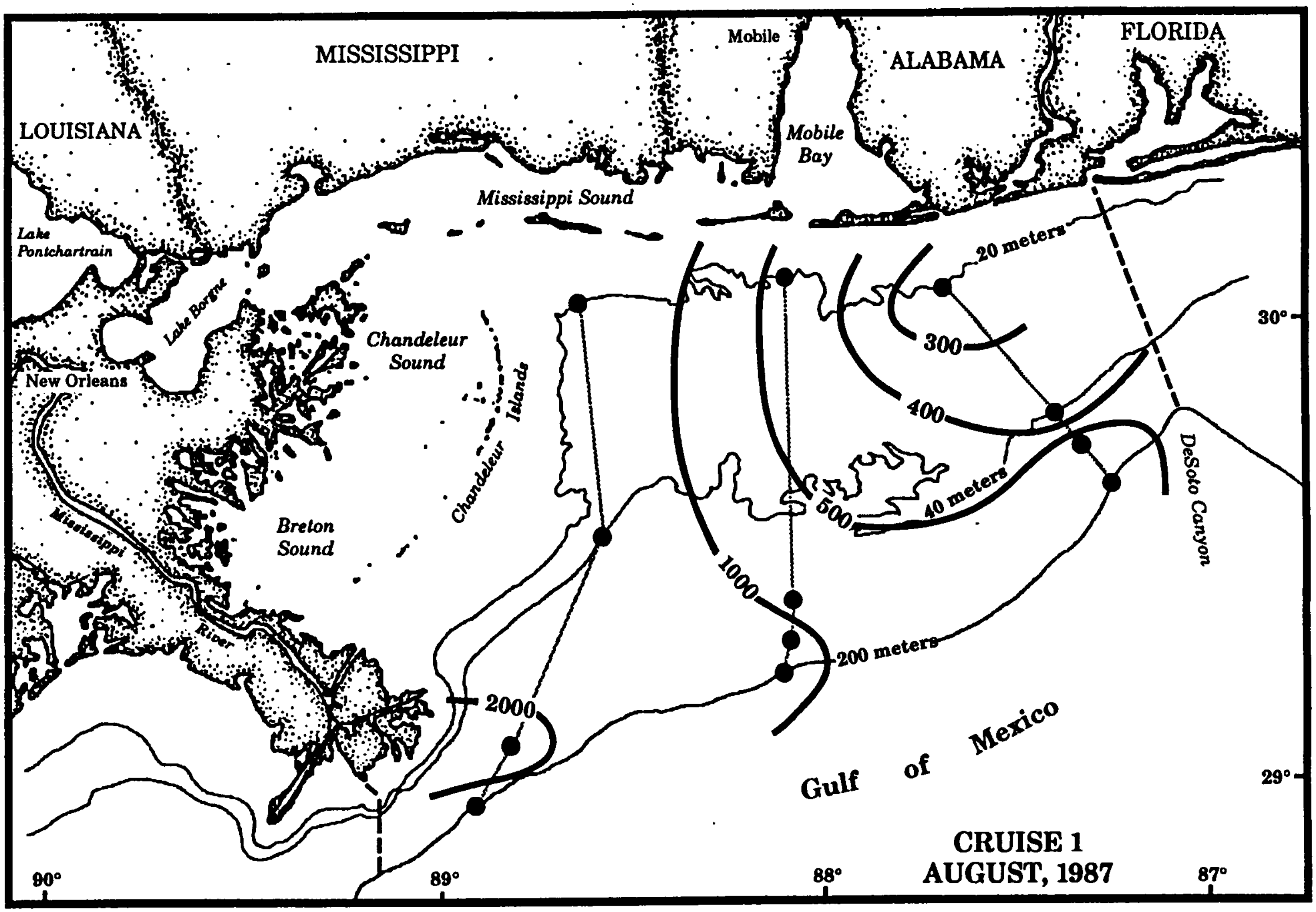


Figure 4-5b. Continued.

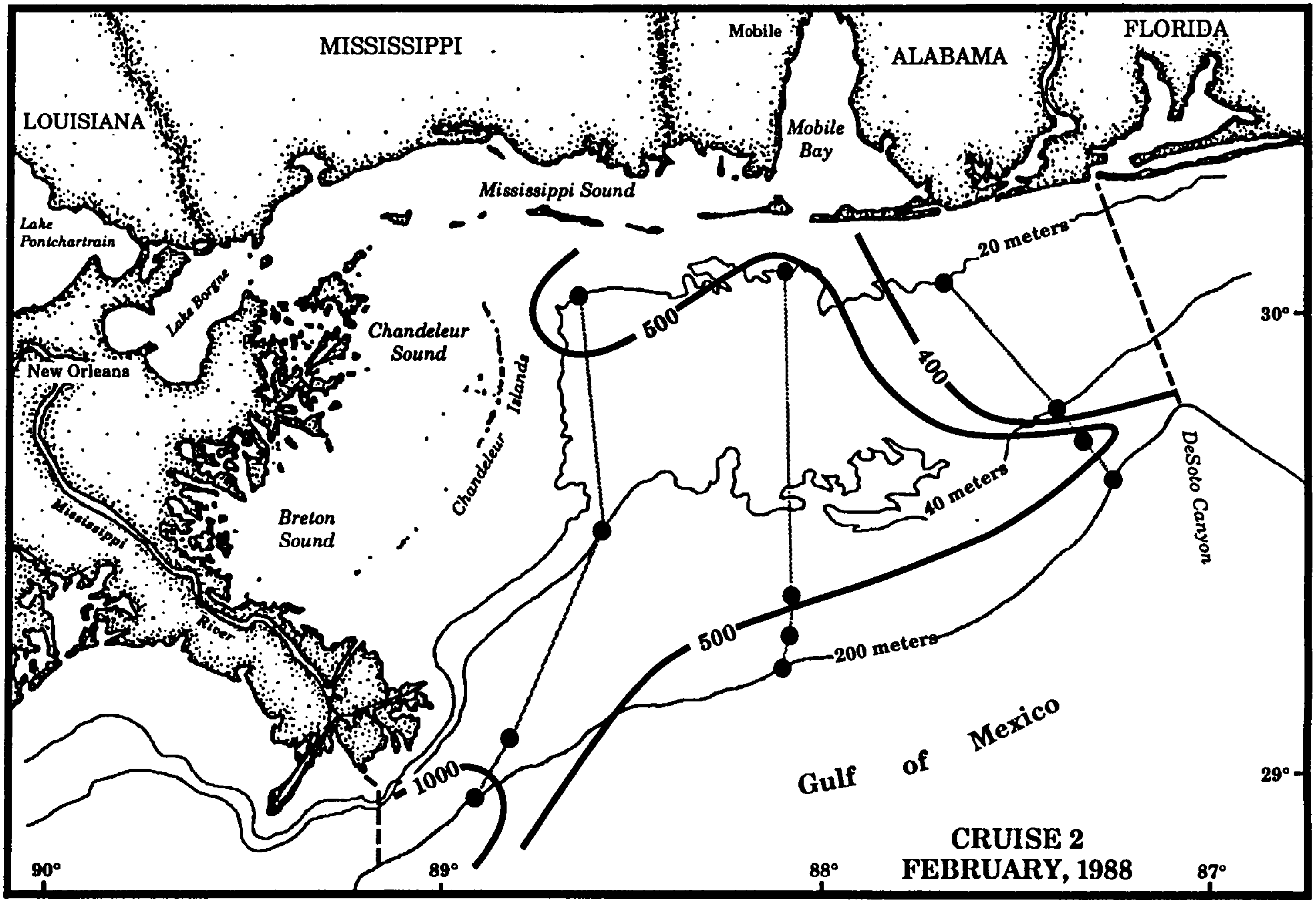


Figure 4-5c. Continued.

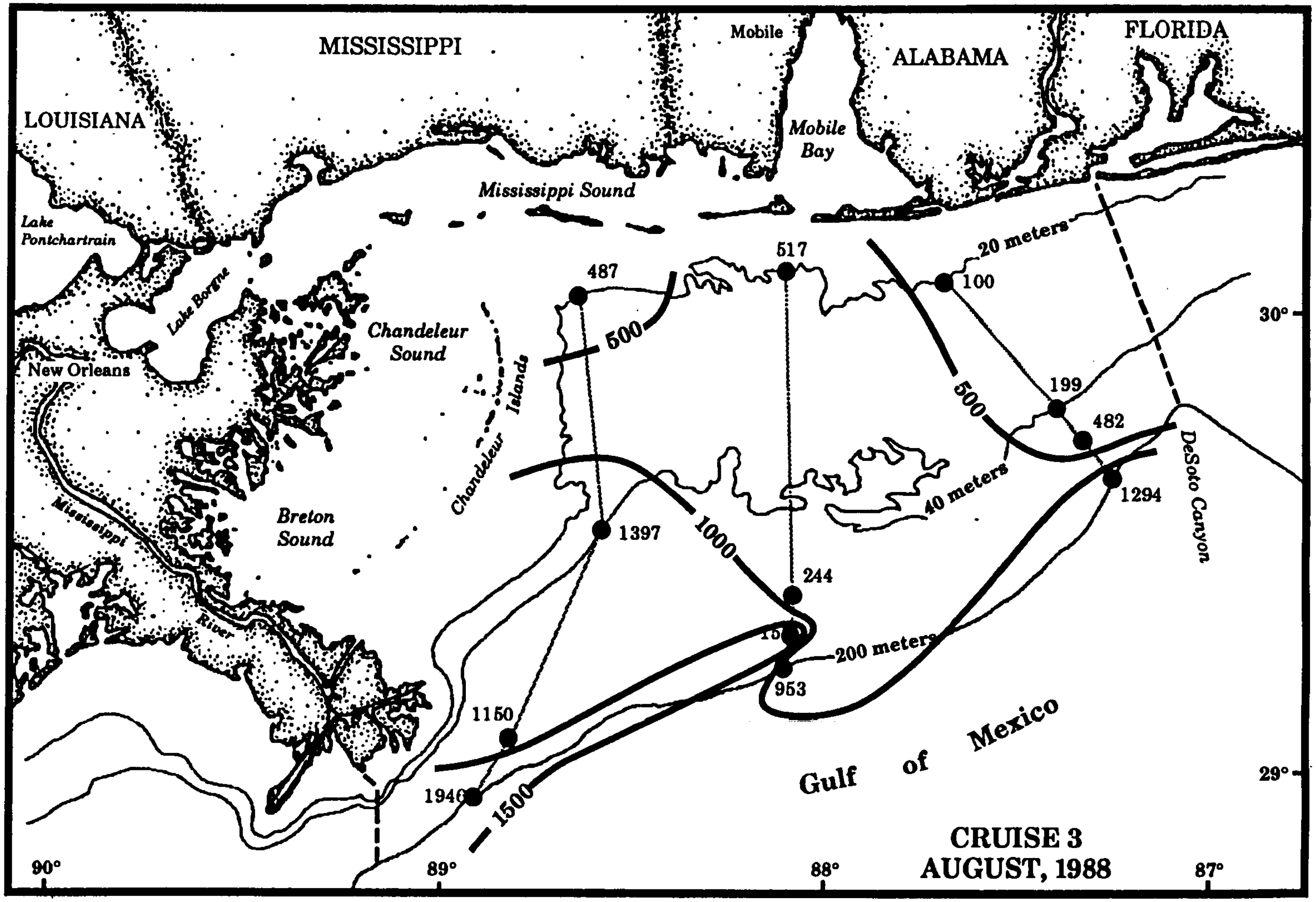


Figure 4-5d. Continued.

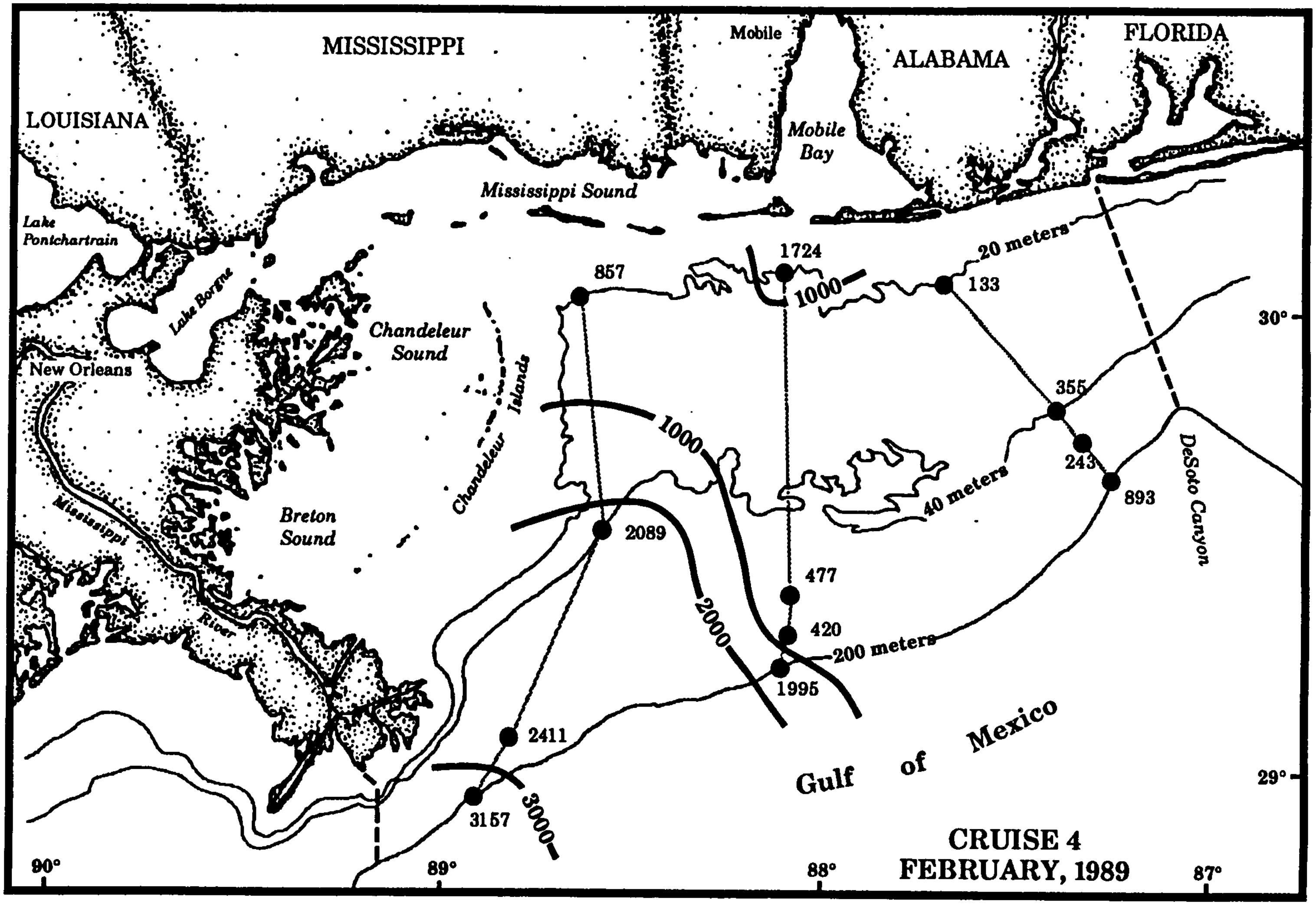


Figure 4-5e. Concluded.

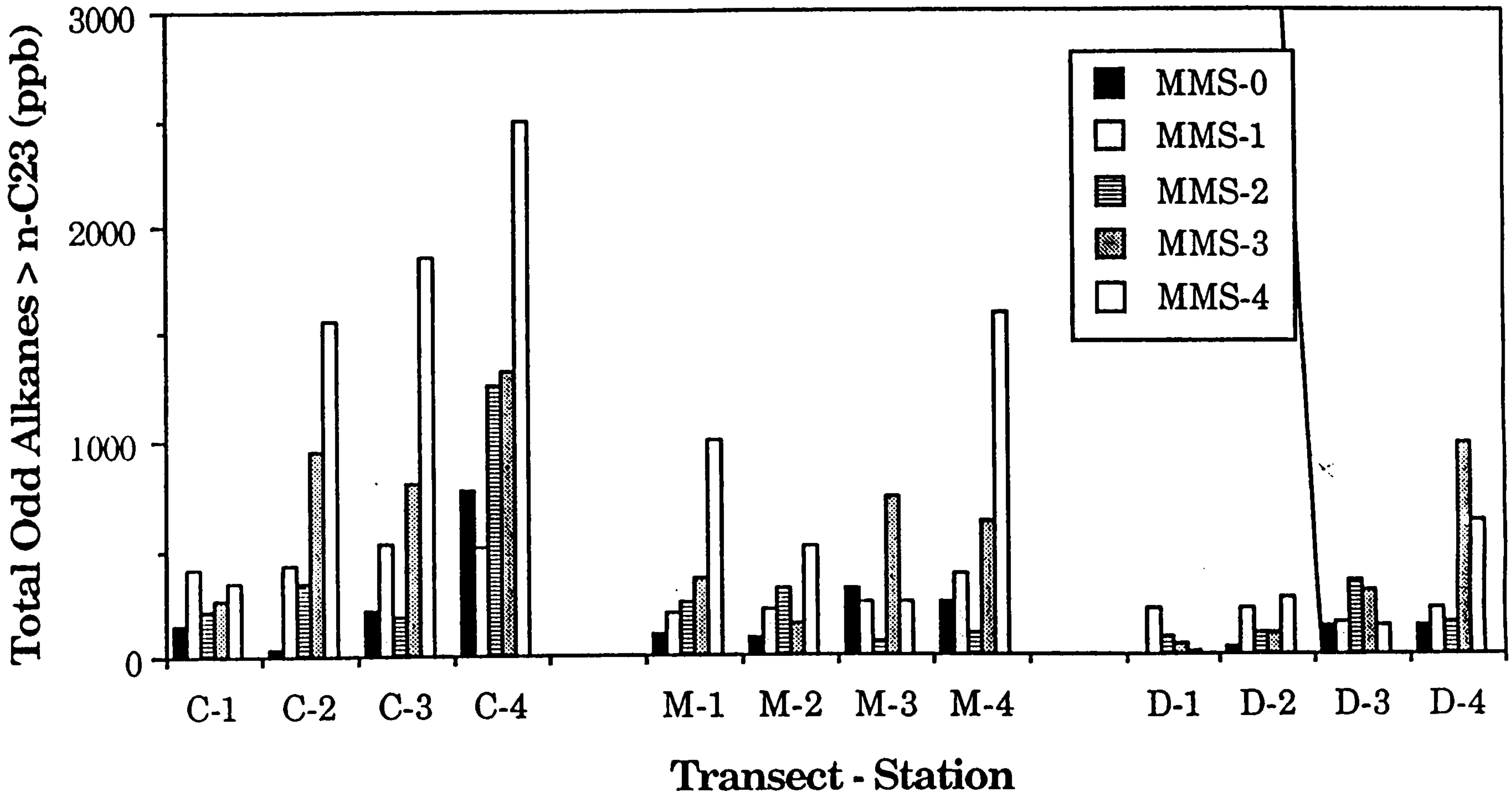


Figure 4-6. Summary of the total concentrations odd-carbon-numbered n-alkanes with 23 to 31 carbons in sediments from the study area.

Aromatic hydrocarbons were present at low levels and varied from less than the detection limit to 673 ppb and averaged 158 ppb. Two to five ring aromatic hydrocarbons were detected (Table 4-6). Molecular compositions were highly variable and anthracene was only sporadically detected (Table 4-6). The highest PAH values were along transect C and at the deepest stations of transects M and D (Figure 4-7a-e). PAH concentrations appear to vary in a cyclic manner over the sampling period, but at varying rates dependent on location (Figure 4-8).

4.4 Discussion

4.4.1 Bulk Parameters

Total organic carbon (TOC) contents, in general, were typical for continental shelf sediments. TOC values in excess of 2% are somewhat anomalous and most likely reflect periodic inputs of large amounts of organic matter as well as enhanced preservation in the sediment. Calcium carbonate content was also highly variable throughout the study area. The deepest water stations of transect D were dominated by shell hash. Station M-3 and D-2 also exhibited occassional high carbonate contents probably reflecting the variable and inhomogeneous nature of sediments in the area. Extractable organic matter (EOM) can have both a biological and anthropogenic source. In general the EOM was highly variable between locations within a single sampling and between samplings at a single location. High organic carbon, high extractable organic matter, and low carbonate contents were concentrated along transect C, nearest to the Mississippi Delta. The deepest water stations were consistently highest in organic carbon content for all three transects suggesting a concentration of clay rich sediments along the 100 to 200 meter isobath.

Based on the difference of the average carbon isotopic composition of terrestrial and marine plants, the relative input of terrestrial and marine organic matter into marine sediments has been inferred (Wickman, 1952; Craig, 1953; Sackett, 1964). This original interpretation is complicated by: (1) the overlap of the isotopic composition of marine and terrestrial plants; (2) the effects of water temperature on the fractionation of carbon in

Table 4-6. Summary of the polycyclic aromatic hydrocarbon data for the study period.

PARAMETER	TRANSECT-STATION											
CRUISE	C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Total Aromatics (ppb)												
Cruise MMS-0	16	6	174	348	*	*	7	112	**	5	6	63
Cruise MMS-1	76	263	288	514	*	6	97	279	6	*	45	192
Cruise MMS-2	14	269	35	331	10	*	147	*	*	*	47	*
Cruise MMS-3	113	243	496	673	*	*	130	280	32	*	68	118
Cruise MMS-4	68	176	296	567	138	18	19	194	*	*	28	114
2-3 Rings (%)												
Cruise MMS-0	32.6	*	23.2	30.9	*	*	*	31.4	**	*	*	72.6
Cruise MMS-1	64.0	52.9	57.3	45.4	*	*	72.5	58.9	*	*	56.0	82.0
Cruise MMS-2	0.0	58.2	20.5	22.2	*	*	18.2	*	*	*	0.0	*
Cruise MMS-3	62.3	25.9	35.6	25.4	*	*	71.2	36.3	*	*	39.2	42.0
Cruise MMS-4	69.4	11.2	24.2	23.7	82.1	*	*	8.3	*	*	51.4	9.1
4-5 Rings (%)												
Cruise MMS-0	67.4	*	76.8	69.1	*	*	*	68.6	**	*	*	27.4
Cruise MMS-1	36.0	47.1	42.7	54.6	*	*	27.5	41.1	*	*	44.0	18.0
Cruise MMS-2	100.0	41.8	79.5	77.8	*	*	81.8	*	*	*	100.0	*
Cruise MMS-3	37.7	74.1	64.4	74.6	*	*	28.8	63.7	*	*	60.8	58.0
Cruise MMS-4	30.6	88.8	75.8	76.3	17.9	*	*	91.7	*	*	48.6	90.9
4-5 Rings/2-3 Rings												
Cruise MMS-0	2.07	*	3.32	2.23	*	*	*	2.19	**	*	*	0.38
Cruise MMS-1	0.56	0.89	0.75	1.20	*	*	0.38	0.70	*	*	0.78	0.22
Cruise MMS-2	*	0.72	3.88	3.50	*	*	4.50	*	*	*	*	*
Cruise MMS-3	0.61	2.86	1.81	2.94	*	*	0.41	1.75	*	*	1.55	1.38
Cruise MMS-4	0.44	7.91	3.13	3.22	0.22	*	*	11.11	*	*	0.95	9.99
Phenanthrene/Anthracene												
Cruise MMS-0	*	*	*	*	*	*	*	*	**	*	*	*
Cruise MMS-1	*	*	*	*	*	*	*	*	*	*	*	*
Cruise MMS-2	*	4.12	*	2.72	*	*	*	*	*	*	*	*
Cruise MMS-3	2.55	*	5.35	5.20	*	*	*	*	1.47	*	*	*
Cruise MMS-4	*	*	*	*	*	*	*	*	*	*	*	*

* = Not determined due to one or more peaks less than the limit of quantitation.

** = Samples not taken during first cruise.

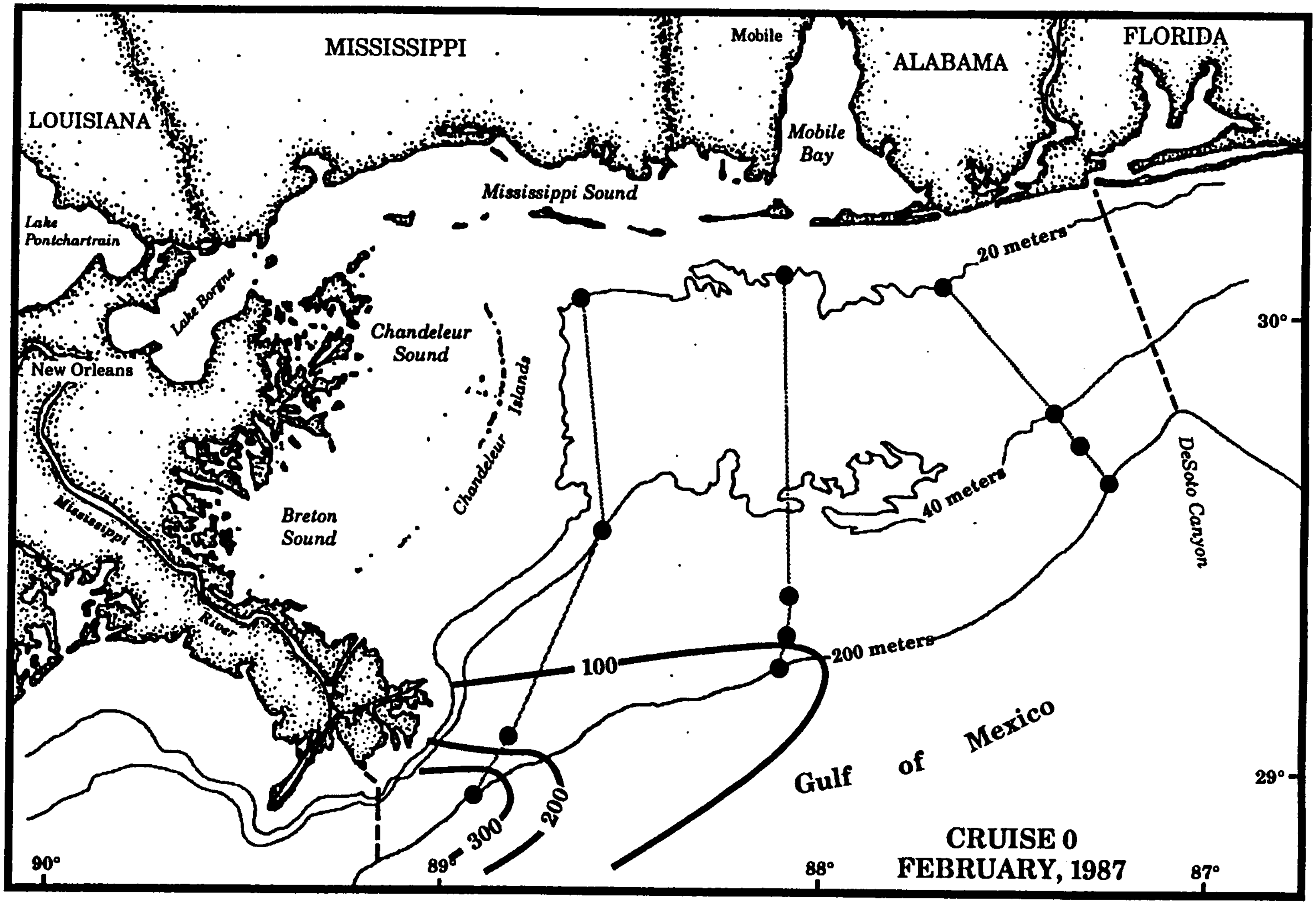


Figure 4-7a. Geographic distributions of the total concentration of measured polycyclic aromatic hydrocarbons (PAHs) during five samplings.

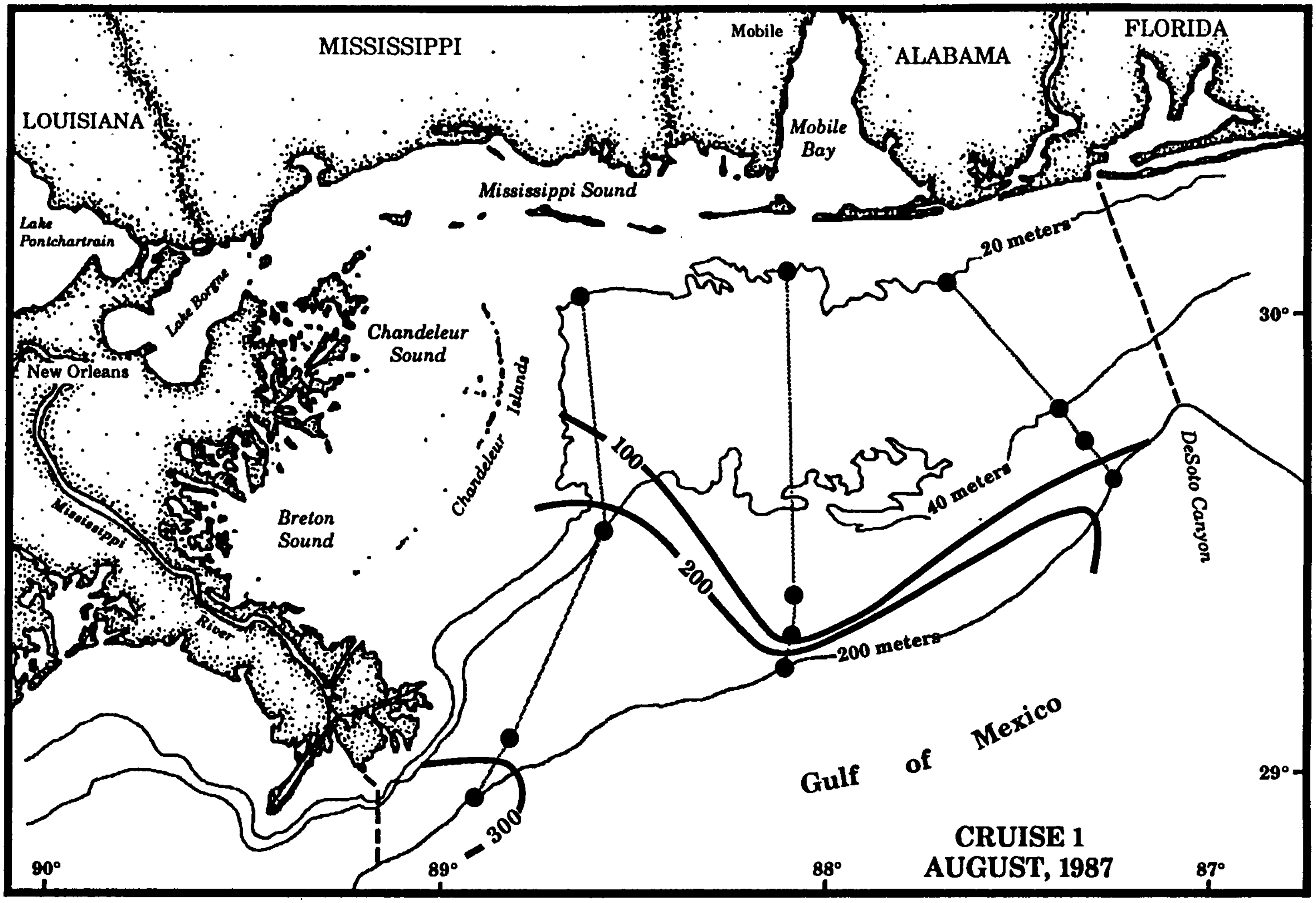


Figure 4-7b. Continued.

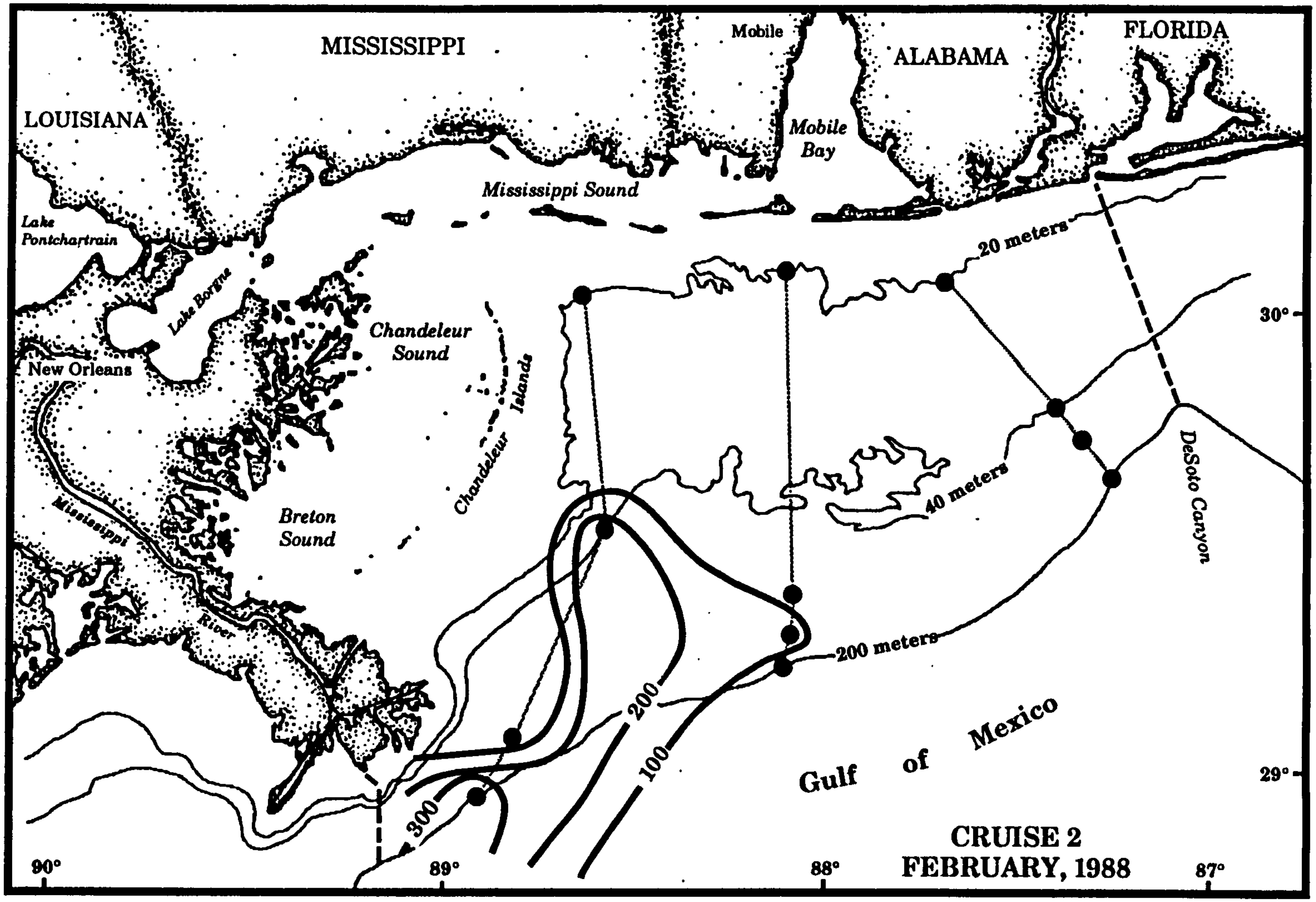


Figure 4-7c. Continued.

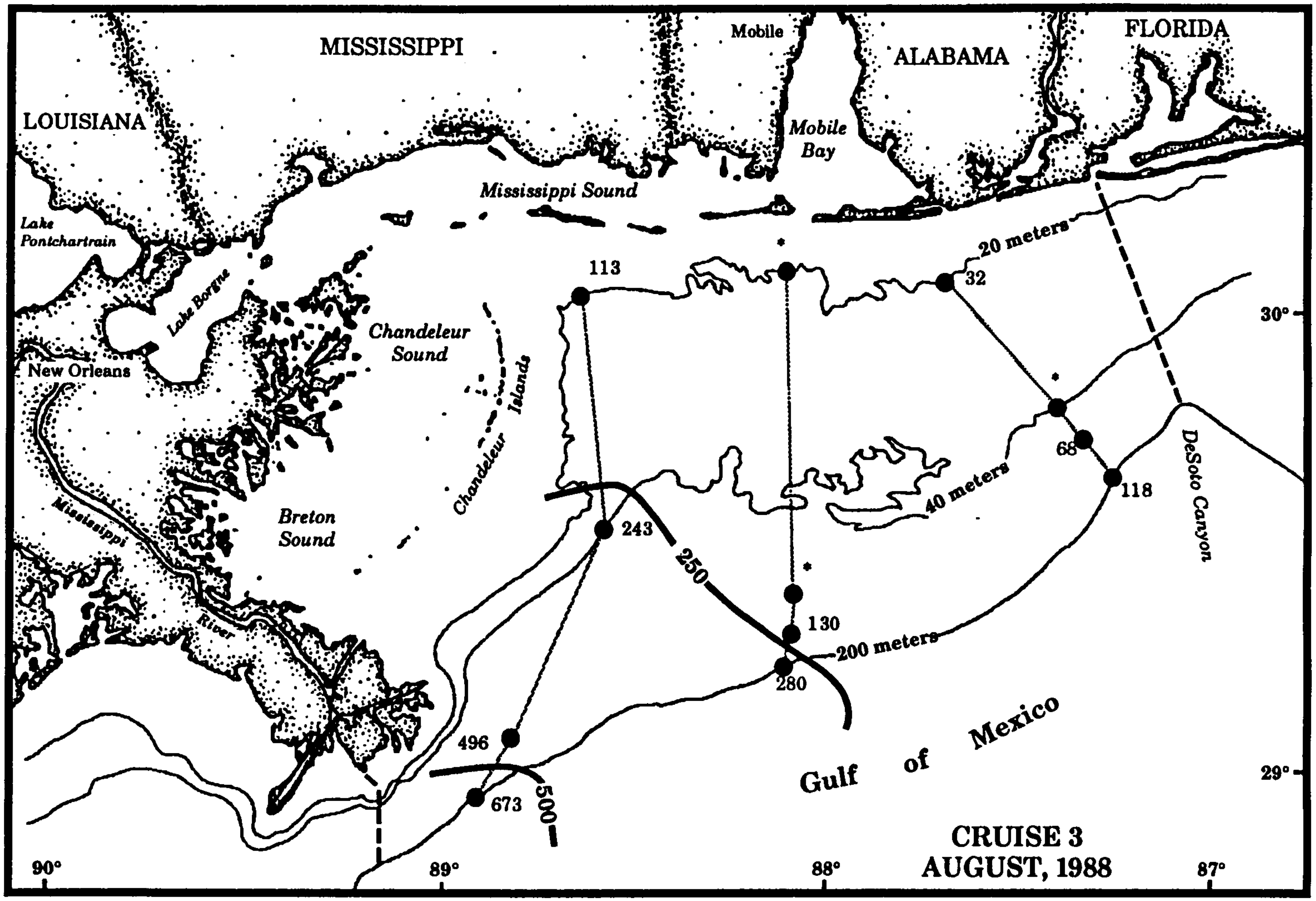


Figure 4-7d. Continued.

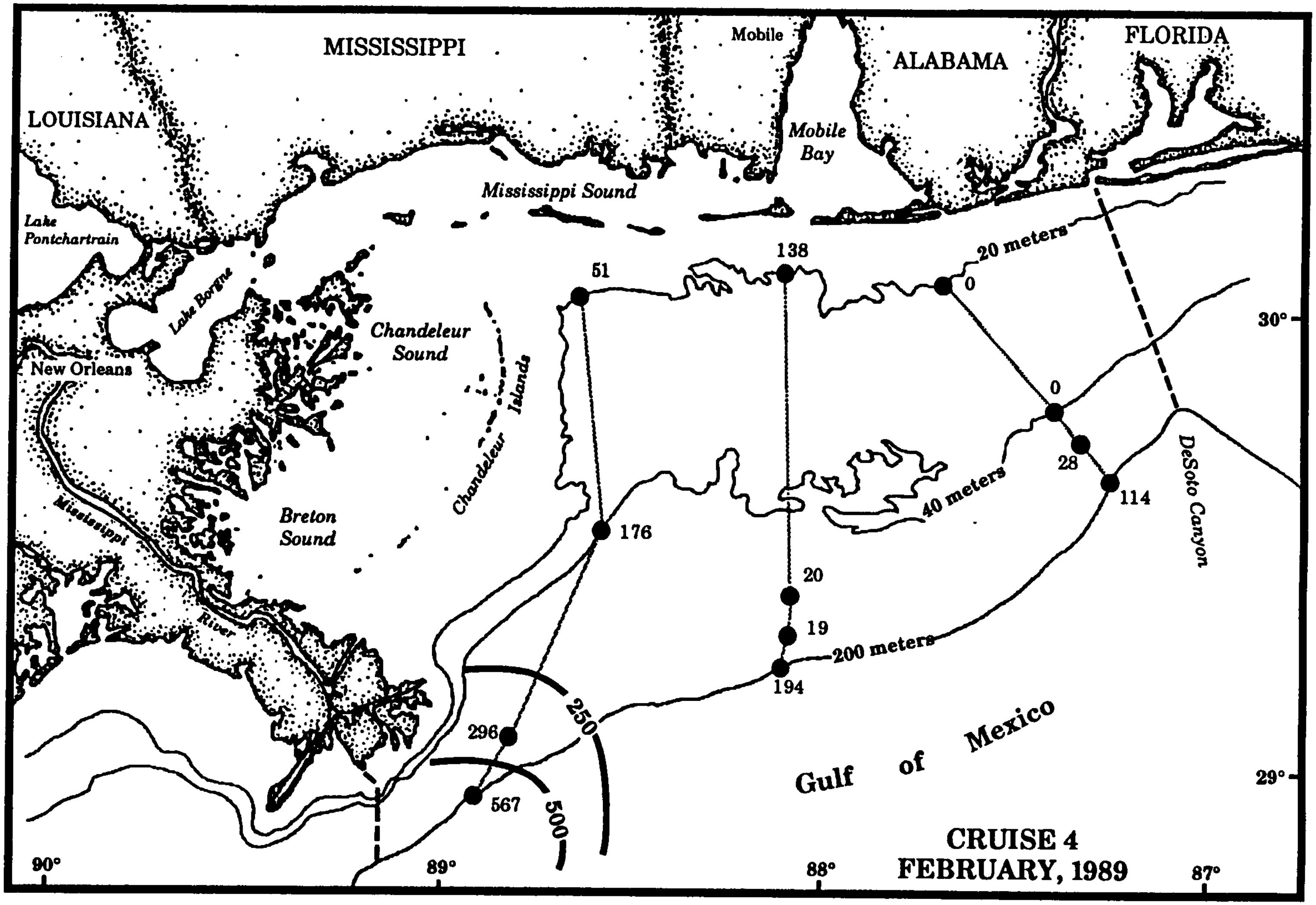


Figure 4-7e. Concluded.

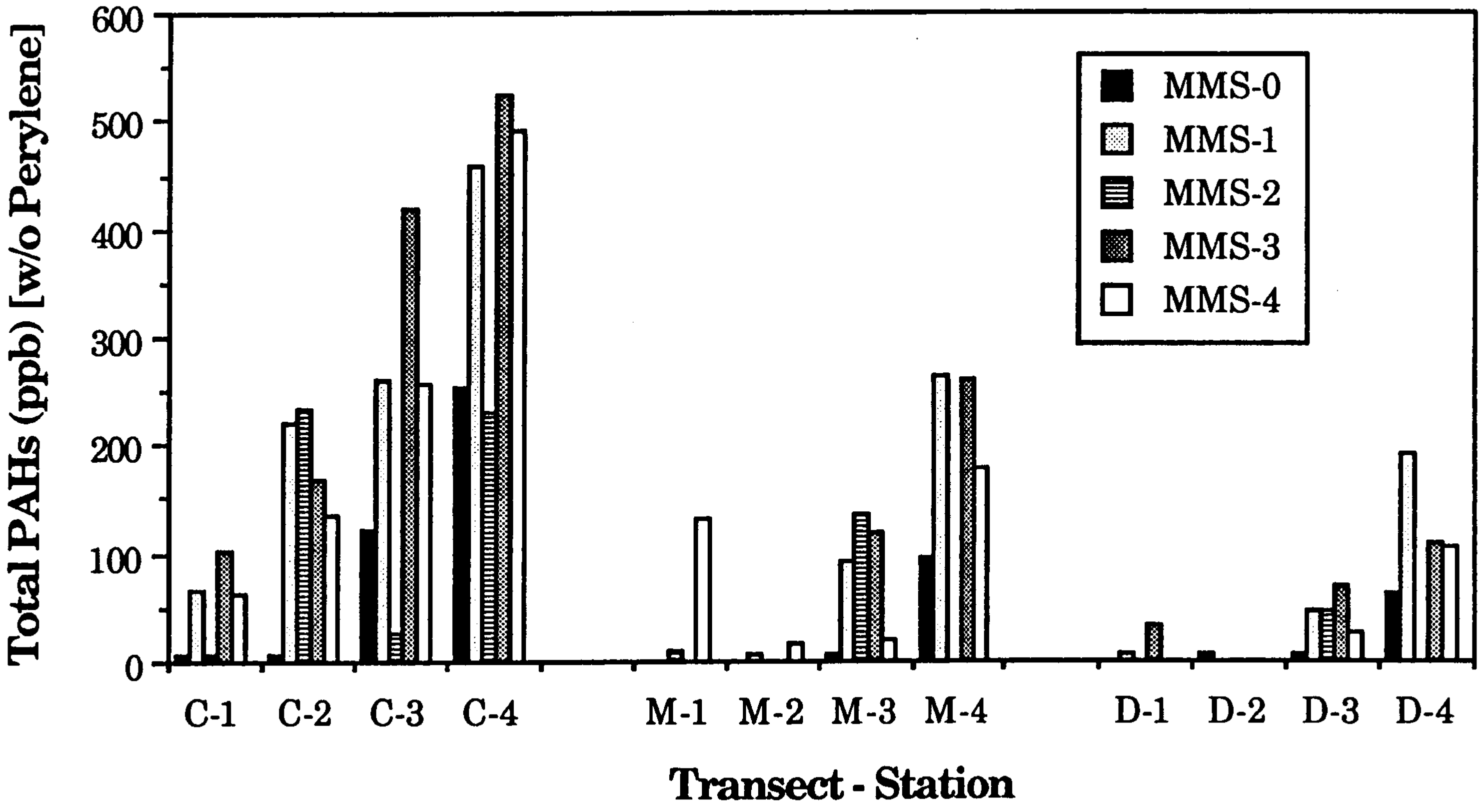


Figure 4-8. Summary of the distribution of total concentrations of PAHs in sediments from the study area.

plankton; (3) the alteration of organic matter isotopic composition during bacterial degradation and diagenesis; (4) migration of thermogenic hydrocarbons from deeper reservoirs to shallow sediments; (5) anomalous isotopic compositions produced in localized (closed) environments; and (6) the incorporation of recycled organic matter into recent sediments. Given these limitations and assumptions the relative importance of land versus plankton derived organic matter can be estimated.

In this particular model the planktonic $\delta^{13}C$ end member is considered to be between -19 and -21‰ and land plant associated organic matter is assumed to be between -26 and -28‰. The maximum and minimum values are calculated and reported in Table 4-7. In general the study area was dominated by planktonic debris during Cruises 0, 3 and 4. Cruises 2 and especially 1 showed significant enhancement in terrestrially derived organic matter. This same sampling coincides with the greatly enhanced silt contents noted in the grain size analysis. High silt content directly corresponds with $\delta^{13}C$ values and the relationship persisted through Cruise 2. Several transects showed a decreasing land plant influence with increasing distance offshore (Cruise 0, transect M; Cruise 1, transect M; Cruise 2, transects M and D). Though the definition of end-members composition is only approximate this model does demonstrate that significant variations in the relative importance of various organic matter inputs were observed over the 2-1/2 year study period.

4.4.2 Aliphatic Hydrocarbons

Aliphatic hydrocarbon compositions have been extensively used to estimate the relative importance of hydrocarbon sources. The use of aliphatic hydrocarbons as indicator compounds is based on the premise that recognizable assemblages of normal and branched alkanes can be associated with specific sources. In nature, however, few unique aliphatic end-members occur. A review of alkane hydrocarbon distributions and their significance has been provided by Brassell *et al.* (1978), Philp (1985) and Kennicutt and Comet (1990). Plankton generally produce simple mixtures of hydrocarbons dominated by n-$C_{15,17,19}$ and pristane (Clark and Blumer, 1967; Blumer *et al.*, 1970; Goutx and Saliot, 1980; Table 4-8). Petroleum also contains these compounds but usually contains nearly equal

Table 4-7. Summary of the maximum and minimum inputs of terrestrial and planktonic derived organic matter modeled on stable c

CRUISE		TRANSECT-STATION											
PARAMETER		C-1	C-2	C-3	C-4	M-1	M-2	M-3	M-4	D-1	D-2	D-3	D-4
Cruise MMS-0													
del 13C (per mil)		-21.3	-20.4	-21.2	-20.4	-25.1	-24.0	-21.5	-20.4	**	-19.1	-21.5	-21.0
Planktonic	Minimum	67.1%	80.0%	68.6%	80.0%	12.9%	28.6%	64.3%	80.0%	**	98.6%	64.3%	71.4%
	Maximum	95.7%	100.0%	97.1%	100.0%	41.4%	57.1%	92.9%	100.0%	**	100.0%	92.9%	100.0%
Terrestrial	Minimum	4.3%	0.0%	2.9%	0.0%	58.6%	42.9%	7.1%	0.0%	**	0.0%	7.1%	0.0%
	Maximum	32.9%	20.0%	31.4%	20.0%	87.1%	71.4%	35.7%	20.0%	**	1.4%	35.7%	28.6%
Cruise MMS-1													
del 13C (per mil)		-23.4	-23.7	-23.4	-23.3	-24.8	-20.5	-23.3	-23.3	-22.9	-23.3	-22.3	-22.7
Planktonic	Minimum	37.1%	32.9%	37.1%	38.6%	17.1%	78.6%	38.6%	38.6%	44.3%	38.6%	52.9%	47.1%
	Maximum	65.7%	61.4%	65.7%	67.1%	45.7%	100.0%	67.1%	67.1%	72.9%	67.1%	81.4%	75.7%
Terrestrial	Minimum	34.3%	38.6%	34.3%	32.9%	54.3%	0.0%	32.9%	32.9%	27.1%	32.9%	18.6%	24.3%
	Maximum	62.9%	67.1%	62.9%	61.4%	82.9%	21.4%	61.4%	61.4%	55.7%	61.4%	47.1%	52.9%
Cruise MMS-2													
del 13C (per mil)		-21.4	-23.5	-23.0	-22.7	-24.9	-23.3	-21.3	-21.7	-24.2	-20.6	-23.2	-22.2
Planktonic	Minimum	65.7%	35.7%	42.9%	47.1%	15.7%	38.6%	67.1%	61.4%	25.7%	77.1%	40.0%	54.3%
	Maximum	94.3%	64.3%	71.4%	75.7%	44.3%	67.1%	95.7%	90.0%	54.3%	100.0%	68.6%	82.9%
Terrestrial	Minimum	5.7%	35.7%	28.6%	24.3%	55.7%	32.9%	4.3%	10.0%	45.7%	0.0%	31.4%	17.1%
	Maximum	34.3%	64.3%	57.1%	52.9%	84.3%	61.4%	32.9%	38.6%	74.3%	22.9%	60.0%	45.7%
Cruise MMS-3													
del 13C (per mil)		-22.6	-21.7	-21.2	-22.1	-21.5	-20.5	-21.3	-20.9	-20.5	-21.9	-20.7	-22.3
Planktonic	Minimum	48.6%	61.4%	68.6%	55.7%	64.3%	78.6%	67.1%	72.9%	78.6%	58.6%	75.7%	52.9%
	Maximum	77.1%	90.0%	97.1%	84.3%	92.9%	100.0%	95.7%	100.0%	100.0%	87.1%	100.0%	81.4%
Terrestrial	Minimum	22.9%	10.0%	2.9%	15.7%	7.1%	0.0%	4.3%	0.0%	0.0%	12.9%	0.0%	18.6%
	Maximum	51.4%	38.6%	31.4%	44.3%	35.7%	21.4%	32.9%	27.1%	21.4%	41.4%	24.3%	47.1%
Cruise MMS-4													
del 13C (per mil)		-21.3	-21.3	-21.1	-21.6	-21.5	-20.7	-20.8	-21.1	-19.0	-21.2	-20.4	-20.4
Planktonic	Minimum	67.1%	67.1%	70.0%	62.9%	64.3%	75.7%	74.3%	70.0%	100.0%	68.6%	80.0%	80.0%
	Maximum	95.7%	95.7%	98.6%	91.4%	92.9%	100.0%	100.0%	98.6%	100.0%	97.1%	100.0%	100.0%
Terrestrial	Minimum	4.3%	4.3%	1.4%	8.6%	7.1%	0.0%	0.0%	1.4%	0.0%	2.9%	0.0%	0.0%
	Maximum	32.9%	32.9%	30.0%	37.1%	35.7%	24.3%	25.7%	30.0%	0.0%	31.4%	20.0%	20.0%

** = Samples not taken during first cruise

Table 4-8. Summary of the major sources of normal and branched alkanes in the geosphere (after Brassell *et al.*, 1978).

Dominant Compounds	Carbon No. Range	Organism
<u>Biological alkanes</u>		
n-C_{17}, n-C_{15}	14-29	photosynthetic bacteria (C_{26}); non-photosynthetic bacteria (17-20); algae, (blue-green, brown red);
n-C_{18} + n-C_{24}	18-34 or 20-28	zooplankton
n-$C_{27,29,31}$	15-37	higher plants (terrestrial)
Monomethyl alkanes	C_{25-31} C_{18}	bacteria, higher plants blue-green algae
Isoprenoids	i-C_{19} i-C_{20}	algae, zooplankton, bacteria
C_{17} cyclopropane		marine benthic algae
<u>Petroleum Related Alkanes</u>		
variable variable an unresolved complex mixture	C_1-C_{35}^+ normal C_4-C_{35}^+ branched C_9-C_{22}^+ isoprenoid cycloalkanes	ancient sediments, shales, coals, oil seeps, anthropogenic inputs

amounts of n-$C_{16,18,20}$ and phytane as well (Farrington and Tripp, 1977; Farrington *et al.*, 1973). Straight chain biowaxes with 25,27,29 and 31 carbons have been used extensively as indicators of terrestrial or land-derived organic matter (Philp, 1985 and references therein). Wax-derived normal alkanes are also found in petroleum but are accompanied by near equal amounts of n-$C_{24,26,28,30}$. Immature sediments also contain these hydrocarbons but exhibit a significant odd carbon preference, similar to the original input.

In general the presence of petroleum is suggested by an unresolved complex mixture in the gas chromatographic analysis. In general aliphatic hydrocarbons (normal and isoprenoid) have overlapping distributions and cannot always be unambiguously resolved. A complete homologous series of *n*-alkanes up to n-C_{40} of near equal abundance is thought to be specific to petroleum. This interpretation is complicated by the presence of fungal and bacterial contributions which can also have a smooth distribution or in some cases show a strong even carbon preference (Nishimura and Baker, 1986). Unless the contributing factors can be fully resolved some doubt always remains in the interpretation of n-alkane environmental data though useful assumptions can be applied.

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. The dominant alkanes were the odd carbon number alkanes with 23 to 31 carbons presumably due to terrigenous plant biowaxes. 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.

4.4.3 Aromatic Hydrocarbons

Aromatic hydrocarbons are widely used as an indicator of petroleum contamination in environmental samples. In general environmental studies consider polyaromatic hydrocarbons consisting of condensed rings and simple alkylations (i.e. naphthalenes, phenanthrenes, fluoranthenes, chrysenes, etc.). Aromatics are ubiquitous in sedimentary environments and can have multiple sources in petroleum, biosynthesis, early diagenesis, coal, combustion and immature/mature sediments (Table 4-9). Molecular compositions have been extensively documented so that these various sources can be recognized based on parent and alkylated homologues and ring number distributions. These basic concepts have been extensively reviewed elsewhere and will not be repeated here (Hites *et al.*, 1980; La Flamme and Hites, 1978; Wakeham *et al.*, 1980a,b; and references therein).

A clear association between petroleum and condensed aromatic compounds (PAH) is evident. The abundance and composition of polynuclear aromatic hydrocarbons are a good indication of petroleum related hydrocarbons. The presence of apparently mature hydrocarbons, as evidenced by a complex mixture of aromatic compounds, in an immature sedimentary sequence can be due to anthropogenic influences, migration from a deeper source, *in situ* formation (unlikely if the section is judged thermally immature), recycling of mature sediments from the continent (exposed source rocks or oil seepage), and/or contamination during sample collection or preparation. Few aromatic hydrocarbons are synthesized by organisms and the complex mixture of alkylated homologues present in petroleum are only formed at elevated temperatures.

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 adjacent bay samples with predominantly pyrogenic PAHs (Figure 4-9). This interpretation is confirmed by the absence of anthracene at most sites, a constituent of pyrogenic hydrocarbons. Unprocessed petroleum can result from natural seepage, urban runoff, industrial complexes, offshore oil production, and shipping or tanker activities.

4.5 Summary

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

Table 4-9. Summary of sources of aromatic hydrocarbons in the geosphere.

Source	Composition
Petroleum	- 1 to 6 or larger rings with zero to 5 or more carbon alkylation - aromatized steranes (primarily mono and triaromatics) - aromatic sulfur compounds - porphyrins
Organism (biosynthetic or early diagentic products in recent sediments)	retene, perylene, octahydrochrysenes, alkyl chrysenes, picene, pimanthrene, tetra and pentacyclic PAH* (see Wakeham *et al.*, 1980a,b)
Immature/Mature Sediments	monoaromatized and triaromatized steranes (as well as the same as petroleum for mature sediments)
Pyrogenic (combustion, forest fires)	parent aromatic compounds are enriched (see Laflamme and Hites, 1978; Hites *et al.*, 1980).

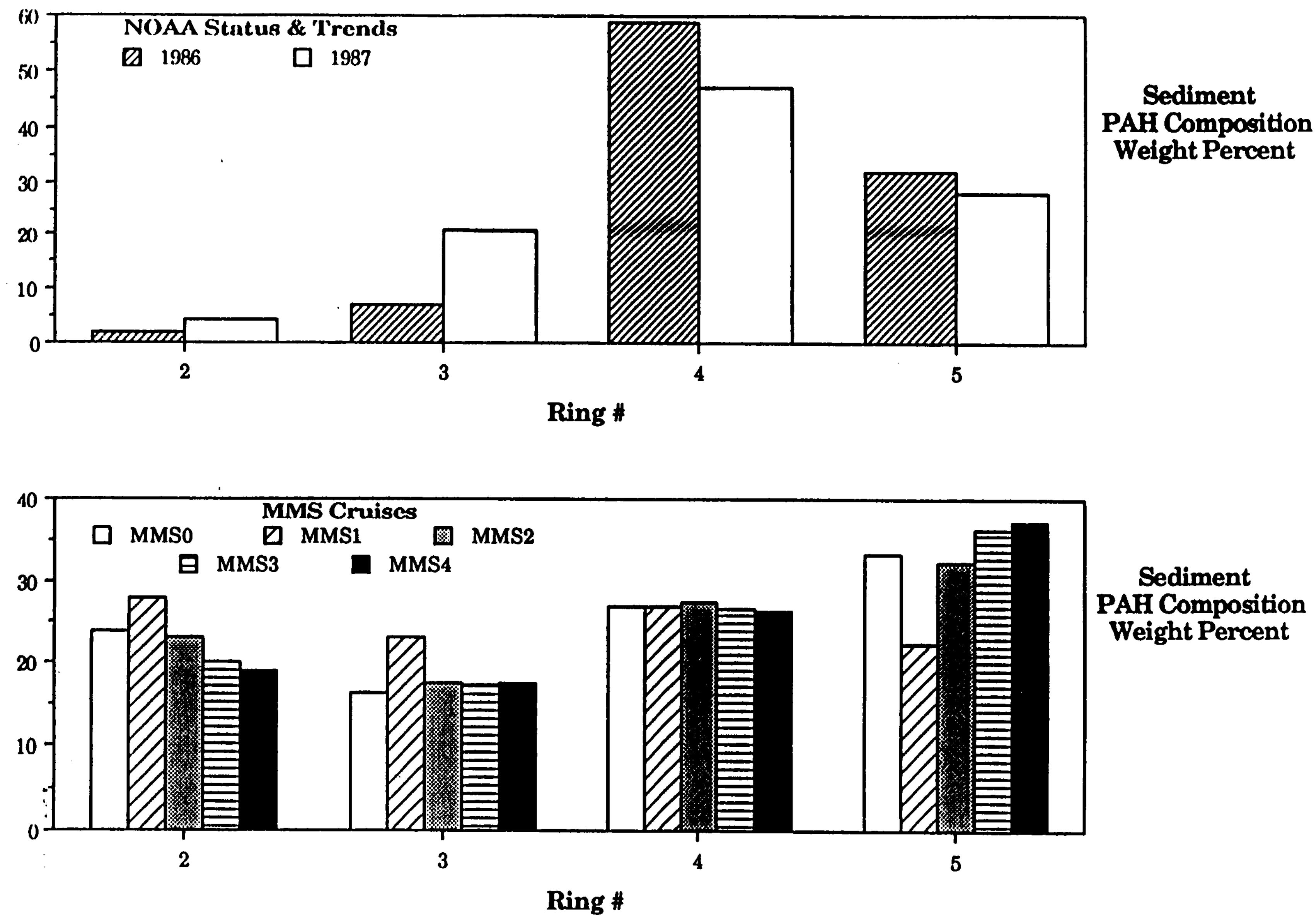


Figure 4-9. Comparison of PAH compositions between sediments in the study area and adjacent bays and estuaries.

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. 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. 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.

The temporal variations in sediment properties in the study area can be explained by various scenarios. Individual sediment components vary independently and are subject to a variety of different processes. These scenarios are as follows:

(1) cyclic - on time frames of 6 months, one year, two years and possibly longer. This can be explained by either regular inputs (such as seasonal variations) being balanced by either removal processes or dilution events (i.e., aromatic and aliphatic hydrocarbons).

(2) steadily increasing - in this scenario input continues overtime with no efficient (or active) removal process. The episodic occurrence of mass movement of sediments only redistributes components within the system. Another possible explanation is input exceeds removal processes thus leading to a build-up (i.e., the unresolved complex mixture - residual petroleum).

(3) random variation - episodic perturbation due to one-time or infrequent events such as major storm events (i.e., extractable organic matter).

(4) no change - could reflect input equal to removal rate with a relatively constant rate of input or the timeframe of change is greatly in excess of the two years monitored in this study (i.e., carbonate content at some locations).

Sediments on the Mississippi-Alabama shelf are very dynamic and change on time scales varying from less than six months to more than two years. Inputs are complex and often independently driven. Removal processes are complex, constituent dependent and vary independently. Sediment properties vary by an order of magnitude or more over the two years of the study. Many of these variations can be directly related to variations in land derived inputs that are mediated by river outflow from the Mississippi River/Delta system as well as other rivers in the area. Hydrocarbon pollutant loading to sediments is primarily derived from fresh, unrefined petroleum closely associated with fine particulates derived from riverine transport. Aeolian transport and outflow from coastal bays appear to be minor influences.

In contrast to the view of sediments as relatively stable repositories of particulate matter, very dynamic interactions are apparent. Clearly if sediments are to be characterized temporal as well as spatial variations need to be considered. As an intimate part of the benthos as well as an interface with the overlying water column, these dramatic variations in sediment composition and character need to be assessed in light of ecological assessments of man's potential impact on these areas.

5.0 TRACE METALS, YEAR II

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 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 five centimeters of all three were used to make a composite sample for analysis.

The composite samples were analyzed for all the elements currently being determined on the NOAA Status and Trends Program except Al 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. In addition, all samples were analyzed for Ba, Cr and Fe by neutron activation analysis, a method known to produce high quality data (Boothe and James 1985).

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.

