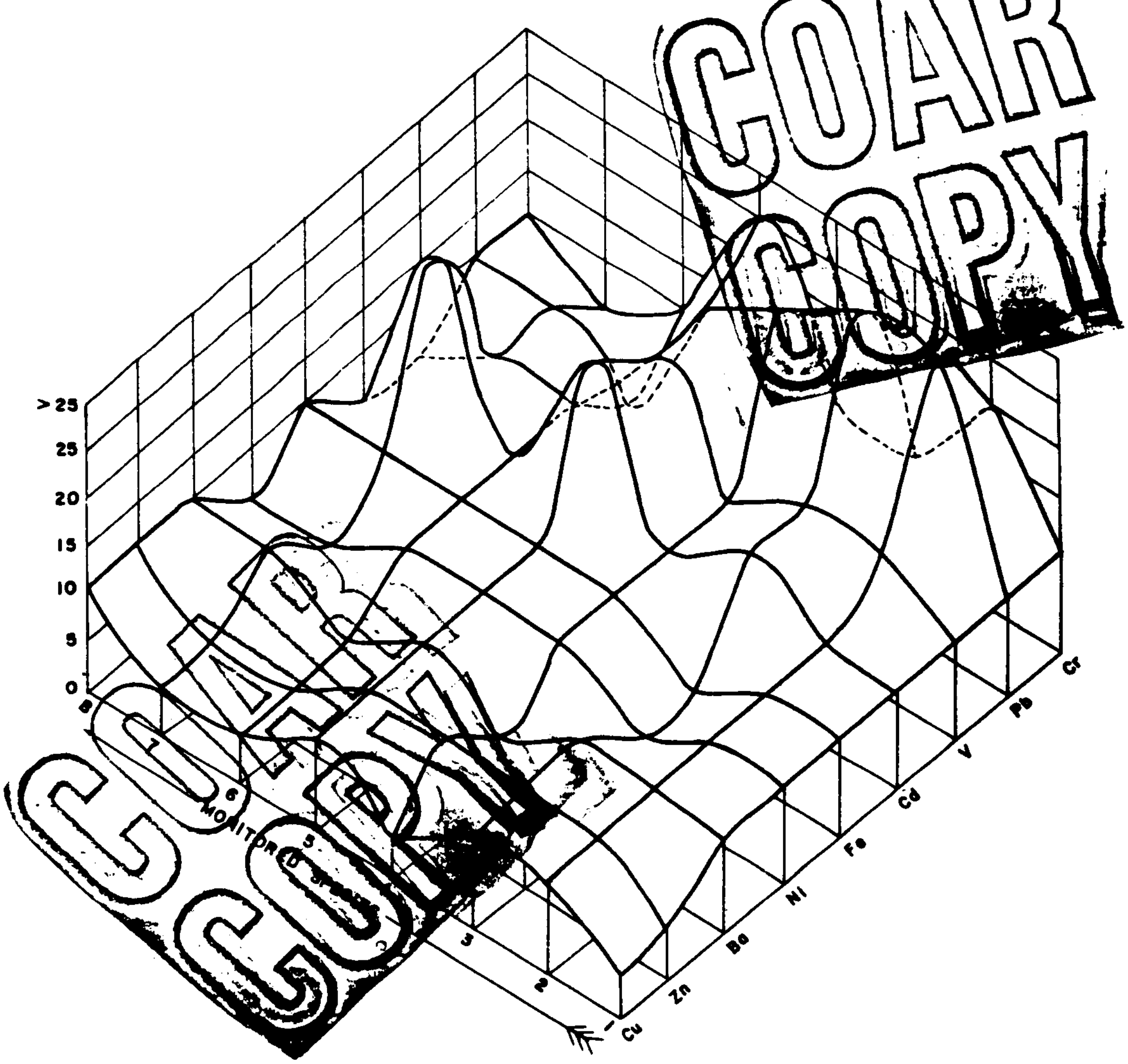
MAFLA
FINAL REPORT

THE MISSISSIPPI, ALABAMA, FLORIDA, OUTER CONTINENTAL SHELF BASELINE ENVIRONMENTAL SURVEY

1977/1978



Prepared by Dames & Moore for the Bureau of Land Management
Contract AA550-CT7-34 January 26, 1979

Volume I-A : Program Synthesis Report

FINAL REPORT

MISSISSIPPI, ALABAMA, FLORIDA OUTER CONTINENTAL SHELF

BASELINE ENVIRONMENTAL SURVEY; MAFLA, 1977/78

PREPARED FOR U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT

CONTRACT AA550-CT7-34

VOLUME I-A

PROGRAM SYNTHESIS REPORT

DAMES & MOORE JOB NO. 08699-008-88

NEW ORLEANS, LOUISIANA

JANUARY 26, 1979

COVER

THE COVER OF THIS REPORT IS A FIGURE DEPICTING THE MINIMUM-NUMBER-OF-REPLICATES-SURFACE OF SELECTED SPECIES TO DETECT A DOUBLING IN ANY OF THE TRACE METALS LISTED. IT IS CHOSEN AS CHARACTERISTIC OF THE NATURE OF THIS PROJECT BECAUSE IT REPRESENTS THE APPLICATION OF SOPHISTICATED ANALYSIS OF COMPLEX, MULTIDISCIPLINARY DATA TO PRODUCE A GRAPHIC OF PRACTICAL APPLICATION.

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ABSTRACT

A third year baseline marine environmental survey was conducted by Dames & Moore for the United States Department of the Interior, Bureau of Land Management in the eastern Gulf of Mexico during 1977-1978, and a synthesis report prepared. Marine geology, physical oceanography, marine biology, trace metal and hydrocarbon chemistry of the water column, sediments and tissues were examined for the Mississippi, Alabama, Florida (MAFLA) outer continental shelf in support of prospective OCS oil and gas development. The physical oceanographic and sediment geology data provided independent variable information to use in understanding the biological and chemical distributions. A data base was created merging data collected from 1974-1978 into a single format, and multivariate analysis was applied to data sets taken from that base to derive the conclusions of the synthesis report. Marine benthic faunal associations generally parallel depth contours, and most show decreasing density and variety with increasing fine sediments (forams show the reverse trend). Fines and total organic carbon both increase northward and offshore. These two variables also strongly influence both hydrocarbon and trace metal distribution. Tissue chemistry varied with diet, location, species and season, with diet an apparent dominant cause of variance in histochemical parameters. No signs of metal contamination were evident. Sediment hydrocarbons increase in petrogenic content offshore and toward the northwest, as do sediment trace metal concentrations. Evidence of tissue petrogenic hydrocarbons was seen at one station (off Panama City, FL) in one season. No water column petrogenics were recovered, and overall the MAFLA area is a healthy environment, with no pathologies observed from a sample of over 14,000 slides from 70 species. Gaps in the existing data base and parameters for use in monitoring studies are identified.

INTRODUCTION

The eastern Gulf of Mexico's Outer Continental Shelf (OCS) was the setting for the first of the United States Department of the Interior, Bureau of Land Management sponsored, offshore oil and gas development related comprehensive marine environmental surveys in 1974. In June 1977, Dames & Moore was contracted to complete a third year's survey and to synthesize the results of the program begun in 1974 into a single final report. This report constitutes that final synthesis effort, as called for in BLM contract AA550-CT7-34.

The area encompassed by the eastern Gulf of Mexico OCS includes the Federal waters off the coasts of Mississippi, Alabama and west Florida (MAFLA). Water depths sampled vary from about 10 to 200 m, and the sampling stations cover the major physiographic and oceanographic sub-units within the MAFLA region. Figure 1 shows the positions of the 1978/79 sampling stations with relation to the active and proposed lease areas. Although the sampling carried out under the present contract was limited to three cruise periods in the 1977/78 year, the report covers the compatible data from the summer of 1974 through the winter of 1978.

This final report is composed of two volumes. Volume I-A, the Data Synthesis Report, is intended as a technical distillation of the Principal Investigators' final reports, and draws upon both the final reports produced in 1975 and 1977 by the State University System Institute of Oceanography (SUSIO), and the retrievable and compatible raw data supporting those reports. The second part of this volume (I-B) is the brief Executive Summary Report. It is a greatly condensed version of the Synthesis Report, and is restricted to statements of the salient findings of the program. Volume II is the Compendium of Work Elements Reports. This volume contains much of the support data used to derive the first volume, and they are primarily composed of the Principal Investigators' (PIs) final reports to Dames & Moore.

None of these reports is complete unto itself. Extensive referencing between documents is necessarily required for substantiation of the summary statements in the Executive Summary Report. In a like manner, the Data Synthesis Report makes regular reference to specific PI reports in Volume II. Moreover, many data products and much of the raw data used by Dames & Moore and by PIs in producing the Work Elements Reports are not included therein, when not specifically required to illustrate or substantiate specific points. All raw data which are in quantitative form are on the Dames & Moore Data Tapes submitted to the National Oceanographic Data Center (NODC) through BLM. A discussion of those tapes, their formats and content is included as Chapter 29 of Volume II.

GOALS OF THE STUDY

The fundamental goal of the MAFLA baseline environmental survey has been to establish the natural range of variability in selected parameters which might be affected by OCS oil and gas development. Parameters selected as dependent variables which would be expected to show changes under some conditions associated with oil and gas development were:

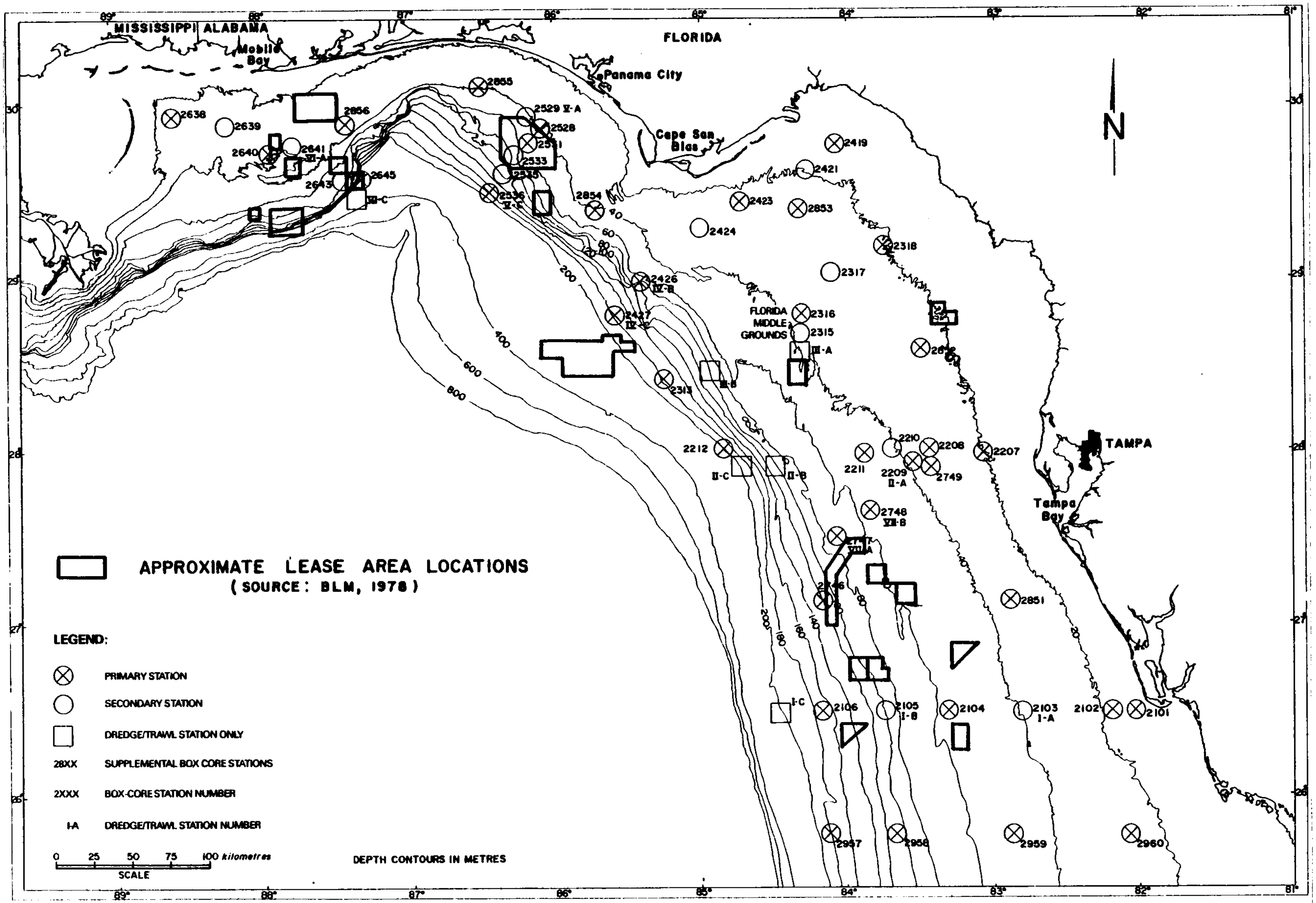


FIGURE I

MAFLA PROPOSED AND ACTIVE LEASE AREAS AND 1977/1978 STATION LOCATIONS

- Hydrocarbon and trace metal composition of the water column, sediments and animal tissues

- Biological community structure including micro and macroinfauna, macroepifauna and demersal fish

- Histopathology and microbial biomass.

Parameters selected as independent variables which would be expected to directly affect the biological and chemical parameters either jointly with or independent of oil and gas development were:

- Geological nature of suspended and bottom sediments including grain size, percent carbonate, total organic carbon (TOC) and clay mineralogy

- Physical nature of the water column including salinity, temperature and transmissivity (a measure of water clarity).

Specific goals of the 1978/79 study as listed in the Request for Proposal, AA550-RP7-10, December 8, 1976 were:

1. Geochemistry Objective; continuation of seasonal studies to determine the range in concentrations of high molecular weight (HMW) hydrocarbons and selected trace metals in the sediments preceding significant oil and gas development;

2. Macrofauna Chemistry Objective; continuation of seasonal studies to determine the existing range of HMW hydrocarbon and trace metal concentrations in selected benthic macrofauna species preceding oil and gas development;

3. Benthic Infauna Community Analysis Objective; continuation of seasonal studies of benthic infaunal (>500 μm) communities, meiofaunal (62-500 μm) communities, and foraminiferal populations to determine the natural ranges of selected parameters as specified;

4. Histopathology Objective; continuation of histological studies to determine tissue condition of selected benthic macrofauna species preceding significant oil and gas development;

5. Descriptive Chemistry Objective; describe seasonal variation in the concentrations of HMW hydrocarbons and selected trace metals in the water column;

6. Supportive Data Objective; collect samples and conduct analyses supportive of benchmark data interpretation.

The nature of the study has been descriptive. Following the 1974 survey in which a large number of stations in scatter arrays were sampled with little replication in one season only (summer), the program evolved into a transect oriented survey with three sample periods each year, and greater replication. Greater emphasis on synopticity and greater concentration on benthic elements were the principal changes between the 1975/76 sampling program under SUSIO and the 1977/78 sampling program under Dames & Moore. In addition, a much greater emphasis on integrated data analysis and the use of descriptive statistical analysis has characterized the current study. These shifts have all allowed a greater focusing of the massive descriptive data base on program goals.

The work products produced under this contract include the volumes of this report, the Dames & Moore Data Tape, and various progress and cruise reports cited in the Reference section of this report. There are three general use areas toward which each of these products is aimed:

- The establishment of a baseline description for use in assessing environmental impacts of oil and gas development and in evaluating areas for restricted development or non-development
- The establishment of a statistical basis for evaluating the natural range of control condition variability in dependent variables for comparison against post-development data
- The determination of the utility of each parameter for inclusion in a monitoring program which will have reasonable probability of being able to discern changes produced from oil and gas development from changes which occur due to natural causes.

The Excecutive Summary Report (Volume I-B) is designed to provide a very general picture of each of the major study parameters in the MAFLA region, how they interact, and which are useful as monitoring tools. In order to keep it as comprehensive as possible, while keeping the volume to an absolute minimum, it is heavily illustrated and contains almost entirely conclusory statements.

This volume, the Data Synthesis Report (Volume I-A), contains the distilled backup for the conclusions expressed in the Executive Summary Report. It is designed as a technical document, but the language has been designed to maximize the breadth of audience for which it may prove useful. The remaining array of documents provide further detail to support Volume I. In addition, most subject areas contain sufficient raw data that much more analysis and interpretation is possible than was attempted here.

THE MAFLA STUDY AREA

The Mississippi, Alabama, Florida continental shelf in the eastern Gulf of Mexico as limited by the discussion in this report includes the Federal OCS lands west of longitude 81° 30', east of longitude 89°, north of latitude 25° 30', and south of latitude 30° 15'. Stations sampled during 1978/79 ranged in depth from 10 m near Sanibel Island in south Florida and southeast of Alligator Harbor on the northeastern Florida Gulf coast, to the 200 m contour (six stations; refer to Figure 1).

From the summer 1975 sampling period through winter 1978, sampling stations were arrayed along transects trending generally in an onshore-offshore direction. For the 1975/76 sampling year six transects were established (series 21XX through 26XX in Figure 1). For the samples collected and analyzed during the Dames & Moore contract, a southern transect (29XX) south of latitude 26°, a diagonal transect (27XX) from the 120 m contour offshore along latitude 27°, running inshore to 30 m off Tampa Bay, and a transect parallel to the shoreline (28XX) and with stations spaced between transects were added.

The region is characerized by a broad transition zone of decreasing Mississippi River sediment influence along the Mississippi-Alabama shelf extending to the western margin of the DeSoto Valley; east and south of that broad submarine valley, the West Florida Sand Sheet covers most of the Florida Shelf. Except for isolated patches of rock, most notably the reefs of the Florida Middle Grounds, the benthic habitats are sedimentary. Water temperatures vary from winter lows below 10°C (50°F) to nearly 30°C (86°F) inshore in the summer. Salinities are typical of open coastal and oceanic regions, varying between 31 and 37 $^{o}/oo$ (parts per thousand; 3.1 to 3.7%). Biologically the region bears more resemblance to Carolinian and Caribbean faunas than to Western Gulf faunas, and its sub-tropical/temperate nature is expressed in the general lack of seasonality among the macrofauna (bottom fish and larger benthic invertebrates).

PARTICIPANTS AND PROJECT STRUCTURE

Dames & Moore contracted 18 Principal Investigators from six universities and three private firms to carry out various work elements of the 1977/78 MAFLA Program. Those investigators and the four Dames & Moore key personnel are listed in Table 1 along with their affiliations and work element assignments. In addition, Dames & Moore retained consultants: Dr. David Johnson, State University of New York, Syracuse, to aid in trace metal data interpretation; Dr. Paul Boehm, Energy Resources Company, Cambridge, sediment hydrocarbon interpretation; and Dr. Rudolph Bieri, Virginia Institute of Marine Sciences, tissue hydrocarbon interpretation. Dr. Donald Reish, California State University, Long Beach, and Dr. C.S. Giam, Texas A&M University were retained as consultants to aid Dr. Harold Palmer of Dames & Moore with Quality Control. Dr. Reish visited the principal biological laboratories at the University of South Florida and University of Alabama's marine station, and participated in all four quarterly meetings; Dr. Giam inspected the hydrocarbon laboratories at ARLI and Texas A&M University, and participated in the first quarterly meeting.

Brief resumes of each of the contributors to Volume II, and of the Dames & Moore key personnel, are contained in that volume. More extensive bibliographies are contained in Appendix 1, Revised Technical Proposal to AA550-RP7-10, from Dames & Moore to the Bureau of Land Management, April 15, 1977.

As program manager, Dames & Moore was responsible for project organization, logistics, maintaining schedule and budget, and coordinating the efforts of the PI's. All data management and data analysis, the writing and production of progress reports, and the organization and direction of

TABLE 1

1977/78 MAFLA PROGRAM PARTICIPANTS

PRINCIPAL INVESTIGATORS	AFFILIATION	PROGRAM WORK ELEMENT
Dr. Wayne Bock	University of Miami	Foraminifera Taxonomy
Dr. Keith Cooksey	University of Miami	Biomass of Microrganisms (ATP)
Dr. Peter Betzer	University of South Florida	Water Column Trace Metals
Dr. Norman Blake	University of South Florida	Histopathology Macroinfauna Taxonomy/Molluscs
Dr. Kendall Carder	University of South Florida	Transmissometry (Water Clarity)
Dr. Larry Doyle	University of South Florida	Standard Sediment Parameters, Clay Mineralogy
Mr. John Caldwell/Dr. Frank Maturo	University of Florida	Zooplankton Taxonomy
Dr. Steve Bortone (with Dr. Robert Shipp)	University of West Florida	Demersal Fish Taxonomy
Dr. Sneed Collard	University of West Florida	Neuston Taxonomy
Dr. Richard Heard	University of Alabama Marine Lab	Macroinfauna Taxonomy/Crustaceans
Dr. Thomas Hopkins	University of Alabama	Macroepifauna Taxonomy
Dr. Susan Ivester	University of Alabama	Meiofauna Taxonomy
Dr. Robert Shipp (with Dr. Steve Bortone)	University of Alabama	Demersal Fish Taxonomy
Dr. Barry Vittor	Barry A. Vittor & Associates, Inc.	Macroinfauna Taxonomy/Polychaetes
Dr. Lela Jeffrey	Texas A&M University	Water Column Hydrocarbon and Organic Carbon
Dr. John Trefry	TerEco Corporation	Sediment Trace Metals
Dr. Robert Shokes	Science Applications, Inc.	Barium, Vanadium Chemistry
Dr. George Gould/Dr. Bud Moberg	Analytical Research Laboratories, Inc.	Hydrocarbon Chemistry/Benthos and Zooplankton; Trace Metal Chemistry, Macrofauna
Mr. Lee Fausak	Dames & Moore	Salinity, Temperature, Density
Dr. Harold Palmer	Dames & Moore	Technical Advisory Committee Chairman
Mr. Peter Feldhausen	Dames & Moore	Data Manager
Dr. Thomas Scanland	Dames & Moore	Program Manager

conferences were also the responsibility of Dames & Moore's Program Management. Each PI was responsible for the technical quality of his work element. Field logistics were contracted through Science, Engineering and Analysis, Inc. (SEA), and ships were leased from Sealcraft Operators, Inc. of Galveston. Dames & Moore provided at-sea supervision and exercised a formal quality control program during both field and laboratory phases of the program.

ORGANIZATION OF THE SYNTHESIS REPORT

The remainder of this report is organized into a summary of methodology and a series of technical sections. The Methods section covers field, laboratory and data handling methodology. The technical sections begin with the discussion of the geological findings and proceed through physical oceanography and marine chemistry, and conclude with the biology discussion. Each technical discussion includes its component parts, the sum covering each work element listed in Table 1. Each work element section begins with a discussion of the function of that element and the definition of the data set utilized, and each concludes with an evaluation of the utility of that parameter as a monitoring tool.

The Executive Summary Report (Volume I-B) is a statement of the conclusions derived in this report. Support for those conclusions is found in this volume and in Volume II. Field methodology and details of field operations (including navigation reports) are included in the four summary cruise reports cited in the References section. Preliminary results, the discussions of the four quarterly meetings, and the sample inventory reports are included in the four quarterly progress reports, also cited at the end of this volume. Lastly, readers are referred to five prior BLM/MAFLA documents which provide background for this document, the Sale 65 FEIS, the SUSIO 1975/76 final report, the SUSIO 1974 final report, the 1975 physical oceanography report and the 1973 literature review. Each is cited in the References section.

METHODS OF INVESTIGATION

FIELD SURVEYS

MAFLA Cruises, 1974-1978

Because the data synthesis portions of this report will include data collected since the inception of the BLM/MAFLA studies program in 1974, a brief listing and functional description of all cruises will be given. Inasmuch as they have been described only in preliminary reports (Dames & Moore, 1977b, 1978a,c,d) before, the cruises undertaken as part of the present contract study will be described in greater detail than earlier cruises from the 1974, and 1975/1976 study periods.

Table 2 lists all cruises undertaken as part of the BLM's environmental benchmark studies of the MAFLA OCS, giving cruise designations, vessels, dates, and functions. The information was derived from reports and computer data files prepared by SUSIO. The data resulting from the diving, geophysical, and rig monitoring cruises are not treated in this report. The cruises

TABLE 2

DESCRIPTION OF BLM CRUISES, 1974-1978 MAFLA OCS STUDY PROGRAM

CRUISE NUMBER	VESSEL	DATES	FUNCTION
BLM 1	R/V Bellows	5/13 - 5/16/74	Water column
BLM 2	R/V Miss Freeport	5/16 - 6/16/74	Box-coring, dredge/trawl
BLM 3	R/V Gulf Researcher	5/15 - 5/22/74	Water column
BLM 4	R/V Bellows	5/18 - 6/30/74	Box-coring, dredge/trawl
BLM 5	R/V Tursiops	5/24 - 6/7/74	Water column
BLM 6	R/V Gulf Researcher	6/17 - 6/22/74	Water column
BLM 7	R/V Gulf Researcher	6/26 - 6/30/74	Water column
BLM 8	R/V Miss Freeport	6/20 - 6/21/74	Water column
BLM 9	R/V Miss Freeport	6/21 - 6/22/74	Water column
BLM 10	R/V Columbus Iselin	5/28 - 6/9/75	Box-coring
BLM 11	R/V Bellows	6/4 - 6/30/75	Diving
BLM 12	R/V Tursiops	6/19 - 7/15/75	Water column
BLM 13	R/V Gyre	7/19 - 7/20/75	Dredge/trawl
BLM 14	R/V Gyre	7/22 - 7/25/75	Box-coring
BLM 15	R/V Bellows	7/23 - 7/28/75	Dredge/trawl
BLM 16	R/V Decca Profiler	6/25 - 8/17/75	Geophysical
BLM 17	R/V Bellows	7/31/75	Box-coring
BLM 18	Unknown	Unknown	Unknown
BLM 19	R/V Bellows	9/4 - 10/5/75	Diving
BLM 20	R/V Tursiops	9/7 - 10/2/75	Water column
BLM 21	R/V Columbus Iselin	9/15 - 9/28/75	Box-coring
BLM 22	R/V Gyre	10/18 - 10/22/75	Dredge/trawl
BLM 23	Unknown	Unknown	Unknown
BLM 24	R/V Bellows	11/20 - 12/6/75	Rig monitoring
BLM 25	R/V Bellows	11/20 - 12/6/75	Rig monitoring
BLM 26	R/V Bellows	1/2 - 1/24/76	Rig monitoring
BLM 27	R/V Bellows	1/2 - 1/24/76	Rig monitoring
BLM 28	R/V Tursiops	1/9 - 2/7/76	Water column
BLM 29	R/V Gyre	1/16 - 1/8/76	Box-coring
BLM 30	R/V Gyre	2/8 - 2/9/76	Dredge/trawl
BLM 31	R/V Bellows	1/2 - 1/24/76	Rig monitoring
BLM 32	R/V Bellows	2/5 - 2/21/76	Diving
BLM 33	R/V Bellows	2/26 - 2/29/76	Dredge/trawl
BLM 34	R/V Bellows	3/4 - 3/11/76	Diving
BLM 35	R/V Tursiops	3/3 - 3/4/76	Dredge/trawl
BLM 36	R/V Tursiops	3/25 - 4/3/76	Rig monitoring
BLM 37	R/V Bellows	6/10 - 7/8/76	Diving
BLM 38	R/V Tursiops	6/10 - 6/17/76	Water column

TABLE 2 (CONTINUED)

DESCRIPTION OF BLM CRUISES, 1974-1978 MAFLA OCS STUDY PROGRAM

CRUISE NUMBER	VESSEL	DATES	FUNCTION
BLM 39	R/V Columbus Iselin	6/23 - 7/9/76	Box-coring
BLM 40	R/V Rounsefell	6/25 - 6/29/76	Dredge/trawl
BLM 41	R/V Tursiops	7/7 - 7/16/76	Water column
BLM 42	R/V Bellows	7/22 - 7/28/76	Water column
BLM 43	R/V Tursiops	8/1 - 8/8/76	Water column
BLM 44	R/V Columbus Iselin	7/10 - 7/14/76	Dredge/trawl
BLM 45	R/V Tursiops	7/23 - 7/28/76	Neuston and zooplankton
BLM 46	R/V Bellows	7/14 - 7/19/76	Dredge/trawl
DM I	R/V Indian Seal	8/13 - 9/9/77	Box-coring and dredge/trawl
DM II	R/V Java Seal	10/21 - 11/18/77	Box-coring, dredge/trawl and water column
DM III	R/V Pacific Seal	2/2 - 2/25/78	Water column
DM IV	R/V Indian Seal	1/31 - 2/20/78	Dredge/trawl, box-coring

fall into seasonal schedule patterns as follows: summer 74, summer 75, fall 75, winter 76, summer 76, summer 77, fall 77 and winter 78.

The original cruise schedule for the 1977/78 program called for a benthic (i.e., box-core and dredge/trawl) cruise in June 77, a concurrent water column cruise in June 77, a benthic cruise in September 77, and concurrent benthic and water column cruises in February 78. Because of both delays in contract authorization and changing oceanographic seasons, the actual schedule was altered somewhat and consisted of a benthic cruise in August-September 77 (DM I), a combined benthic and (abbreviated) water column cruise in October-November 77 (DM II), and concurrent water column (DM III) and benthic (DM IV) cruises in February 78. The survey vessels were all supplied by Sealcraft Operators of Galveston, Texas, and were the 65 m (215 ft.) M/V Indian Seal for cruise DM I and DM IV, the 56 m (185 ft.) M/V Java Seal for cruise DM II, and the 47 m (155 ft.) M/V Pacific Seal for cruise DM III. The vessels were selected for adequate size for efficient at-sea operations, stability, and sea-keeping abilities.

The organization of each cruise was defined by a cruise plan submitted to BLM prior to each field cruise; the plans described the cruise objectives, identified the scientific and support crews, and presented details of sample collection, labeling, treatment, and disposition, among other topics.

The summer 76 cruises were performed by the previous contractor to BLM; the data, however, were unreduced in large part, and most samples were unanalyzed and were to be analyzed as part of this contract and treated in this report. The details of the cruises are given in a summary cruise report for the June-August 1976 period, submitted to BLM under contract AA551-CT6-32 (SUSIO, undated).

Station Distribution

The benthic stations, i.e., box-core and dredge/trawl, occupied during the current 1977/78 MAFLA program have been shown on Figure 1 presented in the Introduction. A total of 49 box-core stations were occupied and included 36 primary stations where either 11 or 16 replicate box-cores were collected, and 13 secondary stations where either one or six box-cores were collected. Six of the primary stations were designated supplemental stations and were occupied only during the summer cruises. Seventeen dredging and trawling stations were occupied as part of the regular sampling effort during the 1977/78 program. The stations were generally arrayed along eight transects; the six supplemental stations were interspersed between the transect lines. One of the primary stations was deleted after the first cruise when no penetration of the solid substrate could be achieved. Additional trawls were made for specific chemistry and habitat samples collection at two stations.

The 1977/78 station plan was altered somewhat from the 1975-76 plan. Nine box-core stations were deleted along Transects IV, V, and VI (2420, 2422, 2425, 2530, 2532, 2534, 2637, 2642, 2644); Transect IX, with four new stations (2957, 2958, 2959, and 2960) was added, and the six supplemental stations were added between existing transect lines. Four of these six coincided with summer 76 supplemental stations, and two were added in the vicinity of summer 76 supplemental stations. Table 3 shows the locations, depth, and station number correspondence of all stations identified from the BLM/MAFLA programs from 1974 through 1978.

Sampling and Measuring Equipment

The three functional types of cruises (box-core, dredge/trawl and water column) comprising the field program had different objectives and used a variety of sampling and measurement equipment. The details of the sampling equipment and their methods of use are given in the cruise reports already submitted and in the third quarterly progress reports submitted by each PI (see Dames & Moore 1977b, 1978a, c, d, e). Only a very brief description will, therefore, be given here.

Benthic samples used for infaunal and sediment studies were collected with a stainless steel box-corer with a 21.3 x 30.5 x 43.2 cm box. The corer weighed approximately 275 kg and was equipped with a weight stand on which an additional 900 kg of lead could be loaded; the corer was always used fully weighted in the 77/78 program. A Smith-MacIntyre grab sampler was used as an alternate sampler if adequate cores could not be obtained with the box-corer.

Trawling for demersal fish and macroepifauna was done with semi-balloon trawls with mouths slightly wider than 9 m. Mesh size was less than 4 cm and heavier trawl doors were used in 1977/78 than in 1975/76 in order to collect a better sample. Dredging for benthic animals was done with a Capetown dredge pulled along the sea floor; the dredge had a rectangular mouth with dimensions of 0.97 m wide by 0.41 m high; a mesh liner with a 1.3 cm mesh was inserted in the dredge (see Volume II, Chapter 17).

Water samples were collected on all four cruises with PVC Niskin water sampling bottles of sizes appropriate for the intended use of the samples. Water samples for salinity analysis and STD calibration were taken with 1.5ℓ bottles equipped with reversing thermometers. Samples for suspended sediment clay mineralogy and trace metal analyses were taken with either 30 or 40 ball-valve Niskin bottles that opened and were flushed only after they had passed through the air-water interface. Water for dissolved and particulate organic carbon and for dissolved and particulate hydrocarbon were collected with 90ℓ Niskin bottles.

Light transmission was measured directly with a Hydro Products model 612/912S transmissometer fitted with a pressure transducer for depth determination. The attenuation of ambient surface light was measured with a Kahlsico model 268WA310 underwater irradiameter. Depth-dependent profiles of salinity and temperature were obtained with two instruments; on cruise DM II (fall 77) a Neil Brown Instrument System model Mark III STD with deck-readout was used, and on DM III (winter 78 water column cruise) a Plessy model 9060 self-recording STD was used.

Neuston samples were collected during cruise DM III. A catamaran-type neuston sled manufactured by Kahl Scientific Instrument Company was used. It was fitted with a 202 μm plankton net affixed to a rectangular

TABLE 3

A. 1977-1978 STATIONS

BLM STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
2101	2101	26.4166	82.2525	10
2102	2102	26.4166	82.4166	16
2103	2103	26.4166	82.9666	39
2104	2104	26.4166	83.3835	53
2105	2105	26.4165	83.8327	98
2106	2106	26.4158	84.2500	168
2207	2207	27.9501	83.1500	17
2208	2208	27.9334	83.4582	28
2209	2209	27.8751	83.5664	33
2210	2210	27.9580	83.7081	36
2211	2211	27.9415	83.8832	45
2212	2212	27.9500	84.7999	190
2313	2313	28.3998	85.2508	175
2315	2315	28.5664	84.3359	38
2316	2316	28.7000	84.3335	37
2317	2317	28.9333	84.1000	30
2318	2318	29.0836	83.7501	21
2419	2419	29.7833	84.0833	10
2421	2421	29.6169	84.2833	19
2423	2423	29.3334	84.7339	30
2424	2424	29.2169	85.0003	28
2426	2426	28.9665	85.3833	83
2427	2427	28.8331	85.6172	177
2528	2528	29.9163	86.0829	39
2529	2529	29.9331	86.1081	39
2531	2531	29.7997	86.1581	48
2533	2533	29.7167	86.2580	68
2535	2535	29.6167	86.3333	118
2536	2536	29.5004	86.4164	184
2638	2638	29.9247	88.5578	24
2639	2639	29.8917	88.2076	32
2640	2640	29.7247	87.9083	36
2641	2641	29.7579	87.7750	36
2643	2643	29.6086	87.4503	68
2645	2645	29.5834	87.3339	98
2746	2746	27.0583	84.2283	121
2747	2747	27.4033	84.1217	75
2748	2748	27.6200	83.8917	50
2749	2749	27.8650	83.4533	30
2851	2851	27.0572	83.0190	33
2852	2852	28.5001	83.4995	24
2853	2853	29.3006	84.3331	25
2854	2854	29.4000	85.7006	38
2855	2855	30.1339	86.5000	33
2856	2856	29.9003	87.4000	27

TABLE 3 (CONTINUED)

A. 1977-1978 STATIONS

BLM STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
2957	2957	25.6667	84.2500	168
2958	2958	25.6667	83.8333	109
2959	2959	26.6667	83.0833	54
2960	2960	26.6667	82.3333	26
2863	2863	26.5000	84.3333	20
I-C	0004	26.4167	84.3333	180
II-A	0010	27.8333	83.5167	35
II-B	0001	27.8333	84.5167	105
II-C	0002	27.8333	84.7000	185
III-A	0005	28.4996	84.3497	39
III-B	0003	28.4333	84.9333	90

B. 1975-1976 STATIONS

PREVIOUS STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
X101	0101	2103	26.4166	82.9666	39
3101	0101	2103	26.4166	82.9666	39
4101	0101	2103	26.4166	82.9666	39
I-A	2103	2103	26.4166	82.9666	39
X102	0102	2105	26.4165	83.8327	98
3102	0102	2105	26.4165	83.8327	98
4102	0102	2105	26.4165	83.8327	98
I-B	2105	2105	26.4165	83.8327	98
X103	0103	0004	26.4167	84.3333	180
3103	0103	0004	26.4167	84.3333	180
4103	0103	0004	26.4167	84.3333	180
I-C	0004	0004	26.4167	84.3333	180
X204	0204	0010	27.8333	83.5167	35
3204	0204	0010	27.8333	83.5167	35
4204	0204	0010	27.8333	83.5167	35
II-A	0010	0010	27.8333	83.5167	35
X205	0205	0001	27.8333	84.5167	105
3205	0205	0001	27.8333	84.5167	105
4205	0205	0001	27.8333	84.5167	105
II-B	0001	0001	27.8333	84.5167	105
X206	0206	0002	27.8333	84.7000	185
3206	0206	0002	27.8333	84.7000	185
4206	0206	0002	27.8333	84.7000	185
II-C	0002	0002	27.8333	84.7000	185
X307	0307	0005	28.4996	84.3497	39
3307	0307	0005	28.4996	84.3497	39
4307	0307	0005	28.4996	84.3497	39

TABLE 3 (CONTINUED)

B. 1975-1976 STATIONS

PREVIOUS STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
2314	2314	0005	28.4996	84.3497	39
III-A	0005	0005	28.4996	84.3497	39
X308	0308	0003	28.4333	84.9333	90
3308	0308	0003	28.4333	84.9333	90
4308	0308	0003	28.4333	84.9333	90
III-B	0003	0003	28.4333	84.9333	90
X309	0309	2313	28.3998	85.2508	175
3309	0309	2313	28.3998	85.2508	175
4309	0309	2313	28.3998	85.2508	175
III-C	2313	2313	28.3998	85.2508	175
2420	2420	2420	29.7000	84.1836	15
2422	2422	2422	29.4986	84.4503	27
2425	2425	2425	29.0836	85.2501	36
X410	0410	0006	29.1500	85.2333	40
3410	0410	0006	29.1500	85.2333	40
4410	0410	0006	29.1500	85.2333	40
IV-A	0006	0006	29.1500	85.2333	40
X411	0411	2426	28.9665	85.3833	83
3411	0411	2426	28.9665	85.3833	83
4411	0411	2426	28.9665	85.3833	83
IV-B	2426	2426	28.9665	85.3833	83
X412	0412	2427	28.8331	85.6172	177
3412	0412	2427	28.8331	85.6172	177
4412	0412	2427	28.8331	85.6172	177
IV-C	2427	2427	28.8331	85.6172	177
2530	2530	2530	29.8495	86.1080	42
2532	2532	2532	29.7657	86.2057	53
X513	0513	2529	29.9331	86.1081	39
3513	0513	2529	29.9331	86.1081	39
4513	0513	2529	29.9331	86.1081	39
V-A	2529	2529	29.9331	86.1081	39
X514	0514	0007	29.6667	86.2833	91
3514	0514	0007	29.6667	86.2833	91
4515	0514	0007	29.6667	86.2833	91
2534	2534	0007	29.6667	86.2833	91
V-B	0007	0007	29.6667	86.2833	91
X515	0515	2536	29.5004	86.4164	184
3515	0515	2536	29.5004	86.4164	184
4515	0515	2536	29.5004	86.4164	184
V-C	2536	2536	29.5004	86.4164	184
X616	0616	2641	29.7579	87.7750	36
3616	0616	2641	29.7579	87.7750	36
4616	0616	2641	29.7579	87.7750	36
VI-A	2641	2641	29.7579	87.7750	36
2637	2637	2637	30.0332	88.6167	20

TABLE 3 (CONTINUED)

B. 1975-1976 STATIONS

PREVIOUS STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
2642	2642	2642	29.6750	87.6167	36
2644	2644	2644	29.6031	87.3919	74
X617	0617	0008	29.5500	87.4000	97
3617	0617	0008	29.5500	87.4000	97
4617	0617	0008	29.5500	87.4000	97
VI-B	0008	0008	29.5500	87.4000	97
X618	0618	0009	29.5167	87.3667	193
3618	0618	0009	29.5167	87.3667	193
4618	0618	0009	29.5167	87.3667	193
VI-C	0009	0009	29.5167	87.3667	193
X719	0719	2747	27.4033	84.1217	75
3719	0719	2747	27.4033	84.1217	75
4719	0719	2747	27.4033	84.1217	75
VII-A	2747	2747	27.4033	84.1217	75
X720	0720	2748	27.6200	83.8917	50
3720	0720	2748	27.6200	83.8917	50
4720	0720	2748	27.6200	83.8917	50
VII-B	0748	2748	27.6200	83.8917	50
A	6001	6001	29.9333	85.9833	32
B	6002	6002	29.7833	88.2167	33
C	6003	6003	28.6000	84.2667	29
D	6004	2747	27.4033	84.1217	75
2851	2851	2862	27.0000	83.0000	33
2853	2853	2863	29.5000	84.3333	27
T-1	T-1	1415	29.2833	87.6667	330
T-2	T-2	1414	29.3667	87.7667	110
T-3	T-3	0011	29.4667	88.8667	Unknown
T-4	T-4	0012	29.5667	87.9833	40
T-5	T-5	0013	29.6667	88.0833	Unknown
T-6	T-6	6002	29.7833	88.2167	33
T-7	T-7	0014	29.8500	88.3000	Unknown
T-8	T-8	0015	29.9500	88.4083	31
T-9	T-9	1412	30.0667	88.5500	14
047	047	2315	28.5664	84.3359	38
062	062	0010	27.8333	83.5167	35
247	247	6003	28.6000	84.2667	29
STD11-750910	STD11-750910	0018	27.5700	87.7200	42
STD16-750912	STD16-750912	0019	29.3000	87.1667	305
STD18-750912	STD18-750912	0020	29.4417	86.5333	275
STD29-750926	STD29-750926	0021	29.3583	83.7333	15

TABLE 3 (CONTINUED)

B. 1975-1976 STATIONS

PREVIOUS STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
STD31-750927	STD31-750927	0022	29.1333	83.9333	24
STD33-750928	STD33-750928	0023	28.8250	84.2167	32
STD39-750930	STD39-750930	0024	28.2833	84.5833	67
STD41-751001	STD41-751001	0025	27.8917	84.6167	53
STD43-751002	STD43-751002	0026	27.8583	83.3500	28
STD10-760112	STD10-760112	0027	29.3167	87.7167	180
STD16-760120	STD16-760120	0028	29.5667	86.4500	168
064(0058-0061 0067-0068 only)*	064	0016	28.3119	83.5134	32
064	064	064	27.8360	83.4180	32
146(0036-0043 only)*	146	0017	28.7818	83.8299	29
146	146	146	28.6853	84.3880	31
147	147	147	28.6131	84.3409	30
151	151	151	28.5377	84.3120	30
251	251	251	28.5422	84.2680	34
1101	1101	1101	27.8500	83.1000	27
1102	1102	2209	27.8751	83.5664	33
1103	1103	1103	27.9167	84.7500	180
1204	1204	1204	29.4333	83.6667	13
1205	1205	1205	29.2667	83.8167	18
1206	1206	1206	29.0167	84.0500	27
1207	1207	1207	28.6333	84.4000	36
1308	1308	1308	30.1167	85.7833	16
1309	1309	1309	29.7333	86.2000	50
1310	1310	1310	29.5167	86.4500	166
1311	1311	1311	29.3500	86.6333	335
1412	1412	1412	30.0667	88.5500	18
1413	1413	1413	29.7833	88.2167	36
1414	1414	1414	29.3667	87.7667	94
1415	1415	1415	29.2833	87.6667	375

*SUSIO DMSAG Sequence Numbers

TABLE 3 (CONTINUED)

C. 1974 STATIONS

BLM STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
01	4001	4001	29.9172	88.7233	21
02	4002	2638	29.9247	88.5578	24
03	4003	4003	29.8919	88.4969	30
04	4004	4004	29.7997	88.5225	27
05	4005	4005	29.9250	88.4167	30
06	4006	4006	29.9750	88.3494	29
07	4007	4007	29.9331	88.2494	32
08	4008	4008	30.0250	88.1997	24
09	4009	2639	29.8917	88.2076	32
10	4010	4010	29.8014	88.2244	34
11	4011	2640	29.7247	87.9083	36
11-A	4012	4012	29.8842	87.1389	35
12	4013	2641	29.7579	87.7750	36
13	4014	4014	29.6417	87.7497	35
14	4015	4015	29.5992	87.8008	36
15	4016	4016	29.5081	87.7833	53
16	4017	2642	29.6750	87.6167	36
17	4018	2643	29.6086	87.4503	68
18	4019	4019	29.5503	87.4000	82
19	4020	2644	29.6031	87.3919	74
20	4021	4021	29.6300	87.3822	85
21	4022	4022	29.9831	86.3836	51
22	4023	4023	29.8141	86.4042	82
23	4024	4024	29.9086	86.2925	64
24	4025	4025	29.8500	86.3081	64
25	4026	4026	29.7669	86.3078	80
26	4027	4027	29.9000	86.2583	57
27	4028	4028	29.8000	86.2581	68
28	4029	2533	29.7167	86.2580	68
29	4030	4030	29.9344	86.2072	46
30	4031	2532	29.7657	86.2057	53
31	4032	2531	29.7997	86.1581	48
32	4033	4033	29.7164	86.1581	42
33	4034	4034	29.6331	86.1747	69
34	4035	2529	29.9331	86.1081	39
35	4036	2530	29.8495	86.1080	42
36	4037	4037	29.7664	86.1081	40
37	4038	4038	29.7997	86.0500	40
38	4039	4039	29.7164	86.0583	38
39	4040	4040	29.7575	86.0142	36
40	4041	4041	29.6747	86.0136	36
41	4042	4042	29.7914	85.9075	31
42	4043	4043	28.6997	84.4417	36
43	4044	4044	28.5000	84.4667	45
44	4045	4045	28.4414	84.3892	46

TABLE 3 (CONTINUED)

C. 1974 STATIONS

BLM STATION NUMBERS	INTERMEDIATE STATION NUMBERS	FINAL STATION NUMBERS	LAT. °N	LONG. °W	DEPTH (M)
45	4046	4046	28.3500	84.3997	53
46	4047	2316	28.7000	84.3335	37
47	4048	2315	28.5664	84.3359	38
48	4049	4049	28.4833	84.3500	40
49	4050	4050	28.4000	84.3500	42
50	4051	4051	28.3167	84.3494	47
51	4052	4052	28.5250	84.2997	26
52	4053	4053	28.2331	84.2922	54
53	4054	4054	28.6997	84.2169	36
54	4055	4055	28.4833	84.1831	34
55	4056	2211	27.9415	84.8832	45
56	4057	4057	28.0106	83.7469	38
57	4058	2210	27.9580	83.7081	36
58	4059	4059	27.7994	83.6922	43
59	4060	4060	27.9167	83.6581	35
60	4061	4061	28.0167	83.5917	31
61	4062	2209	27.8751	83.5664	33
62	4063	4063	27.8336	83.5164	34
63	4064	2208	27.9334	83.4582	28
64	4065	4065	27.8333	83.4167	30
65	4066	4066	27.7583	83.4250	42

mouth with approximate dimensions of 10 cm high by 100 cm wide. Plankton samples (collected only at the Florida Middle Ground station during cruise DM III) were obtained for taxonomic analyses with Niskin plankton nets having 202 μm mesh and one-half metre diameter; samples for trace metal and hydrocarbon analyses were collected with similar nets equipped with opening-closing devices.

Samples and Sample Inventory

Table 4 lists the types of samples and measurement data required and shows their derivation and disposition. Samples were inventoried on board the vessels prior to shipment and again after arrival at the laboratory by the cognizant Principal Investigator; sample inventories, per se, and details of the inventory and sample tracking procedures are described in a following section.

Quality Control

Quality Control (QC) practices were initiated through the formation of a Technical Committee established at the time of contract award. This committee was designed to function as a review and advisory group whose responsibilities included the periodic inspection of analytical laboratories and facilities and a review of the data which they produced. The Committee consisted of the following individuals:

Dr. Harold D. Palmer, Chairman, Dames & Moore
Dr. David L. Johnson, Chemistry, The State University of New York
Dr. Donald J. Reish, Biology, California State University, Long Beach
Dr. James Marlowe, Geology, Dames & Moore
Dr. Thomas F. McKinney, Ships and Logistics, Dames & Moore

In July 1977, prior to any analytical work by PIs, the various committee members performed site inspections and interviews at each laboratory participating in the 1977/78 MAFLA program. The purpose of the site visits was threefold:

- To establish coordination between the PI and Dames & Moore in the area of record keeping and reporting (both analytical and fiscal)

- To establish delivery schedules for performance of staged tasks, and

- To inspect the facility for adequacy of dedicated space and instrumentation and determine that adequate precautions were taken to preclude contamination in both storage and laboratory areas.

As a result of these inspections, modifications were made to certain laboratories and tests were performed to assess the effectiveness of

TABLE 4

SAMPLE COLLECTION AND DISPOSITION

SAMPLE TYPE	CRUISE(S)	EQUIPMENT	RESPONSIBLE PRINCIPAL INVESTIGATOR
Meiofauna	DM I, II, IV	Box-Core	Ivester, Univ. Alabama
Foraminifera	DM I, II, IV	Box-Core	Bock, Univ. of Miami
Macroinfauna	DM I, II, IV	Box-Core	Blake, Univ. S. Florida Vittor, Vittor & Associates Heard, Dauphin Island Sea Lab
Macrobenthos Taxonomy	DM I, II, IV	Dredge/Trawl	Hopkins, Univ. of Alabama
Macrobenthos Histopathology	DM I, II, IV	Dredge/Trawl	Blake, Univ. of S. Florida
Demersal Fish Taxonomy	DM I, II, IV	Trawl	Shipp, Univ. S. Alabama Bortone, Univ. W. Florida
Demersal Fish HC, TM	DM I, II, IV	Trawl	Gould, ARLI; Shokes, S.A.I.
Macrobenthos HC, TM	DM I, II, IV	Dredge/Trawl	Gould; ARLI; Shokes, S.A.I.
Sediment Grain Size, % Carbonate, TOC	DM I, II, IV	Box-Core	Doyle, Univ. S. Florida
Sediment ATP	DM I, II, IV	Box-Core	Cooksey, Univ. of Miami
Sediment Trace Metals	DM I, II, IV	Box-Core	Trefry, Florida Institute Technology (TerEco) Shokes, S.A.I.
Sediment Hydrocarbons	DM I, II, IV	Box-Core	Gould, ARLI
Sediment Clay Mineralogy	DM I	Box-Core	Doyle, Univ. S. Florida
Transmissometry	DM II, III	Transmisso-meter	Carder, Univ. S. Florida
STD	DM II, III	STD	Fausak, Dames & Moore

TABLE 4 (CONTINUED)

SAMPLE COLLECTION AND DISPOSITION

SAMPLE TYPE	CRUISE(S)	EQUIPMENT	RESPONSIBLE PRINCIPAL INVESTIGATOR
Suspended Sediments	DM II, III	30 & 40 Litre Niskin Bottles	Doyle, Univ. S. Florida
Neuston	DM III	Neuston Sled	Collard, Univ. W. Florida
Photometry	DM II, III	Irradiameter	Fausak, Dames & Moore
Zooplankton Taxonomy	DM III	Plankton Nets	Caldwell, Univ. Florida
Particulate TM	DM II, III	30 & 40 Litre Niskin Bottles	Betzer, Univ. S. Florida Shokes, S.A.I.
Zooplankton TM	DM III	Plankton Nets	Betzer, Univ. S. Florida Shokes, S.A.I.
Zooplankton HC	DM III	Plankton Nets	Gould, ARLI
Dissolved and Particulate HC	DM II, III	90 Litre Niskin Bottles	Jeffrey, TAMU
Water Column POC/DOC	DM II, III	90 Litre Niskin Bottles	Jeffrey, TAMU

measures taken to eliminate contamination. QC within the respective laboratories was an integral part of each PIs performance, and these measures are discussed under a subsequent section of this report (Volume II, Chapter 31).

Independent Quality Control Laboratory

The BLM selected the Center for Bio-Organic Studies of the University of New Orleans as their HMW-HC QC laboratory for the MAFLA and other benchmark programs. A similar laboratory for trace metals QC was to have been designated, but no selection was made and no independent QC for metals analyses was performed.

A total of 45 samples from the three benthic cruises were submitted to the QC laboratory. Of these, 16 were bottom sediments, 10 were macroepifauna, and 19 were demersal fish (the Dusky Flounder, Syacium papillosum). Two of the sediment samples were archived materials from the previous MAFLA Program (Summer 1976 Cruise). The results of these analyses have been provided to the BLM under a separate contract in a report by Drs. J.L. Laseter and E.B. Overton. A copy of this report was received by Dames & Moore on June 14, 1978. It is clear from that report that no major discrepancies between data sets exist, and that minor differences may be attributed to experimental and procedural error inherent in analyses conducted by different laboratories.

Contaminant Samples

Sample recovery and handling aboard ship always exposes the materials to potential contamination from a variety of sources. Special precautions were taken during all operations at sea, and a suite of substances which could conceivably contaminate samples was recovered from each vessel at the time of sampling operations. The following samples were stored frozen at ARLI.

ARLI ID# 97046-N	Sample Description
-1	Grease
-2	Hydraulic Fluid & Absorbant
-3	Hydraulic Fluid
-4	Industrial Detergent
-5	Grease
-6	Diesel Fuel
-7	Sediment Exposed to Exhaust
-8	Paint Chips

ARLI ID# 117103-N	Sample Identification
-43	2960 01 49 71117 Algal slick
-44	2960 02 49 71117 Algal slick
-45	Ship's paint
-46	Anchor rust

ARLI ID# 28073-N	Sample Description
-108	2101 97 45 80220 Bearing Seal
-109	2101 97 45 80220 Lube Oil
-110	2101 97 45 80218 Hydraulic Fluid
-111	2101 97 45 80220 Fuel Oil
-112	2101 97 45 80220 Bilge Water

Inasmuch as these materials were considered "contingency" samples, i.e., they would be run only if contamination was suspected, they were retained until all analyses were complete. Since there were no signs in any analyses to indicate field contamination, no analyses of the ship's samples were performed.

Interlaboratory Calibrations and Comparisons

As a check on both analytical precision and accuracy, standard materials were exchanged between laboratories performing HMW hydrocarbon, trace metals and sediment grain-size analyses. These materials consisted of the following substances:

- Kuwait Crude Oil, an American Petroleum Institute Reference Oil.
- Standard Hydrocarbon material from ARLI's previous contracts (their standard HC STD 7-13-77).
- National Bureau of Standards Bovine Liver (NBS catalog #1577) for tissue trace metals confirmation.
- U.S. Geological Survey Sediment Standards (MAG-1 and COMP I/III) provided by the Corpus Christi laboratory of the USGS for sediment trace metal confirmation.
- U.S. Geological Survey Sediment Standards for grain size analyses, also provided by USGS, Corpus Christi.

With the exception of the grain-size standards, all analytical results obtained by the PIs exhibited acceptable accuracy when compared with the standards. Discrepencies in the size analyses were anticipated, since the USGS method differs from that of Dr. Doyle at the University of South Florida. The latter employs sieves and pipette analyses which rely upon mechanical separation of materials coarser than 62 μm (sands), and gravitational settling for the separation of grain size classes in finer materials. Dr. Gerald Shideler of the USGS laboratory employs gravitational settling for sands and measures the finer fractions by means of a Coulter Counter which detects size by displacement of an electrolyte. Sedimentologists acknowledge the difficulty in comparing size analyses performed by differing techniques, and Dr. Doyle's analyses are considered entirely satisfactory by Dames & Moore. A complete discussion of QC procedures is provided in Volume II, Chapter 31.

Summaries of 1977/1978 Cruises

The first cruise under the 1977/1978 contract AA550-CT7-34 was designated DM I and served as a summer benthic sampling cruise. The vessel used was the 65 m M/V Indian Seal. The cruise departed St. Petersburg, Florida on August 13, 1977 and ended on September 9, in Mobile Alabama.

About 5 days were lost due to the passage of hurricanes Anita and Babe, and an additional 6 days of downtime were experienced due to malfunction of the oceanographic winch and the navigational system. Sample retrieval was 97% of that planned; no penetration by the box-core was possible at Station 2749 because of rocky substrate and no trawl was taken at Station 2315 due to the presence of reefs. There was no apparent contamination of the trace metal and hydrocarbon samples. A detailed narrative cruise report including the Chief Scientists' logs and Decca navigation report was submitted to BLM on November 29, 1977 (Dames & Moore, 1977b).

The second cruise (DM II) was a combined water column and benthic cruise comprised of two legs. The vessel used for the cruise was the 56 m M/V Java Seal. The first leg began in St. Petersburg, Florida on October 21 and ended in Mobile on November 2, after collecting dredge and trawl samples at 19 stations and water column samples and measurements at an additional 4 stations. The second leg was devoted to box-coring and departed Mobile on November 4; cores were obtained at 29 primary and 13 secondary stations before the cruise ended in St. Petersburg on November 18, 1977. Eight days of downtime were experienced due to weather and equipment problems. The overall sample recovery rate was 99%; the most significant non-recovery was at Station 2208 (30 m depth off Tampa Bay) where only three cores were obtained from 13 attempts at three locations about the station. No contamination was evident. A narrative cruise report with Chief Scientists' logs, Decca navigation report, and chronology of events was submitted to BLM on January 5, 1978 (Dames & Moore, 1978a).

Cruise DM III obtained time-series data on selected chemical, biological and physical parameters of the water column at four stations in the MAFLA area, each of which was occupied for five days. The cruise ran concurrently with a benthic cruise designated DM IV, and was at sea during the period between February 2 and February 25, 1978. The survey vessel was the 47 m M/V Pacific Seal. Approximately 98% of planned samples, profiles, and measurements were collected; the remainder were lost primarily due to weather downtime. Total downtime due to weather and equipment failure was insignificant for the 24-day cruise; equipment lost or damaged consisted of two broken reversing thermometers. A cruise report with detailed descriptions of sampling procedures, a narrative description of the cruise, and the Chief Scientist's log was submitted to BLM on April 4, 1978 (Dames & Moore, 1978c).

The fourth and final cruise of the 1977/78 MAFLA benchmark survey program was designated DM IV, and served as a winter benthic cruise whose purpose was to increase sample replication and provide winter season data. The cruise was at sea during the period between January 31 and February 20, 1978 and consisted of two legs, the first for dredge and trawl sampling and the second for box coring. The survey vessel was the M/V Indian Seal (also used on cruise DM I) and the navigation system was provided by Decca, as before. A 100% recovery rate of the planned samples was obtained, and the cruise and ship charter time were both completed under scheduled time. A total of five days of downtime due to weather and equipment problems was experienced, approximately half because of delays related to the navigational system. There was no apparent contamination of trace metal or hydrocarbon samples. A cruise report was submitted to BLM on April 10, 1978 (Dames & Moore, 1978d).

The performance of the three vessels supplied by Sealcraft Operators of Galveston, Texas was exemplary. Downtime or delays experienced because of problems with the vessels amounted to no more than a few hours over approximately 140 ship days of use. The vessels were large enough to allow sampling to continue under weather conditions that would have driven smaller craft to shelter.

The navigation system chosen for the benthic sampling cruises was Decca Hi-Fix, a proprietary system supplied by Decca Survey Systems of Houston. The system, like other long-range, shore-based navigational systems, suffers from atmospheric interference, particularly at dawn and dusk, that resulted in significant amounts of non-productive survey time. In addition, and in spite of the best efforts of the Decca personnel, the Hi-Fix equipment caused delays due to electrical or mechanical malfunctions; several unscheduled return trips to port were necessary to obtain spare parts or technical assistance.

The key personnel on board the survey vessels for each of the four cruises is given on Table 5. Complete listings of the scientific crew for each cruise have been given in the cruise report for each survey; these reports have been cited above.

LABORATORY ANALYSES

General Approach

The methods of analyses were given in RFP AA550-RP7-10, including Attachment A, Methods for Hydrocarbon Analyses, and Attachment B, Methods for Trace Metal Analyses. In the course of establishing analytical procedures and sampling techniques at the onset of the program, several departures from the specific contract work scope were deemed desirable from the standpoint of efficiency and/or cost effectiveness. Examples included modifications to the sample treatment for ATP on board ship, changing the normality of HNO_3 in the treatment of sediment samples for trace metal analyses, extending the time for digestion of zooplankton samples in trace metal extractions, and other minor modifications which were considered as improvements over the contract instructions. In every case, a letter requesting such a change, and documentation from the PI to explain why the modification was desirable, were submitted by the Program Manager to the BLM Contracting Officer (Mr. Peter Niebauer, later Mr. Jerry Rourke) and his authorized representative (COAR, Dr. Ed Wood) prior to any change in technique or approach. Upon authorization from BLM, the appropriate changes were initiated.

Table 6 lists the basic sample type and each method of laboratory analysis. Brief descriptions of the methods follow in the next section; detailed descriptions can be found in the third quarterly report of each PI (Dames & Moore, 1978e; Appendix D).

TABLE 5

KEY SHIPBOARD PERSONNEL FOR 1977/78 SURVEYS

Cruise DM I -

Total crew exclusive of ship's compliment: 23

Name and Affiliation	Responsibility
Dr. N. J. Blake, Univ. South Florida	Chief Scientist
L. E. Fausak, Dames & Moore	D&M Representative
Dr. R. L. Shipp, Univ. of Alabama	Trawling
Dr. T. S. Hopkins, Univ. of Alabama	Dredging
G. Hayward, S.E.A.	Logistics Support

Cruise DM II -

Total crew exclusive of ship's compliment: 19 (Leg I) and 16 (Leg II)

Name and Affiliation	Responsibility
Dr. T. S. Hopkins, Univ. of Alabama	Chief Scientist, Leg I
Dr. W. Bock, Univ. Miami	Chief Scientist, Leg II
Dr. J. Marlowe, Dames & Moore	D&M Representative
G. Hayward, S.E.A.	Logistics Support

Cruise DM III -

Total crew exclusive of ship's compliment: 11 (Leg I) and 10 (Leg II)

Name and Affiliation	Responsibility
L. E. Fausak, Dames & Moore	Chief Scientist
J. Bennet, S.E.A.	Logistics Support

Cruise DM IV -

Total crew exclusive of ship's compliment: 16 (Leg I) and 11 (Leg II)

Name and Affiliation	Responsibility
Dr. R. Shipp, Univ. of Alabama	Chief Scientist (Leg I)
Dr. W. Bock, Univ. of Miami	Chief Scientist (Leg II)
Dr. K. Mauzey, Dames & Moore	D&M Representative
Dr. T. S. Hopkins, Univ. of Alabama	Dredging (Leg I)

TABLE 6

SAMPLE TYPES AND METHODS OF LABORATORY ANALYSES

SAMPLE	FUNCTION	RESPONSIBLE PI	LABORATORY METHOD
Sediment From Box-Cores	Grain Size	Doyle	Sieve coarse fraction; pipette analyses of silts and clays
	Percent Carbonate	Doyle	Acid-leaching gas displacement method
	Total Organic Carbon	Doyle	Acid-leaching, combustion CO_2 analysis with Angstrom Carbon Analyzer
	Benthic Clay Mineralogy	Doyle	X-ray diffraction
	Foraminifera	Bock	Sieve, wash, taxonomic identification
	Meiofauna	Ivester	Wet sieve, split, taxonomic identification
	Macroinfauna	Blake, Vittor and Heard	Rough and fine sorting, taxonomic identification
	Trace Metals (except Ba & V)	Trefry	Atomic absorption spectrophometer analyses
	Trace Metals (Ba & V)	Shokes	Neutron activation analysis
	ATP	Cooksey	Extraction; assay with ATP photometer
	Hydrocarbons	Gould	Gas Chromatography; gas chromatographic/mass spectroscopic analysis
Macroepifauna From Dredges and Trawls	Taxonomy	Hopkins	Rough and fine sorting; taxonomic identification
	Histopathology	Blake	Tissue preparation and microscopic examination for pathology
	Hydrocarbons	Gould	Tissue extraction; gas chromatography

TABLE 6 (CONTINUED)

SAMPLE	FUNCTION	RESPONSIBLE PI	LABORATORY METHOD
Macroepi-fauna From Dredges and Trawls (cont'd)	Trace Metals (except Ba & V)	Gould	Atomic absorption spectro-photometry
	Trace Metals (Ba & V)	Shokes	Neutron activation analysis
Demersal Fish From Dredges and Trawls	Taxonomy	Shipp and Bortone	Taxonomic identification
	Hydrocarbons	Gould	Extraction; gas chromato-graphy
	Trace Metals (except Ba & V)	Gould	Extraction from Tissues; atomic absorption spectro-photometry
	Trace metals (Ba & V)	Shokes	Neutron activation analysis
Water Samples	Suspended Sediment Mineralogy	Doyle	X-ray diffraction
	Particulate Trace Metals (except Ba & V)	Metzer	Atomic absorption spectro-photometry
	Particulate Trace Metals (Ba & V)	Shokes	Neutron activation analysis
	Particulate Hydrocarbons	Jeffrey	Soxhlet extraction; gas chromatography
	Dissolved Hydrocarbons	Jeffrey	Chloroform extraction; gas chromatography
	Particulate Organic Carbon	Jeffrey	CO_2 analysis with total carbon analyzer
	Dissolved Organic Carbon	Jeffrey	CO_2 analysis with total carbon analyzer
	Salinity	Fausak	Laboratory salinometer; correction of STD

TABLE 6 (CONTINUED)

SAMPLE	FUNCTION	RESPONSIBLE PI	LABORATORY METHOD
Plankton	Zooplankton Taxonomy	Caldwell	Taxonomic identification
	Zooplankton Trace Metals (except BA&V)	Betzer	Atomic absorption spectrophotometry
	Zooplankton Hydrocarbons	Gould	Extraction; gas chromatography
	Neuston Taxonomy	Collard	Taxonomic identification
Physical Parameters	STD	Fausak	Correction, digitization
	Photometry	Fausak	Correction, digitization
	Transmissometry	Carder	Correction, digitization
	Surface and Bottom Temperatures	Fausak	Correction; calibration of STD

Narrative Methodologies

1. Sediment Grain Size Analysis. Size analysis was performed on the top 10 cm of each box-core subsample. Approximately 15 g splits of each sample were wet sieved on a 63 μm screen; the fine fraction was collected in a 100 mℓ graduated cylinder. The sand-and-gravel fraction was dried and then sieved through a nested set of standard 1 phi interval sieves from -1 phi (gravel) to 4 phi (very fine sand). The sand fraction caught on each sieve was weighed to the nearest gram. The pan fraction (<63 μm) sediments were added to contents of the graduated cylinder. Analysis of the finer-than-sand sediments was executed by standard pipette methods (Folk, 1974). A saturated Calgon solution (10 mℓ) was added to the sediment in the cylinder to disperse the clay and prevent flocculation during sampling intervals. At least one pipette was taken from each sample, and after correction was made for the added Calgon weight, the total fine fraction weight was calculated. For those samples in which this weight exceeded 10% of the total weight, a second pipette was taken so that both percent silt and percent clay could be determined. All full phi fractions were reported as weight percent of the total sample.

2. Percent Carbonate of Sediments. All box-core samples examined for grain size analysis were also analyzed for percent carbonate using standard acid-leaching, gas-displacement methods as described by Ireland (1971). Approximately 10 g of sediments were placed in a tared 250 mℓ beaker. Before treatment the beaker and dried sample were weighed together to the nearest 0.01 g. Ten percent (10%) hydrochloric acid was added carefully to avoid frothing over the top of the beaker. After digestion was completed, the sample was rinsed twice with deionized water and the water was decanted each time following centrifugation. The insoluble residue was dried at 80 to 85°C overnight. The beaker and its contents were weighed, and the amount of insoluble residue remaining was calculated by subtraction of the preweighed beaker. The weight percent of carbonate was taken as the difference in weight between the untreated and treated sample and converted to a percent:

$$\%\ CaCO_3 = \frac{(\text{wgt untreated sample} - \text{wgt insoluble residue}) \times 100}{\text{wgt untreated sample}}$$

Results were reported as weight percent carbonate in a table.

3. Total Organic Carbon (TOC) in Sediments. At least one sample from each box-coring station was analyzed for TOC. After dissolution of the carbonate fraction following the method used by Ireland (1971) and described above, the insoluble residue was oven dried and weighed to the nearest 0.001 g. Approximately one gram of residue was placed into a Leco combustion crucible with like amounts of iron chip and copper metal accelerator. The crucible, with sample and accelerator, was set

within an Angstrom Model 9000 Induction Furnace, and the contents were heated to incandescence. During combustion, organic carbon from the sample mixed with oxygen within the chamber forming carbon dioxide, CO_2. While maintaining a closed system, the gas was piped to an Angstrom Model 7000 Carbomatic Carbon Analyzer which had been calibrated each day to known TOC standards. After analysis the instrument displayed a direct readout of percent carbon, and the data were recorded in tabular form.

4. Clay Mineralogy of Benthic Sediments. One sediment subsample was taken from each box-coring station in the summer of 1977 for clay mineralogy analysis. Approximately 20 to 40 g of sediment were sampled from the uppermost 5 cm of each sub-core to insure that enough clay would be available for analysis. The samples were disaggregated, wet-sieved to separate the coarse fractions, and centrifuged to remove salts. The clay was removed from the remainder of the fine fraction sediments by pipetting after settling, after which organic material was dissolved in hydrogen peroxide. The clay material slurry was placed on a glass slide, dried, and X-rayed on a Phillips Electronics (Norelco) X-ray generator with Wide Range Goniometer. The slides were X-rayed again after treatment with ethylene glycol vapor, and a third time after heating to 550°C. Identification of the major clay minerals was carried out using standard examination techniques as given by Griffin (1962) and Grim (1968). The clay species that were identified included smectite, illite, kaolinite, and mixed-layer clay, while other minerals that were searched for but not usually present were vermiculite and chlorite. Quantification was performed on the basal (001) peaks of each clay type identified from the glycolated slide. Relative proportions of the clays were estimated using peak height to calculate individual peak areas. The proportions of the areas were finally converted to percent clay present and recorded in tabular form.

5. Foraminifera. In the laboratory the samples were sieved through 62 μm sieves and washed with distilled water. They were examined wet (immersed in distilled water) to determine live/dead ratios based on counts of 300 specimens. Identifications of 300 individuals containing protoplasm were made to determine live species composition. Protoplasm in foraminifera is usually colored in mid- and lower latitudes, enabling differentiation, if the specimens are retained wet, of specimens which were live when collected without the use of questionable staining techniques. In addition, the bottom 3 cm of selected subsamples were analyzed for determination of recent changes in the foraminiferal fauna using dead tests only. Identification on all specimens was made to species level. The number of specimens per cm^3 of sediment was calculated by multiplying the amount of sediment containing 300 specimens by the factor necessary to increase or decrease the amount to 1 cm^3 of sediment. Data

were reported as percentage distribution of every species at each station, live/dead ratios, planktonic/benthonic ratios, and dominant species based on occurrence of 5% or greater occurrence of a species in any sample.

6. Meiofauna. Samples were originally processed in the laboratory by elutriating the sample through 0.5 mm and 0.063 mm mesh sieves. The residue remaining on the 0.063 mm sieve was sorted into 28 taxonomic categories by spreading the sample evenly in a grided sorting tray and examining at 120 x or 250 x magnification under a dissecting microscope using double illumination. Because time spent per sample and time constraints of the contract were not compatible, a modified sample processing procedure was adopted for approximately half of the samples from DM I and all from DM II and DM IV. Data collected previous to the modified method have been corrected to correspond. The modified sorting procedure was as follows:

   a. Elutriate entire sample as before
   b. Make up elutriate sample to 200 m
   c. Divide into two ≃ 100 mℓ portions (splits)
   d. Subdivide each split into four 25 mℓ portions and proceed with the following:
   e. i) If there are less than 50 nematodes in the first 25 mℓ portion, count all nematodes and other taxa listed in (f), below, in the entire sample.
      ii) If there are more than 50 nematodes in the first 25 mℓ portions, count all nematodes in this portion, disregard nematodes in remaining 75 mℓ, count and collect other taxa listed in (f) in the entire sample; derive mean of two subsamples of nematodes and multiply by 4 to arrive at estimate of nematodes.
   f. Taxa to be counted and collected include:
      i) Nematodes
      ii) Copepods
      iii) Turbellarians
      iv) Kinorhynchs
      v) Gastrotrichs
      vi) Polychaetes
      vii) Miscellaneous (cnidarians, ascidians, gnathostomulids, tardigrades, oligochaetes, mites, ostracods, nemerteans, priapulids, protozoa).

   All sorted specimens were placed in properly labeled one dram shell vials containing 10% buffered formalin or 70% ethyl alcohol with 15% glycerin depending on the taxa. The glycerin was added to prevent dessication during storage. These specimens are available for use by interested meiofauna specialists. Data were reported as numbers of individuals per 10 cm^2 for the six higher taxa and for the miscellaneous group on the data file forms provided by Dames & Moore. Original data sheets with comments on specific taxa were retained by the PI. Nematodes from stations were identified to generic level after being mounted on glass slides.

7. Macroinfauna. The macroinfauna sample bags were delivered from the ship either to Dr. Blake's laboratory or to Dr. Vittor's laboratory for sorting, biomass determination, and ultimate disposition for taxonomic identification and counting. Transects I, II, VII, and IX were sorted by Dr. Blake and the remainder by Dr. Vittor; the six supplemental stations were divided between the two labs based on geographic location. In the labs, the samples were stained with Rose bengal dye, after which they were "floated" to remove the less dense organisms. All organisms were rough sorted into five groups: mulluscs, polychaetes, crustaceans, echinoderms, and miscellaneous. The rough sorted samples were distributed to other labs in the following manner: molluscs to Dr. Blake, polychaetes to Dr. Vittor, crustaceans to Dr. Heard, and echinoderms and miscellaneous to Dr. Hopkins. Taxonomic identifications were made to the lowest practicable level and NOAA taxonomic code numbers were assigned.

8. Trace Metals in Benthic Sediments. The bottom sediments to be used in the trace metal analyses were received in the laboratory frozen; they were then freeze-dried and heated to remove moisture, homogenized, and split. All samples were analyzed for trace metals after "partial digestion" in HNO_3; one-fourth of the samples were also analyzed after total dissolution with $HF-HNO_3-HClO_4$. A separate 1 g portion of each sample was shipped to Dr. Shokes' laboratory for Ba and V analysis. Atomic absorption spectrophotometric (AAS) analysis of the sediment digests for copper (Cu), chromium (Cr), iron (Fe), nickel (Ni) and zinc (Zn) was carried out using a Perkin-Elmer 460 instrument equipped with a deuterium arc background corrector. A second Perkin-Elmer AAS with an HGA-2100 graphite furnace was used for detecting low levels of cadmium (Cd) and lead (Pb) present. Instrumental settings generally followed the manufacturer's specifications except where optimization techniques could be used to increase sensitivity and stability. The sample splits transferred to Dr. Shokes for determination of barium (Ba) and vanadium (V) by neutron activitation analysis were treated by either of two methods for Ba. The sediments subjected to partial digestion were analyzed for Ba with the Ba-139 procedure; the totally digested samples were analyzed using the Ba-131 (INAA) procedure. Vanadium was determined using the V-52 (INAA) analysis procedure. The details of the methods are given in Dr. Shokes' third quarterly report (Dames & Moore, 1978e). They consist essentially of irradiating the samples for varying time periods in a Torga type reactor at

the University of California, Irvine, and measuring activity levels with a spectrometer after given periods of time.

9. ATP in Benthic Sediment. After arriving in the laboratory, the frozen sediment samples were weighed and treated with sulfuric acid to extract the ATP. Following centriguation, the supernatant was neutralized and assayed for ATP using a modified procedure of the luciferin-luciferase method of Strehler (1968); ATP levels are determined by measuring light emission in a JRB ATP photometer. Replicate samples, two of which were spiked with known amounts of ATP to provide an internal standard, were analyzed separately and the results averaged in order to increase the precision.

10. High Molecular Weight Hydrocarbons (HMWH) in Benthic Sediments. The frozen sediment samples transferred from the survey vessels were first freeze-dried, after which the HMWH were extracted using Soxhlet extraction apparatus and a methylene chloride: methanol (14:1) azeotrope as the extraction solvent. If necessary, the extracts were desulfurized, followed first by saponification then by liquid-solid chromatography of the nonsaponifiable residue to isolate the paraffinic and aromatic fractions. Each liquid chromatography fraction was weighed and then analyzed on one of three gas chromatographs; the chromatograms were displayed on analog format and recorded on magnetic tape. Between five and ten percent of all hydrocarbon samples were further analyzed by gas chromatographic/mass spectroscopic (GC/MS) methods to resolve individual peaks of the gas chromatographs.

11. Macroepifauna from Dredges and Trawls. Upon delivery to the laboratory, the frozen or preserved specimens from each cruise were fine sorted, had the preservate changed, and were catalogued and archived. Identification of specimens was aided by Wild M-5, M-5A, and M-20 microscopes.

12. Histopathology of Macroepifauna. The tissues of various groups of animals were trimmed as appropriate to their structure (refer to Dr. Blake's third quarterly report, Dames & Moore, 1978e, for details of the dissection methods), fixed and preserved. The tissues were embedded in paraffin, sectioned on a Spencer rotary microtome, stained and mounted. All slides were examined by the histopathologist; although all tissues were examined, particular attention was paid to gills, kidneys, digestive diverticula, and gonads.

13. Hydrocarbons in Macroepifauna. The macroepifauna species collected for hydrocarbon and trace metal chemistry varied according to availability from the dredges and trawls, and

dissection techniques varied accordingly. Every effort was made to include only muscle tissue and to obtain 20 g or more of tissue. The organisms were washed with distilled water and methanol to remove sediment and foreign matter prior to dissection. The tissue was digested using methanol and refluxed for four hours or until the tissue was well digested; an equal volume of water was then added and the mixture was refluxed for an additional four hours, at the end of which time an equal volume of NaCl was added. The hydrocarbons were extracted with three 50 mℓ portions of hexane, and subsequently subjected to gas chromatographic analysis as described in number (10) above for sediment hydrocarbons.

14. Trace Metals in Macroepifauna. At the same time that the tissue sample was selected for hydrocarbon analysis, a second tissue sample was taken for trace metals analysis. Every effort was made to make the trace metal and hydrocarbon tissue samples as comparable as possible by selecting tissue for both samples from the same parts of the same specimen. Approximately 10 g of tissue for trace metals analysis were transferred to a tared, nitric acid-washed beaker and weighed to determine the wet weight of the sample. This sample was then frozen, dried on the lyophilizer, and reweighed to permit calculation of the dry-weight tissue. The samples were analyzed for seven trace metals: Cd, Cr, Cu, Fe, Ni, Pb, and Zn. After digestion with nitric acid and hydrogen peroxide, the metal content of the digestates were determined by atomic absorption spectroscopy. An aliquot of the digestate solution of each sample was sent to Dr. Robert Shokes, Science Applications, Inc., La Jolla, California for neutron activation analysis for Ba and V. The metal concentrations of the digestate solutions were determined on a Perkin-Elmer Model 370 Atomic Absorption Spectrophotometer. The instrument was equipped with a deuterium arc background corrector and an HGA-2100 graphite furnace. The Cu, Fe, and Zn content of all samples were determined by using an air-acetylene flame to atomize these elements. Some of the macroepifauna samples also have Cd or Cr contents high enough to be measured in the flame mode. The sample solution was aspirated into the flame for three seconds and the absorbence read from the instrument. The aspiration of the sample was repeated twice, or more often if necessary, and the absorbence values averaged. The procedural blank was then aspirated in the same way, giving an average absorbence for the blank. This absorbence value was subtracted from that of the sample to give the net absorbence due to the element in the sample. Absorbences were then measured for a series of standard solutions containing known concentrations of the element being determined. A concentration versus absorbence curve was then constructed from which the

concentration of the element in the sample was determined. When matrix effects were significant, the method of additions was used to establish the concentration versus absorbence curve. The Cd and Cr content of most samples and the Pb and Ni content of all samples were measured with HGA-2100 Graphite Furnace. This method was used to determine elements present at concentrations too low to be measured effectively in the flame. The aliquots of the digestate for Ba and V determinations were analyzed by neutron activation analysis with the Ba-139 and V-52 (HAP) procedures explained in outline in number (8) above and in detail in Dr. Shokes' third quarterly report (Dames & Moore, 1978e).

15. Taxonomy of Demersal Fish. Laboratory analyses of demersal fish involved identification, counting, weighing, measuring, evaluating obvious abnormalities, and archiving all specimens. On arrival at the lab, sample buckets were soaked for 24-48 h in water, with several changes as dictated by size, volume, etc., to remove formalin. They were then transferred to 40% isopropanol solution. Specimens were rough sorted to species and placed in separate containers. Each species group was then carefully scrutinized to verify identification of each individual specimen. All individuals were towel dried and weighed on a standard triple beam balance to the nearest 1 g. Each was then measured for standard length (SL) to the nearest 0.1 mm. Sex was taken on 10 mature individuals, or as many as were available if less than 10 were taken. Specimens were also examined for obvious pathological/deformity conditions. These data were then recorded on laboratory worksheets, and transferred to data sheets as supplied by Dames & Moore. Each series (consisting of all individuals of a species at a station) were placed together in an appropriate sized glass container and labelled. These activities were carried on simultaneously at the University of South Alabama and the University of West Florida. Frequent calibration was maintained between the two groups to insure accuracy of data.

16. Hydrocarbons in Demersal Fish. The frozen demersal fish specimens were allowed to thaw at room temperature. Then they were quickly washed, first with distilled water and then with methanol to remove as much of the outer mucous layer as possible. Working in an enclosed clean bench, the fish were then transferred to a nitric acid-washed, hexane-rinsed glass tray and the dorsal and ventral fins trimmed away with surgical scissors. With the aid of Pyrex glass probes, stainless steel forceps, and scapel, the skin was carefully removed, the muscle tissue cut into small pieces with the scissors and placed in a tared 250 mℓ flask. Some small bones which could not be readily separated from the

tissue were included with the tissue sample. The flask was reweighed to measure the wet weight of fish tissue. Whenever possible, at least 20 g of tissue were collected for hydrocarbon analysis, although as little as 10 g was used for very small specimens (see ARLI third quarterly report, Dames & Moore, 1978e, and Volume II, Chapter 8). After tissue preparation, the samples were digested and saponified, the HMWH extracted and subjected to liquid-solid and gas chromatography as described in Section 10.

17. Trace Metals in Demersal Fish. At the same time that the fish tissue was prepared for hydrocarbon analysis, about 10 g of tissue was selected for trace metal (TM) analysis. This tissue was transferred to a tared, nitric acid-washed beaker and weighed again to determine the wet weight of the sample. The sample for TM analysis (but not the sample for HMWH analysis) was then freeze-dried and reweighed to permit calculation of dry-weight tissue for both the TM and HMWH samples. The remainder of the analyses for the TMs, including Ba and V are identical to the procedures for TM analysis of macroepifauna described in (14) above.

18. Suspended Sediment Clay Mineralogy. The suspended particulates were collected on 0.45 μm pore-diameter Millipore filters. Each filter was placed in a centrifuge tube to which approximately 8 mℓ of filtered acetone was added; the tubes were shaken by hand until the filters completely dissolved. All tubes were centrifuged at 10,000 rpm for 20 min at a temperature of 3°C. The supernatent acetone was discarded, while special care was taken so that the sediment pellet was not disturbed. Acetone was again added to the tubes and each tube was then sonified using a Heat Systems-Ultrasonics, Inc., cell disrupter equipped with a microtip. Dilute HCl or H_2O_2 was added if the samples contained $CaCO_3$ or organic compounds which interfere with X-ray diffraction analysis. All the tubes were centrifuged, decanted, sonified, and centrifuged again giving a total of three washes in acetone. After the last acetone wash was poured off, 5-6 m of deionized water were added. The tubes were sonified for 30 s to break down the pellets completely. The contents of each tube were vacuum filtered through silver filters (0.2 μm pore size) using a Millipore filtering apparatus. One millilitre was filtered at a time in order to minimize differential settling rates; no additional sample was added until the previous mℓ had passed through the filter. Care was taken so that the filters were not covered too thickly with the suspended sediment. With the sediments on silver filters, the samples were X-rayed on a Rigaku "Miniflex" Model 2005 X-ray Diffractometer. Sediments indicating measurable amounts of clay present were treated with ethlene glycol fumes at 60-80°C for at least 12 h and were immediately

X-rayed to check for expansion of the smectite peak. A final heat treatment to 550°C for one hour followed by X-ray analysis for 3° 2θ to 15° 2θ was performed.

19. Suspended Particulate Trace Metals. The Nuclepore membranes were placed in polyethylene funnels in a laminar flow clean bench and rinsed with deionized water and dessicated for 48 h over silca-gel in order to remove any residual salts. The filters were then weighed and the suspended load was calculated by dividing the difference between the final and tare weights by the volume filtered. The initial dissolution step involved a two hour leach with a solution of redistilled acetic acid (25% v/v), which dissolved the carbonate materials and easily reduced metal hydroxides from the suspended matter. Following leaching, the acid was washed into 25 mℓ volumetric flasks through a Teflon stopcock. To prevent the loss of metal species to the walls of the polyethylene containers the pH was lowered to less than 1 by adding 0.5 mℓ of concentrated, redistilled hydrochloric acid. The refractory metal oxides which were undissolved by the weak acid leach were placed in solution by decomposition in a Teflon bomb. These solutions were analyzed for Cd, Cr, Cu, Fe, Ni, Pb, and Zn using flameless atomic absorption spectrophotometric method. In addition, the weak acid soluble fraction was analyzed for calcium (Ca) and the refractory portion was analyzed for aluminum (Al) and silicon (Si). Analysis of Ca was carried out with an air-acetylene flame. All measurements were made in the absorbance mode, the peak heights being recorded on a Perkin-Elmer Model 56 recorder. The injection of samples into the heated graphite atomizer was made using an automatic injection system. The samples of each group were analyzed with a minimum of three combined standards whose concentrations bracketted those of the samples. To correct for any elemental contributions by the filter membranes, Nucleopore membrane blanks were also run. Aliquots of the particulate samples were delivered to Dr. Shokes for neutron activation analysis for Ba and V, using the Ba-139 techniques and the V-52 (HAP) method.

20. Suspended Particulate Hydrocarbons. The 294 mm Gelman filters on which the particulates had been deposited were first freeze-dried in the laboratory, then extracted and re-extracted for four hours each using nanograde hexane and Soxhlet apparatus. One procedural blank was repeated for every seven particulate samples. After drying, the extracts were weighed on a six-place balance and reweighed on a Cahn Electrobalance. The extracts were then separated into saturates, aromatics, and polar lipids on silica gel columns. Gas chromatography analyses of samples, standards, and blanks were run on Hewlett-Packard Model

5830A gas chromatographs. The analysis procedure is presented in greater detail in Dr. Jeffrey's third quarterly report (Dames & Moore, 1978e).

21. Dissolved Hydrocarbons. The filtrate passing through the Gelman filters used to trap the particulate hydrocarbons wsa retained in acid-cleaned glass carboys. The 90ℓ of filtrate were extracted three times with chloroform; the extracts were evaporated to near dryness in rotary evaporators under vacuum, dried completely in a vacuum dessicator, and weighed. They were then redissolved in chloroform, separated, and run through GC analyses as described in (20) above.

22. Suspended Particulate Organic Carbon. The ampoules in which the filter pads were sealed were heated to convert all organic matter to CO_2. The CO_2 concentration of samples and blanks was then determined on an Oceanography International Total Carbon Analyzer. Carbon dioxide levels from the analyzer were graphically displayed on a strip chart recorder.

23. Dissolved Organic Carbon. Ampoules containing triplicate water samples were treated in precisely the same manner as were the particulate organic carbon samples.

24. Salinity Determinations. Laboratory analysis of water samples for salinity was done with an Autosal laboratory salinometer. The instrument measures the conductivity ratio between a sample of seawater and 35 $^{o}/oo$ water by continuously comparing the seawater sample conductance with an integral reference conductance with an accuracy of ± 0.003 $^{o}/oo$ equivalent salinity.

25. Zooplankton Taxonomy. Each sample was split initially in a Folsom plankton splitter, one-half retained as the archived sample portion, the other half used for counting, identification, and biomass determinations. The counting sample was then split repeatedly until an aliquot of approximately 200 animals was attained. The aliquot was placed in a channeled counting chamber, enumerated, and identified to the lowest possible taxon. Dry weight biomass was determined by washing the entire counting half of the sample in distilled water, placing it in a tared container, and drying to constant weight at 60°C. Ash-free weights were determined by placing the sample in a crucible and then a muffle furnace at 500°C for one hour. The samples were cooled, re-wetted with distilled water, and dried to constant weight at 105°C. Subtraction of the crucible and ash weights from the dry weight yielded ash-free weight.

26. Trace Metals in Zooplankton. Upon return to the laboratory, the zooplankton samples were thawed, dried and then ground in a porcelain lined Spex ball-mill. Half gram amounts of homogenized dried zooplantkon were weighed onto acid-cleaned pyrex watch glasses with a four place Mettler balance. These watch glasses were then transferred to an International Plasma low temperature asher where the organic material was oxidized. The ash was transferred into Teflon bombs, to which 3 mℓ of concentrated redistilled nitric acid was added. Bombs were sealed, and placed in a hot water (95°C) bath for five hours, after which they were cooled in a freezer to prevent any loss of volatile components. This solution was then transferred into 15 mℓ acid cleaned polyethylene centrifuge tubes and spun at 25,000 rpm for 20 min; the supernatant was then decanted into 50 mℓ acid-washed volumetric flasks. Analyses were made by atomic absorption spectrophotometry for Cd, Cr, Cu, Fe, Ni, Pb, and Zn. The procedures used were similar to those for the suspended particulate matter described above. Aliquots of the samples were delivered to Dr. Shokes for neutron activation analyses, as described earlier.

27. Hydrocarbons in Zooplankton. The frozen zooplankton sample was allowed to thaw sufficiently to permit examination under a low power magnifying glass for tar balls or other non-planktonic materials. These were removed with clean forceps. Most of the sample was transferred to a tared flask and weighed to determine the wet weight of the plankton sample. The remainder of the sample was transferred to a small tared beaker, weighed, freeze-dried, and weighed again to permit calculation of the dry-weight biomass of the plankton. From this point on, the digestion, saponification, extraction, and analysis of the plankton is exactly the same as described above for the demersal fish tissue (16).

28. Neuston Taxonomy. Neuston samples recieved in the laboratory were washed, had preservatives changed, and were picked to remove <u>Sargassum</u>, tar balls, plastics, and organisms greater than 2.5 cm in greatest dimension. The samples were then split, identified, and archived.

29. STD Profiles. The STD profiles were digitized using a Tektronix semiautomatic digitizing system consisting of a digitizing table, an interactive graphics terminal, and a magnetic tape storage unit. The profiles were prepared by marking inflection points on the profiles, between which the trace is assumed to be linear, and then entering the surface and bottom temperature and conductivity values, as well as the calibration temperatures from the reversing thermometers and calibration salinities resulting from laboratory analysis of water samples. After the inflection

points were digitized with reference to the raw temperature and conductivity values, an array of interpolated values having 3 m depth intervals was generated. Those values were then used to calculate salinity as a function of temperature, conductivity, and pressure; the program used to compute salinity was based on Fofonoff et al. (1974). Once the salinity was computed at 3 m depth intervals the temperature and derived salinity curves were corrected to correspond to the surface temperature and salinity calibration values. The final array of temperature, salinity, and sigma-t values at 3 m intervals was displayed as a computer printout and as depth-dependent profiles.

30. Transmissometer Profiles. All transmissometer calibrations, corrections, and digitization was done on board the survey vessel. Office tasks consisted of data synthesis.

31. Surface and Bottom Temperatures. Reversing thermometer correction factors were determined using the methods given in U.S. Naval Oceanographic Office Publication No. 608 (1968). The main and auxiliary thermometer readings were corrected according to the individual calibration curves supplied by the manufacturer for each thermometer prior to being used in the correction formula. The four corrected readings for surface and bottom temperature were averaged to obtain the final temperature values entered into the data file and used for STD calibration. Clearly deviant values were discarded.

<u>Quality Control (QC)</u>

As discussed above, QC was achieved through coordination between the PIs and the Technical Committee. However, within each laboratory the PI was responsible for ensuring that proper precautions were made to preclude contamination, and that accountability for sample location, status and integrity was enforced. Their scheduled reports to the Data Manager provided a constant check on sample status. Analytical QC performed as a matter of routine by PIs included frequent calibration of instruments, spiking of samples, performing replicate analyses to assess precision and running frequent procedural blanks during analyses. Precautions against contamination were stressed, and storage and handling practices were designed to minimize exposure of the samples to potential contaminants.

Dames & Moore stressed QC throughout the program, and each PI was required to conform to the analytical technique specified by the BLM in its Statement of Work (SOW). Where a departure from a specified technique offered an improvement in accuracy or precision and/or cost effectiveness, the modification was described by the PI to the Program Manager, and with his concurrence the written request for change was submitted to the BLM. No deviations from the SOW were permitted unless authorized by the BLM. In addition to authorized modifications, two memoranda were received from the Chief Environmental Branch of BLM which called attention to analytical problems experienced in other programs. Appropriate measures were taken by those PIs affected by these communications.

DATA MANAGEMENT AND ANALYSIS

Inventory and Control

Inventory and control activities were performed aboard ship and in the laboratory by the Chief Scientist, Dames & Moore Onboard Representative, and by the scientific team members. Similar activities were performed in Dames & Moore offices and computer facilities by the data management group.

Shipboard and laboratory sample recovery was measured against the sampling plan by use of a pre-printed log maintained by the Chief Scientist of each cruise. A separate log sheet was prepared in advance showing the sampling plan for a given station; the Chief Scientist used this sheet to measure his progress as samples were obtained. In addition the station log documented (a) station number, position, and depth; (b) date and time on and off station; (c) time of sampling; and (d) pertinent weather information and remarks. Separate narrative journals were also maintained by the Chief Scientist and the Dames & Moore Onboard Representative.

A sample inventory report form was maintained aboard ship by the program work element team leaders under the direction of the Chief Scientist. Each sample was assigned a unique sample number and recorded on the form together with a brief description of the sample, its mode of preservation, container code, storage location, inventory dates and ultimate destination. These sample inventory reports served as (a) a shipboard inventory; (b) a packing list when the samples were shipped for analysis; and (c) an inventory document by the data management group.

Data obtained aboard ship or generated in the laboratory that were amenable to analysis by digital computer were encoded by PIs on formatted coding sheets. Formats for these sheets were established by the data management group in coordination with COAR and PIs.

The progress of sample analysis (and data exchange) between PIs was monitored by means of the Analysis Progress Report. This report was compiled weekly to track the actual progress during each phase of analysis and data reduction.

Sample numbers were utilized to prepare a check list for each program work element. This list allowed the PI to track the analytic progress of each sample or to record the exchange of samples with other investigators. Program Management updated the lists weekly and transmitted them to the PIs, who returned the check lists received the previous week.

Assignment of a unique identification number to each data entry was the cornerstone of the data base management system employed during this program. In the most general case, a data entry may be identified by a 13-digit sample number, and/or a 12-digit taxonomic identification (ID) number and a 2-digit specimen number. Each sample was given a 13-digit sample number to represent the four main elements associated with the sample, namely:

1. Station number - 4 digits;
2. Replicate and/or method of sampling code - 2 digits; refer to Volume II, chapter 29;
3. Program element code - 2 digits; refer to Volume II, Chapter 29;
4. Date of sampling - 5 digits;
   a. Year - 1 digit, 7 = 1977, 8 = 1978;
   b. Month - 2 digits;
   c. Day of month - 2 digits.

The sample number alone identifies the location, replicate, method of sampling, program element, and date of sampling.

All stations were assigned a 4-digit number; Table 3 (above) is a station number correspondence chart and may be used to convert station numbers utilized in previous studies to those employed in this program. In addition, Table 3 presents the position and depth values assigned to all stations.

A taxonomic numbering system modeled after that established by NODC was adopted for this program to rapidly sort and retrieve taxonomic information held in the data base. The NODC numbering system and taxonomic ID number assignments tabulated prior to August 1977, were incorporated directly into our system (NODC, 1977). Few new assignments were made from NODC updates as required by NODC to supply codes for submitted taxonomic names. Instead, temporary assignments were made by the PIs. The NODC taxonomic coding system permits any taxon to be represented by an ID number consisting of from 2 to 12 digits. The first four digits indicate the taxonomic classification above the family level, and vary with the size of the phylum. The next digits, taken in pairs, indicate the family, genus, species, and sub-species levels.

On occasion it was necessary to assign a 2-digit specimen number in addition to the taxonomic ID number and the sample number in order to uniquely identify the sample. This was particularly true for chemical analysis of the demersal fish *Syacium papillosum* caught during the summer 1977 cruise, inasmuch as specimens of this fish were analyzed individually and many specimens were obtained at the same station.

Data Base Management

Scientific information wsa received by the data mangement group in the form of station logs, cruise journals, sample inventory reports and analytic results including those contained in previous MAFLA reports and/or data tapes (Volume II, Chapter 29). From this information, data were selected for entry into the data base by applying the criteria:

1. The data must be amenable to meaningful, quantitative manipulation by digital computer; and

2. The data must be compatible with data base entries from the current program.

Data from the current MAFLA program entered the data base via punched cards prepared from coding forms. All data entering the data base were carefully inventoried, controlled, and verified for accuracy.

PIs were responsible for submitting their data in keypunch ready form. Their coding sheets were inspected on receipt and minor corrections made if the entries were unclear or in improper columns. The encoded data forms were then keypunched on standard 80-column computer punch cards. All keypunching was subjected to 100% verification. Card image listings were carefully compared against the original coding sheets and required corrections noted. Copies of proofed and corrected card image listings were sent to PIs for approval and/or correction.

Corrected data were placed into the data base by assignment to the appropriate data base file, reading the associated data cards and transferring the data to magnetic tape as 80-column card images. Access to the data base was made by reading from tape to temporary disc storage so that integrity of the data base was preserved. Corrected data cards provided requisite backup to tape data.

More than 65 data base files were created to permit rapid access and ease in storage of the 1974-1978 MAFLA data base (Volume II, Chapter 29). Descriptions of these files and their format specifications are presented in Appendix A to Volume II, Chapter 29.

Data requiring taxonomic identifiers were initially encoded and entered in the data base with taxonomic ID numbers only. The taxonomic name was omitted because of the space limitations of an 80-column card. However, to optimize name retrieval, alphabetic taxonomic names have been assigned to the data by utilizing columns 81-130.

Dames & Moore has a nationwide contract with United Computing Systems, Incorporated (UCS) of Kansas City, Missouri. The contract enables Dames & Moore offices from geographically separate areas to utilize the same programs and to operate on the same data sets when required.

A UCS proprietary software package entitled Interactive File Manager (IFM) served as the primary computer file management tool (UCS, 1975). IFM is a system level language for organizing, sorting, merging, printing, and performing similar sophisticated file structuring from either the time-share or batch mode of operation. All data listings and reports were generated through IFM. Similarly, all systematic corrections and assignment of taxonomic names to individual data entries were performed with IFM. In contrast, individual data corrections were performed in the time-share editor mode.

Security of the data base files was provided by:

1. Limiting access through use of an account number and password;

2. Use of temporary storage files for data editing and processing;

3. Alternate data tapes of disc storage provided by normal UCS practice; and

4. Punch card backup to magnetic tape storage which was stored separately from the magnetic tapes.

Data Analysis and Synthesis

The data base, composed of samples, laboratory test data, and complementary data from previous MAFLA programs, was subjected to a carefully formulated analytic strategy for data synthesis patterned after Park and Feldhausen (1969) and Park (1974). The strategy is composed of several univariate and multivariate statistical techniques which were applied sequentially to the data.

The primary objectives of the statistical data processing performed under our contract were twofold:

1. To reduce the complex data matrices to descriptive parameters and plots that quantitatively describe the baseline data, and that define, identify, and display significant relationshps;

2. To test the statistical significance of these relationships.

As proposed by Park (1974), these objectives can be met by applying four multivariate statistical techniques in sequence:

1. Variable mode (R-mode) cluster analysis to define significant associations among independent variables and to identify redundant variables which tend to bias subsequent analyses (dependent variables may be treated as "independent" variables in this manner).

2. Sample mode (Q-mode) cluster analysis to partition the samples into discrete classes.

3. Sample mode (Q-mode) ordination to assist in the interpretation of the cluster analysis and to examine gradational relationships among the samples based on their resemblance to one another.

4. Stepwise discriminant analysis to statitistically evaluate the classification, to identify key "species" for distinguishing among the classes, and to classify new samples of unknown affinity.

Gradational relationships among the samples may be quantified by the application of trend surface analyses, which fit mathematical surfaces to the data displayed in two dimensions.

A large bank of computer programs was obtained from several sources in order to have at hand the tools required to accomplish the primary synthesis-analysis objectives stated in the preceding section. Sources of computer programs included:

1. "Canned" program packages held by UCS:

   a. Statistical Programs for the Social Sciences (Nei, et al., 1975),

   b. Biomedical Computer Programs (Dixon, 1973).

2. Proprietary programs in the UCS library;

   a. Interactive File Manager (UCS, 1975);

   b. Computer contouring and plotting packages; and

3. Dames & Moore proprietary programs accessed through special UCS files:

   a. Modular Multivariate Statistical Package (MMSP);

   b. Data digitization program;

   c. Temperature-Salinity-Density relationships program.

Using these, station statistical outputs, histograms, one-way analysis of variance, required number of replicates, moment measures, diversity indices, and outlier analysis were performed for Management and/or PIs as required. Descriptive statistics of the variables found at a station (station statistics) during a sampling period or for pooled sampling periods were reported in several different formats in order to accommodate the several types of data in the data base. Regardless of format the following statistical parameters were calculated to quantify and characterize the data at each station:

1. Arithmetic mean;

2. Variance and standard deviation;

3. Maximum and minimum values; and

4. Range of values.

MMSP program DIVERS was used to calculate several species diversity and evenness indices. In its most simplistic interpretation, the concept of diversity pertains to the distribution of individuals among species. Arithmetically, it is the ratio of the number of species in a sampled habitat divided into the total number of individuals. The program DIVERS calculated this ratio and seven other indices.

1. Species Richness (Margalef, 1968);

2. Number of Moves (Fager, 1972);

3. Shannon-Weiner (Pielou, 1966);

4. Scaled Shannon-Wiener (Fager, 1972);

5. 1-Simpson's Index (Fager, 1972);

6. Standard Deviation (Fager, 1972);

7. Evenness Factor (Pielou, 1966).

The pairwise resemblance or similarity among the variables (R-mode) and among the samples (Q-mode) was measured by one of four similarity coefficients, namely:

1. Taxonomic distance;

2. Bray-Curtis coefficient;

3. Jacard coefficient; and

4. Multiple product moment coefficient.

As used herein, cluster analysis is a classification technique which performs pairwise comparisons of samples (Q-mode) or variables (R-mode). It aggregates the objects by their decreasing similarity to form a hierarchical arrangement displayed as a dendrogram; "natural breaks" in similarity levels allow the PI to define groups at any desired level of similarity.

Q-mode ordinations were constructed by three different methods; namely:

1. Principal components analysis;

2. Conical analysis; and

3. Wisconsin ordination.

In general, these methods of ordination may be visualized as a semi-rigid rotation of the variable axes used to describe the samples in n-dimensional sample space (one dimension for each variable). The axes are rotated to a new orientation where the variance about each axis is minimized. One of these new axes (usually designated the x-axis) accounts for the maximum possible variance in the system (depending on the method used). Each remaining axis (y, z, etc.) accounts for decreasing amounts of the remaining variance. The result of this process is a spatial distribution of the samples in a multidimensional field such that the proximity of one sample to any other sample is directly proportional to their similarity. Thus, close neighbors are highly similar.

In canonical analysis the sample centroid is plotted an the replicates are distributed about the centroid. Dispersion of replicates was used to evaluate within and between sample (station/transect) variability.

In this study ordinations were performed to examine the gradational relationships among samples and to develop synthetic indices (a) for outlier analysis; and (b) for correlation with environmental parameters. Item (b) was particularly useful in assessing the behavior of bottom sediment trace metal data in relation to environmental parameters such as depth of water, sediment textural properties and calcium carbonate concentrations. The assessment was quantified by fitting trend surfaces of sample variable scores and scores for environmental parameters to sample loctions within the ordination x-y plan. By comparing several trend surfaces the environmental significance of the ordination and hence the conditions affecting the distribution of the trace metal samples in the natural environment became apparent.

Trend surfaces (Merriam and Harbaugh, 1964) are mathematical surfaces fitted to two-dimensional data in much the same manner as a straight line may be fit to x, y data by the method of least squares. In their simplest form, trend surfaces are planes defined by a polynomial of order one; hence they are termed first degree surfaces. Higher degree surfaces are curved and may be defined by higher order polynomials.

Discriminant analysis enabled the PI to evaluate the statistical significance of a classification and to derive an objective function for identifying samples of unknown affinity. In essence, discriminant analysis weighted the variables in order to achieve the maximum separation among points in previously defined groups of samples. These weightings were used to generate linear equations, which in turn were used to calculate an approximate F-ratio. Because the analyses were performed in a stepwise manner the output also ranked the variables in order of their ability to discriminate between the input classes.

Incorporation of 1974-1976 Data

The SUSIO data tape contained data files for the period summer 75-winter 76, as established under BLM Contract 08550-CT5-30. The SUSIO data tape and a tape listing were delivered to Dames & Moore Data Management by COAR approximately six months after inception of this program.

The remainder of the data were evaluated on a file by file basis. Present PIs reviewed the work element reports for summer 75-winter 76 (SUSIO, 1976) in order to evaluate field, laboratory, and analytic methodologies. Data were included or excluded based on recommendations that resulted from their evaluations. Table 7 lists those SUSIO data tape files incorporated into our data base as well as those that were excluded and the reason for exclusion.