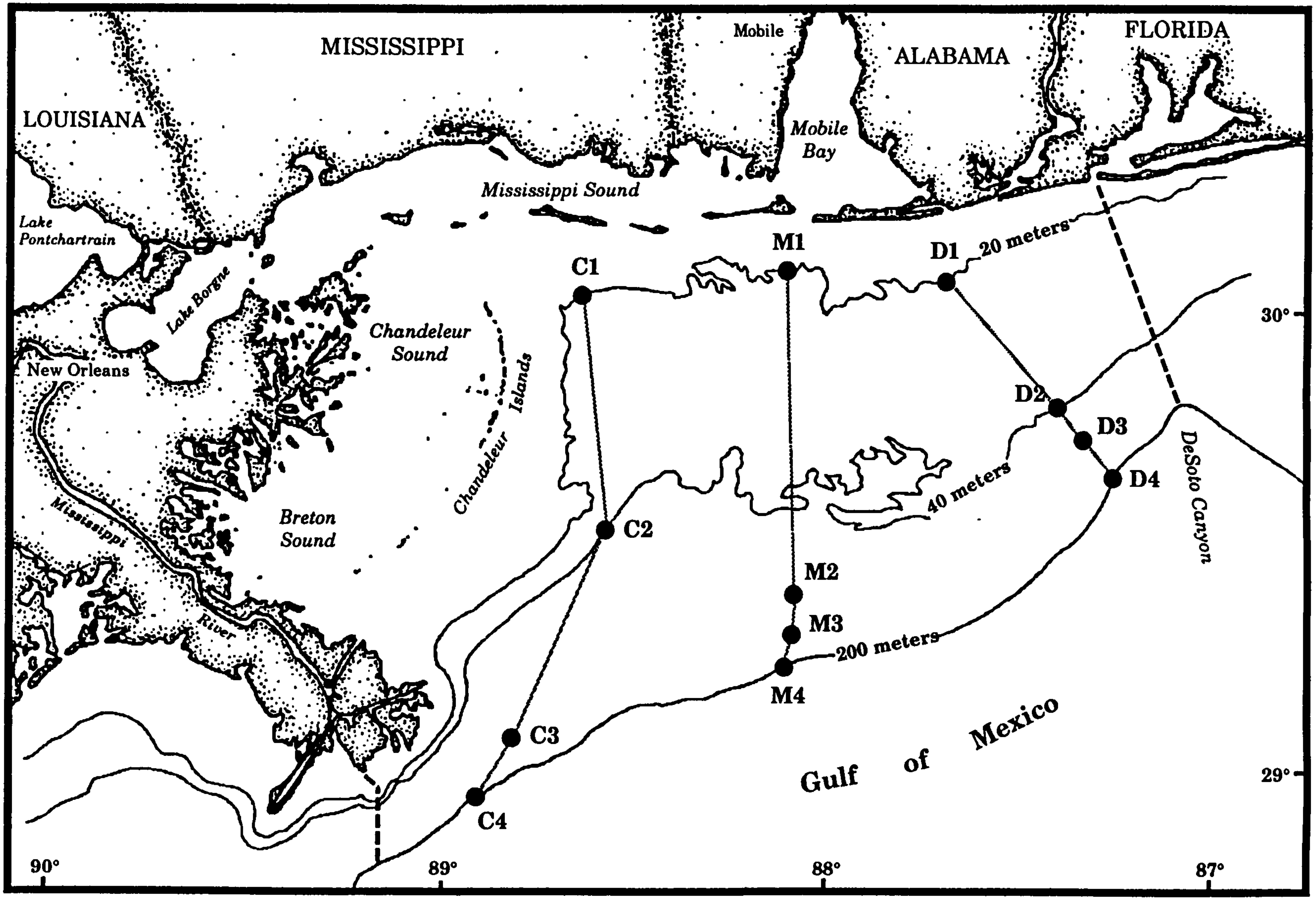


Figure 5-1. Twelve Stations Sampled on Cruise 0, 1, and 2 of the Mississippi-Alabama Marine Ecosystem Study.

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, 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

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, 1976b)	0.1	--	0.5	2	5	10	-	1	0.2	--	-
(Trefry et al. 1985)	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											
Mississippi Suspended Matter (Trefry and Presley 1976b)	1.3	20	80	46	46,000	1300	--	55	46	150	180
(Trefry et al. 1985)	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

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 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 five 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 five 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, fluorine, 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 five 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 meters.

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, four to seven 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 one to three 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 meters. 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

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. (1)

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.

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 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.

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. Weigh 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_3:$HClO_4$. 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 digested included one 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.

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 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 eight 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. The INAA data for Ba, Cr and Fe is included in the data tables but the other INAA data has not been reduced and tabulated as it did not seem important to the present project.

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 cruises, except no sample was collected at Station D-1 on the first cruise. A composite sample made by combining aliquots from the upper five centimeters 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), selenium (Se), tin (Sn), and zinc (Zn). The data are given in Table 5-5 where the cruises are designated as Cruise 0, 1, 2, 3 and 4 respectively. No data is given for Ba in Cruise 2 samples as this data, which is produced by neutron activation analysis, was not available when this

Table 5-5. Trace Metals in Sediments from MMS Cruises 0, 1, 2, 3, and 4.

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
Cruise - 0														
I-C-1	49	12	333	49	47	8	2.20	66	346	8	15	<0.5	1.9	55
I-C-2	18	1	150	19	15	2	0.66	15	141	3	5	<0.5	0.4	20
I-C-3	92	15	895	130	84	22	4.20	83	1239	27	33	<0.5	3.3	126
I-C-4	118	14	890	204	84	23	4.20	96	664	31	34	0.6	2.9	124
I-M-1	11	3	70	13	7	1	0.32	8	65	1	2	<0.5	0.4	11
I-M-2	11	2	44	4	6	1	0.26	8	40	1	2	<0.5	<0.1	8
I-M-3	39	6	170	50	30	6	2.34	24	367	10	10	<0.5	1.4	55
I-M-4	56	8	525	143	76	23	3.58	70	329	31	33	0.6	4.4	71
I-D-1														
I-D-2	22	7	<18	90	13	1	1.13	28	202	4	2	<0.5	0.1	10
I-D-3	12	5	125	83	35	8	2.47	22	264	14	5	0.9	0.1	42
I-D-4	49	4	195	148	52	17	1.79	41	371	23	11	1.2	1.3	56
Cruise - 1														
II-C-1	47	12	310	52	45	8	2.02	27	334	15	15	<0.5	1.0	48
II-C-2	53	10	510	70	62	11	2.80	47	481	18	24	<0.5	1.4	90
II-C-3	76	9	910	140	79	23	3.80	63	433	28	30	<0.5	2.2	137
II-C-4	112	10	770	179	86	22	4.10	81	148	39	40	0.6	2.2	154
II-M-1	19	1	75	4	15	1	0.35	<5	47	1	< 1	<0.5	0.1	2
II-M-2	<10	2	95	11	14	1	0.49	8	74	1	1	<0.5	0.1	7
II-M-3	<10	5	180	54	36	12	2.40	22	271	15	11	<0.5	0.9	59
II-M-4	99	8	510	126	72	19	3.38	85	200	43	32	0.8	1.6	79
II-D 1	<10	2	55	4	16	1	0.20	7	12	4	2	<0.5	<0.1	<2
II-D-2	<10	1	10	4	5	1	0.13	7	20	1	< 1	<0.5	0.3	<2
II-D-3	<10	10	50	59	23	15	2.39	16	484	9	9	1.2	0.4	25
II-D-4	21	3	140	162	48	19	1.64	44	302	20	9	1.1	0.8	55
Cruise - 2														
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-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
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	20	312	22	16	0.8	0.4	59

Table 5-5 (cont.).

Sample	Ag (ppb)	As (ppm)	Ba (ppm)	Cd (ppb)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Se (ppm)	Sn (ppm)	Zn (ppm)
Cruise - 3														
IV-C-1	33	5	185	16	25	3	0.90	20	180	5	8	0.2	0.6	37.8
IV-C-2	65	13	440	65	64	12	2.93	47	515	22	20	0.3	2.0	105.4
IV-C-3	80	14	720	115	78	22	3.77	70	345	25	23	0.2	2.4	124.7
IV-C-4	95	10	790	175	84	18	4.02	85	430	27	29	0.1	2.8	150.0
IV-M-1	11	2	90	43	9	1	0.38	14	40	2	1	<0.10	<0.20	18.5
IV-M-2	5	<1.0	65	15	12	1	0.36	6	65	3	3	<0.10	0.3	17.5
IV-M-3	29	6	250	50	42	6	2.45	20	340	14	13	0.2	0.9	80.0
IV-M-4	65	7	390	120	72	16	3.34	50	390	30	24	0.3	2.2	125.0
IV-D-1	12	<1.0	42	<10.	7	1	0.088	6	11	1	1	<0.10	0.6	11.4
IV-D-2	<10	7	31	41	10	1	0.75	11	145	3	4	<0.10	<0.20	19.8
IV-D-3	26	13	75	105	26	3	1.80	20	395	10	10	0.6	0.2	39.7
IV-D-4	31	2	165	135	48	4	1.62	39	335	21	11	0.6	1.0	65.0
Cruise - 4														
V-C-1	55	8	155	20	26	3	0.92	25	188	1	7	<0.2	0.4	25
V-C-2	70	14	660	55	64	15	2.96	57	520	30	21	<0.2	1.5	86
V-C-3	84	16	755	99	79	25	3.92	83	487	40	29	0.3	2.1	129
V-C-4	104	14	790	181	88	24	4.19	104	514	42	36	0.5	2.6	134
V-M-1	30	12	295	28	33	6	1.31	39	214	9	9	0.4	0.5	39
V-M-2	21	3	85	24	11	2	0.44	22	70	3	3	<0.2	<0.2	8
V-M-3	34	4	150	37	37	4	1.18	21	278	7	10	<0.2	0.7	43
V-M-4	65	9	420	78	74	21	3.52	66	433	39	23	0.3	2.0	106
V-D-1	13	2	45	8	6	1	0.13	3	18	1	2	<0.2	<0.2	<5
V-D-2	<10	3	16	19	4	1	0.17	5	44	1	2	<0.2	<0.2	7
V-D-3	21	13	55	123	16	2	1.42	22	337	8	7	<0.2	<0.2	19
V-D-4	34	5	190	165	50	14	1.69	57	331	22	15	1.0	0.9	52

report was written. In addition, Sb and Ti are not included because these samples were below the detectable levels, therefore they were not analyzed.

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 likely that the surface-most sediments in this shallow water area are somewhat mobile and shift with changing currents. These two phenomena cause not only a variablilty in the trace element concentration of the sediment, but also changes in $CaCO_3$ and organic carbon. The basic character of the sediment thus varies. The most drastic change from cruise to cruise was the result of deliberately slightly 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 0 sample from Station C-2 was generally two to five times lower in trace metals than the samples from the other cruises 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, and 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. Trefry and Presley (1976a) and much unpublished data from Presley's laboratory documents an approximately constant trace metal to iron ratio in most Gulf of Mexico sediments. Based on this observation, high trace metal to iron ratios can usually be taken as an indicator of metal pollution. The trace metal to iron ratio does vary somewhat with sediment type, however, caution should be exercised in concluding that pollutant metal is present. Natural processes such as reduction, diffusion and re-oxidation can also redistribute metals in the sediment column leading to metal enriched layers. This is well documented for manganese (Trefry and Presely 1982) but much less well documented for other metals.

The sediment in the present study area is a very heterogeneous mixture of quartz sand, biogenic carbonate and clay. A given sample can consist of from <5 percent to >90 percent of any of the end member constituents. furthermore, the carbonate end member itself can vary from algae to mollusc shells and in some cases is old material that has been buried and re-exposed by erosion. Quartz sand and especially shell material from some samples has been observed to be stained with iron oxides and cemented with iron oxides and iron carbonates (see section 6.0). No data is available on trace metals in those stains, coatings and cements but they obviously complicate the simple picture of a sediment consisting of iron and trace metal-rich clay diluted by pure calcium carbonate and quartz sand. Low trace metal to iron ratios are more common than are high trace metal to iron ratios in the samples analyzed here, thus it appears that iron oxide coatings and iron carbonate cements must be generally low in trace metal content. This needs to be further investigated.

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.

There is no indication of trace metal pollution from Mobile Bay or the Mississippi River in the samples from this project. 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 Fe and Mn-enriched sediment samples, where the metals mobilized at one place have 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. It will be very difficult to document subtle (<25 percent) enrichments in trace metals in these complex and variable sediments.

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 most 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.

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; but we also need other indicators of sediment transport. Large benthic organisms collected in the area should be analyzed for trace metals for background information and or an indication of trace metal bioavailability.

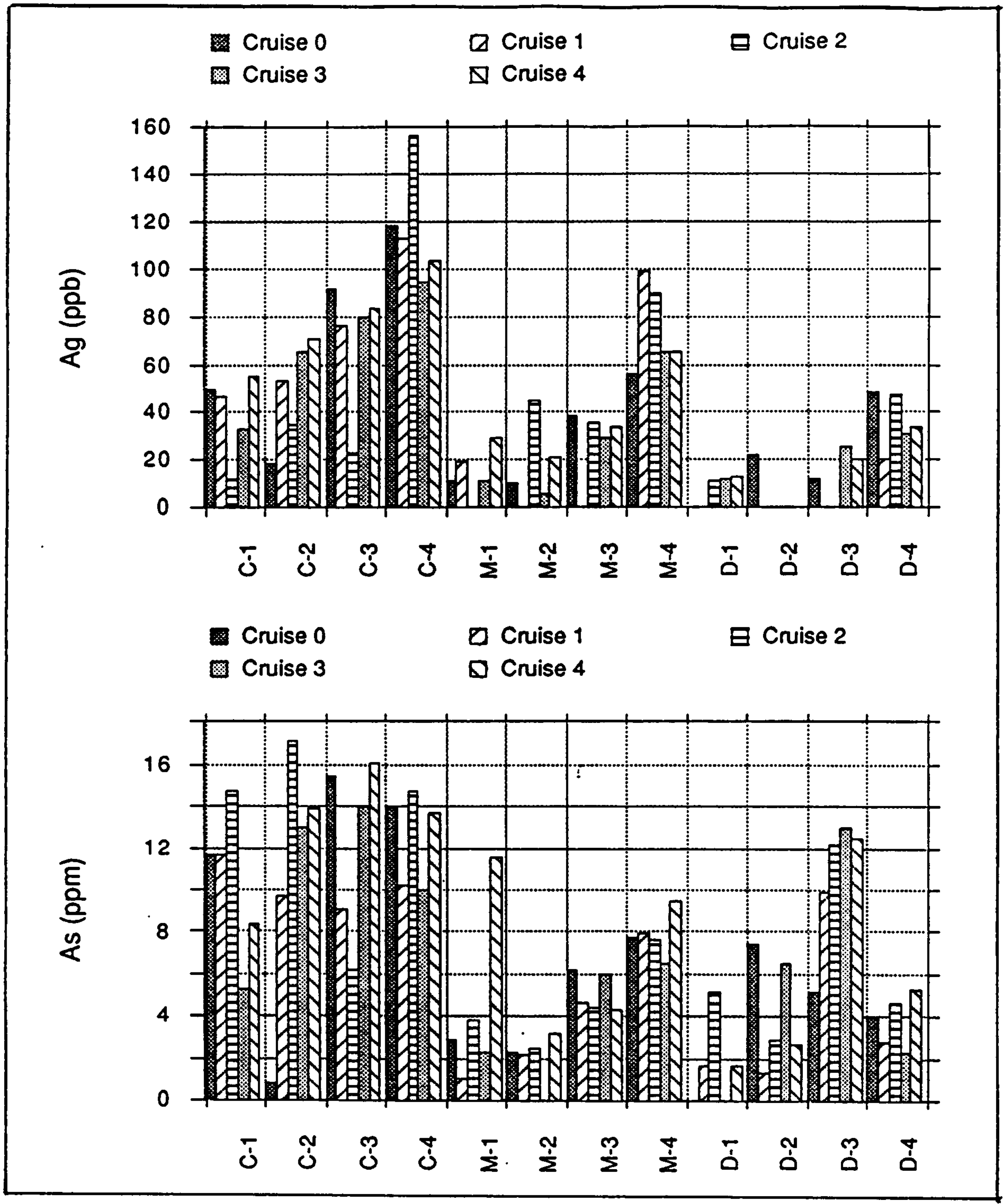


Figure 5-2. Silver and arsenic concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

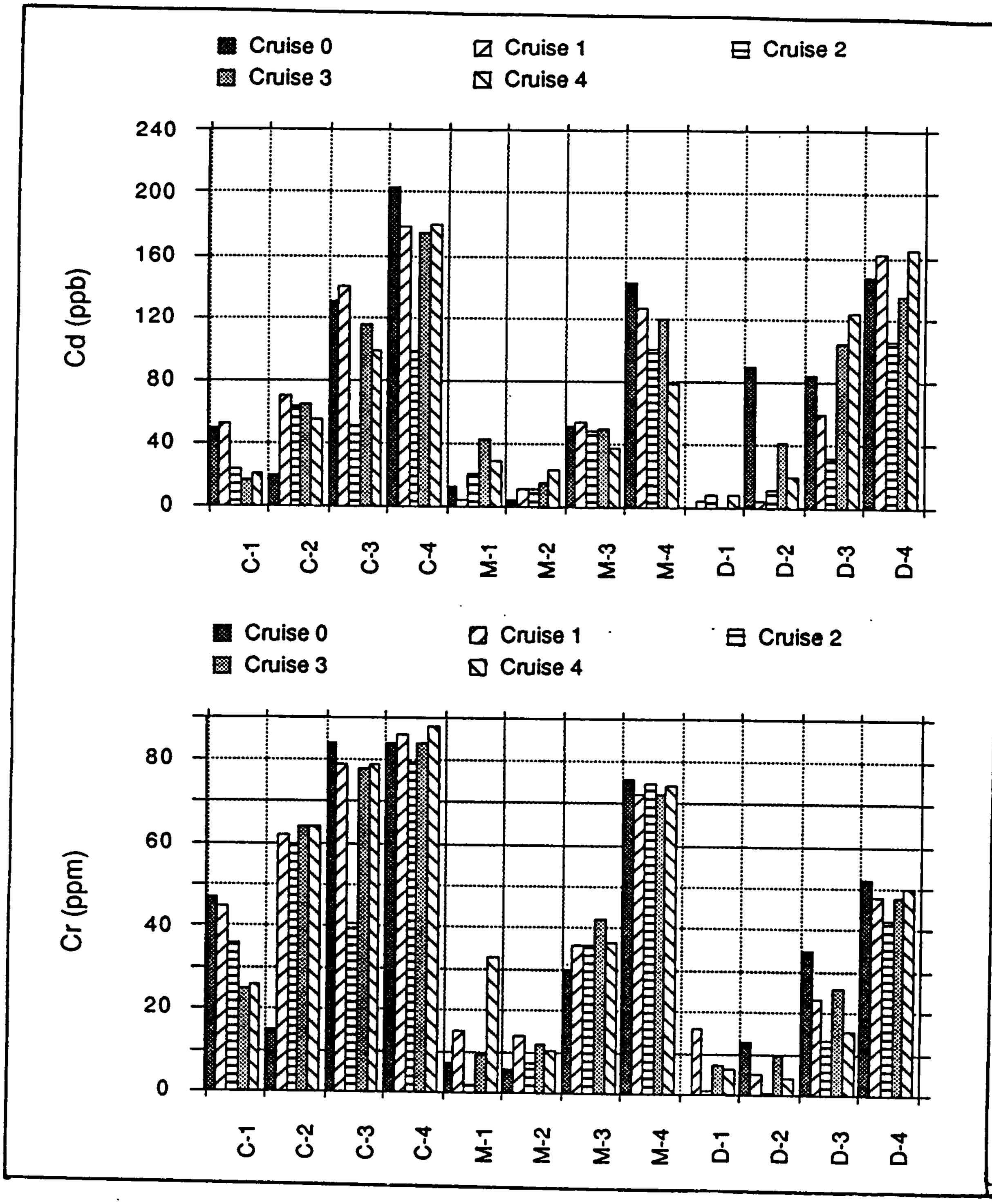


Figure 5-3. Cadmium and chromium concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

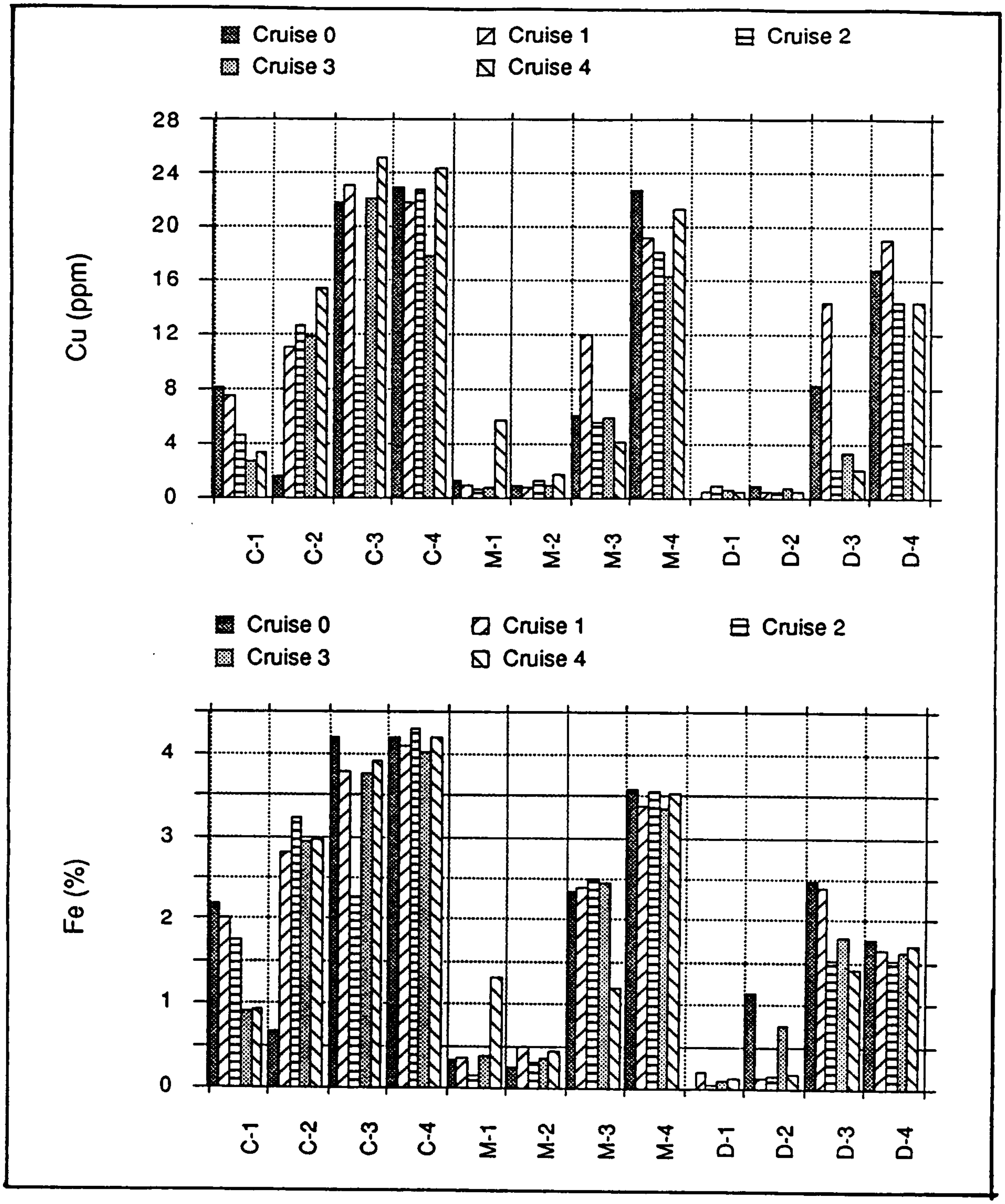


Figure 5-4. Copper and iron concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

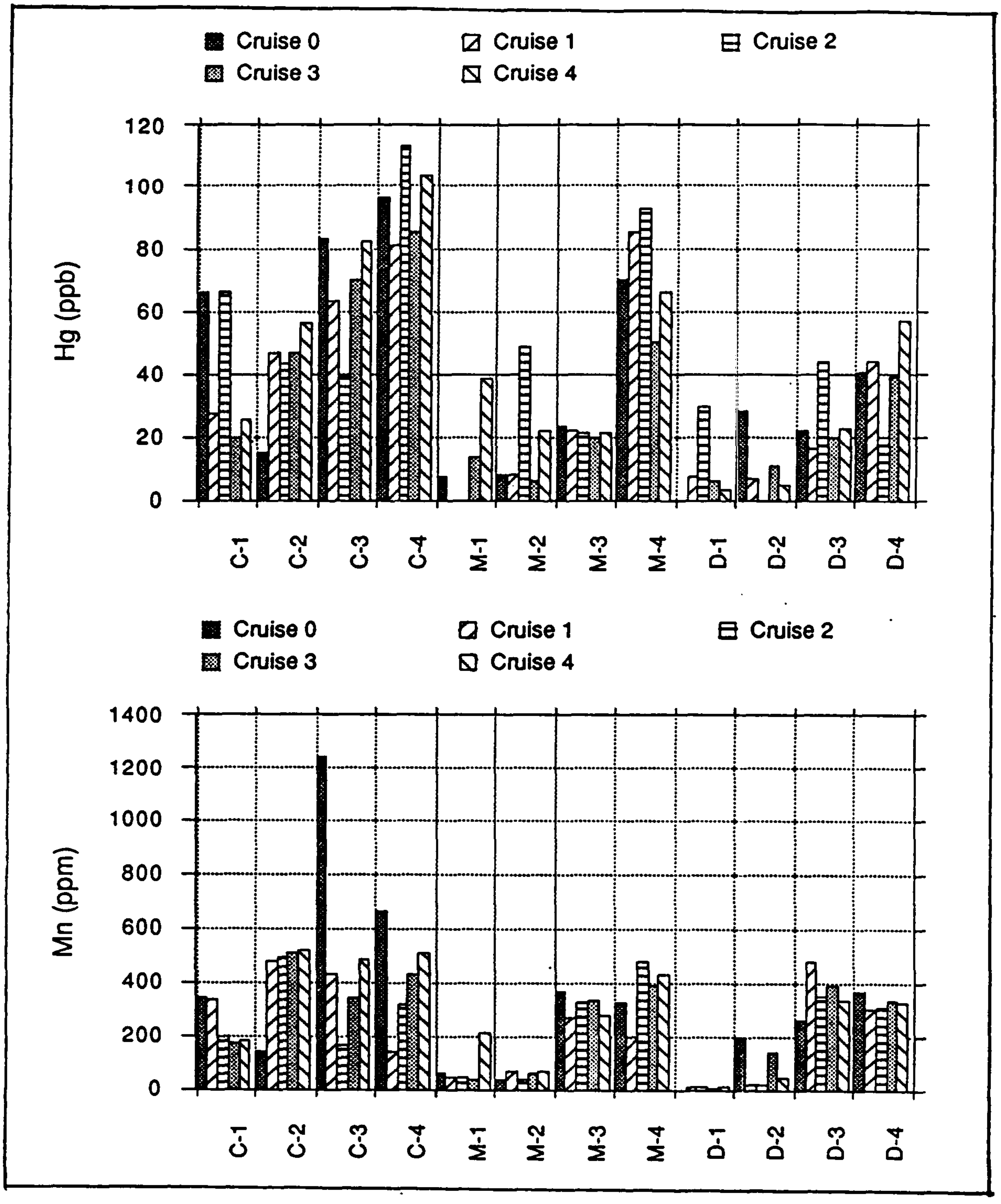


Figure 5-5. Mercury and manganese concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

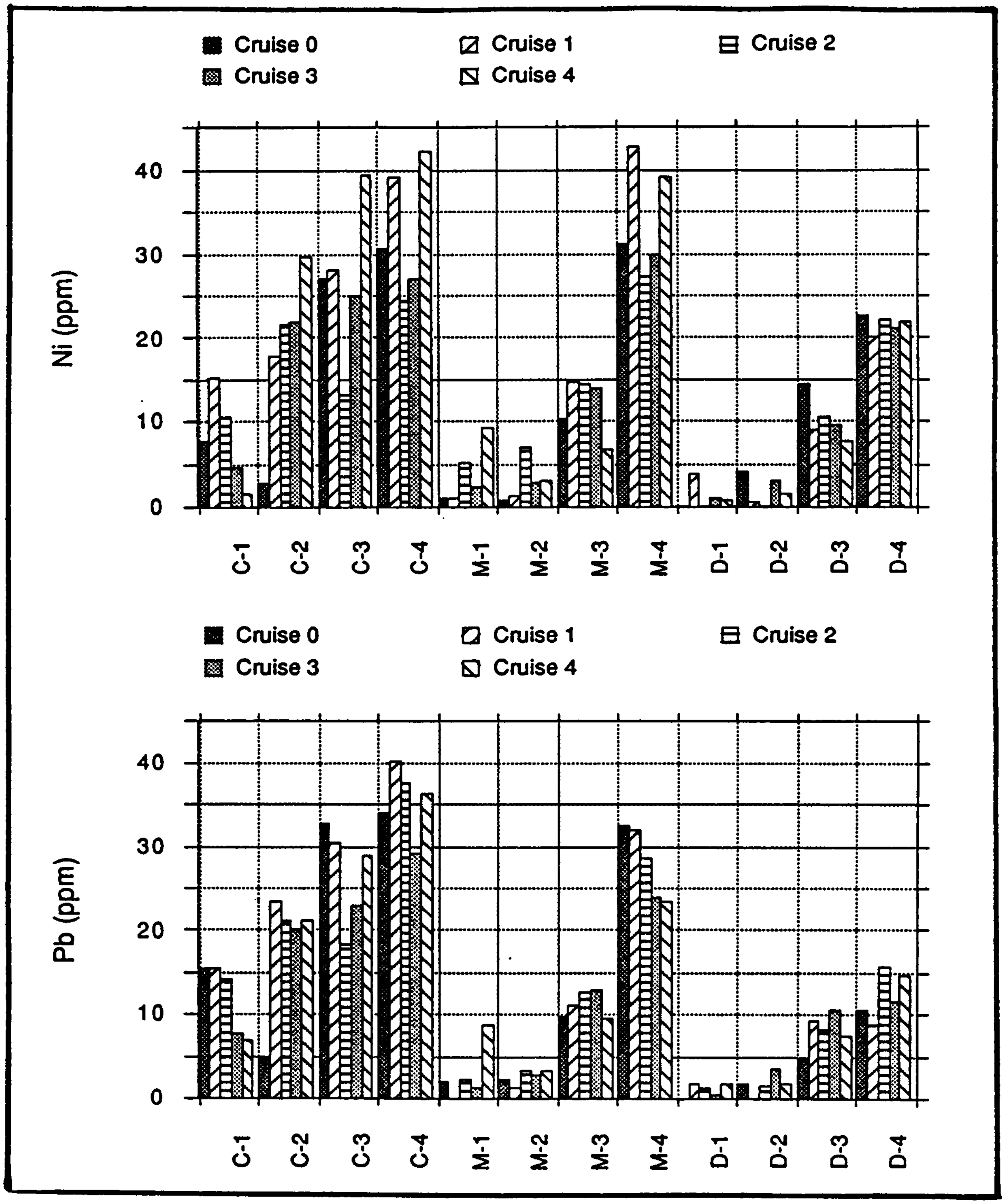


Figure 5-6. Nickel and lead concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

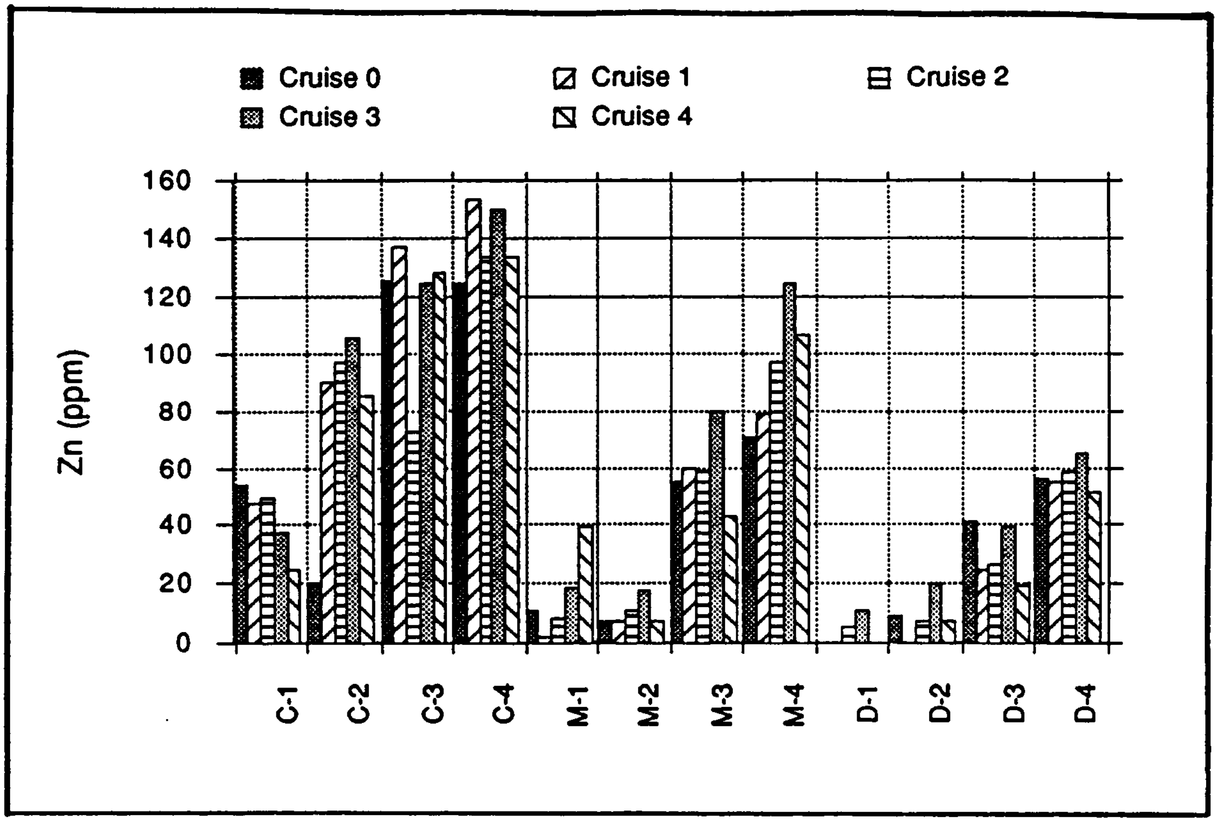


Figure 5-7. Zinc concentrations in sediment samples from five cruises of the MMS Mississippi-Alabama Marine Ecosystem Study.

6.0 SEDIMENT ANALYSES

Richard Rezak, Kenneth S. Davis, and William W. Schroeder

6.1 Introduction

The studies by Ludwick (1964) and Upshaw et al. (1966) of the sedimentary facies on the Mississippi-Alabama continental shelf are still the most comprehensive study of its kind to be conducted in this area. Other studies 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 are references to the study area as part of a larger study (Gould and Stewart 1955; Ludwick and Walton 1957; Swift *et al*. 1971; Pyle *et al*. 1975; Dames and Moore 1979). Boone (1973) is a review paper.

Kindinger *et al.* (1982) and Kindinger (1989a) describe the depositional history of the Louisiana-Mississippi outer continental shelf based on single channel high resolution seismic surveys. Kindinger (1989a) suggests that the surficial sediments of the Mississippi-Alabama continental shelf are relict deltaic deposits of Late Wisconsinan and Holocene age. The source of the Late Wisconsinan delta was to the north and east and he attributed the delta to the paleo-Pearl and/or the paleo-Mobile rivers. Kindinger (1989b) named it the Lagniappe Delta (Figure 6-1). Our work further to the east indicates that the paleo-Mobile River also was building shelf-edge deltas to the east of the Lagniappe Delta. The patchy distribution of sediment facies on the Mississippi-Alabama continental shelf is due to reworking of these delta compexes by shoreline processes and longshore currents during the post Wisconsinan rise of sea level and after the abandonment of the St. Bernard Delta.

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

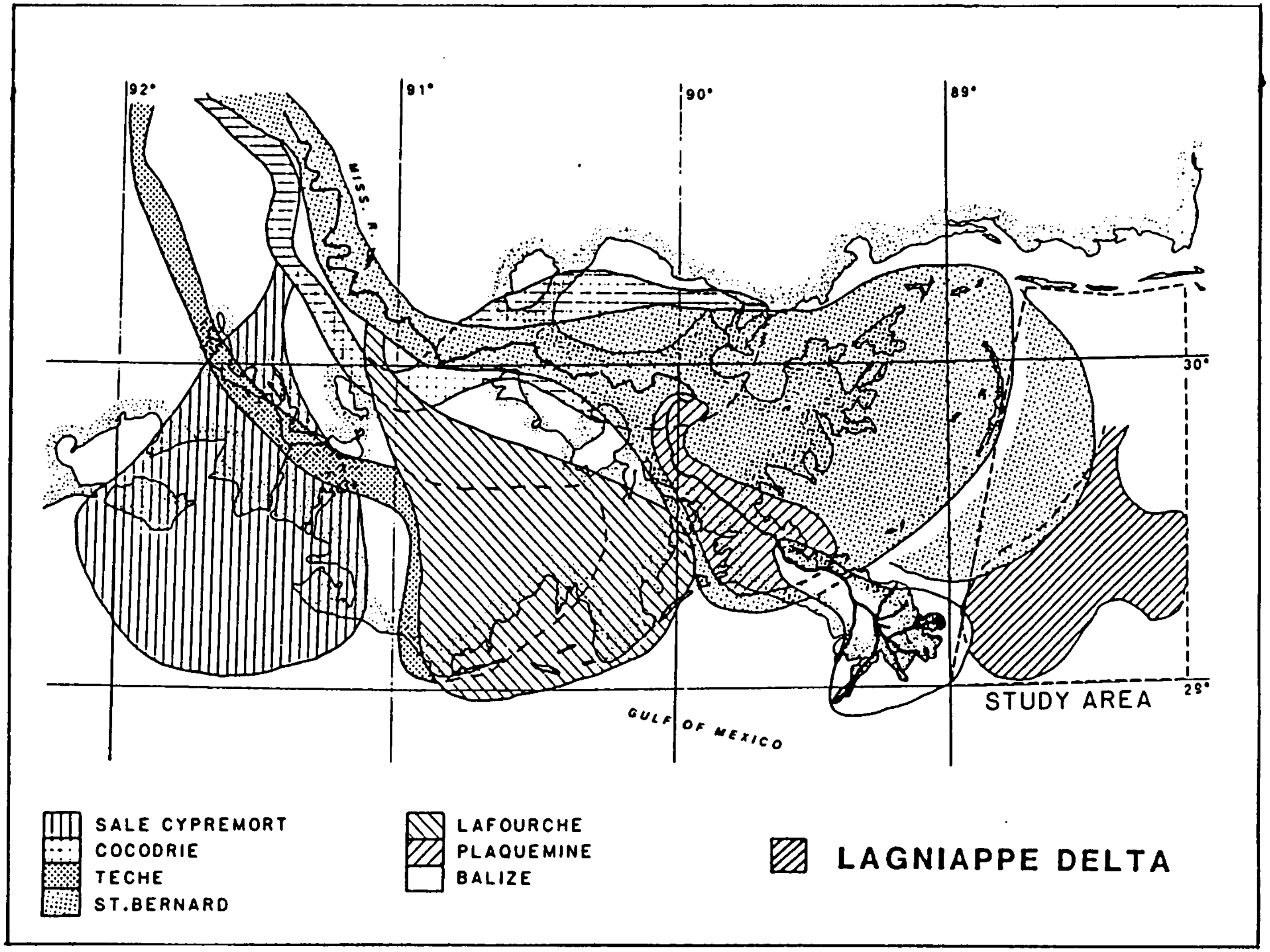


Figure 6-1. Map showing Mississippi River delta lobes including the Lagniappe Delta (from Kindinger, 1989b).

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.

The individual size fraction weights were then entered into a program developed for the Macintosh computer to merge the coarse and fine fractions of each sample and to calculate, using the method of moments, the sediment parameters shown on the sediment compilation sheets. The figures in the "Sorting" column are the standard deviations of the samples and are expressed in Phi units.

6.3 Results

During the five sampling cruises, 450 sediment textural analyses were conducted on samples collected from the twelve transect stations (Figure 6-2). Appendix A contains the sediment data arranged by cruise number in order to give a more or less synoptic view of the grain size distribution. Appendix A contains the compilations of the sediment parameters for all of the samples taken at each station. All of the data for each station is printed on a single page, giving a total of 12 pages for all of the transect stations.

There is considerable variation in the grain size distribution at several of the stations in samples taken during different cruises. There is no apparent seasonal change in grain size distribution although there are drastic changes over the entire sampling period (e.g. C-1, D-2, D-3, and M-1) while there is practically no change at others (e.g. D-1). In the 1988 Annual Report, we attributed the variation in sediment texture reported by Pyle et al. (1975) to the presence on the shelf of relict deposits representing several different environments, including lagoons, barrier islands and bars and coastal dunes. We can add to this list the spectrum of relict deltaic deposits (Kindinger, 1989b), also present on the Mississippi-Alabama outer continental shelf.

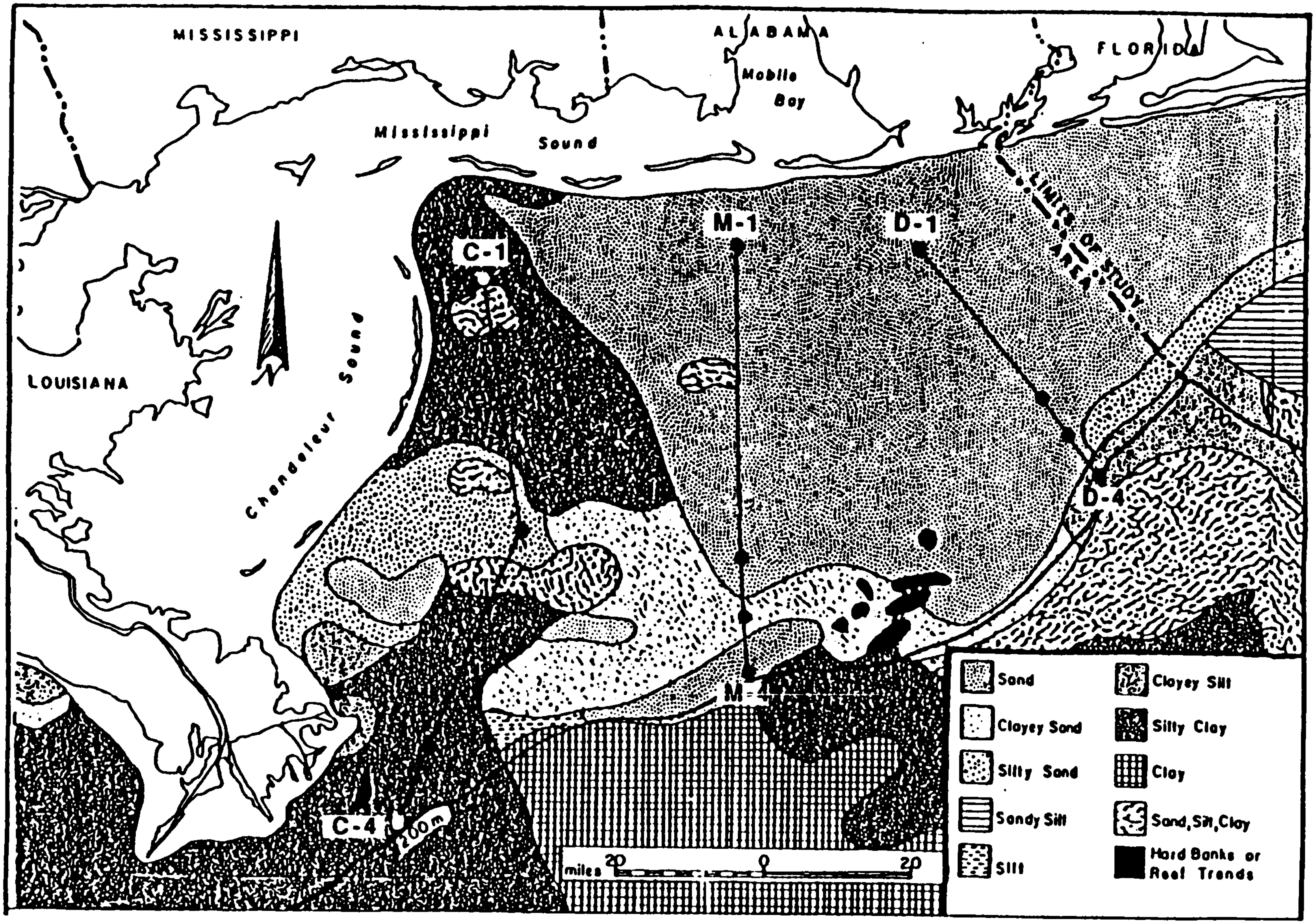


Figure 6-2. Map showing Ludwick (1964) sediment facies and location of transect stations.

Most samples from a given station and cruise show a remarkable degree of consistency. However, drastic differences do occur from one cruise to the next cruise at a given station and are most probably due to the following: (1) proximity to a reef or bank; (2) inability of the ship to maintain its position on station due to strong current or wind conditions; (3) location of the station in a transition zone between two relict facies; (4) aperiodic tropical storms; and/or (5) differences in sampling techniques.

6.4 Summary and Conclusions

Repeated sampling at the twelve transect stations reveals differences in sediment texure that in some instances are quite large. No single cause for these differences has been discovered as yet, but the relict nature of the shelf sediments in combination with one or more of the items listed above are most probably the reasons for the differences.

6.5 Recommendations for Further Study

During the final year of the study, an attempt will be made to correlate the sediment texture data with physical oceanographic data and meteorological observations. The raw data from the sediment texture analyses will also be subjected to Folk's Graphic Method for determining sediment parameters for comparison with the Method of Moments. The Method of Moments seems to work well with fine grain sediments and not so well with sandy sediments.

7.0 MACROINFAUNA AND MACROEPIFAUNA

Donald E. Harper, Jr

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 cannot tolerate the stress, perish. Larvae of these organisms may be unable to settle and metamorphose if the stress persists, 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 (Pavela et al. 1983). 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 in 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 De Soto Canyon. 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 Institute 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. 1985), 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 ppt. Shallower water, in contrast, is much less stable, being subjected to seasonal variations in temperature and salinity. Researchers have classified the shelf inhabitants into assembleges based on depth distributions. These are: the inner shelf assemblage (= "white shrimp grounds" in the western Gulf) from 0-20 m depth; the pro-delta slope assemblage from 4-20 m depth (Defenbaugh 1976); the intermediate shelf assemblage (= "brown shrimp grounds" in the western Gulf) from 20-60 m depth; an outer shelf assemblage from 60-120 m depth; and an upper slope assemblage from 120-200 m depth (Chittenden and McEachran 1976, Degenbaugh 1976, Moore et al. 1970 and Parker 1960).

Abundances of organisms generally decrease with increasing depth across the shelf, 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 indicates 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).

The data presented herein are from Cruise 0, during the winter biological season (January - February 1987), and Cruise 1, during the summer biological season (September - October 1987).

7. 2 Methods

7.2.1 Field Techniques

Stations were located on three transects which originated off Chandeleur Sound (C-transect), Mobile Bay (M-transect) and Pensacola (D-transect) (Figure 7-1). Stations on each transect were located at approximately 20, 40, 100 and 200 m depths. Sampling, where practical, was conducted across the shelf so the physical oceanographer could measure cross-shelf temperature, salinity and D.O. In actuality, the sampling pattern was dictated, at least in part, by 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 (S-M) grab. It was determined during Cruise 0 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 (the only sampler on board) would not penetrate the bottom. Therefore, both machines were used during subsequent cruises. If it was determined that a good sample could not be obtained with the box corer because the substrate composition impeded penetration of the box, the S-M 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 20 or more drops to obtain the requisite nine samples. Of these nine samples, six were used for

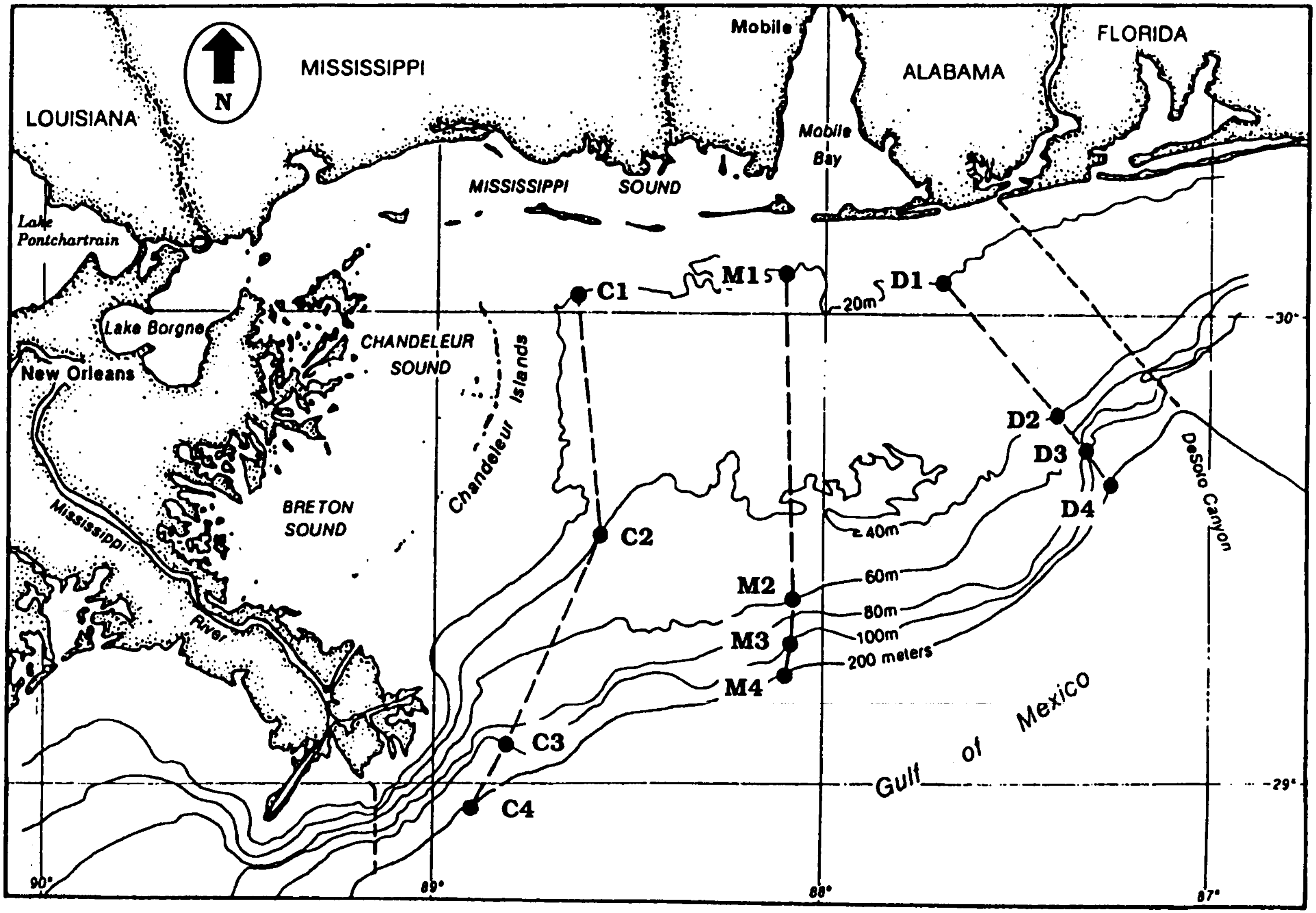


Figure 7-1. Map of the Mississippi-Alabama continental shelf showing locations of sampling stations.

macroinfaunal analysis and three for sediment analyses. When each grab was brought aboard a hose was used to drain supernatant water into a sieve, 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 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 with embossed station and date information were placed in the jar. About 30 minutes after the sixth bucket had been processed, the jar contents were fixed in 5 percent seawater-formalin.

Macroepifauna

Macroepifaunal samples were collected using a 6.6 m otter trawl having solid iron doors and a net having 3.18 cm stretch mesh and a 0.64 cm mesh 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 emptied 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, both identifying the bucket by station and date.

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 and placed in vials of unstained 70 percent ethanol. The vial contents were separated to major taxa (Polychaeta, Crustacea, Mollusca, etc.) and these taxa 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

Field observations indicate the study area has a great diversity of substrate types (Figure 7-2). Stations on the D transect ranged from sand mixed with shell at Station D1 to very coarse sand/coral rubble at Stations D2 and D3, to soft mud at Station D4. Sediments along the M transect were sand inshore (Station M1) through shelly to muddy sand (Stations M2 and M3) to soft mud (Station M4). Sediments at stations on the C transect, adjacent to the Mississippi Delta, were the most similar. Station C1 had muddy sand sediments, but the deeper stations all had soft mud bottoms; Stations C3 and C4 surficial sediments had a very soft composition that was virtually fluid mud. The Smith-McIntyre grab had to be used at stations D1, D2, D3, M1, M2 and M3. The box core was used at all other stations.

7.3.2 Macroinfauna

Polychaeta was the dominant taxon, both in terms of numbers of species (Table 7-1; Note: the numbers of species are conservative because several taxa, chiefly in the Peracarida, have not yeat been identified to species) and numbers of individuals (Table 7-2). However, unlike many assemblages in the western Gulf of Mexico, no single species appeared to dominate the

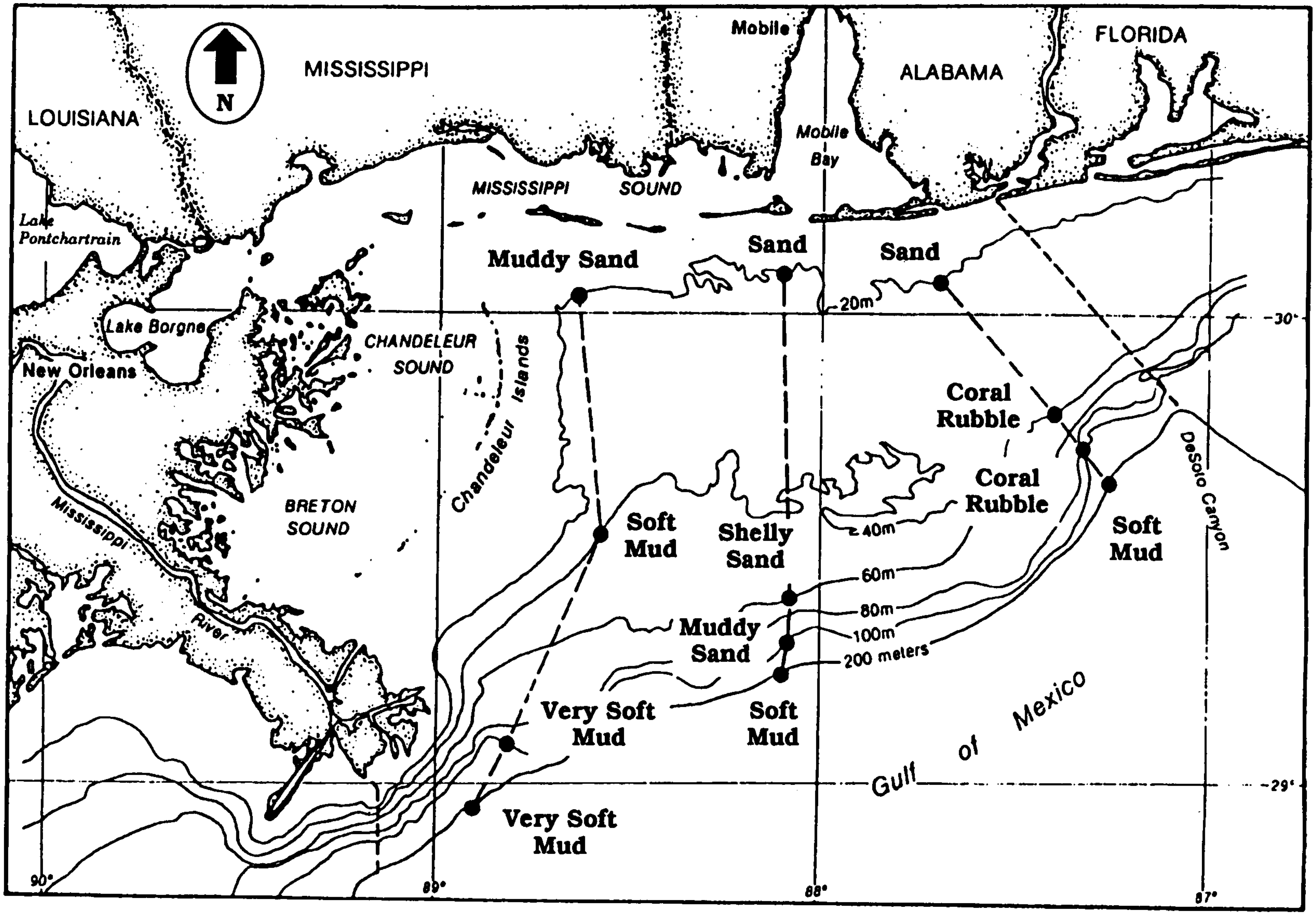


Figure 7-2. Map of the Mississippi-Alabama continental shelf showing the general substrate type, as determined by visual assessment, at each station.

Table 7-1. Comparison of the numbers of species of Polychaeta and Other macroinfaunal taxa collected at each station during Cruises 0 (winter 1987) and 1 (summer 1987).
* - based on two replicate samples

CRUISE 0

	STATION											
SPECIES	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Polychaeta	22	31	23	14	46	27	40	25	11	5	43	20
Other	9	19	11	3	21	15	32	10	8	7	11	13
TOTAL	31	50	34	17	67	42	62	35	*19	*12	54	83

CRUISE 1

	STATION											
SPECIES	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Polychaeta	34	37	38	21	61	66	45	25	68	44	99	19
Other	30	18	13	15	77	51	22	14	60	26	52	7
TOTAL	64	55	51	36	138	117	67	39	128	70	151	26

Table 7-2. Comparison of the mean numbers of individuals/m^2 of Polychaeta and Other macroinfaunal taxa collected at each station during Cruises 0 (winter 1987) and 1 (summer 1987). * - based on 2 replicate samples.

CRUISE 0

SPECIES	STATION											
	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Polychaeta	110	112	142	114	489	105	210	159	125	35	207	84
Other	36	57	42	7	90	33	79	40	45	95	77	33
TOTAL	146	169	184	107	597	138	289	199	*170	*130	284	117

CRUISE 1

SPECIES	STATION											
	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Polychaeta	341	215	175	103	828	560	249	249	129	216	882	68
Other	102	47	13	11	158	90	36	37	280	148	242	24
TOTAL	443	262	188	114	986	650	285	426	409	364	112	92

community. Nor were there any discernable within-cruise patterns of diversity or abundance that could be attributed to inshore-offshore or east-west gradients. This lack of dominance and patterns may change as data from more recent cruises are analyzed. A seasonal trend is apparent at many stations; there was a marked increase in species and individuals at most of the shallower stations between Cruise 0 in the winter and Cruise 1 in the summer. The deeper stations (D4, M3, M4, C3 and C4) had much more stable numbers. The greater environmental stability associated with deep water may cause biological stability. However, the trend of increasing abundance from winter to summer is the inverse of the pattern found in most studies in the western Gulf of Mexico.

The total macroinfaunal biomass (excluding very large single mollusks at Stations M1 and M2) at most stations increased between Cruises 0 and 1 (Figure 7-3, Table 7-3), concominant with the increase in overall abundances. There does not, however, appear to be any pattern to the data.

7.3.3 Macroepifauna

Data on composition and abundance of organisms collected by trawl indicate that the largest numbers of species were collected at stations in intermediate depths, but there is no pattern regarding numbers of individuals (Table 7-4). Crustaceans dominated the macroepifaunal assemblages at most stations. Biomass data for macroepifauna (exclusive of heart urchins) (Figure 7-4, Table 7-5) show no discernable areal pattern. At stations with biomass amounts in excess of 1000 g, portunid crabs (*Callinectes similis* and *Portunus gibbesii, P. spinicarpus*), penaeid shrimps (*Trachypeneus* spp, *Parapaneus politus*) and squills (*Squilla empusa*) were collected in very large numbers. Heart urchins, collected in very large numbers at Stations C3 and C4, are not included in the data for several reasons. They are infaunal, not epifaunal, organisms, and if the substrate was firmer, they would not have been collected. Also, when the trawl was brought aboard, it was difficult to control its movement, particularly when the vessel was pitching, and the winch operator usually dropped the trawl on the deck to stabilize it. This crushed large numbers of urchins and an accurate count was not possible.

7.4 Summary

Polychaetous annelids were the dominant macroinfaunal taxon and constituted 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. There was a marked increase in numbers of species and individuals, and in biomass between the winter and summer cruises

There did not appear to be a consistent pattern of number of macroepifaunal species or individuals. Most stations has larger numbers of individuals in Cruise 1 than in Cruise 0. The numerically dominant macroepifaunal taxon (excluding heart urchins) at most stations was 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. As with the macroinfauna, the numbers of species and individuals increased between winter and summer in 1987.

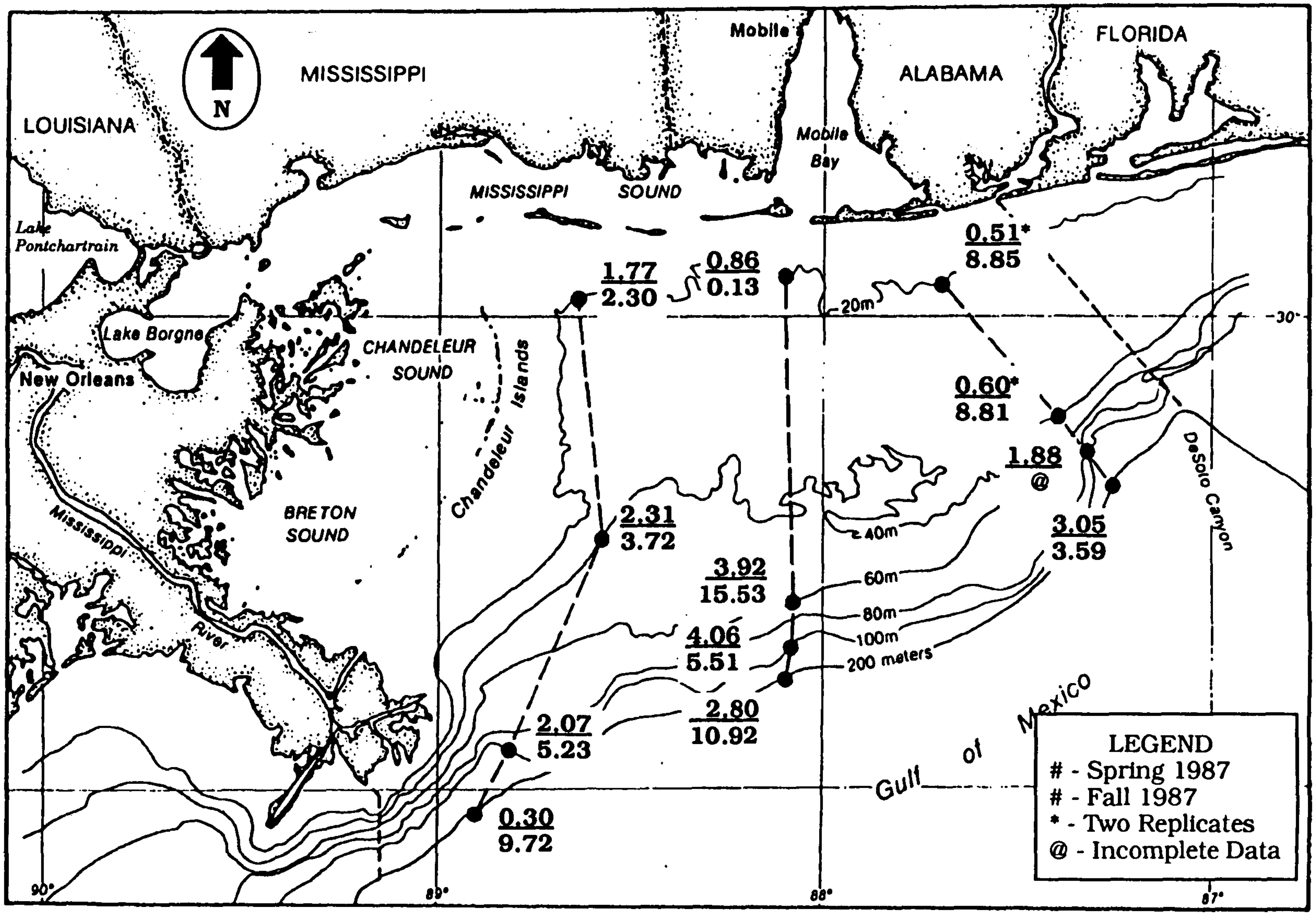


Figure 7-3. Map of the Mississippi-Alabama continental shelf showing macroinfaunal biomass from Cruise 0 (winter 1987) and Cruise 1 (summer 1987).

Table 7-3. Comparison of the mean biomass/m^2 of macroinfaunal taxa collected at each station during Cruises 0 (winter 1987) and 1 (summer 1987).
* - based on 2 replicate samples; P - present, but < 0.01 gram.

CRUISE 0

SPECIES	C1	C2	C3	C4	M1	M2	M3	M4	*D1	*D2	D3	D4
Cnidaria	---	---	---	---	0.01	0.11	-P-	---	0.03	---	-P-	---
Nemertea	0.09	0.02	0.06	---	0.02	---	0.13	0.47	---	---	---	0.02
Mollusca	0.06	0.43	0.1	-P-	0.23	---	0.02	0.03	0.01	0.18	0.03	0.01
Sipunculida	0.03	---	0.02	---	0.02	0.03	0.07	0.07	---	0.02	0.05	0.01
Echiurida	---	---	---	---	---	---	---	---	---	---	---	---
Polychaeta	0.49	0.73	0.39	0.18	0.19	2.16	2.16	0.8	0.04	0.15	1.99	1.64
Bryozoa	---	---	---	---	---	---	---	---	---	---	---	---
Brachiopoda	---	-P-	---	---	0.02	---	---	---	---	---	---	---
Crustacea	0.39	0.05	0.61	-P-	0.04	0.08	0.05	0.05	0.01	0.01	0.05	0.06
Echinodermata	---	0.15	---	---	-P-	0.01	-P-	---	---	---	-P-	0.09
Other (mollusk)	---	---	---	---	---	---	---	---	---	---	---	---
TOTAL	1.06	1.38	1.24	0.18	0.53	2.39	2.43	1.42	0.09	0.36	1.12	1.83
Total/m2	1.77	2.31	2.07	0.3	0.86	3.92	4.06	2.8	0.15	0.6	1.88	3.05
Total w/other												
Total m2w/other												

CRUISE 1

	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Cnidaria	---	---	0.03	---	---	0.7	0.26	---	0.01	0.48	---	---
Nemertea	0.13	0.02	0.13	0.01	0.1	0.08	0.34	2.08	0.04	0.03	---	0.06
Mollusca	0.27	0.55	2	2.65	1.06	6.24	0.84	0.48	1.96	0.35	---	1.57
Sipunculida	---	---	---	---	0.01	0.04	0.1	0.01	---	---	---	0.02
Echiurida	---	---	---	---	---	---	---	---	---	---	---	---
Polychaeta	0.81	0.85	0.66	1.04	1.18	1.93	1.7	1.34	2.53	0.32	---	0.44
Bryozoa	---	---	---	---	0.08	0.05	---	0.03	0.37	0.26	---	0.05
Brachiopoda	-P-	---	---	---	0.07	0.03	---	---	-P-	-P-	---	---
Crustacea	0.15	0.57	0.31	2.12	1.11	0.16	0.02	0.92	0.36	1.25	---	0.01
Echinodermata	0.02	0.24	---	---	0.06	0.07	0.04	0.68	0.03	0.01	---	---
Other (mollusk)	---	---	---	---	36.88	10.1	---	---	---	---	---	---
TOTAL	1.38	2.23	3.13	5.82	3.67	9.3	3.3	5.54	5.3	2.67		2.15
Total/m2	2.3	3.72	5.23	9.72	6.13	15.53	5.51	10.92	8.85	8.81		3.59
Total w/other					40.55	19.4						
Total m2w/other					67.71	32.4						

Table 7-4. Comparison of the numbers of species and numbers of individuals of macroepifauna collected at each station during Cruises 0 (winter1987) and 1 (summer 1987). * - based on 1 replicate sample.