Data Archiving

The Dames & Moore data tape containing the comprehensive summer 74-winter 78 MAFLA data base has been transmitted to BLM as a separate deliverable. This tape was generated to the following specifications:

1. 7 track;

2. External BCD;

3. 800 bpi;

4. Even parity; and

5. Unlabeled and unblocked.

TABLE 7

SUSIO DATA TAPE FILES INCLUDED IN OR EXCLUDED FROM DAMES & MOORE DATA BASE

MAFLA ID	DESCRIPTION	FILE NO.	EXCLUDED	REMARKS
0100				
0101				
0103				
1014	Cruise Station & Misc	020		
203N	Neuston Trace Metal Data		X	Not performed in this program
203R	Suspended Particulate Refactory Trace Metal Data	415 (PE 29)		V excluded; not compatible
203W	Suspended particulate Weak-Acid Trace Metal Data	410 (PE 29)		V excluded; not compatible
203Z	Zooplankton Trace Metal Data	510 (PE 26)		V excluded; not compatible
204M	Macroepifauna trace Metal Data	210, 211 (PE 14)		V excluded; not compatible
204T	Macroepifauna Taxonomic Data for 204M	210, 211 (PE 14)		
205A	Mollusc Abundance Data	723 (PE 56)		
205B	Macroinfauna Biomass Data	733 (PE 06)		
206A,B	Foraminifera Abundance Data	721 (PE 04)		
206R	Foraminifera Relic Abundance Data		X	Not performed in this program
207L	Demersal Fish Meristic Data	737 (PE 19)		
207N	Demersal Fish Taxonomic Data	717 (PE 19)		
209	Water Column HMW-HC Data		X	HMW-HC committee recommended exclusion
210	Neuston Taxonomic and Misc Data		X	PI recommended exclusion
211A	Bottom Sediment Grain Size Data	810 (PE 01)		
211B	Box-Core Color Descriptive Data		X	Not performed in this program
213A	Epifaunal-Epifloral Abundance Data (Diving)		X	Not performed in this program
213D	Macroepifauna Taxonomic /Data	724 (PE 18)		
214A	Surface Sediment Clay Mineralogy	820 (PE 03)		
214B	Suspended Sediment Clay Mineralogic Data	825 (PE 22)		Depth of sampling not compatible with this program
215	Phytoplankton Primary Productivity Data		X	Not performed in this program

TABLE 7 (CONTINUED)

SUSIO DATA TAPE FILES INCLUDED IN OR EXCLUDED FROM DAMES & MOORE DATA BASE

MAFLA ID	DESCRIPTION	FILE NO.	EXCLUDED	REMARKS
216	POC and DOC Data	420 (PE 30,32)		
217A	Polychaete Abundance Data	723 (PE 55)		
217B	Macroinfauna Biomass Data	733 (PE 06)		
218	Sediment ATP Data		X	PI recommended exclusion; laboratory methodology not compatible
219A	Sediment Total Organic	120 (PE 10)		Other organic carbon data excluded
219B-S	Bottom Sediment HMW-HC		X	HMW-HC committee recommended exclusion
221	Transmissiometry Data			
222C	Zooplankton Biomass Data		X	PI recommended exclusion
222M	Meiofauna Taxonomic Data	722 (PE 05)		Laboratory methods not compatible and data assumed to be unnormalized; hence, kept in a file separate from meiofauna data from this program (File 712)
222Z	Zooplankton Taxonomy Data		X	PI recommended exclusion*
223L	Demersal Fish Meristic Data	737 (PE 19)		
223N	Demersal Fish Taxonomy Data	717 (PE 17)		
225	Macroepifauna HMW-HC Data		X	HMW-HC committee recommended exclusion
226A,R	Micro-Mollusc Abundance Data		X	Not performed in this program
227A	Bottom Sediment Total Digest TM Data	115 (PE 07)		
229L	Demersal Fish Meristic Data	737 (PE 19)		
229N	Demersal Fish Taxonomic Data	717 (PE 19)		
232A	Polychaete Taxonomic Data	737 (PE 19)		
232B	Macroinfauna Biomass Data	723 (PE 55)		

TABLE 7 (CONTINUED)

SUSIO DATA TAPE FILES INCLUDED IN OR EXCLUDED FROM DAMES & MOORE DATA BASE

MAFLA ID	DESCRIPTION	FILE NO.	EXCLUDED	REMARKS
233N,P	Carbonate Skeletal Data		X	Not performed in this program
235S	STD Data		X	Data utilized but not included in computer data base
235X	XBT Data		X	PI recommended exclusion

The tape and its contents are further described on NOAA Forms 24-13 and supplemental information appended to them.

Data base formats are presented in Volume II, Chapter 29, Appendix A. A special feature of the Dames & Moore data tape is the fact that these format descriptions have been entered as the first file on the tape. Thus, the detailed format descriptions are not likely to become separated from the data.

Shipboard station logs, cruise journals, inventory and laboratory data keypunch coding sheets, as well as data listings have been identified, labeled, and stored in the Dames & Moore program files.

RESULTS AND DISCUSSION: GEOLOGY

INTRODUCTION

Function of Geology Work Element

The marine geological studies within the MAFLA program have a twofold objective: (1) providing a framework of physical conditions and processes as a setting for the chemical and biological investigations, and (2) helping assess the potential of geological parameters as environmental monitoring indices for offshore oil and gas development.

The PIs report by Doyle in Volume II, Chapter 2 presents the detailed results of a four-year investigation of the surficial sediments of the eastern Gulf of Mexico continental shelf. This work, together with the physical oceanographic data, provides information relating to the sedimentary processes active in the MAFLA area. The regional seafloor sediments have been characterized and supporting data have been provided for correlation with sedimentary chemistry and benthic biological studies.

Geographic Boundaries of Study

The MAFLA study area and offshore geological sampling stations are shown in Figure 2. Some of the major gologic and physiographic features of the region are given in Figure 3. These latter features have played or are playing a role in the development of the present geologic setting and sedimentological characteristics of the MAFLA continental shelf.

Regional geologic aspects have been considered in evaluating the data obtained from the MAFLA area geologic samples, but they have not been investigated as part of this study. Similarly, in this and the oceanography work elements (see below), a knowledge of the general circulation of the gulf of Mexico and discharge patterns of Mississippi River water has contributed to the interpretation of data from the MAFLA sampling stations.

Previous Studies

The geology of the continental margin of the MAFLA region may be divided into western and eastern provinces separated by a transition zone trending southwest from Cape San Blas through the DeSoto Canyon (Martin,

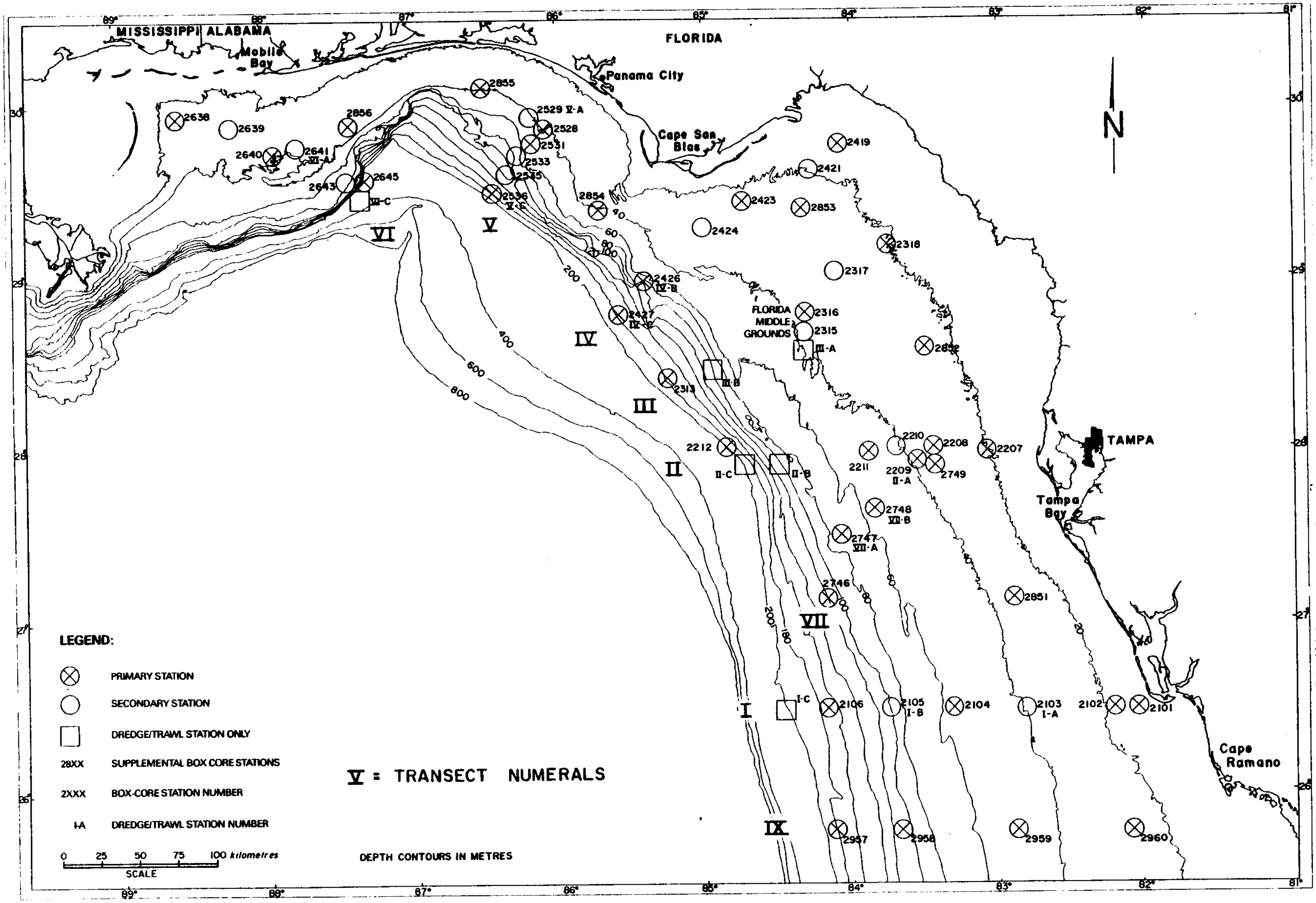


FIGURE 2

BLM 1977/1978 MAFLA SURVEY STATION LOCATIONS

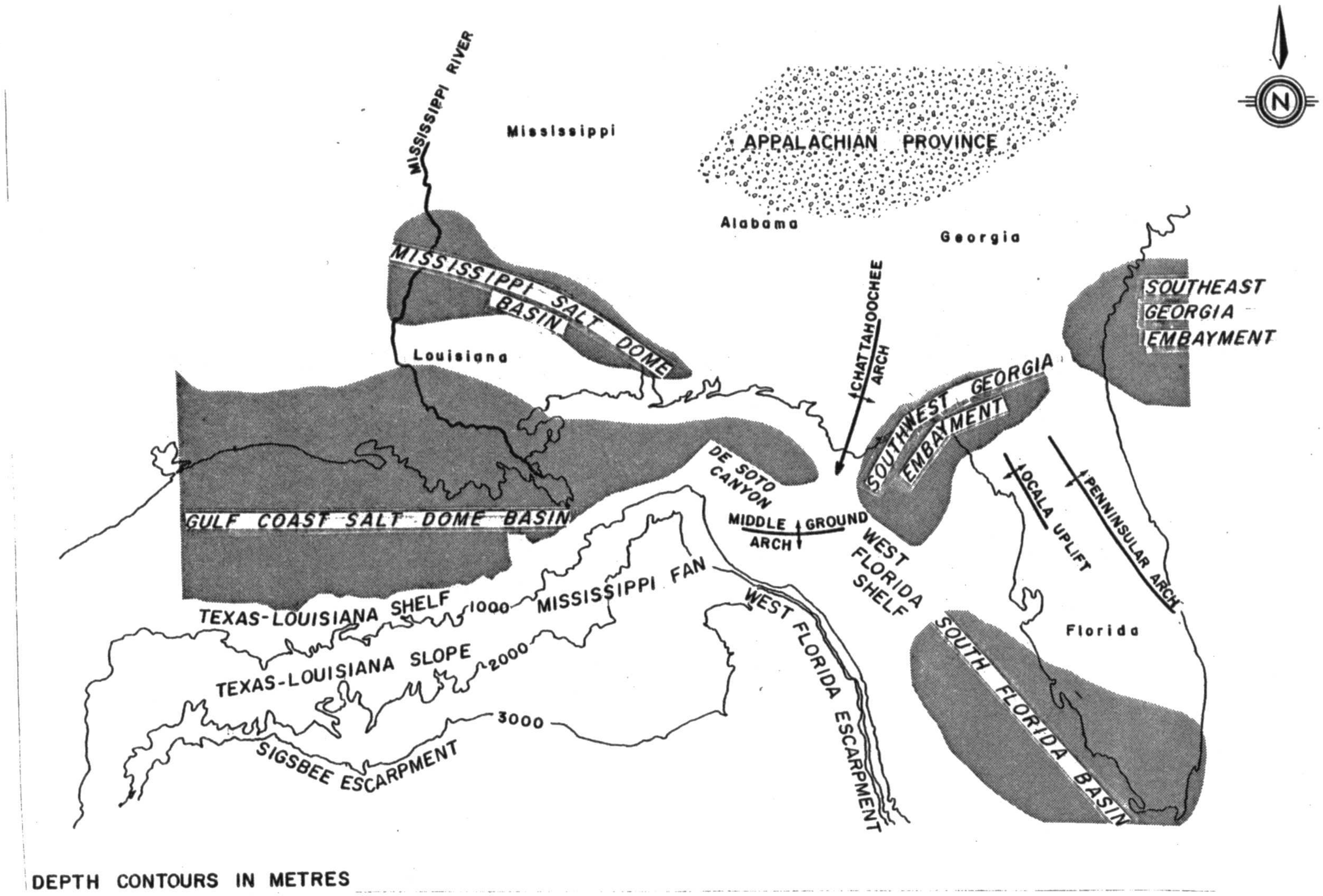


FIGURE 3

GEOLOGIC AND PHYSIOGRAPHIC FEATURES OF THE EASTERN GULF OF MEXICO AND SOUTHEASTERN UNITED STATES

MODIFIED FROM MARTIN, 1976

1976). West of the transition zone is the Gulf Coast Geosyncline which deepens to the west, attaining a thickness of over 30 km. This great mass of clastic rocks (rocks composed of rock and/or mineral fragments) represents the continued accumulation of sediment from the Mississippi River system. It is mostly Cenozoic in age (less than 70 myBP (million years before present)), and is underlain by layered salt deposits of Triassic-Jurassic age (230 to 130 myBP) which are the source rocks for the numerous salt domes characteristic of the Gulf region.

East of the transition zone the nature of the rocks changes dramatically. This region has been cut off from major sources of clastic sediments since Jurassic time, and has accumulated over 4,600 m of carbonates and evaporites. Carbonates are still being slowly deposited. These rocks have been deposited behind a series of shelf-edge algal reef dams, which at various times in the geologic past have restricted circulation (Bryant et al., 1969; Antoine et al., 1974). Pyle et al. (1977) have found vestiges of reef dams on the present shelf edge; but the original reefs of Albian/Aptian age (c. 100 myBP) have subsided over 1800 m and now make up the Florida Escarpment.

Seismic reflection and side scan sonar surveys conducted by Pyle et al. (1977) have shown that east of Cape San Blas a veneer of Holocene sediments only a metre or two thick overlies a ubiquitous surface which they identified as the top of Miocene (20 to 10 myBP) deposits. This surface is exposed and frequently forms ledges distinguishable in seismic and bathymetric profiles. Regions of karst (collapsed solution holes in carbonate rocks) features have also been identified. The sediment veneer displays extensive fields of small to giant sand waves that suggest that these areas of the wide shallow shelf are mobile at least under severe storm and hurricane conditions to which they are periodically subjected.

Gould and Stewart (1955), Shepard (1956), Ludwick (1964), and Grady (1972) have conducted extensive studies of portions of the surface sediments of the region. Shepard (1956) and Ludwick (1964) described the sediments of the Mississippi Delta east to Cape San Blas as consisting of a number of clastic sand, mud, and transitional units, while Gould and Stewart (1955) investigated the central portion of the West Florida Shelf and described it as covered by a series of sediment bands distinguishable by texture, carbonate constituents, and mineralogy. Van Andel and Poole (1960) and Fairbank (1962) described the distribution of heavy minerals in the study area.

Griffen (1962) first described the clay mineralogy of the northeastern Gulf of Mexico, including the West Florida Shelf. However, within this area his samples were from estuaries, and were dominated by the mineral smectite. On the basis of 1974 MAFLA sampling, Huang et al. (1975), showed that east of Cape San Blas, kaolinite rather than smectite was the dominant clay mineral.

Data Base for This Study

Over the past four years the collection of sediment samples in the MAFLA OCS has employed box-corers for bottom sampling and filtration techniques to recover suspended sediments. For the first two years the approach consisted of subsampling from two of the replicate box-cores at each station for each season. During the period of the present contract analyses (summers 76 and 77, fall 77, winter 78) replicates were collected from every box-core at each station in order to evaluate small-scale variability.

Each box-core subsample was analyzed for grain size and percent calcium carbonate and selected samples for total organic carbon (TOC) and clay mineralogy (the last in summer 77 only). In addition, clay mineralogy of suspended sediments was determined for samples collected at four time-series stations in summer 76, fall 77, and winter 78. Other data utilized in this study included MAFLA field collections for summer 74 (SUSIO, 1975), summer 75, fall 75, winter 76 (SUSIO Data Tape), summer 76 (SUSIO archived samples analyzed for this report), summer 77 (DM I), fall 77 (DM II) and winter 78 (DM III and IV). Numbers of samples from the latter four periods are given in Table 8.

GEOLOGIC SETTING

Geologic History

The Gulf of Mexico basin is considered by most workers to be a relatively old feature which has not been significantly affected by the Mesozoic-Cenozic (130 to 50 myBP) sea floor spreading. Various hypotheses have been proposed to account for the passive nature of this basin (see Miser, 1921; Ball and Harrison, 1969; Freeland and Dietz, 1971; Wilhelm and Ewing, 1972) but whatever the reason, plate tectonic processes which have shaped much of the adjacent Caribbean basins have had little effect on the area since at least Jurassic (180 myBP) time. By mid-Mesozoic time (c. 150 to 130 myBP) arid conditions prevailed, as shown by thick sequences of salt and anhydrite of Jurassic age. The basin was essentially isolated for the remainder of the Mesozoic as evidenced by extensive carbonate deposits on the West Florida Shelf and the Yucatan Peninsula. Subsidence of the southeastern portions of the Gulf began in early Cretaceous (120 to 130 myBP) time, and evidence from deep drilling indicates deep water conditions prevailed by Late Cretaceous (Santonian, c. 80 myBP) time (Worzel and Bryant, 1970).

Geophysical and drilling data suggest that for most of the area now forming the modern Gulf of Mexico, nearly continuous sedimentation has persisted since Jurassic time. Conditions in the northern Gulf changed dramatically with the onset of the Cenozoic when clastic sedimentation became the rule across the northern margin of the basin. The influx buried the reefs in Texas and Louisiana and began to fill the northern Gulf. Concurrently, in the southerly reaches of the Florida shelf, reefs continued to flourish as the entire Florida Platform subsided. Throughout the Tertiary Period (70 to 1 myBP) reef building kept pace with this subsidence, and thick carbonate deposits now form the eastern margin of the present Gulf. As a result of these two markedly different sedimentary regimes the present gulf may be divided into an eastern and southern sector of shallow carbonate banks, and a western sector characterized by a thick wedge of terrigenous clastics of Cenozoic age.

TABLE 8

GEOLOGY DATA BASE - NUMBER OF SAMPLES (INCLUDES REPLICATES)

Sampling Periods:	Year Season	1976 Summer	1977 Summer	1977 Fall	1978 Winter
Source:		SUSIO ARCHIVE	DM I	DM II	DM III (Water Column) DM IV (Benthic)
Parameters					
Standard Sedimentary Indices		609	455	322	397
Sediment Clay Minerals		52	49	-	-
Suspended Clay Minerals*		160	-	40	156
Total Organic Carbon		96	119	42	107

* Time-series samples

Geologic Features

Inasmuch as carbonate deposition has been the dominant process over much of the MAFLA area, the growth of the eastern continental margin was primarily vertical, as opposed to the western portions of this region which display wedges of terrigenous clastics which encroach upon and form the region from DeSoto Canyon westward. In that area, the Mississippi Fan reflects the continued influx of clastic materials from the modern Mississippi River.

As pointed out by Antoine et al. (1974) the boundary between the Florida Carbonate platform and the terrigenous wedge approximates the northern extension of the Florida Escarpment and Lower Cretaceous reef trend. The northwest wall of the DeSoto Canyon (in reality a broad submarine valley; see Figure 2) represents the easternmost extension of the modern prograding clastic wedge, and this feature may be considered the transition zone, or boundary, between the two sectors.

Selected seismic reflection records from the West Florida Escarpment (Garrison and Martin, 1973) reveal a thick deposit of carbonates whose age, established by dredged samples from the lower slopes, extends to at least Early Cretaceous time. These samples are reef materials, indicating a subsidence of at least 2.5 km since that time. Thus, the West Florida Shelf is the most recent surface of a thick deposit of Cenozoic carbonates. Structures within these deposits are subtle, but the largest is the broad Middle Ground Arch, an east-west-trending basement feature that separates the zone of piercement structures ("diapiric structures" believed to be salt domes) to the west from the southern region which lacks such features.

The Destin anticline is the other major basement feature within the MAFLA area (Antoine et al., 1973). Located off the panhandle of Florida, it is approximately 80 km long and 38 km wide, and has been the target of exztensive drilling by oil companies. To date, no commercial deposits of hydrocrbons have been reported in these Upper Jurassic-Lower Cretaceous sediments which display nearly 1 km of closure (in this sense, height of potential oil bearing rock).

RESULTS AND DISCUSSION

Benthic Sediment Parameters

The two parameters that are most diagnostic in describing the surface sediments of the MAFLA shelf are texture and carbonate content. Figure 4 is a map of the distribution of the fine fraction (those particles <63 μm) in the sediments of the area. Sand and a small amount of gravel normally make up the remainder of the sediment. Figure 5 shows the percent carbonate in the study area. Averages of all replicates from all sampling periods 1974-1978 have been contoured to produce these figures.

Clay mineralogy (mineral composition of sediments of about 1-4 μm diameter) of the sediments is also very useful for distinguishing between source provenances. Kaolinite (for discussion of clay mineral definitions, see Grim, 1953) is characteristic of the eastern MAFLA area; smectite is

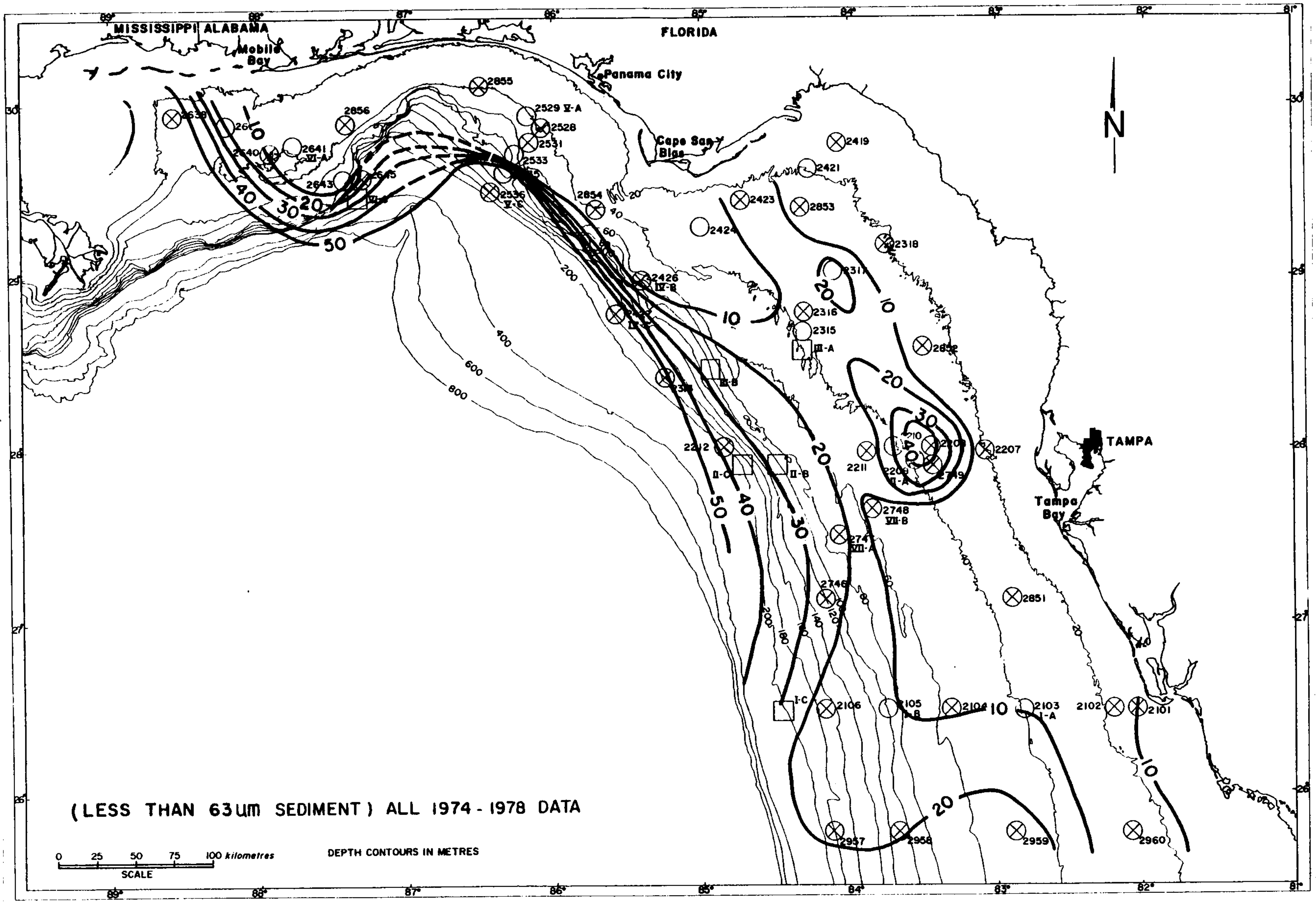


FIGURE 4

AVERAGE PERCENT FINE FRACTION

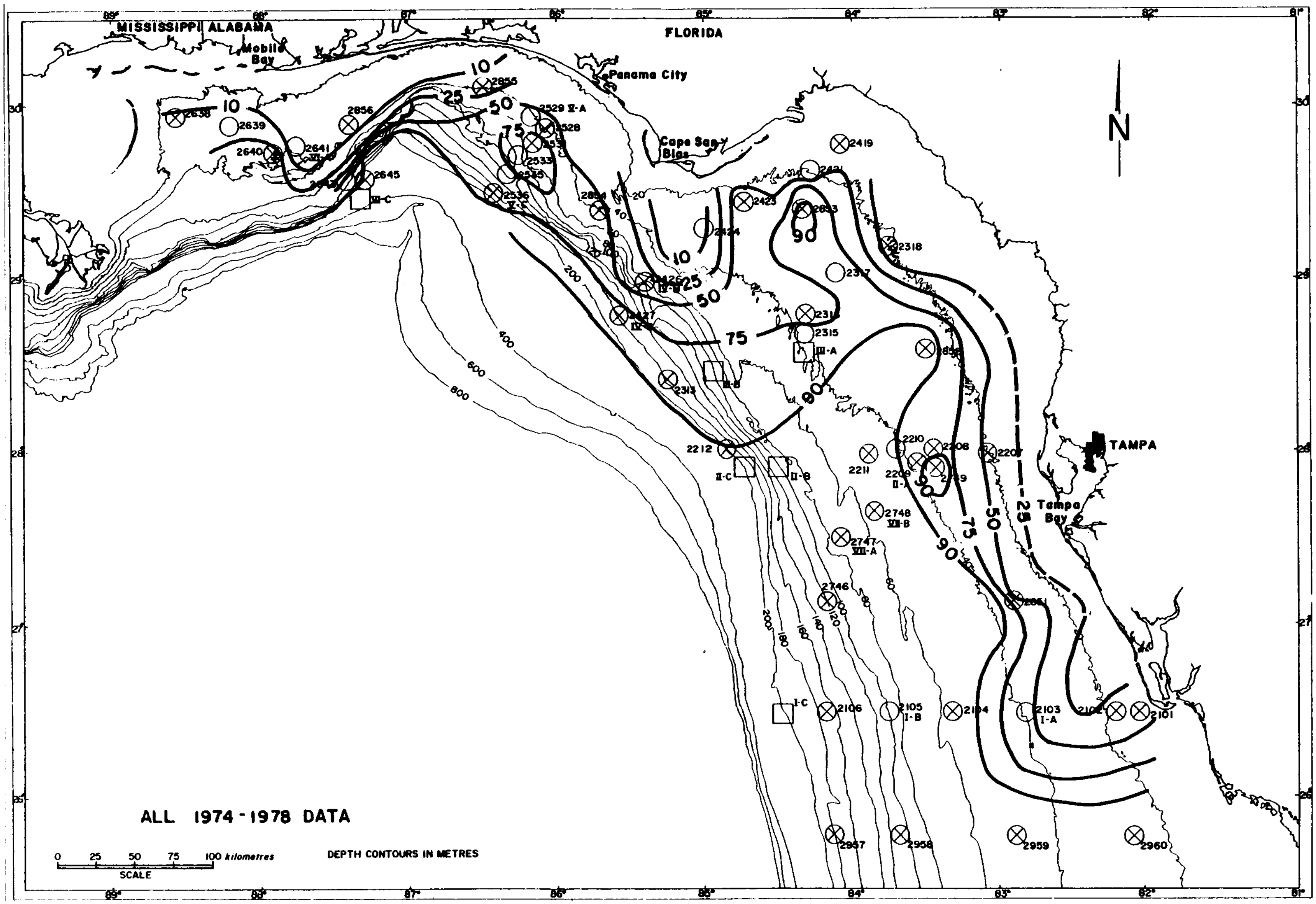


FIGURE 5

AVERAGE PERCENT CARBONATE IN SEDIMENTS

indicative of the western region and is contributed by the Mississippi River. Other sedimentary parameters measured in this study are TOC and adenosine triphosphate (ATP).

Texture

In sedimentology, texture may be defined as the description and shape aspects of a sedimentary material. Sands dominate the eastern MAFLA area except for a large patch of sediments with an elevated content of fines that lies to the west of Tampa Bay in the central shelf region (Figure 4). Highest values in the center of the patch exceed 60% fines. Doyle et al. (1977) have suggested that the patches of finer sediment represent accumulations deposited behind irregularities in the bottom.

The general 20% fine fraction contour lies well out on the shelf edge. Even upper slope sediments of the region contain up to 50% sand, composed almost entirely of the tests of planktonic foraminifera (see Marine Biology section, below). The fine fraction increases rapidly west of Mobile Bay as the Mississippi Delta is approached, and fine sediments also lie in the head of DeSoto Canyon.

Deeper water, finer grained sediments in the study area are generally poorly sorted (σ1.0 to 2.0ϕ, standard grain size notation) while those sands and muds lying on the shelf are generally very poorly sorted (σ2.0 to 4.0ϕ) according to Folk's (1974) classification. Only one station showed greater sorting: Station 2856 which was moderately sorted (σ0.71 to 1.0ϕ).

Carbonate Content

While the shelf sand sheets on both sides of Cape San Blas display textural similarities, Figure 5 shows there is a major compositional break trending slightly east of south from the Cape. The low carbonate contour, which correspond to high quartz content, form a bulge out onto the shelf which marks the transition between western and eastern facies (sedimentary units with distinctive characteristics). The eastern portion is dominated by up to 90% carbonate components while the western portion is predominantly quartz sand. A band of quartz sand also lies inshore to the east of Cape San Blas and makes up the western beaches of the Florida peninsula. The gradational transition between the nearshore quartz band and open shelf carbonate sediments, and the abrupt pinching of the quartz band at the southern limit of the study area are illustrated in Figure 5.

Benthic Clay Minerals

Clay minerals are important in their relationship to the scavenging of trace metals and in their relative proportions which may indicate general water motions and sedimentary source areas. Due to their source in Mississippi River waters, clays are most prominant in the MAFLA area in the northwest section, and in the deeper outer shelf and slope stations.

Clay minerals tend to concentrate or strongly influence the distribution of trace metals (see Marine Chemistry, below, and Chapter 3 of Volume II). There are several reasons for this. Clay minerals are usually of terrigeneous origin, as compared to water-column derived particles, and hence are commonly exposed to sources of metals on land. Clay minerals also carry trace metals within their crystal structures, although these are not necessarily biologically active. Of primary ecological importance in trace metal cycling is the high surface-to-volume ratio of the clay platelettes. These particles adsorb trace metals onto their surfaces where they remain available to benthic deposit or filter-feeders (Trefry, Volume II, Chapter 3). Since many organisms are capable of stripping metals from the surfaces of particles, there is concern for a bio-accumulation, or amplification, of TM concentrations as various trophic levels become involved in a given food web (see Trefry, Volume II, Chapter 3).

Smectite and kaolinite are the predominant clay minerals in eastern Gulf margin sediments. Illite is present in most samples ranging from trace amounts to about 16% and shows a random pattern of distribution within the study area. Mixed layer clays and chlorite are rare and scattered in benthic samples.

Distributions of the dominant clay minerals smectite and kaolinite are shown in Figures 6 and 7, respectively. Values are averaged for summer 76 and fall 77. Smectite, characteristic of the Mississippi drainage system, dominates the clay fraction west of Cape San Blas. From the delta, relative percentages of kaolinite increase eastward toward the Cape. East of Cape San Blas kaolinite becomes more important, and over large portions of the eastern area is dominant in the clay minerals.

Several source areas feed sediments to the eastern Gulf margin. The Mississippi drainage basin is characterized by a clay mineral suite dominated by smectite (Griffen, 1962). Like the coastal plain of the southeastern United States to the north, smectite also dominates the clay mineralogy of those rivers which rise in the Tertiary rocks of peninsular Florida (Huang et al., 1975). These rivers contribute little to MAFLA sediments with the possible exception of the Caloosahatchee River, which empties into Port Charlotte Harbor (inshore Transect I), and where a rise in smectite values is noticeable (Figure 6). Kaolinite dominates the Appalachicola river system, while the Mobile River system has a mixed smectite/kaolinite suite. According to Doyle (Volume II, Chapter 2) who examined the crystalinity of the clay minerals over the MAFLA area, these latter two river systems must be the ultimate source of kaolinite in the eastern Gulf margin.

Total Organic Carbon

The distribution ot total organic carbon in the sediments of the study area is summarized in Figure 8. Like Figures 4 and 5, contours are based upon station averages for all samplings 1974-1978. Values correspond with those of Emery and Uchupi (1972) for sandy shelf sediments.

As is normaly the case in marine sediments, TOC content follows the grain size trends and increases with increases in the amount of fine fraction. This correspondence to sediment fines is also a link between TOC and trace metals. Further, TOC provides for complexation of trace metals by organics in the sediment (see Sediment Trace Metals, below, and Volume II,

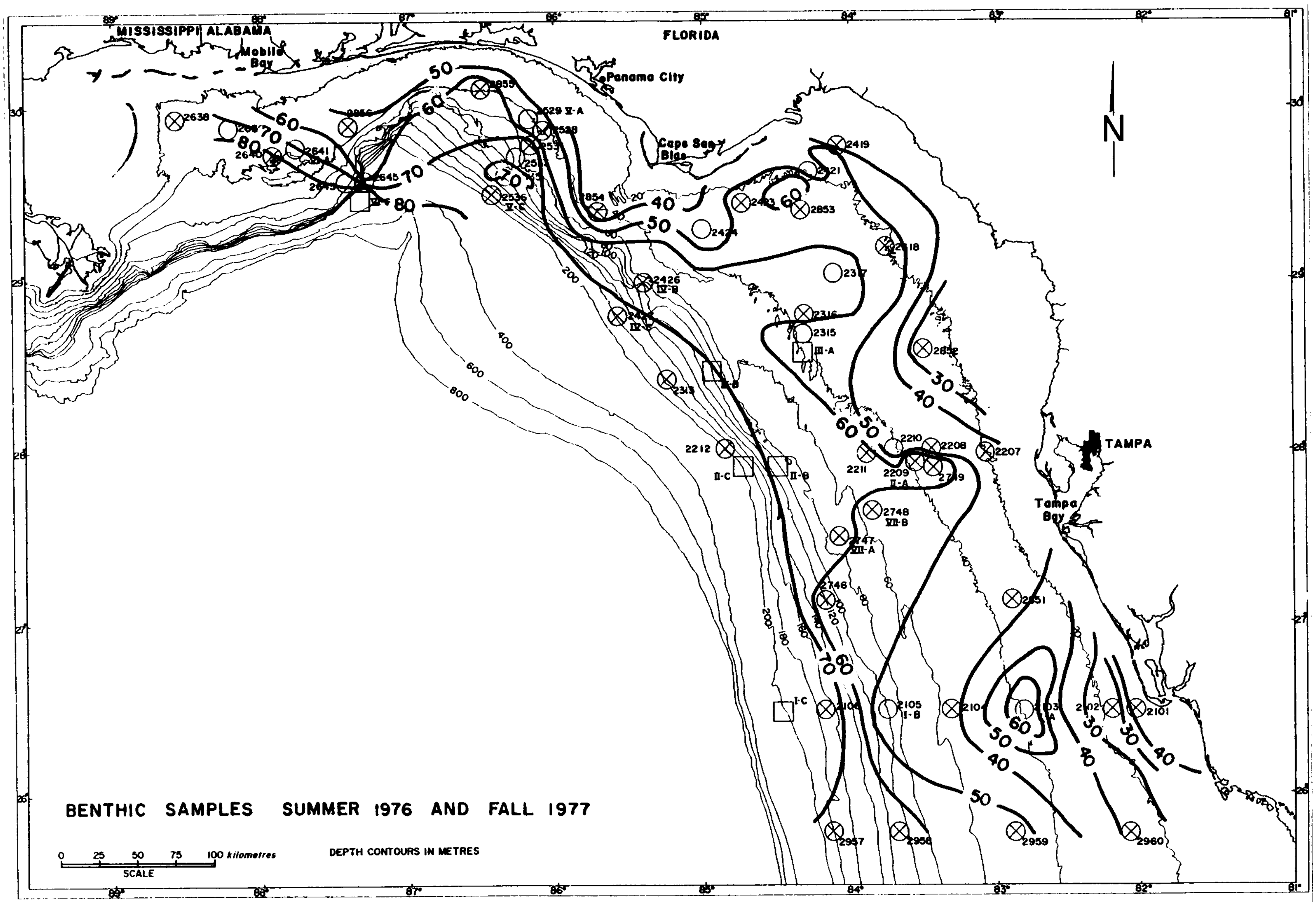


FIGURE 6

AVERAGE PERCENT SMECTITE

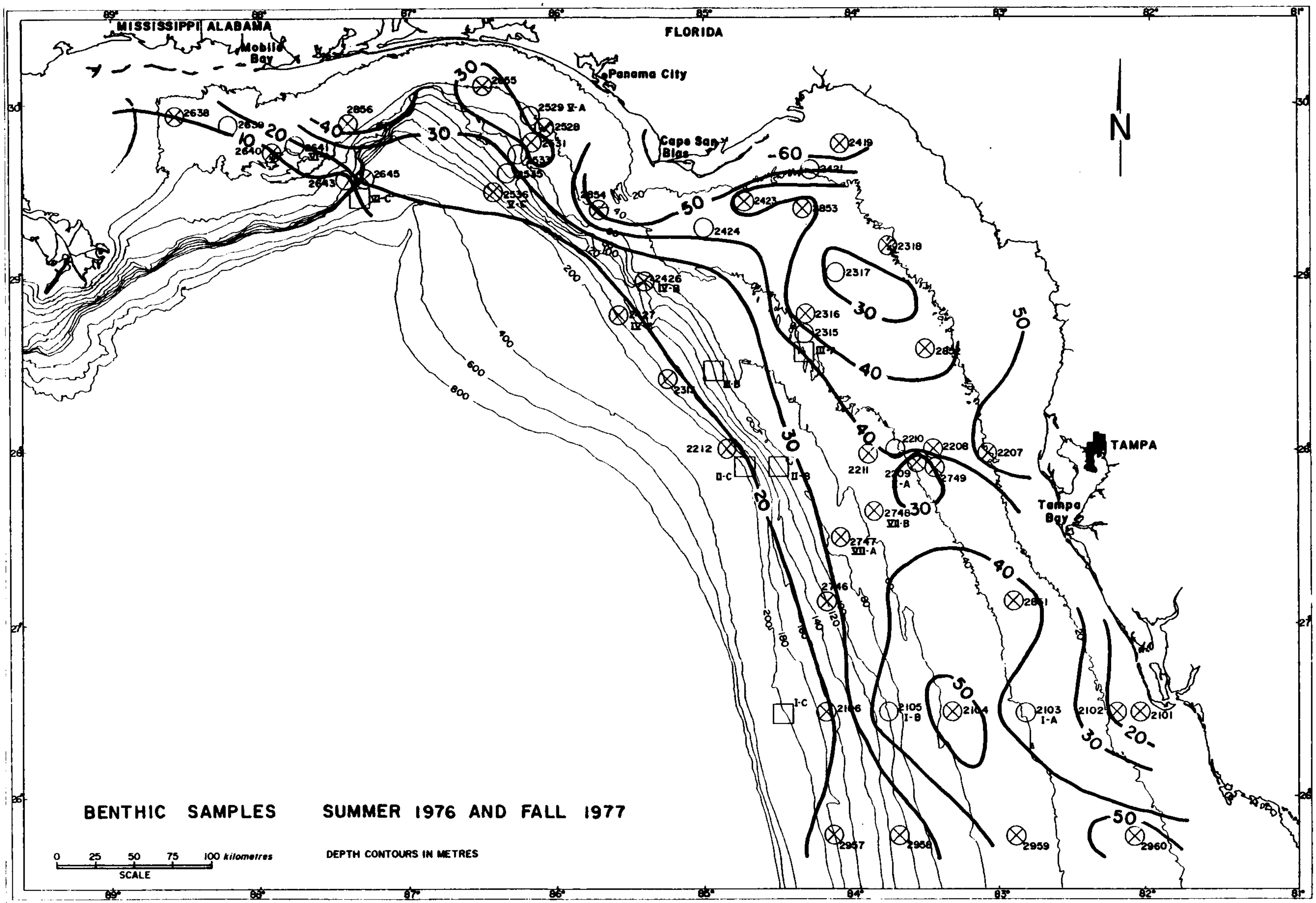


FIGURE 7

AVERAGE PERCENT KAOLINITE

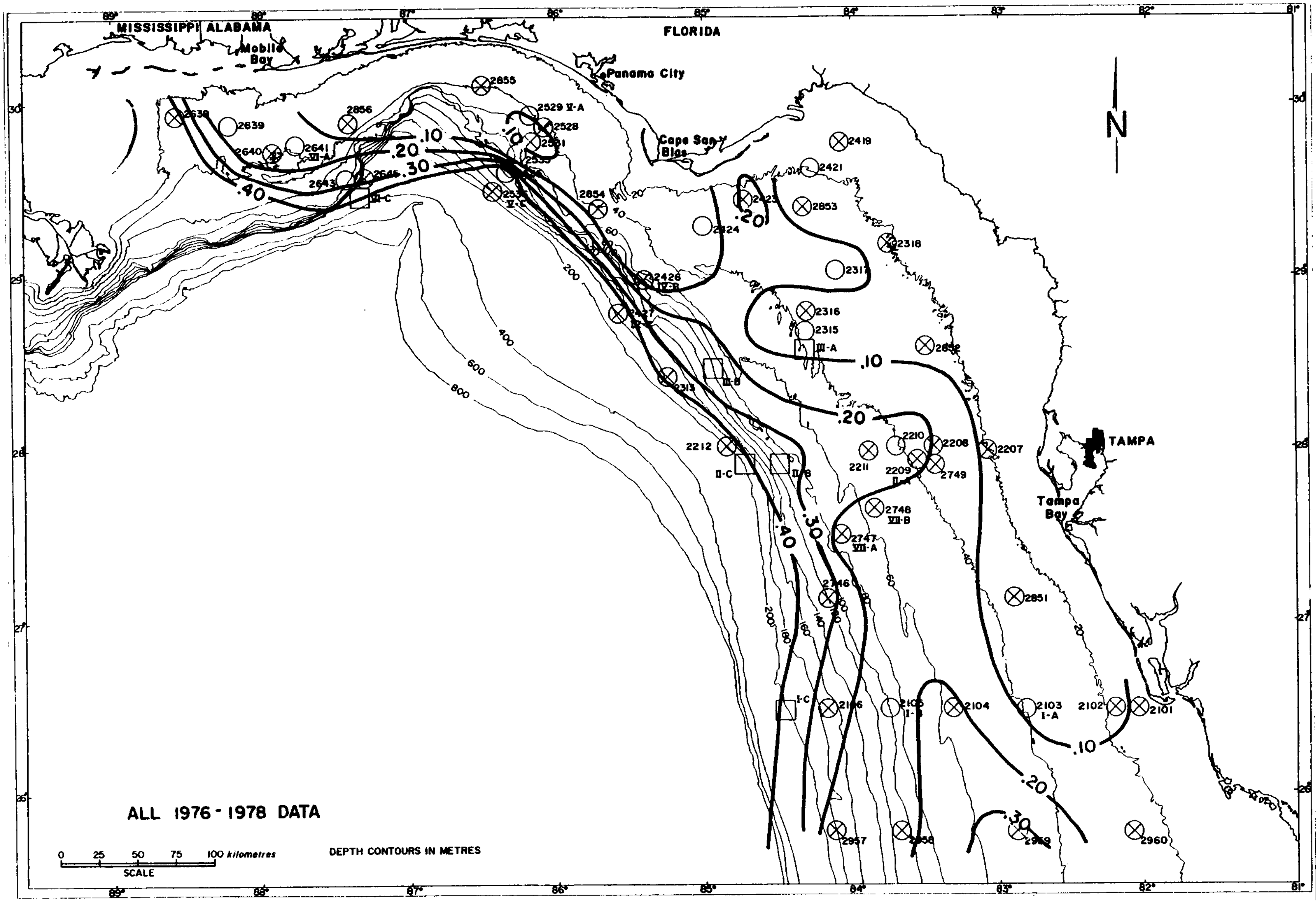


FIGURE 8

AVERAGE PERCENT TOTAL ORGANIC CARBON (TOC)

Chapter 3). Correlations between ATP data and TOC were not evident. La Rock reported an inverse correlation between ATP and TOC (SUSIO, 1977; but see Volume II, Chapter 11). Other investigators have found peak values in sediment ATP to correspond with dissolved organic carbon (DOC) peaks (Karl, et al., 1976), while seasonal studies have shown sediment ATP peaks do not correspond with TOC maxima (Cadee and Hageman, 1977). The relationship between TOC and microbial biomass in the sediment is complex, and depends on the nutritive potential of the carbon and amount of oxygen available. It appears that ATP maxima correspond to TOC levels >0.1 and <0.3%. These may reflect areas of maximum utilizable TOC (see Marine Biology, below).

The stations that have the lowest ATP values in the fall also seemed to have the highest calcium carbonate content (generally >95%). The stations displaying a progressive increase of ATP from summer to winter had intermediate levels of calcium carbonate (50 to 90%). Finally, the northern stations, possessing peak ATP values in the fall, ranged from 6 to 90% $CaCO_3$.

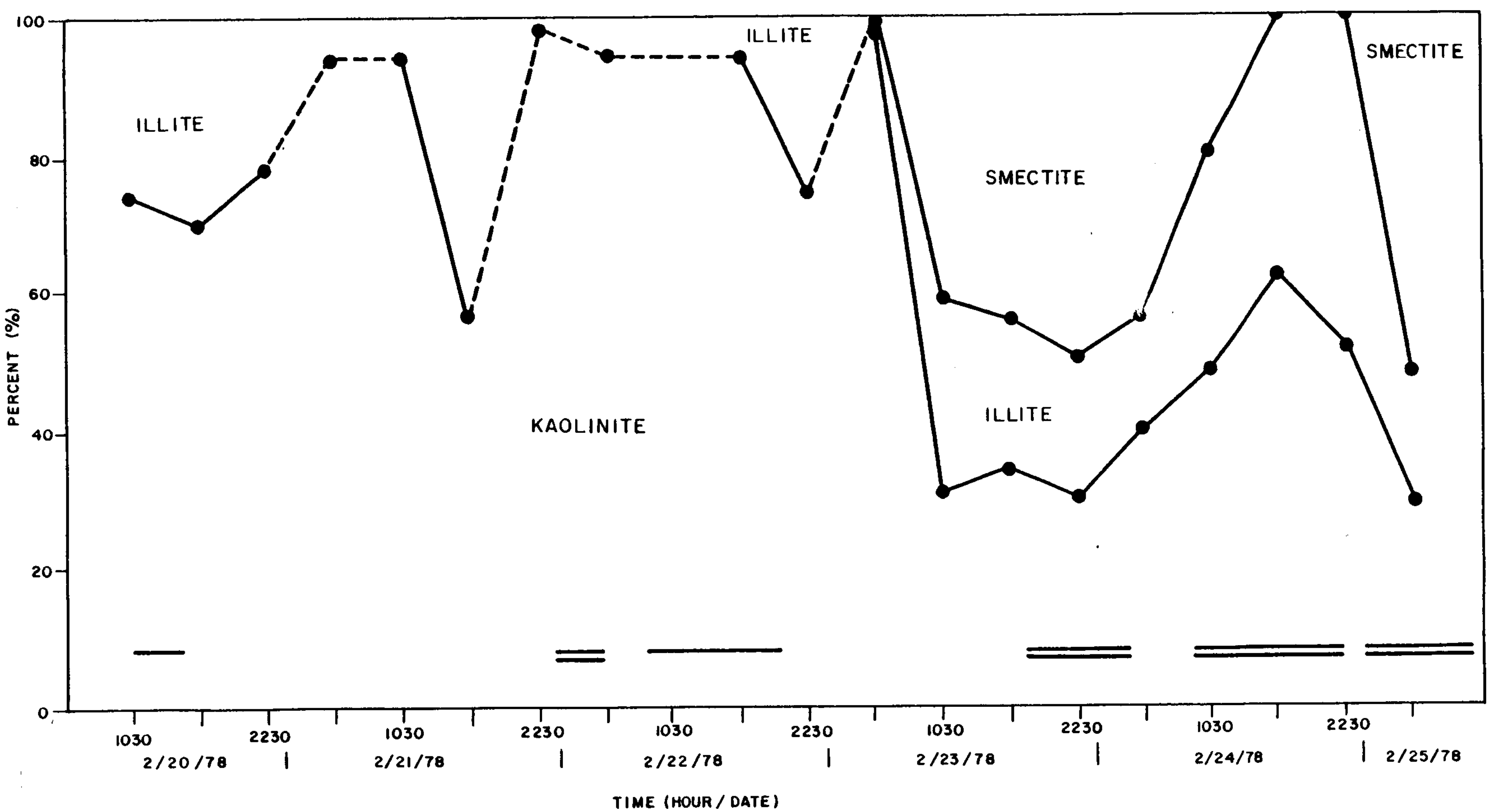
Suspended Clay Mineralogy

The suspended clay mineralogy suite analyzed by Doyle (Volume II, Chapter 2) is similar to that of the benthic sediment with the addition of trace to minor amounts of talc which are present in summer 76 samples. Talc disappears in fall 77 samples but reappears in Station 2747 samples in February 1978. In the last sample it is present in quantities from trace amounts to being the dominant constituent.

Variation over time in clay mineralogy was dramatic in one of the time-series stations occupied in winter 78. Figures 9 and 10 show the variation in surface and bottom samples at Station 2639, south of Mobile Bay over a five-day period. Both samples show marked fluctuations in mineralogy of the suspended clay, with bottom variations being the most pronounced. Fluctuations in mineralogy are not limited to the northwestern area. Station 2747 off Tampa Bay showed significant variation in mineral species over a 13 h time period as shown in Figure 11.

The smectite content appears to "intrude" into a prevailing base level of kaolinite. These clay mineral content variations are compared to concurrent transmissiometry data taken by Carder (Volume II, Chapter 21) on Figures 9 and 10. There is no compelling correlation evident, yet there is a general but inconsistent tendency for the smectite additions to correspond to times of more turbid water.

The general relationship between physical oceanographic parameters (STD, transmissiometry), suspended sediment clay mineralogy, and suspended sediment trace metals is speculated upon by Doyle, Carder and Betzer (Volume II). The general lack of substantiation is discussed in the physical oceanography synthesis, below.



— SHOWS TIME INTERVAL WHERE TRANSMISSOMETER C_P MEASUREMENT AT 3m DEPTH IS 1.00-1.40; LESS THAN 1.00 WHERE UNMARKED

= AS ABOVE, PLUS ENTIRE WATER COLUMN C_P = 1.00-2.00

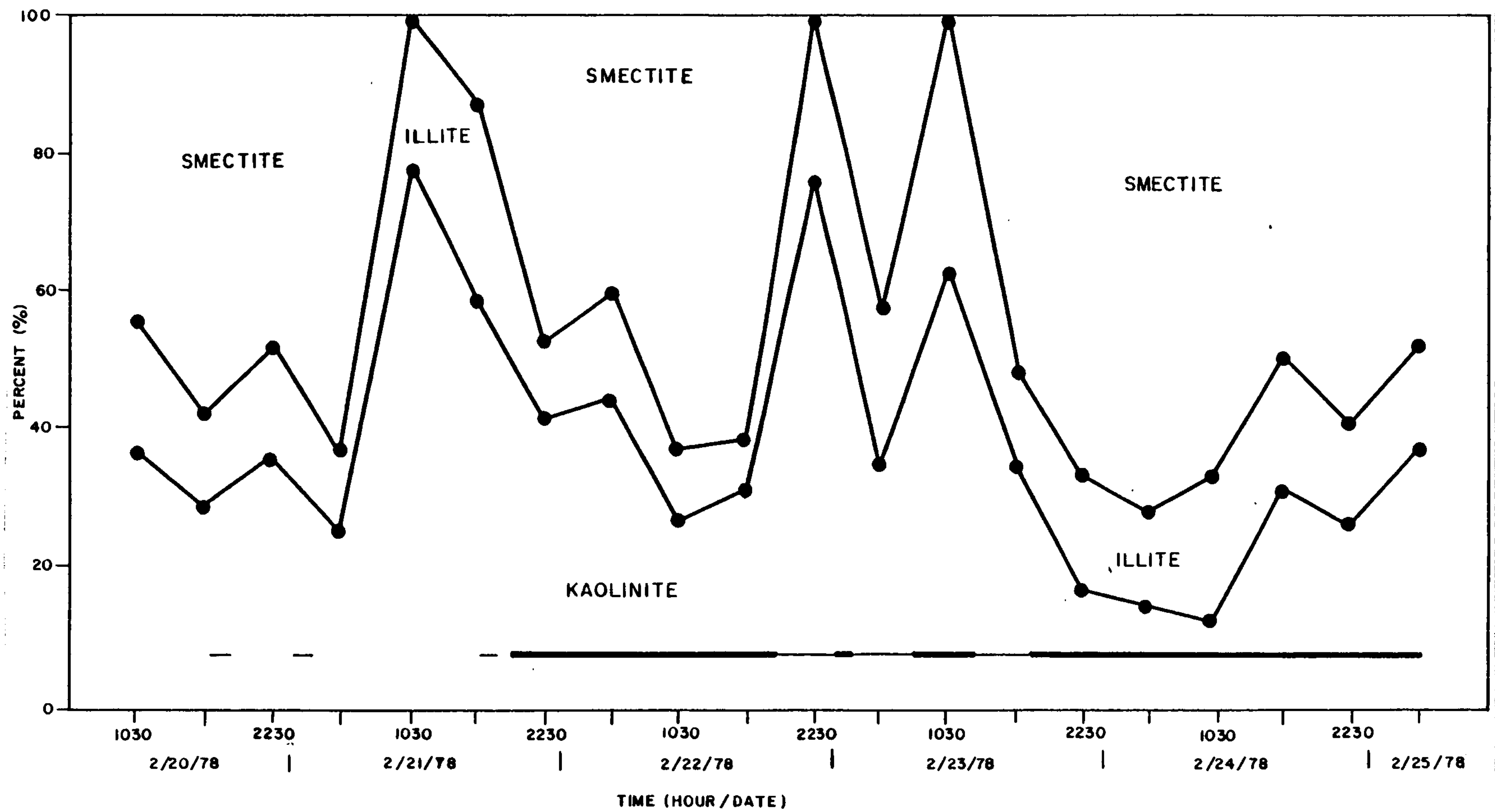
DM III

FIGURE 9

SUSPENDED CLAY MINERALOGY STATION 2639

DEPTH = 31m,

TOP: SAMPLE DEPTH 3m



SHOWS TIME INTERVAL WHEN TRANSMISSOMETER Cp MEASUREMENT AT 28m DEPTH IS 1.00 - 1.40; LESS THAN 1.00 WHERE UNMARKED

AS ABOVE, WITH Cp = 1.40-2.00

DM III

FIGURE 10

SUSPENDED CLAY MINERALOGY STATION 2639

DEPTH = 31m

BOTTOM: SAMPLE DEPTH 28m

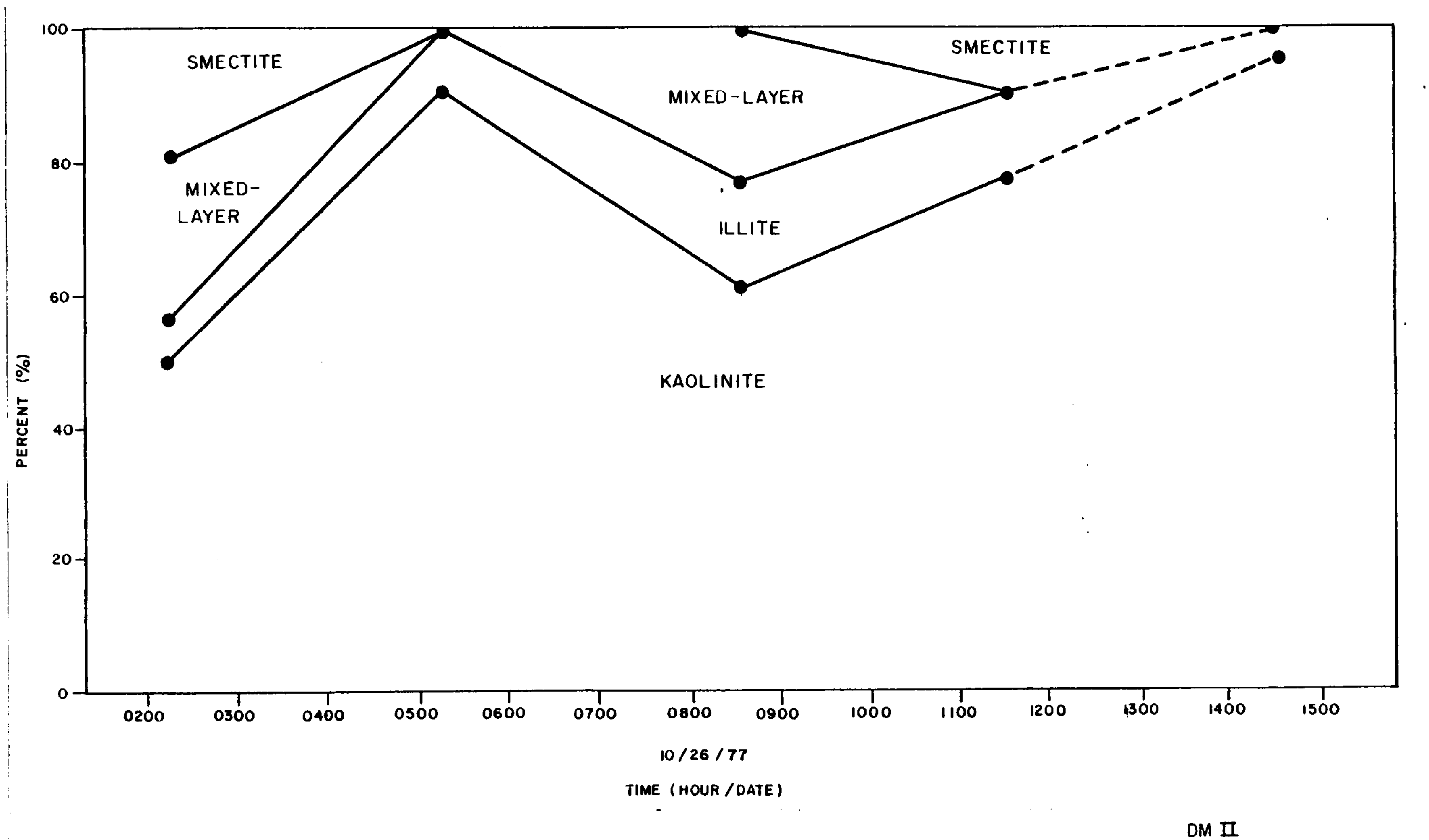


FIGURE 11

SUSPENDED CLAY MINERALOGY STATION 2747

BOTTOM: SAMPLE DEPTH ≃ 70m

Seafloor Sediment Facies

Geologic Description

Surficial sediments of the MAFLA shelf reflect the immediately underlying geology; that is, they may be divided at Cape San Blas into a western region of clastics and an eastern region dominated by carbonates. The facies distributions of surficial sediments in the study area are illustrated in Figure 12, compiled by Doyle (Volume II, Chapter 2).

Most of the sediment load of the Mississippi River is delivered directly to the shelf edge or is carried west due to the orientation of major distributaries and coastal boundary currents acting on the plume. Hence, sediments on the eastern margin of the delta change rapidly from the St. Bernard Prodelta Facies (Ludwick, 1964) which is dominated by mud, to an open shelf clastic facies, here identified as the MAFLA Sand Sheet. Sediments within this sheet are quartz sands with carbonate percentages of generally less than 25%. Van Andel and Poole (1960) and Fairbank (1962) characterize the heavy mineral suite of the area encompassed by the MAFLA sand sheet as reflecting a southern Appalachian provenance.

Within the MAFLA sand sheet and adjacent to the eastern margin of DeSoto Canyon lies the insular Destin carbonate facies which displays contents of carbonate over 75%. Wanless (1977) shows this zone to be a combination of shell hash, lithothamnion algae, and foraminifera. Since the Loop Current turns to the east then south at the DeSoto Canyon, the current may serve to block transport of detrital sediments into this zone, resulting in the accumulation of carbonate sediments similar to those of the West Florida carbonate sand sheet. This facies is so well sorted and coarse that if such currents do account for the facies presence, the currents may be quite strong and regular.

East of Cape San Blas lies the West Florida Shelf which may be divided mineralogically into two facies separated by a rather broad transition zone (see Figure 12). A carbonate sand facies dominates the outer and middle shelf. Rather than being banded with regard to texture and carbonate constituents as described by Gould and Stewart (1955), sediments within it are of patchy distribution in both texture and composition (Doyle, in SUSIO, 1977; and Wanless, 1977). This facies is defined by a carbonate content arbitrarily placed at over 75%. Patches of shell hash, foraminifera, lithothamnion algae, and even oolites (egg-shaped $CaCO_3$ concretions) locally dominate the sediment (Gould and Stewart, 1955 and Wanless, 1977). As expected, detrital heavy minerals are essentially absent in the carbonate facies. Outcrops containing phosphorite (a chemical precipitate rich in phosphorous) of suspected Miocene age are known to be present in some areas.

Shoreward of the carbonate facies lies one transition zone, shown in Figure 12, which includes increasing amounts of quartz toward shore (eastward). The tranisition is gradational and the shoreward boundary is arbitrarily placed at the 25% carbonate isopleth. Shoreward of this transition zone lies a quartz sand facies. This facies consists of very fine to fine sand. Due to its heavy mineral suite, characterized by the resistant minerals zircon, tourmaline, garnet, and staurolite (Fairbank, 1962). It is

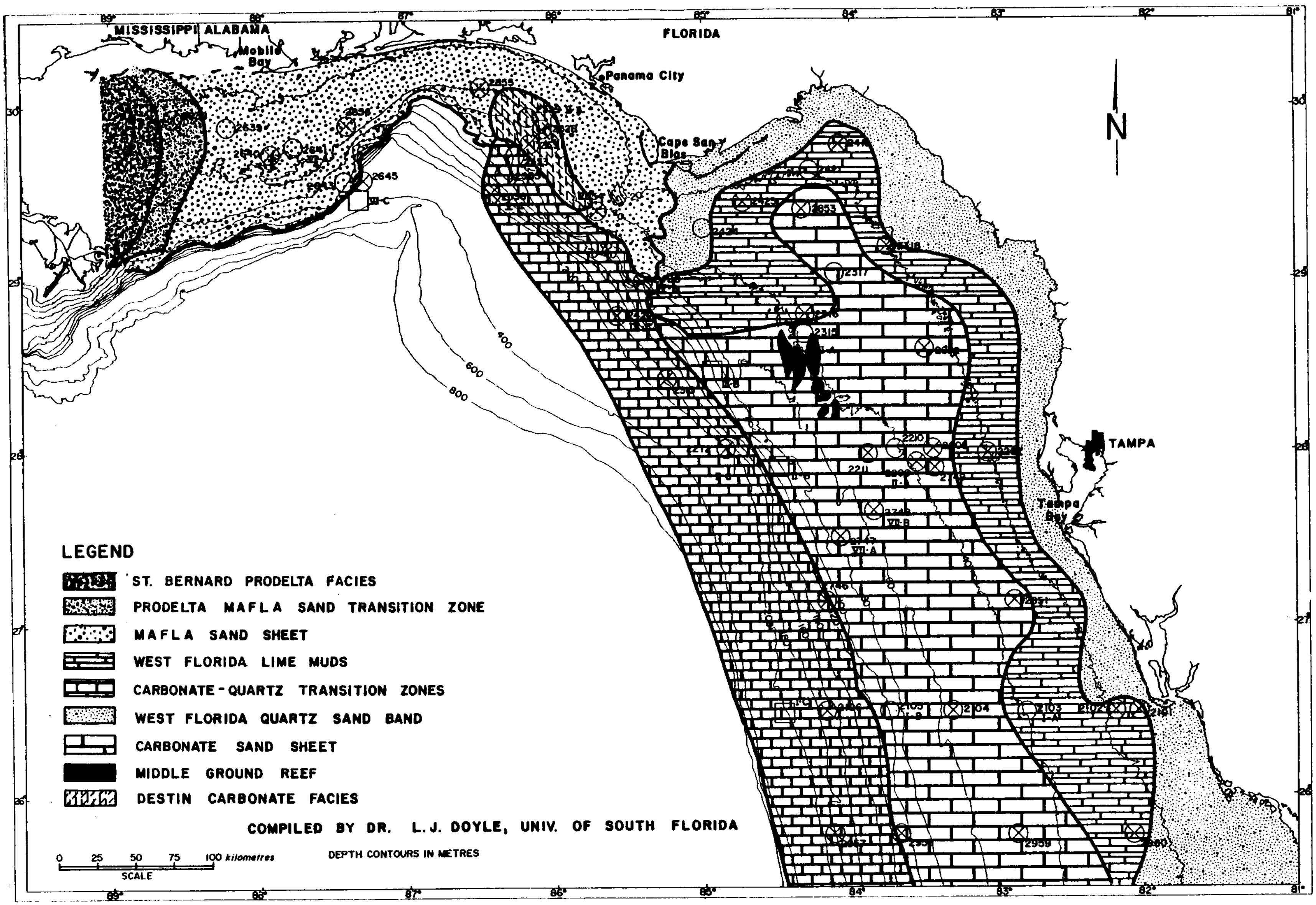


FIGURE 12

MAFLA SEDIMENT FACIES CHART

considered a "mature" sediment; that is, its components have passed through several sedimentary cycles of erosion and deposition. It is significant to note that this inshore quartz band also makes up West Florida's beaches.

The rivers of Florida carry little suspended load and even less bed load. Thus the quartz band does not contain significant amounts of land-derived sediment and it is bordered on the west and south by carbonates. Heavy mineral and clay mineral suites within this band are distinct from those contained in the detrital sediments to the west of Cape San Blas, suggesting that there is little sediment exchange between the two. These observations pose the question that without a constant source for replenishment, why does this band persist? Why hasn't long shore drift removed the quartz with subsequent replacement by carbonate sand?

The answer lies in the seasonal wind regime which prevails in the eastern Gulf of Mexico. Northerly winds dominate this coast during late fall and winter, while southerly winds predominate the rest of the year (Jordan, 1973). This alternating wind pattern leads to a southerly longshore drift in late fall and winter and a northerly drift during the remainder of the year. These two patterns offset so that there is very small annual net drift, and sediments tend to migrate back and forth (Doyle, Volume II, Chapter 2). The result is an exceedingly mature sediment which has lost the original diagnostic character of its heavy mineral suite.

Since quartz is not being fed to the system at present, this band must be "relict" (a deposit remaining from an earlier time of deposition). It may result from quartz sands being brought down from the Tertiary clastic terraces of peninsular Florida during lowered stands of sea level or it may represent the surface of a partially drowned terrace. Since clay mineralogy of the West Florida shelf is dominated by kaolinite and the coastal plain sediments of peninsular Florida by smectite, the northern Appalachicola and Suwannee Rivers may have been the most significant source area, with original smectite being partially masked or winnowed.

Seaward of the carbonate sand facies, the West Florida lime muds (Ludwick, 1964) occupy the continental slope. The clay minerals forming these muds are dominated by smectite (probably the result of Loop Current transport), but fine-grained carbonates (primarily coccoliths) are also important. In many places these sediments may contain large amounts of sand-sized planktonic foraminifera.

Statistically Defined Facies

Cluster analyses were run on the grain size and carbonate data as a tool for statistically differentiating sediments at stations by using all replicates and all measured parameters, i.e., all phi weight percentages, with or without percent carbonate. Since all data, rather than simple summary statistics, are used simultaneously to produce the groupings, cluster analysis provides results that are sensitive, subtle, and especially useful when compared statistically with results of clustering for chemical and biological data using principal component analyses (see Methods and Volume II, Chapter 29).

Geographic distribution of a set of sediment cluster groupings based on grain size distributions of replicates for all seasons for each of the 60 stations, is given in Figure 13. Grand means (1974-1978) from all stations for these sediment groups are listed in Table 9 along with the applicable geologic description of the sediment type, in order to illustrate that the differences between multiple parameter derived cluster groups are also reflected in aggregate statistical parameters.

Another geographic distribution of clustered grouping is given in Figure 14 where the cluster groups are based on the grain size distribution data (as used for Figure 13) plus carbonate content. Grand mean values of selected parameters for these cluster groups are listed on Table 10.

Comparison of Figures 13 and 14 with Figure 12 shows that two quite different kinds of information have been generated. While Figure 12 shows the general geological facies classifications for the surficial sediments, the two cluster figures show similarities of various stations, many of which fall into different geological facies or which display wide geographic separation while being in the same cluster group. The number of cluster groups in any application is a function of selection on the basis of judgment, the primary consideration being the numerical degree of similarity reported by the cluster analysis.

Examination of the area designated by the Destin Carbonate Facies (Figure 12) on the cluster figures shows that this facies has strong similarity to the outer West Florida Shelf sediments. In terms of grain size (Figure 13; cluster group C), the Destin facies has strong similarity to the outer West Florida Shelf sediments. In terms of grain size (Figure 13; cluster group C), the Destin facies is most like the West Florida Shelf sediments between 50 and 100 m depth. When carbonate content is taken into consideration (Figure 14; cluster groups A and D) the Destin area is comparable to West Florida Shelf sediments between 50 and 200 m depth.

Cluster analysis including carbonate data yields three groups of high carbonate content (Table 10; A, D, E) which plot correspondingly in the carbonate facies shown in Figure 12. The finer grained of these (A and E) tend to characterize the Florida Middle Grounds reef area (Figure 14). Looking at grain size distribution without carbonate data, the Middle Ground reef area is characterized by six cluster groups (Figure 13) showing high small-scale geographic variability. This variability also expresses itself in ATP, macrofaunal, trace metal, and hydrocarbon data (see below).

The St. Bernard Prodelta facies (Figure 12) and uniquely identified in Figure 14 since its cluster group (B) is not found elsewhere in the MAFLA area. In Figure 13, this facies is broken into two fine grained clusters (silts) which do have similar sediments in one other location, on the slope above the DeSoto submarine valley.

Variability in Seafloor Sediments

To be useful for environmental studies the characterizations and data related to MAFLA area marine geologic conditions developed in this report must be considered in light of their variability. This variability can be

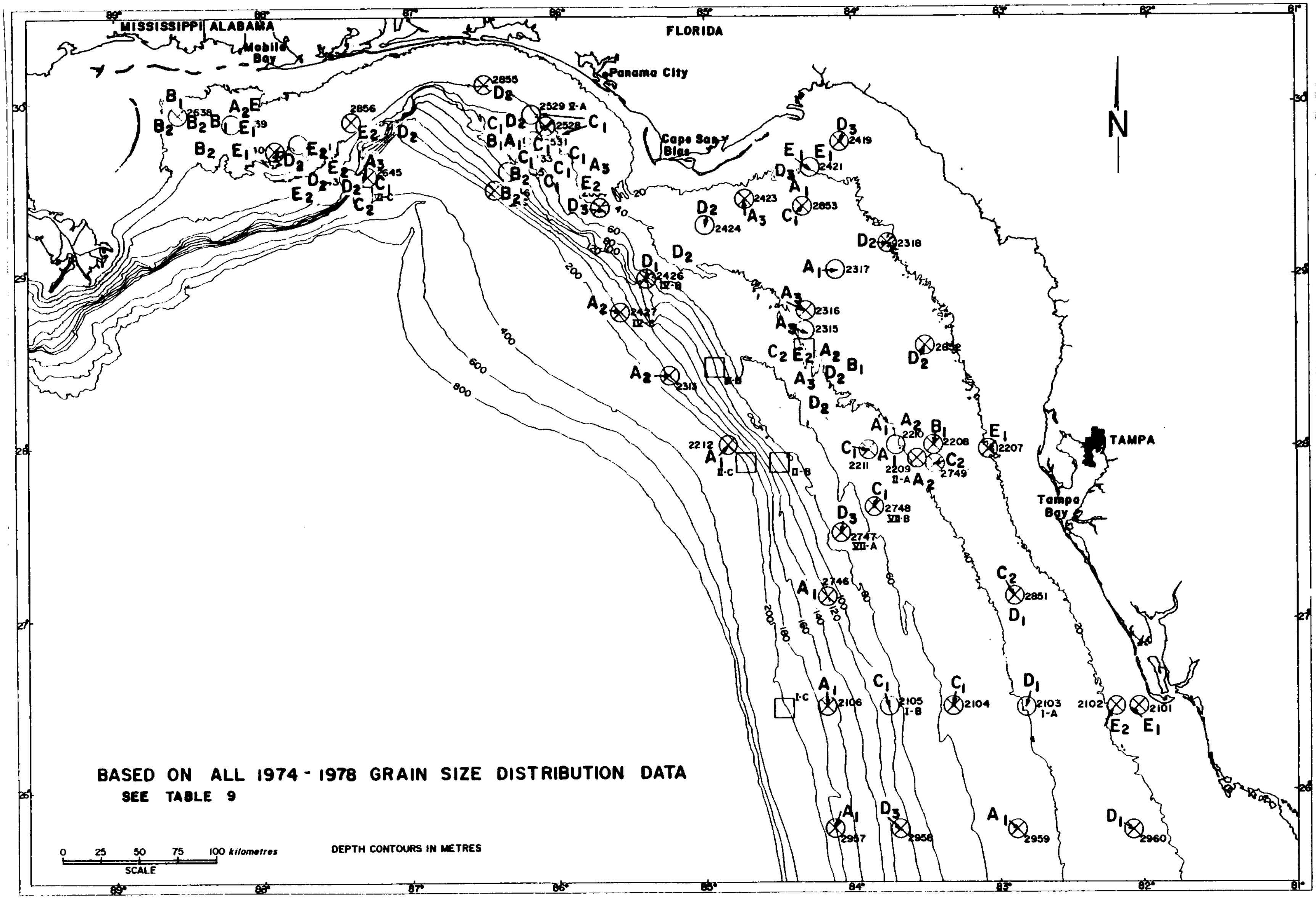


FIGURE 13

BOTTOM SEDIMENT GRAIN SIZE CLUSTERING: CLUSTERS A_1 - E_2

TABLE 9

GRAND STATION MEANS FOR GRAIN SIZE PARAMETERS OF 12 CLUSTER GROUPS (SHOWN IN FIGURE 13)

CLUSTER GROUP	MEAN PHI	% SAND	SAND: FINE RATIO	GEOLOGIC CLASSIFICATION OF SEDIMENT TYPE	% $CaCO_3$*
A_1	3.38	71.65	2.9	Silty, very fine sand	90.8
A_2	4.19	59.37	1.5	Clayey, sandy silt	83.4
A_3	2.18	71.80	5.1	Silty fine sand	73.7
B_1	5.08	39.21	0.7	Sandy silt	48.0
B_2	6.15	21.31	0.3	Clayey silt	52.3
C_1	0.88	83.63	17.9	Coarse sand	84.0
C_2	1.00	83.63	23.9	Medium-coarse sand	70.2
D_3	2.11	89.84	13.5	Fine sand	70.9
D_2	1.29	89.88	30.1	Medium sand	35.6
D_3	1.90	84.63	13.7	Medium-fine sand	64.7
E_1	2.98	87.75	10.0	Fine-very fine sand	40.4
E_2	2.29	93.50	34.2	Fine sand	14.5

*Note that these cluster groups are derived using only grain size distribution data from each replicate taken during all sampling seasons 1974-1978. $CaCO_3$ means given for comparative purposes only.

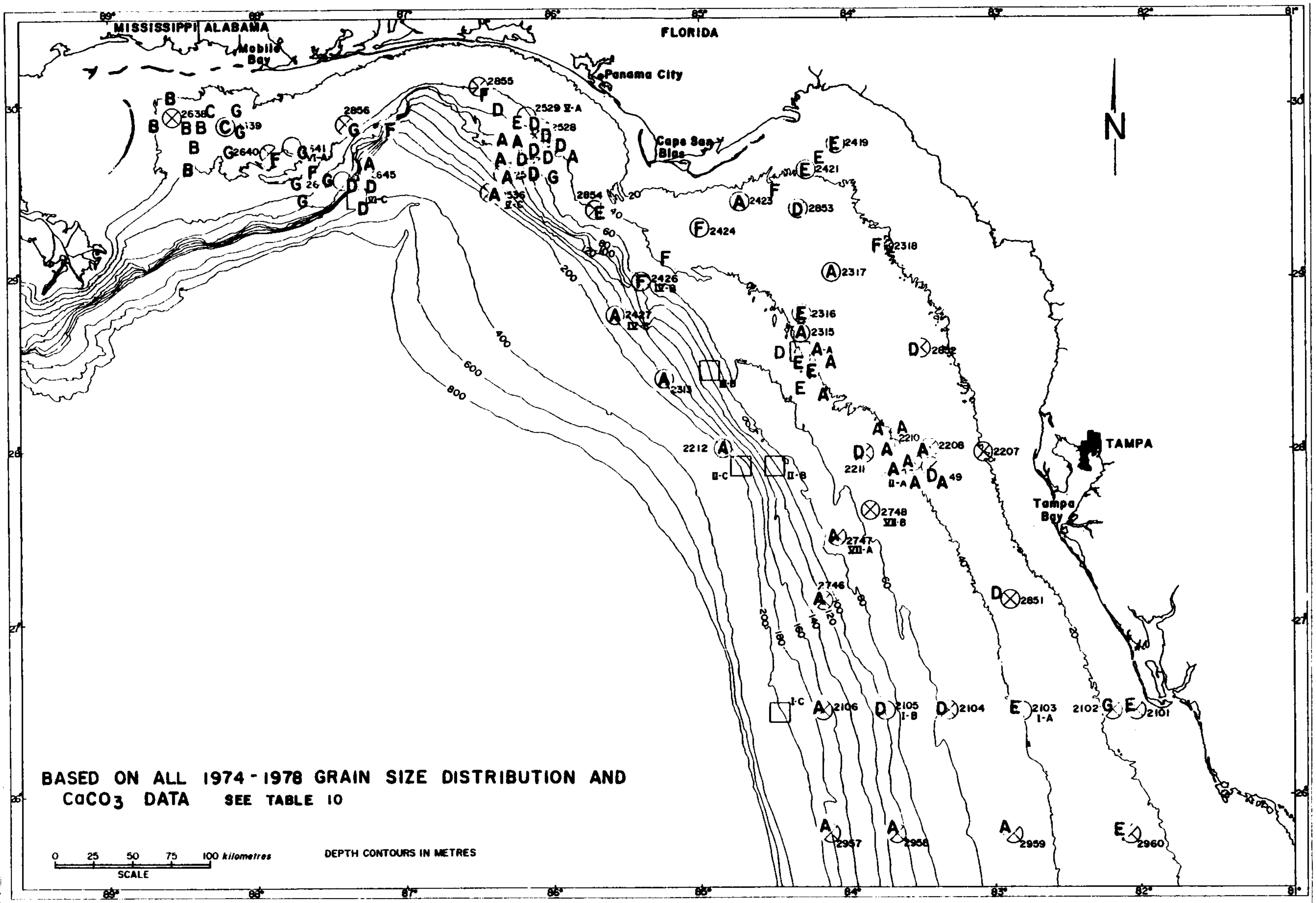


FIGURE 14

BOTTOM SEDIMENT GRAIN SIZE AND $CaCO_3$ CLUSTERS A-G

TABLE 10

GRAND STATION MEANS FOR GRAIN SIZE AND CARBONATE PARAMETERS OF 7 CLUSTER GROUPS (SHOWN IN FIGURE 14)

CLUSTER* GROUP	MEAN PHI	% SAND	SAND: FINE RATIO	% $CaCO_3$
A	3.81	59.42	2.19	81.1
B	6.06	24.88	0.36	14.5
C	4.29	64.40	1.97	18.2
D	0.92	84.22	18.35	78.3
E	2.28	88.91	13.24	62.0
F	1.34	90.51	31.73	22.0
G	2.57	91.05	26.66	13.8

*Note that these cluster groups are derived using both grain size distribution and carbonate content data from each replicate taken during all sampling seasons 1974-1978.

described both qualitatively and statistically for considerations of environmental monitoring and for use in analyses of chemical and biological data from the MAFLA program.

Variabilities in the sedimentary data arise from not only natural interstation and intrastation (replicate) variability, but also from geographic differences, sampling and measuring accuracy and precision, and temporal changes. Statistical and qualitative evaluations of the geological data set have been made during the course of this program to assess variability from all sources.

Statistical methods are discussed in the Methods and in Volume II, Chapter 29. Standard analyses of "outlier" data points were done to identify data points that statistically do not represent the set of samples with which they were collected, and many have a misleading influence on later analyses. Those were checked for recording errors and against local geographic position before continuing with statistical analyses.

Intrastation Variability

Geographic scatter of sample points at stations were examined using the navigation post plots. For example, Station 2316 data had three outlier replicates and exhibited changes in cluster group between three seasonal samplings. The areal variability of replicate sample locations is shown on Figure 15 along with one grain size parameter (percent sand and gravel). The maximum distance between all season samples is less than 600 m. This suggests that this station, at Middle Ground reef, does indeed have statistically significant, very small-scale, areal variability not related to sampling scatter, but to the patchiness of sediments at that station.

Similarly, Station 2207 was assigned to a different cluster group in the fall 77 (DM II) sampling than in the summer 77 sampling. Examination of the navigation plot (Figure 16) comparing DM II sample position with DM I shows the geographic difference to be only about 200 m at this nearshore (20 m depth) station. Thus the seasonal change in sediment character at that station can be concluded to be real, not an artifact of sampling error.

Geographic Variability

Intrastation, interstation, intertransect, and temporal variation have been statistically evaluated using various multivariate analyses. The primary technique is principal component analysis (PCA), which assesses a data matrix for the major combinations of parameters that account for the largest amounts of similarity between samples. A single dimensionless number is calculated for the combination of parameters which account for the majority of variation (dissimilarity or negative similarity) between samples of the data set. PCA uses all data parameters in each sample simultaneously in calculating a component's "similarity indices." These indices are on linear scales, hence the most significant two or three can be plotted against each other in two-dimensional graphs. In most instances of natural science data the first two principal components will account for the majority of the variation between samples. Similarity among objects is then displayed by proximity of points (see Volume II, Chapter 29).

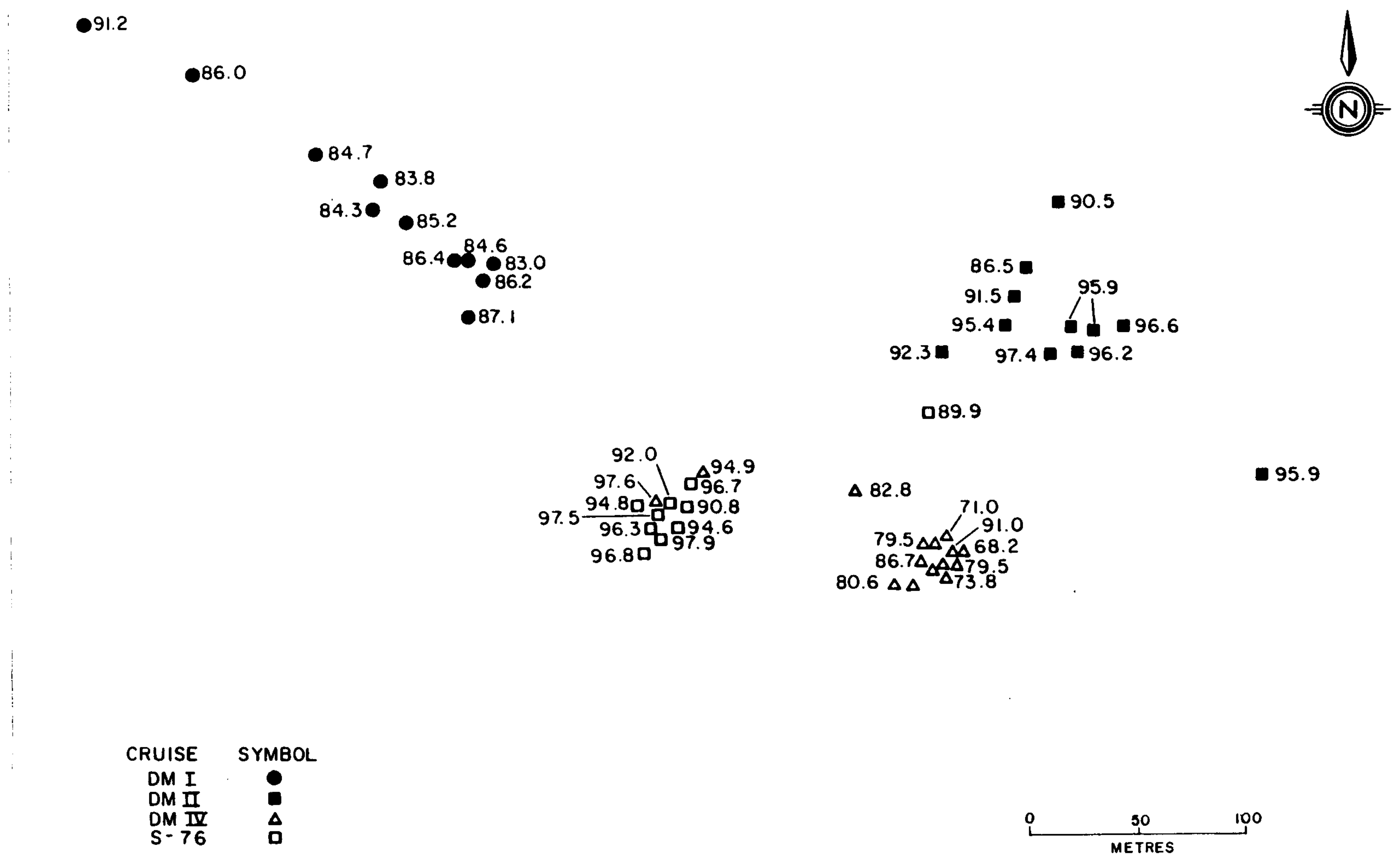
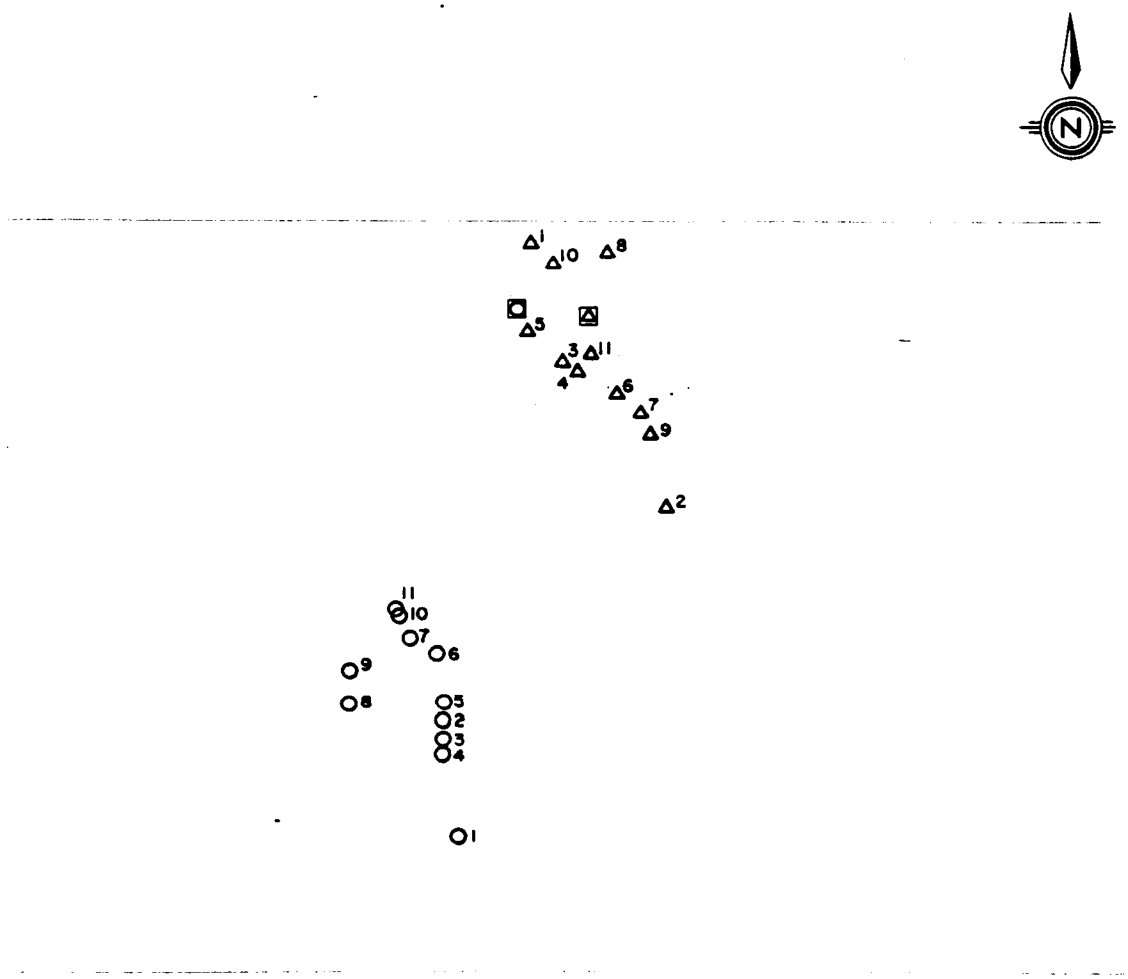


FIGURE 15

STATION 2316

RELATIVE LOCATION OF REPLICATES AND PERCENT SAND AND GRAVEL



LEGEND

CRUISE	BUOY SYMBOL	APPROX DEPTH	LATITUDE DEG. MIN. SEC.			LONGITUDE DEG. MIN. SEC.			REPLICATES
DM I	▣	21m	27	56	53	83	9	1	O6
DM II	◬	17m	27	57	0	83	8	58	Δ2

MAP SCALE = 1 : 3000

0 50 100
METRES

FIGURE 16

BUOY AND BOX-CORE POSITIONS STATION 2207

Intrastation variability is examined on such a graph for Stations 2207, 2208, 2209, and 2211 in Figure 17. This is a canonical analysis plot showing the centroid and scatter of individual samples for all fall 77 (DM II) replicates on this transect. It is evident that for this cruise each of these stations was dissimilar and that Station 2207 had relatively large intrastation variability. These observations are consistent with data from a series of closely spaced samples near Transect II reported on by Doyle (in SUSIO, 1977). Note that envelopes may be drawn around the station centroid and field of replictes to depict the station's variability and degree of overlap in similarity with other sample sets.

Geographical and seasonal variability are displayed in a canonical plot for Stations 2957, 2958, 2959, and 2960 in Figure 18. Envelopes of station variability for fall 77 (DM II) and winter 78 (DM IV) seasonal data permit the following conclusions regarding Transect IX:

a. The shallow inshore station (2960) is dissimilar from the three deeper ones. (Station 2960 falls in the West Florida Quartz Sand facies, while the others are in carbonate facies).

b. The three deeper stations are very similar to each other (refer to Figure 14) and exhibit negligible seasonal variation during this period.

c. Station 2960 shows a slight shift between seasons, as might be expected for a nearshore shallow water location.

Seasonal Variation in Cluster Groups

Variations between seasons in sediment texture cluster groups have been recorded at 8 of the 29 primary stations during the 1976-1978 interval. These stations are indicated on Figure 19. All of these stations showed a change in cluster group for fall 77 sampling and five of them returned to their summer 77 grouping in winter 78 (Table 11). This suggests a fall-season mechanism for sediment alteration during 1977. There was a tendency of stations between the 20 to 40 m isobaths to become coarser in fall 77. Seven of the eight stations are shallower than 40 m.

Two of the stations which exhibit this seasonality (2207, 2208) can be seen in a canonical analysis plot with other Transect II stations in Figure 20. Stations 2207 and 2208 show extreme departure in similarity measure between summer 77 and fall 77, then a return of essentially the antecedent plot in winter 78. The slightly deeper sister stations (2209, 2211) show negligible seasonality for this period. This canonical plot also illustrates extensive small scale geographic variability of the altered sediment at Station 2207 during the fall. Referring back to Figure 16 it can be seen that the replicate sample locations at Station 2207 were not geographically displaced in fall 77 (DM II), so that these observations are not artifacts of sample collection.

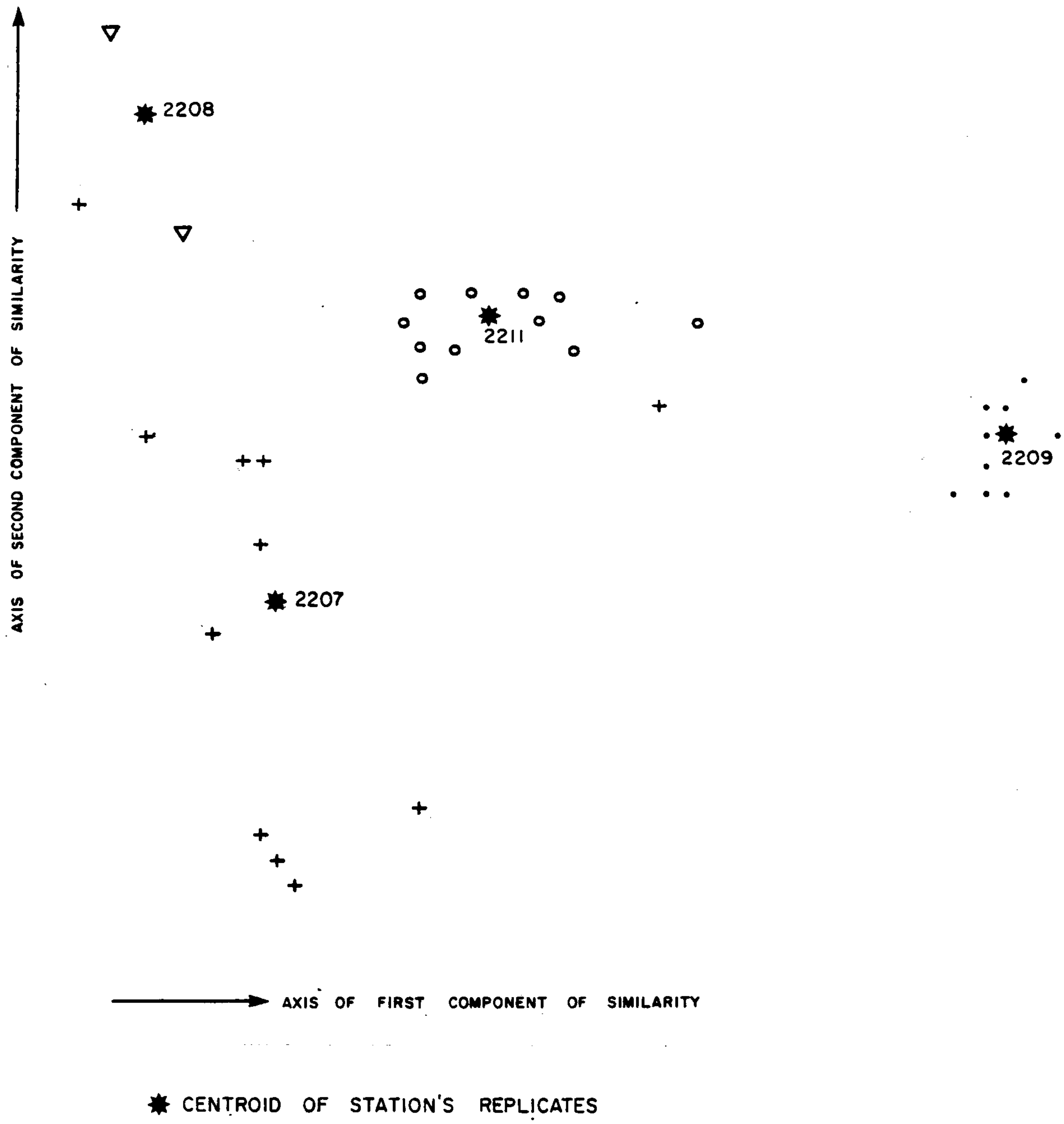
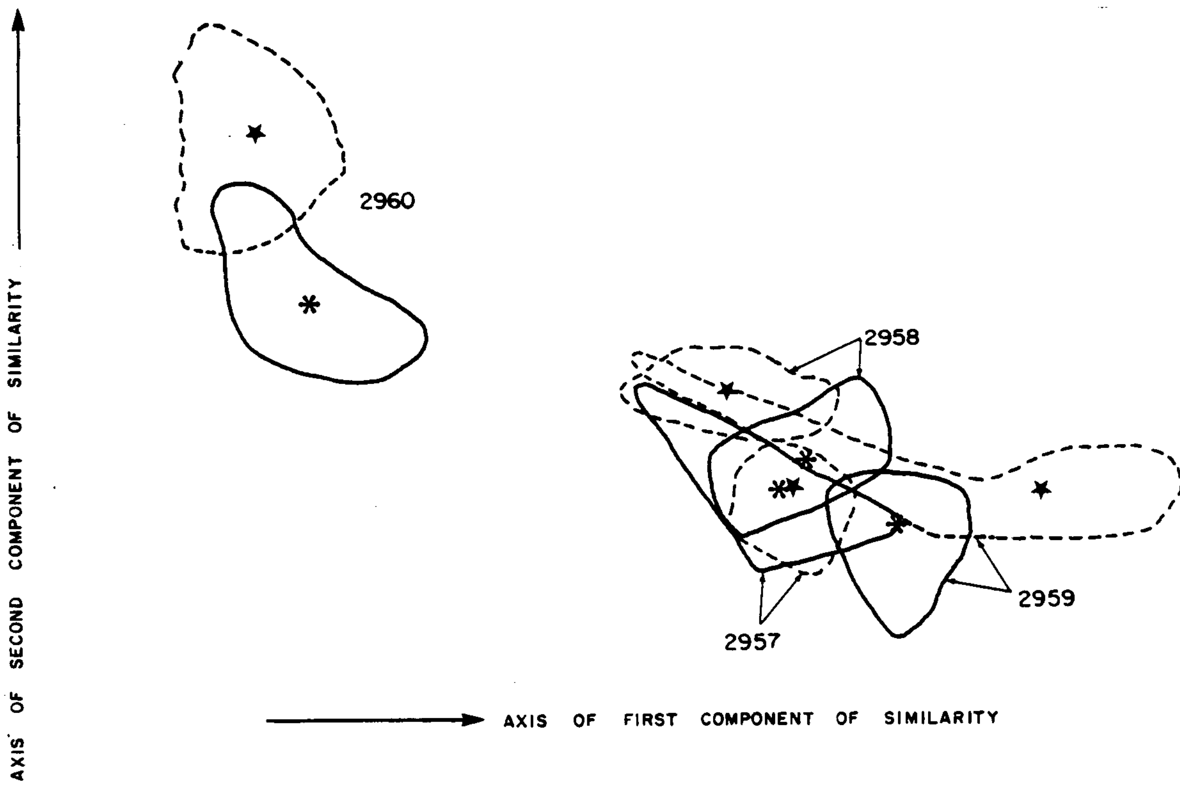


FIGURE 17

CANONICAL ANALYSIS PLOT

FALL 1977 DM II

SEDIMENT SAMPLE REPLICATES STATIONS 2207, 2208, 2209, 2211



* FALL 1977 (DM II) CENTROID AND ENVELOPE FOR STATION
✶ WINTER 1978 (DM IV) CENTROID AND ENVELOPE FOR STATION

FIGURE 18

CANONICAL ANALYSIS PLOT
TRANSECT IX STATIONS
GRAIN SIZE PARAMETERS

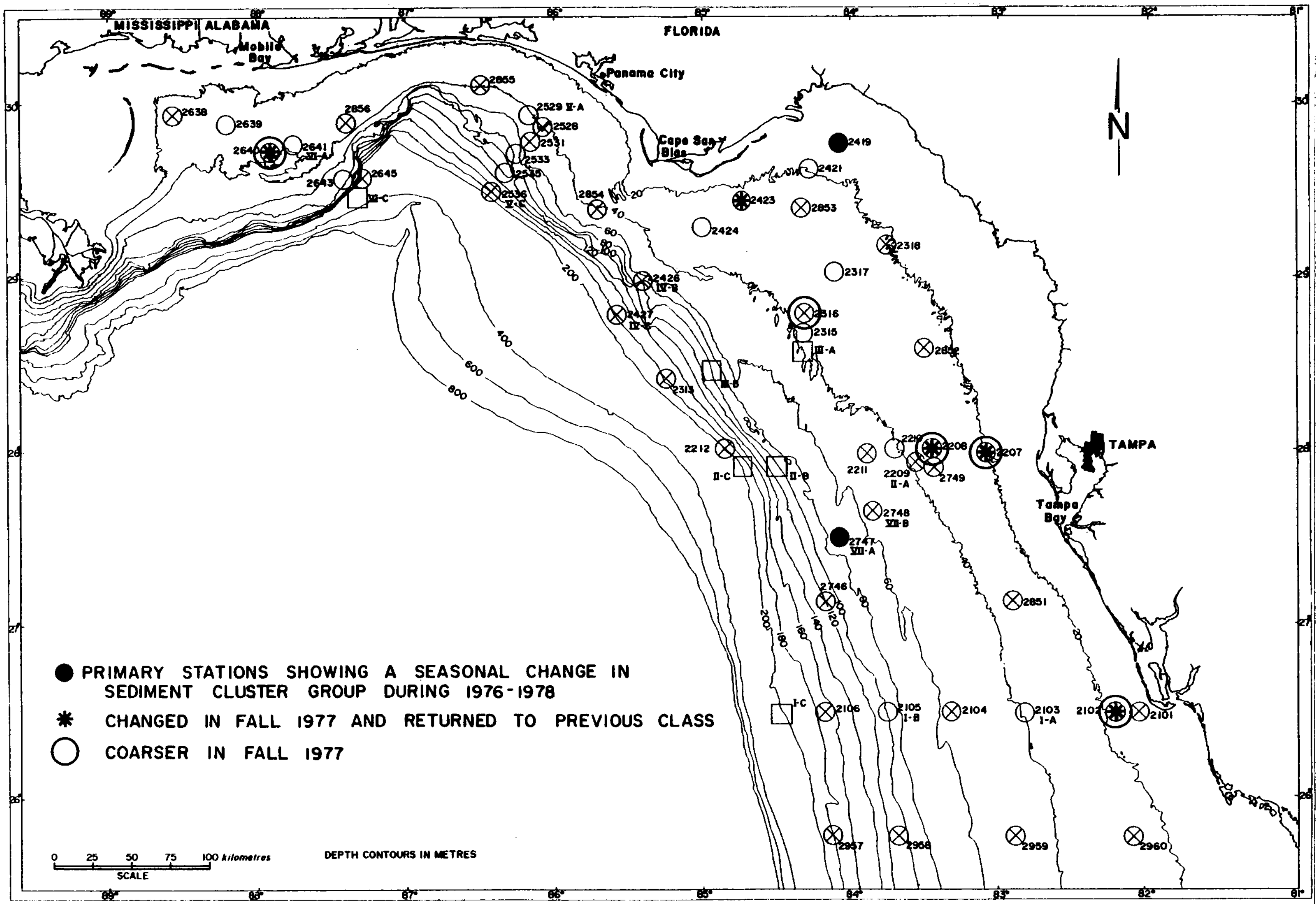


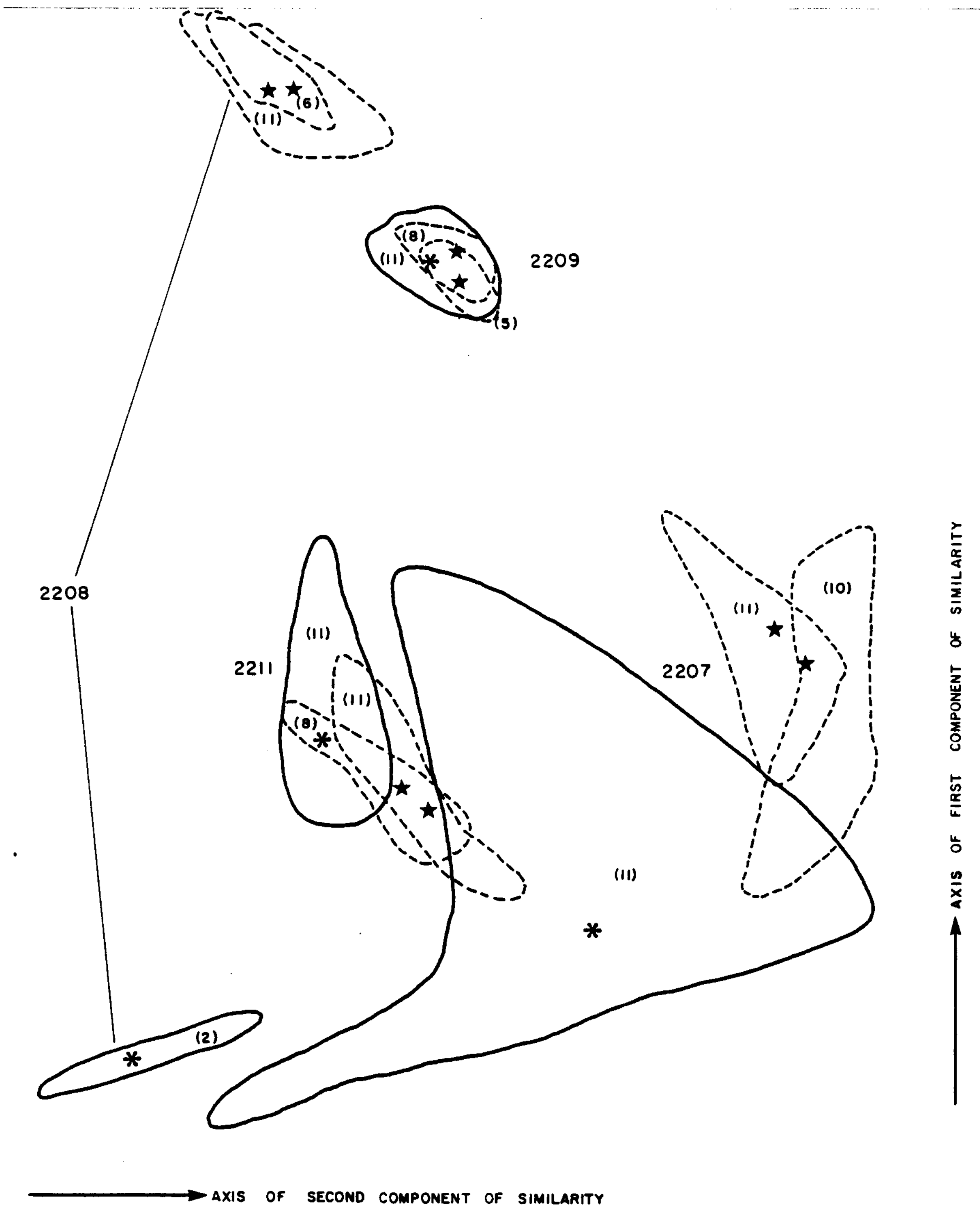
FIGURE 19

VARIATION BETWEEN SEASONS IN SEDIMENT CLUSTER GROUP

TABLE 11

VARIATIONS BETWEEN SEASONS IN CLUSTER GROUPINGS OF PRIMARY STATIONS, 1976-1978

STATION	SUMMER 76 CLUSTER GROUP	SUMMER 76 MEAN PHI	SUMMER 77 CLUSTER GROUP	SUMMER 77 MEAN PHI	FALL 77 CLUSTER GROUP	FALL 77 MEAN PHI	WINTER 78 CLUSTER GROUP	WINTER 78 MEAN PHI
2102	F	2.47	F	2.25	E	1.79	F	2.47
2207	B	3.03	B	3.01	D	2.00	B	3.08
2208	A	4.66		4.70	C	1.05	A	4.65
2316	C	0.89	B	2.88	D	1.57	D	2.58
2419	-	-	E	1.62	B	2.70	C	1.17
2423	C	0.85	C	1.08	D	2.23	C	1.19
2640	D	1.72	C	1.20	E	1.07	C	0.59
2747	C	1.75	C	1.37	D	2.86	D	3.62



✱ FALL 1977 (DM II) CENTROID AND ENVELOPE FOR STATION
★ SUMMER 1977 (DM I) CENTROID AND ENVELOPE FOR STATION
WINTER 1978 (DM IV) CENTROID AND ENVELOPE FOR STATION
(11) NUMBER OF REPLICATES OF SEDIMENT SAMPLES

FIGURE 20

CANONICAL ANALYSIS PLOT
TRANSECT II STATIONS

In explanation of these observations, it should be noted that the relatively short and limited Gulf fetch, coupled with the concave shape of the MAFLA coastline has lead to the area being considered low-energy hydraulic region. Observations of sand waves reported on the shelf (Doyle, Volume II, Chapter 2) argue for some strong, although probably intermittent, sediment transport mechanism, which belies a consistent low-energy region. It is postulated that observed seasonal changes in sediment texture are evidence of the effects of tropical storms (Anita and Babe) which occurred at the end of DM I. The apparent differences between coarser or finer sediment means may result from overall patterns of sediment redistribution during these storms. There appears to be scouring and winnowing in the shallow stations to the south, and deposition of finer material both in the embayment east of Cape San Blas and in deeper water offshore of the scoured area.