CRUISE 0

	STATION											
	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Species	13	34	26	11	6	29	21	0	23	23	19	24
Individuals	157	101	214	75	35	126	278	0	113	83	70	369

CRUISE 1

	STATION											
	C1	C2	C3	C4	M1	M2	M3	M4	D1	D2	D3	D4
Species	22	25	24	11	14	23	22	28	14	39	*21	6
Individuals	599	378	1445	1232	197	325	213	271	215	276	88	47

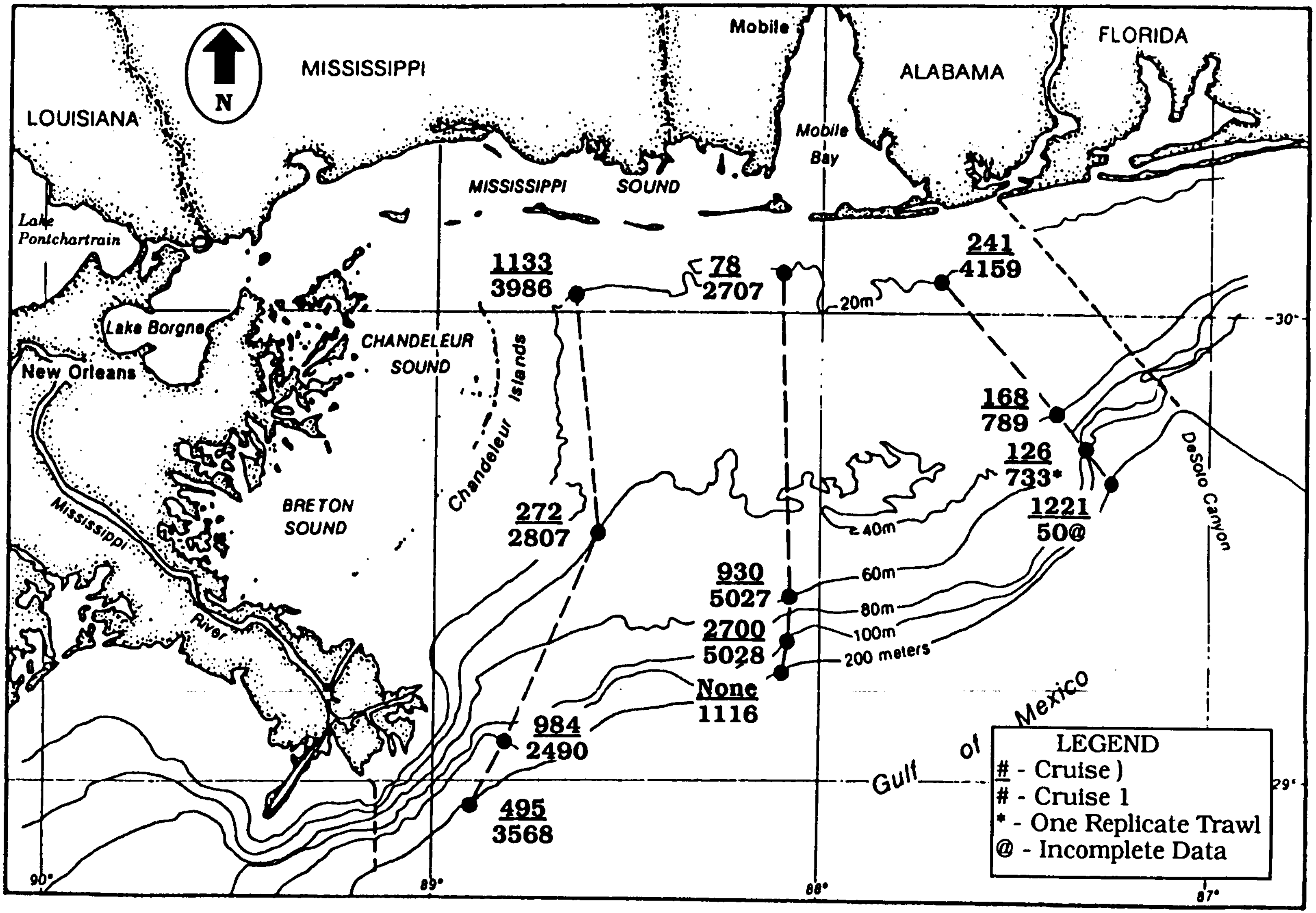


Figure 7-4. Map of the Mississippi-Alabama continental shelf showing macroepifaunal biomass from Cruise 0 (winter 1987) and Cruise 1 (summer 1987).

Table 7-5. Comparison of the numbers of species (spp.), numbers of individuals (ind.) and wet weight biomass (weight) collected during Cruise 1, September-October 1987.

CRUISE 1

SPECIES	C1 Spp	C1 Ind	C1 Weight	C2 Spp	C2 Ind	C2 Weight	C3 Spp	C3 Ind	C3 Weight	C4 Spp	C4 Ind	C4 Weight
Mollusca	5	88	198	4	68	649	2	8	34	5	55	416
Crustacea	15	397	3560	20	289	2144	21	1558	2510	5	1176	3060
Echinodermata	1	109	157	1	21	14	0	0	0	1	1	93
Cnidaria	1	5	71	0	0	0	1	5	35	0	0	0
TOTAl	23	599	3986	25	378	2807	24	1445	2491	11	1232	3568

SPECIES	M1 Spp	M1 Ind	M1 Weight	M2 Spp	M2 Ind	M2 Weight	M3 Spp	M3 Ind	M3 Weight	M4 Spp	M4 Ind	M4 Weight
Mollusca	1	64	53	8	27	50	8	105	739	9	77	444
Crustacea	9	122	2599	10	279	4300	11	99	1074	15	189	662
Echinodermata	4	111	55	5	19	678	3	9	338	4	5	10
Cnidaria	0	0	0	0	0	0	0	0	0	0	0	0
TOTAl	14	197	2707	23	325	5028	22	213	2151	28	271	1116

SPECIES	D1 Spp	D1 Ind	D1 Weight	D2 Spp	D2 Ind	D2 Weight	D3 Spp	D3 Ind	D3 Weight	D4 Spp	D4 Ind	D4 Weight
Mollusca	5	84	2029	5	7	42	2	3	9	6	47	50
Crustacea	3	16	78	23	227	576	15	74	492	0	0	0
Echinodermata	6	115	2052	11	42	171	4	11	233	0	0	0
Cnidaria	0	0	0	0	0	0	0	0	0	0	0	0
TOTAl	14	215	4159	39	276	789	21	88	734	6	47	50

8.0 DEMERSAL FISH TAXONOMY

John D. McEachran

8.1 Introduction (including historical background)

The fish fauna of the Mississippi-Alabama continental shelf has 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 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 Desoto Canyon in the northeastern Gulf of Mexico. Williams and Shipp (1980) described fishes never 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 Texas and Louisiana conducted by the National Marine Fisheries Service Laboratory in Galveston, Texas; (3) trawl samples on the continental shelf off Mississippi and Alabama conducted by Darnell; (4) seasonal trawl collections made at scattered locations by the Bureau of Land Management sponsored 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 extraliminal 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 assemblages appears to be most concentrated off the Mississippi Sound in 60 m or deeper and off Mobile bay in 20 to 40 meters. Common species of this assemblage were: *Arius felis* (sea catfish), *Archosargus probatocephalus* (sheepshead), *Menticirrhus americanus* (southern kingfish), *Lagodon rhomboides* (pinfish), *Bairdiella chrysoura* (silver perch), *Cynoscion arenarius* (sand sea trout), *Micropogonias undulatus* (Atlantic croaker), 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, outershelf species and trans-shelf species.

The mid-shelf species range from 20 to 80 m and include: *Diplectrum bivittatum* (dwarf sandperch), *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 nigromarginata* (west ocellated moray), *G. saxicola* (east ocellated moray), *Synodus poeyi* (offshore lizardfish), *Halieutichthys aculeatus* (pancake batfish), *Centropristis philadelphica* (rock seabass), *Scorpaena calcarata* (smoothhead scorpionfish), and *Cyclopsetta chittendeni* (Mexican flounder). The trans-shelf fishes extend over the entire continental shelf and include: *Synodus foetens* (inshore lizardfish), *Porichthys plectrodon* (midshipman), *Urophycis floridana* (southern hake), *Serranus atrobranchus* (blackear bass), and *Stenotomus caprinus* (longspine porgy).

The syntheses of Darnell (1985) and Darnell and Kleypas (1987) were the first attempts to summarize and standardize the fish species composition and abundance 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 fish communities of the continental shelf off Mississippi and Alabama. 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 variation in species composition and abundance with variation in substrate (across transects), and depth and temperature (along transects). The substrate ranges from fine to coarse from west (off the Mississippi River) to east (off Alabama). Depth and temperature increases and decreases respectively from the inshore stations to the offshore stations along the transects.

8.2 Methods

During the second year of the contract the final two sampling cruises (88-B-3 and 89-B-4) were completed. Two 15 minute trawl samples (replicates) were takes at each of the four stations along the three transects. As on the previous three cruises, the contents of each trawl sample were dumped on a sorting table, and the invertebrates and vertebrates were sorted and preserved separately in 10 percent buffered formalin. Large fishes and those to be used in the food habit analysis were first injected with 10 percent formalin.

8.3 Results

All of the specimens of fishes collected on cruises 87-B-1 and 88-B-2 were sorted, identified, measured and weighed, and all of these data were entered into a computer file, and the file was proofed to remove transcription errors during the second year of the contract. Also all of the specimens of fishes collected on cruise 88-B-3 were sorted, identified and measured. Identifications of these specimens remain to be confirmed before these data are entered on to the computer file.

8.3.1 Cruise 87-B-1

Two samples were obtained at all of the four stations along the three transects, except that only one sample was obtained at Station D3 and no samples were obtained at D4. A total of 3,947 specimens representing 128 species and 49 families of fishes were identified from the samples. An average of one species, represented by several specimens, per sample was not readily identifiable and was not included in the above totals. Experts on these taxa are being consulted to assist with the identifications and data on these species will be incorporated into the Third Year Synthesis Report.

The third station along each transect yielded the highest number of individuals and species, and the fourth station along each transect yielded the lowest number of individuals and species. An average of 261 individuals representing an average of 22.8 species were identified at the third station along each transect, and an average of 90 individuals representing an average of 6.0 species were identified from the fourth station along each transect (Table 8-1).

Transect C yielded the most individuals, while Transect M yielded the most species of the three transects. An average of 251 individuals representing an average of 16.0 species were identified at the four stations along Transect C and an average of 186 individuals representing an average of 18.5 species were identified at the four stations along Transect M (Table 8-1). Transect D yielded an average of 111 specimens representing an average of 17.2 species at the four stations.

There was considerable variation in size of the catch and species composition both within stations (between replicates) and among the same stations (across the three transects). The greatest disparity between replicates in number of individuals occurred at the fourth station of transects C and M where one of the two trawl samples comprised 96 percent and 93 percent of the total catch respectively. The least disparity between replicates in number of individuals occurred at the first stations of the three transects (Station 1). Between 10 percent and 53 percent of the species captured at a station were present in both replicates. The percentage of co-occurrence in the two replicates was greater for the shallower than for the deeper stations.

Species composition among the same stations across the three transects were fairly different but the inshore stations (Station 1) were more similar in species composition than the outer stations (Stations 2,3 and 4); and across the transects stations along transects C and M and M and D were more similar in species composition than were those of C and D. Twenty-nine percent of the species captured at Station C1 were also captured at Station M1 and 30 percent of the species at M1 were also captured at D1 while only 18.4 percent of the species captured at C1 were also captured at D1.

Table 8-1 Total individuals and species of fishes identified from each replicate of each of the four stations along the three transects of Cruise 87-B-1. Numerators equal individuals and denominators equal species.

	transect			
Station/Replicate	C	M	D	x
1/1	389/19	294/20	49/17	
1/2	400/18	264/15	20/9	236/16.3
2/1	37/10	505/39	71/14	
2/2	119/20	81/12	250/18	177/18.8
3/1	498/22	31/9	164/28	
3/2	408/28	204/27		261/22.8
4/1	6/4	102/19		
4/2	153/7	8/7		90/6.0
x	251/16.0	186/18.5	111/17.2	

8.3.2 Cruise 88-B-2

Two samples were obtained at all of the stations along the three transects. A total of 3,435 specimens representing 128 species and 52 families of fishes were identified from samples. An average of one species, represented by several specimens, per sample was not readily identifiable and was not included in the above totals. Experts on these taxa are being consulted to assist in identifications and these data will be included in the Third Year Synthesis Report.

The first station along each transect yielded the highest number of individuals and the third stations along each transect yielded the highest number of species. The second station along each transect yielded the lowest number of individuals and species. An average of 199 individuals representing an average of 18.2 species were identified at the first station along each transect and an average of 149 specimes representing an average of 23.2 species were identified at the third station along each transect (Table 8-2). An average of 90 individuals representing an average of 17.7 species were identified at the second station of each transect.

Transect C yielded the most individuals while transect M yielded the most species of the three transects. An average of 182 individuals representing an average of 17.9 species were identified at the four stations along Transect C and an average of 165 individuals representing an average of 26.3 species were captured at the four stations along Transect M (Table 8-2). Transect D yielded an average of 79 individuals representing an average of 14.1 species.

There was considerable variation in size of the catch and species composition both within stations (between replicates) and among the same stations (across the three transects). The greatest disparity between replicates in number of specimens occured at stations 1 and 2 of Transect D where one of the two replicates comprised 89 percent and 91 percent of the total number of individuals respectively. The least disparity between replicates in number of individuals occurred at the third station of Transect D, the third station of Transect C, and the second station of Transect M where one of the two replicates comprised 49 percent, 44 percent, and 40 percent of the total number of individuals respectively.

Table 8-2 Total individuals and species of fishes identified from each replicate of each of the four stations along the three transects of Cruise 88-B-2. Numerators equal individuals and denominators equal species.

	transect			
Station/Replicate	C	M	D	x
1/1	296/17	142/31	71/12	
1/2	80/20	31/12	30/10	195/17.0
2/1	65/20	196/32	109/12	
2/2	26/11	133/24	11/7	90/17.7
3/1	200/17	161/27	105/21	
3/2	251/27	67/31	110/16	149/23.2
4/1	385/17	69/24	188/18	
4/2	153/15	240/29	71/17	174/19.8
x	182/17.9	165/26.3	79/14.1	

Species compositions among the same station across the three transects were fairly different but the offshore stations (stations 3 and 4) were more similar than the inshore stations (stations 1 and 2). Also stations along Transect C were more similar to those of Transect M than to those along Transect D, and those of Transect M were more similar to those of Transect D in species composition than to those of Transect C.

9.0 DEMERSAL FISH FOOD HABIT ANALYSIS

Rezneat M. Darnell

9.1 Introduction

A thorough literature search revealed about 75 articles, theses, and dissertations dealing with food habits of fishes of the northern Gulf of Mexico, mostly concerned with food habits of species taken from the estuaries. About 260 species were examined in these papers. Of these, 10 percent are limited to freshwater and the fresher portions of estuaries. These species are not expected to appear on the continental shelf. About 11 percent are deepwater demersal or pelagic species which also are not likely to appear on the continental shelf. The remaining 79 percent are shelf residents during at least part of their lives. Some of the species are estuary related, some strictly shelf dwellers, and others inhabit the outer shelf and upper continental slope.

Of the 42 species so far examined in the present study, 30 species (71 percent) have been previously examined by some investigator. However, most of the historical literature deals with the food of the individual fish species as such, and very little is concerned with broader questions of marine ecosystem structure and dynamics.

9.2 Fish Food Analyses Completed

Food analyses have been completed for cruises 87-0 and 87-1. To date, well over 2500 specimens have been examined representing 42 fish species. As shown in Table 9-1, the representation varies greatly among the different species, and this reflects the availability of appropriate specimens. The depth distribution by species is shown in Table 9-2. The totals reveal that 24 species represent the nearshore stations, 23 and 22 species represent mid-shelf stations, and only 12 species represent the deepest stations. Four species occur at all four depths, six species appear at three depths, and 15 species represent two depths. Representation should increase among depth ranges as fishes from the remaining cruises are examined.

Table 9-1. Fish Species from Cruises 87-0 and 87-1 Analyzed in the Fish Food Study.

Scientific Name	Common Name	No. Analyzed
Engraulidae		
Anchoa cubana	Cuban anchovy	40
Anchoa hepsetus	striped anchovy	40
Synodontidae		
Saurida brasiliensis	largescale lizardfish	99
Synodus foetens	inshore lizardfish	90
Synodus poeyi	offshore lizardfish	42
Batrachoididae		
Porichthys plectrodon	Atlantic midshipman	54
Ogcocephalidae		
Halieutichthys aculeatus	pancake batfish	245
Ogcocephalus nasutus	shortnose batfish	25
Gadidae		
Bathygadus macrops	deepwater cod	39
Bathygadus melanobranchus	deepwater cod	32
Steindachneria argentea	luminous hake	21
Macrouridae		
Coelorinchus caribbaeus	blackfin grenadier	33
Serranidae		
Centropristis philadelphica	rock seabass	60
Diplectrum bivittatum	dwarf sand perch	166
Diplectrum formosum	sand perch	43
Serranus atrobranchus	blackear bass	81
Serranus notospilus	saddle bass	39
Carangidae		
Chloroscombrus chrysurus	Atlantic bumper	47
Lutjanidae		
Pristipomoides aquilonaris	wenchman	23
Rhomboplites aurorubens	vermilion snapper	16
Haemulidae		
Haemulon aurolineatum	tomtate	17

Table 9-1. Continued.

Sparidae		
Stenotomus caprinus	longspine porgy	164
Sciaenidae		
Cynoscion arenarius	sand seatrout	7
Leiostomus xanthurus	spot	52
Micropogonias undulatus	Atlantic croaker	68
Percophidae		
Bembrops anatirostris	duckbill flathead	56
Scorpaenidae		
Pontinus longispinis	longspine scorpionfish	116
Scorpaena calcarata	smoothhead scorpionfish	47
Triglidae		
Bellator militaris	horned searobin	55
Prionotus paralatus	Mexican searobin	89
Prionotus roseus	bluespotted searobin	20
Prionotus rubio	blackfin searobin	54
Prionotus salmonicolor	blackwing searobin	80
Prionotus scitulus	leopard searobin	24
Prionotus stearnsi	shortwing searobin	16
Bothidae		
Etropus rimosus	gray flounder	48
Syacium gunteri	shoal flounder	117
Syacium papillosum	dusky flounder	216
Trichopsetta ventralis	sash flounder	113
Cynoglossidae		
Symphurus civitatus	offshore tonguefish	55
Symphurus plagiusa	blackcheek tonguefish	64
Tetraodontidae		
Sphoeroides parvus	least puffer	35
TOTAL		2,748

Table 9-2. Depth distribution of fish species from Cruises 87-0 and 87-1 employed in the fish food analysis study. Stations 1-4 represent the inner, middle (two depths), and outer continental shelf areas, respectively.

Species	Station Number			
	1	2	3	4
Anchoa cubana	x			
Anchoa hepsetus	x			
Diplectrum bivittatum	x			
Diplectrum formosum	x			
Rhomboplites aurorubens	x			
Prionotus scitulus	x			
Sphoeroides parvus	x			
Chloroscombrus chrysurus	x	x		
Hamulon aurolineatum	x	x		
Prionotus roseus	x	x		
Prionotus salmonicolor	x	x		
Etropus rimosus	x	x		
Syacium gunteri	x	x		
Syacium papillosum	x	x		
Symphurus plagiusa	x	x		
Synodus poeyi		x		
Scorpaena calcarata		x		
Bellator militaris		x		
Saurida brasiliensis	x	x	x	
Synodus foetens	x	x	x	
Leiostomus xanthurus	x		x	
Micropogonias undulatus	x	x	x	
Symphurus civitatus	x	x	x	
Pristipomoides aquilonaris		x	x	
Prionotus stearnsi		x	x	
Ogcocephalus nasutus			x	
Steindachneria argentea			x	
Serranus notospilus			x	
Cynoscion arenarius			x	
Prionotus paralatus			x	
Porichthys plectrodon	x	x	x	x
Halieutichthys aculeatus	x	x	x	x
Stenotomus caprinus	x	x	x	x
Prionotus rubio	x	x	x	x
Centropristis philadelphica		x	x	x
Serranus atrobranchus		x	x	x
Bathygadus macrops			x	x
Bembrops anatirostris			x	x
Pontinus longispinis			x	x
Trichopsetta ventralis			x	x
Bathygadus melanobranchus				x
Coelorinchus caribbaeus				x
Total species represented	24	23	22	12

Size class representation of the various species by cruise, transect, and depth is shown in three tables. Table 9-3 gives the combined coverage for the two cruises. Table 9-4 gives the distribution of stomachs examined for cruise 87-0. Table 9-5 provides the same information for cruise 87-1. Efforts are being made to examine at least 20 specimens with food from each size class, depth, and transect category, as available. Continuing efforts will be devoted more to filling out the numbers for species already begun, rather than increasing the numbers of species, except at the deeper stations.

9.3 Results

The types of results expected from the food analysis study are illustrated by the data for the longspine porgy, *Stenotomus caprinus* (Table 9-6). In this table the food habits of the species are examined in relation to size class, depth, and transect. As these fishes grow larger the percentage of polychaetes decreases, and the percentage of crustaceans in the diet increases. Undetermined organic matter constitutes a high percentage of the stomach contents at all stages, and this material is largely mucous (from polychaetes and possibly from the stomach of the fish itself) generally mixed with some sedimentary material. In relation to depth (stations 1, 2, and 3), the percentage of polychaetes remains fairly stable, but the percentage of crustaceans increases with greater depth. Hopefully, sufficient specimens will eventually be available to permit inclusion of the fourth depth (station 4) in the analysis. In relation to transect, the data reveal that polychaetes are important dietary components in the Chandeleur and Mobile transects, but not in the DeSoto Canyon transect. In this area they are replaced by crustaceans. When these data are compared with the sediment content and food availability information forthcoming from the geological and benthic infauna studies, the reasons for these observed food shifts will probably become apparent.

The food of additional species could be reported here, but for most species the number of specimens in one or more categories is still low. However, this one example is used to demonstrate how the trophic dynamics of this ecosystem will be constructed in relation to size class, depth, and transect. To this will be added information concerning species abundance and food availability so that some information on the magnitude of food interactions will be forthcoming.

9.4 Continuation Studies

During the coming year fish food analyses will continue to be carried out, and it is anticipated that there will be no difficulty in completing stomach analyses from the remaining cruises. Efforts will be made to fill in existing gaps rather than increase the number of species except in the case of the deeper stations. Voucher specimens of food items have been retained, and these will be compared with benthic epifauna and infauna specimens to provide finer taxonomic identification. Multiple variable tables (such as Table 9-6) will be prepared for all possible species, and these will be interpreted in relation to sediment type, food availability, and other variables. Trophic spectrum diagrams, conceptual models, and other visual representations will be prepared as aids for the interpretation of the overall trophic structure and dynamics of the Mississippi-Alabama marine ecosystem.

Table 9-3. Species and size classes of fishes from cruises 87-0 and 87-1 (combined) employed in the fish food analysis study.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Engraulidae													
Anchoa cubana	26-50			20									
	51-75			20									
Anchoa hepsetus	26-50		2										
	51-75		17										
	76-100		21										
Synodontidae													
Saurida brasiliensis	26-50					40							
	51-75				11	20		24					
	76-100	1		1	1								
	101-125												
	126-150					1							
Synodus foetens	51-100			3	1		8						
	101-125	2		3			1						
	126-150		4	1			3						
	151-200	9	12	1	1	5							
	201-300	2	1	4	10	7	2	5					
	301-400					4	1						
Synodus poeyi	51-75						20						
	76-100						20						
	101-125						2						
Batrachoididae													
Porichthys plectrodon	51-75				3	5			2			1	
	76-100				5	13		2	12		1		
	101-125	1							1		4	2	
	126-150	1			1								

Table 9-3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Ogcocephalidae													
Halieutichthys aculeatus	26-50	20	3		2		1	13	16				
	51-75	15	1		23	40	15	41	42	4		1	
	76-100						8	1					
Ogcocephalus nasutus	51-75								1				
	76-100							1	20				
	101-125							3					
Gadidae													
Bathygadus macrops	101-150							20	3		7		
	151-200							1					2
	200-250												5
	251-300												1
Bathygadus melanobranchus	101-150										11		
	151-200										19		
	201-250										2		
Steindachneria argentea	101-150							20					
	151-200							1					
Macrouridae													
Ceolorinchus caribbaeus	51-75											2	
	76-100											1	
	101-150											7	
	151-200											20	
	201-250											3	

Table 9-3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Serranidae													
Centropristis philadelphica	76-100				4								
	101-125				2		4	3	6				
	126-175				1			21	10	1		1	
	176-225				2			4	1				
Diplectrum bivittatum	26-50			13									
	51-75	20	16	31									
	76-100	30	25	9									
	101-125		21	1									
Diplectrum formosum	26-50			13									
	51-75			20									
	76-100	10											
Serranus atrobranchus	51-75				8	1							
	76-100				4			40	2			2	
	101-125							21	3				
Serranus notospilus	26-50									19			
	51-75									20			
Carangidae													
Chloroscombrus chrysurus	26-50					2							
	51-75		20	2									
	76-100		20	1									
	101-125		1										
	126-150		1										

Table 9-3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Lutjanidae													
Pristipomoides aquilonaris	26-50					13				1			
	51-76												
	76-100									3			
	101-150							3	2	1			
	151-200												
Rhomboplites aurorubens	51-75		3										
	76-100		13										
Haemulidae													
Haemulon aurolineatum	76-100		1	12									
	101-125			2									
	126-150							2					
Sparidae													
Stenotomus caprinus	51-75	4	16		1								
	76-100	4	33	20	8	10	7	12	26			2	
	101-125			2	2	6	5	1	4			1	
Sciaenidae													
Cynoscion arenarius	151-200								4				
	201-300								3				
Leiostomus xanthurus	101-125	1	2										
	126-150	1	4	3					4				
	151-175	1		14					20				
	176-200								1				
Micropogonias undulatus	101-125		1	2									
	126-150	1	20	28					3				
	151-200			6					7				

Table 9-3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Percophidae													
Bembrops anatirostris	26-50							1					
	51-75							1					
	76-100							6			1		
	101-125								5		6		4
	126-150								4		3	2	4
	151-200								3		10	1	5
Scorpaenidae													
Pontinus longispinis	26-50							4					
	51-75							19	3	5	2	5	
	76-100									1	28	4	
	101-125										31	2	
	126-150										11	1	
Scorpaena calcarata	26-50					13	2						
	51-75	1				22	5						
	76-100					2	2						
	101-125						1						
Triglidae													
Bellator militaris	26-50				1	24	6						
	51-75					22	1						
	76-100					1							
Prionotus paralatus	26-50									1			
	51-75							7					
	76-100							8	20				
	101-125							9	35				
	126-175							1	8				

Table 9-3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Prionotus roseus	51-75						2						
	76-100		2										
	101-125						7						
	126-150						9						
Prionotus rubio	51-75	8											
	76-100	2			3			1					
	101-125				3	2		1	15				
	126-175				1			1	16			1	
Prionotus salmonicolor	0-25			2									
	51-75					1	12						
	76-100		1			7	13						
	101-125	1				1	3						
	126-175					6	33						
Prionotus scitulus	101-125			8									
	126-175			8		8							
Prionotus stearnsi	26-50					2							
	51-75					4							
	76-100					1		1	8				
Bothidae													
Etropus rimosus	26-50					10							
	51-75		13			15							
	76-100		8	1									
	100-125			1									

Table 9.3. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Syacium gunteri	26-50	16			3								
	51-75	21	12	3	14								
	76-100	27	3	6	7								
	101-150				5								
Syacium papillosum	26-50			9		7	2						
	51-75		8	14		23	8						
	76-100		4	1		7	14						
	101-150			1	1	26	33						
	151-250		1	6		10	41						
Trichopsetta ventralis	26-50							3					
	51-75							10	6				
	76-100							20	22				
	101-150							20	27			4	
	151-250											1	
Cynoglossidae													
Symphurus civitatus	26-50							1					
	51-75	1						4					
	76-100	20	2		6				1				
	101-125	6	1		13								
Symphurus plagiusa	76-100	3	3										
	101-125	40	5		2		1						
	126-150	9	1										
Tetraodontidae													
Sphoeroides parvus	26-50	21	6										
	51-75	1	5	2									

Table 9-4. Species and size classes of fishes from cruise 87-0 employed in the fish food analysis study. C, M, and D refer to the transects (Chandeluer, Mobile, and De Soto Canyon).

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				11			22					
	76-100				1								
Synodus foetens	51-100			3									
	101-125	1		1									
	125-150												
	151-200	4		1									
	201-300	2		4	7	5		5					
	301-400					4							
Synodus poeyi	51-75						20						
	76-100						20						
	101-125						2						
Batrachoididae													
Porichthys plectrodon	51-75					4							
	76-100					7			3				
Ogcocephalidae													
Halieutichthys aculeatus	26-50				2			10	16				
	51-76				23	21		20	22				
Ogcocephalus nasutus	51-75								1				
	76-100								20				

Table 9-4. Continued.

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Gadidae													
Bathygadus macrops	101-150								3		7		
	151-200												2
	201-250												5
	251-300												1
Serranidae													
Centropristis philadelphica	76-100				3								
	101-125				2			2	6				
	126-175							7	1				
	176-225				2								
Diplectrum bivittatum	26-50			13									
	51-75		1	30									
	76-100	10	5	6									
Diplectrum formosum	26-50			13									
	51-75			20									
	76-100	10											
Serranus atrobranchus	76-100							22					
	101-125							3					
Lutjanidae													
Rhomboplites aurorubens	51-75		3										
	76-100		13										
Haemulidae													
Haemulon aurolineatum	76-100		12										
	101-125		2										

Table 9-4. Continued.

TAXON	SIZE CLASSES	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
	(mm)	C	M	D	C	M	D	C	M	D	C	M	D
Sparidae													
Stenotomus caprinus	51-75				1								
	76-100		12	18	12	5		6	20				
	101-125			2	2	6							
Sciaenidae													
Cynoscion arenarius	151-200								4				
	201-300								2				
Leiostomus xanthurus	101-125		2										
	126-150		4	3					4				
	151-175			14					20				
	176-200								1				
Micropogonias undulatus	101-125		1	2									
	126-150		20	28					3				
	151-200			6					3				
Percophidae													
Bembrops anatirostris	76-100										1		
	101-125								5		4		4
	126-150								4		2		4
Scorpaenidae													
Pontinus longispinis	76-100										11		
	101-125										11		
Scorpaena calcarata	26-50					13							
	51-75					20							
	76-100					2							

Table 9-4. 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							
	76-100					1							
Prionotus paralatus	76-100								16				
	101-125								19				
	126-150								7				
Prionotus roseus	51-75						2						
	101-125						7						
	126-150						9						
Prionotus rubio	51-75				2								
	76-100				2			1					
	101-125				2			1	11				
	126-175							1	7				
Prionotus salmonicolor	0-25			2									
	76-100					7	3						
	101-125					1							
	126-175					6	5						
Prionotus scitulus	101-125			7									
	126-175			8		8							
Prionotus stearnsi	76-100								8				

Table 9-4. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore C	Nearshore M	Nearshore D	Midshelf 1 C	Midshelf 1 M	Midshelf 1 D	Midshelf 2 C	Midshelf 2 M	Midshelf 2 D	Outershelf C	Outershelf M	Outershelf D
Bothidae													
Syactum gunteri	26-50				3								
	51-75	1		3	13								
	76-100	3		6	7								
	101-150				5								
Syactum papillosum	26-50			9		7	1						
	51-75			13		23	2						
	76-100					7	3						
	101-150					15	13						
	151-250					8	20						
Trichopsetta ventralis	51-75							6					
	76-100							16					
	101-150							14					
Cynoglossidae													
Symphurus plagiusa	101-125	20											
	126-150	3											
Tetraodontidae													
Sphoeroides parvus	26-50	21											

Table 9-5. Species and size classes of fishes from cruise 87-1 employed in the fish food analysis study.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Engraulidae													
Anchoa hepsetus	26-50		2										
	51-75		17										
	76-100		21										
Synodontidae													
Saurida brasiliensis	26-50					20							
	51-75					20		2					
	76-100		1										
	101-125												
	126-150					1							
Synodus foetens	51-100				1		8						
	101-125	1	3				1						
	126-150		4	1			3						
	151-200	5	12		1	5			1				
	201-300		1		3	2	2						
	301-400						1						
Batrachoididae													
Porichthys plectrodon	51-75				3	1			2			1	
	76-100				5	13		2	9		1		
	101-125	1							1		4	2	
	126-150	1			1								
Ogcocephalidae													
Halieutichthys aculeatus	26-50	20	3				1	3					
	51-75	15	1			19	15	21	20	4		1	
	76-100						8	1					
Ogcocephalus nasutus	76-100							1					
	101-125							3					

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Gadidae													
Bathygadus macrops	101-150							20					
	151-200							1					
Bathygadus melanobranchus	101-150										11		
	151-200										19		
	201-250										2		
Steindachneria argentea	76-100												
	101-150							20					
	151-200							1					
Macrouridae													
Ceolorinchus caribbaeus	51-75											2	
	76-100											1	
	101-150											7	
	151-200											20	
	201-250											3	
Serranidae													
Centropristis philadelphica	76-100				1								
	101-125						4	1					
	126-175				1			14	9	1		1	
	176-225							4	1				
Diplectrum bivittatum	51-75	20	15	1									
	76-100	20	20	3									
	101-125		21	1									

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Serranus atrobranchus	26-50												
	51-75				8	1							
	76-100				4			18	2			2	
	101-125							18	3				
Serranus notospilus	26-50									19			
	51-75									20			
Carangidae													
Chloroscombrus chrysurus	26-50					2							
	51-75		20	2									
	76-100		20	1									
	101-125		1										
	126-150		1										
Lutjanidae													
Pristipomoides aquilonaris	26-50					13				1			
	51-76												
	76-100									3			
	101-150							3	2	1			
	151-200								1				
Haemulidae													
Haemulon aurolineatum	76-100	1											
	101-125												
	126-150						2						
Sparidae													
Stenotomus caprinus	51-75	4	16										
	76-100	4	21	2	7	5	7	6	6			2	
	101-125						5	1	4			1	

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Sciaenidae													
Cynoscion arenarius	201-250								1				
Leiostomus xanthurus	101-125	1											
	126-150	1											
	151-175	1											
Micropogonias undulatus	126-150	1											
	151-200								4				
Percophidae													
Bembrops anatirostris	26-50							1					
	51-75							1					
	76-100							6					
	101-125										2		
	126-150										1	2	
	151-200								3		5	1	
Scorpaenidae													
Pontinus longispinis	26-50							4					
	51-75							19	3	5	1	5	
	76-100									1	17	4	
	101-125										20	2	
	126-150										8	1	
Scorpaena calcarata	26-50						2						
	51-75	1				2	5						
	76-100						2						
	101-125						1						

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Triglidae													
Bellator militaris	26-50				1	4	6						
	51-75					5	1						
Prionotus paralatus	26-50									1			
	51-75							7					
	76-100							8	4				
	101-125							9	16				
	126-175							1	1				
Prionotus roseus	76-100		2										
Prionotus salmonicolor	51-75					1	12						
	76-100		1				10						
	101-125	1					3						
	126-175						28						
Prionotus scitulus	101-125			1									
Prionotus stearnsi	26-50					2							
	51-75					4							
	76-100					1		1					
Prionotus rubio	51-75	8											
	76-100	2			1								
	101-125				1	2			4				
	126-175				1				9			1	

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore			Midshelf 1			Midshelf 2			Outershelf		
		C	M	D	C	M	D	C	M	D	C	M	D
Bothidae													
Etropus rimosus	26-50					10							
	51-75		13			15							
	76-100		8	1									
	100-125			1									
Syacium gunteri	26-50	16											
	51-75	20	12		1								
	76-100	24	3										
Syacium papillosum	26-50						1						
	51-75		8	1			6						
	76-100		4			2	14						
	101-150			1	1	11	20						
	151-250		1	6		2	21						
Trichopsetta ventralis	26-50							3					
	51-75							10					
	76-100							20	6				
	101-150							20	13			4	
	151-250											1	
Cynoglossidae													
Symphurus civitatus	26-50							1					
	51-75	1						4					
	76-100	20	2		6				1				
	101-125	6	1		13								
Symphurus plagiusa	76-100	3	3										
	101-125	20	5		2		1						
	126-150	6	1										

Table 9-5. Continued.

TAXON	SIZE CLASSES (mm)	Nearshore C	Nearshore M	Nearshore D	Midshelf 1 C	Midshelf 1 M	Midshelf 1 D	Midshelf 2 C	Midshelf 2 M	Midshelf 2 D	Outershelf C	Outershelf M	Outershelf D
Tetraodontidae													
Sphoeroides parvus	26-50		6										
	51-75	1	5	2									

Table 9-6. Food analysis data (percent composition) for the longspine porgy (*Stenotomus caprinus*) analyzed by size class, depth, and transect. The letter 't' represents a trace amount.

Transect	(combined)			(combined)			C	M	D
Depth	(combined)			1	2	3	(combined)		
Size class	51-75	76-100	101-125	----- 76-100 -----			----- 76-100 -----		
No. with food	20	100	15	31	31	36	28	60	10
Nematodes	t	1	t	t		2	t	1	
Polychaetes	32	21	14	19	23	22	29	21	t
Mollusks	t	t	t	t	1	t	t	t	t
Crustaceans	2	9	13	5	7	15	4	10	22
Echinoderms		t	t		t				
Fishes		2							
Undet. Org. Mat.	53	66	73	73	68	61	63	68	79
Sand/Silt	14	1	t	3	t	t	4	t	t

10.0 PHYSICAL OCEANOGRAPHY/WATER MASS CHARACTERIZATION

F.J. Kelly

10.1 Introduction

The major objective of the physical oceanography component of the project is to characterize the circulation on the outer shelf, with emphasis on the 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 study region during the periods 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 gages.

The work of this project component during the first two years of the study primarily involves the collection of hydrographic and time series data in regions for which there is little historical data. The Year 1 Annual Report (Brooks and Giammona 1988) contains the basic results of the first three hydrographic surveys and a description of the mooring configurations and instruments that were deployed in December 1987 and retrieved in March 1988. This report:

a) presents the basic results of two additional hydrographic surveys,
b) describes the moored instruments deployed during the period of December 1987 through June 1989,
c) summarizes, statistically and graphically, the time-series data collected by the moored current meters, and
d) discusses the results for selected locations and periods of time.

Since the moored-instrument portion of the field program will continue through mid-February of 1990, comprehensive discussions of the complete data set are reserved for the third and final report scheduled for this project. The third report will also include the statistical and graphical summaries of the time-series data collected during the period from June 1989 through February 1990.

10.2 Moored Instruments

10.2.1 Mooring Locations

The moored-instrument portion of this study consists of two deployment periods, each of about one year in duration. The first began in late December 1987 with the deployment of a cross-shelf array of three moorings, designated A, B and C, respectively, and ran through mid-January 1989. The Year 2 deployment period began in mid-February 1989 and will run through mid-February 1990. For Year 2, a cross-shelf array of two additional moorings, designated D and E, respectively, was deployed about 85 km southwest of the first array. Figure 10-1 shows the locations of the five sites (triangles) and Table 10-1 lists their coordinates. Water depths are 31 m at Site A, 60 m at Sites B and D, and 430 m at Sites C and E. The three-mooring array lies between the middle and eastern lines of interdisciplinary sampling stations (circles in Figure 10-1), and will provide information about the exchange of waters between the eastern portion of the shelf and De Soto Canyon. The second array lies between the middle and western sampling lines. Exchange processes between the shelf and the deep Gulf as well as along-slope propagation can be examined with the addition of this array.

At the beginning of the second year, the location of Site A was moved eastward about one-half mile because it was discovered that parties unknown had dumped a car body and a pile of tires about 16 m from the surface witness buoy. The intent was probably to establish an artificial reef for sport fishing. The site was moved to reduce the probability of fishing line entangling the instruments.

10.2.2 Instruments and Mooring Configurations

The Year 1 report (Brooks and Giammona 1988) describes in detail the configuration of the moorings at Sites A, B, and C, and the types of instruments used at each site during the first year of deployment. At the beginning of the second year, one change was made at Site C. The type of current meter at the top of the mooring was changed from an ENDECO Model 174SSM to an Aanderaa Model RCM8. The instruments and mooring configurations at Sites D and E are identical to those at Sites B and C,

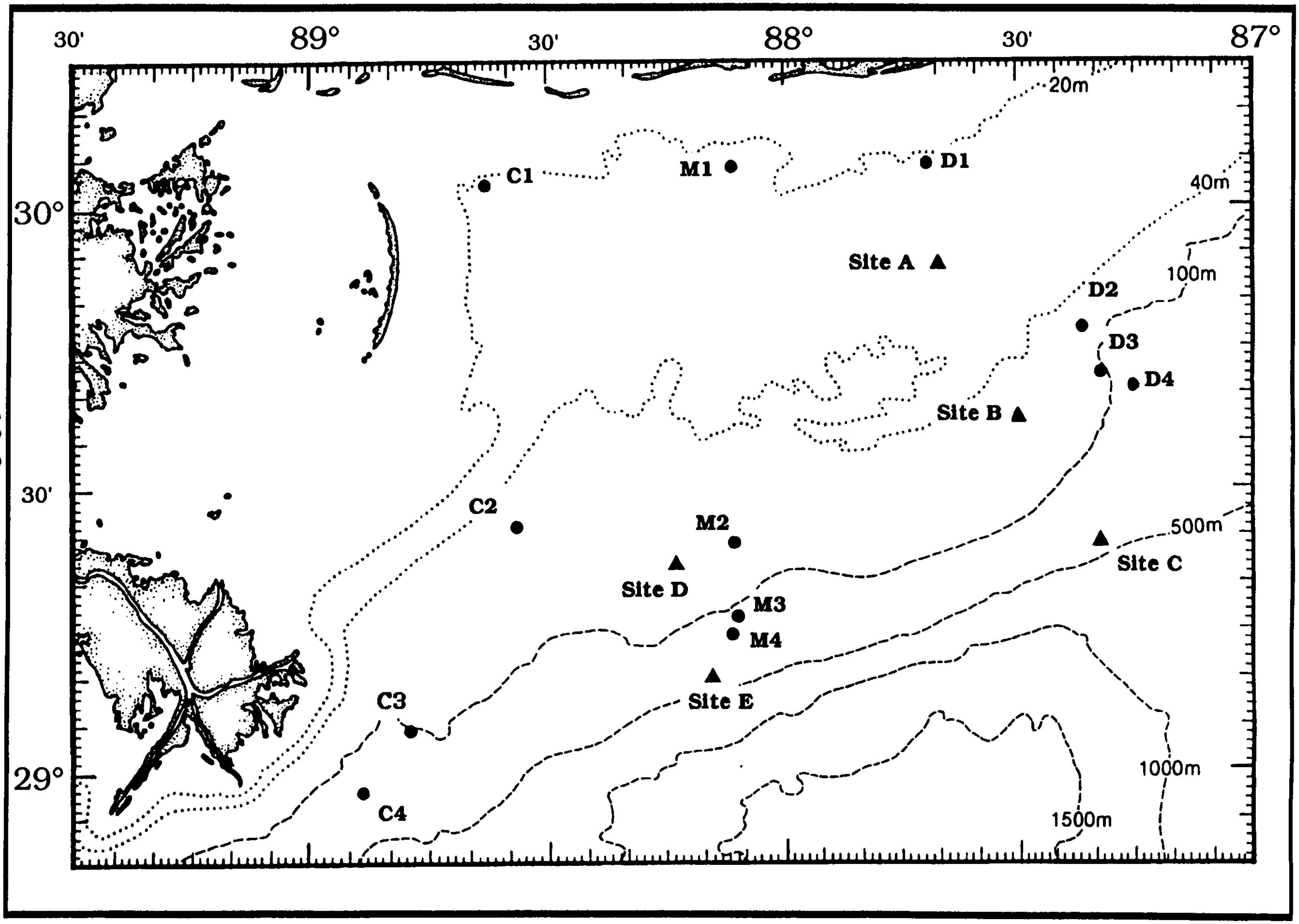


Figure 10-1. Map showing the locations of the five moored instrument sites, A, B, C, D, and E (triangles), and the twelve primary stations for interdisciplinary sampling (circles).

Table 10-1. Coordinates of Sites A, B, C, D, and E.

Site	Latitude	Longitude
	Year 1	
A	29°54.0'N	87°40.2'W
B	29°37.2'N	87°31.6'W
C	29°23.9'N	87°20.7'W
	Year 2	
A	29°54.2'N	87°36.6'W
B	29°37.2'N	87°31.6'W
C	29°23.9'N	87°20.7'W
D	29°21.07'N	88°15.95'W
E	29°09.58'N	88°10.52'W

respectively. Table 10-2 lists the design depths of the instruments and other mooring components at Sites D and E.

10.2.3 Deployment Periods and Data Return

Table 10-3 lists the deployment periods, notes about data return, and parameters recorded for each instrument location, which we define to be a specific depth at a given site. A file name protocol consisting of eight alphanumeric characters identifies the time-series data obtained during each deployment period at each instrument location, e.g., AB612217. The protocol as follows:

POSITION	TYPE	SIGNIFICANCE
1	alpha	site
2	alpha	location on mooring
3	numeric	instrument type: 6=ENDECO 174DMT 7=ENDECO 174SSM 8=Aanderaa RCM8
4-5	numeric	month deployed
6-7	numeric	day of month deployed
8	numeric	last digit of year deployed

Since this study has a maximum of three current meters on a mooring, the letter used for location on the mooring can directly indicate the current meter's position relative to the others: T, M and B stand for top, middle and bottom, respectively. Thus, AB612217 signifies the data file from an ENDECO Model 174DMT current meter deployed at the bottom of the mooring at Site A on December 21, 1987.

The current meters could have potentially collected about 545 parameter-months of data during the period of late December 1987 to mid-June 1989. The major data losses were AT703168 and CT712297, which resulted from a connector problem on the ENDECO 174SSM, and the shortened records CB812297 and CM812297, which resulted from excessive current consumption in the Aanderaa RCM8. Both problems were manufacturer design flaws that were corrected after they were identified.

Table 10-2. Design depths of the instruments and other major components of moorings D and E.

Depth (m)	Component
	Mooring D
5.5	30" Buoy Tec 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 E
15.2	30" Ore Steel Flotation Buoy
17.1	Data Sonics UAT-377 Acoustic Transponder
19.8	Aanderaa RCM8 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 ATR-397/30 Acoustic Release
430.0	Sea Bottom

Table 10-3. List of deployment periods, notes about data return, and parameters recorded (S=speed, D=direction, T=temperature, C=conductivity).

File Name	Depth (m) Inst/Water	Deployed Date	Deployed Time (GMT)	Recovered Date	Recovered Time (GMT)	Parameters	Notes
AB612217	27/30	12/21/87	1500	03/16/88	2200	S,D,T,C	
AB603168	27/30	03/16/88	2020	08/22/88	1311	S,D,T	No conductivity data.
AB608228	27/30	08/22/88	1400	01/14/89	1532	S,D,T,C	Instrument wrote incomplete data blocks on tape. Attempt to manually recover some of data in progress.
AB602179	27/30	02/18/89	0320	06/19/89	1900	S,D,T,C	Instrument wrote incomplete data blocks on tape. Attempt to manually recover some of data in progress.
AT712217	10/30	12/21/87	1500	03/16/88	2200	S,D,T	No conductivity data.
AT703168	10/30	03/16/88	2100	08/22/88	1300	S,D,T,C	Speed sensor fouled by monofilament fishing line during 05/29/88 - 07/06/88
AT708228	10/30	08/22/88	1400	01/14/89	1532		No data. Instrument malfunction.
AT702179	10/30	02/18/89	0328	06/19/89	1908	S,D,T,C	
BB612307	28/61	12/30/87	1610	03/16/88	2350	S,D,T,C	
BB603168	28/61	03/17/88	0100	08/22/88	2320	S,D,T,C	
BB608248	28/61	08/24/88	0400	01/13/89	2125	S,D,T,C	

Table 10-3. Continued.

File Name	Depth (m) Inst/Water	Deployed Date	Deployed Time (GMT)	Recovered Date	Recovered Time (GMT)	Parameters	Notes
BB602169	28/61	02/16/89	1845	06/21/89	1305	S,D,T,C	
BT712307	10/61	12/30/87	1610	03/16/88	2350	S,D,T,C	Data records stop 03/04/88. Low battery voltage.
BT703168	10/61	03/17/88	0100	08/22/88	2320	S,D,T	No conductivity data.
BT708248	10/61	08/24/88	0400	01/13/89	2120	S,D,T,C	
BT702169	10/61	02/16/89	1915	06/21/89	1215	S,D,T,C	
CB812297	426/430	12/30/87	2130	08/24/88	1725	S,D,T,C	Data records stop 05/18/88. Low battery voltage.
CB808258	426/430	08/25/88	0525	01/13/89	1630	S,D,T,C	Data records stop 01/02/89. Low battery voltage.
CB802169	426/430	02/16/89	1500	06/20/89	1830	S,D,T,C	
CM812297	150/430	12/30/87	2130	08/24/88	1725	S,D,T,C	Data records stop 05/29/88. Low battery voltage.
CM808258	150/430	08/25/88	0525	01/13/89	1630	S,D,T,C	
CM802169	150/430	02/16/89	1500	06/20/89	1830	S,D,T,C	Rotor too tight. Speed threshold high.
CT712297	20/430	12/30/87	2130	08/24/88	1725		No data. Instrument malfunction.
CT708258	20/430	08/25/88	0525	01/13/89	1630	S,D,T,C	

Table 10-3. Continued.

File Name	Depth (m) Inst/Water	Deployed Date	Deployed Time (GMT)	Recovered Date	Recovered Time (GMT)	Parameters	Notes
CT802169	20/430	02/16/89	1500	06/20/89	1830	S,D,T,C	
DB602119	56/60	02/12/89	0332	06/22/89	1754	S,D,T,C	Direction sensor stuck whenever speed less than 5 cm/s. Rotor stuck 05/06/89 - 05/14/89 and 06/18/89 - end.
DT702119	10/60	02/12/89	0407	06/22/89	0130	S,D,T,C	Biofouling may have reduced speed sensitivity near end of record.
EB802159	426/430	02/15/89	1920	06/21/89	2230	S,D,T,C	No conductivity data during 02/24/89 - 04/12/89.
EM802159	150/430	02/15/89	1920	06/21/89	2230	S,D,T,C	
ET802159	20/430	02/15/89	1920	06/21/89	2230	S,D,T,C	

Records AB608228 and AB602179 have problems because the instruments, ENDECO 174DMTs, wrote incomplete data blocks on the data recording tapes. The cause for this problem is unknown. Tha data files are being manually edited in an attempt to extract some of the data. In all, 92 to 127 parameter months of data were lost, depending on the quantity of data that can be recovered from AB608228 and AB602179, for a return rate of 77 to 83%.

10.2.4 Quality Control

This study uses three different models of current meters, each of which measures current speed, current direction, temperature and conductivity. Salinity is not measured directly, but is computed from the values of temperature and conductivity. Quality control procedures depend on the instrument type and whether it is serviced in the laboratory or at sea. Texas A&M University (TAMU) developed quality control procedures for the ENDECO models during its long-term studies for the Department of Energy's Strategic Petroleum Reserve Brine Disposal Operations (Kelly *et al.* 1983).

The ENDECO 174DMT and 174SSM models measure speed by means of a neutrally buoyant, balanced, 15-inch diameter impeller (rotor) that rides on glass ball bearings in a Delrin race, while the Aanderaa RCM8 uses a 4-inch diameter, balanced, shielded paddle rotor with a carbide bearing that rides on a stainless steel needle point. The rotation is magnetically passed through the pressure case and digitally encoded. Overall operation of the speed sensing system is checked in the laboratory by turning the rotor at an exact rate using a precision stepping motor. The rate of rotation of a rotor is directly proportional to the velocity of the water, and the linearity is high (Kelly *et al.* 1983) if the rotor is in proper condition and the bearings are in proper adjustment. Rotor imbalance, which can result from physical damage and improper painting, raises the starting threshold. Dirty, damaged or maladjusted bearings affect both the starting threshold and the sensitivity of the rotor. Prior to each deployment, rotors and bearings are carefully checked and adjusted according to the manufacture's recommended procedures, whether in the laboratory or at sea. When a rotor is repainted with anti-fouling paint, a very light even coat is used and care is taken to avoid drips and blobs from collecting at low points.

Current direction is measured by a gimballed, 2-axis, flux gate compass in the ENDECO models and by a magnetic compass with needle clamped to a potentiometric ring in the Aanderaa model. Each meter's direction sensor is checked, and a new calibration curve developed, if needed, whenever the meter is returned to the laboratory. A direction "swing" table, designed and built by TAMU (Figure 10-2), automatically rotates a current meter in 15° ±0.5° increments. The duration at each position is programmable. A Brunton pocket transit, Model F-2061, is used as the calibration standard. To obtain the standard magnetic headings for the "swing" table, the Brunton compass is placed at the center of the platter and the platter is rotated through each of the 15° increments for several revolutions. Values are manually recorded and averaged. When a current meter is calibrated, it is set to record at a one or two minute rate and placed so that its internal compass is over the center of the platter. Then the platter is rotated through several revolutions, stopping typically for 15 minutes at each increment. The data from the meter are processed and the direction values recorded at each increment are averaged. Deviations between directions indicated by the Brunton compass and those recorded by the meter's compass yield the calibration data.

All three models of current meters use thermolinear thermisters in stainless steel cases to measure temperature. In the laboratory, a Hewlett Packard Model 2804A quartz thermometer serves as the temperature standard and an insulated bath (3' x 3' x 3', I.D.) is used to perform temperature calibrations. The bath is not temperature controlled, but it is sufficiently insulated so that temperature changes are slow, typically much less than 0.1°C per hour. The temperature of the bath is accurately monitored as a function of time and related to the temperature time series recorded by the current meter being calibrated. A temperature controlling process is not needed because the the current meters can be set to record at a rapid rate, yielding many values before the temperature of the bath changes significantly. The accuracy (±0.2°C for the ENDECO, ±0.05°C for the Aanderaa) and resolution (0.1°C for the ENDECO, 0.03°C for the Aanderaa) of the temperature sensors on the current meters are much coarser than the accuracy (±0.01°C) and resolution (0.0001°C) of the temperature standard. At sea, the data from the CTD casts made at each mooring also provide a

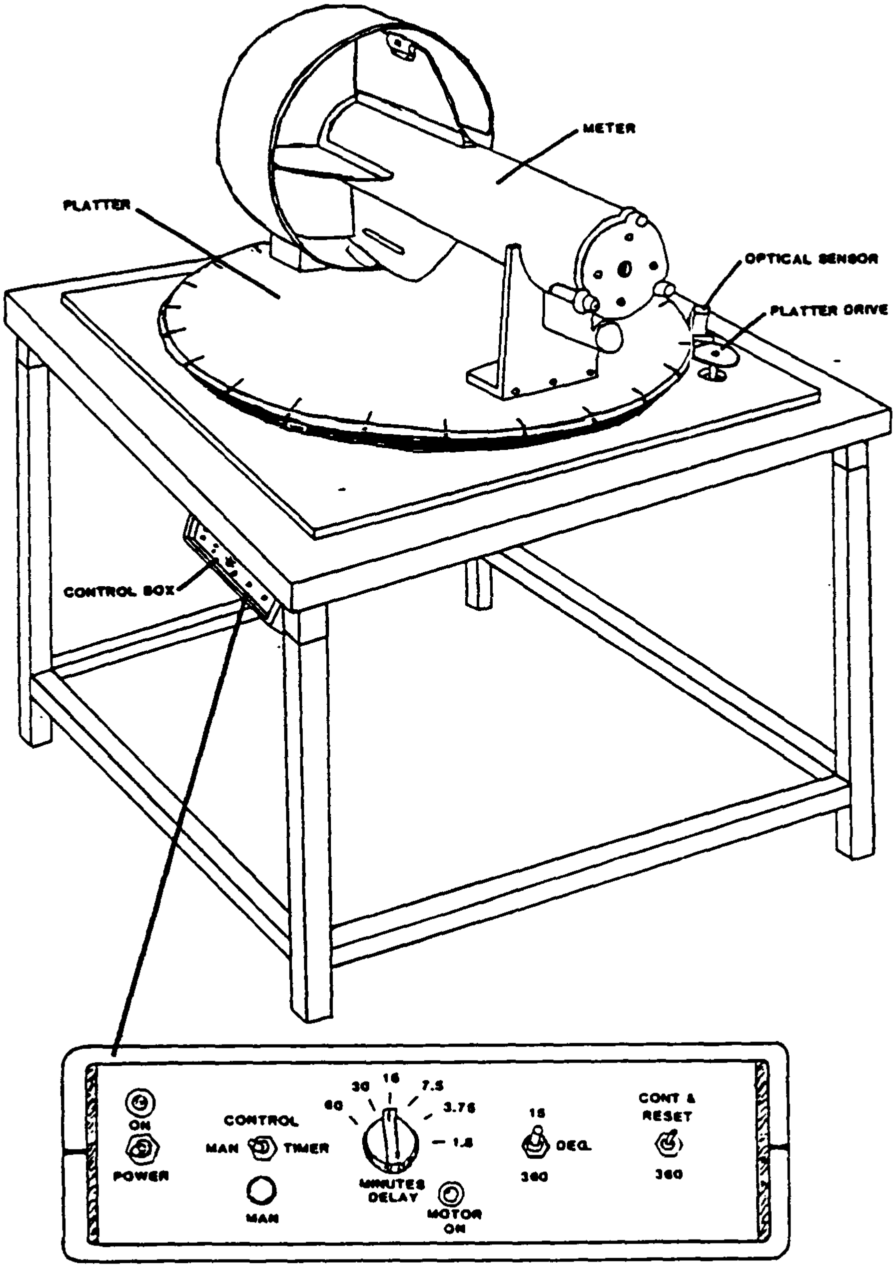


Figure 10-2. Drawing of the "swing" table used to calibrate the direction sensors of the current meters.

calibration check on temperature. The accuracy and resolution of the CTD's temperature sensor is comparable to that of the Hewlett Packard quartz thermometer. In addition, a further check on consistency is made whenever consecutive periods of deployment are available for an instrument location. The last few data values of the instrument retrieved should approximately equal the first few data values (after about one-half hour for equilibration) of the instrument which replaces it, except when a thermocline occurs at the depth of the instrument. This is called an inter-record comparison. The temperature values recorded by an instrument being calibrated are first corrected by the manufacturer's calibration values (developed from a multi-point set of calibrations). The results of calibrations in the laboratory, comparisons with the CTD data and the inter-record comparisons are subjectively combined to develop additional corrections. In most cases, the temperature data recorded by current meters lies within the rated accuracy limits and additional correction is unnecessary.

Both the Aanderaa and ENDECO current meters use inductive type conductivity sensors, but that of the Aanderaa is more accurate (±0.1 mmho/cm versus ±0.5 mmho/cm). Calibration checks are not made for conductivity directly, but rather for salinity, which is computed from conductivity and temperature. As for temperature, the calibration checks are performed in the insulated bath in the laboratory, with the CTD at sea and from inter-record comparisons. In the laboratory bath, various values of salinity are obtained using "instant ocean" type salt. A Grundy Model 6230N Laboratory Salinometer measures the salinity of bath samples, with A.P.S.I.O. Standard Sea-Water as the reference standard. The manufacturer estimates the accuracy of the salinometer to be ±0.003 ppt. The cells of inductive type conductivity sensors are sensitive to any change in inside dimensions. Both painting with antifouling paint and the growth of any organism inside the probe will alter a cell's effective dimensions. Painting produces a systematic error (constant offset), while biofouling causes a slow change or drift. The net magnitude of the error is determined by the various types of calibration checks at the times of deployment and retrieval and then linearly interpolated over the period of the record. Thus far during this study, only the ENDECO conductivity sensors have been painted with anti-fouling paint and required correction. Biofouling has not seriously affected the unpainted Aanderaa conductivity sensors.

10.2.5 Data Processing

The data processing procedures for the ENDECO Model 174SSM and the Aanderaa RCM8 are similar because both types sample speed and direction several times each minute and then internally vector average the current velocity data over a 30-minute recording interval. The instruments store the north-south and east-west components of the vector-averaged current velocity plus single samples of temperature and conductivity in solid-state memory every 30 minutes. After retrieval, a PC-compatible computer extracts the data from the instrument through an RS-232 communication cable using communication software provided by the manufacturer. Another program then converts the raw data to engineering units and applies the initial calibration values that are specific to each individual instrument. Salinity is computed from temperature and conductivity using the standard equations of the Practical Salinity Scale 1978 (UNESCO 1981). Then, a "preview plot" is generated which displays speed, direction, along-isobath and cross-isobath components, temperature and salinity with a time resolution of two days per inch, which permits problems with individual samples to be detected. Figure 10-3 shows an example of part of such a plot. The preview plot reveals problems in the data such as spikes, sticking or drifting sensors, indications of fouled or damaged sensors, etc. When possible, the data file is manually edited. Linear interpolation is applied across short spans of problem data. Long sequences of bad data, however, are flagged as unusable. Finally, the additional corrections for temperature and salinity (Section 10.2.4) are applied, if required. At this point, the time-series data are ready for submission to NODC and for higher level processing.

Processing the data from the ENDECO Model 174DMT is more involved because it records at a 10-minute rate onto a magnetic tape cartridge and does not vector average the current velocity data. An ENDECO Model 2501 Tape Reader reads the tapes, converts the data to 80-byte ASCII records of raw data and transmits them to a personal computer. The data file is then transferred to TAMU's mainframe computer system where the data are converted to engineering units and treated as described above. Salinity

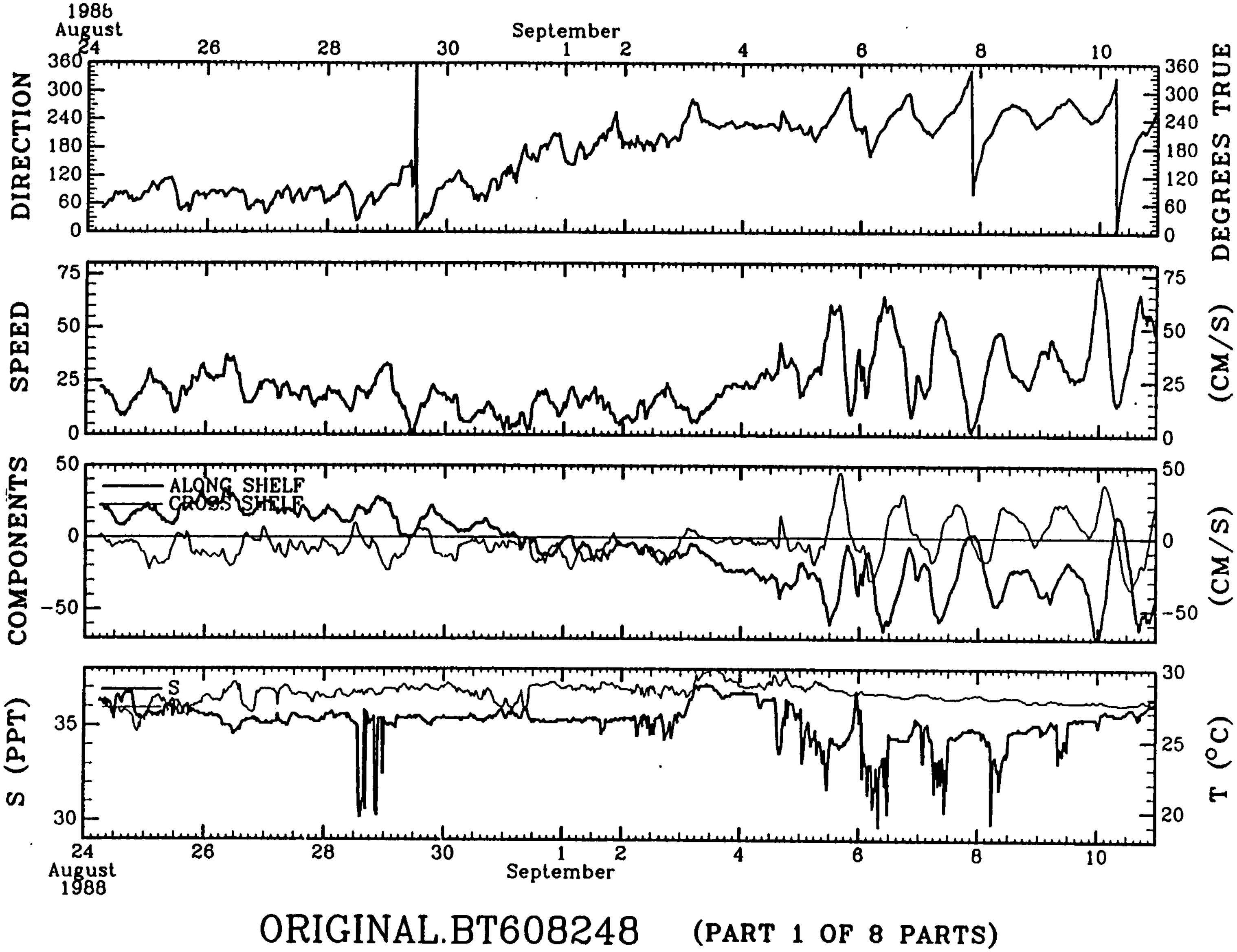


Figure 10-3. An example of a portion of a "preview plot" that is used to inspect the data from a current meter for problems such as spikes, sticking or drifting sensors, indications of fouled or damaged sensors, etc.

however, is computed using the equation of Daniel and Collias (1971), which is a simple polynomial that is computationally efficient and adequate for the coarse salinity accuracy of this instrument. The 10-minute, calibrated and qualified data are then filtered with a 2-hour, low-pass filter (a symmetric Lanczos filter) and subsampled to a 30-minute interval, at which point the data are ready for submission to NODC and higher level processing.