Benthic Clay Mineralogy Variation

Changes in clay mineralogy between summer 76 and fall 77 in the MAFLA area are described by Doyle (Volume II, Chapter 2). Kaolinite values from this investigation are somewhat lower, and smectite correspondingly higher, than those reported by Huang et al. (1975) and by Huang (1977). This suggestion of variability in the benthic clay mineral suite is reinforced by apparent changes in relative percentages of smectite and kaolinite between summer 76, and fall 77, shown in Figures 21 and 22, respectively. Over most of the shelf, smectite decreased dramatically and regularly toward shore while kaolinite increased in relative amounts toward shore.

Significant temporal variation in relative amounts of clay minerals in the benthic sediments over a period as short as one year, to our knowledge has never before been reported. Since clay mineralogy analysis is a semi-quantitative method, differences in measurements must be judged conservatively, especially when conducted in different laboratories. However, factors support the veracity of the relative differences over the time period shown in Figures 21 and 22. Analyses for summer 76 and fall 77, samples were done in the same laboratory by the same personnel during a relatively short period measured in months. Secondly, variations are neither random nor are they larger or smaller by a constant amount. They increase or decrease regularly toward shore, strongly supporting the reality of this trend.

Seasonal or annual variation in kaolinite/smectite ratios on the West Florida Shelf is attributed by Doyle (Volume II, Chapter 2) to the result of varying influence of Mississippi River water, and to the Loop Current which occasionally intrudes upon the area. Since the shelf floor is subject to severe winnowing during major storms, recent shallow water smectite deposits may be short-lived within the MAFLA area.

This phenomenon of short term changes in clay minerals could provide a mechanism for redistribution of trace metals associated with clay minerals. It also suggests that sediment trace metal monitoring should take into account the mineralogy of the clay fraction in at least these shallow, apparently mobile zones, which exhibit clay mineral change.

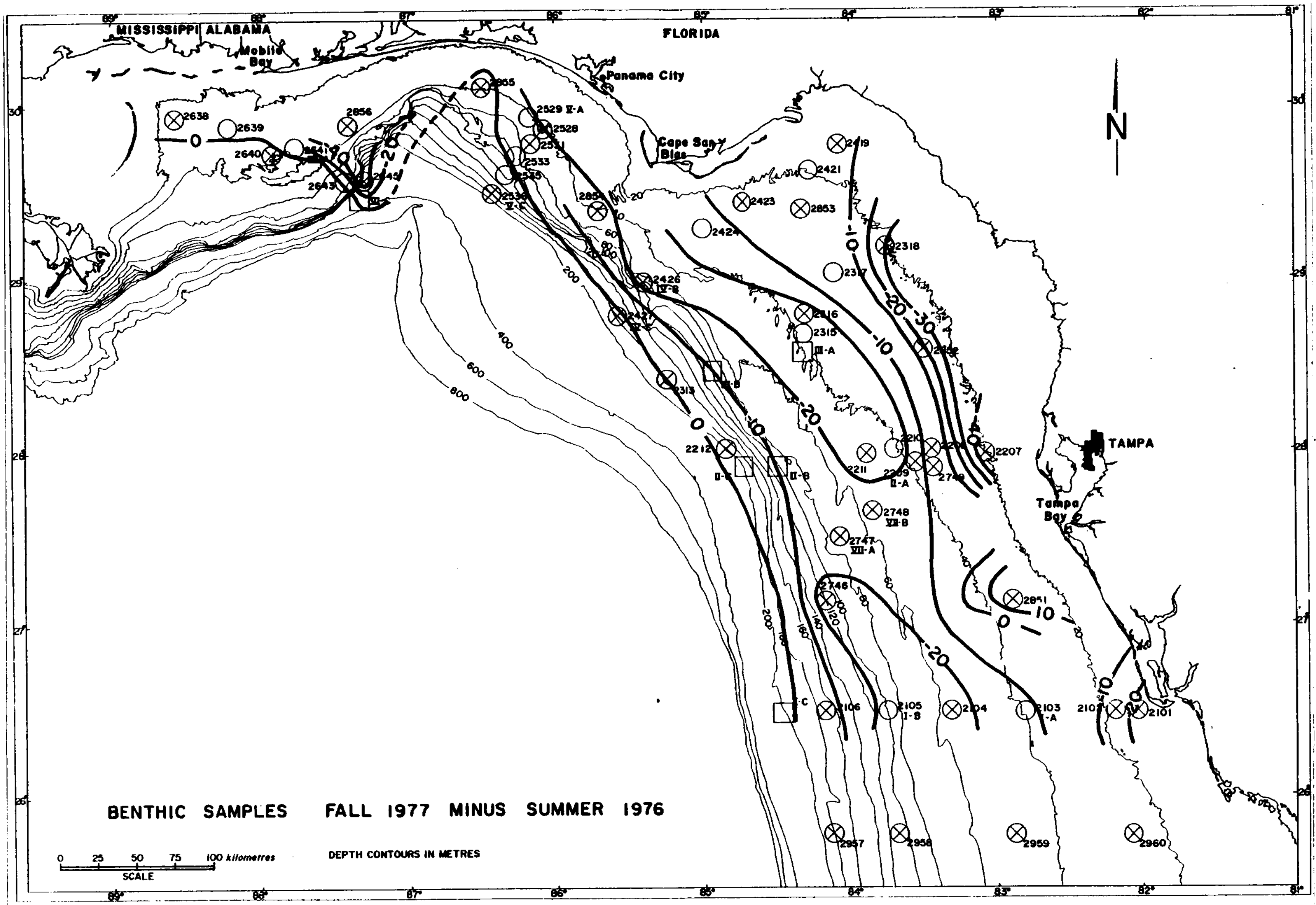


FIGURE 21

PERCENT DIFFERENCES IN SMECTITE

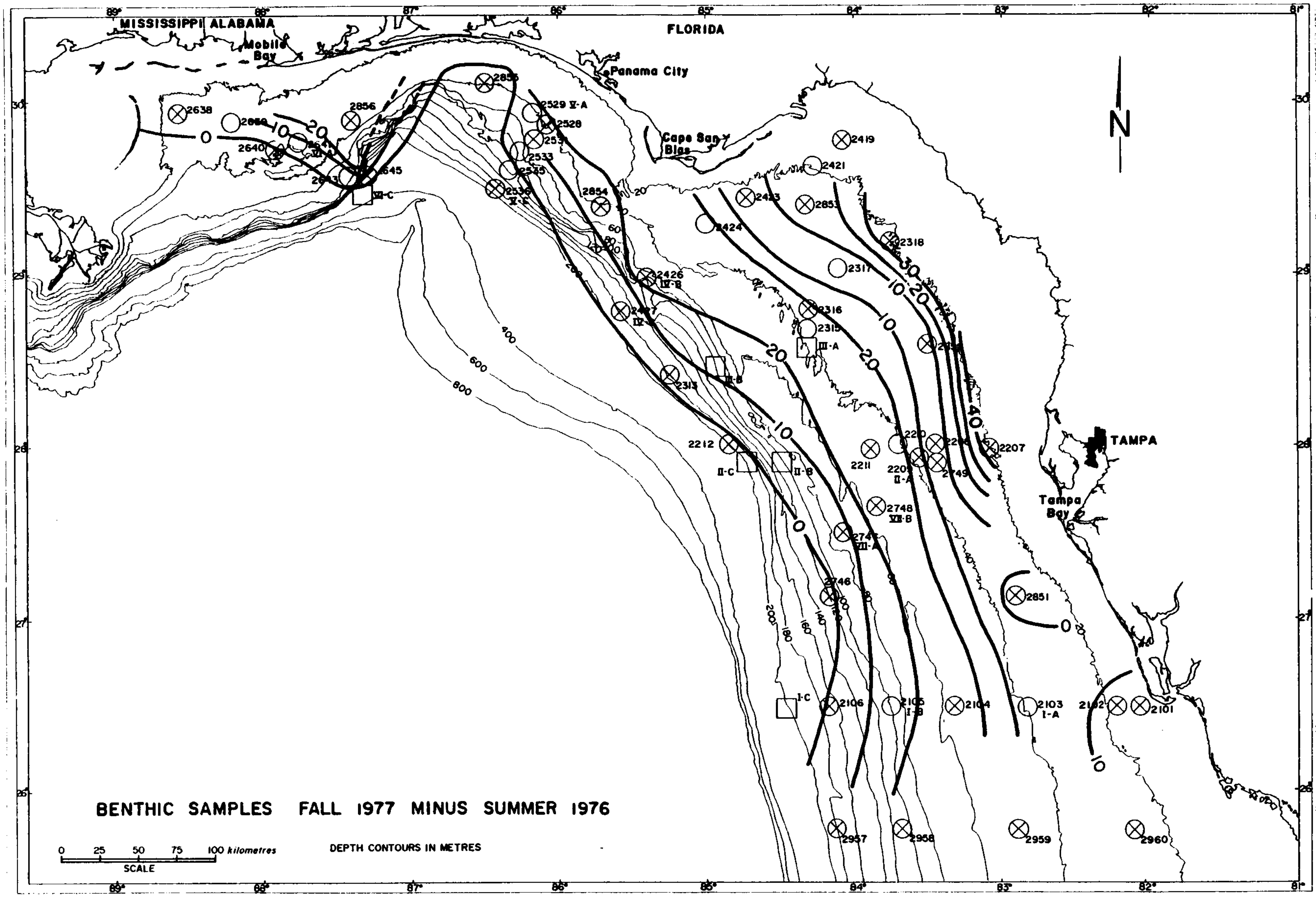


FIGURE 22

PERCENT DIFFERENCES IN KAOLINITE

RESULTS AND DISCUSSION: PHYSICAL OCEANOGRAPHY

FUNCTION OF THE PHYSICAL OCEANOGRAPHY WORK ELEMENT

The studies of salinity, temperature, density, and light penetraton in the water column had two general purposes in the 1977/78 MAFLA program:

- To provide a regional description of the eastern Gulf of Mexico continental shelf water mass, and
- To support other water column and benthic measurements by providing information on conditions at the collection sites.

With only a four station array for limited time-series measurements, and with no current measurements, the first function was satisfied only on a very general level. The second function, however, was vital to determining probable causes of variability in observed dependent variables of selected chemical and biological parameters.

We have included in this study an elucidation of water column structure, general circulation patterns during the study period, analyses of seasonal and short-term variability of physical parameters, and insofar as possible, have related these to forcing functions and to biological and chemical patterns. The emphasis in this summary oceanography section has been to generalize from the data set and to define prevailing patterns. A more complete discussion can be found in the PIs' final reports (Volume II, Chapters 20 and 21).

SOURCE MATERIALS

Previous Investigations

The Gulf of Mexico has been the subject of a number of comprehensive oceanographic studies that have included descriptions of the physical, chemical, and biological environment of the eastern Gulf. The U.S. Department of the Interior, Fish and Wildlife Service (1954) treated, among other topics, the tidal regime, physical oceanography, light penetration and chemical properties of Gulf waters. Capurro and Reid (1972) edited a compendium of works on the physical oceanography of the Gulf, including several studies of the Loop Current. SUSIO (1973) prepared a summary of knowledge of the eastern Gulf of Mexico which was a selective compilation and evaluation of the natural and socioeconomic characteristics of the area. SUSIO (1975) expanded on that compendium with a compilation and summation of historical and existing physical oceanographic data, prepared for BLM in anticipation of the creation of a MAFLA studies program. SUSIO (1977) submitted to BLM the final report for the 1975/76 MAFLA OCS study program; that report is the earlier analog of this report. Much of this information was abstracted by U.S. Department of the Interior, Bureau of Land Management (1978) in the Final Environmental Impact Statement for the proposed OCS sale #65 in the MAFLA area.

A number of more specific studies of the Loop Current, water mass characteristics, and general circulation in the Gulf have been made, and are referenced in the PIs' reports, specifically those of Fausak (Voulme II, Chapter 20) and Carder (Volume II, Chapter 21).

MAFLA OCS DAta Base, 1974-1978

The MAFLA OCS physical oceanography studies program was begun in 1974 and has continued up to, and evolved into, the present contract. The studies that have taken place between 1974 and 1976 have been described in Table 2 (above). That table lists the BLM supported cruises and their functions. Much of the data resulting from the earlier programs have been incorporated into the qualitative and quantitative analyses undertaken here. Additions to the existing data base from the current 1977/78 program for physical oceanographic parameters have included 314 STD profiles, 282 transmissometer profiles, 41 underwater irradiameter profiles, and 850 near surface and near bottom pairs of salinity samples and reversing thermometer temperatures.

OCEANOGRAPHIC SETTING

Location and Basin Morphology

The Gulf of Mexico is a restricted oceanic basin with maximum depths exceeding 3600 m, and having connections to adjacent seas only to the Caribbean via the Yucatan Straits, and to the western Atlantic Ocean via the Florida Straits (Figure 23). The deeper parts of the basin form a bathymetric depression enclosed by a sill depth in the Yucatan Strait of about 2000 m and a sill depth in the Florida Strait of less than 900 m. Broad continental shelves are found along the eastern margin (the West Florida Shelf), northwestern margin (the Texas-Louisiana Shelf), and southern margin (the Campeche Shelf). The area of principal interest in the MAFLA OCS study program lies inshore of the 200 m isobath on the broad West Florida Shelf and the narrow Mississippi-Alabama Shelf. The general bathymetry of the MAFLA shelf area has been shown on Figure 1 in the Introduction.

Circulation Patterns

The circulation of the eastern Gulf of Mexico has been the subject of numerous investigations (Leipper, 1954; Austin, 1955; Chew, 1955; Ichiye, 1962; Leipper, 1970; Nowlin, 1972; Cochran, 1972; Leipper, Cochrane, and Hewitt, 1972; Nowlin and Hubertz, 1972; Ichiye et al., 1973; Morrison and Nowlin, 1977; Maul, 1977; Molinori et al., 1977; Behringer et al., 1977). The general character of the dominant circulation component, the anticyclonic (clockwise) Loop Current, has been well documented and is now understood to be a permanent feature. It enters the Gulf through the Yucatan Strait, progressing north or northwestward for some distance before turning east and then southward and finally exiting through the Florida Strait. There it merges with and comprises a large part of the Gulf Stream. Few direct measurements of current velocity have been made; most of the existing knowledge results from assumptions of geostrophic balance and from

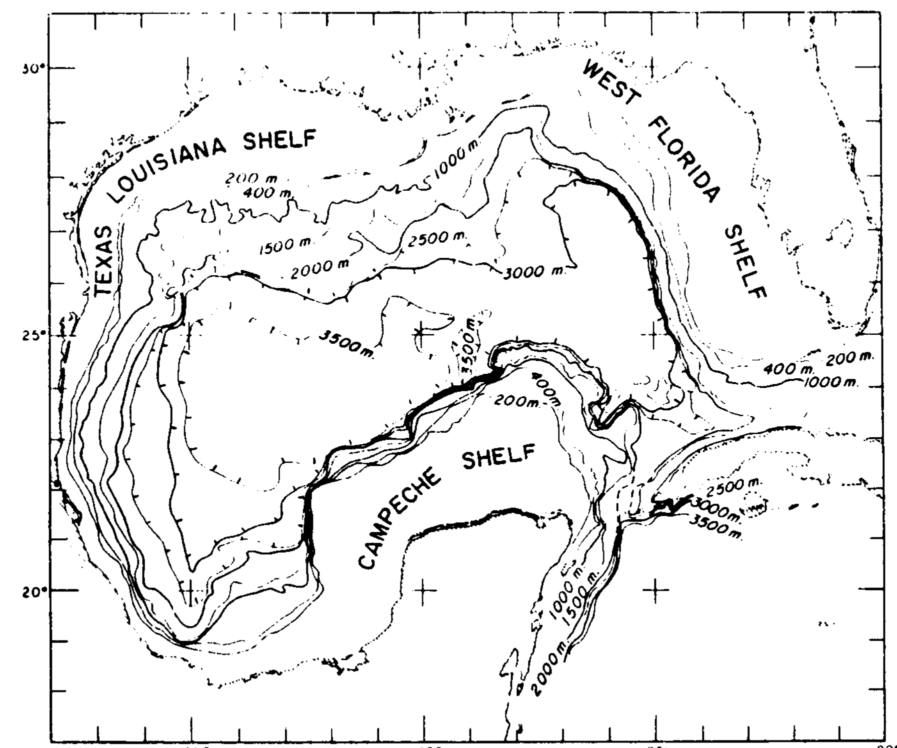


FIGURE 23

BATHYMETRY OF THE GULF OF MEXICO

(AFTER NOWLIN, 1971)

dynamic computations based on salinity and temperature data. The northernmost intrusion of the Loop Current occurs most often in the summer months, but significant intrusions have recently been shown to occur in other seasons (see Volume II, Chapter 20). The forcing function that drives the Loop Current is not understood; the ability to predict deep water intrusions into the eastern Gulf of Mexico is correspondingly poor. The importance to the present study of Loop Current intrusions lies in its transport of warmer, more saline water into the eastern Gulf, and in its influence on shelf circulation and transport patterns.

The circulation patterns of the shelf, which are of more direct interest to the intended users of this report, have received a great deal less attention than have studies of the Loop Current. The complexity of the problem contributes in large part to the lack of information: shelf water circulation results from many inputs, including intrusion of Loop Current, meanders or migration of detached eddies from the Loop Current, from atmospheric disturbances such as seasonal wind changes or the passage of storm systems, from tidal forces, and from horizontal pressure gradients resulting from river runoff. Of particular interest, therefore, is the report by Mooers and Price (1975) of current measurements made at several stations along 26°N latitude during February-March 1973 and October-December 1973 (26°N lies immediately north of Transect IX of this study). They report currents flowing generally parallel to the isobaths in a system of currents and opposed undercurrents (Figure 24); velocities attained a maximum value of about 12 $cm \cdot s^{-1}$. Mooers and Price further report that computed energy spectra of the long period fluctuating flows show periods of from 5 to 20 d; no casual mechanism is suggested. Other information sources, largely empirical (including satellite imagery) suggest a persistent cyclonic eddy lying between the anticyclonic Loop Current and the shoreline; flow variations with depth, areal location, and time remain undefined. Currents on the western part of the Mississippi-Alabama Shelf could be expected to show greater current variability because of the influence (presumably long-period) of river inflow from the Mississippi River and the Mobile Bay and Mississippi Sound systems.

Tides

Changes in tidal elevation and tidal currents are of interest in this study insofar as they provide mechanisms for resuspension and transport of bottom material, biological and chemical species. Several points are worth noting.

- Ranges of tides are small in the Gulf, with maximum amplitude of about 70 cm.
- Tidal current velocity measurements are very sparse; Mooers and Price (1975) have reported tidal velocities of 5 to 20 $cm \cdot s^{-1}$ from their study at 26°N latitude.
- Astronomic tides can be completely masked by atmospheric tides; Mooers and Price (1975) have reported inertial motions induced by meteorological disturbances to have velocities of 10 to 30 $cm \cdot s^{-1}$ on the West Florida Shelf.

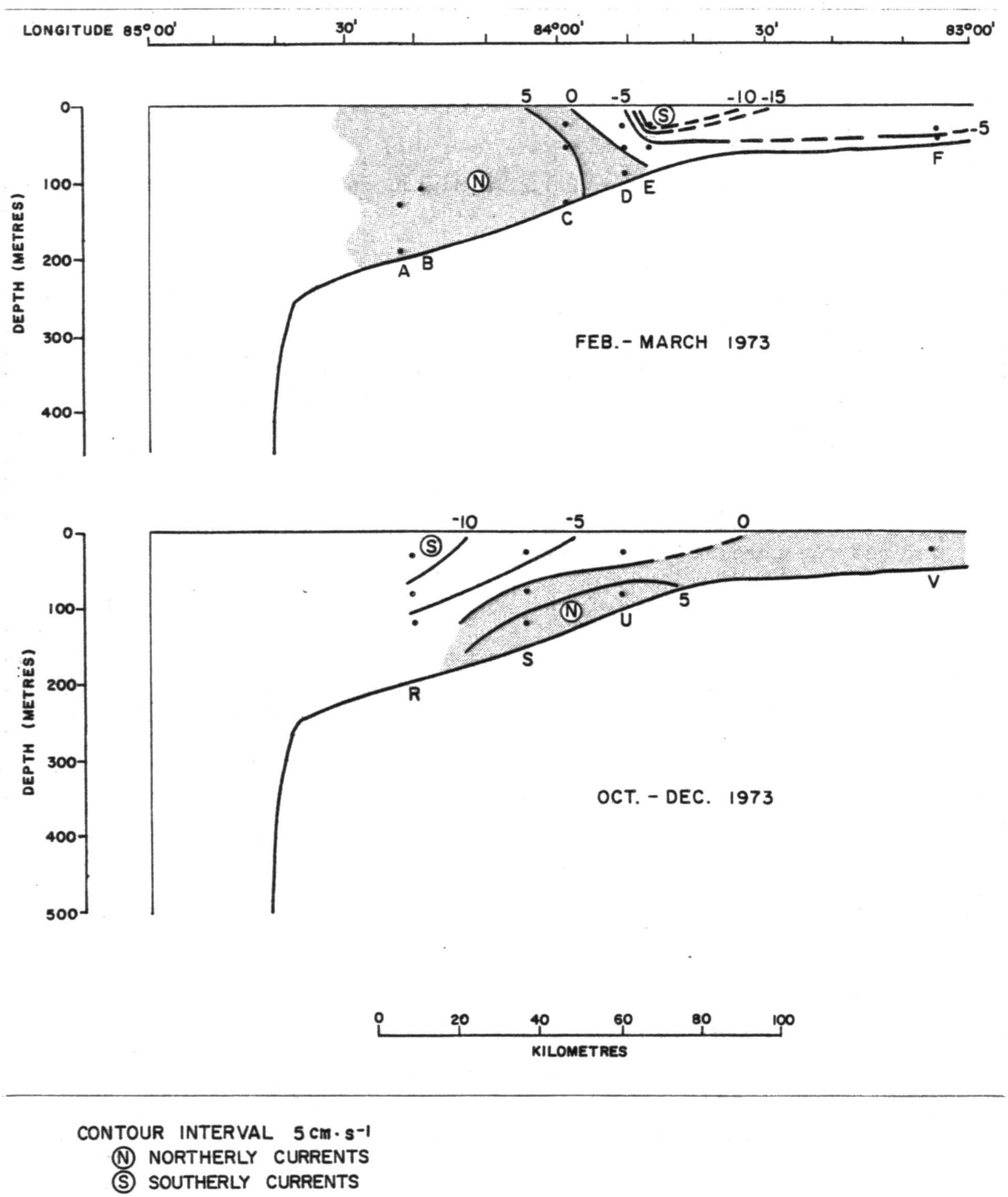


FIGURE 24

CROSS SECTIONS OF CURRENT VELOCITY ALONG 26° N, FEB.—MARCH 1973 AND OCT.— DEC. 1973

(AFTER MOOERS AND PRICE, 1975)

- Internal (or baroclinic) tides which propogate along sharp density gradients can be expected to occur on the outer edge of the shelf and may plan a significant role in horizontal dispersion.

Water Mass Descriptions

The water column in the Gulf of Mexico is a well stratified system composed of several layers of water, distinguished by characteristic maximum or minimum values, or steep gradients, of temperature, salinity, oxygen or other parameters. Figure 25 (from Nowlin, 1971) shows typical temperature (T), salinity (S), and oxygen curves and associated water masses. The surface mixed layer exhibits uniform characteristics and lies above steep gradients of T, S, density, and oxygen; the thickness of the mixed layer changes seasonally. The Subtropical Underwater (SUW) is recognized by a relative salinity maximum (attaining a value of about 36.75 $^{o}/oo$). Because the MAFLA OCS lies inshore of the 200 m isobath, these two layers are the only ones shown in Figure 25 which are of direct interest in this study. Figure 26 shows temperature, salinity, and sigma-t (relative density units) profiles for Station 2313 taken during the fall 77 MAFLA cruise; the uniform surface mixed layer extends to a depth of about 60 m; the salinity maximum that defines the core of the SUW is seen at about 95 m.

The optical character of the waters of the MAFLA area has received little attention prior to the BLM studies. In general, relatively high turbidity is found north and west of Cape San Blas while clearer water is found on the West Florida Shelf; shallow nearshore waters are more turbid than offshore waters. Transparency is particularly high in the core of the Loop Current, and decreases near the edges of the flow where shear turbulance and upwelling cause an increase in particle content.

RESULTS OF THE 1977/1978 STUDY

Areal Variations of Temperature, Salinity, and Optical Character

Horizontal gradients of temperature, salinity, and light transmission generally lie perpendicular to the isobaths, i.e., isopleths of those parameters, whether surface or subsurface, tend to follow the orientation of the coastline. The slope and direction of the gradient vary with the parameter, depth, season, and geographic location. Salinities are consistently greater at the outer ends of the transects for surface and bottom waters. Summertime temperatures are higher in shallow nearshore waters; wintertime temperatures on the other hand, are colder nearshore than offshore. Figures 27 and 28 show the temperature and salinity changes experienced at the bottom for the three benthic cruises undertaken during the 1977/78 program. The greatest range of both parameters occurs in nearshore waters. Contour plots of surface and bottom salinities and temperature are presented and discussed in Volume II, Chapter 20 of this report.

Figure 29 (from Volume II, Chapter 21) shows horizontal distribution of light attenuation coefficients (c_p) during the fall 77 cruise. The most turbid surface waters are found immediately west and south of Tampa Bay, while the clearest occur off the outer edge of the West Florida Shelf.

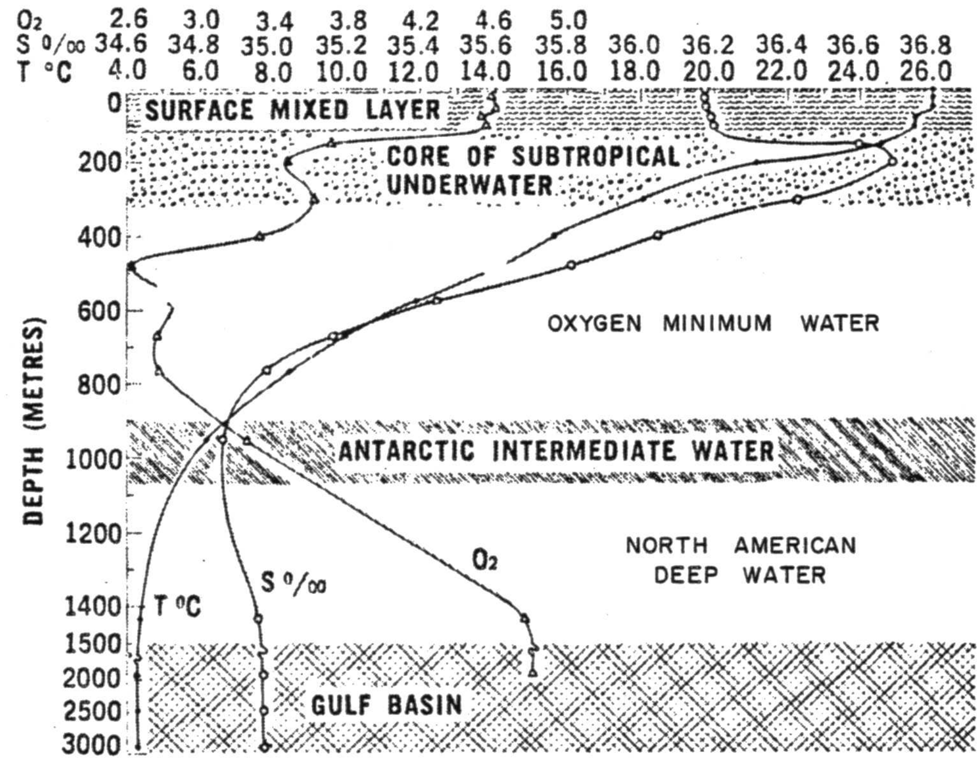


FIGURE 25

WATER MASS IDENTIFICATION IN THE GULF OF MEXICO THROUGH TEMPERATURE, SALINITY, AND OXYGEN PROFILES

(AFTER NOWLIN, 1971)

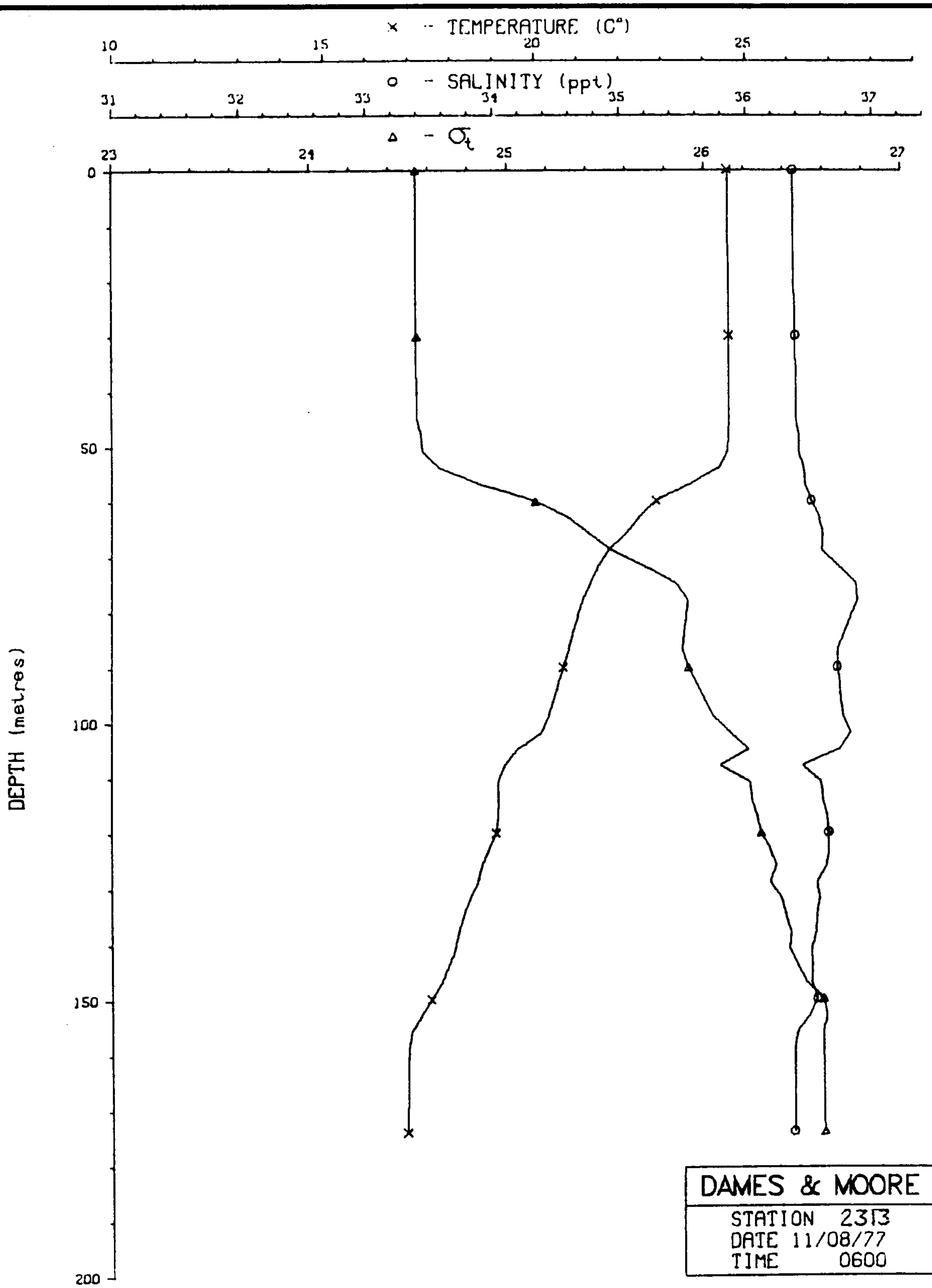


FIGURE 26

COMPUTER-PLOTTED CHARACTERISTIC PROFILES OF TEMPERATURE, SALINITY, AND DENSITY ON MAFLA OCS

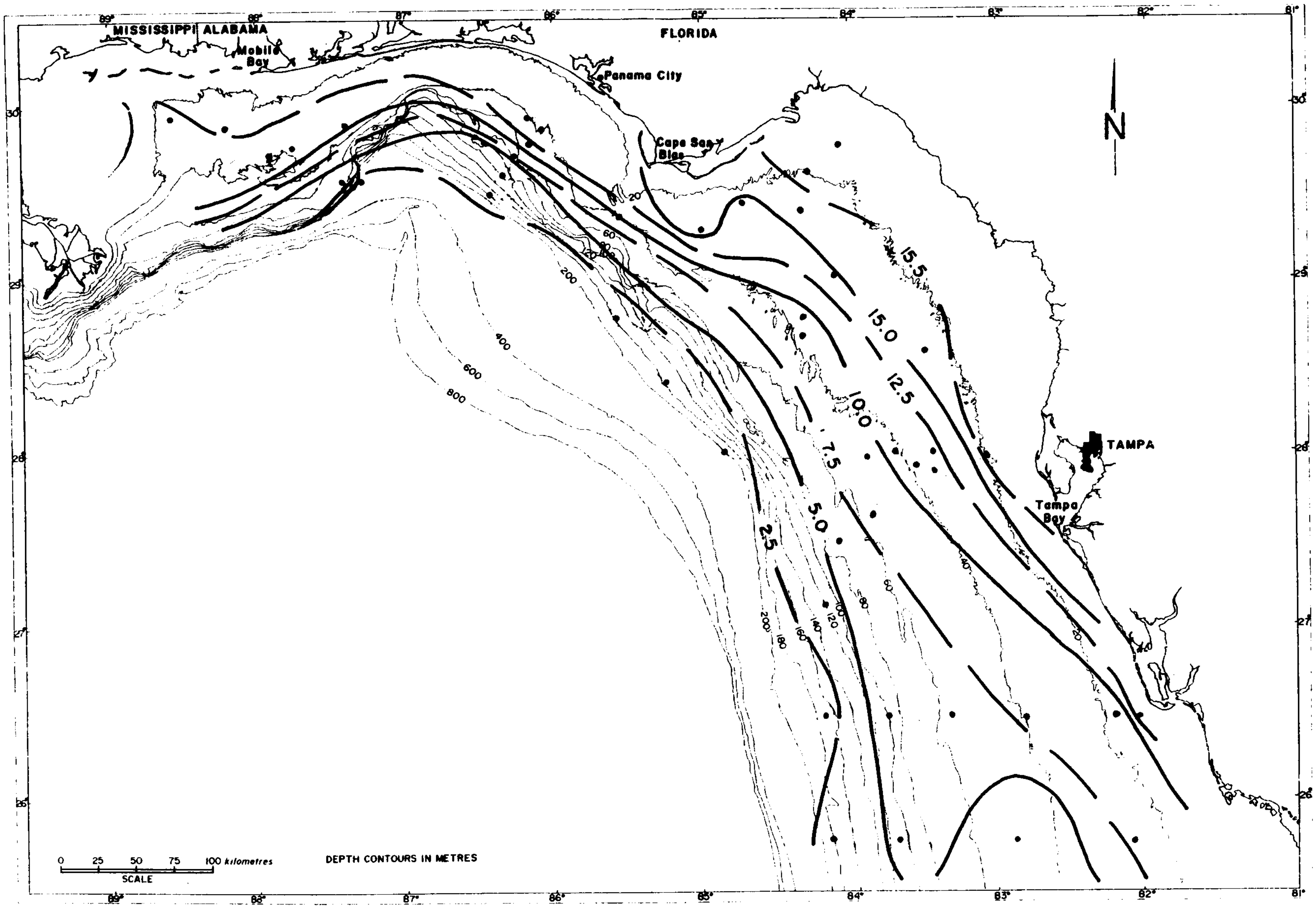


FIGURE 27

BOTTOM ΔT (C°) 1977/1978 CRUISES DM I, II, IV

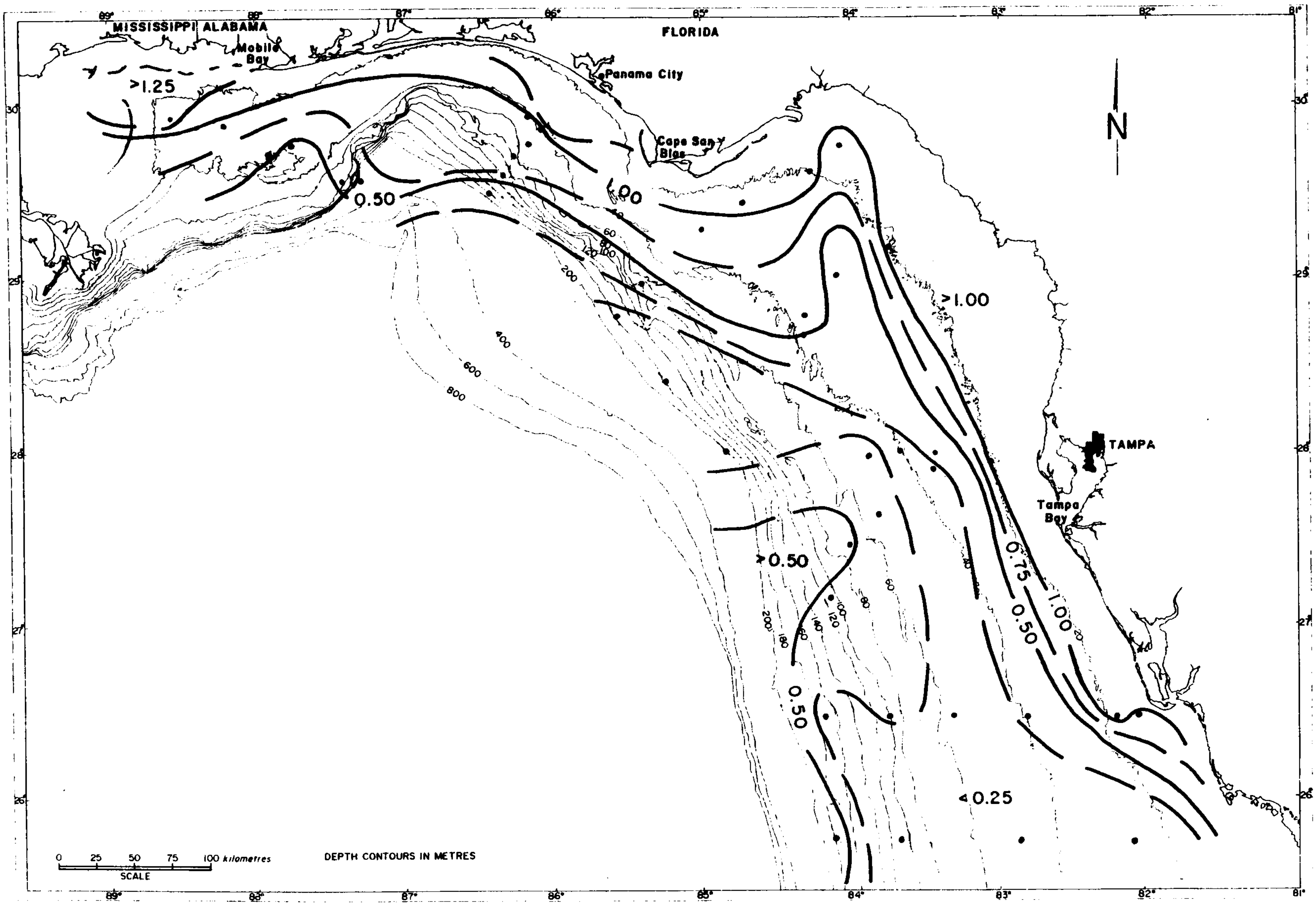


FIGURE 28
BOTTOM △S ‰ 1977/1978 CRUISE DM I, II, IV

Moderately turbid bottom waters are found nearshore off Mobile Bay and Tampa Bay; very turbid bottom waters occur on the southern end of the study area in the mid shelf regions. The moderate to highly turbid waters (i.e., those with high c_p values) are believed to result from erosion and resuspension of bottom materials; the casual mechanism for currents with sufficient speed to erode fine-grained sediments is not clear. Carder (Volume II, Chapter 21) suggests that the Loop Current is resuspending bottom materials, but current meter data presented by Mooers and Price (1975), and discussed earlier, show maximum current speeds of only 5-10 cm s^{-1} which are probably too low to erode bottom materials having 10-20% clays and silts. The areas of highest turbidity occur in the approximate vicinity of the intersection of the pycnocline and the shelf, suggesting that internal waves and/or baroclinic tides propogated along the density interface may also be important, perhaps acting in concert with the Loop Current.

Depth-dependent light-penetration data presented by Fausak (Volume II, Chapter 20) shows increasing light absorption from south to north with a progression from Station 2747 to 2315 to 2528 to 2639. That trend reflects two things: first, the effect of decreasing depth of water and attendent increase of wind-wave stirring of bottom materials, and secondly, the increasing proximity to sources of sediment particulates.

Depth-Dependent Variations

Examples of characteristic water column structure in the deeper parts of the MAFLA OCS have been shown earlier in Figure 26; those profiles illustrate the thermocline (temperature discontinuity), pycnocline (density discontinuity), and salinity maximum. The same temperature and salinity stratification can be seen in the second dimension on Figure 30, which shows cross-sections of T and S between the deep stations on Transects IX, I, II, III, IV, and V. The thermocline lies between 50 and 70 m with essentially isothermal water atop the thermocline. The halocline (salinity discontinuity) falls at roughly the same depth; the salinity maximum and the core of the Loop Current can also be seen. The thermocline becomes shallower during the summer months, and deeper during the winter because of greater mixing. In shallow waters, above the thermocline depth, the waters are essentially uniform in their temperature and salinity.

The depth-dependent variation in light transmissivity is very low at Stations 2747 and 2315, which generally show consistent values through the water column until very near the bottom, when the instrument enters the nepheloid layer. As will be shown with the temperature and salinity, when the transmissivity changes, it tends to do so throughout the water column. Some increasingly stronger gradients of transmissivity appear at Stations 2528 and 2639.

Temporal Variability

Some examples of long-term or seasonal variability have already been given, e.g., the change in stratification with season. Figures 31 and 32 show the seasonal range of surface and bottom temperature and salinity by transect. Surface temperatures (by transect) show greater variability

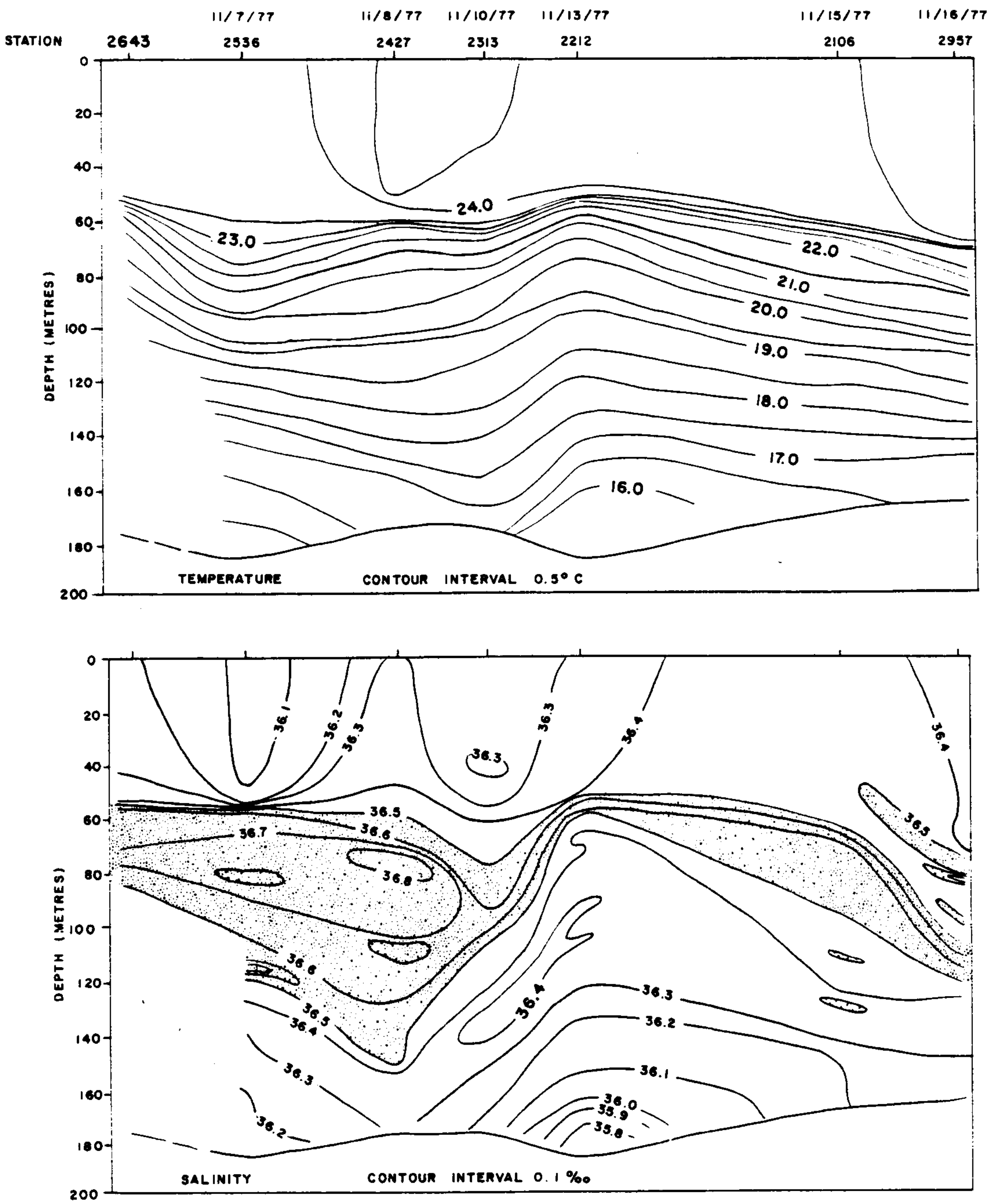


FIGURE 30

TEMPERATURE AND SALINITY CROSS SECTIONS BETWEEN OFFSHORE ENDS OF TRANSECTS, CRUISE DM II, NOVEMBER 1977

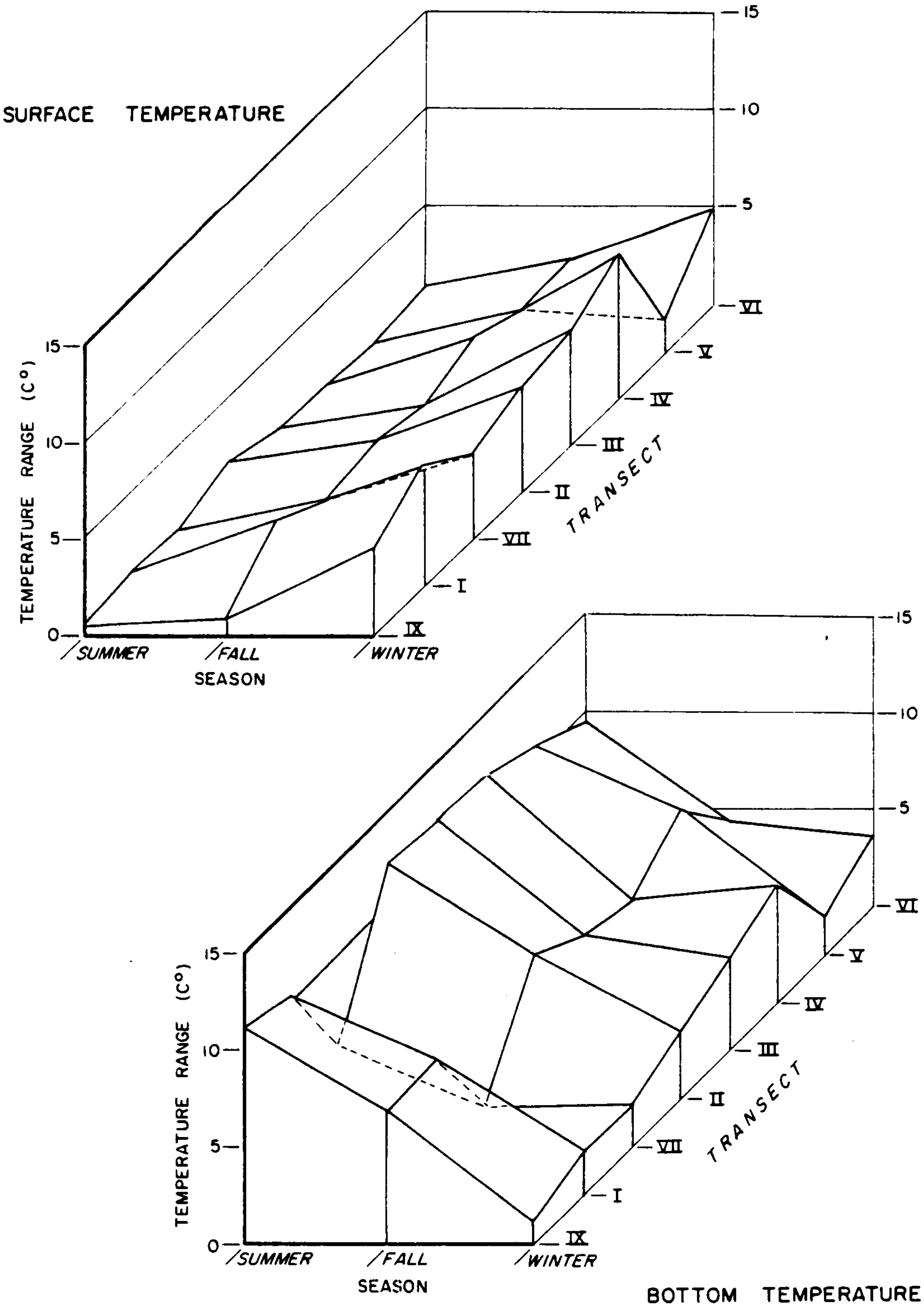


FIGURE 31

RANGE OF SURFACE AND BOTTOM TEMPERATURES FOR ALL 1977/1978 STATIONS BY SEASON AND TRANSECT

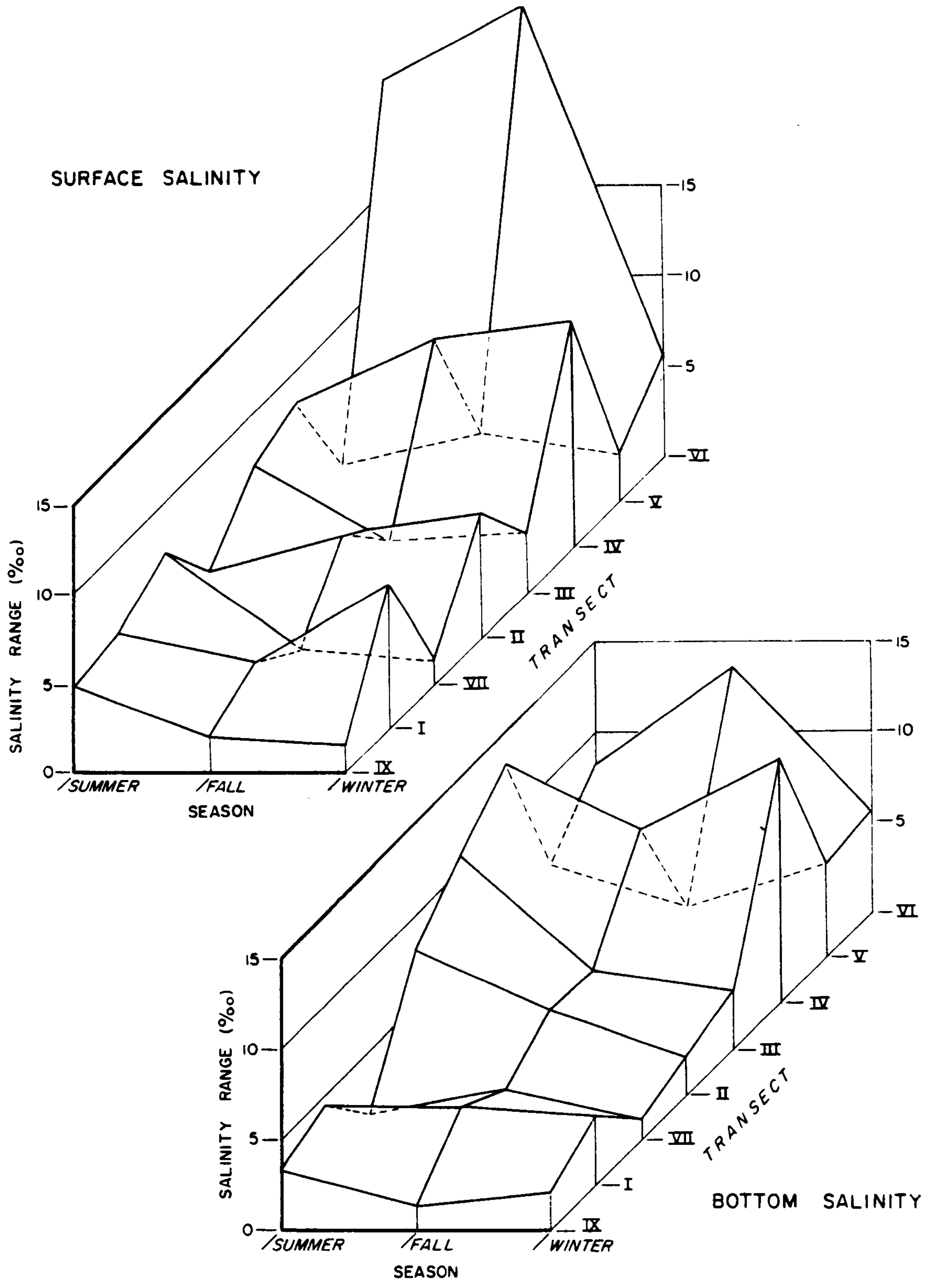


FIGURE 32

RANGE OF SURFACE AND BOTTOM SALINITY FOR ALL 1977/1978 STATIONS BY SEASON AND TRANSECT during the winter season; bottom temperatures show greater ranges during the summer months. Salinity values show less seasonal variation, but much greater ranges with increasing latitude. Transect V appears as an exception to that trend inasmuch as the seasonal variation in range is stable and much lower than for the transects lying to either side.

Seasonal comparisons of light transmission are shown in Table 12 adopted from Carder (in Volume II, Chapter 21). The clearest water was found at the southern stations in the fall, and was only slightly clearer than winter values. Summer values for the northern stations were equally low when Loop Current water was present. The most turbid conditions were found in the nepheloid layers at the northern stations.

The data set for light penetration is small and is derived only from cruises DM II and DM III; temporal comparisons, therefore, are very tentative. Nonetheless, higher levels of light penetration are seen during the fall cruise (DM II) than during the winter cruise (DM III; refer to Volume II, Chapter 20) and do support the light transmission data.

Short-period variability in descriptive water column parameters (on a scale of hours and days rather than months) is best seen on data obtained at the time-series stations occupied during the winter 78 cruise, DM III. Station 2639 offshore of Mobile Bay shows the greatest variability with time and depth; the upper four panels of Figure 33 show temperature, salinity, density (σ_t), and light attenuance (c_p) as contours plotted with depth on the vertical axis and time plotted on the horizontal axis. The salinity panel has the greatest contour density and best illustrates the two- and three-layer stratification. Of particular interest are the rapid changes occurring at a given depth within a very short time span; they are greatest in surface and mid-depth waters where there are temperature changes of about 1°C and salinity changes of almost 2 $^o/oo$ within two hours. The gradients may be entirely destroyed and reformed within a six-hour period, as at about 1800 on 2/23/78. The light attenuance panel derived from the transmissometry investigation of Carder (Volume II, Chapter 21) shows similar rapid changes. The other three time series at Stations 2528, 2315, and 2747 (illustrated in Volume II, Chapter 20) showed increasingly poorer stratification to the south; the time series from Stations 2315 (Florida Middle Ground) and 2747 (offshore Tampa Bay) showed basically homogeneous water column structure.

The sort of short-term variability seen at the winter time series Station 2639 can also be seen, but to a lesser degree, at Station 2528 (offshore Panama City). The first three days of the five-day series showed some stratification, albeit not as pronounced as at Station 2639; the later two days showed absolutely uniform conditions with depth (refer to figures in Volume II, Chapter 20). The Florida Middle Grounds station (2315) and Station 2747, lying offshore of Tampa Bay, showed the same uniform conditions with depth as did the last two days of record at Station 2528. The variability with time at the two southern stations was also slight; water temperature and salinity were essentially uniform.

The underlying causal mechanisms for the short-term temporal variability are unknown. Carder (Volume II, Chapter 21) has suggested that

TABLE 12

SUMMARY OF THE RANGE OF ATTENUATION COEFFICIENTS
VALUES FOUND AT TIME-SERIES STATIONS
(after Carder and Haddad, Volume II, Chapter 21 of this report)

STATION NUMBER*	JULY 1976	STATION NUMBER	OCTOBER 1977	STATION NUMBER	FEBRUARY 1978
			RIVER INFLUENCE		
B	0.07 - 1.29	2639	0.16 - 0.66	2639	0.37 - 3.30
		2529[1]	0.08 - 0.24	2528[1]	0.40 - 2.62
			OCEAN INFLUENCE		
C	0.09 - 0.58	0005[2]	0.04 - 0.34	2315[2]	0.34 - 0.67
D	0.06 - 0.54	2747	0.03 - 0.18	2747	0.05 - 0.50

[1]Includes Stations 2528 and 2529 which lie less than 5 km apart offshore of Panama City, Florida.

[2]Includes Stations 0005 and 2315 which are immediately adjacent to one another over the Florida Middle Ground.

*Refer to Table 3, above, for station location and correspondence between 1976 and 1977/78 station designations.

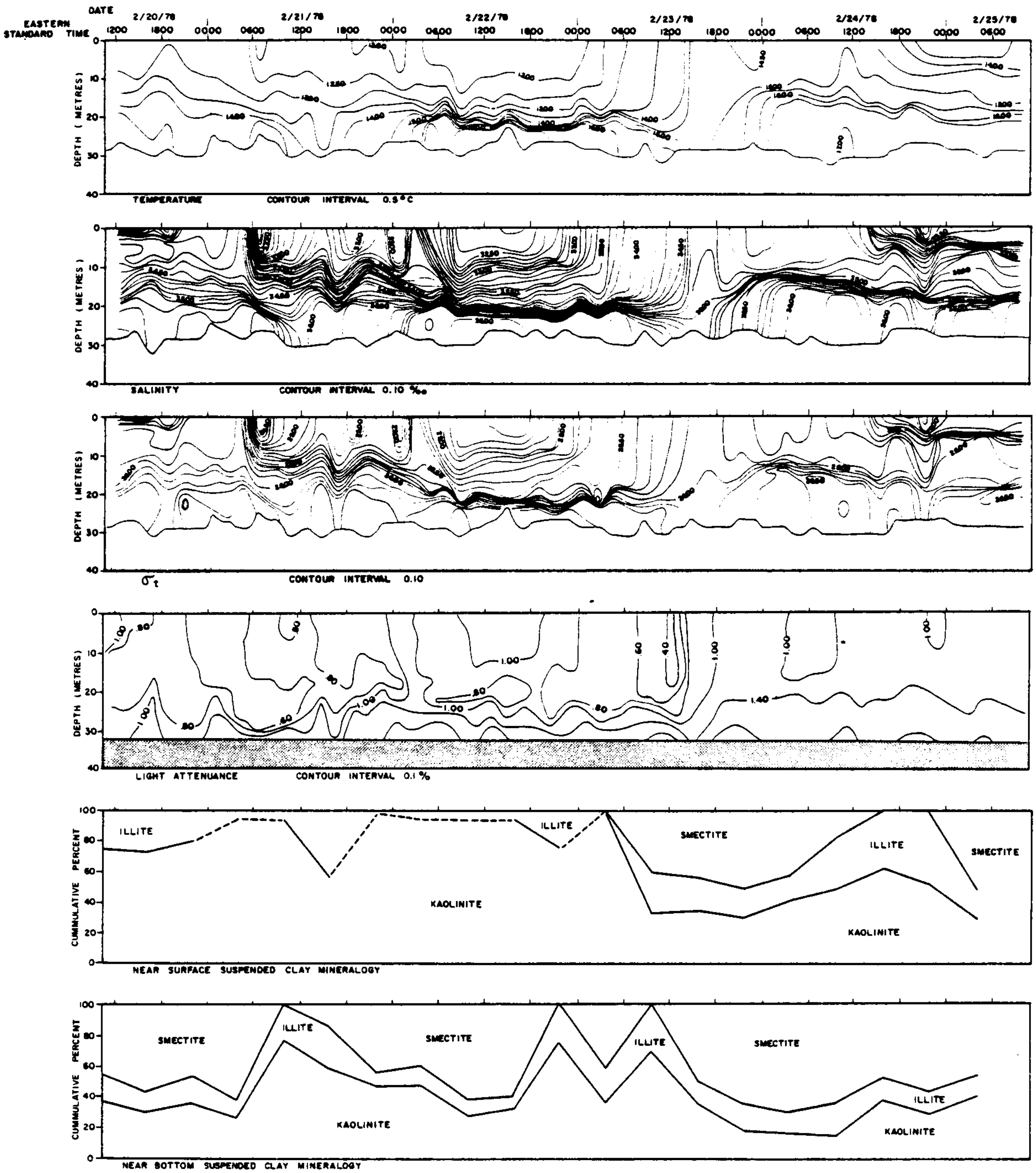


FIGURE 33

TIME SERIES PLOTS OF TEMPERATURE, SALINITY, DENSITY, ATTENUATION COEFFICIENT (C_p), AND SURFACE AND BOTTOM SUSPENDED CLAY MINERALOGY AT STATION 2639, WINTER 1978 seiche induced by the passage of storm fronts and having a period of about 21 h is responsible for resuspending and transporting bottom material. The results of power spectral analyses of transmissometry data presented in their report, however, do not appear to support that hypothesis and in fact suggest that the frequency content of the time series corresponds to components with periods greater than 24 h. Most of the variability appears to be aperiodic or to have cycles longer than can be detected with a time series of such short duration. No frequencies corresponding to tidal periods can be seen in those spectral analyses.

RELATION TO OTHER PROGRAM ELEMENTS

Suspended Particulates: Clay Mineralogy, Trace Metals, Hydrocarbons

The lower two panels of Figure 33 show time-dependent variations in relative amounts of clay minerals for near-shore, near-bottom waters at Station 2639 off Mobile Bay. Although the relative changes in mineralogy are great and occur rapidly, it is difficult to see any correlation between those changes and the variation in water column characteristics. In a very broad sense, high surface concentrations of smectite and illite appear coincident with high near-surface light attenuation coefficients (i.e., turbid water) but the relationship is weak and does not appear to correlate with salinity and temperature variations.

Comparing the variations in near-bottom clay mineralogy with transmissometry data is no more enlightening; while there are three quite distinct and significant periods of high smectite concentration, there are no corresponding periods of high turbidity in near-bottom waters. Doyle (Volume II, Chapter 2) has speculated that the passage of a seiche with a 12 h period was responsible for the variability in clay mineralogy. It is difficult to visually detect a 23 h periodicity in any of the data shown on Figure 22, however, and such an hypothesis is not supported by the power spectrum analysis performed by Carder (Volume II, Chapter 21) and discussed earlier.

The substantially different clay mineralogy suites of the surface and bottom waters for most of the five-day time series at Station 2639 suggest different provenance and transport mechanisms. That reasoning is supported by the two-and three-layer stratification delimited by very sharp gradients of temperature, salinity, and density, which define quite distinct water masses. Betzer (Volume II, Chapter 22), however, showed the ratio of weak-acid soluble iron (Fe) to refractory Fe was similar in bottom and surface waters during winter 78 indicating a common source of particulate iron.

The suspended particle loads for the time-series stations occupied during cruise DM III (winter 78) reported by Betzer (Volume II, Chapter 22) are in good agreement with the attenuation coefficients for the same stations as reported by Carder (Volume II, Chapter 21; and see Table 12 above). They show increasing particulate loads and correspondingly lower light transmission values with the progression from southerly to northerly stations. Both data sets also show higher particulates in winter 78 than in fall 77. The elevated suspended loads for the winter sampling appeared to be related to storms which result in substantial sediment-water interactions and subsequent resuspension of fine-grained bottom material.

The lack of compelling correlations between the physical, geological, and TM chemical characteristics of the water column lead to the conclusion that the variability within and between those data sets results from a complex and poorly understood interaction of periodic, aperiodic, and secular factors. These include, among other factors, intrusions of the Loop Current proper or detached eddies of Loop Current waters onto the shelf, upwelling or downwelling, wind-wave mixing, turbulence resulting from passage of storm fronts, tidal currents (generally thought to be insignificant), river inflow, and biological cycles.

The distribution of both dissolved and particulate heavy hydrocarbons (see Jeffrey, Volume II, Chapter 25) varied in time and space, and suggested a correlation with water mass characteristics. The concentration of both hydrocarbon components was comparable to oceanic waters at all stations during the fall 77 cruise (DM II); they were slightly higher during the winter cruise (DM III). The difference most likely reflected the intrusion of Loop Current waters onto the shelf during the fall 77 cruise and its absence during the winter season. Higher particualte hydrocarbon concentrations at the northern stations (where tar balls were observed in samples collected from neuston tows) probably resulted from the proximity to source areas along the industrialized northern margin of the MAFLA OCS. As these particles are transported southward by the Loop Current, they are weathered and degraded by chemical and biological processes.

Benthic and Water Column Biota

The few correlations observed between water column parameters and the distribution of benthic and water column biota are discussed in the Results and Discussion: Marine Biology section to follow. Some general observations can be made here, however.

Station 2315 at the Florida Middle Ground persistently showed temperature and salinity conditions indicative of offshore waters, which appeared to result from incursions of Loop Current water onto the shelf. The presence of hermatypic (reef building) corals at the Florida Middle Ground certainly suggests more stable and tropical conditions than are found elsewhere on the northern and central portions of the West Florida Shelf.

Carder (Volume II, Chapter 21) has presented transmissometry data for the Florida Middle Grounds which show higher attenuation coefficients during winter 78 than during either fall 77 or summer 76. The higher attenuation may have resulted from greater wave-induced mixing during the winter, but it may also have reflected the very high concentrations of phytoplankton observed during the winter cruise (DM III). The data do not support a compelling conclusion in either direction.

USEFULNESS OF PHYSICAL OCEANOGRAPHIC PARAMETERS IN MONITORING

It is clear that in spite of the size of the MAFLA data base resulting from this and earlier studies, our understanding of the physical oceanographic processes is not only incomplete but at times contradictory. There seem to be as many exceptions as rules. It is equally clear that an understanding of the biological variability (see plankton results, below) will remain tentative without knowledge of the physical processes which serve as major forcing functions.

The circulation on the MAFLA OCS stands as a good case in point. While major circulation patterns of the eastern Gulf of Mexico have been investigated for more than two decades, we as yet have no predictive capability nor do we have an understanding of the effects of Loop Current perturbations on shelf circulation. There is a notable paucity of direct measurement and analysis of bottom currents. Carder, Betzer, and Doyle (all in Volume II of this report) have presented evidence that bottom sediments (and associated parameters) are resuspended at times of Loop Current intrusion onto the shelf. Yet there is no strong evidence to suggest that current speeds associated with Loop Current passage are great enough in water several tens of metres deep to resuspend sediments having 10 to 20% or more fine-grained material. The fact that the stations showing such resuspension also coincide with the approximate depth of the pycnocline suggests internal waves or baroclinic tidal affects, acting along or in concert with Loop Current intrusions. If interest in development of the MAFLA OCS continues, an integral component part of further studies should be concurrent time-series measurements of bottom currents at several stations on the West Florida and Mississippi-Alabama shelves.

Data presented in this report have demonstrated the time and space scales within which some physical oceanographic parameters may vary. Perturbations on both scales occur more frequently at the stations on the Mississippi-Alabama Shelf than on the West Florida Shelf. Given the depth of our data collection and analysis thus far, however, we can not yet define on the fine scale the connection between oceanographic parameters and the provenance of sedimentary or pollutant inputs, nor state with any certainty the relative importance at any time of biogenic or abiotic inputs of chemical species. Clarification of the sources and sinks of sedimentary and/or chemical materials may not require further monitoring, but rather continued analysis of the existing data set. It can be concluded that in addition to the measurement of salinity, temperature and water clarity to the understanding of the chemical and biological variation of an area, simultaneous measurements of currents are necessary.

RESULTS AND DISCUSSION: MARINE CHEMISTRY

FUNCTION OF THE MARINE CHEMISTRY STUDIES

The three work element groups in marine chemisty, hydrocarbons, trace metals and organic carbon, combine to form, with biology, the two major dependent variable classes of study in the MAFLA program. An understanding of the distribution patterns and range of variability of these parameters is vital to the analysis of potential impacts from oil and gas development in the eastern Gulf of Mexico. These data are also required for designing rational monitoring studies and as background data for comparing against post-development levels and patterns.

For crude oil production and transportation, the use of baseline high molecular weight (n-C-14 and higher) hydrocarbon data is self evident. The nine trace metals studied include two that are often associated with drilling muds (barium, Ba; chromium, Cr), two that are abundant in crude oils (nickel, Ni; vanadium, V) four that are toxic to marine organisms and/or to man, and which are often associated with marine structures and man's offshore activities (cadmium, Cd; copper, Cu; lead, Pb; zinc, Zn) and one that can be used as a guide in evaluating expected natural levels of the other eight (iron, Fe).

Studies of high molecular weight hydrocarbons and trace metals in the MAFLA OCS region prior to the initiation of the Bureau of Land Management sponsored field investigations were limited. The SUSIO (1973) literature review, A Summary of Knowledge of the eastern Gulf of Mexico, devotes one page to hydrocarbons, citing a single reference (Stevens et al., 1956) applicable to this study. Trace metals receive slightly greater coverage, with most comparable data coming from Slowey and Hood (1971).

Data collected and analyzed in the 1977/78 survey include: water column particulate and dissolved organic carbon (POC/DOC), sediment total organic carbon (TOC), water column dissolved and particulate hydrocarbons (n-C-14 and greater), hydrocarbons of sediments, zooplankton, macroinvertebrates and demersal fish, water column particulate trace metals, sediment trace metals, zooplankton, macroinvertebrate and demersal fish trace metals. In general, plankton samples were collected from only one station (Florida Middle Grounds), other water column samples were collected from that station and from three others (2747, 2528, 2639; see Figure 1). Frequent time-series samples were collected at the Florida Middle Grounds; daily samples were collected for five days at the other water column stations. Bottom sediments for hydrocarbons, trace metals and TOC were collected at 49 stations along 8 transects, 43 of those stations being sampled seasonally. Of the latter 43 stations, 27 were selected for replicate chemistry sampling by BLM in order to assess small scale variability. Demersal fish (Syacium papillosum, the Dusky Flounder) and 57 species of macroinvertebrates (see Table 14, below) were collected from the seven transects used for dredge/trawl studies. Samples were collected seasonally for those species.

The discussions in the remainder of this marine chemistry section are related to prior BLM/MAFLA studies according to the degree of compatibility of the methods and the retrievability of the data. Readers are specifically referred to the final reports for the 1974 and the 1975/76 MAFLA surveys (SUSIO, 1975, 1977) for background, and to the PIs final reports in this report (Volume II, Chapters 2-10, and 22-26).

This section of the Synthesis Report is composed of the following segments:

- High Molecular Weight Hydrocarbons
  - Water Column Particulates and Dissolved Fractions
  - Sediments
  - Demersal Fish
  - Macrofauna
  - Plankton

- Nine Trace Metals
    - Plankton
    - Water Column Particulates
    - Demersal Fish
    - Macroepifauna
    - Sediments

In each section, the function of the work element, the definition of the data set included, and the usefulness of the work element as a monitoring tool are discussed, in addition to the discussion of the distribution of the parameter in the MAFLA region.

HIGH MOLECULAR WEIGHT HYDROCARBONS

Water Column Particulates and Dissolved Hydrocarbons

Introduction

Hydrocarbons in the marine environment come from a wide array of sources, including recent in-place natural biological production, natural petroleum seeps, spills of crude and refined oil, and airborne and riverine sources of land-derived hydrocarbons. The last group of sources, as with the in-place marine sources, includes biogenic, anthropogenic and petrogenic inputs. The principal mode of transportation and of delivery to the benthic environment of these hydrocarbons is the water column. Under most man-mediated input conditions, the water column is the first part of the marine environment to be impacted by hydrocarbon contamination.

Jeffrey (Volume II, Chapter 25) discusses the dynamics of hydrocarbons in the marine environment, indicating that temporal variability results not only from the aperiodicity of input sources, but from the variety of removal processes. These processes act on biologic and petroleum related hydrocarbons through evaporation, biodegradation, and scavenging by organisms or particulates which may then transport the hydrocarbons to the bottom.

The report by Iliffe and Calder in 1974 on dissolved hydrocarbons in the Loop Current was the only major study of water column hydrocarbons in the Gulf prior to the BLM seasonal transect (1975/76) and time-series (1976/78) surveys. Jeffrey (Volume II, Chapter 25) discusses the prior MAFLA work and other comparable studies.

The data base for this report includes 40 samples from fall 77 (12 h series at four stations) and 68 samples from winter 78 (five-day series at four stations). Due to the subjectivity of the interpretations in gas chromatographic (GC) analyses of hydrocarbons and the lack of interlaboratory calibration between 1975/76 labs and 1977/78 labs, the prior MAFLA studies are used in the same way as other literature sources, i.e., for comparison of ranges but not for inclusion in a common data base. Jeffrey discusses some of the intercomparability problems in Volume II.

Results and Discussion

Total dissolved heavy (greater than n-C-14) hydrocarbons in the MAFLA samples from the 1977/78 collections were all less than 1 $\mu g \cdot \ell^{-1}$. The fall samples were marginally lower than winter with the observed winter phytoplankton bloom being a probable cause of the higher winter values (Jeffrey, Volume II, Chapter 25). The fall samples were comparable to oceanic (low) levels with the maximum being 0.06 $\mu g \cdot \ell^{-1}$. All values are consistent with the prior MAFLA values determined by Calder (<u>in</u> SUSIO, 1977).

GC/MS results indicate that there are no aromatic hydrocarbons in any of the 1977/78 samples (detection limits = 1 $\mu g/\ell$). Unresolved portions of aliphatic GC traces appear to be from terrigenous (land derived) sources. There are no indications from the distribution of GC or GC/MS peaks of petrogenic inputs, with the southern two stations (2747, 2315) being characterized by marine biogenic hydrocarbons and the northern two stations (2529, 2639) by a mix of marine and terrestrial biogenic hydrocarbons.

Although the dissolved hydrocarbons were relatively constant with time and depth, particulate hydrocarbons showed considerable variability within stations in periods shorter than 24 h. This variability is consistent with the particulate organic carbon (POC) data (Jeffrey, Volume II, Chapter 26), and similar short term variability can also be seen in the particulate and zooplankton trace metal data (below, and Volume II, Chapter 22). Water column structure in northern stations, especially in the winter (see physical oceanography discussion above, and Volume II, Chapter 20) gave evidence of aperiodic rapid shifts of structure indicating short term changes in the water mass (and source) at a fixed point. Plankton variability, which would influence particulate hydrocarbons and POC, was extreme, even in physically homogeneous water masses (see plankton discussion, below).

Despite the variability, the total amount of particulate hydrocarbons was relatively low, ranging from 0.01 to 0.3 $\mu g \cdot \ell^{-1}$. Fall 77 values were comparable to DOC values and indicative of oceanic water mass concentrations (0.01 to 0.07 $\mu g \cdot \ell^{-1}$). Although fall values were higher (0.07 to 0.3 $\mu g \cdot \ell^{-1}$) they were still low for coastal and shelf waters. Northern stations had higher levels in both sample sets. These stations are nearer shore (see Figure 1), and under much greater riverine influence than the southern stations, and Betzer (Volume II, Chapter 22) reports that the northern pair of stations have higher total suspended particulates, especially in the winter.

As with the dissolved hydrocarbon samples, there were no aromatics evident from the GC/MS analysis of particulate aromatic fractions. Southern station paticulate hydrocarbons all appear to be from marine biogenic sources. Northern station aliphatic fractions show some unresolved components, but these are interpreted as being of terrestrial origin and not indicative of petrogenic inputs (Jeffrey, Volume II, Chapter 25).

There were no apparent similarities between particulate hydrocarbons and zooplankton hydrocarbons (see below, and Volume II, Chapter 9). GC traces from particulates are much more complex than those from the zooplankton, and show more variability. There was also no apparent correlation between particulate and sediment hydrocarbons. The latter represent long term accumulations (see below, and Volume II, Chapter 10) and have, in turn, much more complex traces than the particulates.

Uses of Water Column Hydrocarbons as a Monitoring Tool

From a theoretical standpoint, the water column ought to be monitored as the first place likely to show the effects of petroleum contamination under most circumstances. In the MAFLA area, that argument is enhanced by both the generally pristine conditions indicated by the low to very low levels of hydrocarbons in the water column, and the total lack of aromatic hydrocargons in samples analyzed in this program. The addition of low molecular weight hydrocarbon analysis to a monitoring program would allow detection of the more soluble and often more toxic fractions below n-C-14. The methodology of Sauer (1978), is recommended for both sampling and analysis.

Sediment Hydrocarbons

Introduction

Sedimentary hydrocarbons are accumulated over time from the water column, from in-place production through sediment transport, and from subsurface oil-bearing rocks (sources, in general, have been discussed in the prior section). Analysis of sediment hydrocarbons shows the effects of both short term (weeks) and long term (years) inputs. Boehm (Volume II, Chapter 10) reviews in more detail these sources and discusses their effect on resultant sediment hydrocarbon "fingerprints."

Complex gas chromatograph patterns may be viewed as the overlapping of several sets of less complex inputs. A series of GC traces of sediment hydrocarbons from the 1977/78 MAFLA program are used to illustrate this point of view and to define the set of hydrocarbon source classes which have been used in describing the sub-region of the MAFLA area. Figure 34 illustrates a sediment whose hydrocarbons (high molecular weight-aliphatic fraction) are dominated by pristane and the hydrocarbon at Retention Index (RI) 2085. (Undefined compounds may be identified by their retention time during the GC analysis; 2085 is an index number indicating a compound whose peak lies between n-C-20 and n-C-21.) These peaks represent hydrocarbons from marine biogenic inputs (Boehm's Class B). Terrestrial biogenic sources are indicated by the tendency of vascular plants to produce hydrocabon suites with high odd to even carbon ratios (Figure 35; Boehm's Class T). An unresolved complex mixture (UCM) of a combination of partly degraded hydrocarbons shows up as a "hump" in the GC trace. An example of a high molecular weight dominated UCM (Boehm's Class U) is shown in Figure 36. A similar shape which is dominated by lower molecular weight hydrocarbons (Figure 37) is usually indicative of a light to medium distillate petroleum input (Boehm's Class L). Lastly, sediments taken from areas where all of these sources are contributing to the sample show two "humps," high amounts of pristane and RI 2085 and high odd-even ratios (Figure 38; Boehm's Class U2).

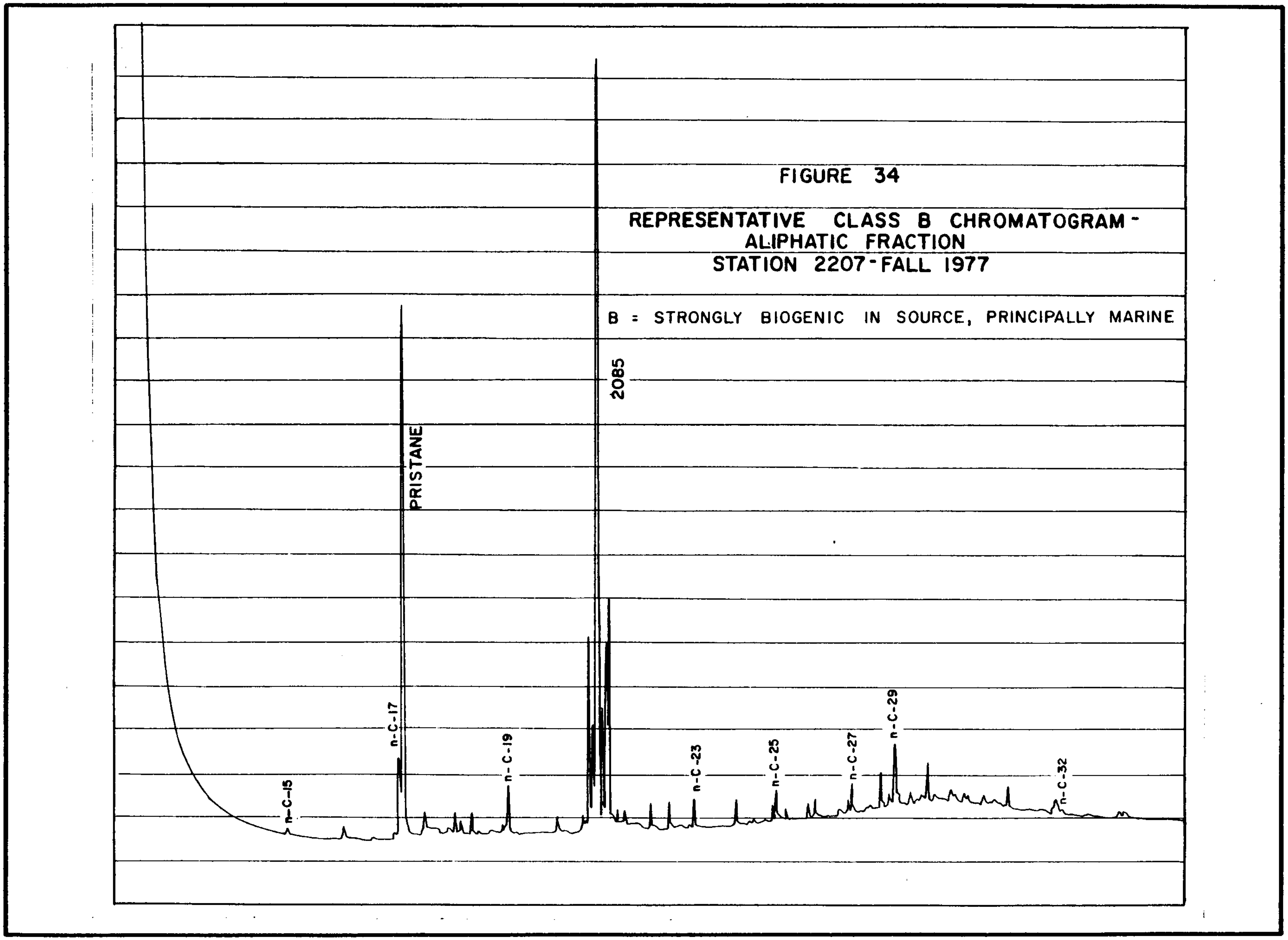


FIGURE 34
REPRESENTATIVE CLASS B CHROMATOGRAM -
ALIPHATIC FRACTION
STATION 2207 - FALL 1977
B = STRONGLY BIOGENIC IN SOURCE, PRINCIPALLY MARINE
2085
PRISTANE
n-C-15
n-C-17
n-C-19
n-C-23
n-C-25
n-C-27
n-C-29
n-C-32

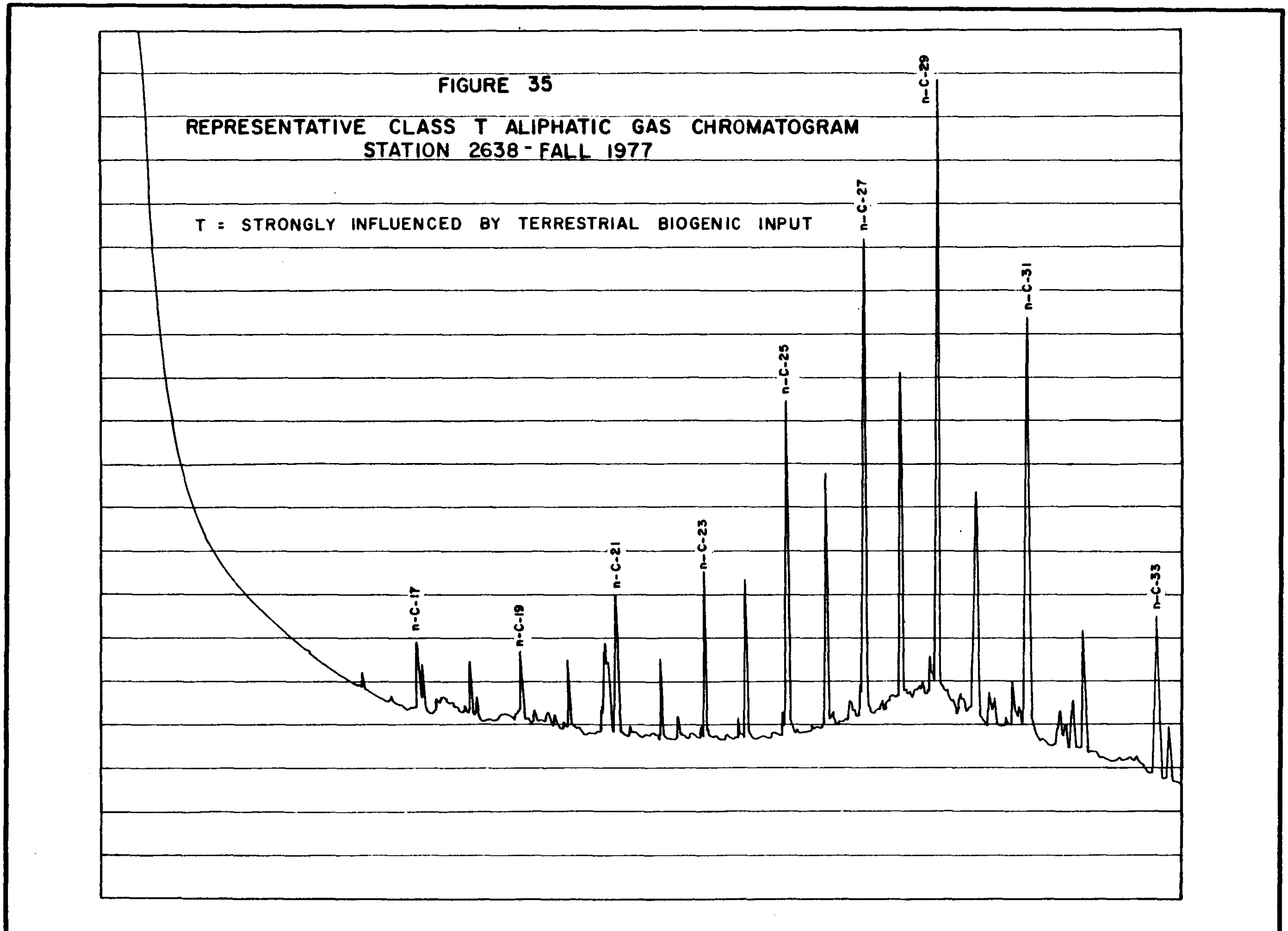


FIGURE 35

REPRESENTATIVE CLASS T ALIPHATIC GAS CHROMATOGRAM
STATION 2638 - FALL 1977

T = STRONGLY INFLUENCED BY TERRESTRIAL BIOGENIC INPUT

FIGURE 36

REPRESENTATIVE CLASS U GAS CHROMATOGRAM - ALIPHATIC FRACTION
STATION 2643 - SUMMER 1977

U = CHARACTERIZED BY A SINGLE COMPLEX MIXTURE

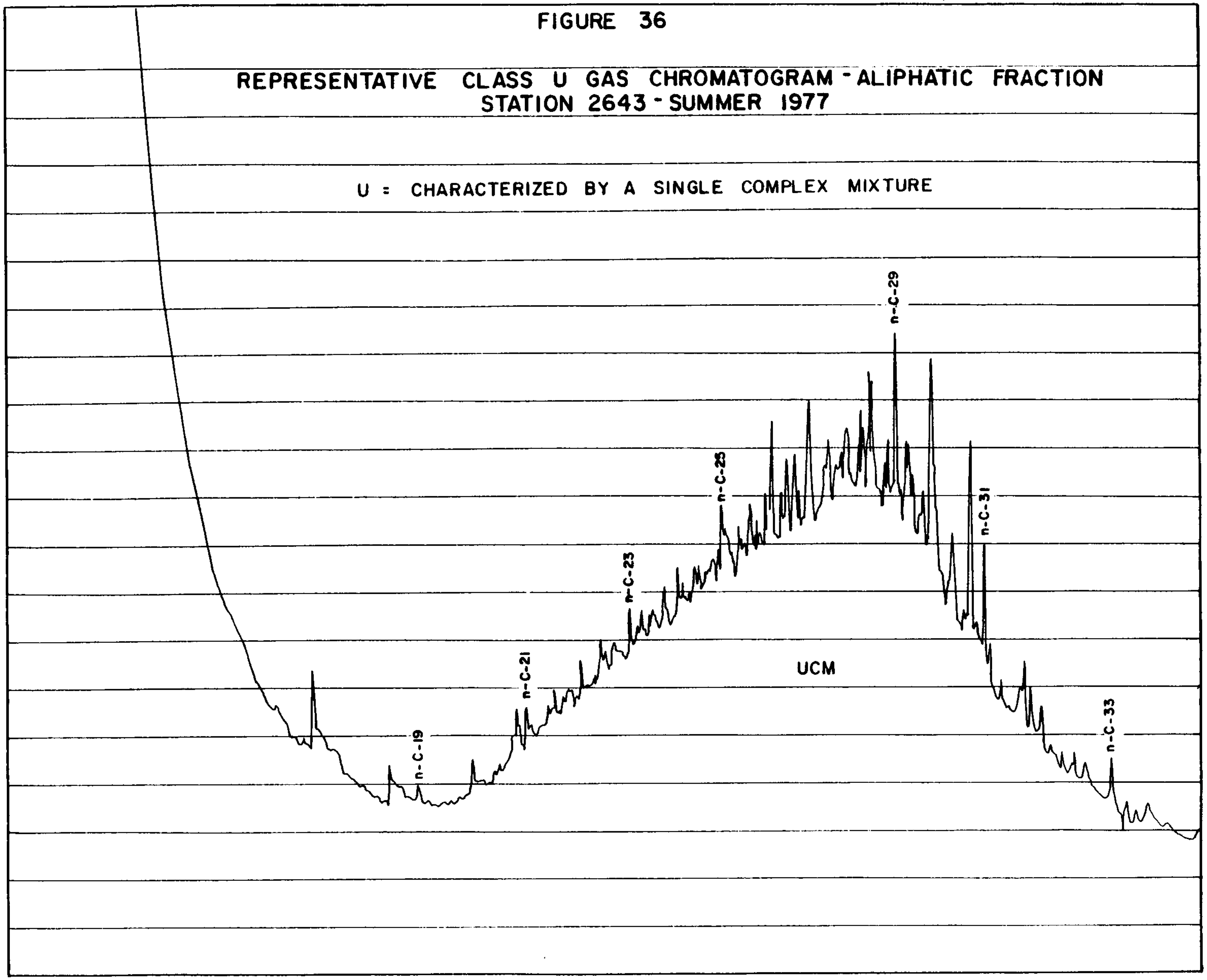
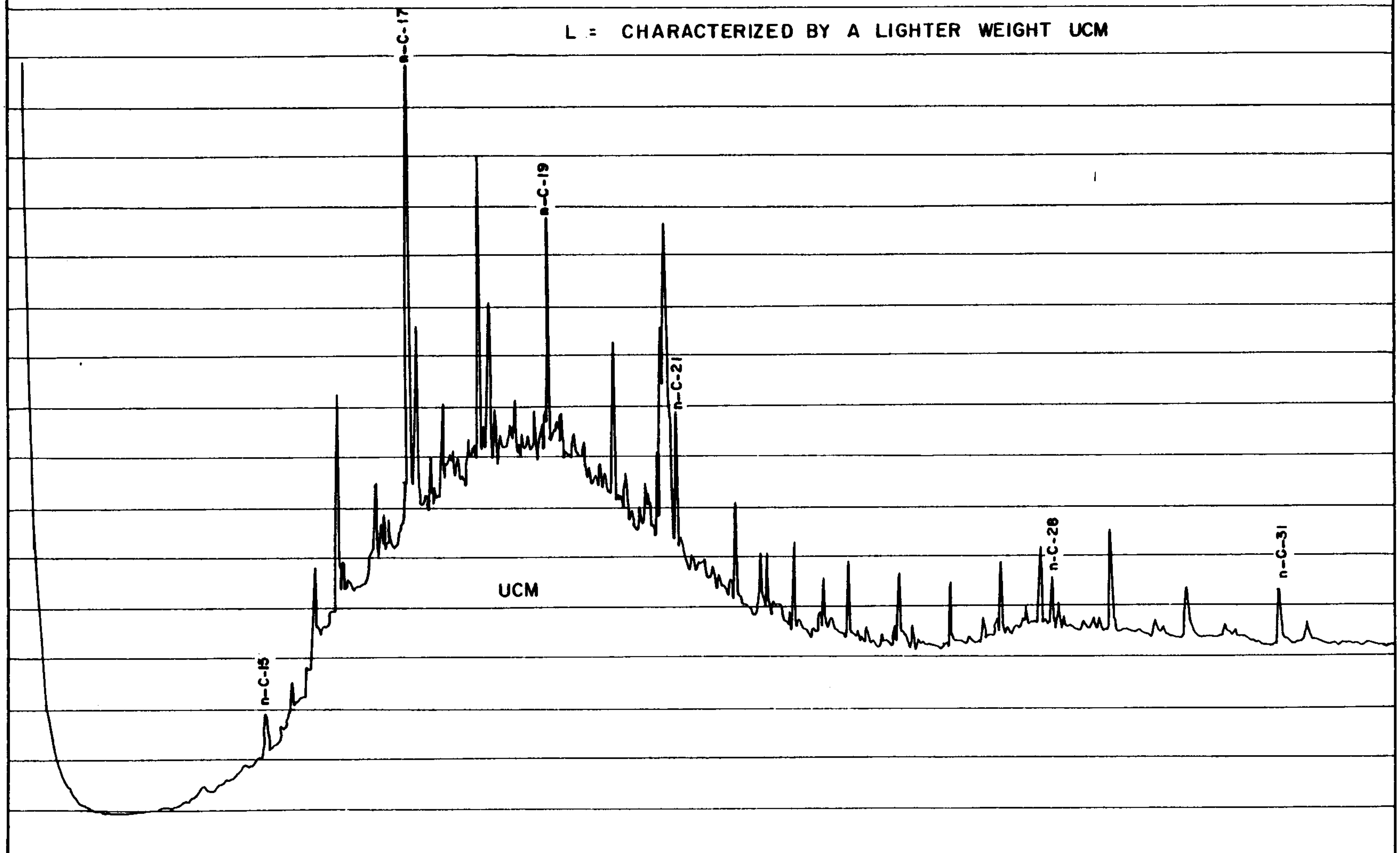


FIGURE 37

REPRESENTATIVE CLASS L ALIPHATIC GAS CHROMATOGRAM
STATION 2426 WINTER 1978 (LUBT*)



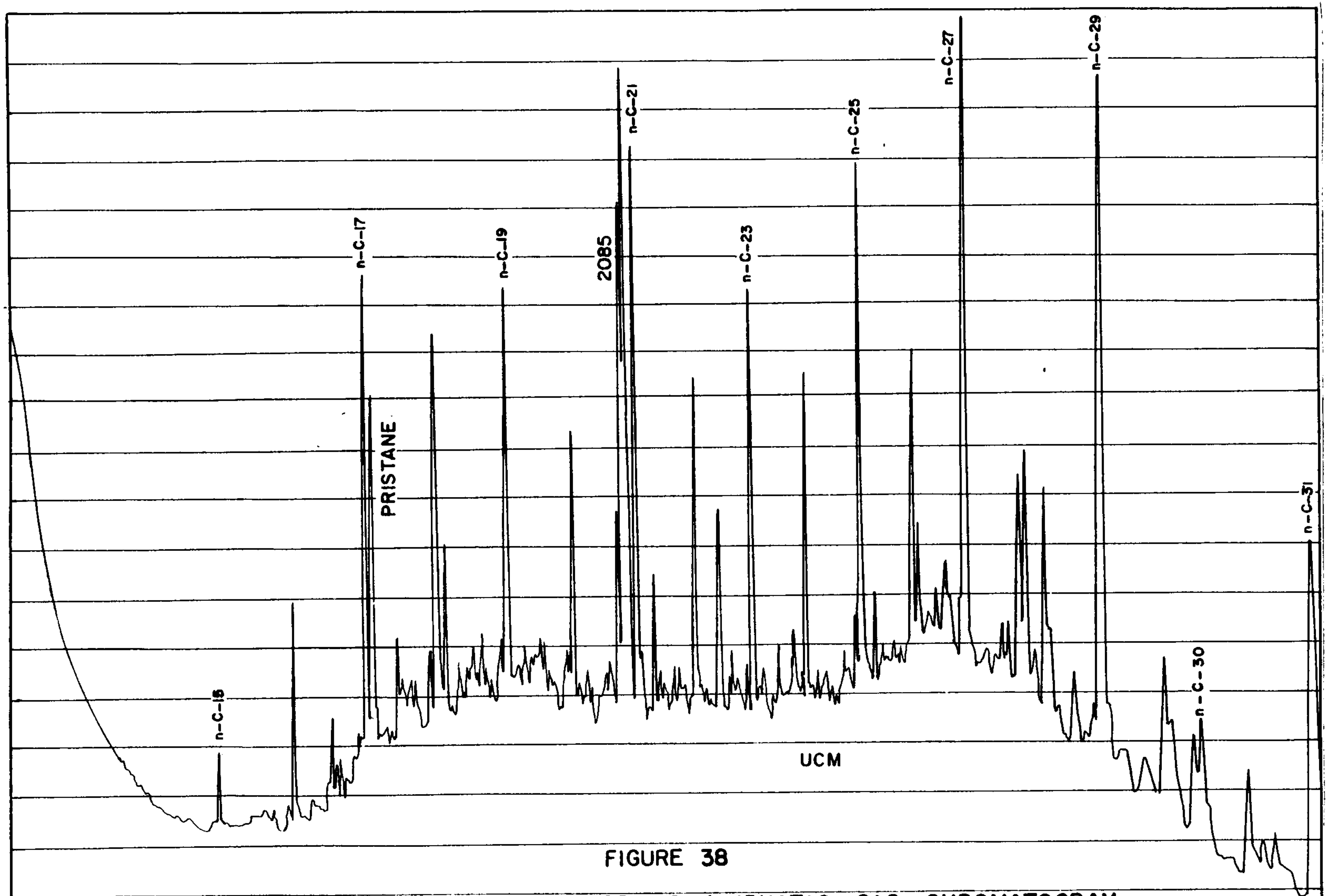


FIGURE 38

REPRESENTATIVE CLASS U2 ALIPHATIC GAS CHROMATOGRAM
STATION 2639 WINTER 1978 (TU2BL*)

U2 = HAVING A BIOMODAL UCM

The BLM program brought the first systematic survey of sediment hydrocarbons in the MAFLA area. The results of the 1976/77 survey have been used in comparing general quantitative and distributive trends from this survey in a discussion of temporal variability (see Boehm, Volume II, Chapter 10). Samples from 1975 to 1978 were collected from box cores along six transects (Stations 21XX through 29XX in Figure 1). Transect VII (27XX) was added in summer 76 and Transect IX (29XX) in summer 77. All of these stations were sampled by single samples, seasonally. Six additional samples were collected from stations between transects (28XX) during summer 76 and summer 77. Finally, replicate chemistry samples were collected from 27 stations during the 1977/78 sampling program (1 sample from each 5 additional box cores per station).

Results and Discussion

Use of gross hydrocarbon parameters (e.g., total aliphatics, total aromatics, resolved aliphatics) without consideration of source characteristics may give misleading results. As an example, Station 2419 (10 m depth; northeast corner of the MAFLA area) in the fall 77 collection had a total sediment aliphatic fraction measured at 0.6 $\mu g \cdot \ell^{-1}$, twice the value for Station 2106 (200 m; offshore southeast section of the MAFLA area). Reference to the two GC traces (Figures 39 and 40) however, indicates that the hydrocarbons at Station 2419 are largely biogenic and mainly marine, while the hydrocarbons at Station 2106 show a large UCM of possible petrogenic origin as well as a large terrigenous biogenic input.

Since summary quantitative data are often misleading, the majority of this discussion will center on a consideration of qualitative evaluations of source areas. Specific quantitative parameters will then be considered within the framework of those source classes.

From an evaluation of the GC traces of sediment samples collected between summer 76 and winter 78, Boehm (Volume II, Chapter 10; based on data from analyses of Analytical Research Laboratories, Inc.) classified the sources of hydrocarbons from 49 stations (Table 13). From that analysis he characterized three general biogeochemical provinces in the MAFLA area. The areas were characterized as having hydrocarbons principally of biogenic origins (Boehm's Class B, T, or BT), biogenic and anthropogenic origins (BTU), or biogenic, anthropogenic and petrogenic origins (BTUL or BTU2L). Region I (BT) lies inshore, mainly within the 40 m contour, along the West Florida Shelf. Region II (BTU) is found in pockets offshore along the West Florida Shelf and in the Mississippi-Alabama Shelf. Region III intermingles with Region II, associated mainly with higher fine sediment fractions. These regions are given rough boundaries in Figure 41. Reference to Table 13 will indicate that for many of these stations, the assignment of a single class does not indicate the temporal instability shown by season-to-season classification. However, the characterization of the shallow Florida Shelf as one generally devoid of petrogenic inputs and the Mississippi-Alabama Shelf as one dominated by mixed anthropogenic and petrogenic inputs does hold up. These findings agree in general with those reported by SUSIO (1977) for the prior MAFLA work.