10.2.6 Basic Analysis Products

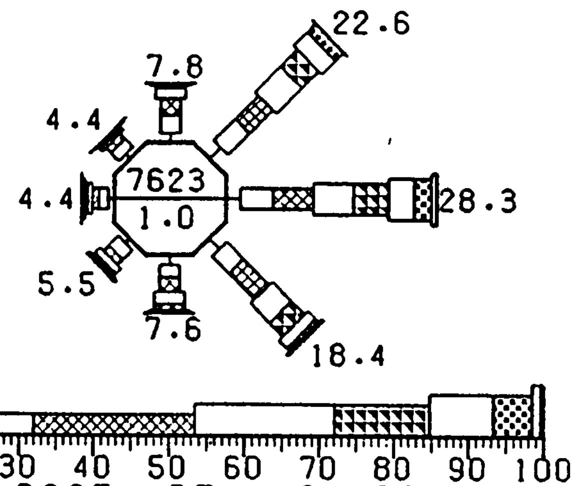
This report contains three types of basic analysis products for the time-series data: tables of monthly statistics, current roses (joint frequency of speed and direction) for each deployment of an instrument, and monthly plots of 3-hour and 40-hour low-pass filtered data. The complete set of basic analysis products can be found in Appendix C. Selected examples are used in this discussion.

Basic statistics for the time series, i.e., minimum, maximum, mean and standard deviation about the mean, are computed for monthly intervals using half-hourly values of the time series. Prior to computing the statistics, the individual time-series records for a given parameter are joined if the time gap between them is short (less than two days). The gap is filled by linear interpolation and the interpolated values are included in the computation of basic statistics. Gaps on the order of days to weeks in duration, however, are not interpolated and are not included in the statistics. Thus, some intervals have fewer than the number of half-hours appropriate for a given month. Table 10-4 is an example of the monthly statistics, in this case for Site B, Top.

A useful way to characterize the basic statistics of a velocity record is in a table of joint distribution of speed and direction and its graphical form, the current rose. This method is applied to the record for each deployment period at each instrument location. Figure 10-4 shows the current rose and its associated table of joint distribution for BT703168. The percentages of joint occurrence are computed from the time-series of half-hourly values of the along and cross isobath components, U and V respectively. The speed ranges are selected so as to provide an optimum resolution in the lower ranges. Calm conditions are defined as speeds lower than typical instrument thresholds of about 1 cm/s. Each value in the joint frequency

Table 10-4. An example of the monthly statistics computed for the time-series data.

Site B Top (10 m/60 m)		Along Isobath (cm/s)					Cross Isobath (cm/s)					Temperature (°C)					Salinity (‰)				
Start	Stop	N	Min	Max	Mean	S.D.	N	Min	Max	Mean	S.D.	N	Min	Max	Mean	S.D.	N	Min	Max	Mean	S.D.
1/1/88 (0000)	1/31/88 (2330)	1488	-38.	31.	2.1	12.2	1488	-24.	21.	0.9	8.7	1488	17.0	20.2	18.9	0.7	1488	35.3	36.3	35.9	<0.0
2/1/88 (0000)	2/29/88 (2330)	1392	-20.	39.	6.8	10.7	1392	-25.	26.	1.0	8.6	1392	14.9	19.3	17.2	1.1	1392	34.4	36.2	35.5	0.3
3/1/88 (0000)	3/31/88 (2330)	903	-30.	35.	-0.6	10.7	903	-22.	30.	-0.2	8.6	903	16.2	20.5	17.7	1.0	187	34.8	35.7.	35.3	0.3
4/1/88 (0000)	4/30/88 (2330)	1440	-37.	36.	-1.5	11.2	1440	-36.	50.	-0.4	12.2	1440	18.4	22.3	20.0	1.1					
5/1/88 (0000)	5/31/88 (2330)	1488	-29.	49.	10.9	12.2	1488	-70.	21.	-7.4	12.1	1488	20.7	24.2	22.5	0.8					
6/1/88 (0000)	6/30/88 (2330)	1440	-6.	48.	11.1	9.0	1440	-38.	18.	-3.6	8.8	1440	23.1	27.3	25.4	0.8					
7/1/88 (0000)	7/31/88 (2330)	1488	-5.	31.	8.5	6.6	1488	-28.	10.	-4.9	7.3	1488	25.2	29.3	27.4	0.7					
8/1/88 (0000)	8/31/88 (2330)	1423	-13.	41.	14.1	10.9	1423	-35.	16.	-8.7	9.0	1423	25.6	29.5	28.1	0.6	372	30.2	36.7	35.4	0.8
9/1/88 (0000)	9/30/88 (2330)	1440	-74.	15.	20.6	19.4	1440	-36.	46.	0.8	12.4	1440	27.2	30.0	28.2	0.5	1440	29.7	37.2	35.1	0.7
10/1/88 (0000)	10/31/88 (2330)	1488	-40.	5	-11.2	7.7	1488	-19.	34.	-0.3	8.0	1488	24.4	28.2	25.7	1.1	1488	29.0	36.7	35.7	0.9
11/1/88 (0000)	11/30/88 (2330)	1440	-29.	16.	-2.5	8.6	1440	-27.	10.	-3.8	6.0	1440	22.4	24.8	23.5	0.6	1440	30.1	36.5	36.2	0.1
12/1/88 (0000)	12/31/88 (2330)	1488	-14.	16.	0.3	4.9	1488	-17.	13.	0.5	4.5	1488	18.2	22.8	21.3	0.7	1488	33.0	36.7	36.2	<0.0
1/1/89 (0000)	1/13/89 (2100)	619	-16.	28.	2.4	8.6	619	-22.	9	-1.2	6.8	619	20.2	21.7	20.9	0.5	619	34.9	36.1	35.7	0.3
2/16/89 (2000)	2/28/89 (2330)	584	-20.	20.	5.1	7.8	584	-33.	13.	-4.6	7.5	584	17.8	21.8	19.9	1.2	584	35.3	35.9	35.6	0.3
3/1/89 (0000)	3/31/89 (2330)	1488	-29.	46.	0.3	13.8	1488	-38.	44.	1.1	11.8	1488	16.5	21.1	19.5	1.0	1488	32.6	35.9	35.1	0.4
4/1/89 (0000)	4/30/89 (2330)	1440	-33.	28.	3.4	9.5	1440	-22.	36.	0.7	8.0	1440	19.8	22.8	21.0	0.6	1440	33.9	35.7	34.8	0.2
5/1/89 (0000)	5/31/89 (2330)	1488	-21.	28.	1.3	6.5	1488	-30.	20.	-0.4	6.1	1488	21.0	25.6	23.4	1.0	1488	26.7	36.3	35.3	0.9
6/1/89 (0000)	6/21/89 (1200)	985	-29.	45.	2.2	9.6	985	-39.	34.	-0.4	9.0	985	23.8	27.9	26.3	1.0	985	32.2	36.0	34.6	1.0



CURRENT ROSE, BT 10M/60M
88/03/17 (0200) - 88/08/22 (2100) (GMT)

DIR	RANGE (CM/S) E.G. 1< V ≤5										AVG SPEED
	1-5	5-10	10-15	15-20	20-25	25-30	30-40	40-50	50+	TOTAL	
N	1.2	2.4	2.2	1.3	0.4	0.2	0.1	+	+	7.8	11.7
NE	2.1	4.1	4.3	4.8	3.2	2.5	1.5	+		22.6	16.4
E	2.0	4.3	5.4	5.4	4.7	3.5	2.3	0.6	0.2	28.3	18.2
SE	2.0	3.1	4.8	3.6	2.5	1.4	0.6	0.2	0.2	18.4	15.6
S	1.3	1.6	1.9	1.6	0.8	0.2	0.2	+		7.6	12.6
SW	0.9	1.8	1.0	0.8	0.5	0.2	0.2			5.5	12.6
W	0.8	1.2	0.9	0.6	0.4	0.4	0.1	+		4.4	12.7
NW	0.9	1.5	0.9	0.5	0.3	+	0.1	0.1	+	4.4	11.7
TOTAL	11.1	19.9	21.5	18.5	12.8	8.4	5.2	1.1	0.4	99.0	15.3
CALM										1.0	

Figure 10-4. An example of a current rose and its associated table of joint frequency distribution of speed and direction.

table represents the percentage of observations that fell in a given speed range and direction sector. The total for a given row gives the percentage of observations that fell in that direction sector regardless of speed (e.g., NE is from 22.5° to 67.5°). The scalar average speed (as opposed to vector average) for each direction sector is given on the far right side of each row. The total for a given column gives the percentage of observations that fell in a given speed range regardless of direction. For ease in visualizing the table, a rose diagram is plotted above it. Each rose petal corresponds to a direction sector in the table. Each segment of a petal corresponds to a speed range, and the length of each segment is proportional to the percentage expressed in the table. The total percentage in that direction is printed at the tip of each petal. A cumulative speed graph is plotted below each rose. It expresses the percentage of observations that fell in a given speed range regardless of direction, and corresponds to the row of totals (second row from the bottom) in the table. The graph runs from 0 to 100%. The scale of the graph and the scale of the rose petals are the same. Thus, if all the petals of a rose are laid end-to-end, the length would equal the length of the graph less the percentage of calms. The total number of observations on which the percentages are based is printed in the upper half of the center of the rose. The percentage of calms is printed in the lower half.

Monthly plots of the time series of current velocity, salinity, and water temperature are constructed for each instrument location First, the individual, 30-minute, time-series records for a given parameter are joined as described for the monthly statistics. Then the time series are filtered with 3-hour and 40-hour low-pass filters. Figure 10-5 shows the plot for May 1989 at Site C, Top. The stick vectors are reconstructed from the 40-hour low-pass filtered orthogonal components at 6-hour intervals [000, 0600, 1200, 1800, (CST)]. For each stick vector, the x-axis is oriented in the cross-isobath direction and the y-axis is oriented along the isobaths. The orientation relative to true north of the y-axes in the along-isobath and cross-isobath component plots is shown in each frame, e.g. 055°-235° (along isobath), 325°-145° (cross isobath). Both the 3-hour low-pass filtered and the 40-hour low-pass filtered series are shown for each component. The bottom frame shows the 3-hour low-pass filtered series for temperature and salinity.

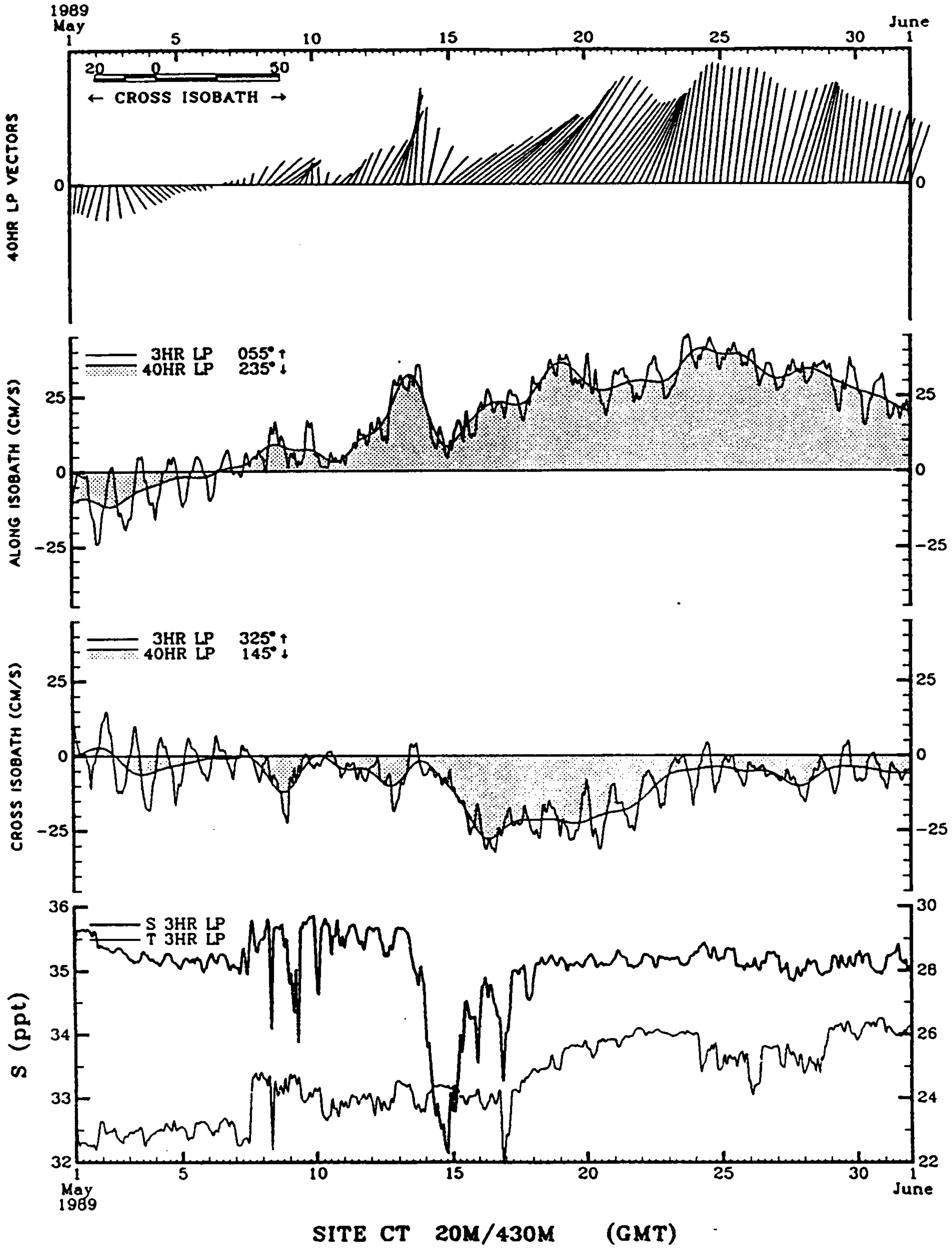


Figure 10-5. An example of a monthly plot of 3-hour and 40-hour low-pass filtered time series data.

10.3 Hydrographic Sampling

Moored instruments collect data sets that are primarily intended to study temporal variability. The cost of operating them limits the number that can be deployed and, therefore, the information they can provide about spatial variation. Synoptic surveys by ship and satellite remote sensing (See Chapter 11) focus on spatial variability. This study has conducted five multidisciplinary cruises to survey the Mississippi-Alabama continental shelf. The first three, designated Cruise 0, Cruise 1 and Cruise 2, were undertaken in March 1987, October 1987 and March 1988, respectively. The Year 1 report (Brooks and Giammona 1988) presents the results. This section describes the hydrographic data collected during Cruise 3 (August 1988) and Cruise 4 (February 1989).

10.3.1 Station Locations

Figures 10-6 and 10-7 show the stations occupied during Cruise 3 and Cruise 4, respectively. CTD/Transmissivity vertical profiles and discrete samples by bottle were obtained at each of the twelve primary stations (solid circles), and CTD/Transmissivity casts, without bottle samples, were made at the mooring sites (solid triangles) and at supplemental stations (crosses) occupied as time and course permitted. The coordinates of the stations are listed together with the data in Appendix C. During Cruise 4, no conductivity data were obtained at Stations C2, C3 and C4 because of problems with the CTD discussed below; salinity profiles for these stations are estimated from the bottle samples. Also, no data were obtained at Stations A and S4.

10.3.2 Instruments and Methods

The CTD is a Sea-Bird Electronics, Inc., Model SBE19 (SEACAT) Conductivity, Temperature, Depth Profiler. A Sea Tech, Inc., 25 cm transmissometer is interfaced to the SEACAT. The CTD/Transmissometer system is coupled to a General Oceanics Rosette Sampler with 1.7 liter Niskin bottles. The Year 1 report (Brooks and Giammona 1988) lists the specifications for the instruments. The SEACAT records data internally into solid state memory, and, at the same time, can transmit the data via cable to an IBM-PC compatible computer.

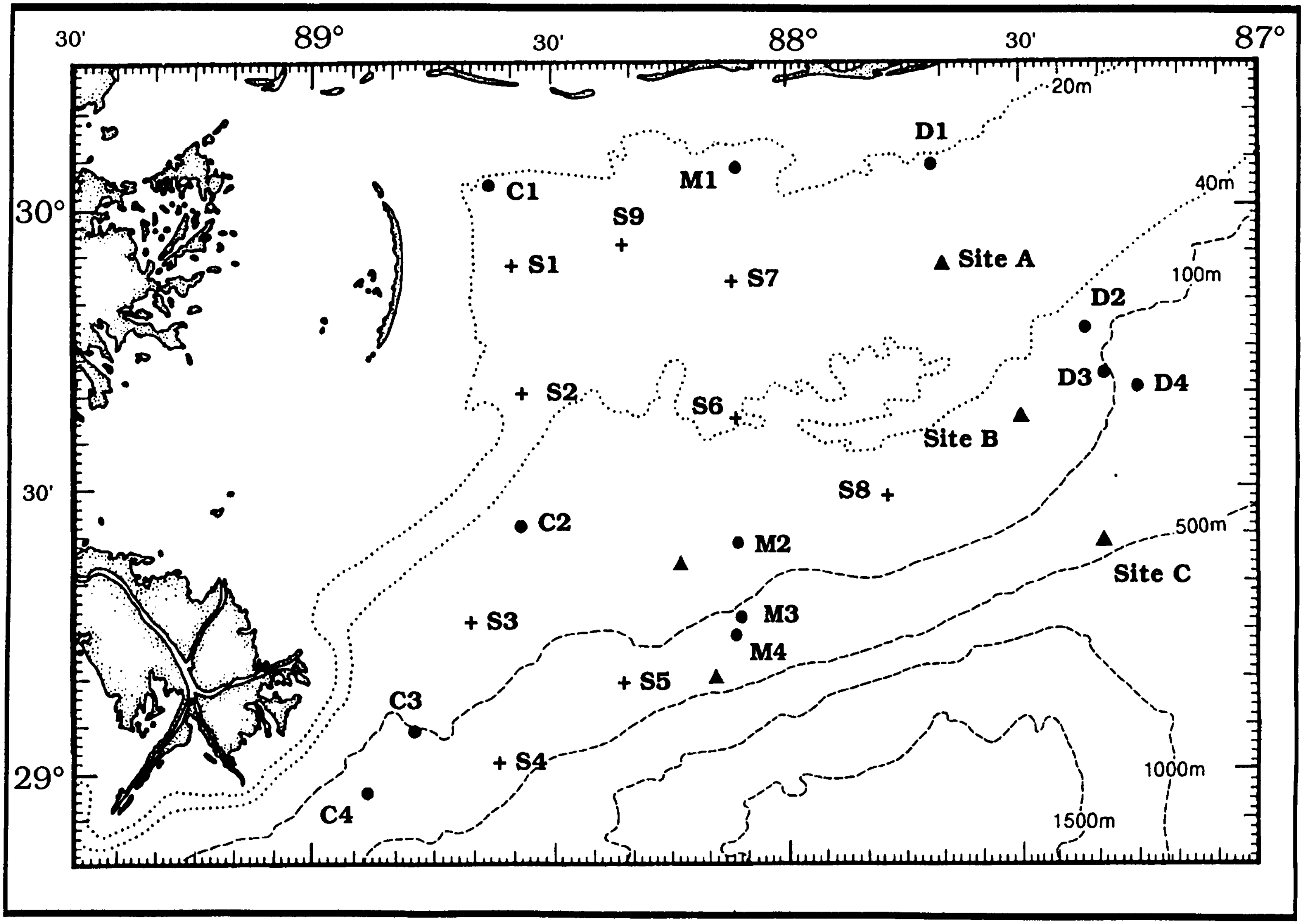


Figure 10-6. Map showing Cruise 3 CTD stations.

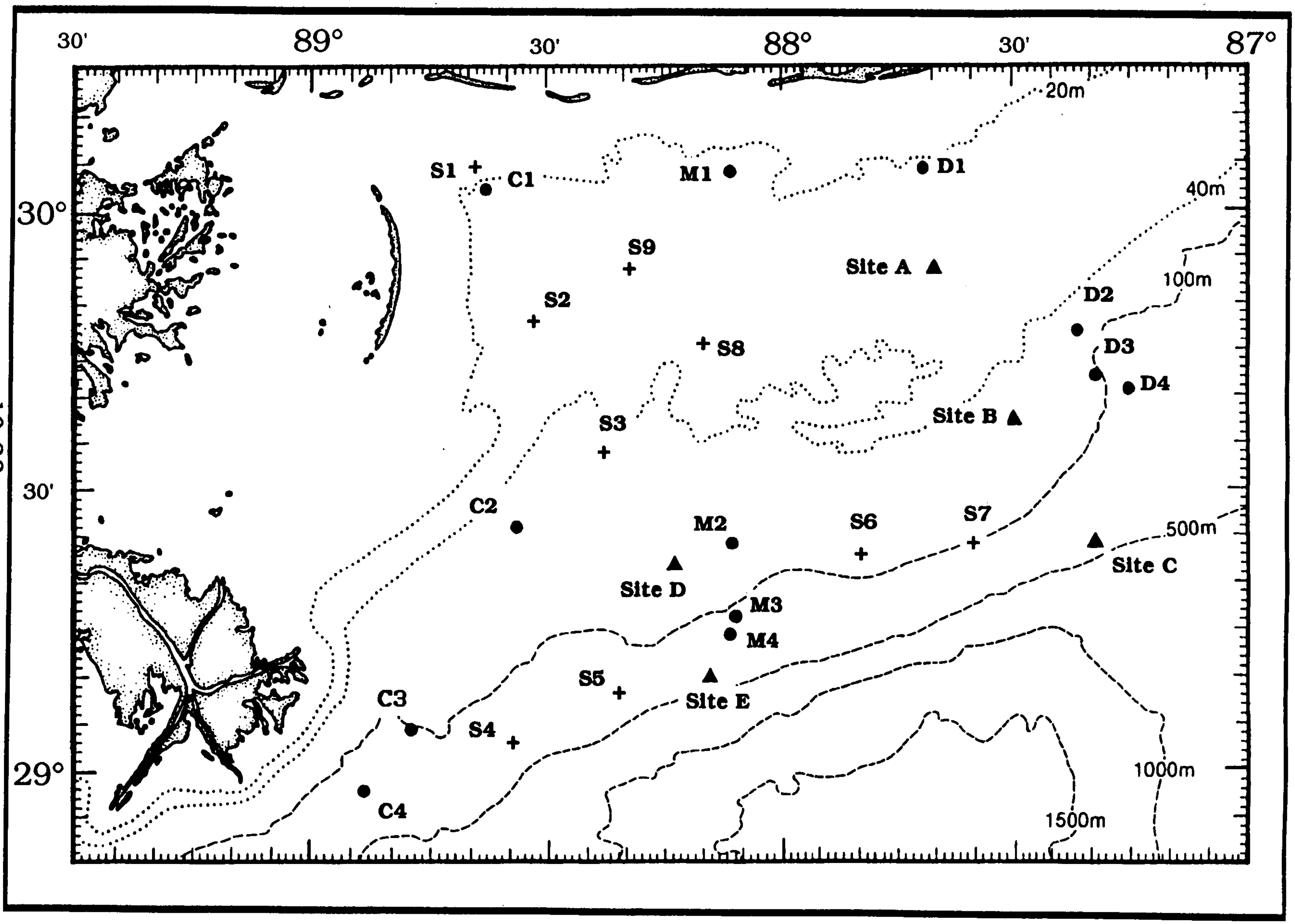


Figure 10-7. Map showing Cruise 4 CTD stations.

Continuous CTD profiles are made during the downcast. It is lowered at a rate of about 0.7 to 1.0 m/sec. The SEACAT samples twice per second. The Rosette sampler collects bottle samples during the upcast. The instrument package is stopped at each depth selected for a bottle sample. If a bottle also has reversing thermometers attached, five minutes are allowed for thermal equillibration.

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

During Cruise 3, a problem developed with the armored conducting cable used to lower the instrument package and transmit the data to the ship. The cable gradually began to leak electrical signals that were picked up by the CTD's sensors. The computation of salinity from temperature and conductivity amplified the effect, which manifested itself as small spikes and noise in salinity profiles. The problem was at first attributed to the problem all CTDs have to varying degree when they pass through strong vertical gradients of temperature and salinity which is caused by the difference between the response times of the conductivity and temperature sensors. After analyzing the data, however, an instrument problem was also considered possible, and the CTD was sent to the manufacturer for repair and calibration. It was returned just before Cruise 4. Everything appeared normal at Stations S1, S2 and S3 of Cruise 4, but beginning with Station C2 the conductivity signal turned to pure noise below about 20 m. A variety of solutions were tried, including alternate conductors in the cable and slip rings, a backup CTD and internal recording. The solution was to not only record data internally but also electrically isolate the CTD from the cable and the frame of the Rosette Sampler, sending no data up the cable. No conductivity profiles were successfully obtained at Stations C2, C3, C4 and S4, although repeated attempts were made during the troubleshooting process. However, the pressure, temperature and transmissivity data from these stations are good.

10.3.3 Quality Control

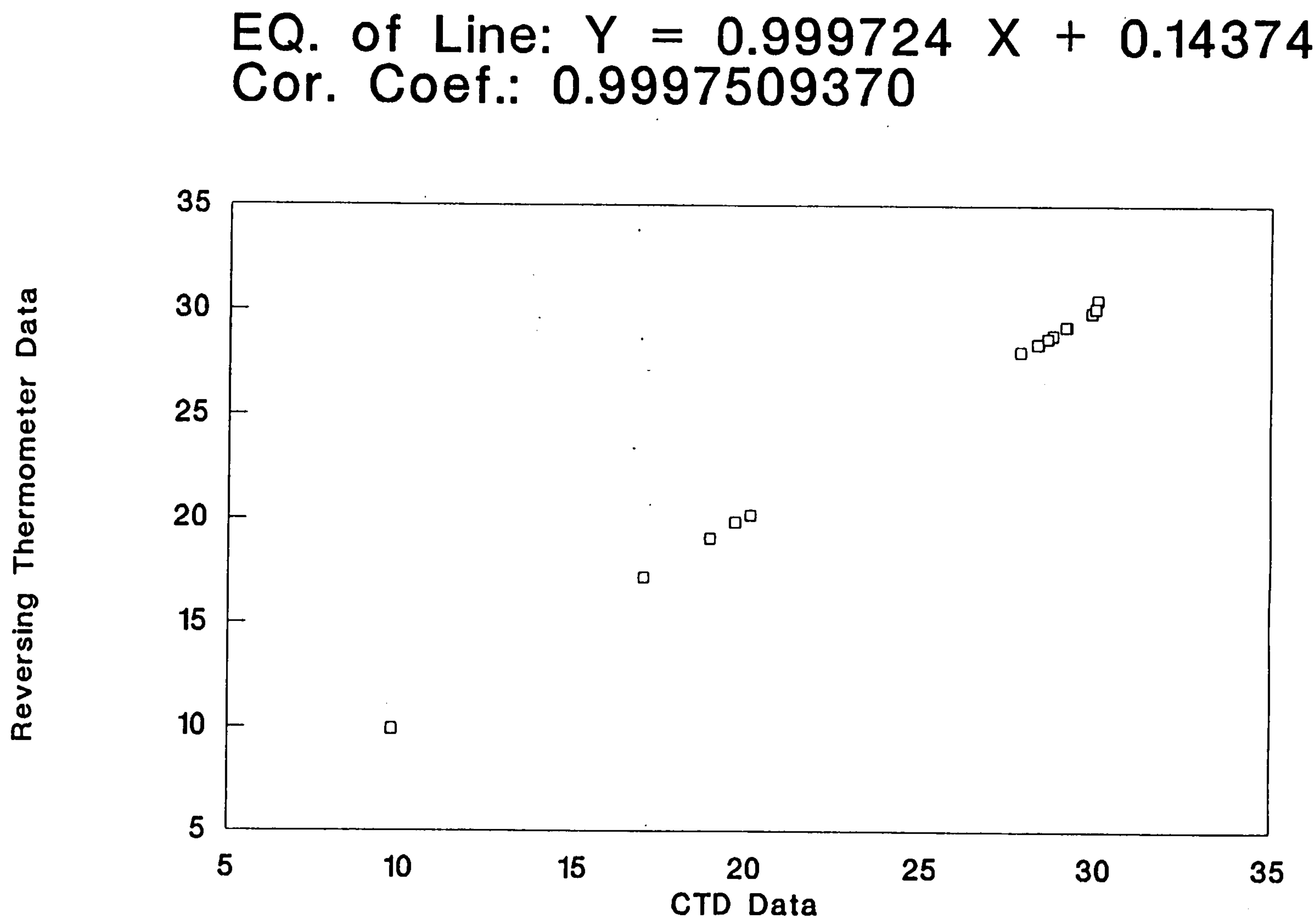
The accuracy of the CTD is checked by linear regression with data obtained from bottle samples and paired reversing thermometers. Salinity values of the bottle samples are determined by means of a Grundy Model 6230N Laboratory Salinometer with A.P.S.I.O. Standard Sea-Water as the reference standard. The CTD values of temperature and salinity corresponding to the thermometer and bottle samples come from the upcast portion of the CTD record. They are an average over a 15-second period about the time the bottle was tripped. Strong vertical gradients, the roll and heave of the ship, and the problem with the armored cable caused numerous outlier points, which are not used in the regression. An outlier is defined as a CTD-bottle difference greater than 0.2 or a CTD-thermometer difference greater than 0.1.

Figures 10-8 and 10-9 show the results of the linear regressions for temperature and salinity for Cruise 3, and Figures 10-10 and 10-11 show them for Cruise 4. Table 10-5 lists the parameters calculated by regression. Salinity is a function of both conductivity and temperature. The manufacturer estimates the accuracies of the temperature and conductivity sensors to be 0.01°C/6 months and 0.0001 mmho/cm/month, respectively. The CTD was calibrated in September 1987 and December 1988. The noise problem during Cruise 3 is evident in the standard error estimates in Table 10-5.

The Sea Tech transmissometer was calibrated by the manufacturer in February 1988. In addition, air and blocked light-path calibration values are obtained during each cruise, per the operating instructions for the instrument.

10.3.4 Data Processing Methods

The raw data of a cast are separated into downcast and upcast parts. Only the downcast data are used to construct a vertical profile. Spiking in the computed salinity record of a CTD cast may occur because of the mismatch between the response times of the conductivity and temperature sensors. The severity of spiking depends on the strength of vertical gradients and the descent rate of the sensors. To ameliorate the effects of the phenomenon, a combination of several procedures are used. First, the



TM B-3 (Aug. 88)

Figure 10-8. Cruise 3 temperature calibration data. Linear regression between temperature measured by the CTD and temperature measured by reversing thermometers yields the equation used to correct the CTD data.

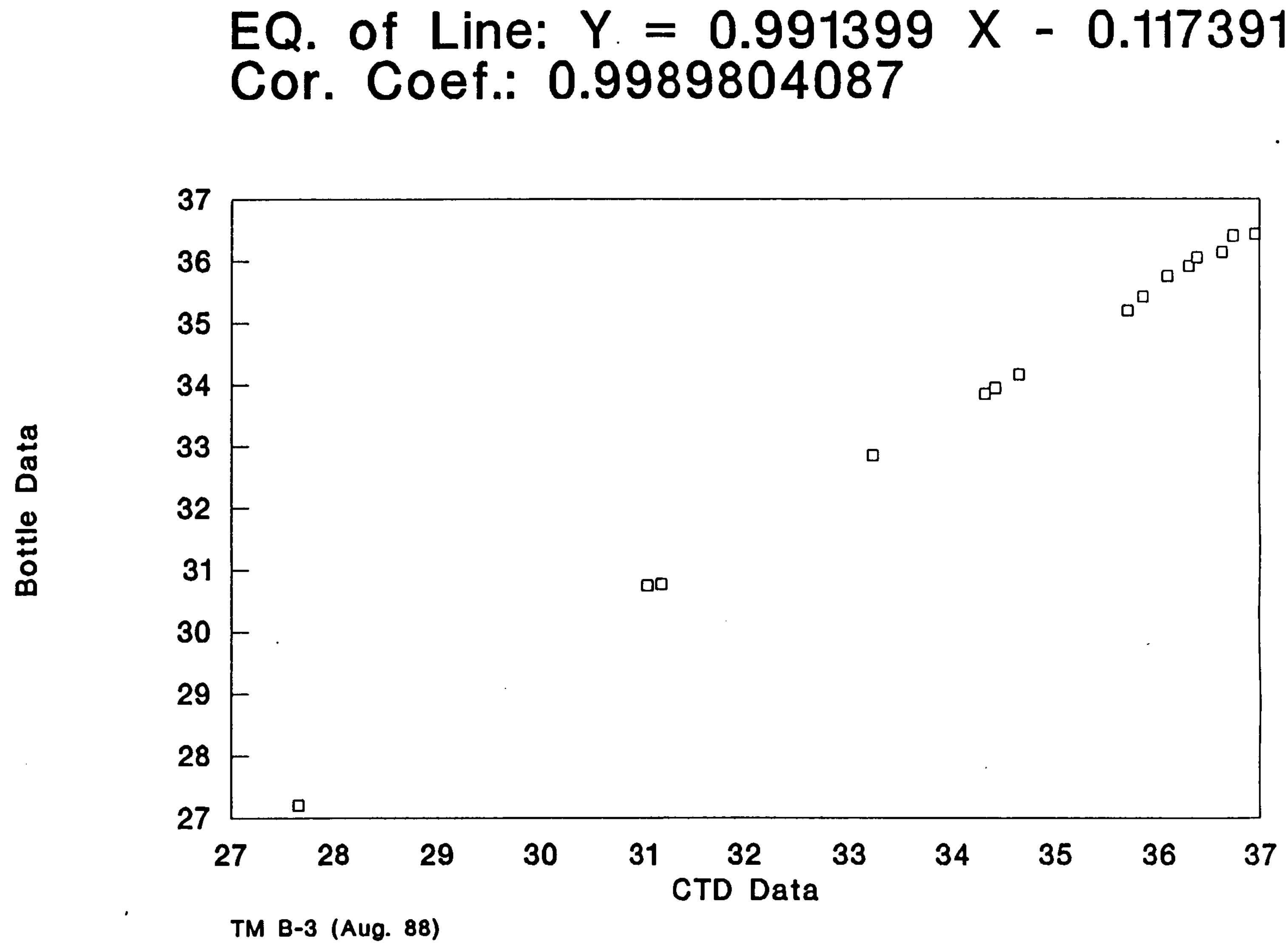
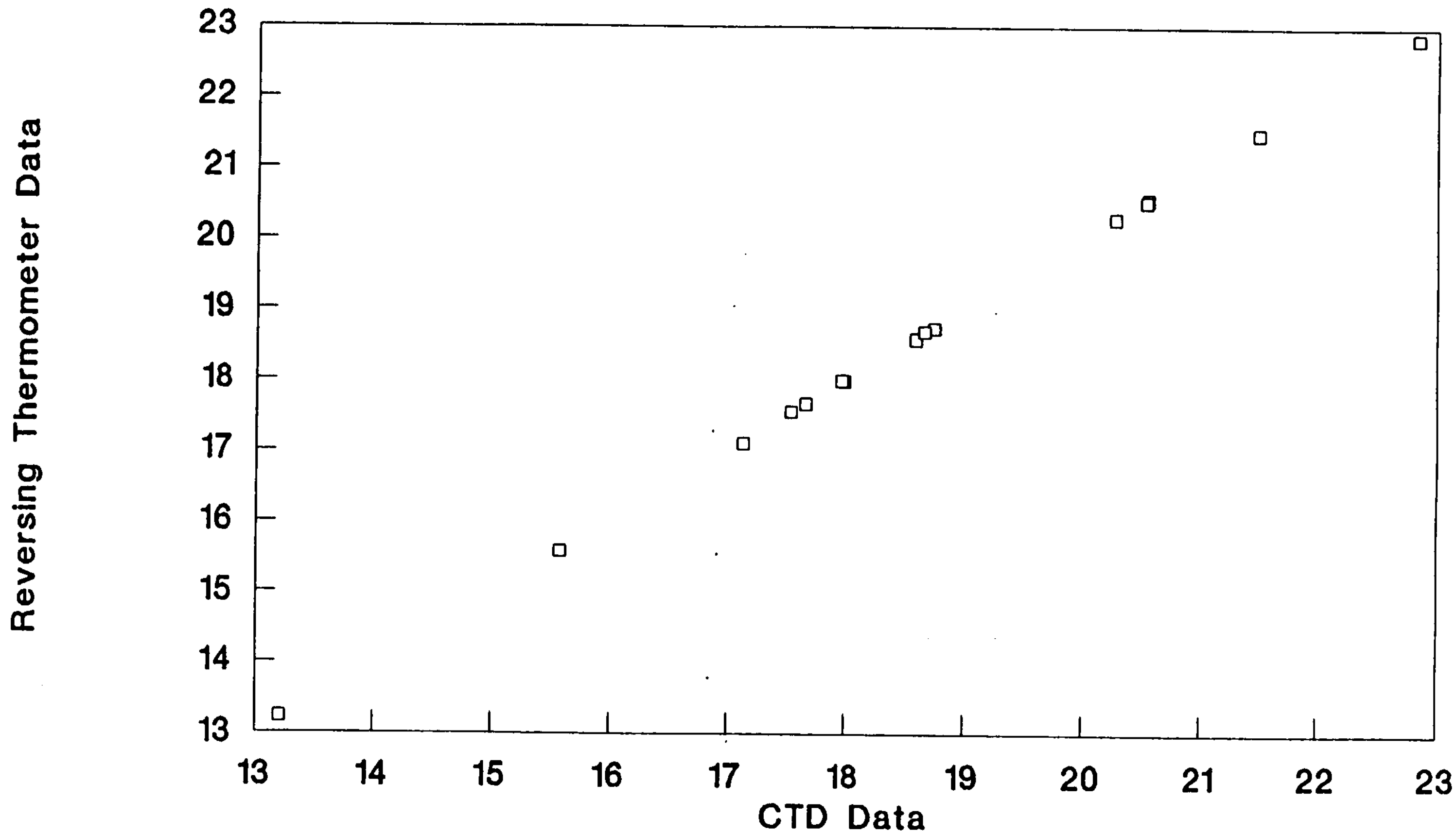


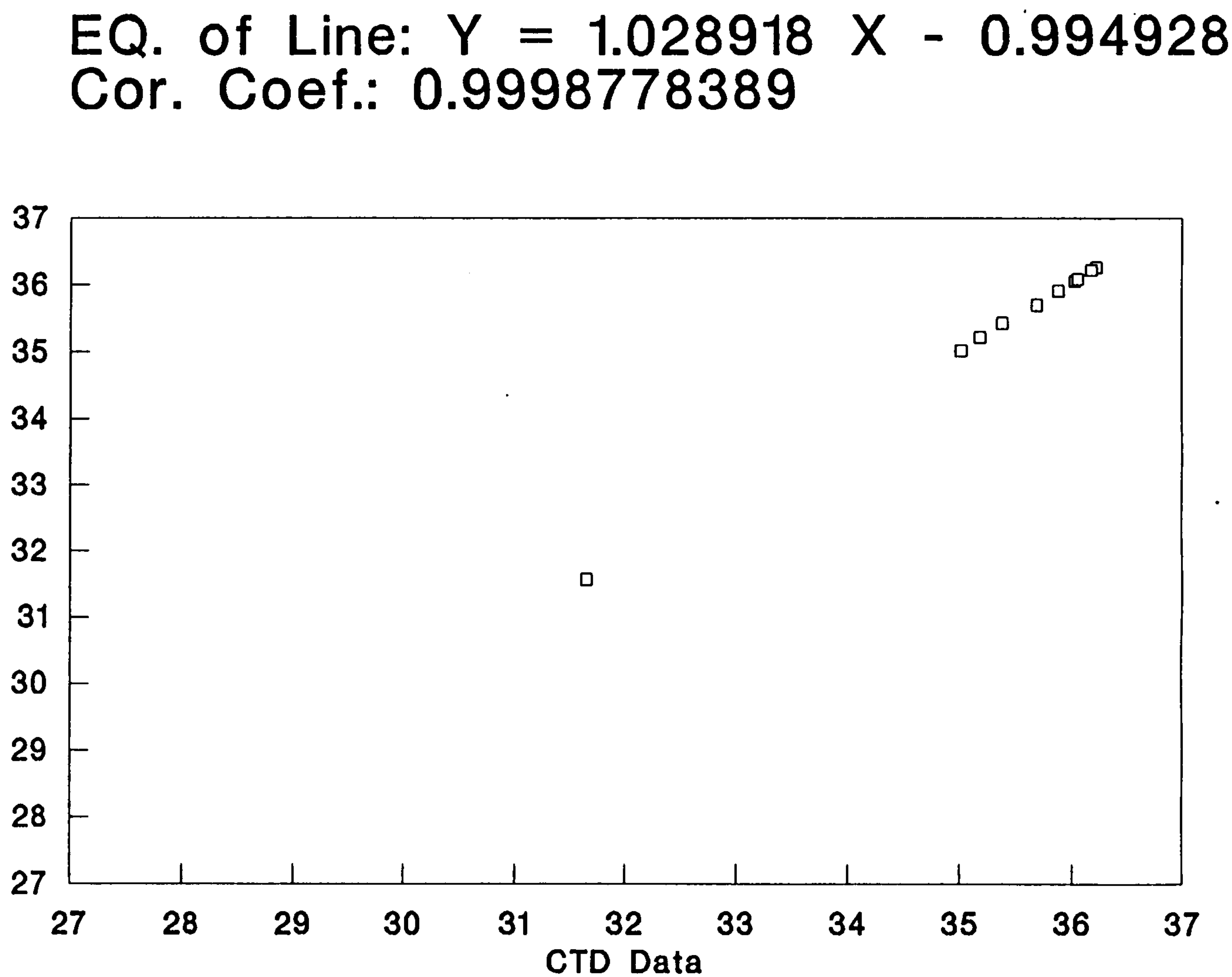
Figure 10-9. Cruise 3 salinity calibration data. Linear regression between salinity measured by the CTD and salinity determined by laboratory analysis of bottle samples yields the equation used to correct the CTD data.

EQ. of Line: Y = 1.000462 X - 0.000875
Cor. Coef.: 0.9999508410



TM B-4 (Feb. 89)

Figure 10-10. Cruise 4 temperature calibration data. Linear regression between temperature measured by the CTD and temperature measured by reversing thermometers yields the equation used to correct the CTD data.



TM B-4 (Feb. 89)

Figure 10-11. Cruise 4 salinity calibration data. Linear regression between salinity determined by the CTD and salinity determined by laboratory analysis of bottle samples yields the equation used to correct the CTD data.

Table 10-5. Results of linear regressions to calibrate CTD data of Cruise 3 and Cruise 4.

	Cruise 3		Cruise 4	
	T	S	T	S
Coefficient	0.9997241	0.9913992	1.000463	1.028918
Constant	0.143746	-0.117391	-0.000875	-0.994928
Std. Err. of Y Est.	0.107	0.079	0.017	0.015
R Squared (adjusted)	0.999751	0.998980	0.999951	0.999878
No. of observations	18	32	15	10
Degrees of Freedom	16	30	13	8

temperature and conductivity records are offset in time to reduce the mismatch in response times of the sensors. The amount of offset is determined by trial and error (typically 0.2-0.4 seconds for the SEACAT sensors). The next step removes scans (sets of samples of the parameters) for which the pressure value is non-increasing or decreasing. Then the data are averaged in 2 m bins. Finally, the temperature and salinity values are corrected according to the equations given in Figures 10-8 through 10-11.

10.3.5 Basic Analysis Products

Appendix C contains tabular listings and plots of the CTD/Transmissometry data from Cruise 3 and Cruise 4.

Figures 10-12 through 10-23 present horizontal distributions of temperature, salinity and dissolved oxygen near the surface (2-4 m below the surface) and near the bottom (2-6 m above the bottom) for Cruise 3 and Criuse 4. The temperature and salinity data are from the CTD casts, except at Stations C2, C3 and C4 of Cruise 4 where the salinity values are from the bottle data. The dissolved oxygen data are from bottle samples.

10.4 Results

Although conclusions cannot be made until the full data set is available, the results thus far suggest that the circulation on the outer shelf is dominated by large-scale, long-period mesoscale flow events. Shorter, synoptic period fluctuations modulate and intersperse the mesoscale events. Figure 10-24 shows the currents observed at Moorings B and C from September through December 1988 in the form of 40-hour, low-pass-filtered stick vectors. The vertical axis in Figure 10-24 is oriented along the direction of the trend of the isobaths, so that vertically up is towards 55° and horizontally to the right is towards 145°. (This orientation emphasizes the along-isobath flow.)

Some flow events, for example the ones that occurred during the periods of 1-20 September and 10-31 November, are coherent between Moorings B and C and are probably caused by mesoscale eddy flow in De Soto Canyon. Also note that the currents at 10 m at Mooring B are more similar to those at 150 m at Mooring C than they are to the shallower currents at 25 m at Mooring C. The temperature and salinity data recorded by the current meters are being studied as part of an analysis of the vertical structure of the currents.

Cross-isobath flow is strong at times in these records, particularly during the longer-period events, as, for example, during the period 10-31 October. Analysis by current roses shows that the dominant flow direction is southeastward, i.e., off-slope, at 25 m at Mooring C during the period of September-December 1988, which is consistent with Dinnel's (1988) analysis of historical hydrographic data for this region. Westward and southwestward directions dominate the flow records from the deeper two meters at Mooring C and both meters at Mooring B.

During Cruise 3 (August 19-25, 1988), the near-surface temperature and salinity distributions (Figures 10-12 and 10-13) were dominated by two water masses. Water cooler than 29°C and saltier than 33 ppt pushed westward over the middle shelf, while warmer, fresher water lay to the northwest, west and southeast. The latter two regions were separated by a tongue of the cooler, saltier water that pushed southwestward between Stations C2 and M2. Higher values of dissolved oxygen (Figure 10-14) were generally associated with the cooler, saltier water mass. Near the bottom, a relatively homogeneous water mass, with salinities above 36.5 ppt and temperatures between 20 and 22°C (Figures 10-15 and 10-16), dominated the middle shelf. North and south of this water mass meridional gradients were strong. A region of relatively low oxygen (Figure 10-17) was centered on Station S7, while a band with values above 6.0 mg/l girded the low region on the south and east. Highest oxygen values near the bottom were found in the northwest corner of the study region, while lowest values lay offshore on the deeper slope.

During the period of Cruise 4, February 11-18, 1989, the infrared satellite images (Section 10.3) clearly show that two warm filaments from the northeast corner of the Loop Current extended onto the shelf. The satellite data confirm the interpretation given the near surface temperature distribution (Figure 10-18) based on the less synoptic data collected during Cruise 4. One filament moved onto the shelf near Stations M3 and M4 and pushed almost as far as stations C1 and M1. The other influenced the eastern portion of the study region. Cool shelf-water moved southward between them. Figures 10-19 and 10-20 show that higher salinity and lower oxygen values were associated with the warmer water, while the cooler, southward moving water was higher in oxygen and much fresher. Near the bottom, the property distributions were oriented along the isobaths. A band of warmer more saline water lay along the line of stations D2, M2, C2. North of this line, oxygen values were relatively uniform, although the distribution suggests that slightly higher values entered from the east. South of the line, oxygen values decreased sharply as bottom depth increased.

For both cruises, the interpretations given the property distributions in the vicinity of moored current meters are consistent with both the mean flows and the temperature and salinity they recorded during the time of the cruises (See the appropriate monthly plots in Appendix C). It should be pointed out that the Year 1 report (Brooks and Giammona 1988) described another case of a filament from the Loop Current interacting with the Mississippi-Alabama shelf. It was detected by the March 1988 cruise (Cruise 2), by the satellite images and by the current meters at Sites A and B. The satellite thermal images suggest such interactions may have occurred at other times as well. The Year 3 Final Report will examine all such cases and compare them with the current meter observations.

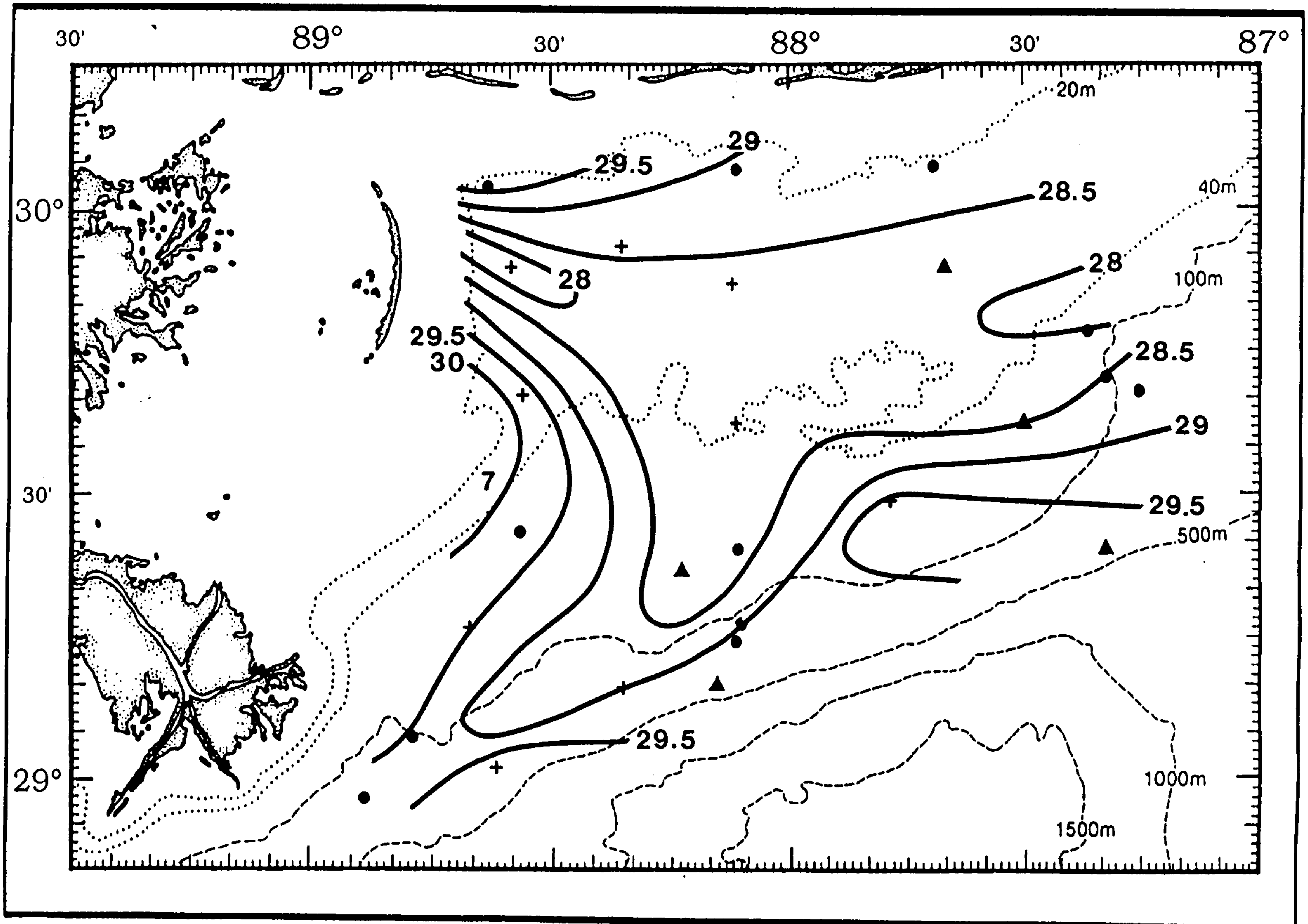


Figure 10-12. Cruise 3 (August 1988) distribution of near-surface temperature (°C).

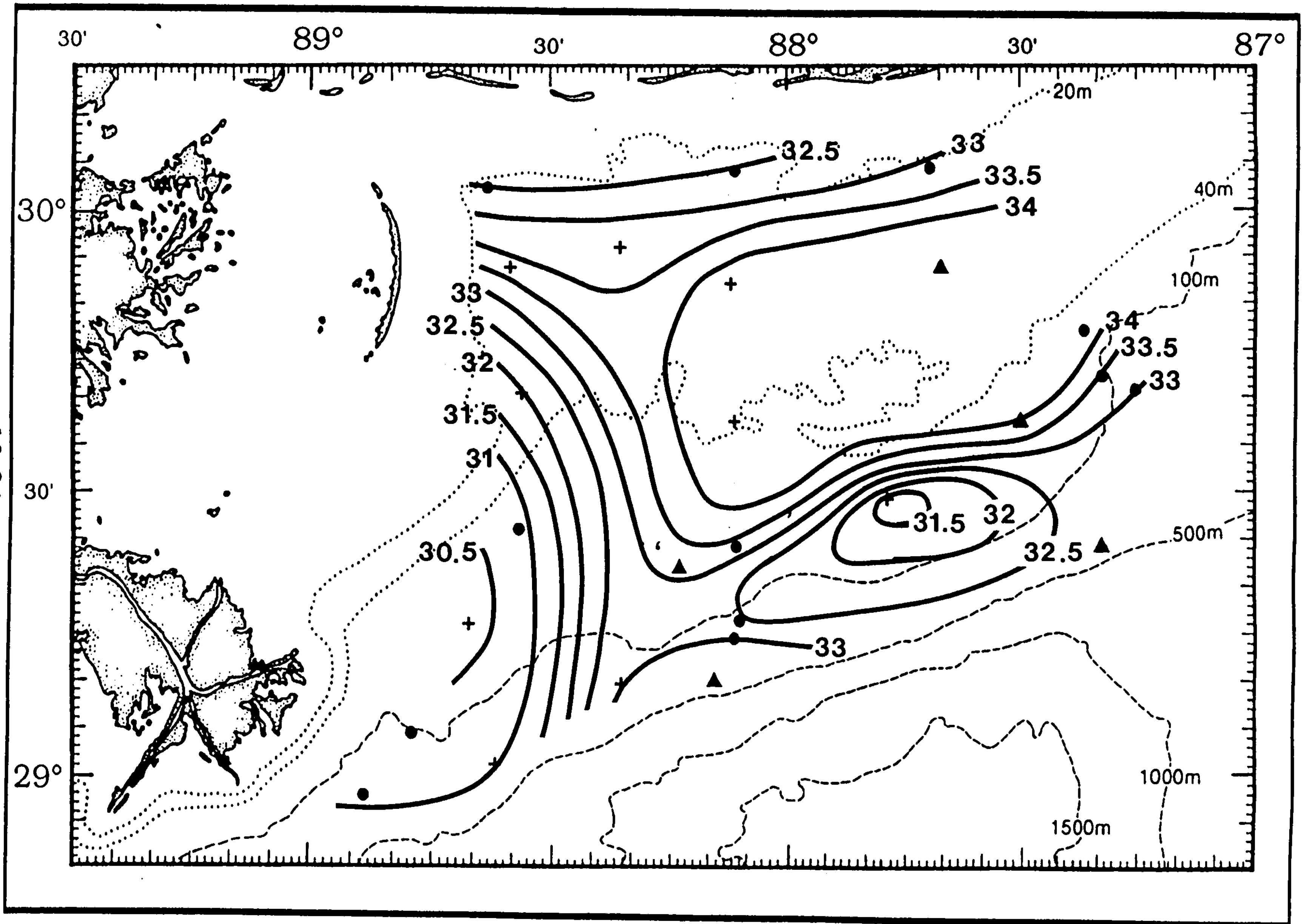


Figure 10-13. Cruise 3 (August 1988) distribution of near-surface salinity (‰).

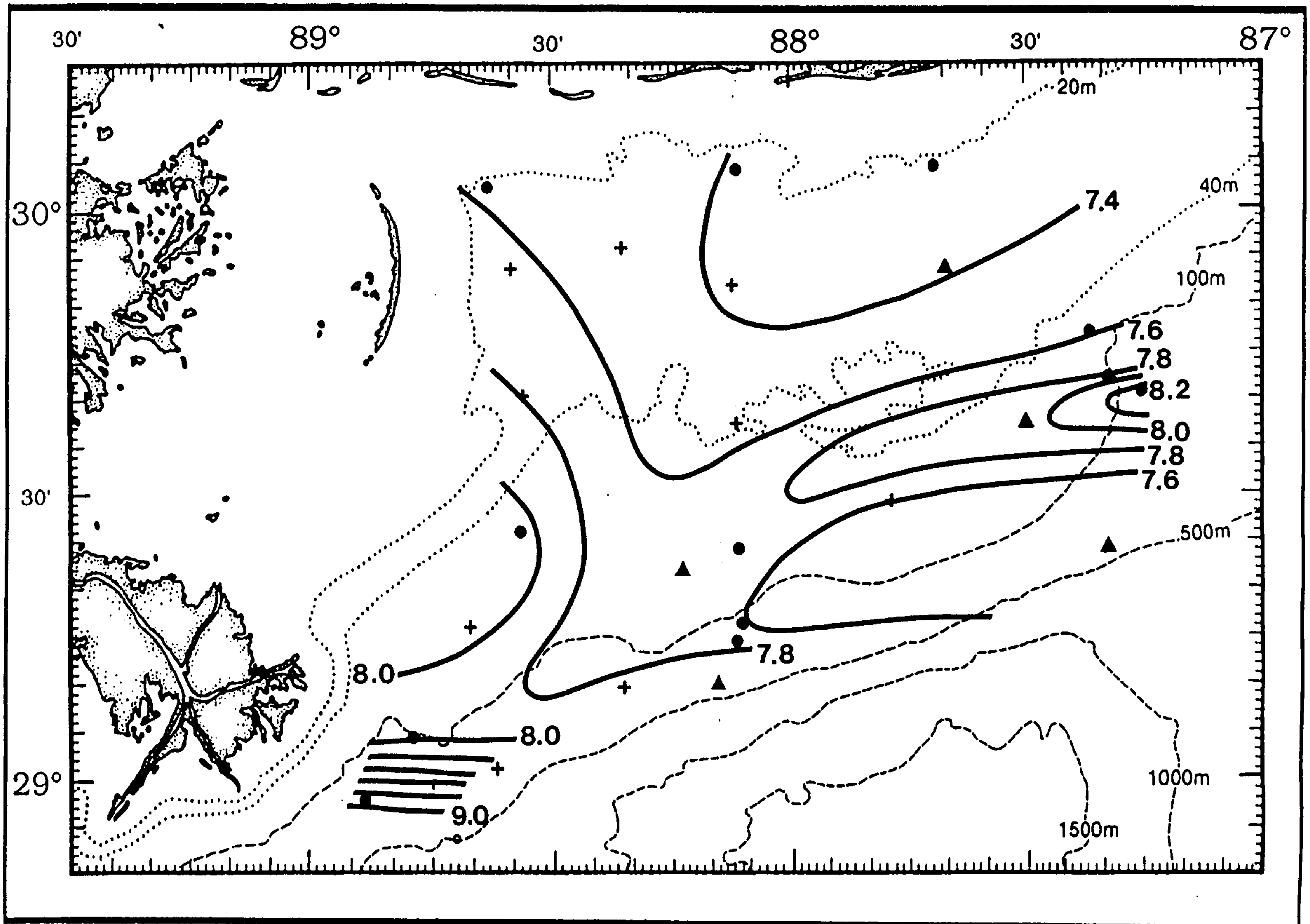


Figure 10-14. Cruise 3 (August 1988) distribution of near-surface dissolved oxygen (mg/l).

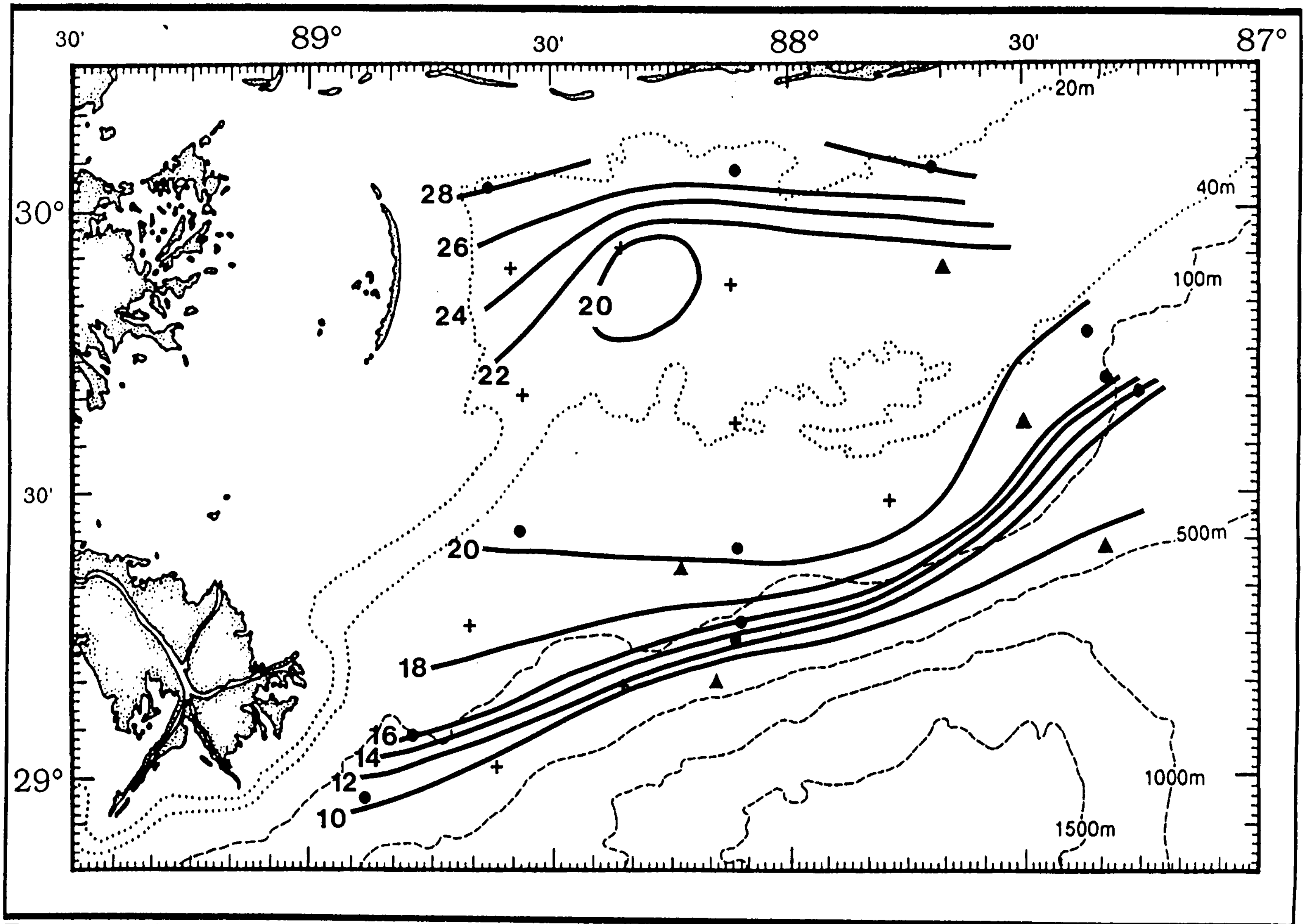


Figure 10-15. Cruise 3 (August 1988) distribution of near bottom temperature (°C).

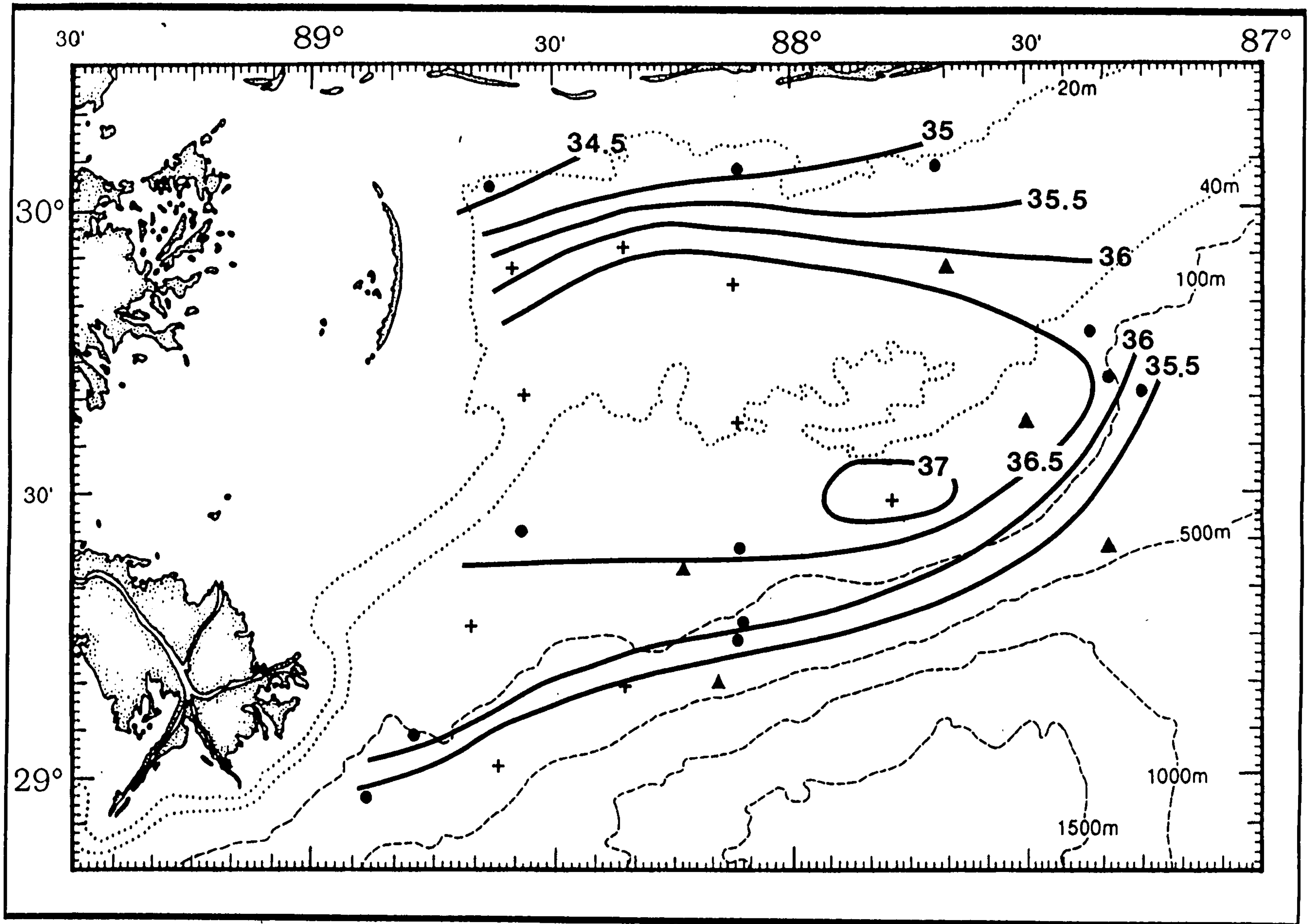


Figure 10-16. Cruise 3 (August 1988) distribution of near-bottom salinity (‰).

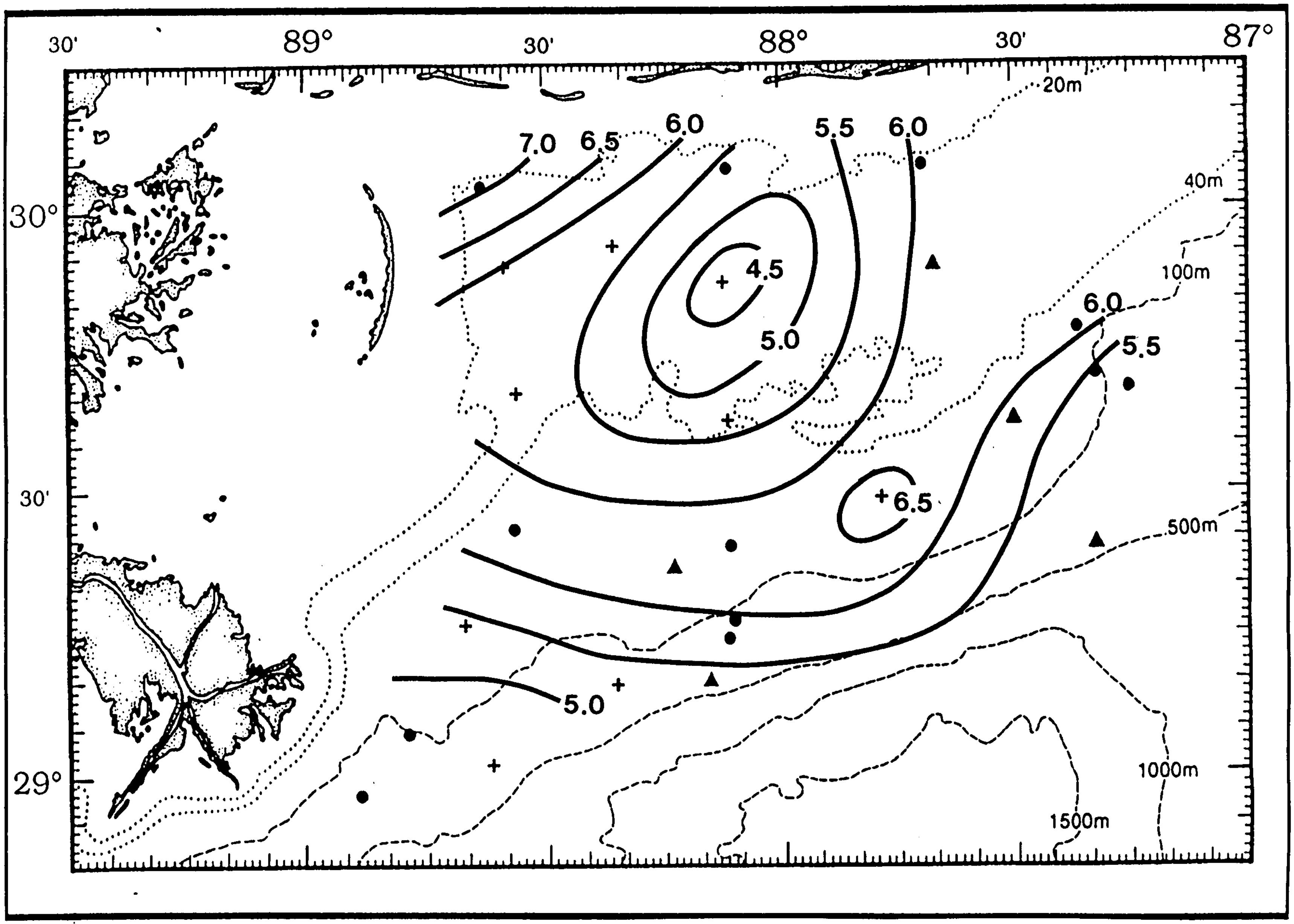


Figure 10-17. Cruise 3 (August 1988) distribution of near-bottom dissolved oxygen (mg/l).

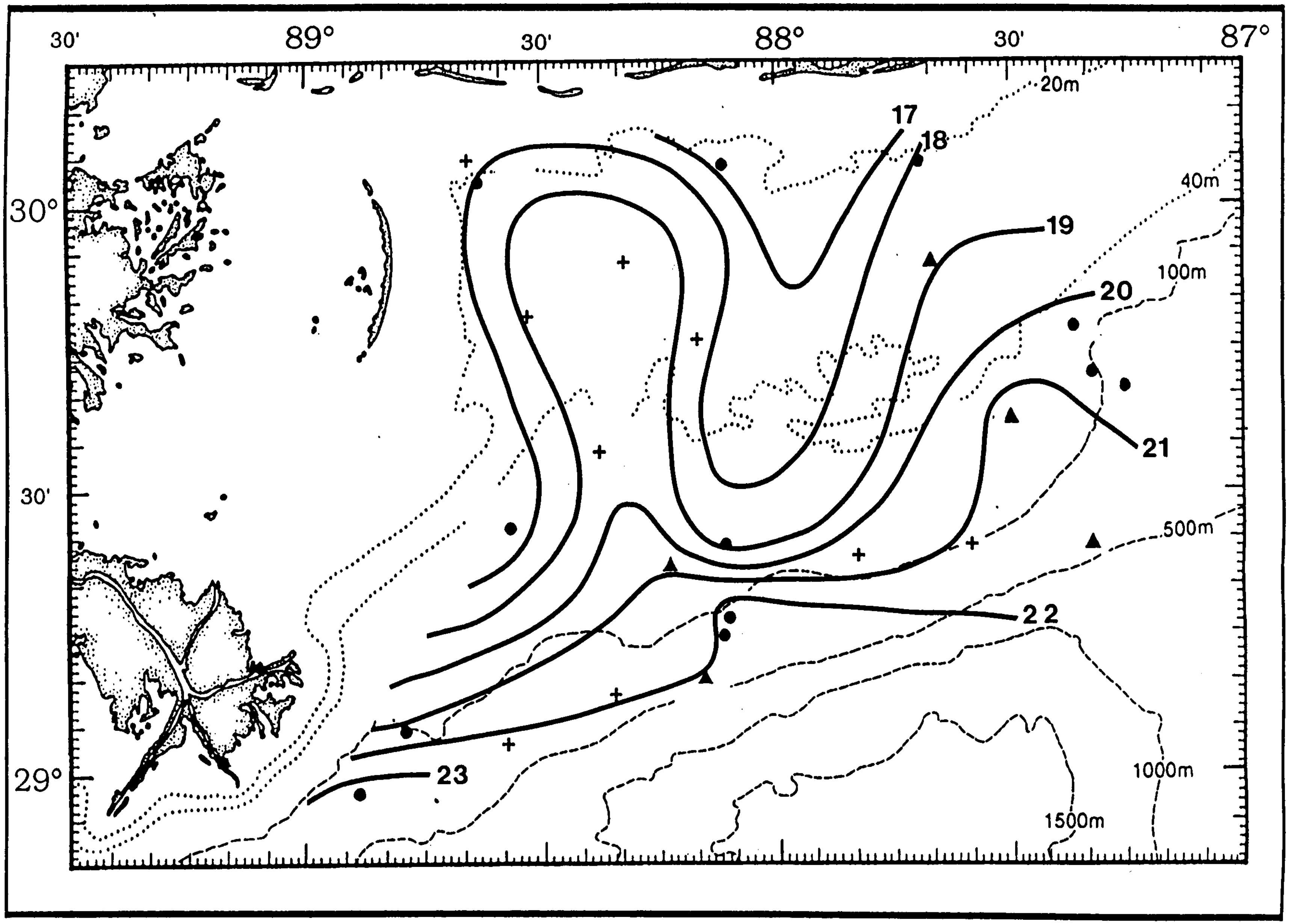


Figure 10-18. Cruise 4 (February 1989) distribution of near-surface temperature (°C).

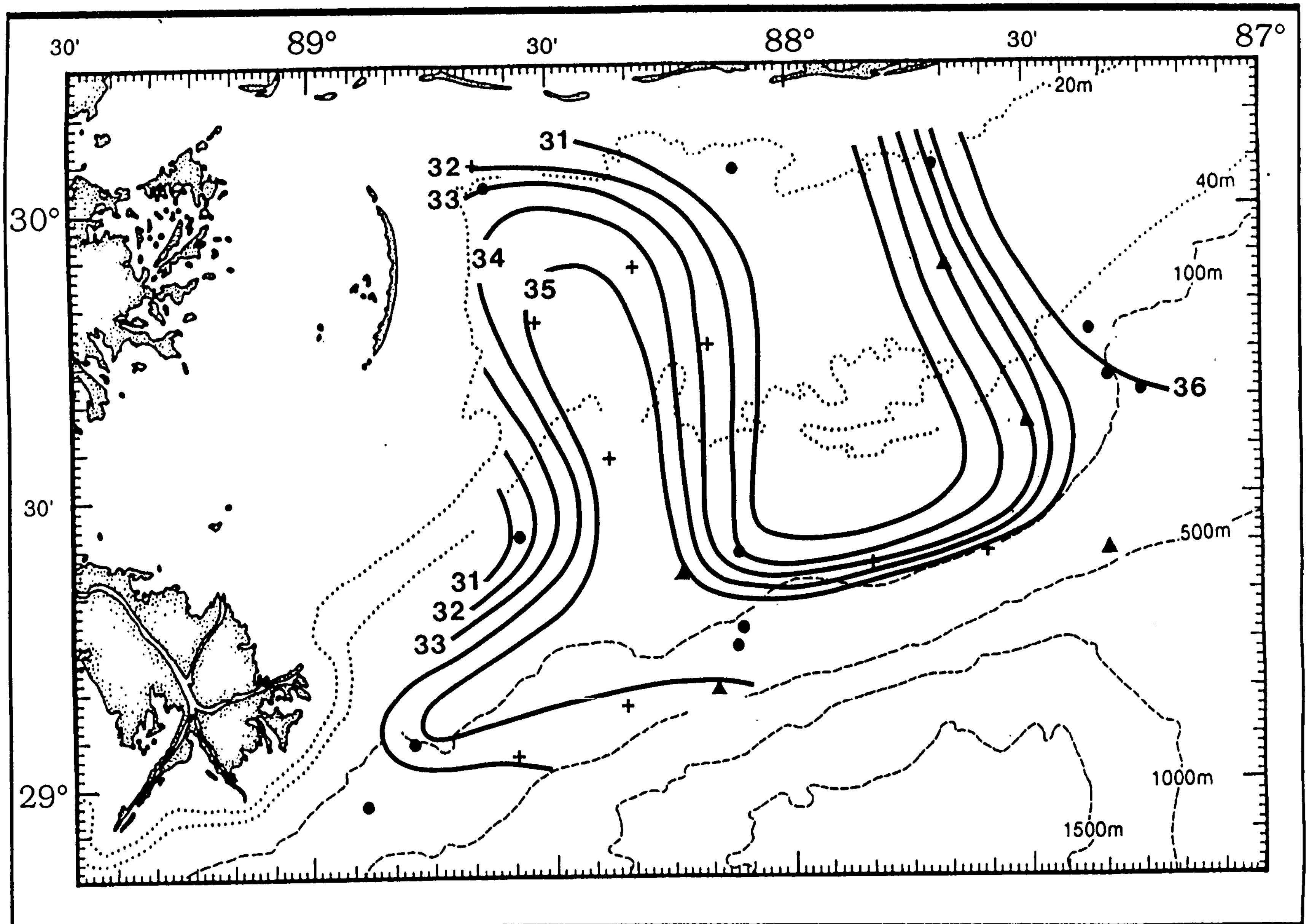


Figure 10-19. Cruise 4 (February 1989) distribution of near-surface salinity (‰).

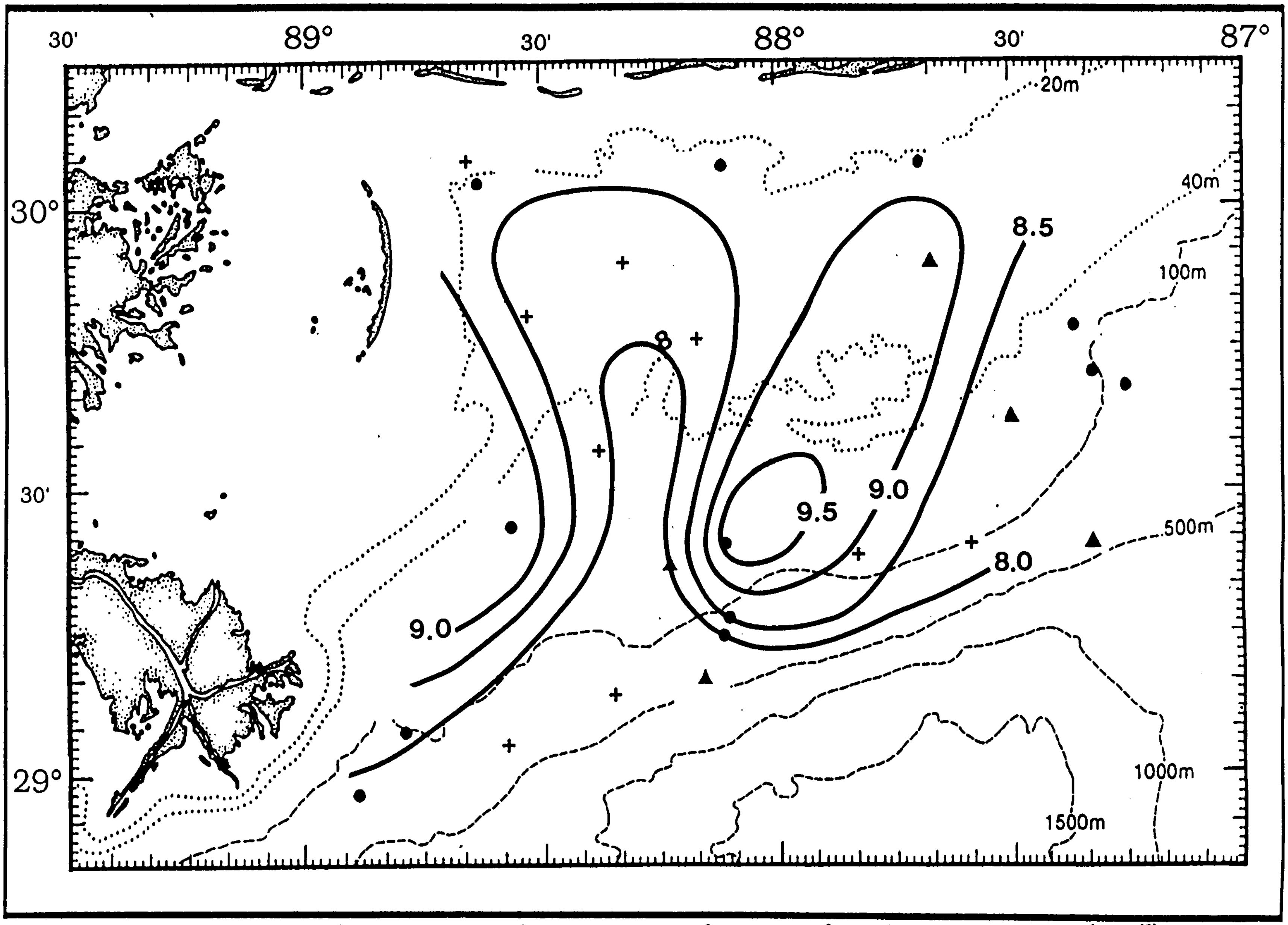


Figure 10-20. Cruise 4 (February 1989) distribution of near-surface dissolved oxygen (mg/l).

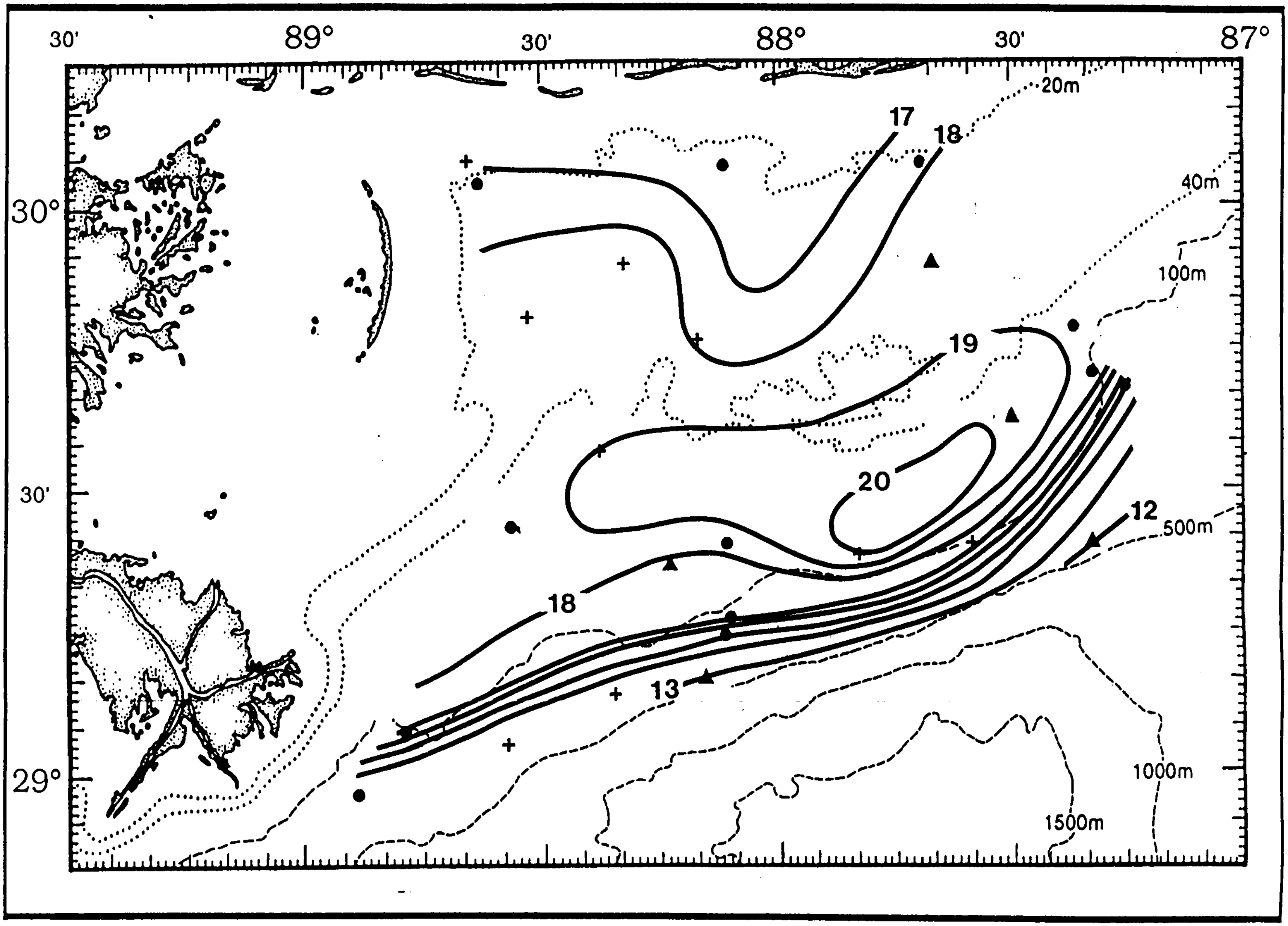


Figure 10-21. Cruise 4 (February 1989) distribution of near-bottom temperature (°C).

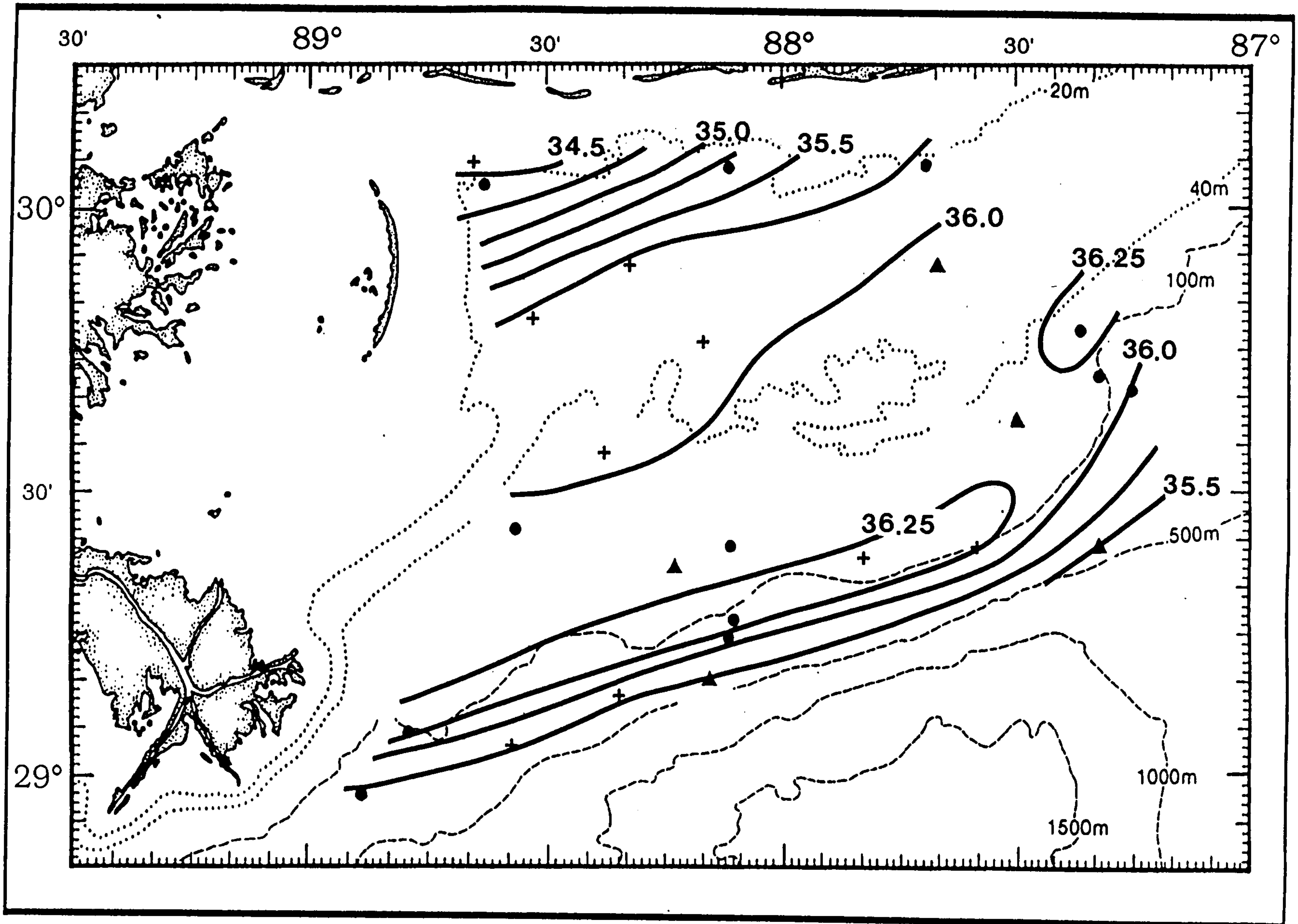


Figure 10-22. Cruise 4 (February 1989) distribution of near-bottom salinity (‰).

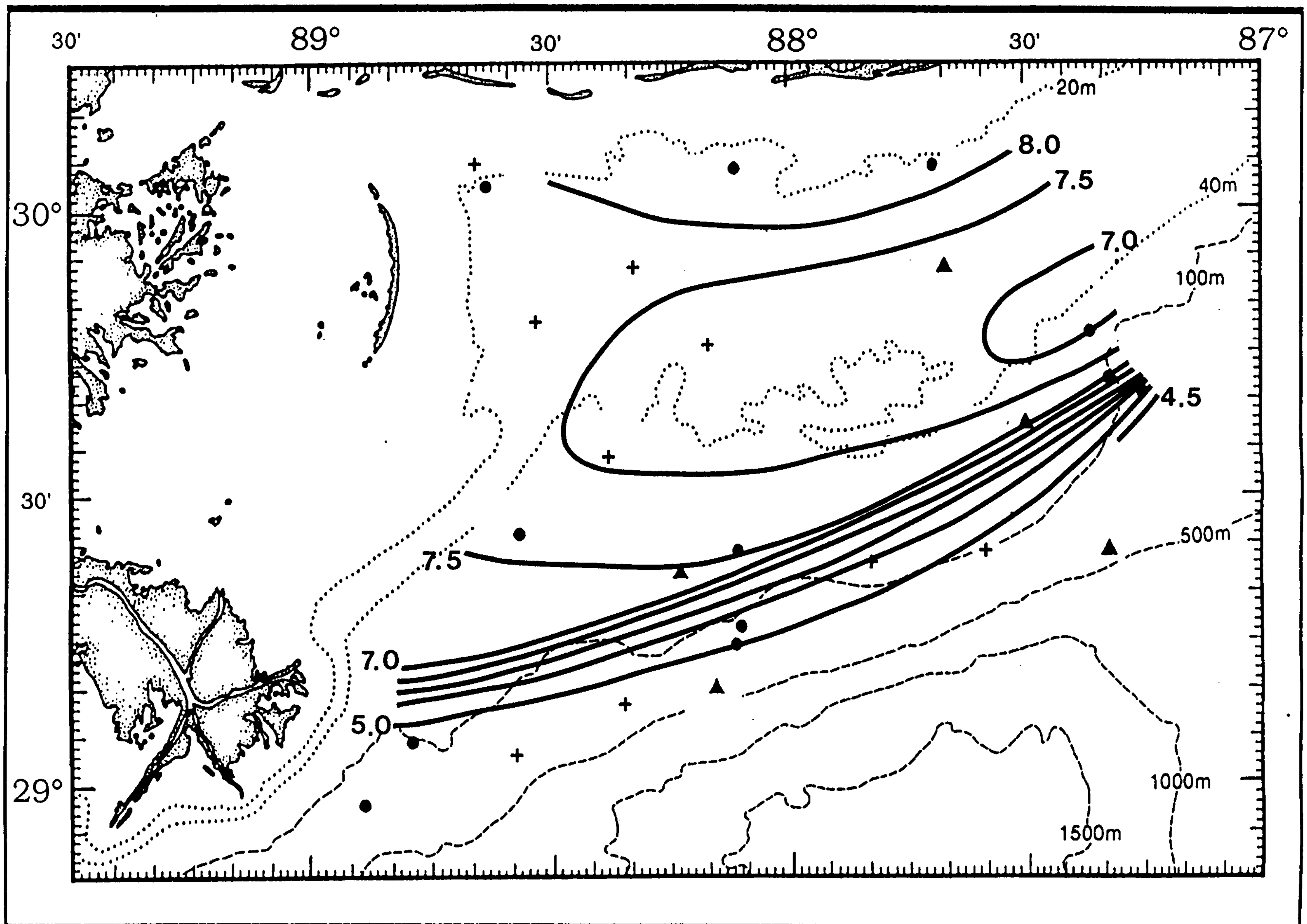


Figure 10-23. Cruise 4 (February 1989) distribution of near-bottom dissolved oxygen.

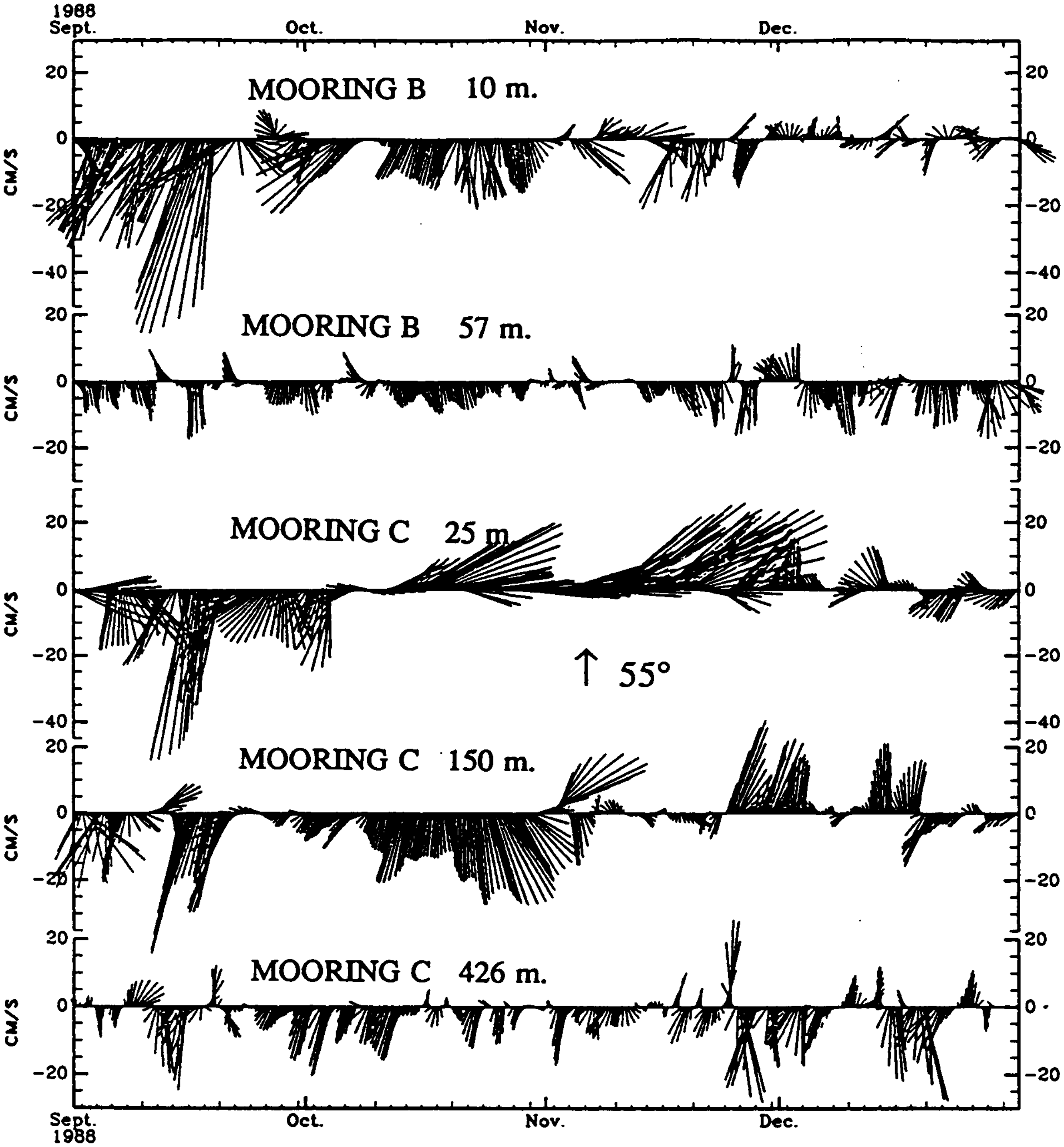


Figure 10-24. Forty-hour, low-pass-filtered stick vectors of current velocity at Moorings B and C during the period September through December 1988. Vertically up is towards 55° True, horizontally to the right is towards 145° True. The water depth is 60 m at Mooring B and 430 m at Mooring C.

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 utilizing NOAA platform, Advanced Very High Resolution Radiometer (AVHRR) remote sensings. 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 Second Year Summary

During the second year, the NOAA-09, 10, and 11 satellites were used to gather additional infrared sensing of upwelling sea surface radiance in the channel four or eleven micrometer band. Sixty-three pertinent scenes were selected between 26 September 1988 and 07 May 1989. Table 11-1 lists each of these scenes in terms of satellite, date, and time.

Each satellite scene is processed to extract a sea surface temperature image, and each is mapped to a Mercator projection. The images cover a region of 8° latitude and 10° longitude.

Table 11-1. Satellite Imagery: 1988-1989

SATELLITE #	DATE	TIME (GMT)	SATELLITE #	DATE	TIME (GMT)
09	Sep 26	11:04	10	Mar 11	01:35
09	Sep 27	22:18	11	Mar 11	18:31
10	Oct 22	13:37	11	Mar 12	06:53
10	Oct 23	00:57	11	Mar 12	18:21
09	Nov 05	21:54	11	Mar 15	17:49
09	Nov 06	21:44	11	Mar 16	19:21
09	Nov 07	21:33	11	Mar 17	19:10
11	Nov 08	10:10	11	Mar 19	07:25
10	Nov 09	01:25	11	Mar 19	18:51
10	Nov 10	01:03	11	Mar 28	07:35
10	Dec 02	01:22	10	Mar 29	01:35
10	Dec 03	01:00	11	Mar 30	18:39
11	Dec 17	07:55	10	Mar 31	00:52
11	Dec 18	07:49	10	Mar 31	01:34
10	Dec 19	01:48	10	Mar 31	13:52
11	Dec 19	07:39	11	Mar 31	18:29
11	Dec 25	19:44	10	Apr 01	00:31
11	Dec 26	19:34	11	Apr 02	08:24
11	Dec 27	19:24	10	Apr 03	14:27
10	Jan 04	00:59	10	Apr 04	01:47
11	Jan 17	07:50	09	Apr 04	09:50
11	Jan 17	19:15	10	Apr 06	00:21
11	Jan 18	07:40	10	Apr 06	12:38
10	Jan 25	01:37	11	Apr 07	07:33
10	Jan 31	13:20	11	Apr 08	07:22
10	Feb 09	13:18	11	Apr 09	07:11
11	Feb 15	07:56	11	Apr 21	08:21
11	Feb 16	19:02	11	Apr 25	07:40
10	Feb 17	01:20	11	Apr 26	07:30
10	Feb 17	13:47	10	May 02	00:23
11	Mar 05	08:07	10	May 06	00:34
11	Mar 09	18:51			

11.3 Images and Analyses

The coastal zone and continental shelf regimes in the MMS study region contain pervasive, episodic mesoscale and submesoscale turbulence. These features are related to riverine and atmospheric forcing as well as intrusions from adjacent slope and oceanic regimes. The satellite research effort is focused on monitoring intrusions and the Loop Current. The two-year image sequence gathered for this objective also provides an opportunity to analyze changes in sea surface temperature patterns and extract advective estimates of sea surface flow. The following discussion includes results produced in initial case studies integrating current meter and hydrographic observations with satellite flow and sea surface temperature distributions.

Satellite images and image sequences have been used in the past to provide descriptions of surface environmental evolution that are primarily qualitative. Recently developed analytical methods use sequential Advanced Very High Resolution Radiometer (AVHRR) images to estimate flow vector fields, derive streamfunction representations in curvilinear boundary coordinates, initialize time-dependent submesoscale resolution circulation models, and predict flow field dynamic evolution.

The physical justification for using sea surface temperature pattern displacements and the subsequent streamfunction treatment assumes that motion can be taken as planar over intervals of approximately one day and that the tracking is done with a conservative scalar quantity. The patterns are then considered to be composed of relatively slowly evolving, smooth sea surface distributions with superimposed deviations generated by small scale turbulent processes. Pattern changes shown by these submesoscale temperature perturbations are interpreted as revealing advective representations of the mesoscale flow regime. These tracked features are selected from those small in relation to the baroclinic radius of deformation. The resulting advective estimates are assumed to be greater than co-existing Rossby or internal wave speeds as well as greater than speeds generated by diffusion, heat exchange or vertical motion over the time interval between sequential image pairs. A mathematical description of these assumptions and the associated limitations on interpretations are given by Vastano and Reid (1985).

Satellite images and current meter observations during late January of the first year of data collection have been used to show the potential for joint analyses. Clear sky conditions over the study area on January 28 and 29, 1988 resulted in the collection of a sequential pair of AVHRR scenes separated by 23.9 hours. Figures 11-1 and 11-2 are distinct realizations of the channel 4, 11 micrometer infrared image for January 28, processed as a Mercator projection of a single channel, brightness temperature version. The northeastern Gulf of Mexico sea surface temperature distribution is shown in Figure 11-1 with a continually varying gray scale palette that utilizes black as the warmest and white as the coldest temperatures corresponding to detected upwelling radiance values for the image. Figure 11-2 is the same image rendered with a palette pattern that contains eight repeats of eight grey scale bands. This latter image is used to reveal the temperature structure of the sea surface. Figures 11-3 and 11-4 are enlargements of Figures 11-1 and 11-2, respectively. The entire project satellite data base has been rendered in this four-picture-per-satellite-scene basis. The physical situation as portrayed by the surface temperatures indicates a generally southwest-to-northeast distribution of warmer waters adjacent to the shelf break. These waters are the northernmost extension of a meander that has reached northward from the Loop Current. The Loop Current is marked by a distinct broken cloud regime in Figure 11-1 and a corresponding fractal pattern in Figure 11-2. The shelf waters south of Mobile Bay are dominated by a cold water jet extending south-southwestward to the edge of the shelf where it develops into paired vortices. Immediately to the east of the jet, an older, cold water plume extends southward from the shelf and terminates in a cyclonically rotating eddy feature over the foot of the continental slope. Further to the east, cold coastal waters reach seaward from the vicinity of Cape San Blas.

Figure 11-5 shows the results of interactively generating advective surface flow vector estimates with the images of January 28 and 29. The MMS project current meter array is portrayed by single labeled dots at their positions and the shelf break at a depth of 200 m is represented by a dashed line. There is a strong organized flow regime associated with the Loop Current intrusion sweeping past the Mississippi Delta and along the shelf break. This flow limits the seaward extension of the jet and is shearing the

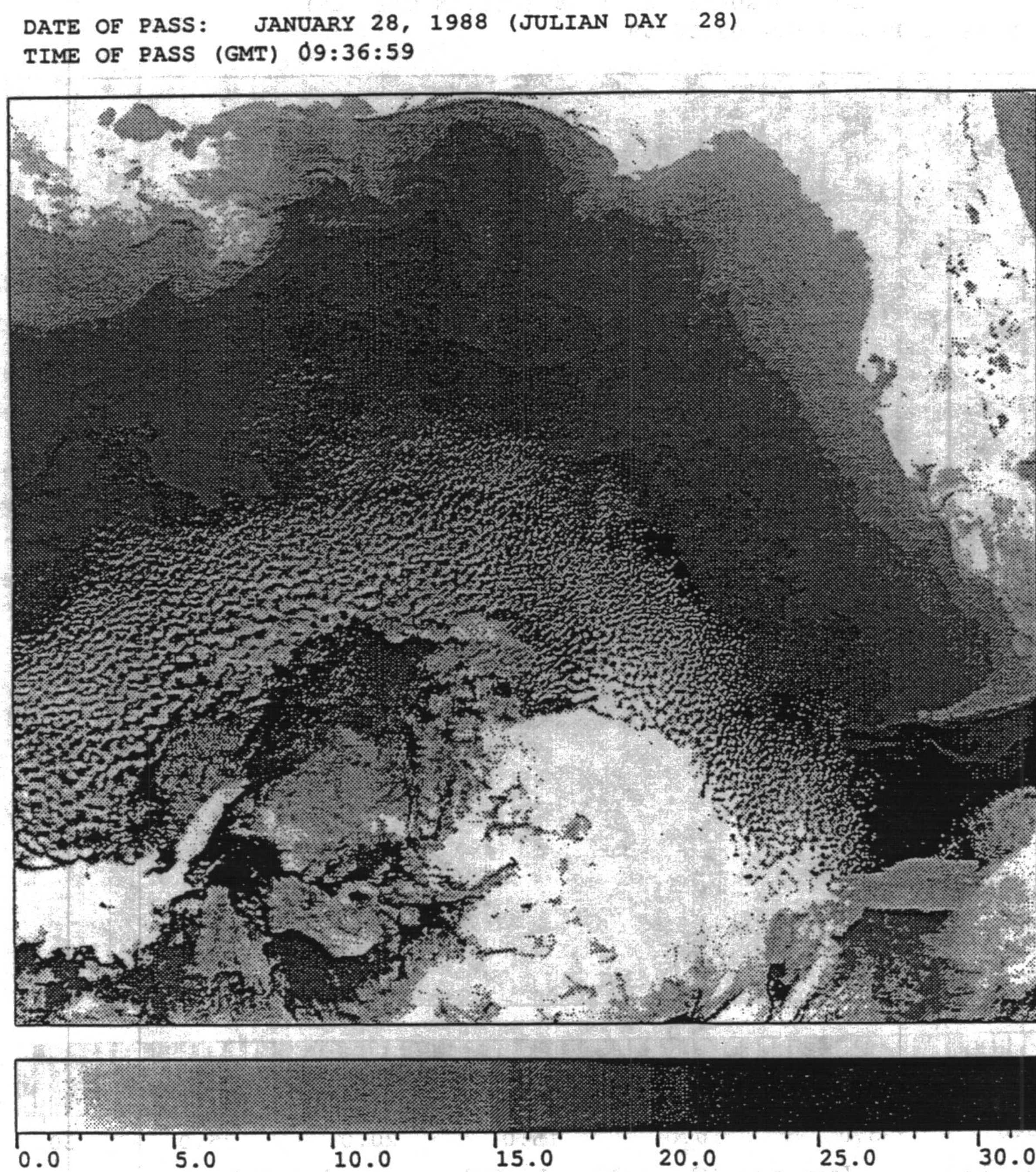


Figure 11-1. January 28, 1988, AVHRR, channel 4 (11 micrometer), sea surface temperature image enhanced for temperature distribution with white as coldest and black as warmest values.

DATE OF PASS: JANUARY 28, 1988 (JULIAN DAY 28)
TIME OF PASS (GMT) 09:36:59

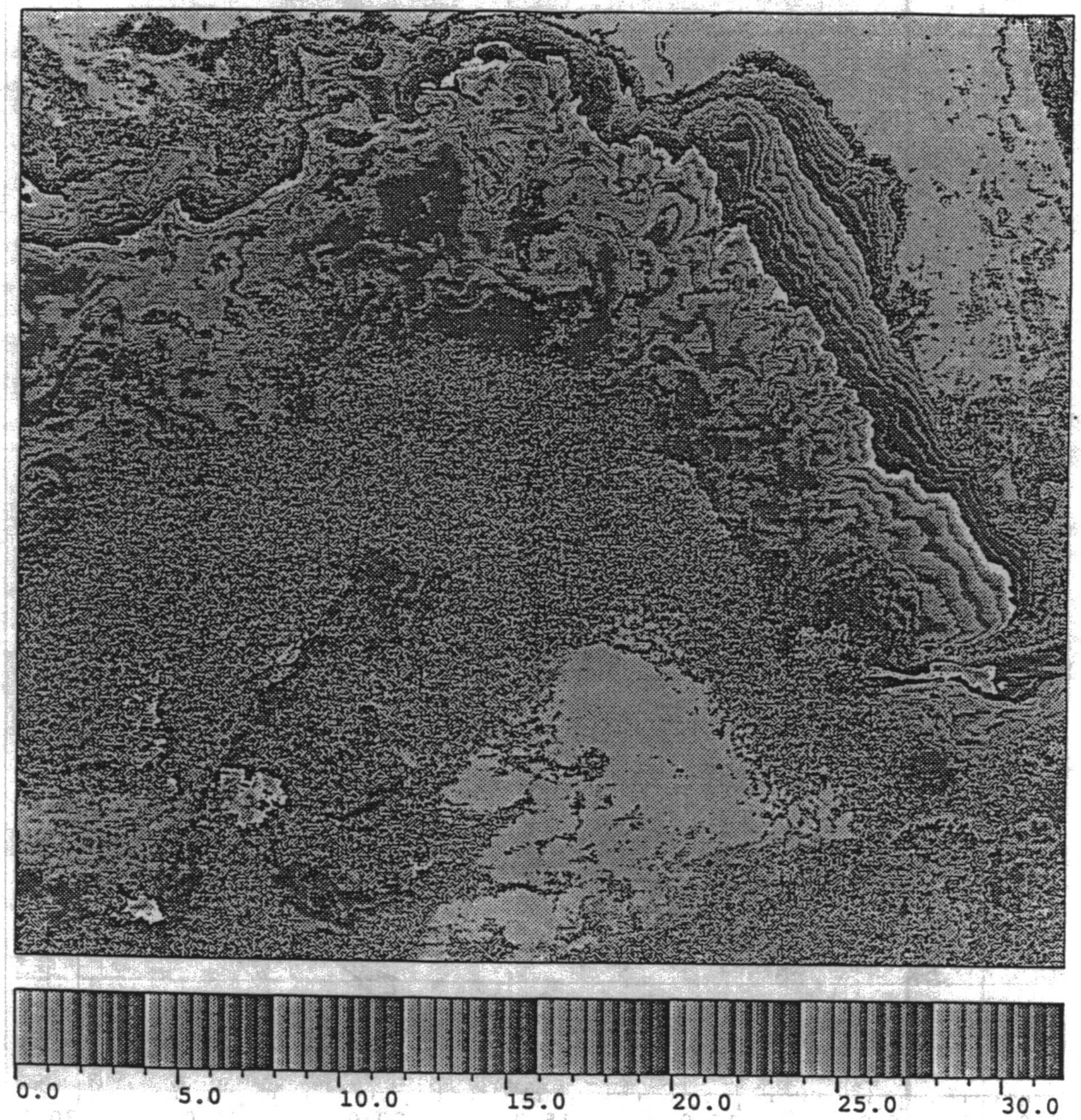


Figure 11-2. January 28, 1988, AVHRR, channel 4 (11 micrometer) sea surface temperature image enhanced for resolution of temperature features by a banded palette.

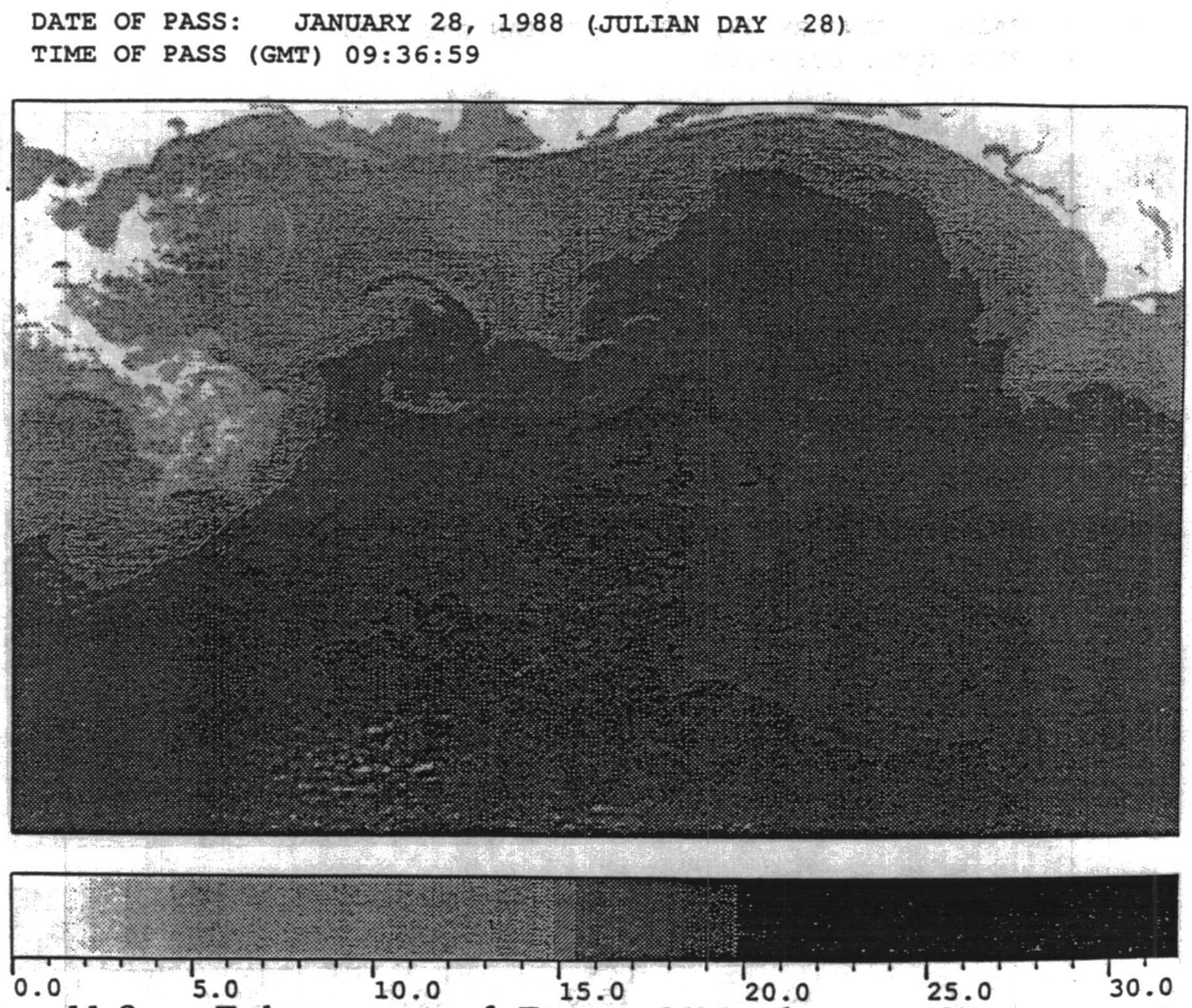


Figure 11-3. Enlargement of Figure 11-1 showing the sea surface temperature distribution in the MMS study region.

DATE OF PASS: JANUARY 28, 1988 (JULIAN DAY 28)
TIME OF PASS (GMT) 09:36:59

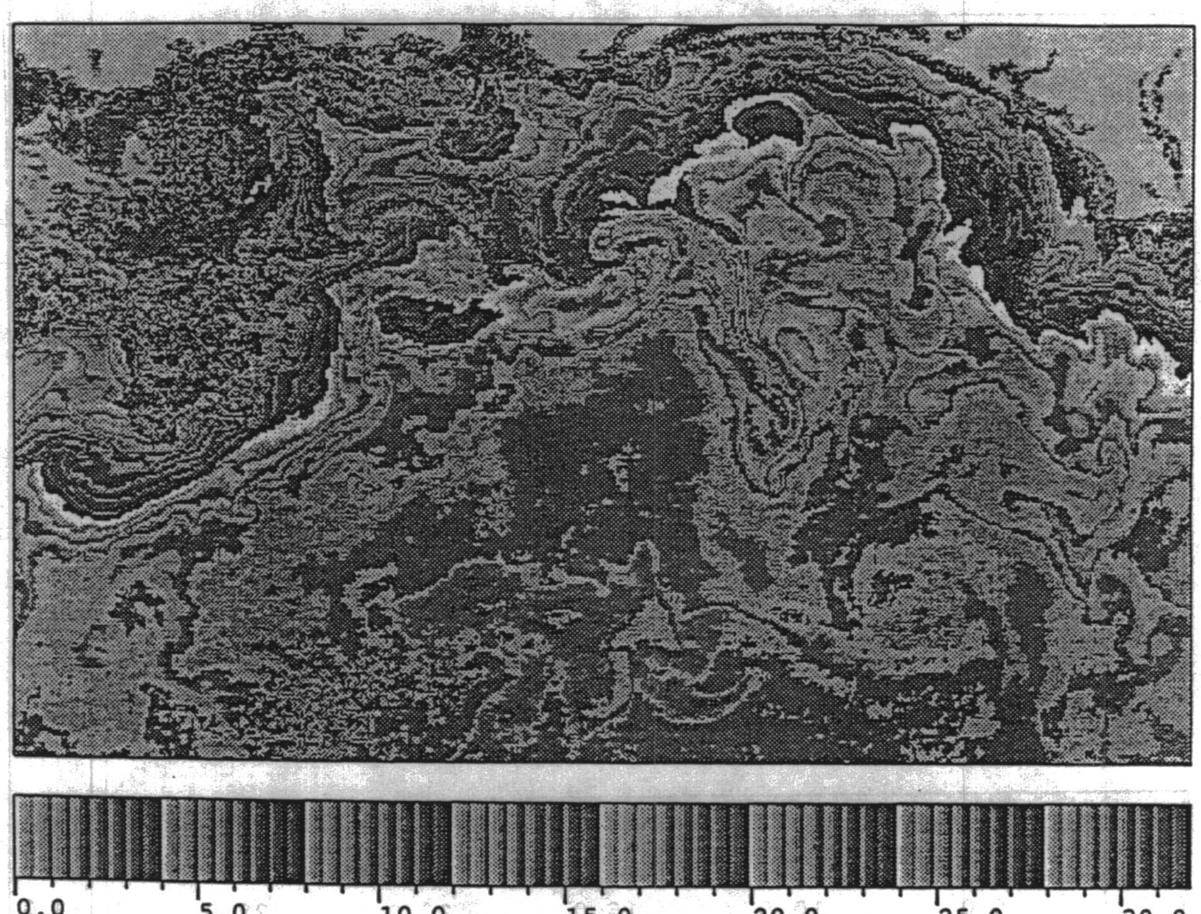


Figure 11-4. Enlargement of Figure 11-2 showing the sea surface temperature structure in the MMS study region.

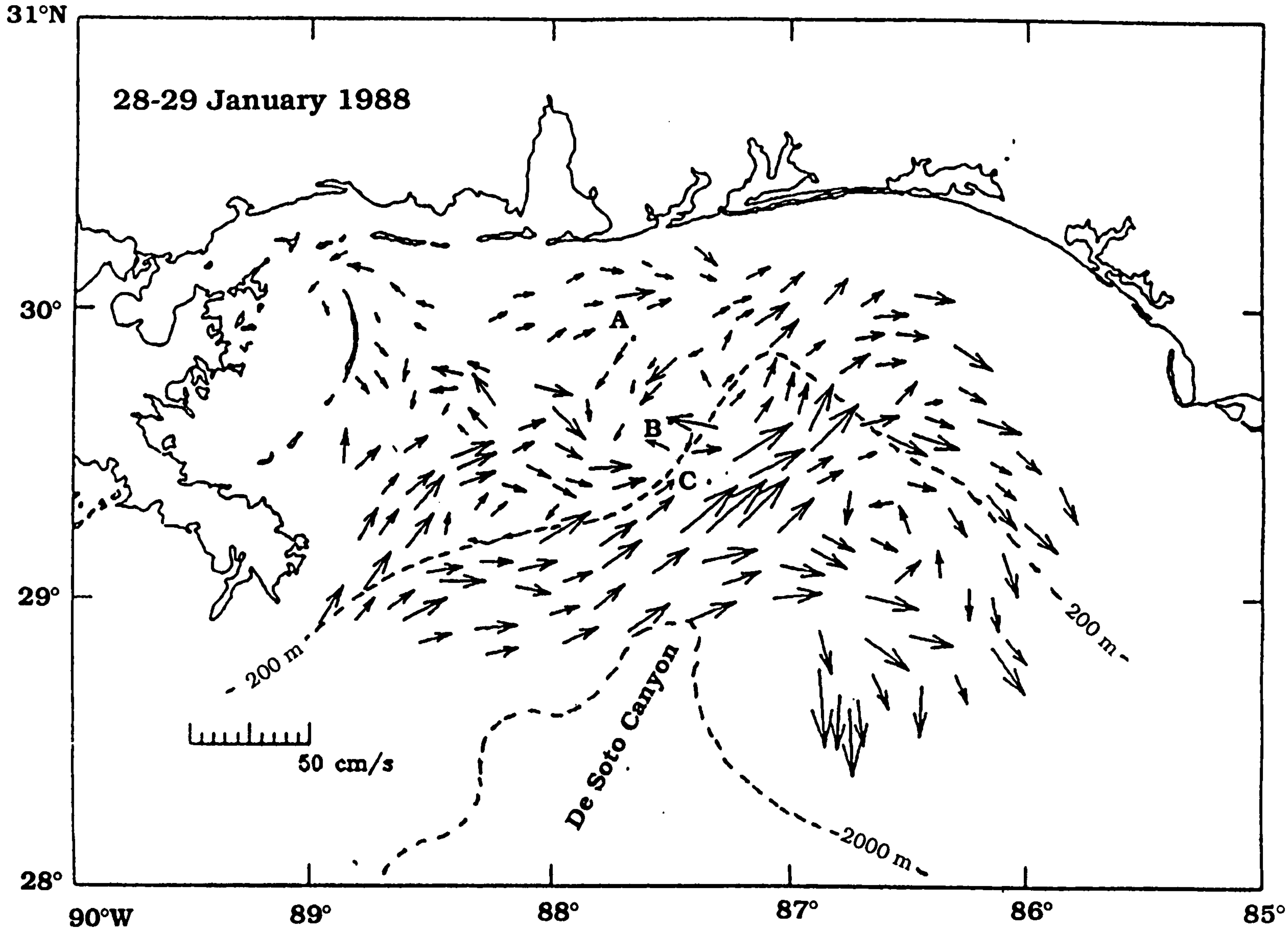


Figure 11-5. Advective surface flow vector estimates and current meter locations.

paired vortices to the northeast. Current meter site A is in the far northeastern portion of the jet stem, while Site B is at the position of the easternmost vortex. The deeper water current meter, C, is at the shelfwise edge of the Loop Current Intrusion, near the head of De Soto Canyon. The Loop Current Intrusion has displaced a small eddy feature from the location of the Canyon head to the position 29.2° N,86.7°W and is severing the surface portion of cold water flow moving southward into the cyclonic eddy over the continental slope.

The following table presents a comparison of the satellite-derived flow estimates with current meter flow estimates at Sites A, B, and C. The satellite estimates are quasi-synoptic and hold for a 23.9 hour interval while the current meter values are taken from a forty-hour, low-pass-filtered version of each record at the midpoint time between the satellite images. The current meter accuracies are [± 1 cm/s ; ± 5°T] in speed and azimuth, respectively (personal communication, Kelly). The inherent discrepancy in speed values for satellite estimates is related to the pixel size (1.1 x 1.1 km) and the time between images. In the present case, this uncertainty is [± 1.8 cm/s]. The azimuthal counterpart can be estimated by examining speed components and is indicated beside the direction in Table 11-2.

Table 11-2 Surface Flow Estimates for 28-29 January 1988

	Current Meter			Satellite	
Location	Depth (m)	Speed (cm/s)	Direction (°T)	Speed (cm/s)	Direction (°T)
A	10	3.1	149	5.1	145 ±12
B	10	26.1	282	22.6	280 ±4
C	150	14.7	055	21.6	063 ±9

The values for speed and direction at Sites A and B are, taking observational uncertainties into account, nearly indistinguishable. The values at Site C appear to be consistent in terms of the current meter position within the frontal regime's warm water flow.

The sea surface temperature distributions observed by satellite imagery confirm the interpretation of the data obtained during Cruise 2 (Brooks and Giammona, 1989) and Cruise 4 (see Section 10.3.5). The hydrographic data suggest that, during each of the two cruises, warm filaments from the Loop Current were pushing onto the shelf and that colder shelf water was flowing offshore to conserve mass. Figures 11-6 and 11-7 show satellite images for these two cases. The entire suite of satellite images is being examined to determine the frequency of this phenomenon.

DATE OF PASS: MARCH 11, 1988 (JULIAN DAY 71)
TIME OF PASS (GMT) 01:10:22

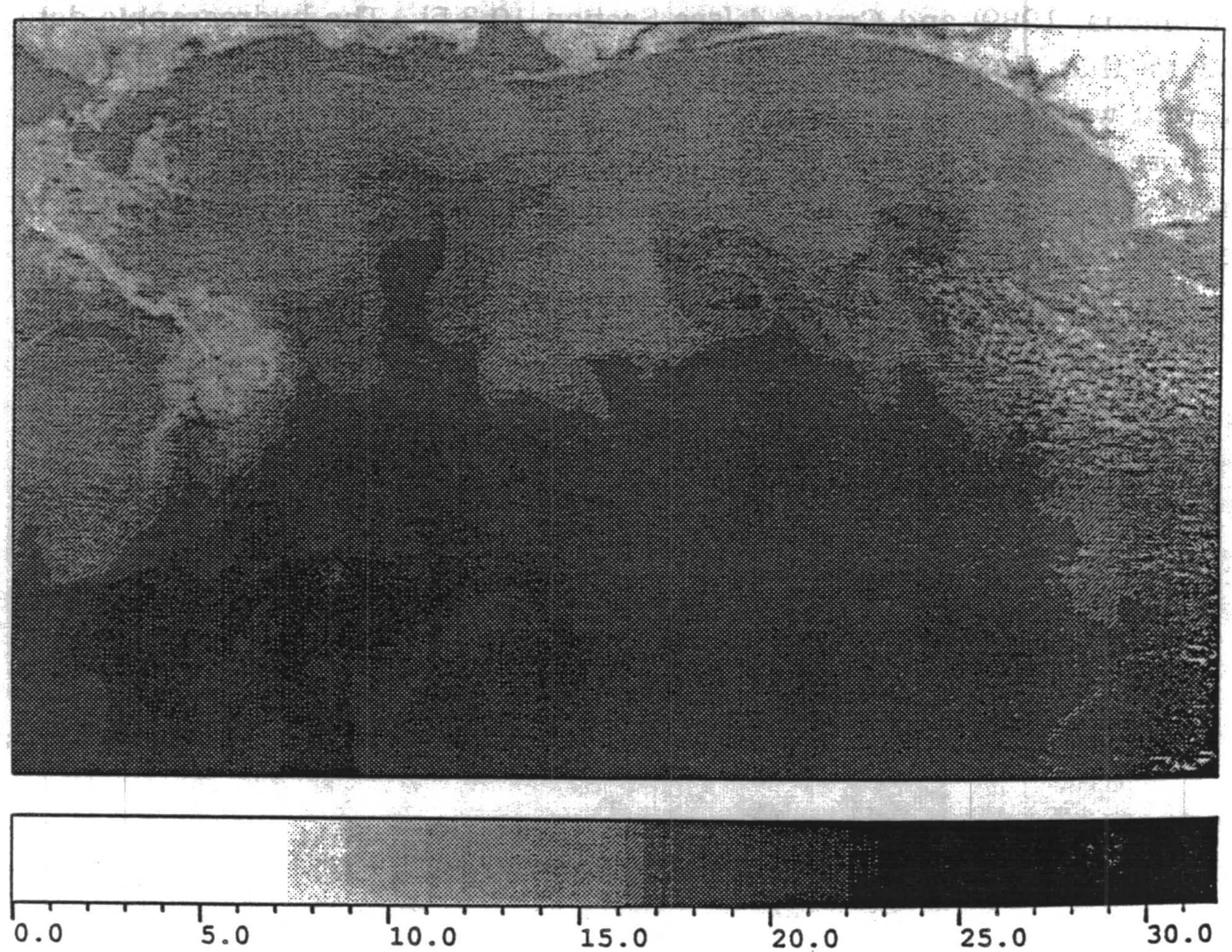


Figure 11-6. March 11, 1988, AVHRR, channel 4 (11 micrometer), sea surface temperature image enhanced for temperature distribution with white as coldest and black as warmest values. Shows the Loop Current filament penetrating onto the Mississippi-Alabama shelf.