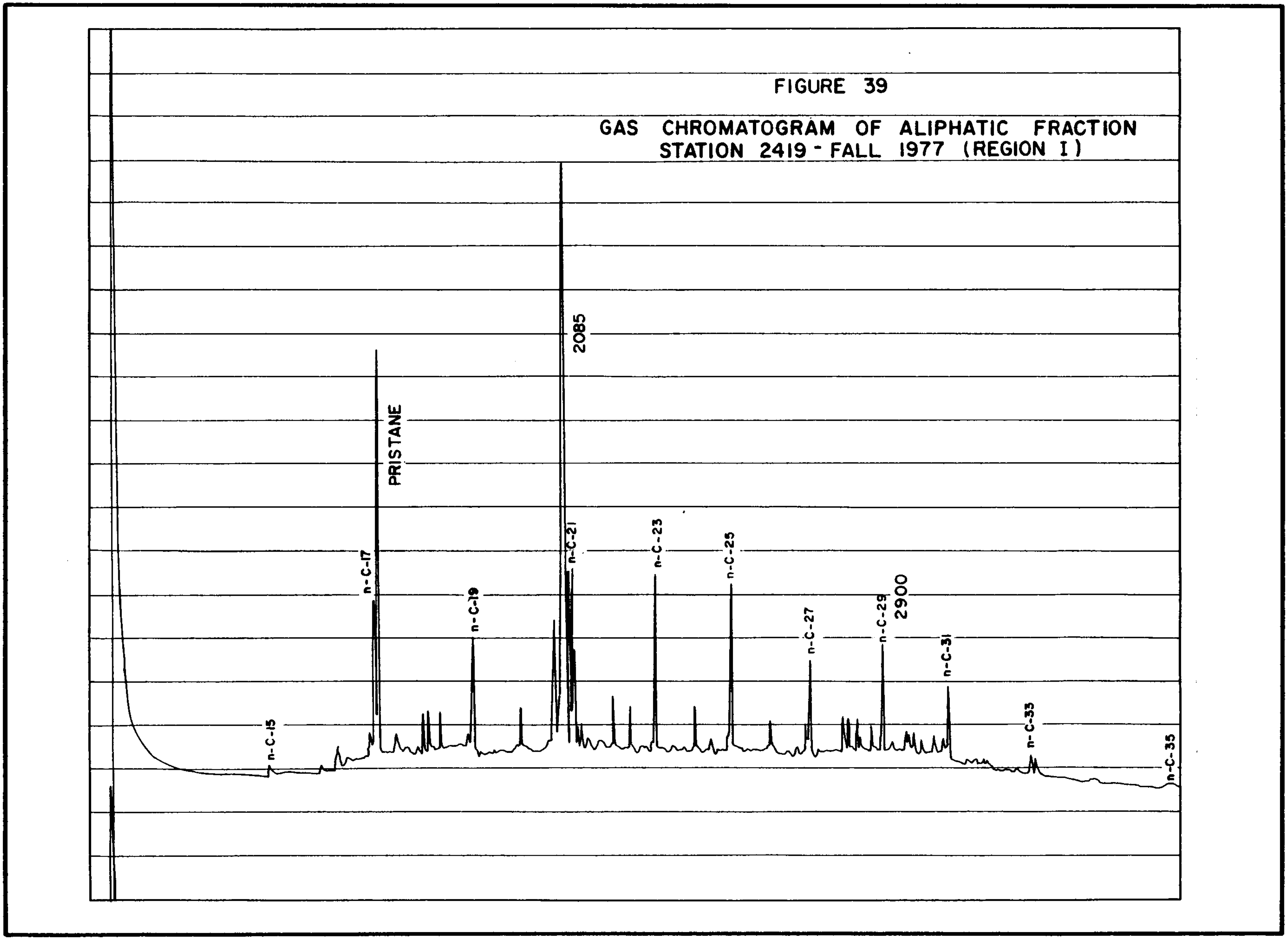


FIGURE 39

GAS CHROMATOGRAM OF ALIPHATIC FRACTION
STATION 2419 - FALL 1977 (REGION I)

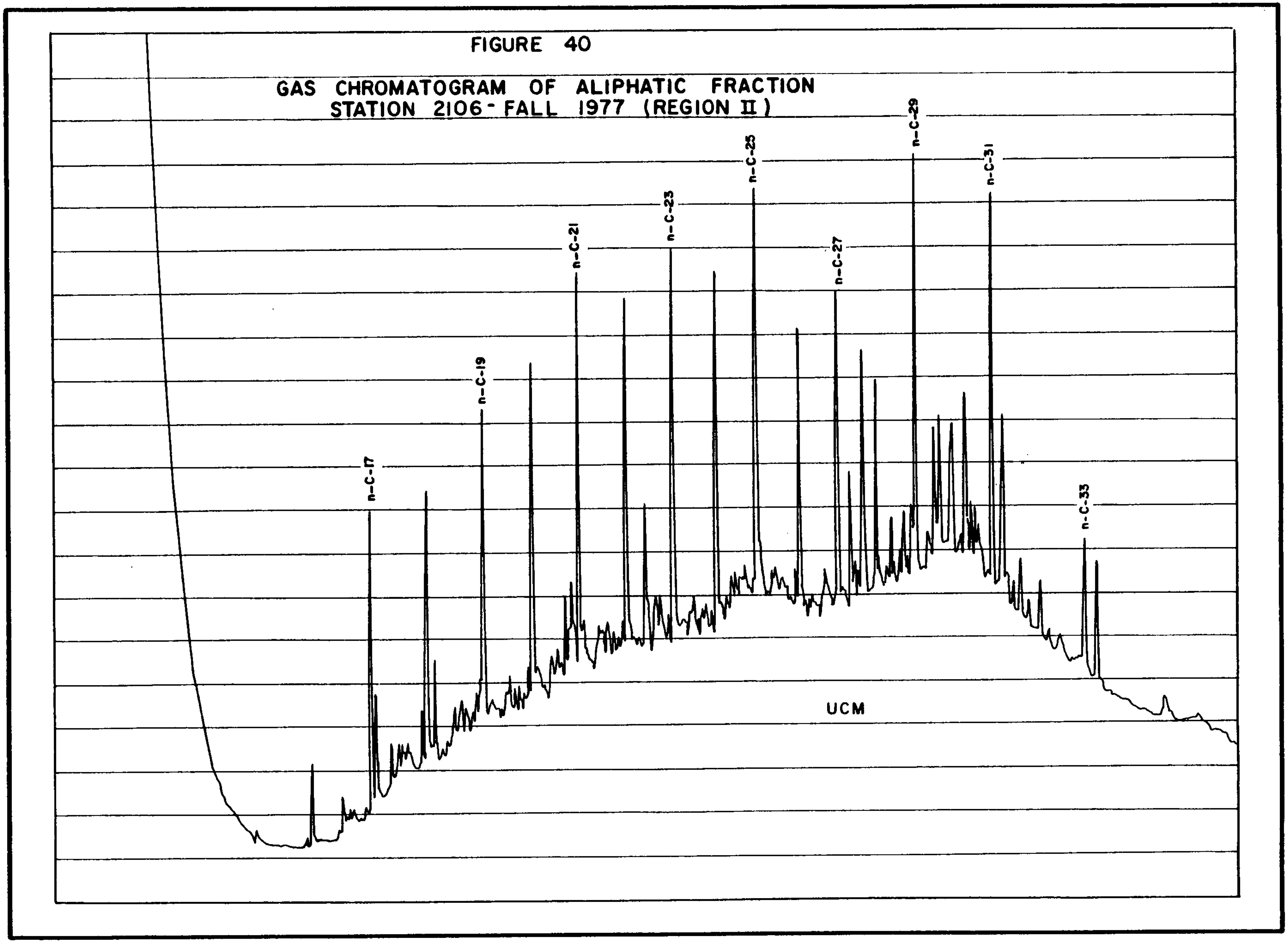


FIGURE 40

GAS CHROMATOGRAM OF ALIPHATIC FRACTION
STATION 2106 - FALL 1977 (REGION II)

TABLE 13

CLASSIFICATION OF SURFACE SEDIMENT HYDROCARBONS AS TO SOURCE

STATION NUMBER	SUMMER 1976	SUMMER 1977	FALL 1977	WINTER 1978
2101	BTU*	B	BU	-
2101	BT	B	B	-
2103	B	B	BT	-
2104	BT	BT	BU	-
2105	TULI*	TUL	B	BT
2106	TLU	TU	TUL*	-
2207	B	TB	B	BT
2208	BT	BT	B	BT
2209	B	B	B	BT
2210	BT	B	B	-
2211	ILTB	BT	B	-
2212	TL	TL	TUBL	TU2L
2313	-	TU	TUB	-
2315	-	BT	BTU	BILU*
2316	-	B	B	BT
2317	-	B	BU	BT
2318	-	BIU	B	B
2419	-	BTLU*	BT	BTLU*
2421	-	BT	B	BTLU*
2423	-	BTL	B	-
2424	-	BTU2L	B	BTLU*
2426	-	BT	TULB	LUBT*
2427	-	TUL	TU2L	LU*
2528	-	B	TUBL*	BUT*
2529	-	BTU	LUB*	LU*
2531	-	TUB	TU2BL*	LU*
2533	-	-	TU2BL	TLU
2535	-	TLB	TB	BU2T*
2536	-	TU2LB*	TUB	TU2BL*
2638	-	TU	TU	TU
2639	-	TUB	-	TU2BL*
2640	-	TU	TUBL	TUBL*
2641	-	TU2LB*	TU2BL*	TU2BL*
2643	-	TU*	TU	TU2BL*
2645	-	TUB	TU2L*	TU2BL*

B - Strongly marine biogenic (n-C-17 pristane, 2085 in hexane fraction)
T - Strongly terrigenous biogenic (n-C-23, n-C-25, N-C-17, n-C-29, n-C-31)
U - Unresolved complex mixture (UCM) a prominent feature (unimodal)
U2 - Bimodal UCM
I - Intermediate n-alkanes prominent (n-C-20 to n-C-24)
L - Lower n-alkanes (n-C-14 to n-C-22) prominent
* - Petrogenic source (L and U components) prominent

TABLE 13 (CONTINUED)

CLASSIFICATION OF SURFACE SEDIMENT HYDROCARBONS AS TO SOURCE

STATION NUMBER	SUMMER 1976	SUMMER 1977	FALL 1977	WINTER 1978
2746	TU2L*	TU*	-	TU2BL*
2747	TU2LB	TULB	-	BTL
2748	TU2L*	TUL	-	BT
2749	-	B	-	-
2851	-	B	-	-
2852	L	B	-	-
2853	B	BL	-	-
2854	BTL	BL	-	-
2855	B	BL	-	-
2856	TUB	BTU	-	-
2957	-	TUL	TUL*	-
2958	-	BUL	TUL	-
2959	-	BTU2	-	-
2960	-	B	B	-

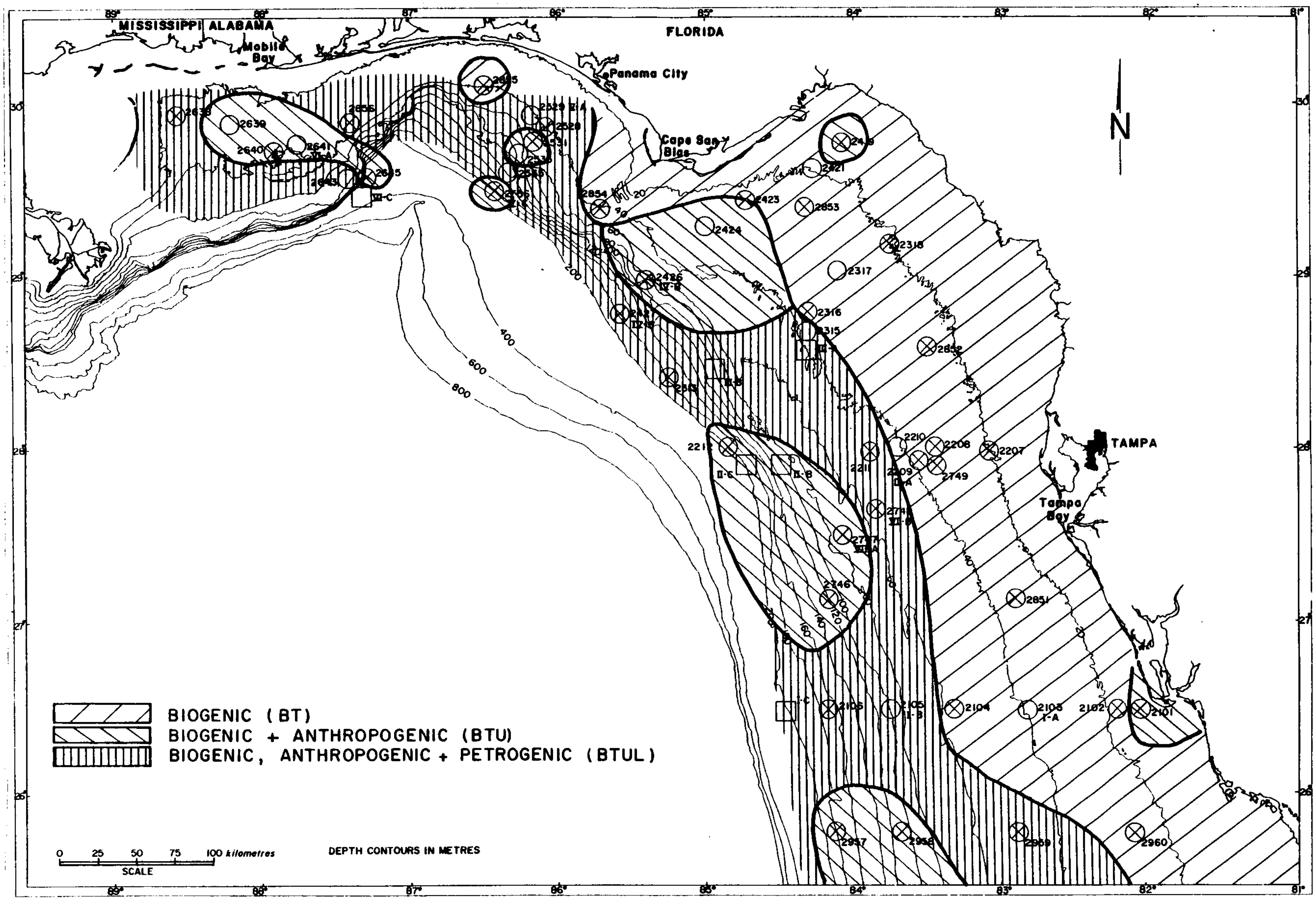


FIGURE 41

SOURCE DISTRIBUTION OF HYDROCARBONS IN MAFLA SURFACE SEDIMENTS

Boehm discusses the region on a transect by transect basis as follows:

Transect I exhibits a direct correspondence of source material with increasing distance from inshore, increasing TOC, and increasing percentage of fines. Stations 2102, 2130, and 2140 are dominated by marine and to a lesser extent terrigenous biogenic aliphatic compounds. At the steeper shelf break, Stations 2105 and 2106 exhibit a combination of terrigenous biogenics and a UCM associated with finer grained sediments. Generally speaking, 2105 and 2106 are typical of Florida shelf stations having a water depth greater than 40 m. Station 2101, closest to shore exhibits indications of anthropogenic inputs (i.e., UCM) during the summer 76 and fall 77 samplings, while exhibiting purely biogenic inputs in the summer 77. This may reflect a seasonal influence of input of sediment from the north (Tampa area).

Stations along Transects II, III and VII behave similarly with respect to source material. Stations at depths from roughly 20-40 m are dominated by peak RI 2085 and to a smaller extent contain terrigenous biogenic n-alkanes. Other clear indications of marine biogenic sources are the presence of the isolated peaks, hepta decane (n-C-17) and pristane. The benzene (f_2) fraction of these sediments contains primarily olefinic hydrocarbons.

Samples taken from deeper waters show increased influence from terrigenous, biogenic, and anthropogenic sources of hydrocarbons originating in the west. Although marine biogenic inputs are still apparent, the hydrocarbon assemblage is dominated by a UCM, either unimodal or bimodal, indicating one or two anthropogenic sources. Stations 2747, 2746 and 2212 exhibit bimodal UCM behavior during at least one of the sampling periods. The lower boiling point ICM with a smooth distribution of n-alkanes and equivalent concentrations of pristance and phytane, on top of the UCM are taken to be of a relatively recent petrogenic origin. In addition, GC/MS analysis of these deeper stations reveals several triterpane compounds (hopanes) believed to originate in petroleum.

An examination of the benzene fraction (f_2) by GC/MS indicates the presence of aromatic hydrocarbons, phenanthrene, pyrene and benzopyrene which probably are present in more abundant quantities than their alkylated homologs indicating the dominance of a combustion source for the aromatics as opposed to a recent oil spillage.

Transect IV appears to lie in a transitional zone with respect to all sediment geological and chemical characteristics. A water depth to hydrocarbon source criterion no longer holds. At different times during the study one or all of these stations have yielded hydrocarbon patterns associated with petroleum inputs. The occurrence of abiogenic compounds at Station 2419 is probably related to its proximity to local inputs (as seen with 2101). However, the combined anthropogenic/biogenic nature of the aliphatic (f_1) chromatograms from Stations 2424, 2426, 2427 and sporadically 2423 is most likely related to the anthropogenic source associated with the western end of the study area.

An examination of the temporal variability in the gas chromatographic character reveals that hydrocarbon sources can vary between primarily anthropogenic and biogenic during the study period of a given station. This may be due to the proximity of this transect to a boundary delineating two geochemical provinces influenced by (1) the Florida carbonates, in-situ productivity and possibly Appalachicola kaolinite and (2) the Mississippi smectite clays associated with anthropogenic hydrocarbons.

Clearly under the influence of the Mississippi silt/clay regime, stations along Transects V and VI are dominated by terrigenous and anthropogenic hydrocarbon inputs. The hexane (f_1) chromatograms are characterized by:

1. N-alkanes associated with terrestrial (vascular) plants
2. An unresolved complex mixture with a maximum detector response at n-C-28
3. The presence of triterpane compounds
4. The sporadic presence of a second UCM
5. The sporadic presence of n-C-16 to n-C-22 alkanes and equivalent concentrations of pristane and phytane
6. The presence of unsubstituted aromatic hydrocarbons.

The benzene (f_2) chromatograms are characterized by major amounts of olefinic hydrocarbons, a UCM, and lesser but significant amounts of aromatic hydrocarbons associated with a combustion source.

Figure 42 summarizes those stations which showed indications of petrogenic input during any of the four sampling periods in 1976/78. They include essentially all of Transects IV-VI, the inshore Station 2101 and a series of 60-200 m stations on the outer West Florida Shelf. The Mississippi River, Mobile Bay and Appalachicola Bay are discussed by Boehm (Volume II, Chapter 10) as the probable source areas for most of these hydrocarbons.

Analysis of quantitative output on specific parameters indicates some trends between the three biogeochemical provinces. Marine biogenic hydrocarbons tend to decrease from Region I to III; while terrigenous inputs tend to increase. TOC is higher in Regions II and III than in I, and most of the TOC in Region I is probably biogenic (see discussion of refractory TOC in microbial biomass section, below). For the most part, the error calculations were too high to allow determination of the validity of any of those trends (see Volume II, Chapter 10).

To assess temporal variability, both qualitative and quantitative comparisons between collection periods were made. Table 13, above, indicates that temporal variability in biogeochemical province assignment of a station was low, with the exception of Transect IV. Its combination of relatively (to Transect VI) coarser sediments and proximity to land with relatively (to the Mississippi River) small and sporadic runoff makes it a transition zone between the three provinces. In addition, Boehm analyzed the range of values for concentrations of selected parameters (total hexane fraction, total benzene fraction, 2900, 1700, 2085 and pristane) and found that on a station-by-station basis they exceeded the analytical variation

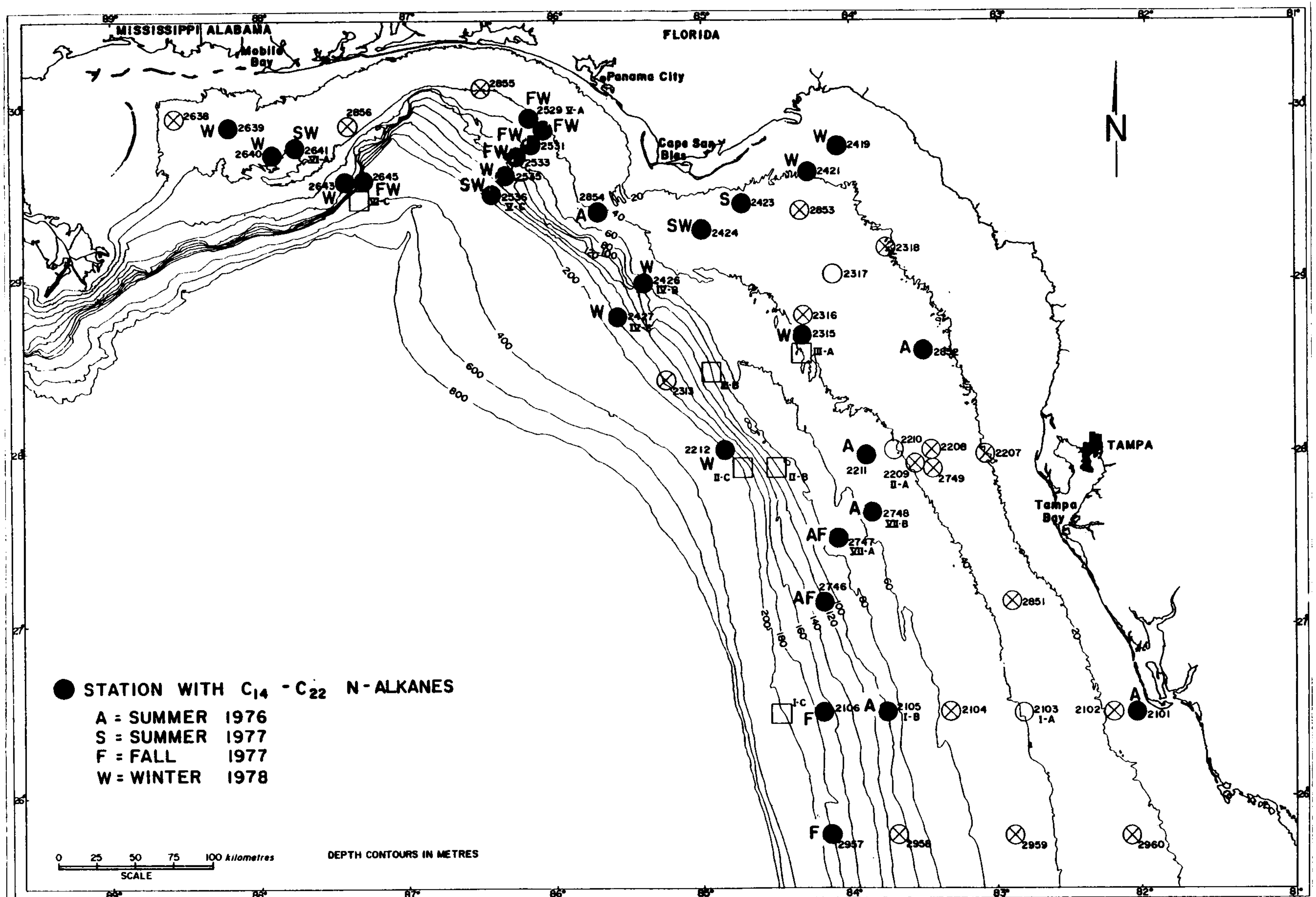


FIGURE 42

SEDIMENTS EXHIBITING LMW (C_{14} - C_{22}) n-ALKANE DISTRIBUTION WITH UCM (based on triplicate analysis of each of two separate samples) by about an order of magnitude (Volume II, Chapter 10).

For each of the three regions Boehm has constructed similarity matrices to examine the correlation between selected hydrocarbon parameters and potential dependent variables (including other hydrocarbon parameters). Only correlation coefficients in excess of $r^2 = 0.6$ were examined. Each gives credence to the previously stated relationships between the groupings of GC trace types and probable sources. For instance, Figure 43 is the similarity matrix for Region I. The resolved hexane fraction can be seen to be highly correlated to RI 2900 and RI 2085, indicating its biogenic nature. The covariance of RI 2085 and TOC indicates the probable biogenic nature of the TOC in Region I. The correlation between the benzene fraction and the RI 1700 peak indicates that the benzene fraction probably has few aromatic hydrocarbons of petrogenic origin, but is likely to be of phytoplankton origin. This result is in keeping with the water column hydrocarbon studies for the same area (see above, and Volume II, Chapter 25).

Similarly for Region II the unresolved hexane fraction shows a string of correlations with TOC, fine sediments and TMs. Boehm interprets this as showing the common origin of the TMs and Region II anthropogenic hydrocarbons, i.e., the Mississippi River. For this region Boehm calculates the predictive model:

$$\text{TOC} = 7.07\ (\text{conc. of RI } 2900) + 1454\ (\text{conc. of pristane}) + 0.149$$

Using measures of pristane and n-C-29 from the region, an expected TOC value could be calculated. Deviations would indicate changes in the region with underestimates of TOC indicating environmental deterioration.

For Region III the similarity as indicated by the correlation matrix of resolved benzene fractions to other hydrocarbon fractions indicates a nearby major anthropogenic source. The RI 2085 peak is strongly suggested to be of terrestrial source by the string of terrigenous indicator correlations. Boehm derived an equation for this region which requires only the measuring of peak RI 2085 as follows:

$$\text{TOC} = 15.73\ (\text{conc. of RI } 2985) - 0.134$$

Boehm and Quinn (1978) have defined a similar one-on-one dependence between TOC and RI 2085 for a nearshore biogeochemical province in New England. Again, underestimates of TOC would indicate deteriorating environmental quality.

Summary

Sediment hydrocarbons in the MAFLA area show the effects of accumulations from their various source areas. The West Florida Shelf in less than 40 m depth appears to be generally isolated from any measurable sources of anthropogenic or petrogenic hydrocarbons. The hydrocarbons in these sediments are principally marine biogenic compounds produced in place. Most of the TOC in this region would be expected to be of local biogenic origin as well. The deep water off the West Florida Shelf and Transects IV through VI

	TOC	MED SAND	FINE SAND	VERY FINE SAND	FINES (SILT & CLAY)	SILT	CLAY	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	2900	1700	PRISTANE	2085	RES. HEXANE	UCM HEXANE	RES. BENZENE	UCM BENZENE	Ba	$CaCO_3$
2900	.67		.66	.71	.69	.74	.71			.65				.72					.73	(.81)	.69			.66	.65
1700																						(.72)	(.72)		
PRISTANE			.71																						
2085	(.74)				.76	.72	.60													(.76)					
RES. HEXANE	.66				.68	.73	.61							.62							.64				
UCM HEXANE		.72					.62		.66	.62	.65	.65	.65		.68										
RES. BENZENE																							.79		
UCM BENZENE																									

○ = DISCUSSED IN TEXT

FIGURE 43

SIMILARITY MATRIX OF SELECTED HYDROCARBONS VS POTENTIAL DEPENDENT VARIABLES
REGION I

show some chromatograms which are definately indicative of a petroleum source. Tar balls are reported in the region of Transect V in the water column cruise logs, and observations of particulates of suggested kraft mill origin indicate the extent of anthropogennic influence in the region. However, none of the regions in the MAFLA area show any indication of recent in-place crude oil contamination which is in keeping with the water column hydrocarbon data. Means are described to detect petroleum related degradation of each of the three geochemical provinces either by qualitative examination of chromatograms in Region I, or by predicative equations of TOC in Regions II and III.

Usefulness of Sediment Hydrocarbons as a Monitoring Tool

Gross hydrocarbon parameters appear to be of little use in assessing petroleum contamination of sediments. Results of the present investigation show that total amounts of natural, in-place biogenic compounds may greatly exceed the amounts of hydrocarbons in petrogenically contaminated sediments. In addition, the UCM of aromatic fractions may be largely (or in the case of water column samples, entirely) of biogenic origin. However, the use of qualitative interpretation of GC traces, especially evaluating the relative amounts of alkyl substituted aromatics vs parent compounds and the mapping of source types, can provide a very sensitive means of determining the impacts of oil and gas development on MAFLA sediments. A set of geochemical equations has been provided to quickly assess quantitative changes in the amounts of petrogenic input to sediments in the two areas where existing GC traces already show qualitative signs of being influenced by petrogenic sources.

Hydrocarbons in Demersal Fish Tissues

Introduction

As seen in the Introduction in the last section, the hydrocarbons of sediments may be derived from a number of sources, and, as a result, may be very complex. Most demersal fish and benthic macroinvertebrates either directly ingest sediments, or prey on species which ingest sediments. Thus, the complexity of sediment hydrocarbons may be raised to much higher levels by organisms which feed, directly or indirectly, on those sediments.

Bieri (Volume II, Chapter 9) reviews the sources of hydrocarbons in animal tissues, and discusses the routes of selective or non-selective depuration (loss of contaminant hydrocarbons from tissues). In summary, the hydrocarbons in animal tissues may reflect some or all of the following dynamic input/output mechanisms:

- In-tissue synthesis of hydrocarbons
- Ingestion and selective or non-selective uptake
- In-tissue modification of ingested hydrocarbons
- Partitioning directly from or to the water across membranes (especially of dissolved fractions)

- o Active or passive changes in diet by individuals among species
- o Bioconcentration of specific compounds or elements
- o Variations in endosymbiotic bacteria
- o Changes in individual or populational enzymes for hydrocarbon breakdown with season, time span or physiological state.

Because the presence of petroleum-related hydrocarbons in animal tissues is dynamic, and since tissue residence times tend to be less than environmental residence times (Bieri, Volume II, Chapter 9), tissues will tend to cleanse themselves of hydrocarbon pollutants when the organisms are exposed to a less heavily polluted environment. The significance of examining demersal fish and macroinvertebrates for hydrocarbons in their tissues is, then, related to (1) the degree of toxicity (acute or chronic) directly to the organisms as that affects community ecology, (2) the degree it directly or indirectly impacts fisheries resources through stock depletion or tainting, and (3) the potential for impacting human health. In addition, for macroinvertebrates, the studies of tissue hydrocarbons are undertaken to provide potential correlates for the histopathology studies. Lastly, these studies are undertaken to provide a data base of existing variability of tissue hydrocarbon characteristics against which to compare post-development conditions.

Prior studies of tissue hydrocarbons in the MAFLA OCS are restricted to those of the previous BLM contract (SUSIO, 1977). Those data have not been utilized in current data analyses due to the lack of intercalibration, the subjectivity of the interpretations, and difficulties in attempting to extract the prior data from the SUSIO Data Tape. As with the water column hydrocarbons, the prior studies' final reports have been used here as comparable literature.

The data base for the 1977/78 demersal fish chemistry studies consists of replicate samples of a flounder collected from seven transects (21XX-27XX in Figure 1). The same individual or pool of individuals was used to provide sample material for both hydrocarbon and trace metal studies, in order that the potential of correlative contamination could be investigated. Eleven or more individuals were collected from one station on each transect to provide the sample material.

The fish species required for demersal fish chemistry analyses by the contract was the Dusky Flounder, Syacium papillosum. Although not of specific commercial interest (Juhl, 1966) due to its small size (maximum whole weight about 0.27 kg from regression in Topp and Hoff, 1972) it is a common to dominant constituent of trawls in all seasons throughout the MAFLA area.

The species is recorded from less than 20 m to more than 300 m depth (Bullis and Thompson, 1965), but is uncommon beyond 100 m depth. Topp and Hoff (1972) report S. papillosum to range along the whole of the West Florida Shelf and westward to about 88°W longitude. Their 3,500 specimens which were collected during the Hourglass cruises ranged in size from 18 to

253 mm. These data agree closely with the measurements of more than 1,100 specimens collected in the MAFLA program from summer 76 through winter 78. Specimens from the MAFLA studies in 1977/78 were of about equal abundance in 40 and 100 m collections (558 vs 551), with less than 20 specimens being collected from 200 m stations. Extreme distant trawl transects (I and VI) yielded equivalent numbers of individuals (202 vs 197), and Transect II had the highest yield (387).

Topp and Hoff (1972) report S. papillosum to have a breeding season in the Gulf which lasts from February to November, with a peak in May and June. The protracted breeding season makes it difficult to infer growth rates from seasonal shifts of modal lengths because of the relatively constant input of new recruits. However, all three sets of composite histograms (pooled separately by collection period, by depth and by transect) of length frequency on S. papillosum from the MAFLA data of summer 76 through winter 78 show a broadly overlapping bimodal distribution of lengths (Figure 44, for example). It can be inferred from this distribution of lengths that the population consists of two year classes which have standing modal lengths of about 60 to 80 mm and 130 to 140 mm, respectively. Since Topp and Hoff (1972) report that sexual maturity occurs in the range 100 to 300 mm, the second year class is composed mainly of breeding individuals. The modal lengths, maximum size and expected upper age all point to annual growing rates of about 70 mm (2.75 in.).

The diet of S. papillosum is highly varied with more than 65 taxa from 5 phyla being identified in Topp and Hoff (1972) from 134 specimens which had identifiable stomach contents. This diet included six species of crabs and shrimps which were selected for tissue chemistry analysis in the 1977/78 MAFLA program.

The advantages which this species has as a tool for determining the range of trace metal and hydrocarbon values in demersal fish tissues from the eastern Gulf of Mexico are its distribution throughout the region in relatively high quantities and during all seasons, and the very restricted home range of individuals (Dr. Robert Shipp, personal communication). Its broad diet makes determining the presence of contaminants that are transferred through food webs highly probable, but makes tracing specific contributor pathways difficult. Specimens below the second year modal length will usually not yield a sufficiently large tissue sample to split adequately between trace metal and hydrocarbon analyses, but sufficient numbers of specimens are nearly always available so that pooling would prove feasible.

Limitations on Use of the Data

Before discussing the tissue hydrocarbon data from the MAFLA 1977/78 program analyses, the sources of restriction on interpretation need to be understood. These sources arise from the samples themselves, from the analytical methodology, and from the restraints on interpretation.

Where spilled oil has a dominating influence on tissue concentrations, and weathering has not proceeded too far, the presence of petroleum hydrocarbons in tissues is not difficult to detect (Bieri, Volume II,

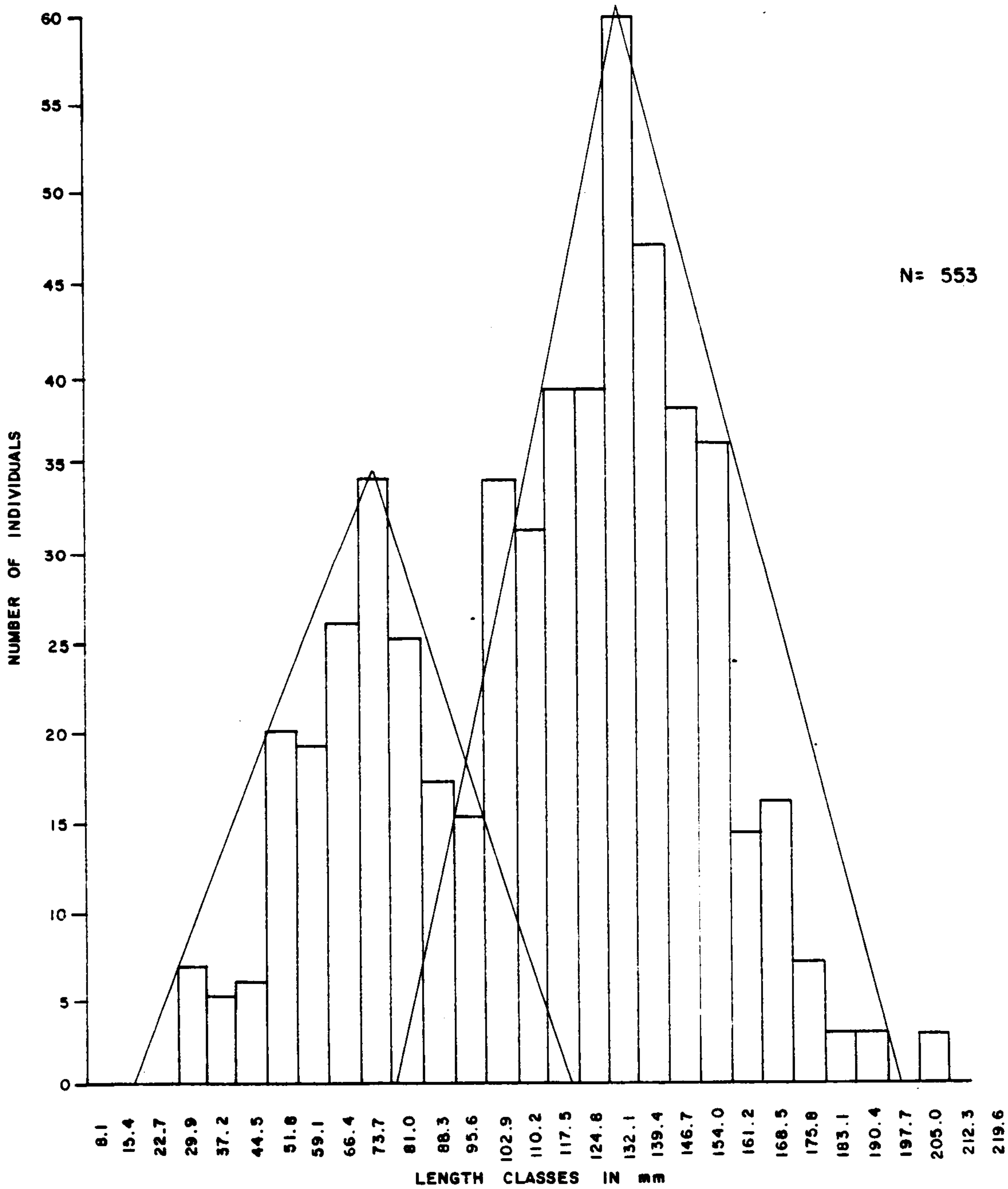


FIGURE 44

SIZE FREQUENCY HISTOGRAM OF SYACIUM PAPILLOSUM

ALL STATIONS POOLED, WINTER 1978

Chapter 9). However, after the dispersion of oils, and their physical fractionation, and biochemical and photochemical alterations, the concentrations in tissues will drop below the levels of natural hydrocarbons. These altered inputs are superimposed on the remains of past inputs and further confused by new, low level inputs. Thus, in most environments, including the MAFLA area, the resulting hydrocarbon composition can not be consistantly determined to be different from natural hydrocarbon uptake and synthesis. The low levels of non-biogenic components are then more difficult to detect when the tissue samples are small (see discussion of Syacium papillosum size, above, and macroinvertebrate size, below).

Hydrocarbon analysis by gas chromatography under ideal conditions is subjective and varies with individual sample characteristics. However, for the purpose of maximizing inter-program comparability and in order to process the very large volume of samples collected, BLM has found it necessary to require relatively rigid sample analysis conformance among its contracted laboratories. This loss of subjectivity in treating individual samples does not always lead to the best resolution of tissue hydrocarbons. Moreover, to handle the vast amounts of data generated, computer assistance in plotting and identifying components of GC traces is required. Computers may incorrectly identify or combine closely spaced peaks, and have difficulty in calculating the quantities of peaks which have complex geometries. These problems are discussed in detail by Bieri in Volume II.

Lastly, the constraints in producing an interpretive report in a relatively short time frame requires that the analysis be limited to the most readily interpretable data. In particular, the specific identity of peaks, and the separation of GC "aromatic" fractions into confirmed aromatic hydrocarbons or other compounds such as olefins (see, for instance, the discussion of dissolved hydrocarbon benzene fraction, above, and in Jeffrey, Volume II, Chapter 25), requires extensive inspection of GC/MS data. For each of the tissue samples which were subjected to GC/MS analysis by Analytical Research Laboratories, Inc., (Volume II, Chapter 8) a "book" of computerized reference curves was produced. Another full year of analysis time, with no new data, might be sufficient to digest this material.

Results and Discussion

From the total data set of 204 separate analyses of individual Dusky Flounder (Syacium papillosum), the 10 most abundant hexane fraction compounds (computer selected peaks identified by Retention Index, (RI)) of each were listed. This resulted in a set of 26 compounds, identified as n-alkanes, branched alkanes or olefins (Figure 45). Compound RI 2800 has the highest frequency, with RI 2200, 2000, 1700, and 2500 following in order. Although seasonally separated pools of these data show slightly different arrangements (see figures in Volume II, Chapter 9), the general trend holds. If oil contamination were abundant, all n-alkanes would have about the same frequency, with slightly higher amounts in the higher molecular weight compounds to account for weathering. The difference in frequencies suggests that oil contamination of demersal fish in the MAFLA area is not common. All trends suggested by computer analysis were corroborated by subjective evaluation of individual GC traces, and such inspection supports this conclusion of the uncommon occurrence of oil contamination in S. papillosum (Bieri, Volume II, Chapter 9).

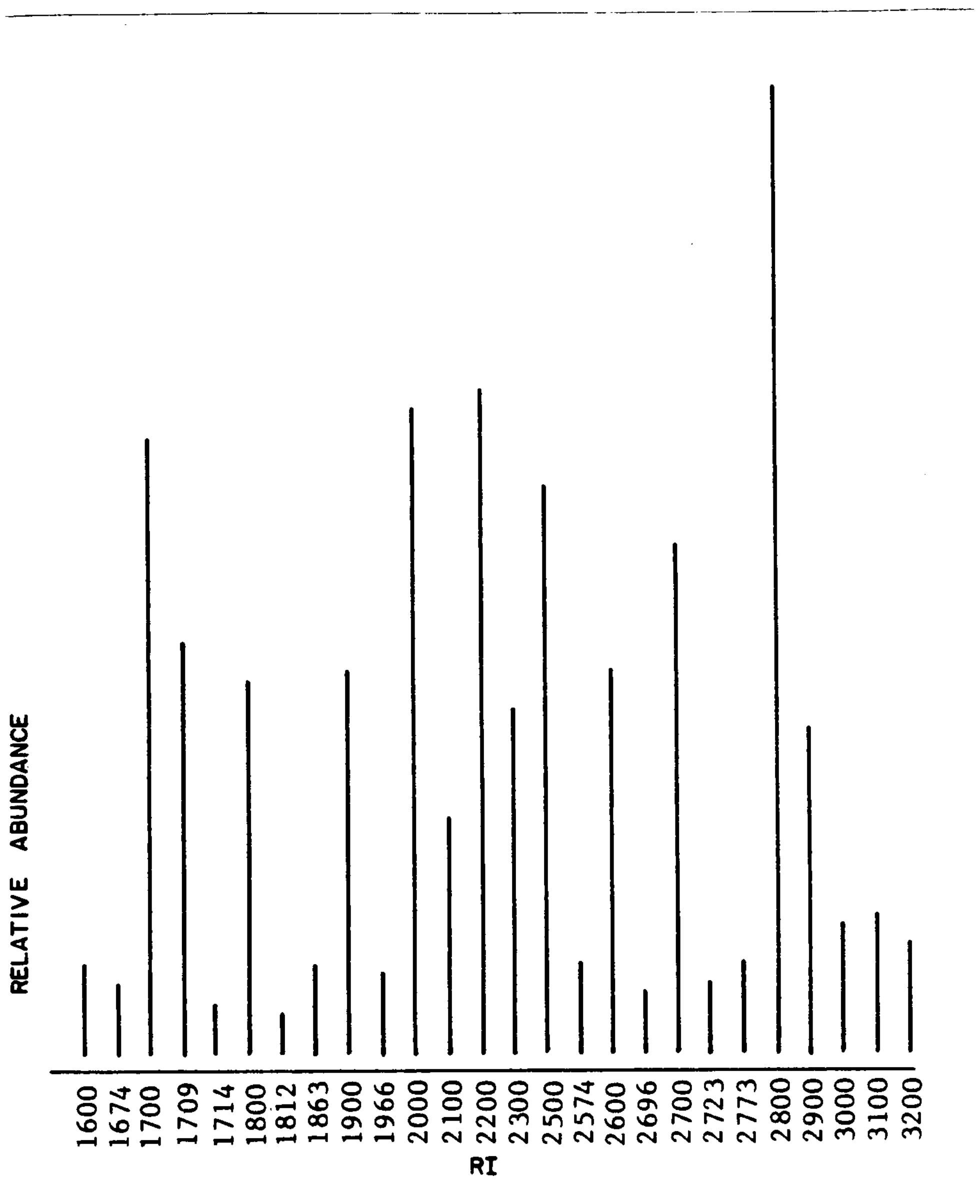


FIGURE 45

HISTOGRAM: 10 MOST ABUNDANT COMPOUNDS FROM EACH SAMPLE
ALL SAMPLES POOLED

Pooling seasons to examine inter-station variability indicate considerable locational influence on relative hydrocarbon concentrations (Figures 46 and 47, for example; and see figures in Volume II, Chapter 9). Splitting seasons at individual stations also indicates measurable short-term temporal variability. Examination of individual GC traces supports the suggestion that local effects are diet mediated, and reflect the varied diet of this species (see Introduction to this section). The diet of mainly crustaceans, polychaetes and small fish would in turn reflect the effects of the variability in station-to-station as well as inter-transect sediment hydrocarbons (see above, and Volume II, Chapter 9). A clear case for such a linkage between the diet of Syacium and the diet (eventually sediments) of its prey is evidenced in the tissue trace metal data (see below, and Volume II, Chapter 6).

Most of the GC traces are relatively simple, and are dominated by single peaks, or a few peaks without UCM "humps" suggesting biogenic sources. Figures 48 and 49 are two examples containing peaks of probable biogenic origin at n-C-18, 20, 22, and 28 (and compare, for their relative simplicity, with Figure 38, above). The exception to the generality of petrogenically clean samples occurs from the Transect V specimens of Syacium collected in the winter at about 100 m depth off Panama City, Florida (Figure 50). Bieri (Volume II) suspects that the lighter molecular weight centered hump may be an artifact, but the regular series of evenly distributed n-alkanes, with no odd-even bias is a positive indication of petroleum contamination.

Inshore (100 m and above) stations on Transect V are also in Boehm's (above, and Volume II, Chapter 10) anthropogenic + petrogenic source province, despite their rather coarse sediments (see discussion in meiofauna section, below, and see Doyle, Volume II, Chapter 2). The inner stations on this transect do support varied and abundant biotas (see macroinfauna, macroepifauna, below), with no indication of stress in either community characteristics (e.g., diversity) or by the presence of stress indicator species (see foraminifera, below, and see Bock, Volume II, Chapter 12). The winter 78 benthic survey that collected these samples was run concurrently with a water column cruise that sampled the area inshore of Station 0007. No petroleum hydrocarbons were detected in the dissolved or particulate hydrocarbons, although there were more indications of terrigenous biogenic compounds than at southern water column stations (see Jeffrey, Volume II, Chapter 25). Ship's logs from Station 2529 in winter 78 have the regular notation of observation of tar balls.

Summary

Demersal fish in the MAFLA area (as represented by the single species Syacium papillosum, the Dusky Flounder) were not in general contaminated by petroleum hydrocarbons. Most of the hydrocarbons present in their tissues appeared to be biogenic. There was short-term temporal variability in their tissue hydrocarbons, but most variability appeared to be geographic, and that in turn appeared to be related to this fish's diet. Winter 78 samples from Transect V showed clear petroleum hydrocarbon contamination. This was in agreement with sediment hydrocarbon data for the area and the source may be from the adjacent coastline.

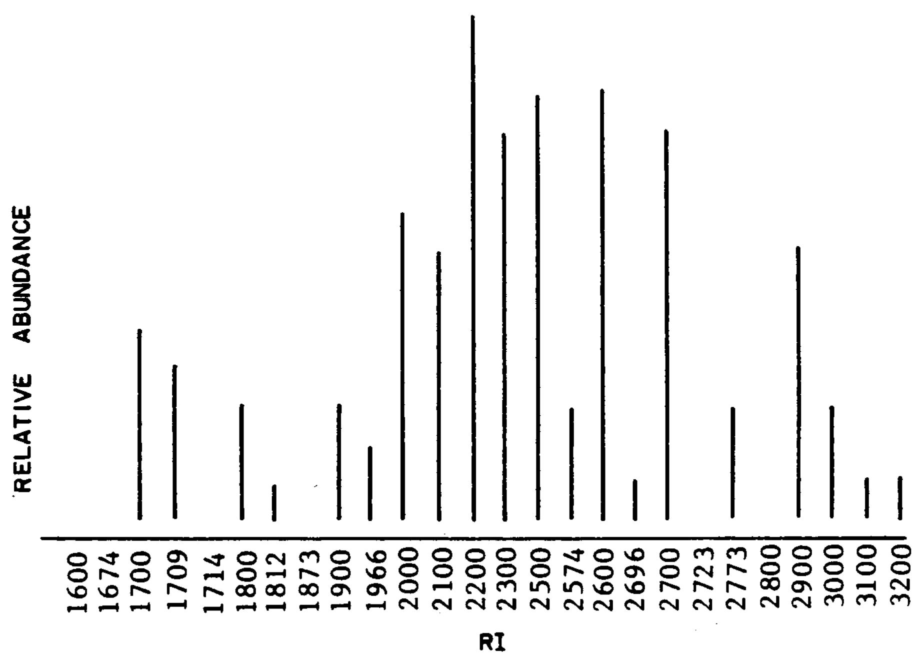


FIGURE 46

HISTOGRAM: 10 MOST ABUNDANT COMPOUNDS FROM EACH SAMPLE
STATION 0007, ALL YEARS

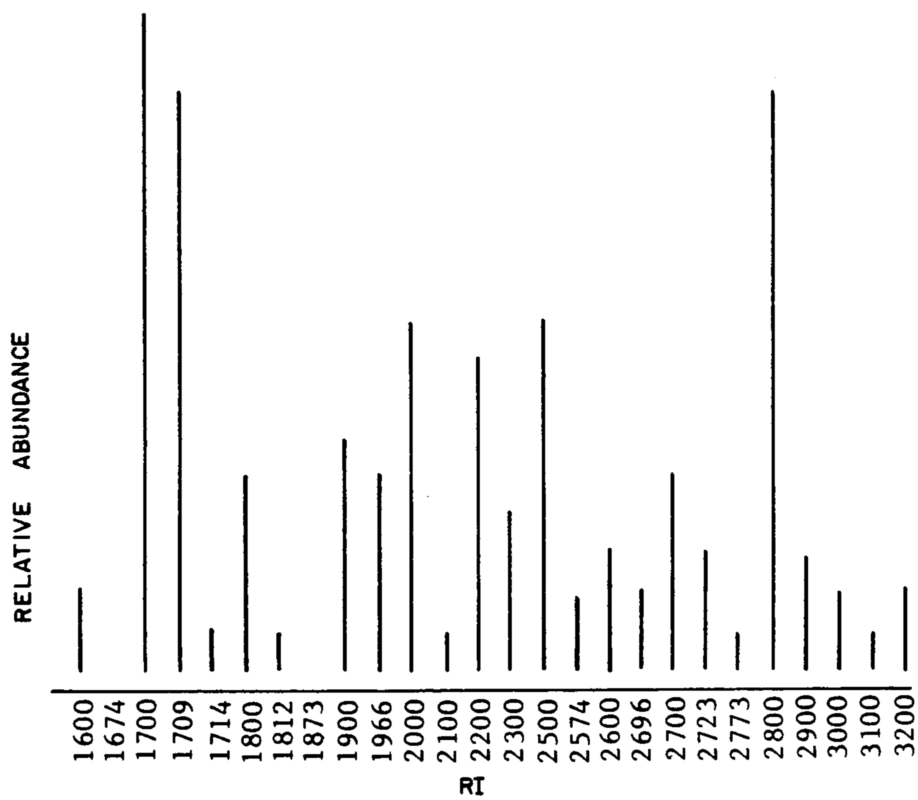


FIGURE 47

HISTOGRAM: 10 MOST ABUNDANT COMPOUNDS FROM EACH SAMPLE
STATION 2209, ALL YEARS

FIGURE 48

GC EXAMPLE OF POSSIBLE BIOGENIC PEAKS n-C-18, 20, 22
FROM *SYACIUM PAPILLOSUM*

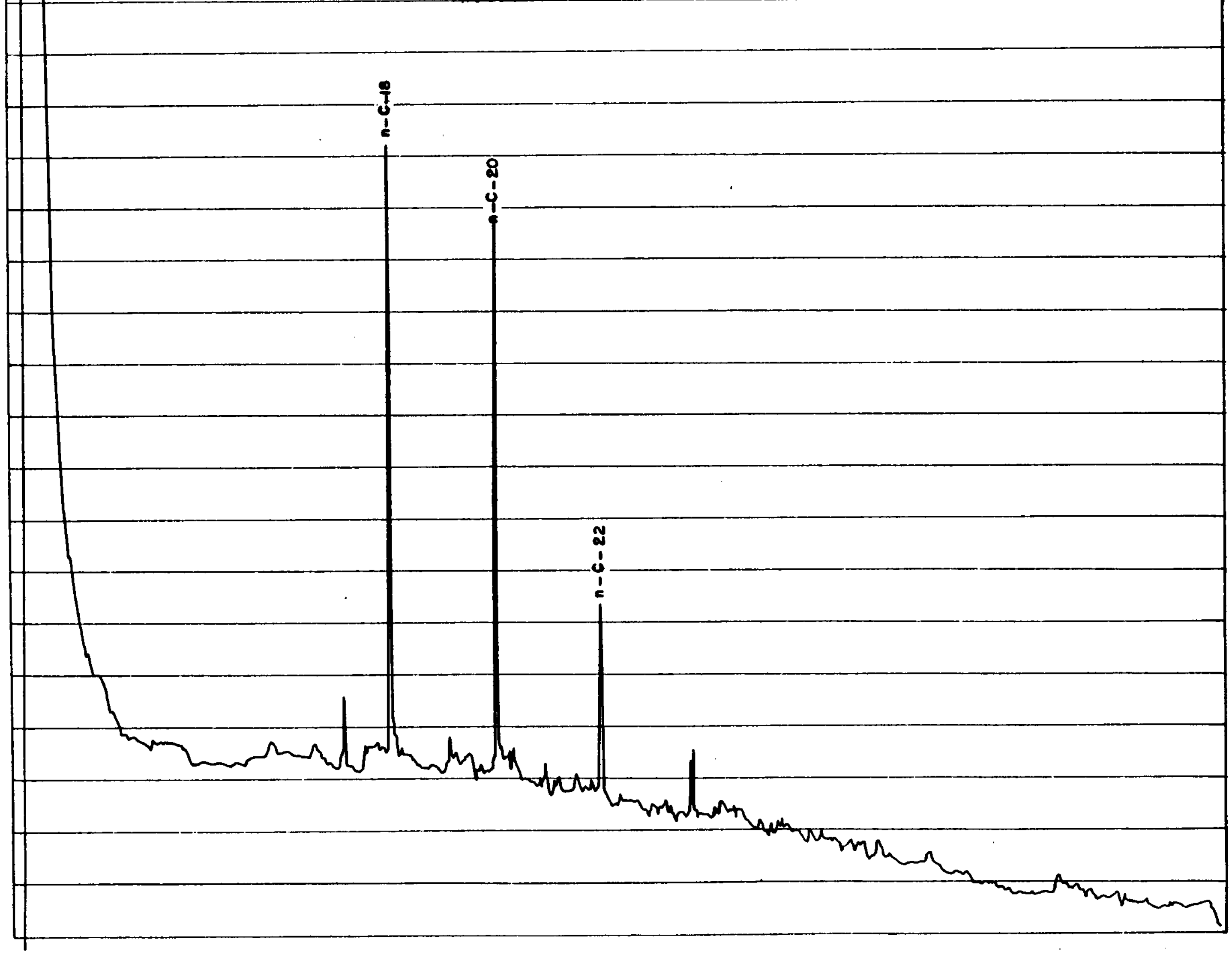


FIGURE 49

GC EXAMPLE OF POSSIBLE BIOGENIC PEAK n-C-28 FROM SYACIUM PAPILLOSUM

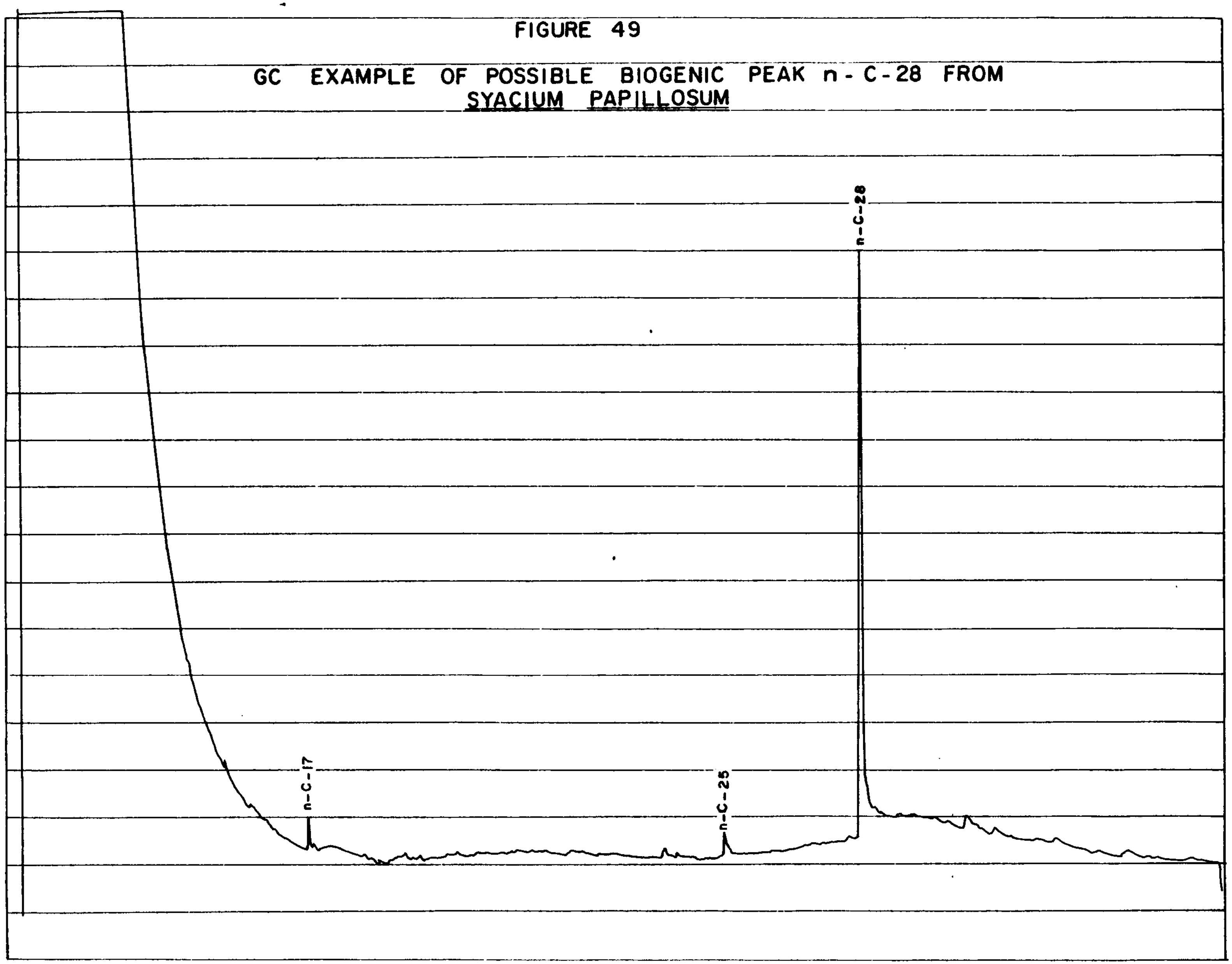
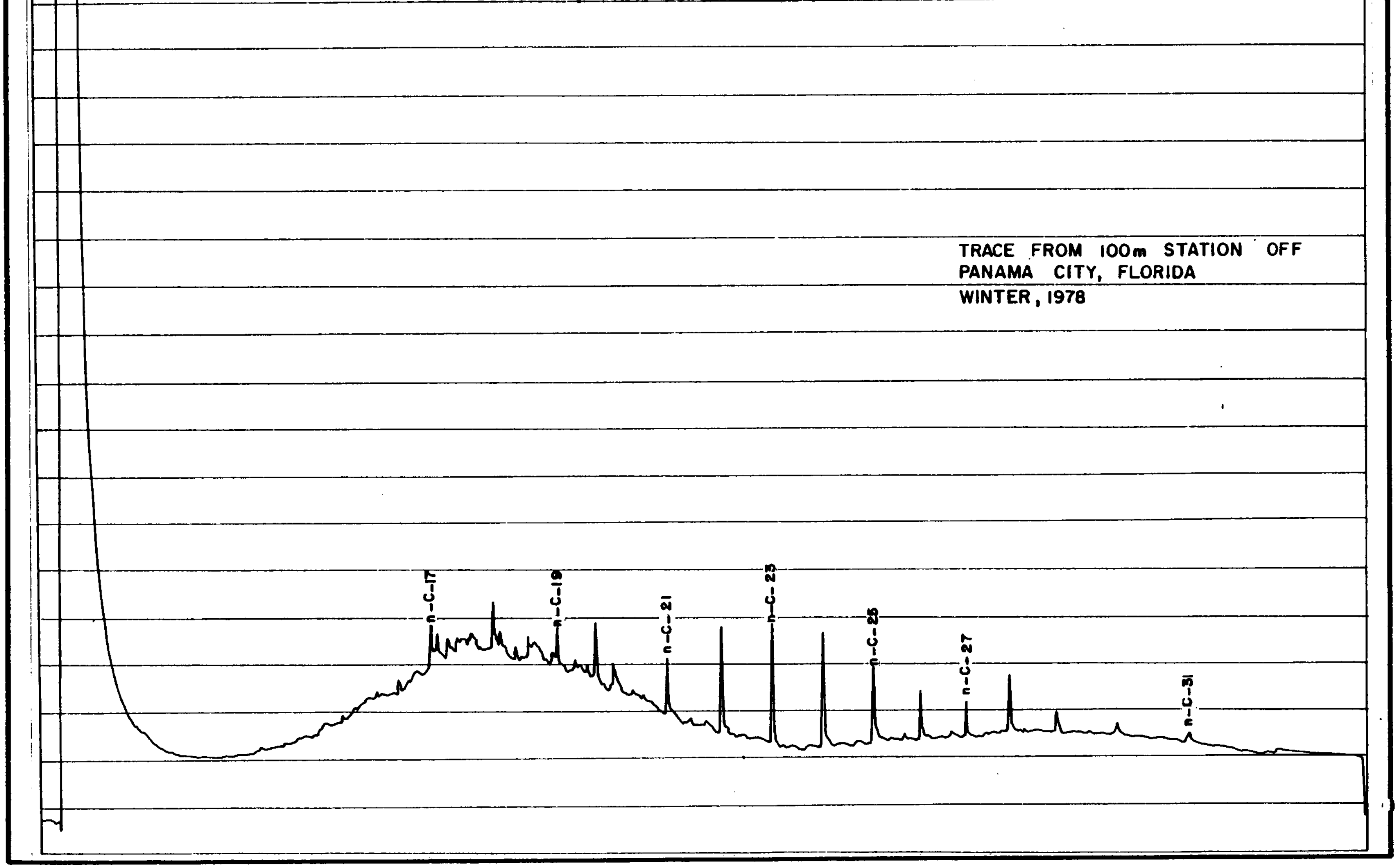


FIGURE 50

UNRESOLVED HUMP AND REGULAR *n*-ALKANE SERIES INDICATIVE OF OIL CONTAMINATION IN *SYACIUM PAPILLOSUM*



Usefulness of Demersal Fish Hydrocabons as a Monitoring Tool

Despite the many problems related to inherent variability, methodology and time considerations, the 1977/78 sampling program has shown that in the MAFLA area the demersal fish (as represented) appear to have very little contamination, and that when contamination does occur it can be detected by the analytical and interpretive means applied here. The baseline Syacium is sufficiently broad in time and geography to use as a before-development standard. Consequently, demersal fish hydrocarbons are strongly recommended as an integral part of a monitoring program. It is apparent that the greatest gap in the existing data base is the lack of samples from other species. Larger, more long-lived species wuld be most useful to sample for determining the extent to which Syacium does represent the MAFLA area demersal fish histochemistry. Data on size and abundance of all fish species collected in this program (see Volume II, Chapter 19) are available from the Dames & Moore Data Tape for purposes of selecting species to monitor.