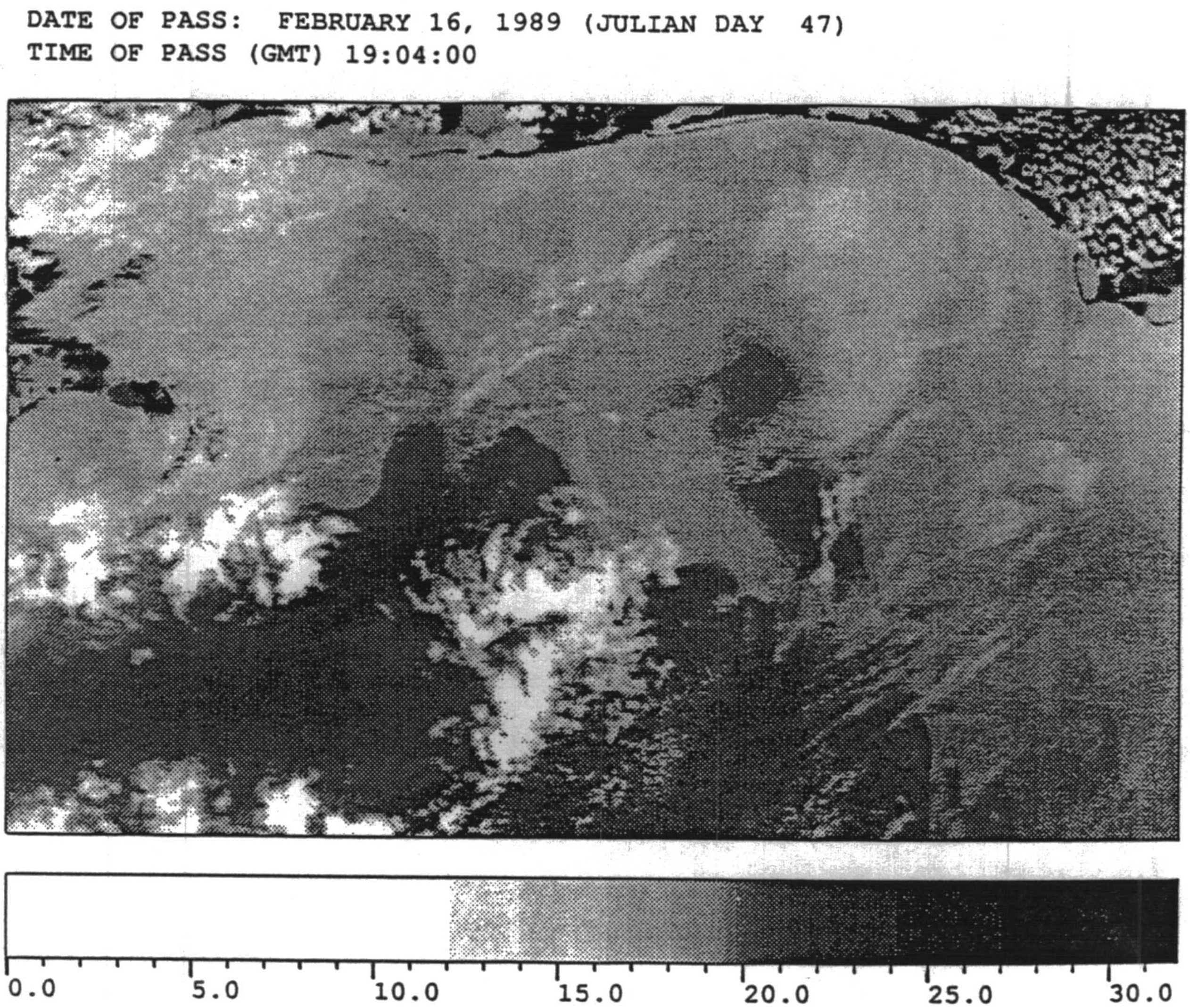


Figure 11-7. February 16, 1989, AVHRR, channel 4 (11 micrometer) sea surface temperature image enhanced for temperature distribution with white as coldest and black as warmest values. Shows the Loop Current filament penetrating onto the Mississippi-Alabama shelf.

12.0 GEOLOGICAL CHARACTERIZATION

W. W. Sager, W. W. Schroeder, J. S. Laswell, and R. Rezak

12.1 Introduction

The middle and outer continental shelf off Mississippi and Alabama, between the Mississippi River mouth and DeSoto Canyon, has previously received little attention from marine geologists. There has been only one previous attempt at a comprehensive synthesis of the geology of the outer shelf region (Ludwick and Walton 1957). Other studies have either focused on the inner shelf, omitted discussions of topographic features and hard bottoms, or examined only small, selective areas of the outer shelf (Moore and Bullis 1960; Ludwick 1964; Upshaw et al. 1966; Shipp and Hopkins 1978; Doyle and Sparks 1980; Kindinger 1988; Schroeder et al. 1988a; 1988b). Additionally, a few commercial reports of geologic studies of small areas (usually one lease block) exist.

Ludwick and Walton (1957) found that topographic features, which they called "pinnacles", were found in clusters along the outer Mississippi-Alabama shelf. They noted that these were not like those commonly found farther west in the Gulf of Mexico. In the northwest Gulf, topographic highs generally tend to be the result of uplift caused by salt, or occasionally shale, diapirs (Rezak et al. 1985). However, on the Mississippi-Alabama outer shelf, topographic features are apparently calcareous reef structures built during the Holocene rise in sea level. They also surmised that these reefs were not actively growing, but were instead in an intermediate stage between active growth and fossilization.

Our study has verified many of these conclusions, but more importantly, it has shown that there exists a far greater diversity and distribution of topographic features than envisioned by Ludwick and Walton (Schroeder et al. 1989). The topographic features range from less than two meters to greater than 20 m in height. Most are patch reefs which are more-or-less equidimensional in plan view and occur singly or in clusters often along preferred isobaths. However, there are also numerous linear ridges and scarps, up to eight meters in height, which are probably constructed of indurated sand, shell, and gravel. Additionally, most topographic features are associated with hardbottoms, which are areas of indurated seafloor sediments.

During the first year of geophysical surveying, approximately 1166 nautical miles of side-scan sonar and subbottom profile data were collected. All of this data was collected in a reconnaissance mode with the side-scan sonar imaging a wide swath of seafloor (half-width either 300 or 400 m). The second year surveys were of two types (see Section 3.1), reconnaissance surveys similar to those of the Year 1 effort and detailed surveys of features observed during the Year 1 cruises. The latter used the side-scan sonar in a narrow swath mode (half-width 100 or 200 m) with closely spaced ship tracks.

The reconaissance surveys extended east and west from the area surveyed during Year 1 and were positioned to follow the 40 fathom (73.2 m) isobath (see Figure 3-1) which was found to be the locus of numerous topographic features in the previous survey. Approximately 335 nautical miles of geophysical data were collected in the reconaissance mode along 20 lines to the west of the Year 1 survey area and 3 lines to the east (see Figures 3-2 and 3-3). About 19 nautical miles of detailed side-scan sonograms were obtained from four areas (see Figure 3-1). In the northwest portion of the Year 1 survey area, detailed studies were done on a cluster of large flat-topped reefs and on a section of the linear ridges following the 60 meter isobath. Detailed images were also obtained of the patch reef field (previously called "boulder field") in the center of the Year 1 area and of some large reefs along the 40 fathom trend in the southeast portion of the Year 1 area.

Two types of maps were initially planned to be produced from the geophysical data, bathymetry maps and composite mosaics of sonograms recorded by the side-scan sonar. However, a third type of map, reflection character, is also being constructed.

12.2 Methods

12.2.1 Bathymetry

Bathymetry and subbottom profile data were gathered with either of two systems, an EDO-Western 4 kHz or Raytheon CESP 3.5 kHz echo sounder. Raw reflection data were recorded on an analog electrostatic plotter. Event marks were used to record the locations of navigational fixes (shotpoints) and allow correlation of bathymetry with side-scan and navigational data. Bathymetry measurements were made by digitizing the seafloor echo on the analog reflection records. The following process was used. The horizontal distance (in inches) of each shotpoint on the record was determined with the digitizer. Similarly, the horizontal and vertical distances (also in inches) of selected seafloor points on the record were also digitized. Comparison of the horizontal distance of each bathymetric point with the shotpoint list allowed its location to be expressed in shotpoint coordinates using linear interpolation. The seafloor depth was determined by computing the two-way-travel-time of the seafloor echo and using 1500 meters/second as the speed of sound in water. A correction for the depth of the transducer below the sea surface was applied. Finally, the bathymetric points were placed into geographic coordinates by merging the navigation, consisting of latitude, longitude pairs corresponding to shotpoints, with the shotpoint-depth lists.

A rough analysis of the digitizing process suggests that it contributes less than about three meters error in the horizontal position of each depth value. This is less than the five to seven meter accuracy of the navigation. In the determination of depth values, the digitizer should contribute an error of only about one centimeter. The major contributors to the uncertainty the of bathymetric values are probably the variation in the depth of the transducer caused by changes in ship speed and wave action. It is estimated that these factors result in an average uncertainty of 0.5-1.0 m, depending on the sea state during the survey.

Bathymetric values for all geophysical cruises have been digitized, corrected, and merged with navigation; however, only the Year 1 bathymetric data has been contoured. Ten meter contours have been drawn for the Year 1 survey area and combined with the side-scan mosaics. Initially, a series of two meter contour maps was planned; however, it is felt that these would be impractical. This is because of the morphology of the shelf which consists of large expanses of virtually flat seafloor separating topographic features of limited lateral extent. Few of these features are crossed by more than one ship track, so it is difficult to draw bathymetric contours for them with accuracy. Nevertheless, the possibility of using a slightly coarser contour interval, five meters for example, is being examined.

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 analog and digital forms. The digital data were recorded on nine-track tapes aboard ship with a PERTEC tape drive. The digital data allow us to replay selected sections of the data at different gain settings, if needed. The sonar data were also recorded using a 10 inch electrostatic plotter. These analog records need to be photographed and reduced in size for use in making sonogram mosaics. The Year 1 records were photographed onto 35 millimeter microfilm with a flow-camera at the U. S. Geological Survey in Menlo Park, California. From the microfilm, three inch prints were made for mosaic construction. The Year 2 records have not yet been photographed, as it was decided to delay this until after the Year 1 mosaics were completed.

Because the Year 1 survey area was much longer than wide, it was necessary to subdivide it for mosaic construction. That way mosaics could be constructed with a minimum loss in record detail due to the reduction. The Year 1 survey was subdivided into 11 sections, six on the north side and five on the south side (Figure 12-1). A convenient division was at line 18 where the swath width (and hence scale) was changed. The north-south divisions were constructed to keep the mosaics approximately square.

The mosaics were constructed in the following manner. A base map of shotpoints was plotted at the appropriate scale and a mylar sheet was placed on top of it with marks to preserve the registration. The reduced records were taped to the mylar sheet with the shotpoint marks on the records registered with the plotted shotpoint locations. Where features visible at the edge of one record were visible on the adjacent record, an attempt was made to register the two images thereby reducing navigational errors. Once the mosaics were complete, bathymetric data were plotted at the same scale and contoured at a 10 m interval. The bathymetric map was drafted to contain latitude and longitude lines and UTM coordinates. The bathymetric maps and mosaics were photographed at the same scale and superimposed in one photographic negative. The result is a side-scan sonogram mosaic overlain by bathymetry contours and a coordinate grid. An example mosaic is shown in Figure 12-2.

It was decided that the best way to present the mosaics is in atlas form. The atlas, which is still being constructed, will have pages approximately 22 inches square. This large size is necessary to preserve many of the details on the original records. Because the mosaics are not easily interpreted by the untrained eye, an interpretation map will be constructed for each mosaic. These figures generalize the different types of bottom echos and show the locations of topographic features. The interpretation figures are completed for the Year 1 survey mosaics. An example is shown in Figure 12-3.

12.2.3 High Resolution Subbottom Profiles

Subbottom reflection records were obtained during the Year 1 and part of the Year 2 surveys with an EDO-Western 4kHz echo sounder. For cruise 88-MMS-G2A, a Raytheon PTR-105 3.5 kHz unit was used. Reflection profile data were recorded in analog fashion using either an EDO or EPC 20 inch electrostatic plotter. These profiles will be analyzed using standard seismic stratigraphic techniques to define the facies of the uppermost sediment layers. In the study area, the seafloor is unusually reflective and subbottom acoustic penetration is limited to less than 10-15 meters. The lowest layer that can be reliably imaged over the entire survey area is the late Pleistocene sea level lowstand erosional surface. On top of this lies a variable amount of Holocene sediments and the reef features. An isopach map of these sediments will be produced. It will show a pronounced thickening in the east central part of the Year 1 survey area, perhaps the result of a lobe of river sediments.

12.2.4 Sediment Texture

Textural analyses of the Smith-MacIntyre grabs have been completed and the results are listed in Table 12.1. The sediment data is so new that we are just begining to synthesize the results with the sidescan and subbottom data. However, from interactions between the groups working on sediment analyses and geophysical data, a picture is beginning to emerge. Sediment samples typically contain sand with variable amounts of silt and

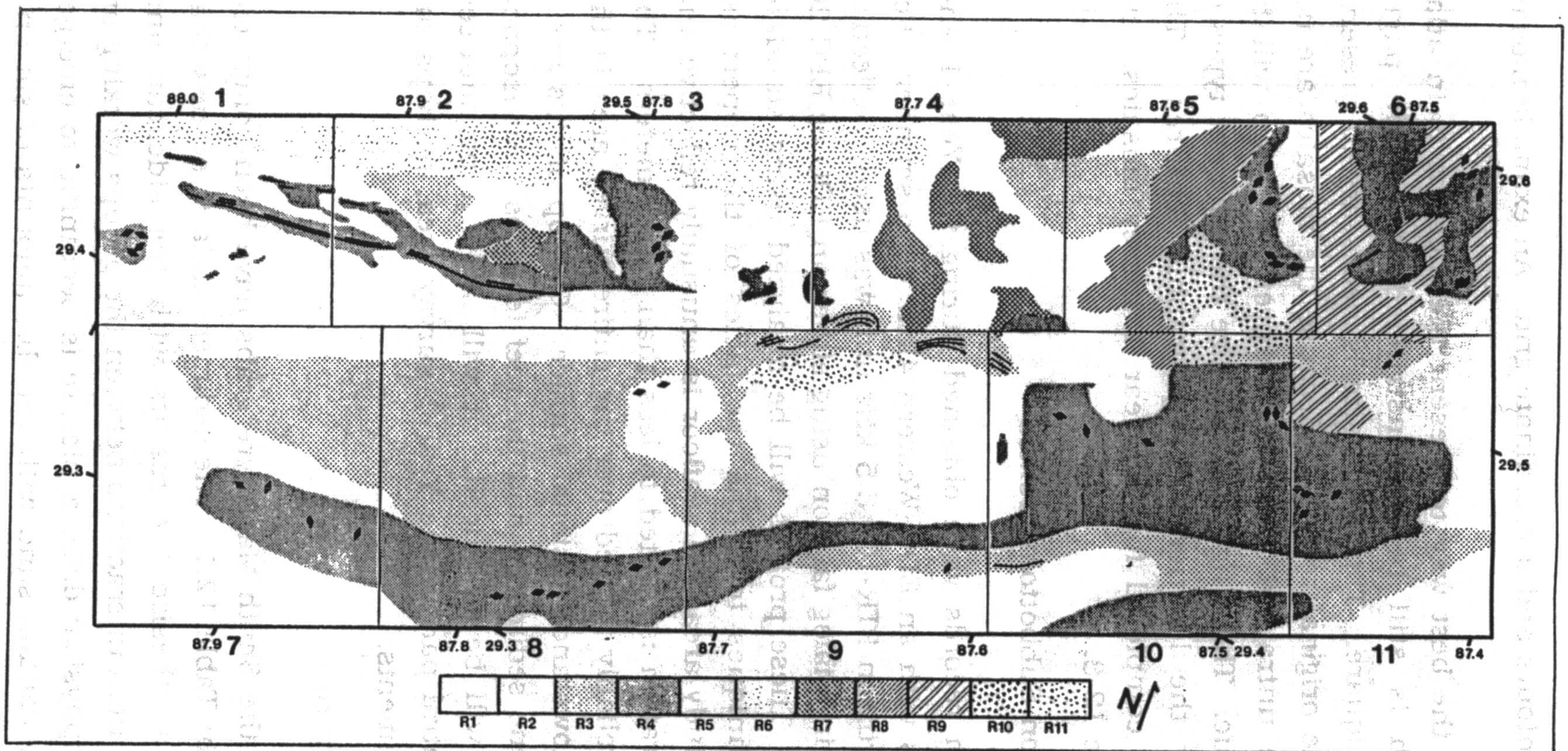


Figure 12-1. Generalized sketch map of bottom reflectivity character in the year 1 survey area interpreted from side-scan sonar mosaics. Thin lines denote mosaic boundaries; mosaics identified by bold numbers. Patterns represent different reflection characteristics, labeled R1-R11 and discussed in text. Diamonds show locations of large (diameters greater than about 150 meters) reef features or reef clusters. Long axis of diamonds show orientation of long axis of elongated reefs. Lines show linear ridge features.

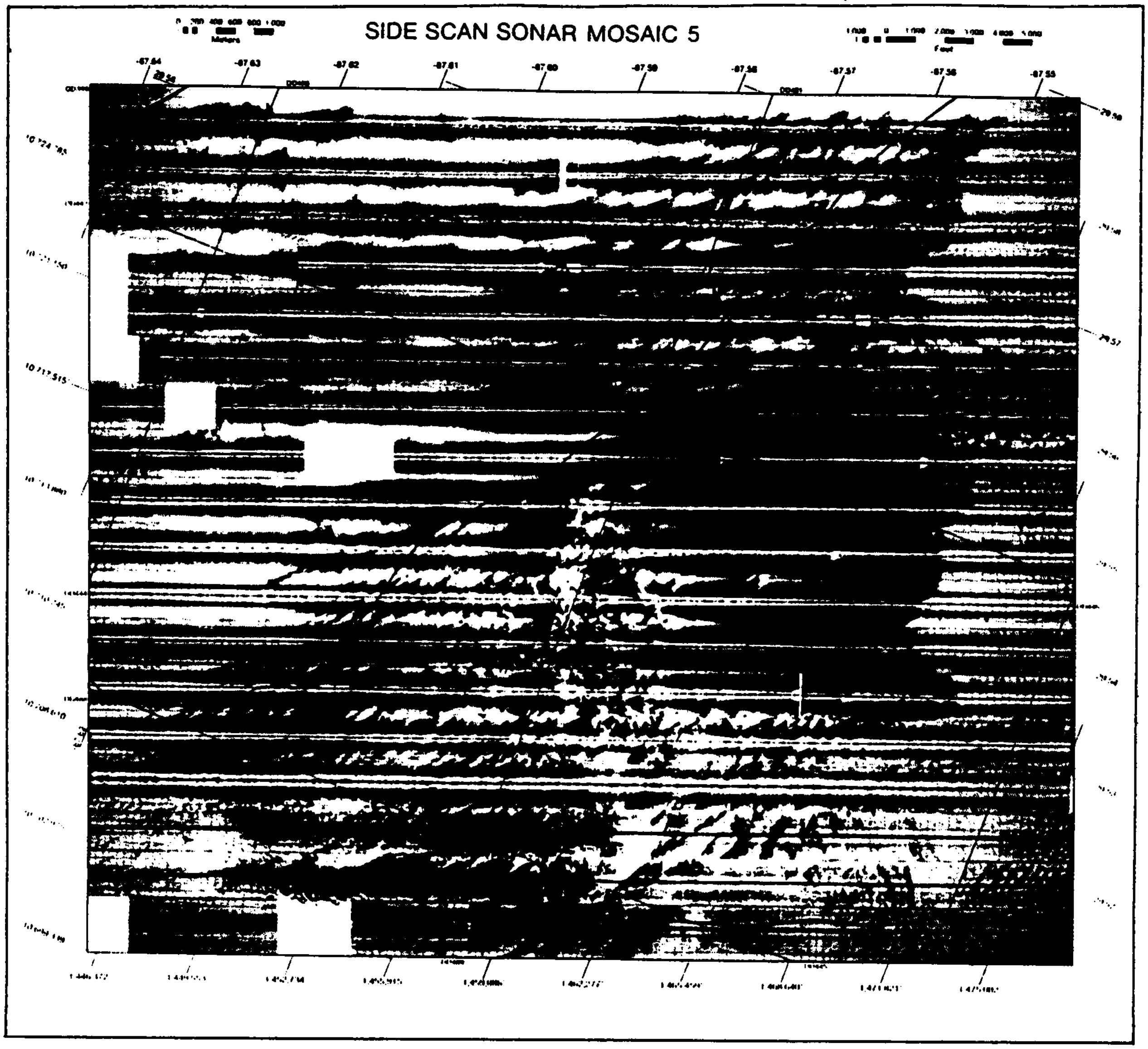


Figure 12-2. Example of one of the side-scan sonar mosaics, Mosaic #5. Coordinates are latitude, longitude and UTM.

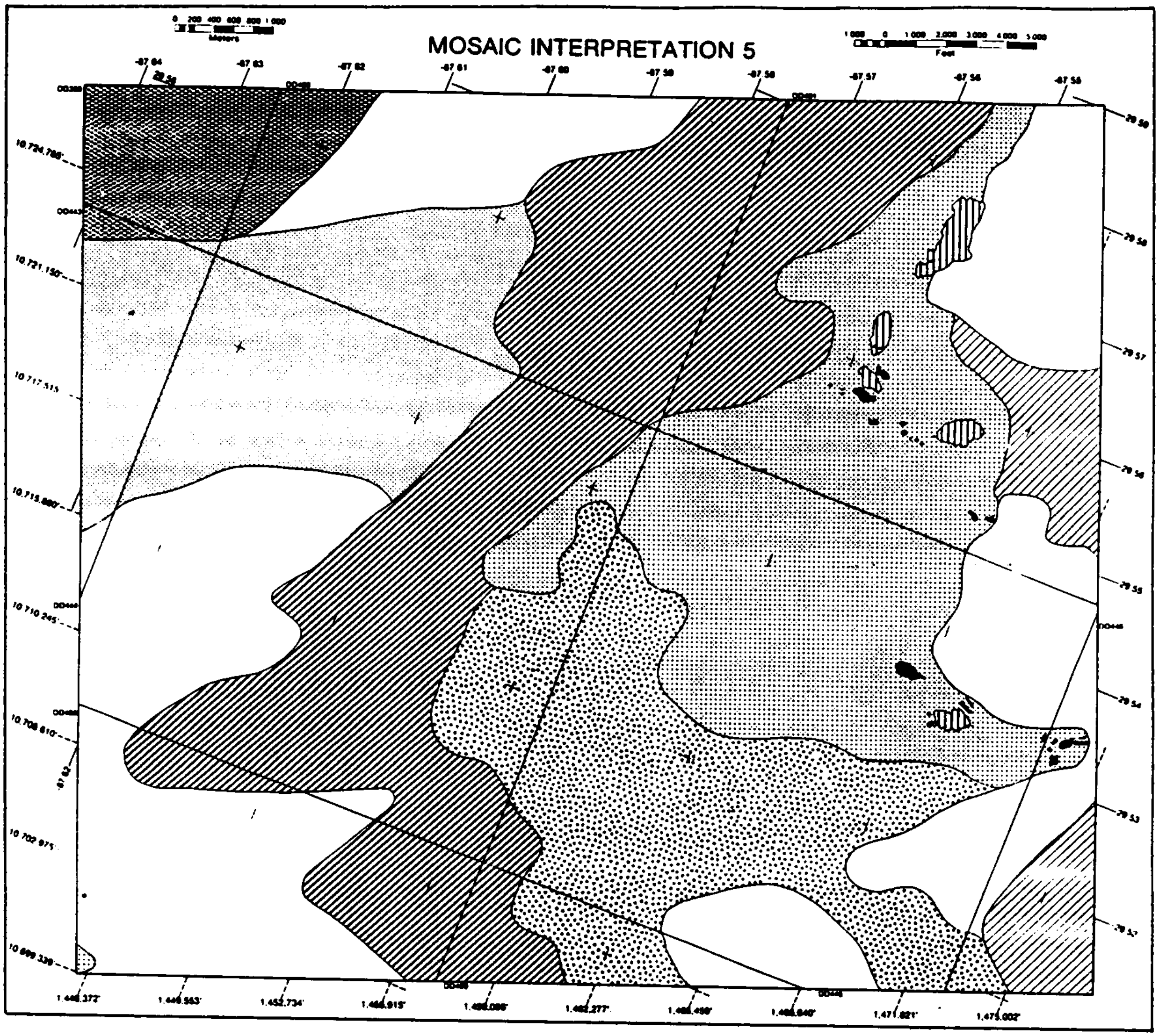


Figure 12-3. Example of one of the side-scan sonar mosaic interpretation figures, corresponding to Mosaic #5. Reflectivity patterns are outlined in Figure 12.1 and in the text.

Table 12-1. Smith-MacIntyre Sediment Analysis.

SAMPLE ID	% GRAVEL	% SAND	% SILT	% CLAY
SM-1	3.4	91	4.6	1
SM-2	3.7	90.4	4.9	1
SM-3	7	88.3	4.5	0.2
SM-4	3.3	80.1	8.5	8.1
SM-5	3.7	79.7	8.5	8.1
SM-6	13.6	60.3	14.6	11.5
SM-7	23.6	52.9	12.9	10.7
SM-8	11.4	55.1	17.9	15.6
SM-9	0	51.1	26.3	22.5
SM-10	0	54.9	24.4	20.5
SM-11	11.7	24.8	33.4	30.1
SM-12	13.1	30.2	30.3	26.4
SM-13	3.9	47.3	25.3	23.5
SM-14	3.5	39.1	30.3	27.1
SM-15	6.6	40.3	27.5	25.6
SM-16	0.01	55.3	24.2	19.4
SM-17	13	64.8	11.9	10.2

clay. Biologic debris is also a component of the sediments, with shell "hash", consisting mainly of molluscan fragments, being common. The primary difference between the areas of high and low reflectivity noted in the side-scan sonar records seems to be the content of shell hash. The high reflectivity sediments have it in abundance and the low reflectivity sediments do not.

12.2.5 Ground Truth

During the Year 2 ROV cruises, 88-MMS-ROV-1 and 88-MMS-ROV-2, geologic samples were obtained partly for the purpose of ground truthing the side-scan sonar records. On cruise 88-MMS-ROV-1, 15 rock dredge and 16 Smith-Mac grab stations were completed. During cruise 88-MMS-ROV-2, 23 box cores and two additional dredges were completed. Most of the dredges returned various biologic samples and debris such as shell hash (see Table 12-2 and Section 13.0). Several, however, also returned fragments of indurated material (e.g., bioclastic limestones, shelly sandstones, and possibly sideritic sandstones and mudstones) which are currently being studied.

12.3 Results

12.3.1 Year 1 Surveys

12.3.1.1 Bathymetry

Bathymetry plots have been made for the Year 1 survey area and contoured at 10 meter intervals. Generally, the shelf and slope are smooth, except where they are punctuated by topographic features which are usually limited in areal extent. An accurate evaluation of the area covered by the topographic features has not yet been made, however, it appears to be small, about five to 10 percent. The depth ranges from about 38 m along the north side of the survey to over 250 m in the southwest corner and 330 m in the southeast corner. The shelf generally has a low slope to a depth of about 90 m past which it deepens rapidly to the south and southeast.

Table 12-2. Ground Truth Samples.

Site	Location	Description
Cruise 88-MMS-ROV-1		
RD-1	29° 26.62' N 87° 39.47' W	Edge of "boulder field"; No Sample.
RD-2	29° 26.62' N 87° 41.79' W	"Boulder Field"; Lost dredge.
RD-3	29° 32.04' N 87° 27.83' W	Low topographic feature; Coarse to medium sand.
RD-4	29° 33.17' N 87° 29.23' W	Linear "shoreline" feature; Coarse sand, fine shell hash, shell fragments.
RD-5	29° 27.35' N 87° 39.62' W	Linear "shoreline" feature north of patch reef field; Large shell fragments, some cemented together.
RD-6	29° 26.49' N 87° 41.16' W	Linear "shoreline" feature north of patch reef field; Large shells and shell fragments; indurated rock fragments (bioclastic limestone ?).
RD-7	29° 25.57' N 87° 53.34' W	Near western linear "shoreline" feature; Shells and coral fragments.
RD-8	29° 25.26' N 87° 54.65' W	Near western linear "shoreline" feature; Shells, corals, mud lump.

Table 12-2. Continued.

Site	Location	Description
RD-9	29° 23.12' N 88° 00.01' W	Patch reef field ("boulder field"); Bioclastic nodule (cemented shell hash and coral debris).
RD-10	29° 23.14' N 88° 00.01' W	Patch reef field ("boulder field"); Bioclastic nodule (cemented shell hash and coral debris).
RD-11	29° 24.56' N 87° 44.38' W	Linear "shoreline" feature; Shell, bioclastic nodules, mud lump.
RD-12	29° 23.57' N 87° 39.50' W	Shallow depression ("footprint") field; 2 rock fragments, bioclastic nodule.
RD-13	29° 24.37' N 87° 35.37' W	Linear ridge ("snake ridge"); 2 bioclastic nodules.
RD-14	29° 24.09' N 87° 35.38' W	Linear ridge ("snake ridge"); Clay, shells, rock fragments.
RD-15	29° 24.03' N 87° 32.24' W	Deep (94 fathom) patchy reflectivity ("pox") field; bioclastic nodules, shells, castings.
SM-1	29° 30.80' N 87° 39.47' W	Patchy reflector ("pox field"); Medium to coarse sand, fine shell hash, medium shell fragments.

Table 12-2. Continued.

Site	Location	Description
SM-2	29° 30.80' N 87° 39.75' W	Patchy reflector ("pox field"); Medium to coarse sand, fine shell hash, one disarticulate shell valve.
SM-3	29° 31.63' N 87° 28.09' W	Low topographic feature; Coarse sand, fine shell hash, shell fragments.
SM-4	29° 32.11' N 87° 28.65' W	Linear reflectors ("wave field"); Coarse sand, shell fragments.
SM-5	29° 33.29' N 87° 29.19' W	Linear ridge ("shoreline") feature; coarse sand.
SM-6	29° 27.85' N 87° 39.48' W	Linear ridge ("shoreline") feature; Coarse sand, fine shell hash, shell fragments.
SM-7	29° 26.97' N 87° 40.87' W	Patch reefs ("boulder field"); Coarse sand, fine shell hash, shell fragments, silt and clay.
SM-8	29° 25.10' N 87° 54.72' W	Western linear ridges ("shoreline" features); Coarse sand, fine shell hash, shell fragments, silt and clay.
SM-9	29° 24.66' N 87° 57.17' W	Near ROV #8; Fine sand, silt, and clay.
SM-10	29° 23.89' N 87° 58.88' W	Near ROV #8; Fine sand, silt, and clay.

Table 12-2. Continued.

Site	Location	Description
SM-11	29° 23.77' N 87° 59.07' W	Reef top; Piece of shell.
SM-12	29° 23.77' N 87° 59.07' W	Reef top; Fine to medium sand, silt, clay, and coral pieces.
SM-13	29° 23.88' N 87° 59.54' W	Sediment apron west of ROV #8; Coarse sand and shell hash.
SM-14	29° 23.14' N 88° 00.01' W	Coarse sand with some silt and clay, fine shell hash.
SM-15	29° 24.57' N 87° 44.85' W	Linear ridge ("shoreline") feature; Coarse sand, fine shell hash, silt, and clay.
SM-16	29° 24.21' N 87° 35.37' W	Sinuous linear ridge ("snake ridge"); Medium sand, fine shell pieces.
Cruise 88-MMS-ROV-2		
RD-16,17 and BC-1 through -23	29° 26.48' N 87° 34.53' W	23 Box cores (16 successful) and 2 rock dredeges (1 successful) all at same site. RD-16 retrieved very small sample. Box cores returned coralline algae.

12.3.1.2 Side-Scan Sonar

In the first year annual report, topographic features were highlighted. Three different classes of feature were recognized: (1) coral-algal reefs, (2) linear ridges, and (3) depressions. The reef category contains most of the topographic features mapped in the surveys. These range in size from about 20 m tall and hundreds of meters across (pinnacles and banks) to smaller than one to two meters in height and less than 10 m across (patch reefs). They often occur in clusters but are also found as isolated features. The second class, linear ridges, occur in various localities, but mainly along the 60 m isobath. These are thought to be shoreline sand ridges that have become indurated. The last class contains enigmatic features that were nicknamed "footprints" because they are small, often elongated, shallow depressions. These depressions are usually found in clusters and are on the order of 10 m in length. One ROV station was devoted to these features, but nothing other than apparently flat seafloor was observed (see Section 13.0). It is not clear whether these features are so subdued as to be hard to see with the ROV cameras or that they are simply so small and widely spaced as to be hard to find with the ROV.

The completion of the side-scan sonar mosaics for the Year 1 survey area has shown that although the topographic features are interesting, they are only one facet of the overall geologic story. The most impressive aspect of the side-scan mosaics is the complex variation of seafloor reflections. These reflections were divided into twelve classes as follows.

R1- Low reflectivity. Homogeneous light area on side-scan record showing usually featureless bottom. Weak seafloor echo.

R2- Moderate reflectivity. Homogeneous, often featureless bottom producing moderate acoustic backscatter.

R3- Moderate to high reflectivity. Homogeneous, often featureless bottom producing moderately high acoustic backscatter. Greater reflectivity than R2, but less than R4.

R4- High reflectivity. Homogeneous, often featureless bottom producing high acoustic backscatter. Bottom appears black on side-scan records. Strong seafloor echo.

R5- Patchy reflectivity. Discontinuous, but predominantly strong acoustic backscatter. Areas of strong reflections are usually equidimensional, hundreds of meters across, and show no preferred trend.

R6- Moderate reflectivity with linear, high-reflectivity patches. Seafloor dominantly low to moderate reflectivity. High- reflectivity patches usually lineated, can occasionally be traced between tracklines, and often show preferred trends within a small area. However, overall trends are somewhat variable.

R7- Mottled reflectivity. Discontinuous moderate to high acoustic backscatter. Areas of high reflectivity are usually equidimensional and show no preferred trend, but are smaller in size than in R5. Called "pox" in previous reports

R8- Linear reflectivity, large features. Predominantly strong acoustic backscatter with lanes of lower reflectivity. Lineations are subparallel, trending generally northeast. Lineations are wide and long, measuring on average about 150-200 m across and 500 to 1500 m or greater in length.

R9- Linear reflectivity, small features. Similar to R8 except that areas of strong reflectivity are smaller and shorter, averaging about 50-75 m across and less than 500 m in length. There is also a greater area of low to moderate reflectivity between the linear features than in R8.

R10- Confused reflectors. Strong acoustic backscatter with properties of R7, R8, and R9. Areas of high reflectivity separated by areas of low to moderate reflectivity, but with no preferred orientation.

R11- Patch reefs. Areas containing many small patch reefs, five to10 m across and two to five meters high. Previously called "boulder fields".

R12- Other topographic features. Areas of strong reflectivity and shadow caused by topographic relief.

Figure 12-1 shows the areal distribution of the different types of seafloor reflections. The areas of high reflectivity are mainly organized into two patches and one long band. One patch is in the northeast part of the survey and has no dominant trend and the other patch is a small linear band in the northwest part. The long band trends across the southern part of the survey. Most of the large reefs are associated with these areas of highly reflective seafloor. Furthermore, most of the linear ridges are associated with the northwestern band of moderate and high reflectivity sediments.

The high reflectivity sediments are found mainly at three different depths, 60, 70, and 105 meters. The southern band of high reflectivity is misleading in Figure 12-1 because it includes seafloor at two of these levels. In mosaics 7 and 8 the high reflectivity seafloor runs along a trend of large reefs (the "pinnacles" of Ludwick and Walton 1957) located at a depth of about 105 m at the edge of the shelf. To the northeast, in mosaics 10 and 11, at the other end of this band of reflective sediments the high reflectivity is again associated with reefs, these at depths of 70-75 m (the "40 fathom fishing ground" of Schroeder et al. 1988a). The high reflectivity sediments in the northwest section are associated with the linear sand ridges. In mosaic 1 there is a patch of high reflectivity, located seaward of the ridges, which contains a cluster of flat-topped reefs at a depth of about 65-70 m, a depth that suggests a relation to the reefs at a similar depth in mosaics 10 and 11. The linear ridges follow the 60 m isobath from mosaic 1 through 2 and 3 and back and forth across the northern borders of mosaics 9 and 10 and the southern edge of 4. Although the linear ridges gradually end in the northwest corner of mosaic 10, areas of high reflectivity and linear reflectors are associated with the 60 meter isobath as it trends across the bottom of mosaic 5 and diagonally northeast across mosaic 6.

The different levels of high reflectivity and associated reefs suggest that there were several episodes of reef formation at different stages of the Holocene transgression. Ludwick and Walton (1957) suggested that the reef trends formed when sea level was lower and Poag (1973) cites evidence for several sea level stillstands in the Gulf of Mexico during the last transgression. Our results are consistent with these interpretations and suggest at least three levels. The deepest level was near the shelf edge and there the pinnacles in the southwest part of the survey were formed. A shallower level was around 60 meters. At this isobath the sand ridges formed, associated with shoreline beaches. During this stillstand reefs formed just offshore in shallow water, now at a depth of 65-75 meters. A third, even shallower level is implied by the reefs found landward of the 60 m isobath. These clearly had to have formed south of the coast which may have been located somewhere along the north side of the survey area or further landward.

Another effect of sea level is evident in the lineated reflectors found in the northern part of the survey area. Reflector types R6, and R8-R10 are characterized by linear "wavelike" features. These features have little or no topographic relief, appearing instead to be caused mainly by variations in the composition of the sediments. All of these reflector types are located on the north side of the survey, in the shallowest water. This association suggests a link with present sea level. A reasonable possibility is that the linear features are caused by sediment sorting associated with large storm waves. The depth of some of these features, down 60-70 m, implies that these waves must be very large, perhaps so much so that they could only be from a major hurricane. If this is the case, then the pattern found during 1987 and 1988 may be ephemeral, created by the last large hurricane and bound to be reworked by the next one.

12.3.2 Year 2 surveys

12.3.2.1 Bathymetry

Bathymetric data for the Year 2 surveys has been digitized, but not contoured. Both the East and West Addition surveys were designed to follow the 40 fathom isobath; consequently, the long axis of each survey parallels the shelf edge. There were no surprises in the bathymetry. Generally, the shelf was smooth and occasionally punctuated by a topographic feature like those found in the Year 1 survey.

12.3.2.2 Side-Scan Sonar

Production of mosaics from the Year 2 surveys is awaiting the finishing of the Year 1 mosaics and interpretation figures. Consequently, our observations from the Year 2 sonograms are only preliminary. The four detailed surveys provide the basis for a closer look at several interesting features. In particular, the flat-topped reefs survey shows that the tops of these features are very smooth. These flat surfaces may represent sea level surfaces, formed either by erosion or by limiting the upward growth of the reef. Additionally, the "boulder field" survey helped to confirm our suspicions that the "boulders" are small patch reefs.

Songrams from the East Addition survey were surprising in that the three lines show little but nearly featureless bottom. This is in distinct contrast to the Year 1 survey (Figure 12-1) in which there are no featureless areas this large.

Similarly, the northern part of the West Addition survey is also nearly featureless. It is not until about line 10 that significant reflectivity variations and topographic features are found. The topographic features imaged within the West Addition are similar to those mapped in the Year 1 surveys; however, they are not as plentiful, as varied, or as large. This finding is expected as the West Addition is closer to the Mississippi delta and so there should be more sediments suspended in the water, blanketing the seafloor and homogenizing its reflective properties as well as stifling the growth of reef building organisms. There is one exception. This is a tall, steep-sided reef imaged near the west end of line 14. It is about 65 m in diameter and its shadow on the sonogram indicates a height of 18 meters. This feature will be investigated during the Year 3 ROV cruise.

12.4 Conclusions

Side-scan sonar mosaics show twelve different types of seafloor reflection character demonstrating the complexity and variety of the geologic environment in the study area. There are basically three different types of reflection character: (1) topographic features, which are primarily reefs and ridges, (2) homogeneous seafloor with low to high acoustic backscatter, and (3) seafloor with patchy reflections, either with linear trends or with no particular trend. The reefs occur mainly in conjunction with the areas of high reflectivity. Furthermore, the distribution and depths of the reefs and high reflectivity seafloor suggest that they were formed at successively higher sea level stands during the Holocene transgression. At least three sea level stands are implied by the data from the Year 1 study area. Additionally, the distribution of linear patches of high reflectivity are found in the shallowest water in the survey area implying depth control over their formation. These features may be created by large waves during major hurricanes.

The new survey data from east and west of the Year 1 survey area imply that it is unique. Three lines extending eastward show virtually featureless seafloor in contrast to the varied seafloor within the Year 1 survey. Similarly, although the 20 lines run to the west of the initial survey do show topographic features and reflectivity characteristics similar to those mapped previously, these features are not as varied, complex, large, or plentiful as those mapped during the Year 1 survey. At least in the western survey, this may be a result of sediment blanketing because of its proximity to the mouth of the Mississippi River.

13.0 TOPOGRAPHIC FEATURES CHARACTERIZATION - BIOLOGICAL

Stephen R. Gittings, Thomas J. Bright, Ian R. MacDonald, and William W. Schroeder

13.1 Introduction

Various types of hardgrounds occur in waters off Mississippi, Alabama and eastern Louisiana. The distribution of some of these was mapped in a cruise 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 et al. 1988a, b). Additional rock outcrops have been reported on the shelf edge and continental slope in depths of 73 to 365 m in the area from south of Mobile Bay (Ludwick and Walton 1957; Moore and Bullis 1960; Ballard and Uchupi 1970) and eastward toward the DeSoto Canyon (Shipp and Hopkins 1978). The rim of the DeSoto Canyon is composed of flat limestone blocks encrusted with biota of various invertebrate groups (Shipp and Hopkins 1978). Some hardgrounds in the Mississsippi Bight may represent "drowned reefs" or "paleo-reefs" (Ludwick and Walton 1957; Ballard and Uchupi 1970). Some of these, especially in deeper water, may have begun development on hard substrates provided by authigenic carbonate production (Roberts et al. 1988).

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 40-55 fms. The average relief of the pinnacles was 10 m, but some were 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 the pinnacles, some of which are being 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 1985a; Schroeder unpublished data). Biotic assemblages were considered to be of tropical Atlantic origin and dominated by ahermatypic hard corals (e.g. *Oculina?*), octocorals, crinoids, and hydroids. Other organisms included antipatharians, various crabs, asteroids, ophiuroids, and fishes commonly associated with hard bottom habitats in the Gulf of Mexico. The biotic assemblage was considered by Continental Shelf Associates (CSA 1985a) 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 reef-dwelling species in common, including the Bank butterflyfish, *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.

Within the boundaries of the Mississippi-Alabama Marine Ecosystems Study, MMS requested complete side-scan coverage and selective video reconnaissance of topographic features in the following area (Figure 13-1):

	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

This area contains a number of sites of known or suspected hard bottoms. Many topographic features within this area are of sufficient relief that they could support communities distinct from those of surrounding habitats. Such hard bottom areas often contain biological communities of sensitive nature. That is, they are composed of organisms intolerant of unnatural perturbations such as may occur with anthropogenic insult. Such areas, termed "live-bottom areas" by MMS are defined as "...those areas which contain biological assemblages consisting of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, or corals living upon and attached to naturally occurring hard or rocky formations with rough, broken, or smooth topography; or areas whose lithotope favors the accumulation of turtles, fishes, and other fauna." (MMS

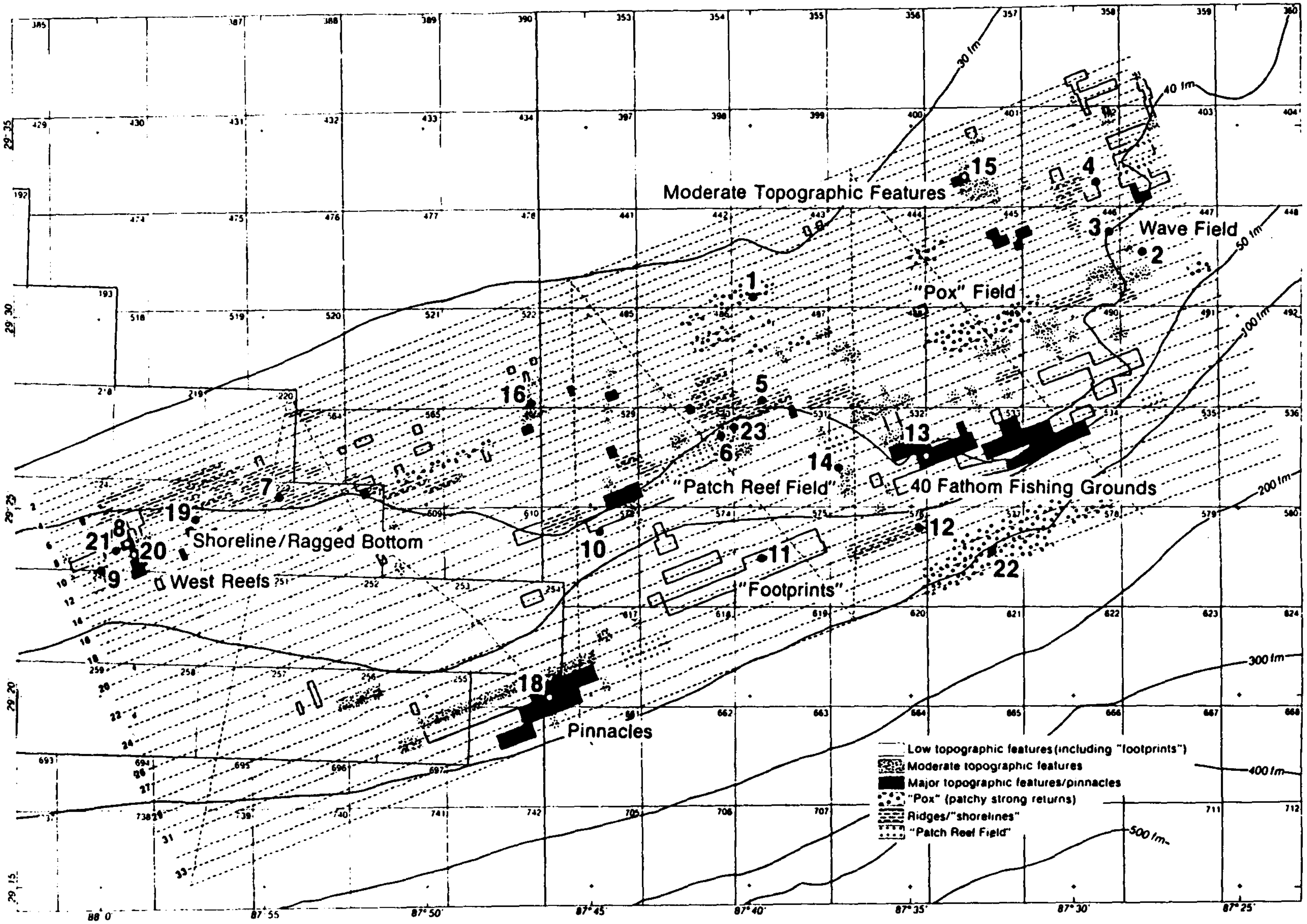


Figure 13.1. Map of hard-bottom study region, showing preliminary feature interpretation and sample site locations.

1987) The reconnaissance carried out by Texas A&M is designed to evaluate the nature and extent of live-bottom assemblages in the area outlined above.

13.2 Methods

13.2.1 Preliminary Analysis of Side-scan Sonar and Subbottom Records/Target Site Determinations

The actual coverage by side-scan sonar and subbottom records acquired during Year 1 of this study is given by the following coordinates:

	Latitude	Longitude
Northwest Corner	29°25'19.8"N	88°02'00.8"W
Southwest Corner	29°15'02.6"N	87°57'14.3"W
Southeast Corner	29°26'23.2"N	87°23'41.6"W
Northeast Corner	29°36'45.5"N	87°28'14.5"W

A preliminary analysis of side-scan and subbottom survey records was carried out in the fall of 1987 and spring of 1988 in order to determine which areas should be visited on the ROV cruise in July 1988. This preliminary analysis was done prior to the compilation of the side-scan mosaic that has more recently been constructed. Habitat information was transferred from side-scan and subbottom records onto a cruise track chart which indicated the locations of shot points surveyed during the side-scan cruises. ROV survey sites were chosen on the basis of topography and apparent relationships to regional geologic features. Surveys were conducted in regions of topographic relief varying from virtually none (soft and sandy bottom areas) to over 15 m relief (pinnacle reefs). Within this range existed very low topographic features (less than 0.5 m relief), moderate features with two to four meter relief and larger reef structures with approximately 10 m relief.. Hard bottom areas ranged from isolated features to continuous, linear series of ridges or outcrops nearly 20 km long. Structural complexity on the tops of large features varied from virtually flat reef tops to very rugged topography. The particular survey sites proposed seemed to provide a reasonable continuum of topographic relief and habitat complexity over which live bottom comparisons could be made.

13.2.2 Remotely Operated Vehicle (ROV)

A Benthos RPV-2000, medium-sized, remotely operated underwater vehicle was used for the site survey work. The camera capability consists of a Subsea Model CM-8 low light sensitive S.I.T. black-and-white video camera, a 3-CCD Photosea 3000 series color video camera and a Photosea 2000 Series 35 mm stereo camera. Lighting on the unit consists three banks of two Birns Snooperette flood lights each and two strobes. The color video camera is a modified Sony DXC-3000 3-CCD video unit. Two underwater optical lasers are installed adjacent to the video/stereo package near the bottom of the ROV and in a parallel configuration at a prescribed spread (15 cm), allowing size and scale determinations on video images. The ROV has a present depth capability of 200 m due to cable length limitations, but has equipment ratings of 600 meters. It is acoustically tracked with ultra-short baseline navigation using a Ferranti/ORE Trackpoint II system.

Predetermined sites were surveyed using the ROV, providing video footage and still photographs of bottom surficial geology and topography and biological communities. Video footage was recorded on MBR-60 tapes (3/4 inch U-matic format) and backed up concurrently on T120 VHS format tapes. Verbal annotations were also recorded. Video data also included time, depth, date, and depth.

13.2.3 Rock Dredge

Several short rock dredge transects (5-10 minutes each) were made during some site surveys. The dredge provided small samples of what are probably the dominant hard bottom fauna inhabiting the topographic features of the study area. The samples were also analyzed for their geologic characteristics.

The rock dredge used has an opening which measures 0.70 m by 0.32 m and a collection cage depth of one meter. The mesh of the cage is 12.7 mm by 38.1 mm The dredge is equipped with jagged edges on all sides of the mouth, so that collections can be made regardless of orientation.

The number of collections varied between sites. Our second attempt to dredge, near some small reefs, resulted in the loss of one of two dredges. A total of 17 successful dredge samples were collected from the 23 stations surveyed during two cruises.

13.2.4 Smith-Macintyre Grabs

Seventeen successful grab samples were taken at 15 different stations. In some cases the grab was used to collect hard bottom organisms from reefs with topography rugged enough to make rock dredging ill-advised. In these cases, samples sometimes consisted of repeated collections of small numbers of organisms. In hard bottom areas, dozens of grab attempts were unsuccessful. The grab was also used to test sediment texture for ground truth of side-scan sonar records.

13.2.5 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. We were particularly interested in comparing species caught on hook-and-line and those observed during ROV surveys. Fishing was carried out during the evening or morning hours, or when other equipment could not be used.

Species identifications were made at sea, and stomachs were extracted, preserved, and distributed to project personnel involved in trophic studies.

13.2.6 Reconnaissance Surveys

Cruises 88-MMS-ROV-1 and 88-MMS-ROV-2 were conducted aboard the R/V TOMMY MUNRO (chartered from the Gulf Coast Research Laboratory). The first cruise began on 19 July, and ended on 23 July 1988. The objective was to visit as many of the different types of features observed on side-scan sonar records (collected on geological cruises 87-MMS-G1 and 88-MMS-

G1A) as possible. During this cruise, seven of 18 planned ROV sites were successfully surveyed (Stations 1 through 7 in Appendix D) and bottom samples were acquired at these and other sites. In all, 15 rock dredges and 15 bottom grabs were collected.

On the second cruise (88-MMS-ROV-2, 23-27 September 1988), the proposed site reconnaissance sequence was finished. Ten additional stations were surveyed using the ROV, and collected rock dredge and grab samples at two sites.

In all, reconnaissance surveys using the ROV were conducted at 17 sites over two cruises and 10 days. Twenty-one separate dives were made. The length of surveys at each site depended on factors controlling the ability to identify and classify the biotic communities (e.g. water clarity, bottom topography and community complexity). Adequate coverage of individual hard bottom features required one- to three-hour surveys with camera-to-subject distances of one to three meters. Closer approaches and camera zooming were occasionally necessary for organism identification. Stereo photographs were taken frequently at sites where water clarity was sufficient for high quality photos.

We found that an anchored operation is preferable to drift surveys in rugged areas. With two-point anchoring, the optimal ship orientation is cross-current with the current coming from the starboard if operating from the port side. This puts the ROV on the downcurrent side of the ship at the surface and allows the operator to maneuver more easily. If operating with a single anchor, the ROV was best deployed from the stern. Significant drawbacks of two-point anchoring include first, the time required to set anchor, and second, the possibility of hanging at least one anchor on bottom features. Over two cruises, we lost two stern anchors to snags. At ROV Station 8, the stern anchor had to be sacrificed after it snagged a bottom feature. A spare anchor was rigged and we also surveyed site ROV-9 using a two-anchor mooring. The stern anchor again snagged and was lost, forcing us to rerig the ROV to operate from the stern, mooring by use of the bow anchor only. All subsequent sites were surveyed in this manner. Fortunately, we did not experience sufficient ship drift on anchor during subsequent ROV dives, which might endanger the operation by snagging the ROV on submerged features.

ROV survey patterns of the bottom were monitored using the acoustic tracking system. We attempted to achieve nearly complete site coverage by plotting the ROV cruise track on a transparent overlay on the tracking system display, which shows the ROV location relative to the mother ship. In one case we found it possible to also chart small, isloated, hard bottom feature locations on the overlay.

13.2.7 Laboratory Analysis of Samples

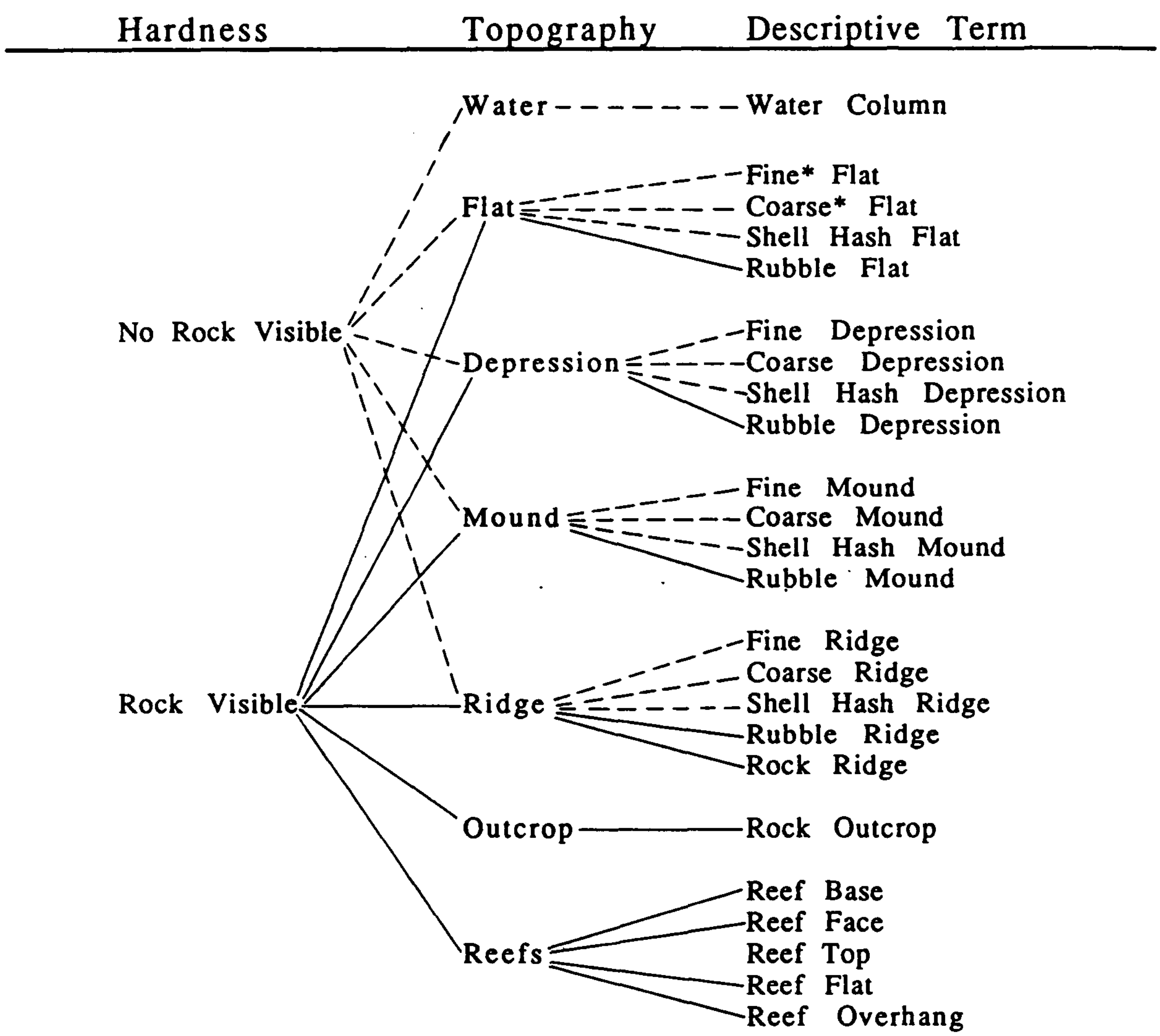
Rock dredge and grab samples were sorted in the laboratory and species identifications made to the lowest feasible taxa for all samples collected during the first ROV cruise. These collections are valuable to the video and photographic analysis in that they often contain species that are commonly observed on tapes and slides. Taxonomic assistance for ahermatypic stony corals was provided by Walter C. Jaap, and for octocorals by Jennifer Wheaton (both of the Florida Marine Research Institute, St. Petersburg, FL). Assistance in fish identification from video tapes and photographs was provided by Dr. John McEachran and Mr. George Dennis. Data are entered using a database management program called Reflex Plus on a Macintosh computer.

Records of observations made on video tapes and photographic records include time of day, descriptions of the habitat, organism identification, a qualitative descriptor of abundance for that species or taxon, quantity, where appropriate, depth of observation, and comments relating to the observation. The database also contains information regarding ROV dive numbers, station numbers, visibility during dives, shallowest and deepest depths at each site (e.g. feature crests and bases), length of surveys, and human impacts or disturbance at the sites. All these data are also entered into computer files in the database.

A list of bottom types was compiled from initial review of video tapes. The categorization considers bottom hardness, topographic relief, and detail of the surface (Table 13-1).

Qualitative descriptors for taxa at each station are modifications of those used by Stark (1968) for fish abundance at Alligator Reef, in Florida, and Dennis (1985) for fish abundances on hard banks in the northwest Gulf of

Table 13.1. Bottom type descriptive terms used in video and photographic analyses.



*"Fine" and "Coarse" refer to apparent sediment texture

Mexico. It is important to understand these terms as defined in the present study because they are commonly used in site descriptions. They are:

Rare - seldom observed, or a very small percentage of observations at a site; usually only once or twice at any given station, but possibly several times at sites with very high overall abundances.

Occasional - Sporadic observations, usually at irregular intervals; generally several observations, or a higher number at stations with very high overall abundances, but not frequent.

Frequent - encountered regularly; common; seen in a large portion of their preferred habitat at a survey site. For purposes of this study, we consider "frequent" and "common" (used by Stark [1968] and Dennis [1985]) to be synonymous.

Abundant - a regularly encountered species observed in high numbers, representing a high percentage of observations.

13.2.8 Biological Community Composition

For each station visited, the information resulting from video tape, stereo photograph and sample analyses was synthesized into a site description. The standard format for presentation of site descriptions includes most or all of the following information: location, date of survey, total hours of video acquired, total number of ROV dives, time of survey, visibility, side-scan interpretation, depth, relief, bottom types encountered, attached epifaunal assemblage, biotic zonation, associated benthic invertebrates, fish and nekton encountered, abundance, human impacts, and comparison with other sites.

Qualitative comparisons between sites are made on the basis of habitat and community characteristics, biotic zonation and the factors most likely influencing biotic assemblages. Habitat differences include sediment texture, the extent of outcrops or reefs, topographic complexity, vertical relief, relative depth of turbid water layers, and crest depth. Biological community characteristics that can be compared are species composition, apparent abundances, apparent diversity, and the number of distinct biotic assemblages. Biotic zonation comparisons are made with respect to the composition, number, extent, and depth distribution of zones, and the parameters that most affect the observed zonation.

13.2.9 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, substrate type, amount of relief (which influences the number of refuges 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. Correlations between some of these factors and biotic composition and zonation patterns are discussed.

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

One objective is to determine the biogeographic affinities of assemblages on outer continental shelf topographic features within the Mississippi Bight. Comparisons are 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, 1983; Rezak et al. 1985; Bright et al. 1984), on other hard substrates in the northeastern Gulf (Moore and Bullis 1960; Schroeder et al. 1988a, b), and on live-bottom areas on the Florida shelf (e.g., at the Florida Middle Ground; Hopkins et al. 1981). Communities in this region are also compared to those at similar depths on hard substrates off eastern Florida (Avent et al. 1977; Reed 1980).

13.2.11 Community Health (Condition)

The evaluation of the health, or condition, of hard bottom communities generally involves a subjective comparison of a given area to similar habitats observed in the past. Objective criteria that can be incorporated into this evaluation which include: (1) the evidence of mass mortalities having occurred [e.g. sea grasses (Tutin 1938); sponges (Galtsoff 1940); sea urchins (Lessios et al. 1983, among others)], (2) abnormally high cover or abundances of atypical species (Hughes et al. 1987), (3) the deterioration of individual organisms or colonies (e.g. zooxanthellae explusion in corals under stress; Jaap 1979), (4) 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 (reviewed by Gittings 1988), and pollution (e.g. solid wastes, hung and discarded fishing nets, etc.).

During video tape analyses, abnormalities on sites were noted and are presented in station descriptions. This will provide a partial record of both natural and human impacts in the habitats. The information may be useful as baseline data on community condition for future studies.

13.2.12 Categorization of Features

The objective of the categorization effort will be 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.

Like the scheme used by Rezak and Bright for the banks of the northwestern Gulf of Mexico, a categorization of the Mississippi Bight topographic features can be based on the features' geological and biological characteristics and degree of development. However, since most hard substrates encountered in this part of the Gulf of Mexico are not associated with salt diapirs, are not as large in areal extent as those described in the northwestern Gulf, and do not have as much vertical relief, classification on the basis of biotic zonation is not nearly as feasible. A classification will be developed, however, that takes into account primarily geological structure and biological community development. This effort will take place during Year 3 of the project, after records from all reconnaissance sites have been analyzed in detail, and after geologic interpretations are completed.

13.3 Results

The features chosen for reconnaissance represented a cross-section of hard bottom and soft and sandy bottom areas within the study region. The locations of the sites are given in Appendix Table A.1 and Figure 13-1. We sampled the following features using the ROV, rock dredges, or bottom grabs:

- two areas of acoustically transparent sediment, which generally indicates fine textured, soft bottom (Stations 19 and 20);
- one "wave field" (closely spaced, low relief sand waves on bottom; Station 3);
- two areas of patchy hard bottom returns (Stations 1 and 22);
- one area that may be part of a "sediment apron" of relatively coarse sand surrounding a reef structure (the sediment produces a very strong return on side-scan records; Station 21);
- one field containing what appear to be small depressions in the bottom (Station 11);
- four sites along an apparently continuous paleo-shoreline (this may be a Pleistocene still-stand erosional feature; Stations 4, 5, 7, and 10);
- one site along a shorter, deeper ridge or paleo-shoreline (Station 12);
- two fields of reefs comparable in size to present-day lagoonal patch reefs (Stations 6 and 9 and a dredge sample at 23);
- one area containing features of low topographic relief (Station 2);
- two features of moderate topographic relief (Stations 15 and 16);and

- four features of major topographic relief (some over 15 m tall; some are smooth-topped, some knobby, some broad, and some spire-like; Stations 8, 13, 14, and 18).

Video tapes from the first of the two ROV cruises (88-MMS-ROV-1, 19-23 July 1988) have been thoroughly reviewed. Tapes from sites visited on the second cruise (23-27 September 1988) have only been reviewed in a preliminary manner to develop classification schemes based on bottom types, develop qualitative descriptors of organism abundance, and to standardize organism identifications. Preliminary site descriptions for features visited during the second cruise are provided, but should not be considered complete. All stereo photographs have been analyzed.

13.3.1 Detailed Site Descriptions

13.3.1.1 Station 1 - Pox Field

Video Survey - Station 1 was located at 29°30.50'N, 87°39.95'W. The survey started at 0843 on 20 July 1988 and ended at 1135 (video records totaled 2.70 hours). The area was 57-58 m deep and consisted of moderately bioturbated, shelly sand. Variability in the amount of shell material in the sand may account for the patchy strong returns seen on the side-scan records, but this variability could not easily be detected on video records. In one area, however, there seemed to be somewhat higher levels of shell hash on the surface of the bottom sediments. Continental Shelf Associates (1985b) noted similar, but possibly darker, "polka dot" sonar returns on side-scan records from the southwest Florida shelf and found them to be associated with live-bottom areas. They also make reference to "similar, though less distinct, patterns..." off northwest Florida, the cause of which is unknown.

Sandy mounds in the present study area were seldom taller than five to seven centimeters or broader than 10-12 centimeters. Numerous small holes (probably fish and callianasid shrimp burrows) and one burrow surrounded by small rocks were seen. Several depressions were observed approximately 30 cm across and 15 cm deep, filled with rubble and algal, sponge, or gorgonian coral debris. No rock outcrops were seen and there was little evidence of subsurface hard bottom (e.g. only one attached hard bottom organism, a white sea whip (*Elisella funiculina*?), was seen projecting through overlying bottom sediments). There were no sand waves on the bottom. The only sign of anthropogenic debris was one piece of rope on the bottom.

At least three species of sea stars were observed. One species (*Astropecten*? sp.) was common, but not abundant. Many sea star-shaped depressions were observed. Other organisms included several squid, one 20-25 cm pennatulacean (sea pen), two featherduster polychaete worms, one pycnogonid measuring over 10 cm, and one olive shell? (Olividae). One orange, tubular sponge was seen, measuring 15-20 cm tall and 20-25 cm wide, having six spires. Two other sponge species were found, one a brown tubular colony and the other a small brown knobby colony. Fish included *Prionotus* sp., sea robin (occasional); *Serranus phoebe*, tattler (occasional); and *Centropristis ocyurus*, bank sea bass (rare); three flounders, five Synodontidae lizardfish (including *Synodus intermedius* Sand diver), and *Equetus punctatus*, high hat (one).

Grab Characterization - Grabs 1 and 2 consisted of medium to coarse sand, fine shell hash, some medium shell fragments, and one disarticulated shell valve.

13.3.1.2 Station 2 - Low Topographic Features

Video Survey - An area of mostly coarse, shelly sand, but with scattered low topographic features exhibiting up to about 0.5 meter relief, was surveyed during Dive 2 (29°31.78'N, 87°27.98'W). The survey started at 1634 on 20 July 1988 and ended at 1831. The total video time was 1.93 hours. Visibility during the survey was very good. The depth of the bottom varied only slightly from 73 m (±0.5 m). Features on the bottom were often mounds covered by a veneer of coarse sand, or depressions with exposed rubble or rock. Some mounds were capped by fine sand. Other features were low ridges of coarse sand, possibly covering hard substrata. Where hard bottom organisms were observed at the site, there was probably a hard substrate beneath the sandy veneers that acted as sites of attachment. The fact that patches of hard bottom organisms existed on and followed topographic relief seems to support this. The most prolific growth, however, was observed on mounds and in depressions that clearly had rock outcrops or large accumulations of rubble.

Bottom types noted in video tapes included:

- Coarse flats - fields of coarse sand (about 95 percent of the survey area) ;
- Coarse depressions - averaging less than 0.5 m wide;
- Coarse mounds - less than 0.3 m high and averaging one meter wide;
- Rubble flats - rubble lying on top of the flat, sandy bottom;
- Rubble depressions - rubble exposed in depressions;
- Rubble mounds - accumulations of rubble (<0.3 m relief and 1 m wide);
- Coarse ridges - ridges to 0.3 m high covered by coarse sand; and
- Rock outcrops.

Based on a preliminary analysis of side-scan records, it was believed that this survey area contained a moderate topographic feature (survey line 18, shotpoints 122-123). During the video survey, we did not encounter the feature, but we may have been nearby. This might explain the presence of a large number of features of low topographic relief and low rocky outcrops. One portion of the survey site consisted of a large number of small exposed features. It is possible that this area may have been close to the moderate topographic feature.

Cover by hard substrates in the area averaged less than five percent of the seabottom. Where hard bottom organisms existed there was typically exposed rock, rubble, or sand covered mounds probably consisting of hard substrates with a coarse sand veneer. Exposed rock and rubble was either above the surface of surrounding sand (mounds) or in depressions. In nearly all cases, the presence of exposed hard bottom coincided with the occurrence of attached suspension-feeding epifauna. Abundance of epifauna varied with the amount of exposed rock. Diversity was quite variable, even between features with similar topography.

Hard bottom epifauna were distributed in patches ranging in size from less than 10 cm to nearly two meters in diameter. Several dozen of these were observed in the two hour survey. Distance between the patches ranged from less than one meter to over 15 m, and averaged around 10 meters. Most high density patches were dominated by comatulid crinoids and also consisted of bushy antipatharian corals (*Antipathes* sp.), the coiled sea whip, *Cirrhipathes* sp., *Elisella* sea whips (*E. barbadensis*, *E. elongata*, and *E. funiculina*?), and *Thesea* spp. (small branching paramuriceid gorgonians). Other high density patches appeared to have equally high populations of comatulid crinoids and *Antipathes* spp. Patches of lower density were dominated either by crinoids, by *Thesea* and *Antipathes* and having few or no crinoids, or by *Antipathes* spp. or *Thesea* spp. Only one patch was dominated by *Elisella* sp. Very small patches that existed in small depressions or on small rubble accumulations were dominated by comatulid crinoids. *Cirrhipathes* colonies were frequently observed, within and outside of patches, probably attached to hard substrates beneath the sand.

Epifauna associated with the patches included several species of small unidentified crabs, basket stars (*Astrophyton*; occasional), branching foliose bryozoans growing on rocks or gorgonian skeletons (occasional), calcareous sponges (probably three or four species with no more than two individuals of any species), sea stars (rare: three were seen), and possibly two solitary corals (possibly the caryophylliid, *Oxysmilia* sp.). Three pennatulaceans (sea pens) were seen near patches. One seemed to be over 30 cm tall. The others were approximately 15 cm tall.

Fish species associated with the low topographic features and attached epifauna were: *Pristigenys alta*, the short bigeye (frequent; observed at about half of the hard bottom patches); *Serranus phoebe*, the tattler (frequent); *Liopropoma eukrines*, the wrasse bass (occasional: five were seen); *Chaetodon aya*, the bank butterflyfish (occasional: five); *Chromis enchrysurus*, the yellowtail reeffish (occasional: four); *Centropristis ocyurus*, the bank sea bass (occasional: four); a scorpaenid (rare: two); *Halichoeres bivittatus*, slippery dick (rare: two); a mottled flounder (rare: one); and *Synodus intermedius*, the sand diver lizardfish (rare: one on sand). *Calamus* *bajonado*, the jolthead porgy, was a frequent nektonic species. There was no indication of human interference at this station.

Dredge Characterization - Rock Dredge Sample 3 contained coarse to medium-grain sand, a sea urchin (*Stylocidaris affinis*), a sea biscuit (*Brissopsis* sp.) and a crinoid (*Comactinia echinoptera*), which is commonly seen on hard substrates throughout the study area. Also included were serpulid worm tubes, bioclastic shell material, scaphapods (two live *Dentalium laqueatum*), the gastropods *Crucibulum auricula*, *Murex recurvirostris*, *Turritella exoleta*?, *Polystira vibex*, *Distorsio clathrata*, and the pelecypods *Tellina squamifera*, *Tellina* sp., *Ventricolaria rigida*?, *Chione clenchi*, *Macrocallista maculata*, *Pitar* sp., *Anadara notabilis*, and the pectinids *Chlamys benedicti*, *Argopecten gibbus*?, and *Argopecten* sp.

Grab Characterization - Grab 3 contained coarse sand, fine shell hash, and shell fragments.

13.3.1.3 Station 3 - Wave Field

Video Survey - The wave field survey site is located at 29°32.12'N, 87°28.97'W. The area consisted of mostly coarse sand with a mixture of silt. Depth varied between 71 and 72 meters. Mounds surrounding invertebrate burrows (probably callianassid shrimp) were abundant. These mounds were up to 15 cm tall, but averaged 10 cm in height. Depressions measuring approximately one meter across and 0.3 m deep were also observed. Some contained small accumulations of debris. Holes occupied by eels and fish were frequently seen. No hardgrounds were encountered. The wave features observed on side-scan survey records were not detected during the ROV survey.

This wave field was surveyed at night, between 2356 hours on 7/20/88 and 0159 hours on 7/21/88. Video records of the bottom were taken on Dive 3 for 2.03 hours. Visibility was very good, except when silt was resuspended by ROV motors or fish activities.

Benthic activity was very high, due to the time of the survey. Video records at similar sites during the day indicated little biological activity (e.g. Station 1). Over 350 fish and invertebrates were recorded at this station (172 per hour; most observations were of fish which were feeding, and much activity near the limits of the camera's field of view was not recorded). Only 97 observations were recorded at Station 1 (36 per hour), most of which were inactive sea stars.

The most common invertebrates were two species of ommastrephid squid (both frequent) which were seen swimming individually or in small schools of up to 12 individuals; some were sitting on the bottom bobbing up and down, or feeding on benthic organisms. Two other species were seen, one small and red and the other large and red with white iridescent spots (both rare). Other observations consisted of white brittle stars (*Ophiothrix?* sp.) with long arms extending up into the water column (occasional: 18); *Clypeaster* sp., domed sand dollars (occasional: 13 were seen); tan sea urchins with medium length spines (occasional: 10); an orange portunid crab (rare: four); a white, stalked sea anemone with long tentacles (rare: two); a red pagurid crab (rare: one); a majid crab (rare: one); *Scaphella dubia kieneri*, Keiner's volute (rare: one); and a crinoid with orange arms and black pinnules (*Comactinia echinoptera?*, rare: one). Several other small crabs were also seen but could not be identified.

Fish were far more conspicuous at the site. At least 19 species were seen. The most abundant was *Decapterus* spp., the scads (abundant: over 55 separate observations). *D. punctatus*, the round scad, appeared to dominate the genus. The scads were commonly seen in the water column well above the bottom, but often came to the bottom, apparently attracted to the lights of the ROV. No feeding by these fish was observed.

The urophycids were also abundant. At least two species were seen in the 53 observations. *Urophycis floridanus*, the southern hake (frequent), accounted for 31 sitings and a second species with large blotches of dark coloration on its sides (occasional) accounted for at least five others. These fish were commonly seen searching for food along the bottom. Some were also seen with their heads protruding from burrows in the bottom.

Ophichthid eels were frequent (36 observations). The most conspicuous was *Ophichthus ocellatus*, the spotted snake eel (frequent: 32). An ophidiid eel (*Lepophidium jeannae*, the mottled cusk eel) was rare, but was seen at least three times. These eels were commonly seen swimming very near the bottom, probably in search of food. One charged, collided with, and attemped to bite the video camera lens. Moray eels (Muraenidae) of the genus *Gymnothorax* were also seen (occasional: eight). The only species that could be identified was *G. ocellatus*, the ocellated moray (rare: one). These eels were seen swimming in a snake-like fashion near the bottom, but on their sides, so that body oscillation was in the vertical direction rather than laterally, as in the ophichthids and ophidiids.

Another frequent fish was *Centropristis ocyurus*, the bank sea bass (32 sitings). This is the only species common at both this site and sites surveyed during daylight hours.

Other fish sitings included *Synodus* sp., small lizardfish (occasional: 13); *Menticirrhus* sp., whiting (occasional: five); flounders (occasional: five); scorpaenids (rare: four); *Synodus intermedius*, the sand diver lizardfish (rare: three); *Peprilus burti*, the Gulf butterfish (rare: three); ogcocephalids, batfish (rare: two); *Prionotus* sp., sea robins (rare: two); *Diplectrum bivittatum*, dwarf sand perch (rare: one); *Sarda sarda*, the Atlantic bonito (rare: one); *Hoplunnis macrurus*, the silver conger (rare: one); an unidentified serranid (rare: one); and an unidentified sparid (rare: one).

There was no indication of human interference at this station.

Grab Characterization - Grab 4 contained coarse sand and shell fragments.

13.3.1.4 Station 4 - Shoreline/Ragged Bottom

Video Survey - An area of ragged bottom was surveyed at 29°33.48'N, 87°29.60'W on 21 July 1988. The survey time totaled 1.78 hours. The dive took place during daylight between the hours of 1130 and 1320.

Depth at the site varied negligibly from 66 meters. The site consisted of greater than 95 percent coarse, flat sandy bottom. Less than five percent of the survey area consisted of hardgrounds or live-bottom assemblages. Hard areas appeared to be rock outcrops. All were of relief less than 0.5 meters. Some were small and apparently isolated outcrops. One feature was semi-continuous and linear in nature and presumably part of what we have tentatively termed a paleo-shoreline (this site location was intentionally located on one of the linear features seen on side-scan records). Most live-bottom areas were on exposed rock, but a small number were low mounds covered by sand. The most prolific growth was on a linear series of rock outcrops of approximately 0.5 m relief. A few live-bottom assemblages existed on apparently flat sandy bottoms. In these cases, rock probably existed beneath the sand veneer. Other assemblages were associated with sandy depressions in which hard rock substrates may have been exposed. In the two latter cases, however, the areal extent of the assemblages was less than one square meter.

Bottom types noted in video records included:

- Coarse flats - greater than 95 percent of the area surveyed;
- Coarse depressions - very few were noted, averaging <0.5 m wide;
- Coarse mounds - less than 0.5 m high and one to two meters in diameter (few were seen);
- Rubble flats - small pieces of rubble lying on sand;
- Rubble depressions - burrows under large pieces of rock or rubble;
- Rock outcrops - isolated features - most common observation;and
- Rock outcrops with linear orientation - paleo-shoreline? (contained the majority of hard bottom organisms in the area).

Live bottom assemblages were typically dominated by comatulid crinoids (probably three species). Where crinoids did not dominate, small gorgonians such as *Thesea* sp. and *Bebryce* sp. did. Associated attached benthic organisms included white *Elisella funiculina*? sea whips (frequent), *Cirrhipathes* sp. (coiled sea whips; occasional), sponges (at least three species; occasional), and bushy antipatharians (*Antipathes* sp.: occasional).

One patch of a pink/purple coralline algae was also seen, suggesting that some carbonate production may presently be occurring on exposed surfaces in this area. It also suggests that water clarity may remain high for relatively long periods of time in this region.

Associated motile benthos included *Astrophyton* sp., basket stars (rare: four), *Hermodice carunculata*, fire worms (rare: three), *Scaphella dubia kieneri*, Kiener's volute (a gastropod: rare: one), and *Stenorynchus seticornis*, the arrow crab (rare: one).

At least 15 fish species were observed. Typically, each live bottom observation included sitings of virtually the same suite of three fish species. There was a fairly equitable distribution of *Pristigenys alta*, the short bigeye (frequent: 38); *Chaetodon aya*, the bank butterflyfish (frequent: 28); and

Chromis enchrysurus, the yellowtail reeffish (frequent: 24), at each live-bottom patch. At least one of each species occurred at nearly all patches. More individuals occurred on denser or larger patches, or at small patches with burrows or depressions, presumably owing to a higher number of refuges. Other fish species varied in their consistency but were loyal to live-bottom patches. These included *Serranus phoebe* (occasional: 19); *Centropristis ocyurus*, the bank sea bass (all five were seen at two sites); *Halichoeres* sp. (rare: five at one site); *Muraena retifera*, reticulate moray (rare: one); *Holacanthus bermudensis*, the blue angel (rare: one); *Holanthias martinicensis*, the roughtongue bass (rare: one); and one unidentified wrasse (rare).

Species having no apparent hard bottom fidelity (generally fish passing through the area) included *Hemanthias aureorubens*, the streamer bass (one school of 26); *Seriola dumerili*, the greater amberjack (rare: two); and *Seriola rivoliana*, Almaco jacks (rare: two). Sandy bottom associated species included *Synodus intermedius*, the sand diver lizardfish (rare: one), and an unidentified Synodontidae (rare: one).

Other observations included one string of *Busycon* sp. (whelk, a gastropod) egg capsules on a sand bottom, and a sea urchin test adjacent to a rock outcrop.

The only evidence of human interference at this site was an aluminum can on a sand bottom adjacent to a small rock outcrop. The biological assemblages of this site were very similar to those at Station 2, an area of low topographic features unassociated with this paleo-shoreline. It is likely that the similar nature of the rock substrates at the two sites, and possibly their proximity, accounts for the similarity in biological composition and density. The sandy areas surveyed at this site are more similar to those at Station 1 (Pox Field) than Station 3 (Wave Field). This is probably because Station 1, like the present area, was surveyed during daylight (0843-1130) rather than at night, as was Station 3 (2356-0159 hours).

Dredge Characterization - Three rock dredges were made near this ROV station (Samples 4, 5, and 6). Two are characterized in detail below (one is on loan to the project's geological investigators). Rock Dredge 4 contained the echinoderms *Stylocidaris affinis* (one), *Comactinia echinoptera* (one), *Asteroporpa annulata* (two), and *Narcissia trigonaria* (two). It also contained an arrow crab, *Stenorhynchus seticornis*, two small bryozoan mounds, and one small foliaceous bryozoan colony.

Rock Dredge 6 contained a tan branching sponge, the echinoderms, *Asteroporpa annulata* (one), *Comactinia echinoptera* (four), and a golden crinoid (possibly *Antedon* sp.: one). Bryozoans included one encrusting form, small branched colonies and one massive branching form. There were also thin antipatharian skeletons, one thick branching antipatharian (similar to precious black coral), the foram *Homotrema rubrum*, an encrusting white sponge, a solitary coral of the family Dendrophyllidae, and an oyster shell (*Neopycnodonte cochlear*).

Grab Characterization - Grab 5 contained coarse sand and a polychaete, the fireworm, *Hermodice carunculata*.

13.3.1.5 Station 5 - Shoreline North of Patch Reef Field

Video Survey - An area of hardgrounds apparently representing outcroppings of a paleo-shoreline was surveyed at 29°27.86'N, 87°39.29'W. The survey was carried out on 21 July 1988. The video records total 1.80 hours. The ROV dives (two deployments) took place between 1819 and 2237 hours.

Depth at the base of the shoreline feature was 66.7 m (219 feet). The shallowest hard substrate was at 63.7 m (209 feet), but the majority of observations were made at depths of 64 to 66 meters. Most of the survey area consisted of rugged hard substrates. Some sand was encountered in depressions between outcrops, but no areas of extensive sandy bottom were encountered.

Bottom types noted in video records included:

• Fine sediments - "silt apron" at base of rock outcrops, fine sediment in small depressions, and fine veneer covering some rock outcrops (references to "silt" are somewhat misleading and not intended to be accurate in the sedimentologic sense, since a distinction between silt and other fine sediments cannot be easily made using video observation techniques).;
• Coarse flats - sandy bottom between outcrops;

• Rubble flat - small area with cobble-size rubble accumulation ; and
• Rock outcrops - generally along a semi-continuous ridge.

Turbidity at the site was quite high during both ROV deployments. Visibility on the bottom seldom reached two meters. Above 63 m depth, however, the water was clear. Surveys carried out two months later near this site were in much clearer water, illustrating the transitory nature of such conditions.

The turbidity at this site resulted in rather blurry video records. Even with this difficulty, however, the records indicate a fairly diverse assemblage on these rock prominences. Gorgonians and antipatharians dominated the biological assemblage. Bushy antipatharians (*Antipathes* sp.) were frequent, as was *Cirripathes* sp. (coiled sea whips), *Thesea* spp. and possibly *Nicella guadalupensis* (small orange sea fans). Also frequently observed were small patches of an orange sponge encrusting rock outcrops. Other attached epibenthos included comatulid crinoids, the sea whip *Elisella barbadensis*, white encrusting sponges, the ahermatypic stony coral *Rhizopsammia manuelensis*, a white sea fan, and possibly *Oculina* sp. (all occasional). Rarely occurring attached epibenthos included solitary white stony coral polyps (four), pennatulaceans (three sea pens), vase sponges (two), branched and tubular sponges (two), *Neopycnodonte cochlear* (an offshore oyster species which grows in clumps), several species of gorgonian sea fans, two to three species of large globose sponges (one black, and two yellow to white), patches of coralline algae, and *Siphonogorgia agassizii*? (an orange, fruticose alcyonacean).

Associated benthic invertebrates included *Astrophyton* sp., basket stars (occasional), a species of sea star with pale annulations on each arm (occasional: five), two species of sea urchins (rare: one each), *Stenorhynchus seticornis*, the arrow crab (rare: one), and a pagurid hermit crab (rare: one). One string of *Busycon* egg capsules was also seen.

The fish and nekton were fairly diverse at this station (at least 22 species). Most species, however, were only occasionally or rarely observed. The only frequently encountered species was a small unidentified nektonic species (possibly a synodontid) that darted in and out of view of the camera. Occasionally observed species included *Holanthias martinicensis*, roughtongue bass (12); *Rhomboplites aurorubens*, vermilion snapper (nine); *Chaetodon aya*, bank butterflyfish (seven); juvenile *Caranx* sp., jacks (five); synodontid lizardfish (five); *Liopropoma eukrines*, wrasse bass (four); *Serranus phoebe*, tattlers (four); and a species of schooling serranids (several observations of schools).

Rare fish and nekton dominated the species list and included *Micropogonias undulatus*, Atlantic croaker (one school of four, and one solitary); *Pristigenys alta*, short bigeye (two); *Stenotomus caprinus*, longspine porgy (three); *Centropristis ocyurus*, bank sea bass (one confirmable, and three questionable observations); *Rachycentron canadum*, cobia (two); *Diplectrum bivitattum?*, dwarf sand perch (one); *Epinephelus nigritus?*, Warsaw grouper? (one); *Apogon pseudomaculatus*, two-spot cardinalfish (one); an unidentified holocentrid squirrelfish; *Prionotus* sp., sea robin (one); *Peprilus burti*, Gulf butterfish (one); *Decapterus punctatus?*, round scad (one); and possibly *Centropristis philadelphica*, rock sea bass (one). One unidentified squid was also noted.

The only evidence of human interference at this site was one piece of rope or cable on a rock outcrop.

The nature of this paleo-shoreline and the fauna associated with the feature are similar to the patch reefs (Station 6) in some respects. The vertical relief is comparable (around three meters), as is the nature of the bottom. The dominant epifauna are also similar. The patch reefs differ from this area, however, in their horizontal extent and their discontinuous nature. The shoreline appears to consist of a continuous hard bottom along which relief may vary, but bottom type remains similar. Between patch reefs, on the other hand, there are extensive areas of coarse sand.

Grab Characterization - Grab 6 contained coarse sand, fine shell hash and shell fragments.

13.3.1.6 Station 6 - Patch Reefs (formerly called Boulder Field)

Video Survey - This site was surveyed on three different occasions. The first survey was carried out on 22 July 1988 during a period of time in which bottom water turbidity was very high. During the second visit on 26 September 1988, an Atlantic bonito (*Sarda sarda*) lodged in the ROV in the space between the video camera and the ROV frame. The fish could not be detected underwater and caused considerable turbidity by thrashing back and forth in front of the video. The final visit occurred on 27 September 1988 and was carried out under nearly ideal conditions of visibility. The descriptions below are based on the first and last visits to the area, though the details provided were obtained from videos made during the first visit.

Side-scan records suggested that this ROV site contained hundreds of small, roughly circular patches of hard bottom. Measurements from side-scan and subbottom records indicated that most features were less than 10 meters across and less than three meters high. During one survey we encountered 14 reefs in a circular area 60 m in diameter. The area between features was flat, sandy bottom.

Video records made on 22 July 1988 totaled 1.96 hours and were made between 0157 and 0356 hours at 29°26.63'N, 87°41.15'W. Due to the high turbidity during this visit, it was difficult to determine whether the observations on this dive confirmed interpretations of side-scan records. Visibility was nil on the bottom at 75.6 m (248 feet) and less than one meter up to two meters above the bottom, making most video images unclear. The depth at the top of this turbid water layer varied between 73 and 74 meters.

Reefs were isolated structures separated by expanses of coarse sand bottom. The bases of the reefs were all at slightly below 75 m (between 247 and 248 feet). The tops of the reefs varied in depths from 72.5 m (238 feet) to 73.5 m (242 feet), They averaged slightly over two meters in height. The reef faces were invariably rugged and generally vertical. Some had overhanging substrates. The tops were generally five to 10 m in horizontal extent, and in most cases rather smooth. The shallowest reef, which peaked at 72.5 m depth, had a rough, rounded top less than two meters in diameter. Where the bases of reefs were visible, "silt aprons" often existed. These consisted of fine sediments that appeared to extend up to 0.5 m up the reef face and the same distance out over the surrounding coarse sand bottom.

The depth of the tops of these reefal features is approximately six meters below the deepest portion of the shoreline feature suveyed at a site just to the north (Station 5). The shape of these features, their abundance, and their location relative to the paleo-shoreline suggest that they may represent drowned lagoonal patch reefs that existed in a pre-Holocene bay or lagoon, possibly behind a larger reef system. Similar reefs are abundant, for example, in shallow water on the Bermuda Platform (Ginsburg and Schroeder 1969; Morris et al. 1977). The smaller Bermuda patch reefs are similar in size to those observed in this study. Also on the Bermuda Platform, there exist "cup reefs", or "boilers", which are of similar size and shape, grow in clusters in some places, and are composed primarily of encrusting coralline algae (*Lithothamnium*), vermetid gastropods, and *Millepora* corals.

There was significant vertical variation in the cover and abundance of hard bottom organisms on the patch reefs. The biotic assemblages on tops of the reefs were, with one exception, dominated by a higher diversity community than the reef faces. This assemblage included gorgonian and antipatharian corals, and ahermatypic scleractinian (stony) corals. The non-stony coral community included pale bushy antipatharians (*Antipathes* sp.: occasional), *Cirrhipathes* sp. (occasional), *Elisella barbadensis* (occasional), *E. funiculina*? (occasional), *E. elongata* (occasional), bushy orange sea fans (rare), *Bebryce* sp. (occasional), possibly *Thesea* spp. (occasional), possibly *Nicella* sp. (occasional), and one white branched gorgonian (possibly *Muricea pinnata*). Hard corals included *Rhizopsammia manuelensis* (frequent), *Madrepora carolina* (occasional) and possibly *Oculina* sp. (occasional). Apparent on some patch reefs were encrusting orange (frequent) and white (rare) sponges.

The one exception to the above pattern of reef top community development was at a reef with a very limited reef top area. This reef was dominated by the hard coral *Rhizopsammia manuelensis* and contained only isloated individuals of the species *Cirrhipathes* sp., *Madrepora carolina*?, and *Elisella barbadensis*. The limited area and rugged nature of this reef top may have precluded the gorgonian and antipatharian community that seems to occur on other, larger reefs at this and other sites of the study region. In fact, the *Rhizopsammia* dominated area looks much like those seen on the upper reef face of the other patch reefs, and on the reef faces and tops of the pinnacles farther offshore, all of which are characterized by rugged topography rather than flat hard bottom areas.

The reef faces, or sides, of the patch reefs were dominated by *Rhizopsammia manuelensis* (frequent on reef faces). That is, the relative abundance of this coral was considerably higher than on the tops of the patch reefs. Other corals included *Elisella barbadensis* (occasional), *Cirrhipathes* (occasional), *Madrepora carolina* (occasional), and *Oculina?* (occasional), and one bushy orange sea fan. Orange encrusting sponges were occasionally observed. Also seen was one large clump of the oyster *Neopycondonte cochlear.*

Though the relative abundance of the scleractinian coral *R. manuelensis* was highest on reef faces, the species was probably most abundant on reef tops. The abundance decreased significantly with depth as the bottom was approached. Cover in general was low on reef faces. Most of the rock area was devoid of conspicuous macrofauana. Furthermore, cover and diversity decreased with depth and became nearly zero within approximately 0.2 m of the bottom.

Epifauna associated with the highest diversity reef top areas (those populated by gorgonians, antipatharians, and hard corals) were relatively few. This may have been an artifact of the poor visibility during the first visit to the patch reefs. The fauna included *Astrophyton* sp. (basket stars; five), an unidentified ophiuroid (brittle star: one) on a gorgonian, and *Scaphella junonia* (a volute gastropod: one). None of these species were observed on reef faces, reflecting the low diversity of epifauna on these surfaces.

Fifteen species of fish were observed during the first survey of the patch reef field. The fish fauna associated with reef tops included two species of unidentified Holocentridae, squirrelfish (on reef top and reef face: two); *Chaetodon ocellatus*, spotfin butterflyfish (one); *Apogon pseudomaculatus*, twospot cardinalfish (one); *Serranus phoebe*, tattler (one); and *Centropristis ocyurus*, bank sea bass (one).

The only fish seen on reef face surfaces and not elsewhere included the whiting, *Menticirrhus saxatilis?* (one).

Species on or near sandy bottoms included *Synodus intermedius*, the sand diver lizardfish (two); *Stenotomus caprinus*, longspine porgy (one); and *Prionotus* sp., sea robin (one).

Water column species included carangids (possibly *Trachurus lathami*, the rough scad: frequent between 74 and 76 m); unidentified, small, dark colored, darting, synodontid-like fish also seen at Station 5 (frequent);

Peprilus burti, Gulf butterfish (three); unidentified sparids (porgies: two); and *Rhomboplites aurorubens*, vermilion snapper (73 and 74 m: two).

There were no indications of human interference noted during the first dive at this ROV site.

Grab Characterization - Grab 7 contained coarse sand, fine shell hash, shell fragments, and a small silt/clay fraction. It was most likely taken from an area of sandy bottom between patch reefs.

13.3.1.7 Site 7 - Shoreline in Western Portion of Study Area

Video Survey - This portion of the supposed paleo-shoreline was chosen for video reconnaissance because subbottom data indicated an increase in depth of some eight meters over a distance of one to 200 m across the feature. It seemed a likely area for considerable hard bottom exposure and benthic community development. Depth in the survey area (29°25.33'N, 87°54.68'W) ranged from 65.8-67.7 m (216-222 ft.) with depth increasing rapidly to the southwest. Two circular areas with radii approximately 60 m each and separated by 40 m were surveyed. Video survey time was from 0758 to 1037 (2.03 hours of video records). Turbidity here was quite high with visibility near the bottom less than five feet.

Hardgrounds were abundant. Hard substrates consisted of areas with rubble on coarse flat bottom, hard surfaces covered with fine sandy veneers, and rock outcrops up to one meter in height. One outcrop had a small "silt apron" around its base, suggesting the accumulation of fine sediments by the feature. Another outcrop had a small, 0.3 m overhang approximately 0.5 m above the bottom. In addition to hardgrounds, three, 10-15 cm tall mounds were seen in coarse sediments between rocky features. The nature, extent, and diversity of the biological communities on hardgrounds suggests that burial of these substrates is not a common event under typical conditions, despite their low topography. This does not preclude the possibility that these features may be affected by storm events. The slope of the substrate in this region, however, may prevent the accumulation of sediments.

All hard bottoms had surprisingly well developed gorgonian and antipatharian communities. This development included higher diversity and higher abundances than had been seen in other areas of comparable topography. This assemblage was dominated by bushy antipatharians (*Antipathes* sp., frequent) *Thesea*? sp., and *Bebryce*? sp. (frequent). These organisms were present and occasionally abundant in all areas containing hard substrates. Other species included small white sea fans (occasional), at least two species of white branching gorgonians (occasional: 14), *Cirrhipathes* sp. (occasional), thick-branched orange gorgonians (occasional), thick-branched brown gorgonians (occasional), *Nicella guadalupensis* (occasional), very densely branched, bush-shaped coral colonies (occasional), brown, sparsely branched sea fans (*Nicella*? sp., rare), *Elisella barbadensis* (rare: four, pinnate gorgonians (rare: three on one rock outcrop), a thin gorgonian? with very long, non-branching axial rods (rare: two groups), large brown sea fans (rare: three), two colonies of *Nidalia occidentalis*, a mushroom shaped alcyonacean corals on stalks, and thin-branched orange gorgonians (rare: one). Due to the poor visibility, there are undoubtedly also unrecognized species.

Hard corals were apparently rare, or possibly occasional, on the outcrops along this shoreline. *Rhizopsammia manuelensis* was seen on only five occasions and was not abundant. The only other coral observed was a solitary, white polyp with a diameter of two to three centimeters (*Oxysmilia*? sp.).

The sponge fauna was more diverse here than at any sites previously described. This included both orange and white encrusting colonies (occasional), white globose colonies (occasional: eight), orange globose colonies (occasional: seven), pale globose colonies (rare: four at one outcrop), orange branched colonies (occasional: four), and black sponges (rare: two).

Invertebrates associated with hardgrounds included orange crinoids with black pinnules (*Comactinia echinoptera*, occasional: nine), pennatulaceans (sea pens, occasional: six), *Astrophyton* sp. (basket star, occasional: four), tan crinoids (rare: one), *Busycon* sp. (rare: one), a sea star (one Goniasteridae, rare: two), and *Stenorhynchus seticornis*, the arrow crab (rare: one).

The fish fauna appeared rather depauperate at this site. Species included *Centropristis ocyurus*, bank sea bass (occasional: 13), *Serranus phoebe*, tattler (occasional: five), *Holanthias martinicensis*, roughtongue bass (rare: two), another Serranidae, sea bass (rare: two), *Pristigenys alta*, short bigeye (rare: two), *Chromis enchrysurus*, yellowtail reeffish (rare: one), *Apogon* sp., cardinalfish (rare: at least two in a depression), possibly *Microspathodon chrysurus*, yellowtail damselfish (rare: two), a Sparidae, porgy (rare: two), *Liopropoma eukrines*, wrasse bass (rare: one), another Labridae, wrasse (rare: one), and a Muraenidae, eel, in a burrow (rare: one).

Comparison of data from this site with those from other sites of comparable topography suggests not only a relatively high diversity here, but also lower abundances of the same species dominant at other sites. In particular, very few crinoids, only four *Elisella barbadensis* colonies, and two short bigeyes, *Pristigenys alta*, were observed at this survey site. Along with *Thesea* sp., *Antipathes* sp., and *Cirrhipathes* sp., these species were conspicuous at other outcrops along paleo-shorelines and on low topographic features. Interestingly, where *P. alta* were seen, they occurred with *Chromis enchrysurus*, the yellowtail reeffish, just as they did on other low topographic features.

The only sign of human interference at this station was a (metal?) bar approximately 0.5 m long and two to three centimeters in diameter lying on a rubble covered bottom.

Dredge Characterization - Rock Dredges 7 and 8 were taken at this site. Both contained diverse collections. Rock Dredge 7 contained the gastropods *Scaphella junonia* (two, one live), *Polystira* sp. (live), *Terebra floridana* (live), and *Cassus* sp. (fragment), the pelecypods *Astropecten nitidus*, *Plicatula gibbosa*? (attached to *Oculina diffusa* fragment), *Ventricolaria rigida*, *Ventricolaria rugatina* , *Eucrassatella speciosa* (live), *Lyropecten nodosus*, and other Pectinidae. It also contained the hermit crab *Dardanus insignis* (in *Polystira* sp.), a batfish, *Ogcocephalus nasutus*, and a small, purple globose sponge.

The coral fragments in Dredge 7 were particularly interesting. They consisted of the telestacean *Telesto flavula*? (live), fragments of *Oculina diffusa* (dead), the solitary Caryophylliidae *Paracyathus pulchellus* (one live, five dead), and the agariciid *Agaricia fragilis* (dead). The presence of *Telesto* suggests that some of the low cover observed on hard substrates may consist of this species. The occurrence of *Oculina* and *P. pulchellus* in sediments supports our identification of the species on reef substrates. The occurrence of *A. fragilis*, a hermatypic (reef-building) species found on actively growing coral reefs suggests a potential relationship between hard substrata in the study region and reef-building corals.

Rock Dredge 8 contained the echinoderm *Linkia nodosa* Perrier, *Brissopsis* sp., and an echinoid test. It also contained a convoluted tan sponge, a golfball-size mass of serpulid worms, branching bryozoans, branching hydroids, the gastropod *Phalium* sp. (fragment), the pelecypods *Ventricolaria rigida* (three live, 17 valves) and *Amygdalum sagittatum*?, a platyhelminth, the crab *Rochinia tanneri*, and a number of colonies of the paramuriceid coral *Bebryce cinerea*. It is likely that *Bebryce cinerea* is among the species making up the low understory of many hard substrates in the study area.

Grab Characterization - Grab 8 contained coarse sand, fine shell hash, shell fragments, and a small silt/clay fraction.

13.3.2 Preliminary Site Descriptions

The following site descriptions are based on the preliminary analyses of video tapes, stereo photographs, rock dredge samples, and grab samples taken primarily during 88-MMS-ROV-2 (September 1988). Detailed site descriptions will be provided in the Year 3 annual report.

13.3.2.1 Station 8 - West Reefs

Reefs of major topographic relief exist seaward of the paleo-shoreline. Their crests are at depths of approximately 63 m (nearly coincident with, but shallower than, the depth of the nearby paleo-shoreline) and their bases are at approximately 75 meters. Some have rugged reef tops while others are decidedly flat-topped. Individual reefs may be over 100 m across. One formation exists that appears to contain several separate reefs crowded together. This formation is over 500 m long. All reefs seem to contain rugged, and in some places, nearly vertical reef faces. They are surrounded by expanses of coarse-grained sediments.

Epibenthic biological community development is extraordinary. The tops of the features are inhabited by large populations of gorgonian corals, antipatharians, and crinoids. Reef faces are dominated by ahermatypic scleractinian corals (especially *Rhizopsammia manuelensis* and *Oculina* sp.), but also contain antipatharians (*Cirrhipathes* sp. and *Antipathes* sp.) and gorgonians. Sponges are present, but do not seem to be as abundant as they are on top of the reefs at the 40 Fathom Fishing Grounds (Stations 13 and 14 below).

The fish population at this station may have been the largest of any observed. The top and edges of the reefs were inhabitat by dense schools consisting of a number of species. Identifications are difficult, since the fish scattered when the ROV approached, but species present seemed to include primarily the roughtongue bass, *Holanthias martinicensis* and the streamer bass, *Hemanthias aureorubens*. One blue angelfish, *Holacanthus bermudensis* was also seen within a school. The schools contained mostly small individuals (less than 20 cm).

13.3.2.2 Station 9 - West Patch Reef Field

Approximately two kilometers southwest of Station 8, an area was surveyed that appeared on side-scan records to be similar to, but less extensive than, the Patch Reef Field (Station 6). That is, reefs seemed to be of moderate topographic relief, but areally restricted.

The bottom depth was 75-76 m and consisted of a mixture coarse grained sediments containing shell hash, and silt. The shallowest feature crested above 71 m and did not have a flat reef top. The assemblage inhabiting the reef was similar to that on the vertical and sloping faces of other reefs, and included the hard corals *Rhizopsammia manuelensis* and *Oculina* sp., a number of gorgonian corals, the basket star *Astrophyton*, and the ophiuroid *Ophiothrix* sp. There were also a number of low topographic features between larger formations. These were generally less than one meter high rock outcrops or rubble mounds. On these structures, gorgonian assemblages dominated and ahermatypic scleractinian corals were nearly lacking, probably as a result of sediment resuspension effects on small, low growing colonies.

Fish species observed were similar to other reefs and topographic features in the study area, including, among others, *Chaetodon aya* (bank butterflyfish), scorpaenids, *Holanthias martinicensis* (roughtongue bass), and sparids (porgies).

In some respects, the reef formations at this site were similar to the reefs at Station 6, in that formations were separated by expanses of coarse sandy bottom tens of meters in extent and contained similar faunal assemblages. The formations here, however, were smaller and fewer in number than at Station 6. Though a small number of reefs nearly identical in size to the patch reefs were surveyed, most were low topographic mounds and outcrops. At Station 6, few low features were encountered.

13.3.2.3 Station 10 - Shoreline/Ragged Bottom

This section of the presumed paleo-shoreline was approximately six kilometers southwest of the patch reef field (Station 6). The deepest bottom depth was over 73.5 meters. It was an area with a large number of low relief features, most between 0.5 and one meter high. The shallowest crested at 67.5 m and was over four meters tall. The few features taller than two meters had bases in depths shallower than 72 meters. Beyond this depth, there were more features of low relief and more coarse sand bottom. Based on the depths observed during the dive, our survey site appeared to be located on a sloping bottom somewhat seaward of the crest of the shoreline feature. Surrounding sediments near hard bottoms appeared to contain higher levels of silt than areas away from the reefs, and the bases of reefal structures were frequently covered by "silt aprons" extending upward less than one meter. These aprons may be the result of accumulation by the reefs of resuspended fine sediments in the nepheloid layer.

Benthic biological communities and fish populations were composed of the same species as found on other hard bottom structures. Epibenthic assemblages were fairly dense, especially on features of highest relief. Some benthos included the hard corals *Rhizopsammia manuelensis*, *Oculina* sp., and *Madrepora carolina*, the antipatharians *Cirrhipathes* sp. and *Antipathes* sp., the gorgonians *Thesea*? sp., *Bebryce* sp., *Elisella* spp., *Nicella guadalupensis* and other fan shaped gorgonians, and crinoids (especially *Comactinia echinoptera*). At least two species of encrusting sponges were occasionally seen. As at other sites, hard corals were more abundant on higher relief features. Gorgonians and comatulid crinoids were present on virtually all outcrops and dominated those of low relief.

13.3.2.4 Station 11 - Footprints

This survey site was chosen because the side-scan records indicated a number of anomalies resembling depressions in the bottom on the order of 10 m across and deep enough to produce side scan "shadows" in their centers. They were called "footprints" because they appeared to be oblong rather than circular.

The bottom depth during the survey varied negligibly from 96 meters. Turbidity was fairly high in places and visibility was sometimes less than one meter. The bottom appeared to consist of a mixture of medium-grained sand and finer sediments. Shell hash was rare. Small burrows were abundant. Mounds and small depressions were also occasionally seen. Though rare, coiled sea whips (*Cirrhipathes* sp.) were seen protruding through the sand, but no hard bottom was detected at this site. Though one synodontid (*Synodus intermedius*?) and one flounder were seen, virtually no biological activity was detected at the surface. This may have been partly due to the fact that the survey took place during the day (around 0900 hours).

We did not detect the unusual features noted on side-scan records during this survey. Even if the features had been visited, the limited visibility may have precluded their detection.

13.3.2.5 Station 12 - Snake Ridge

Side-scan records from this site suggested a sinuous ridge nearly four kilometers long running northeast-southwest, apparently having highly reflective sediments and exposed, patchy hard bottom on the seaward side and less reflective sediments landward. Depth recordings made during 88-MMS-ROV-2 suggested that the ridge appearance was probably caused by a change in slope that occurs coincidently with the feature. That is, depth increases rapidly as one crosses the feature from the north side.

The survey site was located on this steep slope. The deepest survey depth was 116 m and occurred at the south boundary of the station. The shallowest depth was 109 m less than 50 m to the north. Depth records showed that the top of this slope was at approximately 102 m and indicated a seaward slope of over 10°. Unfortunately, we were not able to locate the ship over this depth and did not survey the top of the slope.

On the south side of the ridge at Station 12, sediments were coarse with abundant shell hash (including *Neopycnodonte* oyster shells) and rubble was frequently observed. One small rock outcrop was seen at 116 m, which contained two short bigeyes (*Pristigenys alta*), *Nicella* sp. sea fans, and *Paracyathus*? sp. ahermatypic corals. Species observed on the sandy bottom were those seen at many other sites, and included scorpaenids, tattlers (*Serranus phoebe*), flounders, and sea stars. Fish burrows were occasionally observed.

13.3.2.6 Stations 13 and 14 - 40 Fathom Fishing Grounds

The 40 Fathom Fishing Grounds, though not commonly known by this name, are apparently well known to local fishermen. Fishing boats were seen during at least one side-scan cruise and both ROV cruises within the area containing these features.

The reefs in this area arise from surrounding depths of 73 to 78 m and crest at various depths depending on the extent of reef development. The shallowest seen by us crested at 62.5 m and was over 14 m tall with an extensive, flat reef top which contained a number of sand flats. This and other accordant reefs (i.e., same crest depths), namely those surveyed at Station 8, 40 km to the west, all appear to contain this type of reef top. They also appear to be the largest reefs, by basal area, of the region. Those whose crests are below this depth have rugged topography on their tops and are generally smaller in total area.

The structure of the reef faces is nearly identical to reef faces seen at Station 8 (West Reefs) and Station 18 (Pinnacles). That is, all had rugged, sometimes overhanging, rocky faces. In many places, reef faces were vertical. While benthic communities were fairly well developed in certain areas on the reef faces, large patches of what appears to be heavily bioeroded reef rock containing virtually no epifauna suggest the reef faces may be gradually deteriorating.

Reef flat communities on these features are very well developed. Very little hard bottom space is unoccupied. The community is a lush assemblage of gorgonian corals, antipatharians, many types of sponges, several species of crinoids, bryozoans, holothurians, sea urchins, basket stars (*Astrophyton*), patches of coralline algae, and fish. The fish fauna is dominated by a huge population of roughtongue bass (*Holanthias martinicensis*; virtually every crevice was occupied during our night survey), but also includes vermilion snappers (*Rhomboplites aurorubens*), short bigeyes (*Pristigenys alta*), butterflyfish (*Chaetodon* spp.), cowfish (Ostraciidae; our siting of the honeycomb cowfish, *Lactophrys polygonia*, confirmed by Mr. George Dennis, Univ. of Puerto Rico, is the first for the Gulf of Mexico), puffers (Tetraodontidae), scorpaenids, and others. Besides vermilion snappers, commercially important species included amberjacks (*Seriola dumerili*, generally in schools) and a small number of red snapper (*Lutjanus campechanus*).

Few ahermatypic scleractinian corals were seen on reef flats. They may be affected by sediments that have accumulated on the reefs. On the sides and edges of the reef, however, these corals abound. The hard coral fauna on reef faces is dominated by *Rhizopsammia manuelensis*, *Madrepora carolina* and *Oculina*? sp. Other conspicuous organisms included crinoids, antipatharians, and sea whips (*Elisella* spp.), all of which are common reef face dwellers on other high relief features in the study area.

13.3.2.7 Stations 15 and 16 - Moderate Features

These sites were visited because they appeared on side-scan records to represent geological structures intermediate in size between low and high topographic features. The vertical relief of the largest features, at Station 15, averaged only two to three meters, but the reefs had basal diameters of several tens of meters. Small outcrops 0.5 to 1.5 m tall and one to two meters across surrounded the larger reefs. There was no evident association between these features and other geologic structures in the study region. That is, they appeared to be isolated structures. They existed behind (i.e. shoreward of) the paleo-shoreline and in shallower water.

The surrounding depth at Station 15 was 63 to 64 meters. Minimum depth was approximately 60 meters. Surrounding sediments appeared to be coarse with little fine fraction and had small ripples and mounds. The sides of the features were rugged compared to their flat tops and harbored the hard corals *Rhizopsammia manuelensis*, and possibly *Oculina* sp. and *Madrepora carolina*, gorgonians, including *Elisella* sp., *Nicella* sp., and *Thesea*? sp., antipatharians, sponges, and large amounts of crustose coralline algae compared with other survey sites (possibly because they are somewhat shallower).

The flat reef top area supported a gorgonian dominated assemblage similar to those observed at Stations 8, 13, and 14, but with much lower population levels and density. Furthermore, fewer large gorgonians were observed. Sand, which was more abundant on the reef top than had been seen at higher relief stations, may inhibit community development on these reefs. The comparatively low relief of these features and their flat tops may enhance the accumulation of this sediment.

Station 16, 24 km to the southwest of Station 15, and at the same depth, was quite different. No significant relief was seen during the survey. Rock substrates were no higher than one meter above the bottom. Hard bottom organisms were scattered, but may have been attached to moderate sized subsurface features, since community boundaries were fairly large (10 or more meters across). Community development was poor on most outcrops and appeared to be comparable to that on low topographic features at Stations 2 and 6. Between patches of hard bottom organisms were expanses of silt-laden coarse sediments. This silt and sand, along with limited substrate availability, may limit community development.

13.3.2.8 Station 17

Due to a logging error, no station was assigned as number 17. To avoid confusion in sample labels, field logs, etc., a decision was made not to change previously assigned station numbers. Therefore, Station 17 does not exist.

13.3.2.9 Station 18 - Pinnacles

The pinnacles, which were first described by Ludwick and Walton (1957), are tall, thin biogenic prominences arising from present-day depths of 99 to 109 meters. Over 100 of these features exist in an area five by five nautical miles at the edge of the continental shelf south of Mobile Bay. This area was surveyed in detail by Ludwick and Walton. The shallowest pinnacle mapped peaked at 87.8 meters. The tallest was over 16 m, but the average height was nine meters.

Reef rock was found to contain the remains of crustose coralline algae (*Lithothamnium*), serpulid worm tubes, bryozoans, ahermatypic corals, and forams (Ludwick and Walton 1957). No living calcareous algae were found, suggesting that the pinnacles are not living reefs and should be considered at a stage intermediate between living and fossil geological structures.

On 88-MMS-ROV-2, we surveyed a pinnacle located at 29°19.94'N, 87°46.37'W. This location coincided with a mapped pinnacle that peaked at 49.5 fm (90.5 m). In fact, this was the shallowest depth recorded during our survey of the feature. It was among the three shallowest peaks noted in the 1957 survey. The surrounding depth was between 102 and 105 meters. The pinnacle was approximately 12-15 m tall.

Unlike some geologic features surveyed at Stations 8, 13, and 14, the pinnacle tops are not accordant. Peaks depths range from 88.7 to 109 m for those shoreward of the 120 m contour. Furthermore, based on previous mapping and more recent video surveys, the tops of the features do not have extensive reef flats like Stations 8, 13, and 14. Reef flats may be caused be either truncation during low sea level stands, or by upward growth to sea level and death due to rapid sea level rise. Regardless, it is likely that these mechanisms did not affect top reef topography of the pinnacles.

Since very few horizontal surfaces are available on the pinnacles, biological communities are composed of those species able to attach and grow on rugged, often vertical, and occasionally overhanging reef rock. The assemblage resembles those inhabiting the reef faces (not reef flats) of the other large reefal structures in the study region, namely, Stations 8 (West Reefs), 13, and 14 (40 Fathom Fishing Grounds), and to some extent, Stations 6 (Patch Reefs) and 15 (a moderate feature). Virtually all the dominant species are suspension-feeding invertebrates. The most conspicuous are the ahermatypic corals *Rhizopsammia manuelensis* and *Madrepora carolina*, other solitary and colonial ahermatypic scleractinian corals, gorgonian corals, including *Nicella guadalupensis*, *Elisella* spp., *Thesea* sp., and large sea fans, one alcyonarian (*Siphonogorgia agassizii*?), several species of crinoids, basket stars (*Astrophyton*), and oyster clumps (*Neopycnodonte cochlear*).

Preliminary analysis of video tapes corroborates the suggestion by Ludwick and Walton of an absence of living coralline algae on the pinnacles. Unlike the pinnacles, however, coralline algae appears to be frequent on the reef flats and reef tops of structures in shallower water that peaked in 62 to 64 meters. What we assume to be coralline algae crusts were observed in at least 70 m of water on the faces of these reefs. Crusts were also seen at 66 m on outcrops along the paleo-shoreline at Stations 4 and 5, but not at 73 m on top of the patch reefs (at least on 88-MMS-ROV-1, when turbidity was high). Thus, environmental controls in this part of the Gulf of Mexico appear to limit the distribution of calcareous algae to a depth between 70 and 90 m, and possibly between 70 and 75 meters.

Despite the absence of coralline algae, the reef face community on the pinnacles may be more highly developed than communities on the other reefs, in that densities appear higher, and larger colonies are commonly observed. Species richness may, however, be comparable to other major topographic features of the study area. One factor likely contributing to this superior development is a larger amount of rugged reefal substrate than other reefal tracts. Another may be the pinnacles' shelf-edge locations, which may result in generally clearer water, less frequent episodes of turbid water, a more favorable current regime, and possibly episodic upwelling.

13.3.2.10 Stations 19 through 23 - Rock Dredge and Grab Sample Stations

Station 19 (29°24.66'N, 87°57.17'W) was in the western portion of the study area. It produced a side-scan record suggesting non-reflective sediments and no topographic relief. We took a grab sample (Grab 9) and confirmed the presence of fine sand containing some silt and clay. Such sediment would be expected to produce this signature on side-scan records.

Stations 20 (29°23.89'N, 87°58.88'W) and 21 (29°23.88'N, 87°59.54'W) were located adjacent to a large, flat-topped reef (Station 8). Station 20 was located about 600 m southeast of the reef in non-reflective sediments. Station 21 was located a similar distance to the west in highly reflective sediments which appeared to compose a "sediment apron". Station 8 and other topographic features in the study area commonly exhibited sediment aprons several hundred meters long on their west and southwest sides, with limited expression on the east sides. Station 20, on the southeast side of Station 8, consisted of fine sand containing some silt and clay (Grab 10). Station 21, west of the reef, consisted of coarse sand and shell hash (Grab 13).

Station 22 (29°23.89'N, 87°32.42'W) was the deepest station sampled in the study. Side-scan records indicated an area of patchy strong returns in the area. This signature was similar to that at Station 1, but was at 172 meters. The samples have yet to be analyzed. Field description of the dredge sample (Dredge 15) indicated "castings - bioclastic nodules - shells". Grab samples from Station 1 (Grabs 1 and 2) included medium to coarse sand, fine shell hash, shell fragments and one disarticulated shell.

Station 23 (29°27.12'N, 87°40.44'W) was located between Stations 6 (Patch Reef Field) and 5 (Shoreline North of Patch Reef Field). Two rock dredges were attempted at this site. The first dredge (Dredge 1) returned empty and may have been dragged over an area of clean sediment. No shell hash or other material was dredged. The second attempt at this location resulted in the dredge hanging on a reef. After about two hours of ship maneuvering and tugging, the dredge had to be sacrificed. The effort, however, underscores the variable nature of the bottom over very limited areas in this portion of the study region.

13.4 <u>Discussion</u>

13.4.1 Biological Community Composition

Biotic assemblages on hard bottom areas within the Mississippi-Alabama study region consist of predominantly suspension-feeding invertebrates. Epibenthos include gorgonian corals, ahermatypic scleractinian corals, antipatharian corals, sponges, comatulid crinoids, bryozoans, alcyonarians, and oysters (roughly in this order of abundance). Coralline algae crusts are frequent on hard bottom features shallow enough to allow sufficient light penetration and sufficient vertical relief to reduce the effects of smothering by fine sediments. They may be absent on hard bottoms below approximately 70 meters.

Abundance and diversity vary considerably between features. Both appear to increase with the amount of exposed hard bottom, rugosity, and the complexity of the features (i.e. the number of bottom types available to hard bottom organisms). Very small outcrops and very low topographic features were barren only when sediment blanketed them completely. Most contained a low diversity assemblage consisting of some of the epibenthos mentioned above (usually crinoids, gorgonians, or antipatharians), and associated invertebrates (mostly occasional sitings of crabs, molluscs, and echinoids). Nekton typically included short bigeyes (*Pristigenys alta*), yellowtail reeffish (*Chromis enchrysurus*), bank butterflyfish (*Chaetodon aya*), and tattlers (*Serranus phoebe*). On bottom features of intermediate size and complexity (e.g. outcrops along the paleo-shoreline, the moderate features, and the patch reefs), diversity and abundance of benthic epifauna, associated benthos, and associated nekton were higher.

Though data have not yet been analyzed in detail, the highest diversity and abundance appears to be on major topographic features. However, habitat complexity (the number of bottom types available to hard bottom organisms) may affect both these parameters on major features. For example, while live-bottom assemblages on both the Pinnacles and on flat-topped reefs in the 40 Fathom Fishing Grounds can clearly be defined as "lush", the presence of reef flats on the latter features results in an extensive and diverse reef flat biotic assemblage consisting of gorgonians, sponges, crinoids, antipatharians, coralline algae, and a large number of bottom associated fish (especially roughtongue bass, *Holanthias martinicensis*). Sponges and gorgonian corals on the Pinnacles are less abundant, apparently limited by the lack of horizonal expanses on these rugged reefs.

Fauna associated with epibenthic communities vary in type. Some are suspension feeders, such as the basket stars (*Astrophyton*, frequently attached to gorgonian corals), crinoids, serpulid worms, pennatulaceans, and the brittle star *Ophiothrix* sp.. Some are sandy bottom deposit feeders, such as the echinoids *Clypeaster* sp., and *Brissopsis* sp. Most others are probably omnivorous, opportunistic scavengers, such as the gastropods *Scaphella* spp., sea stars, *Stenorhynchus seticornis* (the arrow crab, Williams 1984), and other crabs (e.g. *Rochinia tanneri* and pagurid hermit crabs). Sea urchins are typically considered grazers. Filamentous and leafy algae were not recorded from hard bottoms in this study, suggesting the sea urchins may also depend on opportunistic scavenging. One predatory invertebrate may be the fire worm, *Hermodice carunculata*, a polychaete which is known to feed on corals. The fish fauna probably consists of infaunal feeders, browsers, and predators. Table 13-2 lists fishes observed during detailed analysis of video tapes from ROV Stations 1 through 7 and during preliminary analysis of tapes and photographs from other stations.

13.4.2 Associations with Environmental Parameters

The effects of sedimentation may be the principal environmental control giving rise to variation in hard bottom epibenthic community development at different sites in this study area. The variation between biotic assemblages at different sites correlated with such parameters as the areal extent of features, vertical relief, habitat complexity, and the nature of surrounding sediments. These factors, however, invariably result in differential sedimentation effects at different sites. Because all these habitats are dominated by suspension feeders, this factor alone can have significant impact on population levels.

For example, the sides and tops of high relief reefs with rugged topography were dominated by low growing, ahermatypic hard corals. The smooth tops of reefs with extensive reef flats were dominated by the taller

Table 13.2. Fishes observed during detailed analysis of video tapes from ROV Stations 1 through 7 and during preliminary analysis of tapes and photographs from other stations (* indicates species observed only in sandy-bottom habitats).

CLASS ELASMOBRANCHIOMORPHA (Cartilaginous fishes)

Order RAJIFORMES
Family Rajidae
Dasyatis sp. - stingray *

CLASS OSTEICHTHYES

Family Muraenidae
Gymnothorax moringa - spotted moray
Gymnothorax ocellatus - ocellated moray
Muraena retifera - reticulate moray

Family Nettastomatidae
Hoplunnis macrurus - silver conger *

Family Ophichthidae
Ophichthus ocellatus - spotted snake eel *

Family Synodontidae
Synodus intermedius - sand diver (lizardfish)

Family Batrachoididae
Opsanus beta - Gulf toadfish

Family Ogcocephalidae
Ogcocephalus corniger - longnose batfish
Ogcocephalus nasutus - shortnose batfish

Family Gadidae
Lepophidium jeannae - mottled cusk eel

Family Ophidiidae
Urophycis floridanus - southern hake

Family Serranidae

Centropristis ocyurus- bank sea bass
Centropristis philadelphica? - Rock sea bass
Epinephelus nigritus?- Warsaw grouper
Serranus phoebe - tattler
Serranus tabacarius? - tobaccofish
Diplectrum sp. - sand perch
Liopropoma eukrines - wrasse bass
Hemanthias aureorubens - streamer bass
Holanthias martinicensis - roughtongue bass

Family Priacanthidae

Priacanthus arenatus - bigeye
Pristigenys alta - bigeye

Family Apogonidae

Apogon pseudomaculatus - 2-spot cardinalfish

Family Rachycentridae

Rachycentron canadum - cobia

Family Carangidae

Caranx? sp. - jack (juv.)
Decapterus punctatus? - round scad
Trachurus lathami? - rough scad
Seriola dumerili - greater amberjack
Seriola rivoliana - almaco jack

Family Lutjanidae

Lutjanus campechanus - red snapper
Rhomboplites aurorubens - vermilion snapper

Family Sparidae

Calamus bajonado - jolthead porgy
Calamus nodosus - knobbed porgy
Pagrus sedecim - red porgy (uncertain record)
Stenotomus caprinus - longspine porgy

Family Sciaenidae

Equetus punctatus - high hat
Menticirrhus sp. - whiting (*M. saxatilis or M. americanus*)
Micropogonias undulatus - Atlantic croaker

Family Chaetodontidae

Chaetodon aya - bank butterfly
Chaetodon ocellatus - spotfin butterfly
Chaetodon sedentarius - reef butterfly

Family Pomacanthidae

Holacanthus bermudensis or isabelita - blue angel

Family Pomacentridae

Chromis enchrysurus -yellowtail reeffish
Microspathodon chrysurus - yellowtail damselfish (uncertain record)

Family Labridae

Halichoeres bivittatus - slippery dick

Family Scombridae

Sarda sarda - Atlantic bonito

Family Stromateidae

Peprilus burti - Gulf butterfish

Family Triglidae

Prionotus spp. - sea robins

Family Bothidae - left-eye flounders

Family Ostraciidae

Lactophrys quadricornis - scrawled cowfish
Lactophrys polygonia - honeycomb cowfish (first record from Gulf of Mexico)

gorgonian corals. Hard corals may have been limited by accumulations of sediment on the reef tops. Low topographic features and small outcrops also had limited populations of hard corals and were generally dominated by gorgonians and antipatharians. It is likely that resuspended sediments limited hard coral populations on these features.

The effects of periodically resuspended sediments can be seen near the base of many topographic features. Within approximately 0.5 m of the surrounding bottom on some rocky features, very little epibenthic growth was noted. Typical reef face assemblages existed above these levels. The lack of growth near reef bases is likely attributable to smothering of suspension feeding organisms. Furthermore, some features had accumulations of fine sediments around their bases. These "silt aprons" typically extended upward 0.2 to 0.5 m and outward from the reef base 0.5 to one meter. The accumulations are probably transitory, but recurrent.

Depth did not appear to play a role in varying community development, with the exception of the occurrence of coralline algae and possibly one alcyonacean coral. Crusts of calcareous algae have not yet been seen on the Pinnacles (over 90 m deep), but were observed to at least 70 m depth on reefs at the 40 Fathom Fishing Grounds and on other features shallower than 70 meters. One alcyonacean coral was more abundant on the Pinnacles (Station 18) than other high relief structures, but it is not known whether the depth distribution of this species or other factors influenced its abundance. Other species making up the hard bottom assemblages were found at all depths and exhibited no apparent vertical zonation related to depth.

Had more depth variation occurred between features, zonation patterns might have been noted. Schroeder et al. (1988a) found that *Leptogorgia virgulata* and *Lophogorgia hebes*, both gorgonian corals, dominated biological assemblages on inner-shelf hard bottoms off Alabama to at least 35 meters. Shipp and Hopkins (1978) reported *Lophogorgia* spp. at 50-55 m depth on the northern rim of the DeSoto Canyon. Other gorgonians, antipatharians, and ahermatypic corals (*Rhizopsammia manuelensis*, *Madrepora carolina* and *Oculina* sp.) dominate the assemblage on features near the shelf edge (60-100 m). On a large reef at 230-280 m 74 km east of the Mississippi River, Moore and Bullis (1960) reported *Lophelia prolifera*, an ahermatypic species which also forms reefal structures elsewhere in deep water (e.g. Newton et al. 1987). Though *Leptogorgia* and *Lophogorgia* may occur in the present study area, they were not considered among the dominant species. *Lophelia* was not found in the study area.

13.4.3 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). Reefs in the southern Gulf are decidedly tropical in nature (Rezak et al. 1985), having community structure and dominance patterns similar to coral reefs in the Caribbean, the Florida Keys, and the Bahamas. Reefal assemblages in the northern Gulf of Mexico (including the Flower Garden reefs [Rezak et al. 1985] and the Florida Middle Ground [Hopkins et al. 1981]) are less diverse. Near-shore benthos (both hard and soft bottom organisms) in the northern Gulf 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).

Based on community similarity, Bright et al. (1984) hypothesized that the tropical fauna and flora on reefs of the northwestern Gulf of Mexico are derived from reefs in the southern Gulf (those on the Campeche Bank and southwestern Gulf). Coral assemblages on the Florida Shelf are more likely derived from larval transport and recruitment of Caribbean biota via the Yucatan Current and the Loop Current in the eastern Gulf.

The topographic features near the edge of the continental shelf off Mississippi and Alabama may be of similar age and origin to those described in the northwestern Gulf of Mexico (south Texas relict carbonate banks of Rezak et al. 1985), off Cape San Blas, Florida, and on the east coast from North Carolina to south Florida (see references and Table 1 in Avent et al. 1977). The majority of these relict (pre-Holocene) reefs arise from bottom depths of 75 to 125 m, are 10 to 25 m tall, and exhibit ages of 10,000-20,000 years bp. The reefs were probably formed by coralline algae and hermatypic corals near late Pleistocene shorelines. The presence of oceanic water masses near the shelf-edge shoreline during this period may have stimulated this growth (interestingly, many of the features have morphologies similar to present-day "pinnacles", "patch reefs", "table top reefs", and "cup reefs" found in shallow water on the Bermuda Platform [see Ginsburg and Schroeder 1969], which is influenced by the Gulf Stream). Reef building in the study area likely stopped because the features drowned with rapidly rising sea level. Their surfaces are now occupied by a variety of tropical, subtropical, and warm temperate organisms, depending on their location and environmental extremes. Present day communities vary considerably. Dominant organisms vary, but may include *Oculina* (e.g., Reed 1980), other ahermatypic scleractinian corals, coralline algae, gorgonian corals, antipatharians, crinoids, serpulid worms, and possibly others.

Few benthic organisms observed on the hard bottoms in the Mississippi-Alabama study area are typical, shallow-water, tropical reef species. In fact, none of the dominant species on features in the Mississippi Bight were found on the shallow portions of the Flower Garden Banks (Rezak et al. 1985) or the Florida Middle Ground (e.g. Grimm and Hopkins 1977), the nearest reefal environments to the study area. With the exception of coralline algae crusts, no living hermatypic species have yet been found. These features contain hard bottom communities similar to those on the deeper portions of topographic prominences in the northwestern Gulf of Mexico (see Rezak et al., 1985) and those on hard substrates on the northern rim of the DeSoto Canyon (see Shipp and Hopkins, 1978), both of which consist of assemblages predominantly of tropical origin. More specifically, species composition is comparable to the Antipatharian Zones and the Nepheloid Zones on outer shelf, midshelf and south Texas banks described by Rezak and Bright (1978) and Rezak et al. (1985). Their description of the fauna inhabiting drowned reefs, which exist below 82-88 m on shelf-edge features in the northwestern Gulf, is nearly identical to many hard bottom site descriptions given here. These zones contain limited crusts of coralline algae, several species of ahermatypic hard corals, sizeable populations of octocorals, including sea whips (Ellisellidae) and fans (Paramuriceidae and Ellisellidae), and antipatharians, comatulid crinoids, encrusting sponges, and "expatriate" reef fishes.

Features in the present study area, however, also have some elements of Rezak and Bright's Algal-Sponge Zone. For example, some have considerable amounts of crustose coralline algae. This component of the community, however is not nearly as well developed on reefs in the Mississippi Bight. On the other hand, development of the octocoral, sponge and crinoid assemblages on some reefs, primarily the reef flat communities at Stations 8, 13 and 14, appear to be much more highly developed than those in comparable biotic zones on the banks of the northwest Gulf.

The depth of Antipatharian Zones on shelf-edge banks in the northwestern Gulf is 52 to over 90 meters. Observations made in this study were on features from 60 to over 100 meters. The description by Rezak et al. (1985) of the deeper portion of the Antipatharian Zone (80-90 m) and on drowned reefs at the Flower Gardens is very similar to observations made over all depths in the present study. Differences in the depth range of these communities undoubtedly reflect differences in water quality. In fact, the depth ranges of Antipatharian Zones of South Texas mid-shelf banks and some North Texas-Louisiana mid-shelf banks are coincident with depths in which similar communities were observed in the present study area.

Minnery et al. (1985) reported coralline algae crusts (*Lithothamnium* sp.) at depths over 100 m on shelf-edge banks in the northwestern Gulf (though cover is sparse below 82-88 m). On banks off South Texas, crusts are present but cover is sparse on the features' crests near 60 meters. On Sonnier Bank, a North Texas mid-shelf feature, encrusting corallines occur down to 47 meters. The depth distribution of corallines on mid-shelf banks is limited, however, by a thick nepheloid layer covering the lower portion of these banks.

On reefs in the northestern Gulf, coralline algae have not been seen below 70 meters. This suggests that characteristics of water quality, particularly light penetration, near topographic features on the shelf-edge off Mississippi and Alabama may be intermediate between shelf-edge and mid-shelf features off Texas and Louisiana.

In the northwest Gulf, large areas on the deeper portions of topographic features are covered by a nepheloid layer that can be up to 20 m thick. These hard bottoms are subjected to high turbidity, sedimentation, resuspension and secondary deposition. They typically consist of rock outcrops or drowned reefs containing a depauperate and variable epifaunal component, containing deep-water octocorals and hearty solitary stony corals. Unlike banks in the northwestern Gulf, the effects of turbid water layers in the present study area seem to be limited to the lower portions of topographic features. Where heavy sedimentation by resuspended sediments was observed, however, depauperate communities similar to those inhabiting similar features in the northwestern Gulf were found.

13.4.4 Community Health (Condition)

Human interference in the form of discarded debris and community disturbance appeared to be minimal in virtually all habitats surveyed. Where debris was encountered, it was limited to individual articles (e.g., plastic cups, aluminum cans, or [metal?] bars), or cables or rope on the bottom and draping over reef structures. Monofilament line and ropes or cables were seen at the pinnacles, at one shoreline station and at one sandy bottom station. The cables or ropes may be lost long-line fishing gear or trawl cable. These are unlikely to cause mechanical damage at these depths once anchored against the reef.

The condition of individual organisms appeared normal. Evidence of disease on coral colonies or in solitary organisms was not noted. In fact, the development of some of the larger organisms or colonies suggests favorable environmental conditions. This was especially true on the larger reef structures, such as those at the 40 Fathom Fishing Grounds, West Reefs, and the Pinnacles. Low relief structures generally contained smaller organisms, probably because water-borne sediments affect these environments more than they do larger or taller structures.

Interestingly, long-spined sea urchins, *Diadema antillarum*, were occasionally observed in reefal habitats. Mass mortality of this species occurred throughout the Western Atlantic Ocean between January 1983 and August 1984. Over 98 percent of these sea urchins died on coral reefs throughout the region. Whether the individuals in the northeastern Gulf of Mexico were affected has not been reported, but CSA (1985a), who surveyed some reef features in this region using television, still cameras and dredges in November 1984, did not record *D. antillarum*. This region might be one of few places where considerable recovery of the *D. antillarum* population has occurred, or one of a very few places where the mortality was not extensive.

It is difficult to address the effect of fishing on reef fish populations in this area using observational data. Fishing boats are frequently sighted on both the Pinnacles and the 40 Fathom Fishing Grounds. Sightings of the most important commercial species were not common, but included amberjacks (*Seriola* spp., usually in schools), Atlantic bonito (*Sarda sarda*, in schools), red snapper (*Lutjanus campechanus*, rare), and grouper (one *Epinephelus* sp. was seen). The most abundant commercial species on these reefs appears to be vermilion snapper (*Rhomboplites aurorubens*, mostly small individuals) and porgies (mostly *Calamus bajonado*, the jolthead). These two species were by far the most commonly observed and were also the most commonly caught fish on hook-and-line.

On reefs where the most fishing appears to take place, the fewest observations of these commercial species were made (excepting vermilion snappers). Furthermore, these reefs contained the largest and densest populations of small reef fishes (especially roughtongue bass, *Holanthias martinicensis*). The abundance of fish in small size classes may be an indication of fishing pressure on these reefs.

13.5 Summary/Conclusions

Biological assemblages dominated by tropical hard bottom organisms and reef fishes occupy a variety of topographic features that exist between 60 and 110 m in the northeastern Gulf of Mexico between the Mississippi River and the DeSoto Canyon. The origins of the carbonate features vary. Some are small, isolated, low to moderate reefal features or outcrops of unknown origin. Some appear to be hard substrates exposed by erosion during sea level still-stands along late Pleistocene shorelines. Others appear to be small reefs that existed near these shorelines. The largest features appear to have been offshore reefs. Formation of the largest features probably occurred prior to the Holocene Transgression. Some additional growth of these features and growth of other smaller reefs on exposed substrates may have taken place during the early transgressional period. The structure of the summits of some reefs may also have been modified by Holocene erosional events following their initial period of growth (namely, the flat-topped reefs). Most currently appear to be deteriorating under the influence of bioerosional processes.

The hermatypes that contributed to the development of these structures probably included coralline algae, reef-building corals, bryozoans, foraminiferans, and molluscs, among others. Present-day production of calcium carbonate is probably limited to an impoverished calcareous algae population on features above 70-75 meters. Features below this depth can most likely be considered completely drowned reefs.

The topographic features in the northeastern Gulf may be of similar age and origin to those that exist in a number areas along the outer continental shelf of the Gulf of Mexico and the east coast of the United States. The depth ranges of many of these features are similar, and most are non-growing reefs inhabited by tropical to warm temperate, hard bottom organisms most commonly found below the depths of living coral reefs.

Present-day biological assemblages on features in the northeastern Gulf are dominated by suspension feeding invertebrates. Populations are depauperate on features of low topography, those in habitats laden with fine sediments, and at the base of larger features (where resuspension of sediments limits community development). On larger features, the diversity and development of communities appears to depend on habitat complexity, that is, the number of habitat types available to hard bottom organisms. On reefs containing extensive reef flats on their summits, there are rich assemblages distinguished by a high relative abundance of sponges, gorgonian corals (especially sea fans), crinoids, and bryozoans. Due to the generally accordant depth of flat-topped reefs (62-63 m), coralline algae are also in abundance. Other organisms on reef flats include holothurians, basket stars, and myriads of fish (mostly the roughtongue bass, *Holanthias martinicensis*). On reefs lacking this reef flat habitat, as well as on reef faces of flat-topped features, the benthic community is characterized by a high relative abundance of ahermatypic corals (both solitary and colonial scleractinians). Other frequently observed organisms on these rugged, often vertical reef faces include crinoids, gorgonians, sea urchins, and basket stars.

Human impact in these environments appears to be minimal at present. Discarded debris, though present at many sites, was not abundant, and therefore poses little threat to the environment. Cables and ropes can affect shallower reef communities, but probably have little impact at these depths once they become tangled on or lodged against reefal structures. Fishing pressure on these relatively small features may reduce the population of the larger, commercially important species, and may explain the abundance of smaller individuals of unprofitable species on heavily fished reefs.

14.0 DATA MANAGEMENT AND DELIVERABLES

Gary A. Wolff

14.1 Introduction

The principal responsibilities of the data management group are: (1) the maintenance of a centralized data storage and retrieval system, (2) the control and protection of the data system, (3) the transmission of validated data to the National Environmental and Satellite Data Information Service (NESDIS) data bank in National Oceanic Data Center (NODC) format and the National Geography Data Center (NGDC), and (4) 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 to store and process 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.

After entering the data on-line, a cycle of validation is initiated through the appropriate principal investigator and the data management

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	Macintosh	Bright/Gittings

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 for 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 through 14-6 summarize the status of all data collected during the sampling period (Cruises 1 - 4) 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 (e.g. meteorology) are not provided until the summary report.

Table 14-2. Data Summary of Cruise 0.

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

Table 14-3. Data Summary of Cruise 1.

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

Table 14-4. Data Summary of Cruise 2.

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

Table 14-5. Data Summary of Cruise 3.

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

Table 14-6. Data Summary of Cruise 4.

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

15.0 SUMMARY/SYNTHESIS

Rezneat M. Darnell

15.1 Background

In the First Annual Report of the Mississippi-Alabama Marine Ecosystems Study, I presented five major ecological questions which should be addressed in detail by the end of the study. Briefly, these relate to: (1) structure of the ecological system; (2) primary pathways of nutrient and energy flow; (3) seasonal events; (4) estuary-shelf-slope relationships; and (5) influence of the Mississippi River on the area. In addition, I posed four management oriented questions which include: (1) background levels and biological effects of chemical pollutants; (2) identification and definition of sensitive biological areas; (3) definition and effests of human intrusion; and (4) identification amd needed research of knowledge gaps. Taken together, these questions will form the organizational framework for the present discussion.

However, a review of historical information, together with new knowledge gained from the present study, has raised another major consideration which relates in a significant way to all of the matters listed above. This will be explained prior to the major body of the summary/synthesis discussion. This question relates to the stability of the physical and biological systems of the area. Several scenarios are possible, but I will present the two extreme cases.

Case 1 - The water currents are relatively gentle and seasonally predictable. Suspended sediments are brought in seasonally and are moved around gently but in regular seasonal fashion. Bottom sediment types are basically fixed in position but undergo small and regular seasonal changes. The infauna is adapted to the normal sediment distribution patterns and reaches equilibria which display regular seasonal characteristics. The macroepifauna as well as demersal and nektonic species undergo regular seasonal changes but otherwise present equilibrium patterns which are predictable. The environmental and ecological systems are so well orchestrated and organized that natural deviation from the patterns is low, and the impact of present and future human intrusion is readily detectable.

Case 2 - The water currents, although generally predictable, are quite dynamic and subject to sudden and major increases in intensity. Suspended sediment loads brought to the area, although generally regular in seasonal distribution and quantity, are subject to large increases. Bottom sediment distribution patterns tend to approach equilibrium with the regular transport forces of the water column, but they are frequently subject to violent disruption and transport, resulting in dramatic new sediment distribution patterns. The infauna pursues equilibria which it never really reaches due to the constantly shifting nature of the sediments. Macro-eipfauna and the demersal and nektonic species must be quite mobile to search widely for bottom food resources in and upon the shifting bottoms. Ecological relationships are loose and tenuous. Individual species populations are characterized by large annual and shorter-term fluctuations. Selection is for pioneers and generalists rather than for equilibrium species and specialists (R-type rather than K-type selection). Natural variation in the system is so great that it tends to mask any effects of human perturbations.

Conceptually, these two scenarios represent cyclic vs. episodic control of the ecosystem. The differences between the two perspectives are dramatic, and they bear important implications for management. Definitive answers concerning the degree to which Case 1 and Case 2 apply are likely to come only from especially designed process oriented studies. However, both cases should be kept in mind as possibilities as we proceed to examine the historical and newly acquired information. Since the present report is not definitive, the various sections will be somewhat brief, and the depth of coverage of the various topics will not be uniform.

15.2 Organization of the Summary/Synthesis Chapter of the Final Report

The Summary/Synthesis (S/S) chapter of the final report will be based upon recently acquired knowledge interpreted within the framework of historical published information relating to the East Mississippi Bight and other marine areas. This chapter will provide a broader and more interdisciplinary overview than can be achieved within the more disciplinary chapters. Emphasis will be placed on the external driving mechanisms, internal dynamic relations, and system gains and losses. Quantitative data will be included where possible, and conceptual models will be employed where appropriate. As presently conceived, the S/S chapter will include four main sections, viz., The Natural System, Human Effects, Sensitive Biological Areas, and Knowledge Gaps.

15.3 The Natural System

A tentative outline of the section dealing with The Natural System is presented in Table 15.1, and each of the major topics is discussed briefly below.

Ecological setting - This section will provide an introductory overview of the area. Emphasis will be placed on the physical and biological structure of the system and on the physical/biological interactions (relations of current patterns with bottom sediment types, relations of sediment types with benthic biological distribution patterns, etc.). Attention will also be given to the inputs and outflows from the system.

Cyclic and episodic events - This section will describe the normal seasonal patterns discernible in the physical and biological parameters of the system as well as the dramatic aperiodic changes which take place in response to extreme physical perturbations. Regular seasonal physical patterns will be presented as shown in Figures 15.1 and 15.2. Regular seasonal biological patterns will be presented as shown in Figure 15.3. Figure 15.4 shows the distribution of trawl stations made during the present study, as well as those reported in the literature, providing information on the areal and/or seasonal distribution of the macroepifauna. The seasonal distribution of demersal and nektonic fishes will be based primarily upon information from the present study as well as that of Darnell (1985) and of Darnell and Kleypas (1987). Evidence for episodic events will show up as deviations from the normal seasonal patterns, and an example of deviation in sediment distribution patterns is shown in Figure 15.5.

Table 15-1. Outline of "Natural System" section of the Summary/Synthesis chapter.

A. Ecological Setting

1. Description of the East Mississippi Bight
2. External influences
3. Internal structure
    a. Physical spatial patterns (water column, sediments)
    b. Biological components of spatial patterns
4. Physical/biological relationships

B. Cyclic (seasonal) and Episodic Events

1. Cyclic events
    a. Physical
    b. Biological
2. Episodic events
    a. Physical
    b. Biological
3. Physical/biological relationships

C. Ecosystem Dynamics

1. Trophic relations
    a. Food habit studies
    b. Presumed additional trophic relations
    c. Tophic models of nutrient and energy flow
2. Passive import and export of nutrients and energy
3. Active transport of nutrients and energy (migration)
4. Reproductive transport phenomena (esp., eggs and larvae)
5. Conceptual models of ecosystem dynamics

D. Estuary/Shelf/Slope Relationships

1. Import/export phenomena
2. Biological migration phenomena
3. Conceptual models of estuary/shelf/slope relationships

E. Influence of the Mississippi River on the Area

1. Direct and indirect physical influences
2. Biological influences
3. Conceptual models

Weather

Solar radiation
Cloud cover
Incident radiation
Wind-direction/speed
Rainfall
Storms
Hurricanes

Hydrography

Temperature - surface
- bottom
Salinity - surface
- bottom
Current - direction
- speed
Turbidity
Freshwater input
Miss. River input
Sed. load input

Nutrients

Coastal input
Oceanic input
Regeneration

Sediments

Sedimentation
Erosion

J F M A M J J A S O N D

Figure 15-1. Regular seasonal physical patterns: methods of representation.

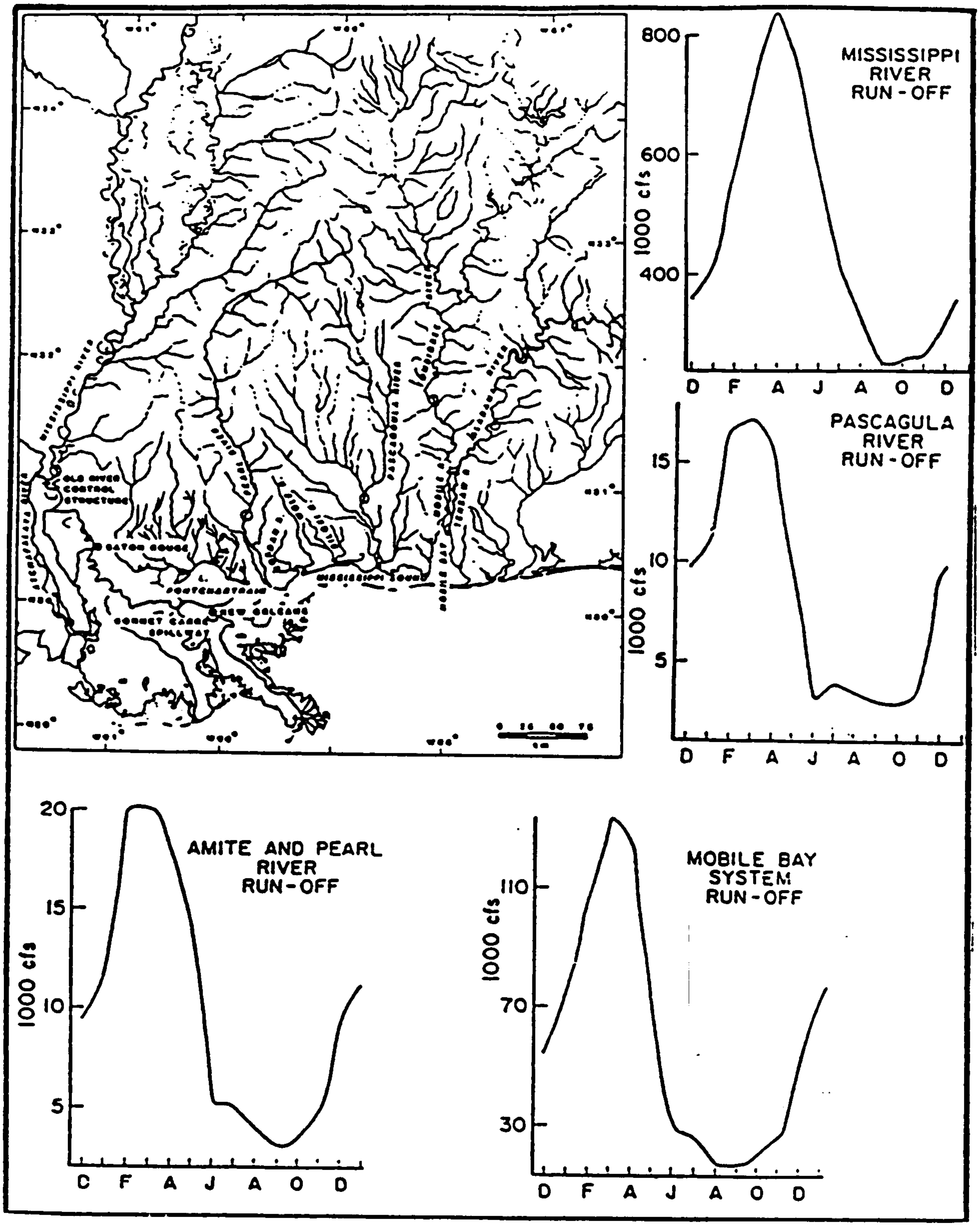


Figure 15-2. Drainage network and annual cycle of discharge for the main rivers entering the East Mississipi Bight.

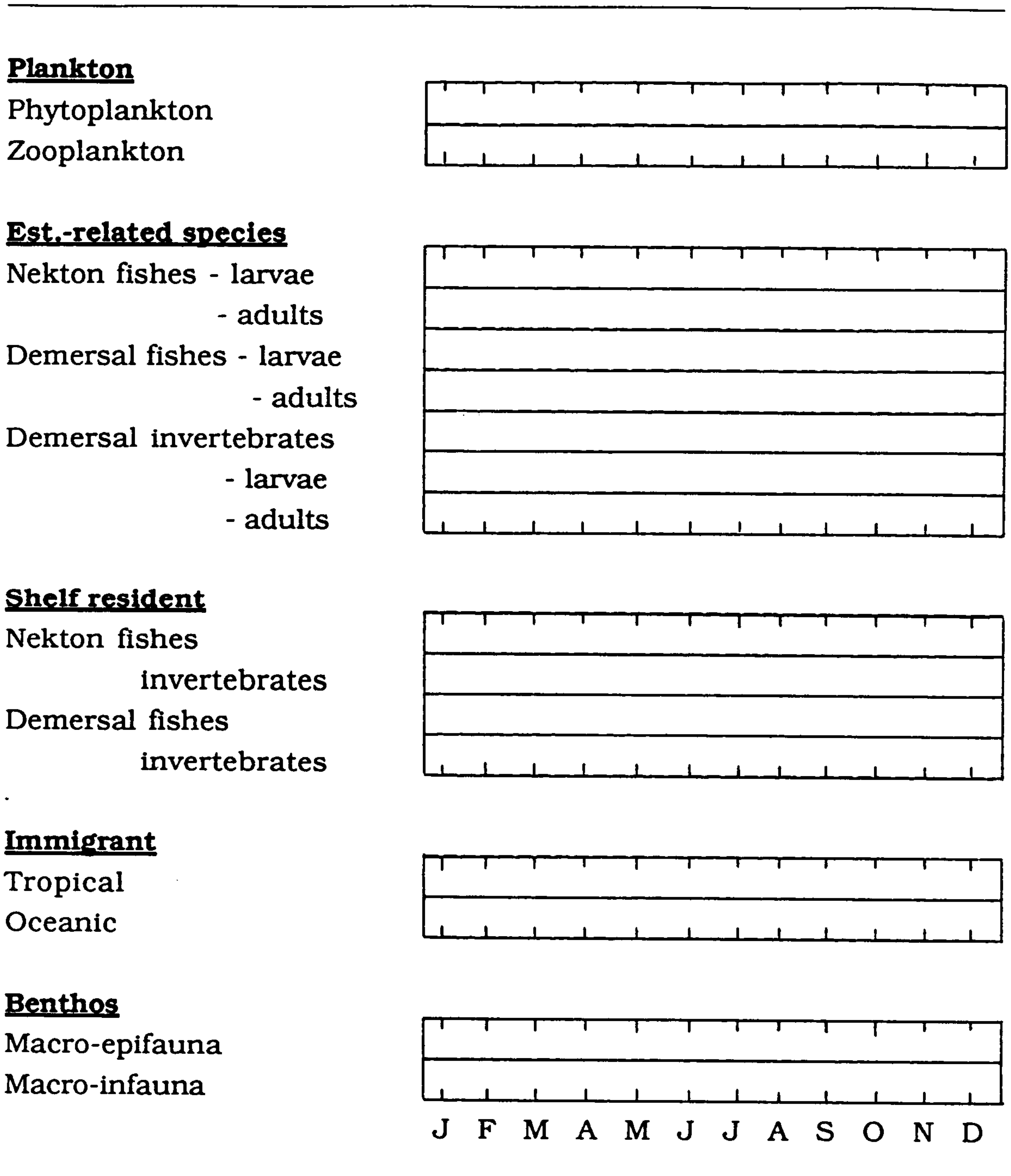


Figure 15.3. Regular seasonal biological patterns: methods of representation.

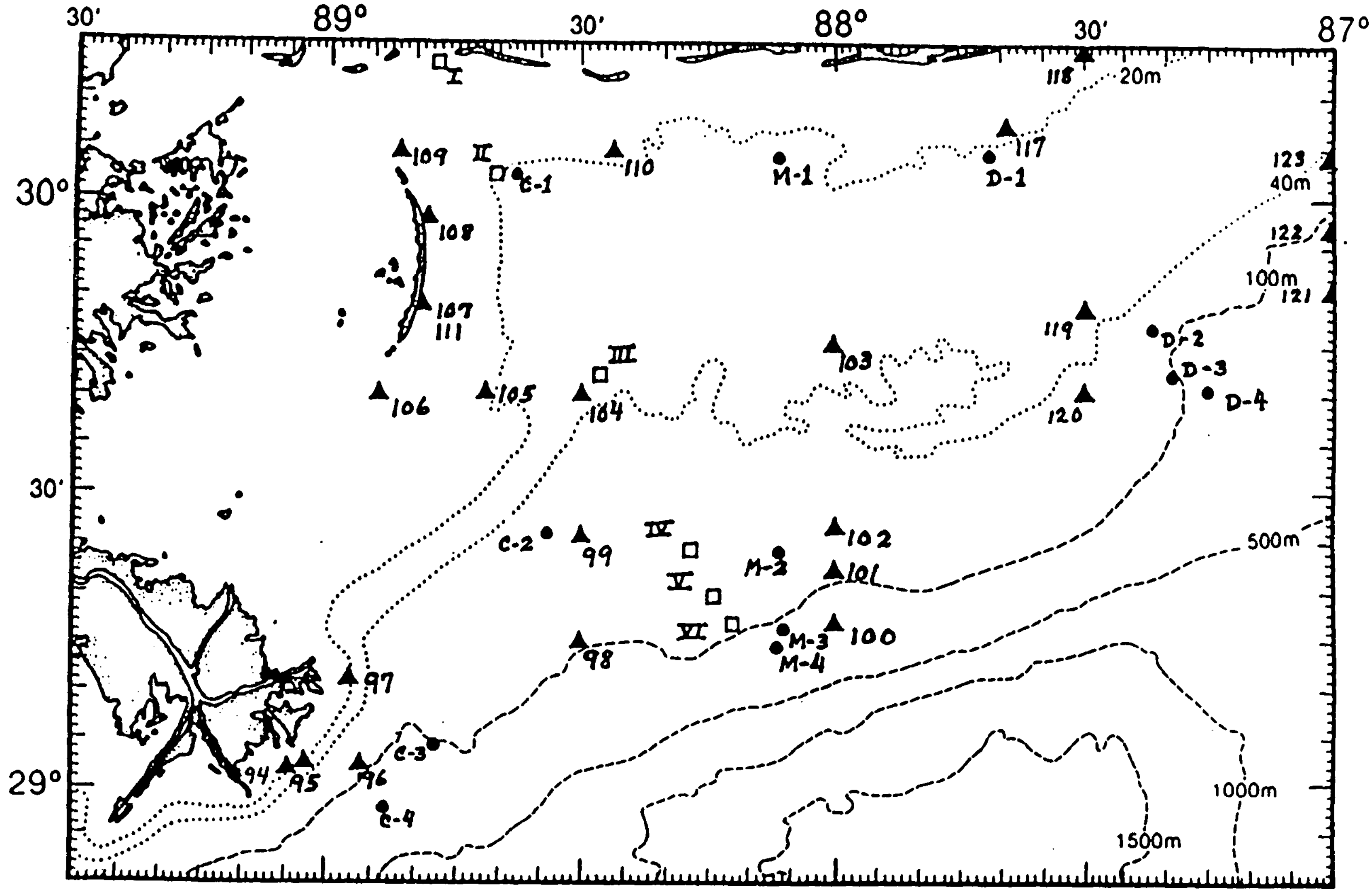


Figure 15-4 Distribution of trawl stations in the study area. Circles denote stations made during the present study. Open squares indicate monthly stations made by the Gulf Coast Research Laboratory (Franks et al. 1972). Triangles are stations made by Defenbaugh (1976).

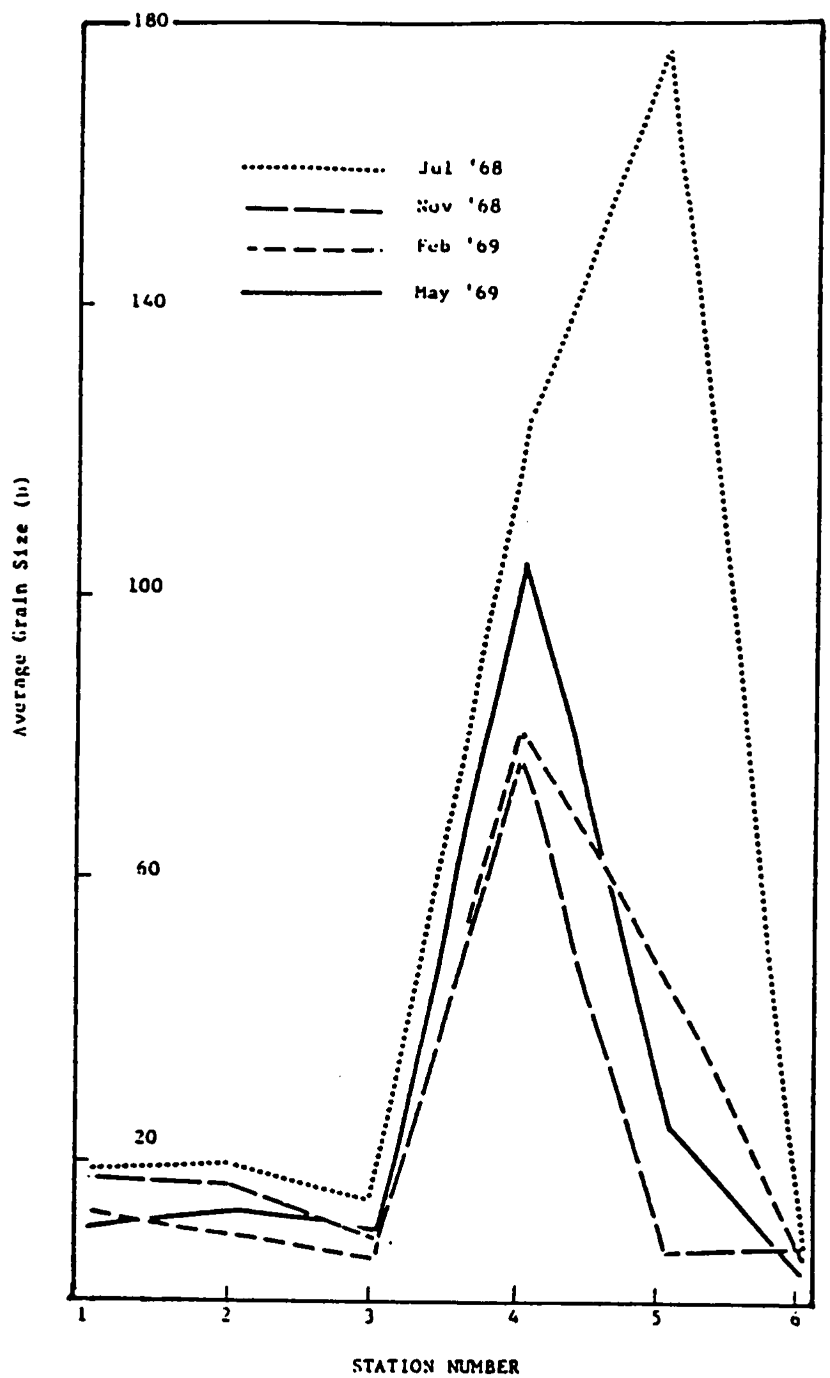


Figure 15-5. Average grain size of sediments taken during seasonal GCRL cruises (see Figure 15-4). High grain sizes at stations 4 and 5 on the July cruise suggest intrusion by a sand sheet. (From Franks et al., 1972)

Ecosystem dynamics - This section will focus upon the phenomena associated with nutrient and energy transport, exchange, and storage, especially in relation to the biological components of the system. The core of this discussion will concern the trophic relations, as revealed in the fish food studies and as can be deduced from the literature and from other known relationships. Attention will also be give to nutrient transport by water currents, reproduction and larval transport of eggs and larvae, and seasonal migration phenomena. Where appropriate, conceptual models will be employed to depict the relationships discussed.

Estuary/shelf/slope relationships - Exchange phenomena between the continental shelf and the adjacent estuaries and the continental slope will be examined to provide a perspective on the ecological roles of the shelf in relation to the adjacent marine areas. Attention will be given to the passive import/export phenomena as well as to active mechanisms such as species migration.

Influence of the Mississippi River on the area - The Mississippi River is one of the chief sources of influence on the Gulf of Mexico, and its relationships with the study area merit special attention. Included will be both the direct and indirect effects as they relate to physical, chemical, and biological factors. Since this section of the chapter concerns the natural system, efforts will be made to consider the effects prior to the influence of human society.

15.4 Human Effects

As shown in Table 15.2, human effects on the East Mississippi Bight area will be considered under five topical headings which treat, respectively, engineering activities, commercial and recreational fishing, commercial ship traffic, chemical changes, and oil and gas development. Each of these topics is discussed briefly below.

Effects of engineering activities - This section will deal with the indirect effects of upstream and coastal activities as well as the direct effects of activities in the nearshore area and on the continental shelf. Upstream dams, diversions, levees, etc., all affect the quantity as well as areal and seasonal distribution of freshwater and sediment loads reaching the shelf.

Coastal wetland modifications impact the habitats of many shelf migrant species. Nearshore and onshelf dredging, channelization, and spoil placement affect the water currents and sediment distribution patterns and potentially affect the habitats, migratory patterns, and spawning grounds of numerous coastal species.

Effects of commercial and recreational fishing activities. Artificial reefs, commercial and recreational fishing, boating, and scuba diving all influence the shelf habitat and biological populations. Massive commercial harvest may change the structure of the ecological systems. Some of these activities also have the potential for damaging sensitive biological areas.

Effects of commercial ship traffic - Commercial ship traffic may intrude upon the area primarily through excess noise, anchor damage, and the discard of solid and liquid wastes. Increasing ship traffic through the area heightens the risk of collision and spillage from powered ships and barges.

Changes in the chemical environment - Changes in the nutrient inputs result primarily from upstream agricultural runoff and municipal sewage release and from alteration of freshwater inflow patterns. Chemical pollution may result from agricultural and municipal runoff, upstream industry, and a variety of coastal activities. Ship and barge traffic may create chronic as well as episodic chemical pollution problems.

Effects of oil and gas activities - Although oil and gas development in the area is modest at the present time, such development is expected to increase in the future. From knowledge gained during the present study and from other historical information, the present and potential future effects of oil and gas development can be determined with some accuracy. Available information will be brought together and focused on this set of problems.

15.5 Sensitive Biological Areas

From the accumulated knowledge base it will be possible to identify sensitive biological areas in a generic sense as well as in site specific cases. It should also be possible to indicate the sensitivities and intrusive dangers associated with each area identified.

Table 15-2. Outline of "Human Effects" section of the Summary/ Synthesis chapter.

A. Effects of Engineering Activities

1. Upstream modifications
    a. Mississippi River
    b. Mobile River
2. Coastal zone modifications
3. Nearshore and continental shelf modifications

B. Effects of Commercial and Recreational Fishing Activities

1. Emplacement of artificial reefs
2. Trawling and other commercial fishery harvest
3. Recreational fish harvest
4. Boating and scuba diving

C. Effects of Commercial Ship Traffic

D. Changes in the Chemical Environment

1. Nutrients
2. Pollutants

E. Effects of Oil and Gas Activities

1. Effects of rigs, platforms, and pipelines
2. Pollutants
3. Other effects

15.6 Knowledge Gaps

Broad scale consideration of the ecological system and the available historical literature base should reveal any major gaps in our knowledge of the natural system or of human effects upon this system. These knowledge gaps will be identified and discussed in terms of importance and in terms of research required to fill the gaps.

16.0 BIBLIOGRAPHY

Andren, A.W. and R.C. Harriss, 1975. Observations on the association between mercury and organic matter dissolved in natural waters. Geochim. Cosmochim. Acta, 39, 1253-1258.

Avent, R.M., M.E. King, and R.H. Gore. 1977. Topographic and faunal studies of shelf-edge prominences off the central eastern Florida coast. Int. Rev. ges. Hydrobiol. 62(2):185-208.

Ballard, R.D. and E. Uchupi. 1970. Morphology and Quaternary history of the continental shelf of the Gulf coast of the United States. Bull. Mar. Sci. 20(3):547-559.

Benson, N.G. 1982. Life history requirements of selected finfish and shellfish in Mississippi Sound and adjacent areas. U.S. Fish and Wildlife Service. Office of Biological Services. Washington, D.C. FWS/OBS 81/51:1-97.

Berryhill, H.L. (ed). 1977. Environmental Studies, South Texas Outer Continental Shelf, 1975: An atlas and integrated study. Final report to Bureau of Land Management. 303 pp.

Blumer, M., M. Mullin and R. Guillard. 1970. A polyunsaturated hydrocarbon (3,6,9,12,15,18-heneicosahexaene) in the marine food web. Mar. Biol. 6: 226-235.

Boehm, P. 1979. Interpretation of sediment hydrocarbon data, Chapter 10, pp. 572-607. *In* MAFLA (Mississippi, Alabama, Florida) OCS Study. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA., prepared by Dames and Moore for Bureau of Land Management, Contract AA550-CT7-34.

Boone, P.A. 1973. Depositional systems of the Alabama, Mississippi, and western Florida coastal zone: Gulf Coast Assoc. Geol. Soc. Transactions:266-277.

Boothe, P.N. and W.D. James, 1985. Neutron activation analysis of barium in marine sediments from the north central Gulf of Mexico. J Trace and Microprobe Tech., 3: 377-399.

Boothe, P.N. and B.J. Presley, 1985. Distribution and behavior of drilling fluids and cuttings around Gulf of Mexico drilling sites. Final Report to the American Petroleum Institute.

Boothe, P.N. and B.J. Presley, 1987. The effects of exploratory petroleum drilling in the northwest Gulf of Mexico on trace metal concentrations in near rig sediments and organisms.

Boothe, P.N. and B.J. Presley, 1988. unpublished data

Boyle, E.A., D.F. Reid, S.S. Huested and J. Hering. 1984. Trace metals and radium in the Gulf of Mexico: An evaluation of river and continental shelf sources. Earth Planet Sci. Letters 69, pp. 69-87.

Brassell, S.C., G. Eglinton, J.R. Maxwell and R.P. Philp. 1978. Natural background of alkanes in the aquatic environment. In: Aquatic Pollutants, Transformations and Biological Effects (ed. O. Huntzinger, L.H. van Lelyveld and B.C.J. Zoetman) Pergammon Press, pp. 69-86.

Briggs, J.C. 1974. Marine Zoogeography. McGraw-Hill, New York. 475 pp.

Bright, T.J., G.P. Kraemer, G.A. Minnery and S.T. Viada. 1984. Hermatypes of the Flower Garden banks, northwestern Gulf of Mexico: a comparison to other Western Atlantic reefs. Bull. Mar. Sci. 34(3):461-476.

Brooks, J.M. and C.P. Giammona, eds. 1988. Mississippi-Alabama Marine Ecosystem Study Annual Report, Year 1. Volume I: Technical Narrative. OCS Study/MMS 88-0071. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Regional Office, New Orleans, La. 258 pp.

Brooks, J.M., T.L. Wade, E.L. Atlas, M.C. Kennicutt II, B.J. Presley, R.R. Fay, E.N. Powell, and G. Wolff. 1988. Analyses of bivalves and sediments for organic chemicals and trace elements from Gulf of Mexico estuaries. Second annual report for NOAA's National Status and Trends Program, Contract 50-DGNC-5-00262.

Bruland, K.W. 1983. Trace elements in sea water. In, Riley, J.P. and Chester, R. (eds) Chemical Oceanography, Vol. 8, Academic Press.

Buat-Menard, P. 1986. The Role of Air-Sea Exchange in Geochemical Cycling. D. Reidel Publishing Co., Boston, 549 pp.

Bullis, H.R., Jr. and J.R. Thompson. 1965. Collections by the exploratory vessels OREGON, SILVER BAY, COMBAT, and PELICAN made during 1956-1960 in the southwestern north Atlantic. USFWS Spec. Sci. Rept. Fish. 339 pp.

Chittenden, M.E. and J.D. McEachran. 1976. Composition, ecology and dynamics of demersal fish communities on the northwesten Gulf of Mexico continental shelf, with a similar synopsis for the entire Gulf. Texas A&M University Sea Grant Publication TAMU- SG-76-298.

Christmas, J.Y., L.N. Eleuterius, W.W. Langley, H.M. Perry, and R.S. Waller. 1973. Phase IV biology, pp. 141-434. In: J.Y. Christmas, ed. Cooperative Gulf of Mexico estuarine inventory and study, Mississippi. Gulf Coast Research Laboratory, Ocean Springs, MS.

Church, T.M. J.N. Galloway, T.D. Jickells and A.H. Knap. 1982. The Chemistry of Western Atlantic precipitation at the mid-Atlantic coast and on Bermuda. J. Geophys. Res. 87(C13), pp. 11,013-11,018.

Clark, Jr. R. and M. Blumer. 1967. Distribution of *n*-paraffins in marine organisms and sediments. Limnol. and Oceanogr. 12: 79-87.

Collins, G.A. 1975. Geochemistry of Oilfield Waters. Elsevier Publishers. 496 pp.

Continental Shelf Associates, Inc. 1985a. Live-bottom survey of drillsite locations in Destin Dome Area Block 617. Rep. to Chevron U.S.A., Inc. 40 pp + Appendices.

Continental Shelf Associates, Inc. 1985b. Southwest Florida shelf regional biological communities survey: Year III Final Rept. Prepared for U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Office. Contract No. 14-12-0001-29036. MMS-86-0108.

Craig, H. 1953. The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53-92.

Curtis, W.F., J.K. Culbertson and E.B. Chase. 1973. Fluvial sediment discharge to the ocean from the conterminous United States. U.S. Geol Surv., Circ. 670, 17 pp.

Dames and Moore. 1979. The Mississippi, Alabama, Florida, outer continental shelf baseline environmental survey, MAFLA 1977/1978. v. 1-A, Program synthesis report. Bureau of Land Management, Washington, D.C., BLM/YM/ES-79/01-Vol-1-A., 278 pp.

Daniel, R.A. and E.E. Collias. 1971. Inductive and conductivity probe calibration. In Proceedings of 1971 IEEE International Conference on Engineering in the Oceanographic Environment, p. 16-18.

Darnell, R.M. 1985. Distribution of fishes and penaeid shrimp of commercial and recreational importance on the continental shelf off Mississippi and Alabama. v + 62 pp. (Appendix B). In: Barry A. Vitter & Associates, Inc. Tuscaloosa Trend Regional Data Search and Synthesis Study. Report to Minerals Management Service, Metairie, LA. 2 vols.

Darnell, R.M. and J. A. Kleypas. 1987. Eastern Gulf Shelf Bio-Atlas, A Study of the Distribution of Demersal Fishes and Penaeid Shrimp of Soft Bottoms of the Continental Shelf from the Mississippi River Delta to the Florida Keys. OCS Study MMS 86-0041. xv + 548 pp., 209 pls.

Davis, G.E. 1977. Anchor damage to a coral reef on the coast of Florida. Biol. Conserv. 11:29-34.

Defenbaugh, R.E. 1976. A Study of the Benthic Macroinvertebrates of the Continental Shelf of the Northern Gulf of Mexico. Ph.D. Dissertation, Texas A&M University, College Station, TX 476 pp.

Dennis, G.D. 1985. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. M.S. Thesis, Texas A&M University, College Station, TX. 184 pp.

Dinnell, S.P. 1988. Circulation and sediment dispersal on the Louisiana-Mississippi-Alabama continental shelf. Ph.D. Dissertation. Louisiana State University. xii + 173 pp.

Doyle, L.J. and Sparks. 1980. Sediments of the Mississippi, Alabama, and Florida (MAFLA) continental shelf. Jour. Sediment. Petrol. 50, 905-9

Farrington, J.W., J.M. Teal, J.G. Quinn, T.L. Wade and K. Burns. 1973. Intercalibration of analyses of recently biosynthesized hydrocarbons and petroleum hydrocarbons in marine lipids. Bull. Environ. Contamin. Toxicol. 10: 129-146.

Farrington, J.W. and B.W. Tripp. 1977. Hydrocarbons in western North Atlantic surface sediments. Geochim. Cosmochim. Acta 41: 1627-1641.

Fitzhugh, K. 1984. Temporal and spatial patterns of the polychaete fauna on the central Northern Gulf of Mexico continental shelf. pp. 211-226. In: Proceedings of the First International Polychaete Conference. P.A. Hutchings (ed.). Linnean Society of New South Wales.

Fairbank, N.C. 1979. Heavy minerals from the eastern Gulf of Mexico Deep-Sea Res., 9, pp. 307-338.

Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphill Publishing Company, Austin, TX, 184 pp.

Franks, J.S. J. Y. Christmas, W.L. Siler, R.Combs, R. Waller, and C. Burns. 1972. A study of nektonic and benthic faunas of the shallow Gulf of Mexico off the State of Mississippi as related to some physical, chemical, and geological factors. Gulf Res. Repts. 4(1): iv + 148 pp.

Galtsoff, P.S. 1940. Wasting disease causing mortalities of sponges in the West Indies and Gulf of Mexico. Third Proc. of the 8th Amer. Sci. Cong. 3:411-421.

Garrels, R.M. and F.T. Mackenzie. 1971. Evolution of Sedimentary Rocks. Norton and Co., New York, 397 pp.

Gearing, P., J.N. Gearing, T.F. Lytle and J.S. Lytle. 1976. Hydrocarbons in 60 northeast Gulf of Mexico shelf sediments: a preliminary survey. Geochim. Cosmochim. Acta 40: 1005-1017.

Gettleson, D.A. and C.E. Laird. 1980. Benthic barium in the vicinity of 6 drill sites in the Gulf of Mexico. In: Symposium/Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, Florida. Jan. 21-24, 1980.

Ginsburg, R.N. and J.H. Schroeder. 1969. Introduction to the growth and diagenesis of Bermuda reefs. Manuscript prepared for Bermuda Conf. on Carbonate Cement. Bermuda Biological Station. 13 pp.

Gittings, S.R. 1988. The Recovery process in a mechanically damaged coral reef community. PhD. Dissertation. Department of Oceanography. Texas A&M University. 228 pp.

Gittings, S.R. and T.J. Bright. 1986. Assessment of coral recovery following an incident of anchoring damage at the East Flower Garden bank, northwestern Gulf of Mexico. Rep. to NOAA National Marine Sanctuary Division, Washington, D.C. Contract No. NA85AA-H-CZ015. 45 pp.

Glynn, P.W., L.R. Almodovar and J.G. Gonzalez. 1964. Effects of Hurricane Edith on marine life in La Parguera, Puerto Rico. Carib. J. Sci. 4:335-345.

Gould, H.R. and R.H. Stewart, 1955. Continental terrace sediments in the northeastern Gulf of Mexico. in Finding Ancient Shorelines, SEPM Spec. Paper 3, Tulsa, OK, pp. 3-20.

Goutx, M. and A. Saliot. 1980. Relationship between dissolved and particulate fatty acids and hydrocarbons, chlorophyll *a* and zooplankton biomass in Villefranche Bay, Mediterranean Sea. Mar. Chem. 8: 299-318.

Grimm, D.E. and T.S. Hopkins. 1977. Preliminary characterization of the octocorallian and scleractinian diversity at the Florida Middle Ground. Proc. Third Int. Coral Reef Symp. (Miami) 1:135-141.

Hanor, J.S. and L.H. Chan. 1977. Non-conservative behavior of Ba during mixing of Mississippi River and Gulf of Mexico Waters. Earth Planet. Sci. Lett., 37, pp. 242-250.

Harper, D.E., Jr. and R.J. Case. 1975. Numerical analysis of benthic data. In: SEADOCK, Inc., Environmental Report: Texas Offshore Crude Oil Unloading Facility. Vol. 2, Chapt. 10, Sect 10.4, pp. 531-537. Texas A&M Research Foundation project 945 final report to SEADOCK, Inc.

Harper, D.E., Jr., L.D. McKinney and J.M. Nance. 1985. Benthos. In: Offshore Oceanographic and Environmental Monitoring Services for the Strategic Petroleum Reserve. Annual report for the Bryan Mound site from September 1984 through August 1984. R.W. Hann, C.P. Giammona and R.E. Randall (eds). Texas A&M Research Foundation project 4900 report to Department of Energy on contract DOE-P010850-4.

Harper, D.E., Jr. and J.M. Nance. 1985. Response to decision makers' questions: Benthos. Vol. 5, 75 pp. In: Offshore Oceanographic and Environmental Monitoring Services for the Strategic Petroleum Reserve. Texas A&M Research Foundation project 4900 report to the Department of Energy on contract DE-AC96-83P010850.

Hildebrand, H.H. 1954. A study of the brown shrimp (Penaeus aztecus Ives) grounds in the western Gulf of Mexico. Publications of the Institute of Marine Science, University of Texas. 3(2): 233-366.

Hites, R.A., R.E. Laflamme, J.G. Windsor Jr., J.W. Farrington and W.G. Deuser. 1980. Polycyclic aromatic hydrocarbons in an anoxic sediment core from the Pettaquamscutt River (Rhode Island, USA). Geochim. Cosmochim. Acta 44: 873-878.

Holmes, C.W. 1973. Distribution of selected elements in surficial marine sediments of the northern Gulf of Mexico continental shelf and slope. U.S. Geol. Surv. Prof. Paper 814, 7 p.

Hopkins, T., W. Schroeder, T. Hilde, L. Doyle and J. Steinmetz. 1981. Florida Middle Ground. Vol. V of Rezak, R. and T.J. Bright, Northern Gulf of Mexico Topographic Features Study. Rep. to U.S. Dept. of Interior, Bureau of Land Management, OCS Office, New Orleans, LA. Contract No. AA551-CT8-35. Texas A&M Dept. of Oceanography Technical Rep. 81-2-T.

Huh, O.K., W.J. Wiseman, Jr., and L.J. Rouse, Jr. 1981. Intrusion of loop current waters onto the West Florida continental shelf. J. Geophys. Res. 86(C-5):4186-4192.

Humm, H.J. and R.M. Darnell. 1959. A collection of marine algae from the Chandeleur Islands. Publ. Inst. Mar. Sc., University of Texas, Austin, TX 6: 265-276.

Jaap, W.C. 1979. Observations on zooxanthellae expulsion at Middle Sambo Reef, Florida Keys. Bull. Mar. Sci. 29(3):414-422.

Kelly, F.J., J.E. Schmitz, W.F. Ulm. 1983. Physical Oceanography. *In* R.W. Hann, Jr. and R.E. Randall, eds. Evaluation of brine disposal from the Bryan Mound site of the Strategic Petroleum Reserve Program: Bryan Mound field and laboratory procedures manual. U.S. Dept. of Energy, Contract No. DE-FC96-79P010 114.

Kennicutt, M.C. II, and P.A. Comet. 1990. Resolution of Sediment Hydrocarbon Sources: Multiparameter Approaches. In: John Hunt Commerative Volume (ed. J. Whelan and J. Farrington), in press.

Kindinger, J.L., 1988. Seismic stratigraphy of the Mississippi-Alabama shelf and upper continental slope. Mar. Geol., 83, 79-94.

Kindinger, J.L., 1989a. Upper Pleistocene to Recent shelf and upper slope deposits of offshore Mississippi-Alabama, GCSSEPM Foundation Seventh Annual Research Conference Proceedings, April 1, 1989 p. 163-174.

Kindinger, J.L., 1989b. Depositional History of the Lagniappe Delta, northern Gulf of Mexico, Geo-Marine Letters, v. 9, no. 2, p. 59-66.

Kindinger, J.L., R.J. Miller, C.E. Stelting, and A.H. Bouma, 1982. Depositional History of Louisiana-Mississippi outer continental shelf, U.S. Geological Survey Open-File Rept. 82-1077, 55 p.

La Flamme, R.E. and R.A. Hites. 1978. The global distribution of polycyclic aromatic hydrocarbons in recent sediments. Geochim. Cosmochim. Acta 42:289-303

Landry, A.M., Jr., D.E. Pitts, Jr. and T.L. Kirby. 1985. Nekton. In: Offshore oceanographic and environmental monitoring services for the Strategic Petroleum Reserve. Annual report for the West Hackberry site from September 1983 through August 1984. R.W. Hann, C.P. Giammona and R.E. Randall (eds). Texas A&M Research Foundation project 4900 report to Department of Energy on contract DOE-P010850-5.

Leifeste, D.K. 1974. Dissolved solids discharge to the ocean from the conterminous United States. U.S. Geol. Surv., Circ. 685, 8 p.

Lessios, H.A., P.W. Glynn and D.R. Robertson. 1983. Mass mortality of coral reef organisms. Science 182:715.

Ludwick, J.C. 1964. Sediments in the northeastern Gulf of Mexico. In: R. L. Miller, ed. Papers in Marine Geology, Shepard Commemorative Volume. Macmillan, NY. 204-238.

Ludwick, J.C. and W.R. Walton. 1957. Shelf edge, calcareous prominences in the northeastern Gulf of Mexico. Amer. Assoc. Petrol. Geol. Bull., 41(9), 2054-2101.

Martin, J.M. and M. Whitfield. 1983. The significance of rive input of chemical elements to the ocean. In: Trace Metals and Sea Water, C.S. Wong et al. eds. Plenum Publishers:265-296.

McCaffrey, P.M. 1981. Studies on the composition and organization of the demersal ichthyofauna of the continental shelf zone in the northeastern gulf of Mexico. Fla. Dept. of Env. Res. Tech. Ser. 6:1-576.

McKinney, L.D., D.E. Harper, Jr. and J.M. Nance. 1984. Benthos. In: Offshore oceanographic and environmental monitoring services for the Strategic Petroleum Reserve. Annual report for the West Hackberry site from September 1983 through August 1984. R.W. Hann, C.P. Giammona and R.E. Randall (eds). Texas A&M Research Foundation project 4900 report to Department of Energy on contract DOE-P010850-5.

Middleditch, B.S. 1981. Environmental effects of off-shore production: the Buccaneer Gas and Oil Field study. Plenum Press, New York.

Minerals Management Service. 1987. Draft Environmental Impact Statement. Proposed oil and gas lease sales 113/115/116. Gulf of Mexico OCS Region. MMS-87-0019.

Minerals Management Service. 1988. Minerals Management Service OCS Report 88-0010. U.S. Department of the Interior.

Minnery, G.A., R. Rezak, and T.J. Bright. 1985. Depth zonation and growth form of crustose coralline algae: Flower Garden Banks, northwestern Gulf of Mexico. In: D.F. Toomey and M.H. Nitecki (eds.), Paleoalgology: Contemporary Research and Applications. Springer-Verlag, Berlin. Ch. 18, pp. 237-246.

Moore, D. R. and H.R. Bullis, Jr. 1960. A deep water coral reef in the Gulf of Mexico. Bull. Mar. Sci. Gulf Caribb., 10, 125-128.

Moore, D, H.A. Brusher and L. Trent. 1970. Relative abundance, seasonal distribution, and species composition of demersal fishes off Lousiana and Texas, 1962-1964. Contributions in Marine Science, 15: 45-70.

Morris, B. J. Barnes, F. Brown, and J. Markham. 1977. The Bermuda marine environment. Bermuda Bio. Station Spec. Publ. No. 15. 120 pp.

Nelsen, T.A. and J.H. Trefry. 1986. Pollutant-particle relationships in the marine environment: A study of particles and their fate in a major river-delta-shelf system. Rapp. P.-V. Reun Const. Int. Explor. Mer., 186, 115-127.

Newton, C.R., H.T. Mullins, A.F. Gardulski, A.C. Hine, and G.R. Dix. 1987. Coral mounds on the West Florida slope: unanswered questions regarding the development of deep-water banks. Palaios 2:359-367.

Nishimura, M. and E.W. Baker. 1986. Possible origins of n-alkanes with a remarkable even-to-odd predominance in recent marine sediments. Geochim. Cosmochim. Acta 50: 299-305.

Parker, R.H. 1960. Ecology and distributional patterns of marine macroinvertebrates, northern Gulf of Mexico. F.P. Shepard, F.B. Phleger, and T.H. van Andel (eds). American Association of Petroleum Geologists, Tulsa, Oklahoma. pp. 203-337.

Pequegnat, W. 1987. Special applications and concepts. In: Beneficial Used of Dredged Material. Proceedings of the First Inter-agency Workshop, Pensacola, Florida, 7-9 Oct. 1986, Technical Report D-87-1, Waterways Experiment Station, Vicksburg, MS, M. C. Landin and H. K. Smith (eds.).

Philp, R.P. 1985. Fossil Fuel Biomarkers: Application and Spectra. Methods in geochemistry and geophysics, 23 Elsevier, NY 294 pp.

Pickett, R.L. and D.A. Burns. 1987. Currents off Pensacola, Florida. NORDA, NSTL, MS (unpublished manuscript).

Poag, C. W., 1973. Late Quaternary sea levels in the Gulf of Mexico. Trans. Gulf Coast Assoc. Geol. Soc., 23, 394-400.

Presley, B.J., J.H. Trefry, and R.E. Shokes. 1980. Heavy metal inputs to Mississippi Delta sediments: A Historical View. Journal of Water, Air and Soil Pollution, 14(4), 481-494.

Pyle, T.E., V.J. Henry, J.C. McCarthy, R.T. Giles, and T.W. Neurauter. 1975. Baseline monitoring studies, Mississippi, Alabama, Florida, outer continental shelf, 1975-1976. Volume 5. Geophysical investigations for biolithologic mapping of the MAFLA-OCS lease area. Bureau of Land Management. Washington, D.C., BLM/ST-78/34. 267 pp.

Reed, J.K. 1980. Distribution and structure of deep-water *Oculina varicosa* coral reefs off central eastern Florida. Bull. Mar. Sci. 30(3):667-677.

Rezak, R. and T.J. Bright. 1978. South Texas topographic features study. Rep. to U.S. Dept. of Interior, Bureau of Land Management, OCS Office, New Orleans, LA. Contract No. AA550-CT6-18. 772 pp.

Rezak, R and T.J. Bright. 1983. Classification and characterization of banks, pp. 311-139. *In* Rezak, R., T.J. Bright and D.W. McGrail eds., Reefs and banks of the northwestern Gulf of Mexico: their geological, biological, and physical dynamics. U.S. Dept. of Interior, Minerals Management Service, OCS Office, New Orleans, LA. (Also Dept of Oceanography, Texas A&M University, College Station, TX Tech. Rep. 83-1-T).

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and banks of the northern Gulf of Mexico: their geological, biological, and physical dynamics. John Wiley and Sons, New York, 259 pp.

Roberts, H.H., R. Sassen, and P. Aharon. 1988. Petroleum-derived authigenic carbonates of the Louisiana continental shelf. Proc. Oceans '88 Conf., Baltimore, MD. Vol. 1, pp. 101-105.

Roithmayr, C.M. 1965. Industrial bottomfish fishery of the northeastern Gulf of Mexico, 1959-63. USFWS Spec. Sci./ Rept. Fish. No. 518:1-23.

Russell, M. 1977. Apparent effects of flooding on distribution and landings of industrial bottomfish in the norther Gulf of Mexico. Northeast Gulf Sci. 1(2):77-82.

Sackett, W.M. 1964. The depositional history and isotopic organic carbon composition of marine sediments. Mar. Geol., 2, 173-185.

Schroeder, W.W., S.R. Gittings, M.R Dardeau, P. Fleisher, W.W. Sager, A.W. Shultz, and R. Rezak. 1989. Topographic features of the L'Mafla continental shelf, northern Gulf of Mexico. Proc. Oceans 89 Conf., 54-58.

Schroeder, W.W., M.R. Dardeau, J.J. Dindo, P. Fleisher, K.L. Heck Jr., and A.W. Shultz. 1988a. Geological and biological aspects of hardbottom environments on the L'Mafla shelf, northern Gulf of Mexico. Proc. Oceans 88 Conf., 17-21.

Schroeder, W.W., A.W. Shultz, and J.J. Dindo. 1988b. Inner-shelf hardbottom areas, northeastern Gulf of Mexico. Trans. Gulf Coast Assoc. Geol. Soc., 38, 535-541.

Shiller, A.M. and E.A. Boyle. 1983. Trace metals in the plume of the Mississippi Rivers (abs) EOS, 64, 1021.

Shiller, A.M. and E.A. Boyle. 1987. Variability in dissolved trace metals in the Mississippi River. Geochim. Cosmochim. Acta, 51, 3273-3277.

Shipp, R.L. and T.S. Hopkins. 1978. Physical and biological observations of the northern rim of the DeSoto Canyon made from a research submersible. N.E. Gulf Sci. 2(2):113-121.

Slowey, J.F. and D.W. Hood. 1971. Cooper, manganese and zinc concentrations in Gulf of Mexico waters. Geochim. Cosmochim. Acta, 35, 121-138.

Smith, G.B. 1976. Ecology and distribution of eastern Gulf of Mexico reef fishes. Fla. Dept. Nat. Mar. Res. Lab. Res. Publ. 19:1-78.

Southwest Research Institute. 1981. Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico. C.A. Bedinger, Editor. Final report to the Bureau of Land Management on contract AA551-CT8-17.

Springer, S. and H.R. Bullis. 1956. Collection by the Oregon in the Gulf of Mexico. Lists of crustaceans, mollusks, and fishes identified from collection made by the exploratory fishing vessel Oregon in the Gulf of Mexico and adjacent seas 1950 through 1955. USFWS Spec. Sci. Rept. Fish. 196 pp.

Stark, W.A. 1968. A list of fishes of Alligator Reef, Florida with comments on the nature of the Florida reef fish fauna. Undersea Biol. 1:4-40.

Swift, D.J.P., D.J. Stanley, and J.R. Curray. 1971. Relict sediments on continental shelves: a reconsideration. Jour. Geol. 79:322-346.

Tillery, J.B. and R.E. Thomas. 1980. Heavy metal contamination from petroleum production platforms in the Central Gulf of Mexico. In, Symposium/Research on Environment Tate and Effects of Drilling Fluids and Cuttings, Lake Buena Vista, Florida Jan. 21-24, 1980.

Trefry, J.H. and B.J. Presley. 1976a. Heavy metals in sediments from San Antonio Bay and the northwest Gulf of Mexico. Environ. Geol., 1, 282-294.

Trefry, J.H. and B.J. Presley. 1976b. Heavy metal transport from the Mississippi River to the Gulf of Mexico. In: Windom, H.L. and Duce, R.A. (eds) Marine Pollutant Transfer, D.C. Heath and Co., 39-76.

Trefry, J.H. and B.J. Presley. 1982. Manganese fluxes from Mississippi Delta sediments. Geochim. Cosmochim. Acta, 46, 1715-1726.

Trefry, J.H., S. Metz, and R.P. Trocine. 1985. A decline in lead transport by the Mississippi River. Science, 230, 439-441.

Tutin, T.G. 1938. The autecology of *Zostera marina* in relation to its wasting disease. The New Phytologist 37(1):50-71.

UNESCO. 1981. The Practical Salinity Scale 1978 and the International Equation of State of Seawater 1980. Tenth Report of the Joint Panel on Oceanographic Table and Standards. UNESCO Technical Papers. In Marine Science, No. 36, UNESCO, Paris, France.

Upshaw, C.F., W.B. Creath, and F.L. Brooks. 1966. Sediments and microfauna off the coasts of Mississippi and adjacent states. Bulletin 106, Mississippi Geological, Economic, and Topographical Survey, Jackson, 127pp.

Van Andel, T.H. 1960. Sources and dispersion of Holocene sediments, northern Gulf of Mexico. In: F.P. Shepard, F.B. Phleger, and T.H. Van Andel, eds. Recent Sediments, Northwestern Gulf of Mexico. Amer. Assoc. Petrol. Geol. Tulsa, OK. 34-55 pp.

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

Vastano, A.C. and R.O. Reid. 1985. Sea Surface Topographic Estimation with Infrared Satellite Imagery. Jour. Atmos. and Ocean. Tech. 2(3):393-400.

Vittor, B.A. and Associates. 1985. Tuscaloosa Trend regional data search and synthesis study, volume 1 - synthesis report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office. Metarie, LA, 14-12-0001-30048.1, 477 pp.

Wakeman, S.G., C. Schaffner, and W. Giger. 1980a. Polycyclic aromatic hydrocarbons in recent lake sediments - I. Compounds derived from biogenic precursors during early diagenesis. Geochim. Cosomochim. Acta 44: 403-413.

Wakeham, S.G., C. Schaffner and W. Giger. 1980b. Polycyclic aromatic hydrocarbons in recent lake sediments - II. Compounds derived from biogenic precursors during early diagenesis. Geochim. Cosomochim. Acta 44: 415-429.

Wickman, F.E. 1952. Variations in the relative abundance of the carbon isotopes in plants. Geochim. Acta, 2, 243-254.

Williams, A.B. 1984. Shrimps, lobsters, and crabs of the Atlantic Coast of the Eastern United States, Maine to Florida. Smithsonian Inst. Press, (Washington, D.C.). 550 pp.

Williams, J.T. and R.L. Shipp. 1980. Observations on fishes previously unrecorded or rarely encountered in the northeastern Gulf of Mexico. Northeast Gulf Sci. 4:17-27.

Windom, H.L. 1981. Comparison of atmospheric and river transport of trace elements to the continental shelf environment. In: River Input to Ocean Systems, Martin, J.M., Burton, J.D. and Eisma, D. (eds) UNEP/UNESCO.

Woodward-Clyde Consultants. 1979. Eastern Gulf of Mexico marine habitat study. Rep. to U.S. Dept. of Interior, Bureau of Land Management, OCS Office, New Orleans, LA. Contract No. AA551-CT3-22.

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