Hydrocarbons in Macroepifaunal Tissues

Introduction

The general purpose of tissue hydrocabon studies is discussed above, under the section on demersal fish hydrocarbons. Macroepifauna extend those studies to a broad range of species with a wide variety of feeding types. Their inclusion not only allows broadening the scope of species for the purpose of creating a representative data base, but also allows examination of potential food web pathways to the demersal fish.

The macroinvertebrates selected for tissue chemistry analysis are shown in Table 14. That table also lists the range of each species in the MAFLA region and the feeding types. The 57 species represent 5 phyla. They include 9 sponges, 8 molluscs, 17 crustaceans and 22 echinoderms. The species have been selected for their (relative) large size in order to allow sufficient tissue for splitting each individual into aliquots for trace metal and hydrocarbon chemistry. They represent all levels of benthic food webs except primary producers (filter feeders, deposit feeders, mixed predator-deposit feeders and predators are represented). They have been collected from all seasons and all geographic areas.

The two most abundant species analyzed were the shrimp, Sicyonia brevirostris, and the swimming crab, Portunus spinicarpus. The former is expected to be a mixed deposit feeder and predator on small, soft-bodied macroinfauna. The latter is expected to be a predator on other crustaceans, on thin-shelled molluscs and polychaetes. Both have been identified specifically from the stomach contents of the Dusky flounder, Syacium papillosum. Scallops and commercial shrimps were also included in the mix of macroepifauna collected for hydrocarbon and trace metal analysis.

Sample collection for macroepifaunal histochemistry followed the pattern of the demersal fish collections. The difference was that more species (minimum three per transect) and fewer individuals (minimum three as opposed to eleven for demersal fish) were collected. Comments in the

TABLE 14

MACROINVERTEBRATE TISSUE CHEMISTRY SPECIES

SPECIES	COMMON NAME	MAFLA DISTRIBUTION	PROBABLE FEEDING HABITS*
Porifera			
Agelas dispar	Sponge (4)**	2315	Filter feeder
Cinachyra	Sponge (1)	2103	Filter feeder
Craniella	Sponge (6)	FMG***	Filter feeder
Haliclona urceola	Sponge (2)	2103,FMG	Filter feeder
Neofibularia nolitangere	Sponge (1)	2103	Filter feeder
Phyllangia americana	Sponge (1)	2426	Filter feeder
Placospongia carina	Sponge (4)	2103	Filter feeder
Pseudoceratina crassa	Sponge (7)	2103,FMG	Filter feeder
Verongia cauliformis rufa	Sponge (1)	2103	Filter feeder
Cnidaria			
Oculina diffusa	Hard coral†	Mid-transect:I-VI	Plankton predator and symbiotic algae
Mollusca			
Aequipecten glyptus	Scallop (3)	200m Contour:I-VI	Filter feeder
Argopecten gibbus	Scallop (1)	Mid-transect:I-VI	Filter feeder
Lima scabra	Attached clam (1)	Mid-transect:III & IV	Filter feeder

TABLE 14 (CONTINUED)

SPECIES	COMMON NAME	MAFLA DISTRIBUTION	PROBABLE FEEDING HABITS*
Loligo pealeii	Squid (2)	Throughout region	Predator of fish
Murex beauii	Snail (5)	100-200m:I-VI and FMG	Predator on molluscs
Pteria colymbus	Attached clam (1)	100m contour:III-VI and FMG	Filter feeder
Spondylus americanus	Attached clam (6)	40-60m:I-III	Filter feeder
Turgurium caribaeum	Snail (1)	200m:I-V and FMG	Deposit feeder
Crustacea			
Acanthocarpus alexandri	Crab (13)	200m:II-VI	Limited predation, scavenger and deposit feeder
Iliacantha subglobosa	Crab (3)	100-200m:I-VI	Deposit feeder
Mesopenaeus tropicalis	Shrimp (6)	60-200m:I-VI and to 40m:II	Deposit and filter feeder
Munida irrassa	Galatheid crab (3)	40-200m:I-VI	Deposit and filter feeder
Myropsis quinquespinosa	Crab (1)	60-200m:I-VI	Deposit feeder
Paguristes spinipes	Hermit crab (2)	100-200m:I-VI and FMG	Scavenger and predator; may filter feed
Parapenaeus longirostris	Shrimp (6)	40-200m:I-VI	Deposit and filter feeder
Penaeus aztecus	Brown shrimp (1)	40m contour:II-VI	Deposit and filter feeder

TABLE 14 (CONTINUED)

SPECIES	COMMON NAME	MAFLA DISTRIBUTION	PROBABLE FEEDING HABITS*
Penaeus duoarum	Pink shrimp (2)	40m contour:I-VI	Filter and deposit feeder
Penaeus setiferus	White shrimp (1)	40m:II	Filter and deposit feeder
Portunus spinicarpus	Crab (25)	Throughout region	Predator and scavenger
Portunus spinimanus	Crab (4)	40-60m:I-VI	Predator and scavenger
Pyromaia cuspidata	Crab (1)	100-200m:I and V	Deposit feeder and predator
Scyllarus chacei	Slipper lobster (2)	40-150m:I-VI	Deposit feeder and predator
Sicyonia brevirostris	Shrimp (22)	Throughout region except 200m contour	Deposit and filter feeder
Solenocera atlantidis	Shrimp (5)	Throughout region	Deposit and filter feeder
Stenorhynchus seticornis	Crab (6)	Throughout region except 200m contour	Deposit feeder and predator
Echinodermata			
Anthenoides piercei	Starfish (1)	60-200m:I-VI and FMG	Deposit feeder and predator
Araeosoma violaceum	Sea urchin (2)	150-200m:I	Deposit feeder
Arbacea punctulata	Sea urchin (2)	40-60m:I-VI	Algae and deposit feeder
Astrocyclus	Basket star	100-200m:III-VI	Deposit feeder
Astropecten articulatus	Starfish (1)	40m contour:I-VI	Predator

TABLE 14 (CONTINUED)

SPECIES	COMMON NAME	MAFLA DISTRIBUTION	PROBABLE FEEDING HABITS*
Astropecten duplicatus	Starfish (3)	40-60m:I-VI	Predator
Astropecten nitidus	Starfish (4)	40-200m:I-VI	Predator
Astrophyton muricatum	Basket star (2)	2103 and FMG	Deposit feeder
Astroporpa annulata	Basket star (15)	60-100m:I-VI	Deposit feeder
Benthopecten claviger	Starfish (1)	200m:I	Predator and deposit feeder
Clypeaster ravenelli	Sand dollar (17)	60-100m:II-VI and FMG; 200m VI	Deposit feeder
Comactinia meridionalis	Crinoid (4)	60m:I, II and VI	Filter feeder
Diadema antillarum	Sea urchin (1)	40-100m:III-VI	Deposit and algae feeder
Encope michelini	Sand dollar (2)	40m:I-IV	Deposit feeder
Echinaster	Starfish (1)	40-60m:I-V	Deposit feeder
Eucidaris tribuloides	Sea urchin (8)	40m contour:I-VI	Deposit and algae feeder
Goniaster tesselatus	Starfish (3)	40-100m:II-VI	Deposit feeder; may be predator
Henrecia	Starfish (1)	40-100m:I-VI	Deposit feeder
Luidia clathrata	Starfish (8)	40-60m:I-VI	Predator
Lytechinus variegatus	Sea urchin (6)	40-100m:I-VI	Deposit and algae feeder

TABLE 14 (CONTINUED)

SPECIES	COMMON NAME	MAFLA DISTRIBUTION	PROBABLE FEEDING HABITS*
Ophioderma januarii	Brittle star	40m contour:I-VI	Deposit feeder
Stylocidaris affinis	Sea urchin (10)	40-100m:I-VI 200m:VI	Deposit feeder and browser

* Based on known feeding habits of the taxonomic group

** Number in parentheses ( ) indicates number of analyses of trace metals; hydrocarbon analyses were fewer due to very small size of available animals

*** FMG = Florida Middle Grounds

† No analyses were run due to insufficient tissue in sample

preceding section relative to the prior MAFLA work on demersal fish, and on the limitations on the data use also apply here.

Results and Discussion

The questions to be answered about macroepifaunal hydrocarbon chemistry are:

- Can the results of the fish analyses be extended to the macroinvertebrates?
- Are the macroinvertebrates contaminated by petrogenic hydrocarbons?
- What are the sources of variability in macroepifaunal hydrocarbons?

In answering these questions, the major advantage of the macroepifaunal studies over the demersal fish studies (variety of species) is related to its greatest weakness (lack of abundant replication, especially over broad geographic areas; Bieri, Volume II, Chapter 9, elaborates on this problem). Consequently, the kinds of pooling that could be done for the demersal fish cannot be applied here, due to the known inherent differences between species.

Cluster analysis of all transects with each season entered separately, indicated that the major sources of variation in hydrocarbon content were (in decreasing order) species variety, feeding type, geographic location and season. The macroepifaunal GC traces support the general conclusion of the demersal fish section, that petroleum hydrocarbons in tissues were not common. There were no clear indications of oil related hydrocarbon contamination in the macroepifauna, and probable biogenic compounds generally dominated the GC traces.

Pure filter feeders (see Table 14) show compounds RI ~2800, 1700, 3200 and pristane as most abundant hydrocarbons. These probably reflect their intake of plankton as a primary food source (see Figure 51, below of zooplankton hydrocarbon occurrence). Most the n-C-17 (RI ~ 1700) and pristane were from four species with the remaining eleven filter feeders showing essentially flat GC traces. Most of the mixed deposit feeders-predators (e.g., most of the shrimps and crabs) showed high peaks at RI ~ 2800, with low levels at RI 2100 and 2300. The pristane, n-C-17 and RI 2000, 2200, 2500, and 2700 peaks were similar frequency, at about one-half the frequency of the 2800 peak. In this regard, they are very similar to the pooled results for the demersal fish, whose prey they represent. Bieri (Volume II, Chapter 9) cautions against making a firm conclusion in that regard.

No evidence of the petroleum contamination found in demersal fish from Transevt V was evident in the macroepifauna. The abundance and variety of both branched alkanes and olefins were greater in macroepifauna than in fish. The pristine condition of the macroepifaunal tissue hydrocarbon results is consistent with the histopathology findings (below, and see Blake, Volume II, Chapter 18).

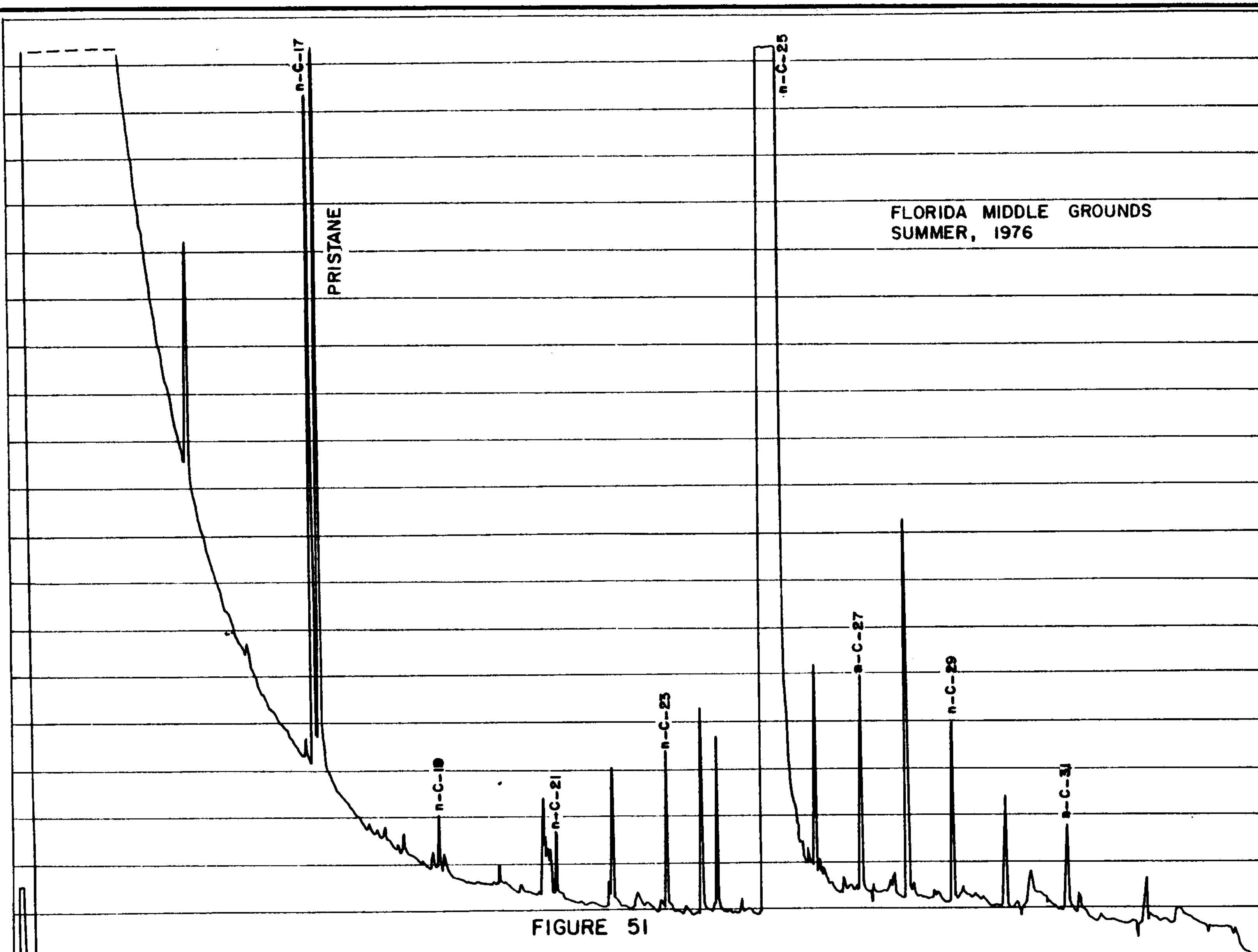


FIGURE 51

GC TRACE FROM ZOOPLANKTON SHOWING OVERWHELMING DOMINANCE OF n-C-25 AND n-ALKANE SERIES OF POTENTIAL OIL ORIGIN

Usefulness of Macroepifaunal Hydrocarbons as a Monitoring Tool

As with the demersal fish, it can be said that a wide array of obstacles, including much greater inherent (species specific) variability was surmounted in the macroepifaunal tissue hydrocarbon analyses, and that several concrete results germane to baseline condition description and monitoring planning were realized. As a result, inclusion of macroepifauna in a histochemistry monitoring program would be recommended. The major disadvantage in the MAFLA area is that abundant, wide spread species tend to be of small size, and thus, create additional analytical problems. For monitoring purposes, it would be recommended that fewer species be used. The following would appear to offer a combination of availability and geographic coverage:

Portunus spinicarpus: (swimming crab)	Throughout region in good numbers, a predator
Sicyonia brevirostris: (shrimp)	Throughout region in 100 m and less, in moderate numbers, and a mixed deposit/filter feeder
Papapenaeus longirostris: (shrimp)	40 to 200 m, throughout the region, in moderate numbers, a mixed deposit/ filter feeder
Acanthocarpus alexandri: (crab)	200 m throughout the region, in good numbers, a mixed predator/deposit feeder
Astroporpa annulata: (basket star)	Mid-depths throughout the region, in good numbers, a deposit feeder
Clypeaster ravenelli: (sand dollar)	Mid-depths Transects II-VI, in good numbers, a deposit feeder
Aequipecten glyptus: (scallop)	200 m contour throughout the region, in good numbers, a filter feeder

Specific abundance and distributional data on these and the other macroepifaunal species are contained in the Dame & Moore Data Tape.

Hydrocarbons in Zooplankton

Introduction

Zooplankton are the most likely part of the fauna to be exposed first to man-induced oil and gas development related contaminants. Many of them are filter feeders and would have an opportunity for either or both of partitioning or ingestion mediated uptake of hydrocarbons. Results of the zooplankton hydrocarbon data can be used to corroborate both dissolved and particulate hydrocarbon data, and the zooplankton represent a mechanism for distributing hydrocarbons to the benthic envirnoment.

Prior zooplankton hydrocarbon data in the MAFLA area are those reported in SUSIO (1977). The data base in the 1977/78 study included limited time series samples (four each day for five days) from one station (Florida Middle Grounds) collected by double oblique tows (surface to bottom and back) in two time periods (summer 76 and winter 78). Zooplankton taxonomy samples were taken during the same time period to allow some intercomparison.

Results and Discussion

Despite the known variability of zooplankton in ocean waters (see zooplankton ecology section, below) and the high variability in plankton composition shown in this program (see zooplankton section) even in the very homogenous water mass conditions of the winter 78 samples at the Middle Grounds (see physical oceanography, above, and Fausak, Volume II, Chapter 20), the results of the zooplankton hydrocarbon analyses were strikingly similar to one another.

The samples were generally dominated by pristane with smaller amounts of RI ~ 2080. Summer 76 samples had high concentratons of n-C-17, but it was nearly absent in winter 78 samples. On the other hand, n-C-17 was abundant in winter 78 samples and nearly absent in samples from summer 76 (see Figure 51). The pristane is biosynthesized by zooplankton (Bieri, Volume II, Chapter 9), but the RI ~ 1700 and 1900 compounds probably represent alteration of phytoplankton hydrocarbons. All are expected to be biogenic. The peak at RI 2080 is also suggested to be of biogenic origin. In Figure 51 the peak at RI ~ 2500 overwhelms the sample. This peak can also be seen dominating Figure 48 from the demersal fish hydrocarbons, and is probably of biogenic origin. The run of n-alkanes in Figure 51 suggests a possible oil contamination input, but there is no large UCM "hump" accompanying the n-alkanes.

In general, the zooplankton hydrocarbons corroborate the results of Florida Middle Grounds dissolved and particulate hydrocarbon fraction analyses (above) and appear to show links both up and down their food webs. The broad scale variability in plankton composition is not expressed in their hydrocarbon composition.

Usefulness of Zooplankton Hydrocarbons as a Monitoring Tool

As a demonstrated link between hydrocarbon composition of phytoplankton and benthic species, it is recommended that zooplankton hydrocarbons be included in oil or gas development monitoring programs in the MAFLA area. To be of use, however, samples from more locations and more time periods need to be examined. In addition, the samples should be stratified within the water column to fix the depth of mixing by zooplankton of any induced hydrocarbon contamination. Lastly, it should be realized that these are not really "zooplankton" results, but towed-net-collected suspended particulate results, including zooplankton, phytoplankton and inanimate suspended particulates.

TRACE METALS

Trace Metals in Zooplankton

Introduction

Zooplankton, in their role as active feeders in the water column and especially surface layers, might be expected to be sensitive indicators of trace metals (as well as other) contamination from petroleum exploration, development, and production activities. The zooplankton utilize suspended particulates (including phytoplankton) and each other as food sources, and thereby may ingest and to some degree concentrate trace metal pollutants; they aide in extracting particulates and incorporating them into larger particles (fecal pellets, exoskeletons and their own tissues) which may settle more rapidly than the fine particulates.

MAFLA OCS data considered here consisted of 15 samples from summer 75, 16 samples from fall 75, 15 samples from winter 76, 20 samples from summer 76, and 18 samples from winter 78. Data from the first three cruises were obtained from stations along transects such that there was broad geographic coverage but no sample replication. The data from the last two cruises (summer 76 and winter 78) were collected at the Florida Middle Grounds Station only, but over five-day periods (four samples per day). Metals analysed were cadium (Cd), copper (Cu), chromium (Cr), iron (Fe), lead (Pb), nickel (Ni), zinc (Zn), barium (Ba), and vanadium (V). It should be noted that the data represented results from a very mixed assemblage of zooplankton, phytoplankton, and fish larvae, as well as inorganic particulates; as noted earlier, these results are not from zooplankton, per se, but are from particulates sampled throughout the water column with a towed net.

Results and Discussion

The mean concentrations of nine metals in mixed zooplankton samples from the northeastern Gulf of Mexico are presented in Table 15, which includes data from other investigators as well as from the current MAFLA program (including analysis of samples collected in summer 76).

Ba and V values were determined by neutron activation analysis, while all others resulted from atomic absorption spectroscopy. For details of the methods and results, see Betzer et al. (Volume II, Chapter 22) and Shokes et al. (Volume II, Chapter 23).

Results compare most favorably to these reported by Martin and Knauer (1973) for the open Pacific and with some of the other authors, although some differences are noted. The determinations of lead and iron in zooplankton values are substantially lower than those reported by most other investigators. Possible explanations for these differences include the proximity of their sampling areas to regions of high terrigenous input or from contamination. MAFLA samples taken during winter 76 near the mouth of the Mississippi and Mobile Rivers illustrate the impact that terrigenous (clay) material can have on the iron content of zooplankton. Here, the mean iron content of the zooplankton samples was nine times greater than the

TABLE 15

AVERAGE METAL CONCENTRATIONS OF MIXED ZOOPLANKTON FROM BLM SURVEYS (1975-1977) IN NORTHEASTERN GULF OF MEXICO AND COMPARISONS WITH OTHER STUDIES

	Ba	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn
N.W. Gulf of Mexico(1)	--	1.9*	--	16.2	1,181	3.9	10.0	--	91.0
Mediterranean(2)	--	0.74	0.85	48.0	64	0.66	1.1	--	62.0
Monterey Bay (Cal.)(3)	--	6.2	<1	5.4	344	3.9	6.9	--	88.5
Eastern Pacific and Hawaii(3)	--	2.3	<1	11.5	100	8.4	2.1	--	180.0
Clyde Sea(4)	--	1.0	--	16.2	--	--	15.0	--	228.0
Puerto Rico (Caribbean Sea)(5)	--	--	--	41.0	1,200	42.0	49.3	--	428.0
BLM-1 Spring-Summer (1975)	--	7.0	0.7	15.0	137	2.08	1.87	--	--
BLM-2 Fall (1975)	--	8.5	0.9	22.4	92	3.76	2.44	--	--
BLM-3 Winter (1976)	--	5.8	0.8	16.6	439	2.41	2.34	--	--
BLM-4 Summer (1976)	69.0	1.9	0.8	29.3	102	2.76	5.27	1.3	80.0
DM III February (1978)**	5.4	2.5	0.8	42.3	191	3.70	2.60	2.0	71.1

*Concentration in ppm dry weight.
**Sample Zp 14 was excluded because of suspected point contamination (see Betzer, Volume II, Chapter 22).

(1) Sims, 1975; (2) Fowler, 1977; (3) Martin and Knauer; 1973; (4) Topping, 1972; (5) Martin, 1970.

winter mean. Suspended material, collected at the same stations as zooplankton tows, was characterized by iron levels that were five times greater in the Mississippi-Mobile area than in the other areas sampled. Therefore, it would appear that inputs of terrigenous material with higher elemental levels can at times affect the apparent chemical composition of zooplankton samples. Again, however, it is not possible in these samples to separate ingested or adherent particulates from the zooplankton tissues, and these data must be considered in that light.

The cadmium concentrations in zooplankton also showed interesting changes that are not so readily explained. Mean cadmium concentrations for the three transect cruises were more than twice those taken on the time series cruises of July 1976 and February 1977, and from those of other investigators. It is possible that the large standard deviations around the mean metal concentratons for the transect cruises of the MAFLA studies (SUSIO, 1977) are related to the species composition of the zooplankton living in offshore versus inshore areas. The onshore/offshore zooplankton difference is discussed in the plankton section of the marine biology discussion, below, and may be related to differences in productivity (El Sayed et al., 1972). In fact, there is some evidence from the transect cruises that the zooplankton species composition in inshore communities were distinct from those of offshore areas (SUSIO, 1977).

The mean barium values in the plankton samples from the summer 76 cruise (BLM-4) were significantly higher than those from the winter 78 cruise (DM III), 69 ppm vs 5.4 ppm, respectively. The probable explanation is that the plankton samples from the summer consisted mostly of zooplankton, while those collected in the winter were dominated by phytoplankton. The biomass of zooplankton was relatively high in the summer and at a minimum in the winter, whereas phytoplankton was most abundant in middle to late winter. Zooplankton, which include some organisms with calcareous inclusions in their skeletons, have been shown to concentrate barium to elevated levels (Martin and Knauer, 1973). The elevated barium levels in the plankton from BLM-4 were, therefore, most likely related to the difference in species composition between summer and winter.

Vanadium levels in plankton remained similar through both sampling periods, with all values being relatively low (0.32 to 2.9 ppm). The time of day in which plankton samples were collected was apparently not responsible for any trends in either barium or vanadium concentrations. A few trends are noteworthy. First, variation in barium during the summer was greater than during the winter, and the concentrations were generally higher. No trends at all existed with time of day, but even though the variation (1 standard deviation) estimates were large, the first day's collections from the summer 76 cruise (7/23) apparently provided samples of substantially higher barium relative to the other (consecutive) days of sampling. Vanadium, on the other hand, was remarkably consistent for all days of sampling. Vanadium, on the other hand, was remarkably consistent for all days and at all times of the day. The cause of the unusually high barium levels found on 7/23 were not apparent. Although previous studies have measured barium and vanadium concentrations in plankton, few efforts exist with which to compare the present values, since most prior analytical methods have been relatively insensitive (Nicholls et al., 1959;

Vinogradov, 1953). However, Betzer and Peacock (in SUSIO 1977) determined a mean vanadium concentration in plankton at the Florida Middle Grounds of 1.9 ppm (by atomic absorption spectrophotometry) compared to 1.6 ppm determined in this survey.

The statistical results for the elemental zooplankton composition from the time series cruises indicate that, based on their variation about the mean, there are two groups of elements. The first group, Cd, Cr, Fe, Ni, and Pb have standard deviations less than 50% of the mean. The second group includes Cu and Zn, which have standard deviations greater than 50% of the mean. The large variances in copper and zinc concentrations may have resulted from contamination by brass flakes and/or anti-fouling paint (see Betzer et al., Volume II, Chapter 22).

Usefulness of Zooplankton Trace Metals as a Monitoring Tool

The collection of zooplankton samples is subject to potentially severe contamination problems which are extremely difficult to avoid given the present sampling state-of-the-art. Furthermore, the compositional makup of the collected sample is unknown and would be time consuming to ascertain (and would, in fact, introduce yet another possible avenue of contamination). Nonetheless, the importance of plankton as front-line indicators of pollution, and their role as concentrators and conveyors of particulates to the benthic environment, argue for their continued analyses as part of a monitoring program. The value of the data would be increased substantially by identification and segregation of species within a sample, and exclusion of detritus.

Trace Metals in Suspended Particulates

Introduction

Suspended particulates support the major flux of several metals through the marine environment. Metals enter the marine system either already associated with particles or as dissolved ionic species which, at the ionic strength of seawater, partition effectively to the particulate phase. Marine particulates consist primarily of a combination of land-derived detritus and plankton mediated materials (either living or dead). For the most part, metals associated with these kinds of particles are either absorbed onto their surfaces, bound into their mineralogical phases, or incorporated into biological particles.

The following metals were analyzed from suspended particulate samples in the 1977/78 MAFLA program: alluminum (Al), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), nickel (Ni), silicon (Si), vanadium (V), and zinc (Zn). Concentrations of Ba and V were determined by neutron activation analysis; all other were analyzed by atomic absorption spectroscopy. Metals were separated into those fractions that were soluble in weak acetic acid, and thereby presumably available to organisms, and those remaining after acid leaching (the refractory fractions). Values for Ni were in all cases below detection limits of atomic absorption spectroscopy (100-140 ppb Ni/absorbance unit); increased volumes of suspended material retained on the filters would have allowed detection of Ni. Concentrations of zinc were not determined because of systematic errors in the laboratory, where zinc contaminants were introduced from polypropylene volumetric flasks (see Betzer, in minutes, second quarterly meeting and Summary of Problems Encountered, p. 8, second quarterly report, Dames & Moore, 1978b).

The immediate provenance for most metals entering the marine system is one of three input sources: atmospheric fallout, inflow from streams, rivers or outfalls, and at-sea discharge or spillage from vessels, platforms, or pipelines. Many of the metals of concern, such as copper, iron, and zinc are physiologically essential micronutrients for marine life, but are highly toxic in increased concentrations (see Johnson, Volume II, Chapter 6).

It is difficult to ascertain normal or expected ambient concentrations of metals for suspended particulates, because trace metal burdens and partitioning metals between the solid and dissolved phases in the water column are dependent upon local fluctuations in salinity, total suspended materials, level of biological productivity, and equilibria with other chemical factors. Additionally, the concentrations of metals found in this study were very close to the elemental detection limits of the analytical techniques used, resulting in high relative analytical errors. At such extremely low levels of concentration even minute amounts of contamination from sampling and analytical processes may overwhelm natural levels.

The data set used in this report was derived from 180 samples obtained during three cruises: summer 76, fall 77, and winter 78. The summer 76 samples were collected more than a year earlier than the last two sample sets.

Results and Discussion

Table 16 shows average concentrations and ranges of concentration of 12 metals in suspended sediments from the MAFLA area (extracted from the reports of Betzer and Shokes in Volume II of this report). Also given is the estimated standard deviation, based on the method of Tate and Clelland (1954). The values reported represent mean values for all stations, all cruises, surface and bottom samples. A comparison of the values from the MAFLA OCS with other reported values shows that, in spite of the variability of the MAFLA data (often one or two orders of magnitude), the mean values were generally less than previously reported data. The MAFLA region in general appeared to be pristine and uncontaminated by trace metals (Volume II, Chapters 22 and 23).

Several trends appeared in the data set but most were weak and had many exceptions:

1. The highest concentrations of most metals were found during the fall 77 period; the lowest tended to occur most often in the data from summer 76. Total suspended material was lower in the fall 77 samples than for the other two periods.

TABLE 16

TRACE METAL CONCENTRATIONS FROM THE MAFLA AREA, 1977/78[1]
Suspended Sediments

	Mean of Means	Range of Means	Estimated Standard Deviation[2]
AL	17.825*	1.268 - 89.000	21.933
Ba	<0.462	BDL[3] - 3.000	0.750
Ca	19.862	1.720 - 193.492	47.943
Cd	0.024	0.001 - 0.149	0.037
Cr	0.154	0.002 - 0.695	0.173
Cu	0.126	0.124 - 0.487	0.116
Fe	11.127	1.556 - 42.816	10.315
Ni	BDL	---	---
Pb	0.120	0.019 - 0.447	0.107
Si	92.468	17.603 - 206.452	47.212
V	79.000	BDL - 0.250	0.063
Zn	---	---	---

(1) Data from Final Reports of Betzer and Shokes, Volume II, Chapters 22 and 23, of this report
(2) Estimated standard deviation from Tate and Clelland (1954)
(3) BDL = below detection limits
* All values of $\mu g \cdot \ell^{-1}$

2. Although total suspended materials were more abundant off Mobile relative to the other stations, there was no apparent systematic increase in trace metal levels approaching Mobile. The Mobile station showed highest levels of Al, Fe, and Si, and lowest Ca, all of which would appear to be related to high terrigenous input.

3. The composition of material resuspended from bottom sediments was generally higher in its metal content than the underlying sediments. This suggested preferential resuspension of the fine-grained, metal-rich bottom material relative to the coarser, metal-poor carbonate sediments.

4. Barium concentrations were highest at the Florida Middle Grounds station, and may reflect the tendency for Ba to substitute for Ca in carbonate skeletal material (see Shokes, Volume II, Chapter 4B). Ba also showed a trend toward higher concentration in near-surface water.

5. Aluminum and silicon consistently showed lower concentrations at the surface than at the bottom. Other metals did not appear to exhibit that pattern with depth, and in some cases (notably Ba), the trend seemed to be reversed, with higher near-surface concentrations.

6. Short-term variability in trace metal burdens can be large with order of magnitude changes occurring over a period of only a few hours. There did not appear to be statistically significant, systematic changes in metal concentration with time of day. There were suggestions of increasing trends over periods of days (e.g., Ba), but the variability between successive samples was so great that the trend may not be real.

Because of the high variability in the suspended material trace metal data, it is difficult to make useful generalizations concerning causes for the observed distributions. It is interesting to note, however, that during the fall 77, when maxima occurred for nine of the ten metals for which data were available, the Loop Current had its maximum observed intrusion onto the shelf. If that observaton is valid it suggests one of two things; either that the Loop Current is entraining waters rich in trace metals from the Mississippi River and transporting them eastward and southward, or that Loop Current waters are inherently high in some trace metals. The results of Slowey and Hood (1971) argue for the latter.

Usefulness of Particulate Trace Metal Analysis as a Monitoring Tool

In spite of the high variability of trace metal content in suspended particulates, the potential for use of selected metals as environmental indicators is great. The problems associated with sample collection, handling and analysis, particularly contamination problems, appear to be less severe and more easily quantifiable than those associated with towed-net particulate trace metal analyses. Some metals, namely barium and vanadium, can be directly linked through relatively well-defined pathways to petroleum development and production and to crude and refined products. The relationship of the other metals to offshore development is discussed in the introduction to the marine chemistry section.

Trace Metals in Demersal Fish Tissues

Introduction

In the introduction to the marine chemistry section, the trace metals analyzed in this program and their utility in a baseline study are discussed. Also discussed in the secton dealing with hydrocarbons of demersal fish tissues is the population structure and descriptive ecology of the Dusky Flounder (*Syacium papillosum*), the fish used in this study.

In the context of this baseline survey, trace metals in demersal fish are studied to provide an estimation of natural variation in the tissue burden of possible oil and gas development related pollutants, and to aid in the design of monitoring programs. In addition, relationships established in the study of the relatively more simple suite of nine metals may be applied to understanding relationships between tissue hydrocarbons and the environment.

Trace metals of demersal fish were not studied in the prior MAFLA program, and there were no comparable studies in the eastern Gulf of Mexico before the BLM studies began. Johnson (Volume II, Chapter 6) cites the work of Horowitz and Presley (1977) and National Marine Fisheries Services (1975) in the western Gulf as the most applicable studies in the region.

The data set for the 1977/78 contract consisted of subsamples of the same specimens used for hydrocarbons analyses (see above). Due to the ability of the trace metal methodologies used in this program to obtain reliable results with smaller amounts of tissue (than the hydrocarbons), the problem of very small tissue quantities was less an impact on these results. Any 100 m or shallower station in the MAFLA area would be able to provide a specimen of *Syacium* in any season which would be large enough to allow analysis of the full suite of trace metals.

Laboratory calibration was performed on National Bureau of Standards reference samples (see ARLI, Volume II, Chapter 5). Sample blanks were also run by ARLI. The analytical variation for MAFLA samples was generally between that of the sample blanks and that of the standard, indicating acceptable within-treatment analytical precision. ARLI's determinations of NBS standards were within expected analytical range indicating acceptable analytical accuracy for all metals tested.

Results and Discussion

The means of each metal in *Syacium* for each of the sample sets winter 78, fall 77, summer 77, are shown in Figure 52 in relation to the overall sample mean, and with the ± 1 standard deviation bars indicated (sample size from the summer 76 collection was too low to calculate or estimate the standard deviation). Barium and iron were lower than the pooled mean in the

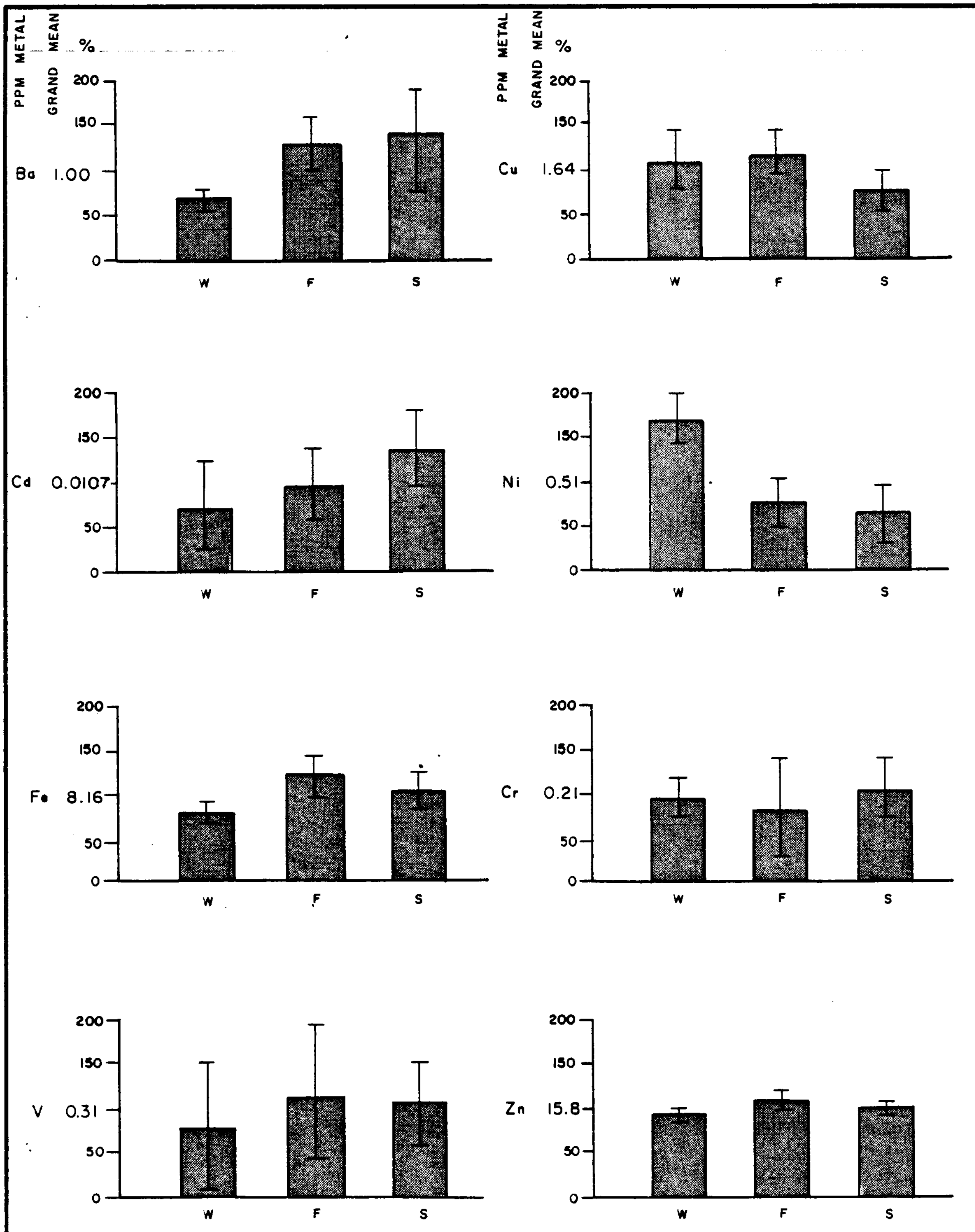


FIGURE 52

SEASONAL PLOTS FOR SYACIUM DM IV, II, I
TRACE METALS

February 1978 samples while copper and nickel were lower in the summer (1 S.D. bar does not cross mean). Lead results were nearly all below the 0.3 ppm detection limits and less than 0.1 ppm in more than one-third of the samples. For the remaining metals the analytical variation plus the natural variation combined to make between-collection comparisons non-significant. Where comparisons with other Gulf studies were available, these values were equivalent or lower by a fraction of between 1 and 20. Levels of trace metals can be seen to be generally low in the tissues of Syacium in the eastern Gulf, and the metals can be seen to behave differently in their short-term temporal variability. Johnson and Shokes (Volume II, Chapter 6 and 7) suggest the change in metal values between seasons may be diet related.

Shokes found no geographic trends in the distribution of Ba or V in Syacium (Volume II, Chapter 6). Johnson subjected the remaining metals to ordination analysis. In this analysis a single point represents each collection location in a two-dimensional space. The position of the point is based on the similarity of seven pooled metal values in Syacium tissues, and all specimens for each station were considered in a single pool. The resulting array indicates similarity of sources of variation in trace metals, with the proximity of points denoting similarity of tissue trace metals (Figure 53). In an independent analysis the stations had been classified into groups based on the similarity of these same trace metals in the sediments of these locations. Then the points representing tissue trace metal similarities were enclosed by boundaries drawn on the basis of the similarities of each station by sediment trace metals (weak acid soluble fractions; classes called B, C, and E in this case). Non-overlap of the boundaries of the envelopes indicates very high covariance of weak-acid soluble (available) trace metals in sediments and those in the tissues of Syacium in the same station groups. The three stations which lie outside the bounds of the sediment classes are stations which had no samples for sediment trace metals (dredge/trawl stations were not always coincident with box-core stations; see Figure 1). Considering the amount of variability associated with analytical error (see Johnson, Volume II, Chapter 6) this close relationship is highly remarkable, and indicates strongly that Syacium tissue trace metal burdens are very closely related to local sediment available trace metal concentrations.

To determine the general trend of the relationship between geographic location and individual trace metal behavior in Syacium tissues, Johnson plotted a one-dimensional array of stations in which position along the line indicates similarity of locations on the basis of sediment trace metals against mean concentration of each metal at those stations for Syacium tissues. Significant positive or negative linear trends of the tissues single metal values along the locational similarity gradient indicate that the geographic similarity is expressed by a cline in concentration of the measured metal in the tissues. Figures 54 and 55 show the two trends which appeared. Cr (and Cd, Ba, Cr, Fe, and Zn) showed a positive correlation between the sediment available trace metal similarity progression and tissue metals, i.e., the source of variation which makes stations similar on the basis of their sediment trace metals expresses itself in an increase in tissue trace metal levels. The same station similarity trend reflects a decrease in tissue levels of Cu and Ni (Figure 55 and see Figures 6a and 6b

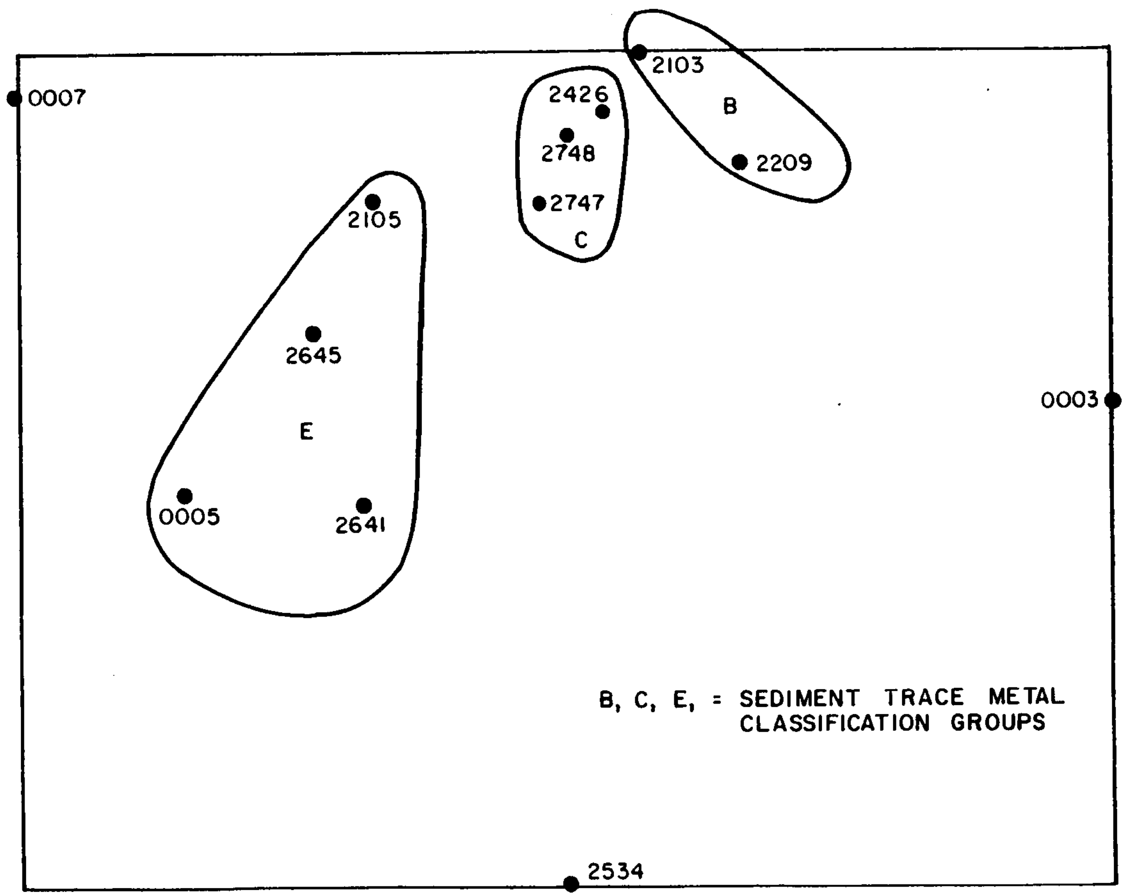


FIGURE 53

BRAY CURTIS Q MODE CLUSTER OF 6 TRACE METALS IN *SYACIUM* PLOTTED IN ORDINATION

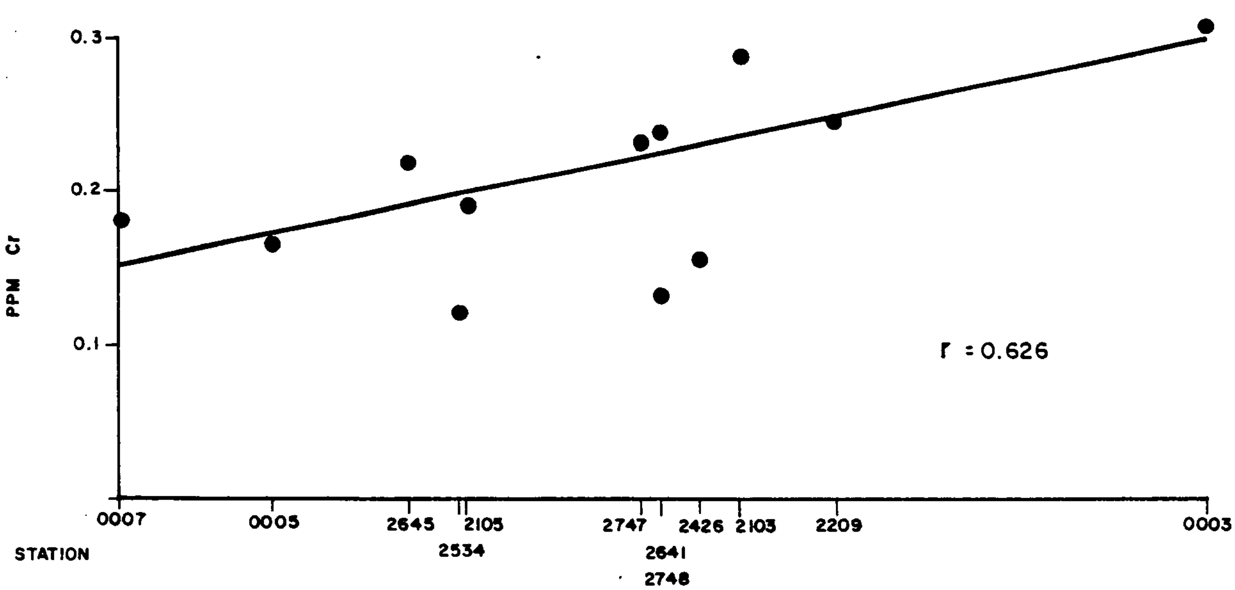


FIGURE 54

MEAN Cr IN SYACIUM VS STATION

BRAY CURTIS Q MODE

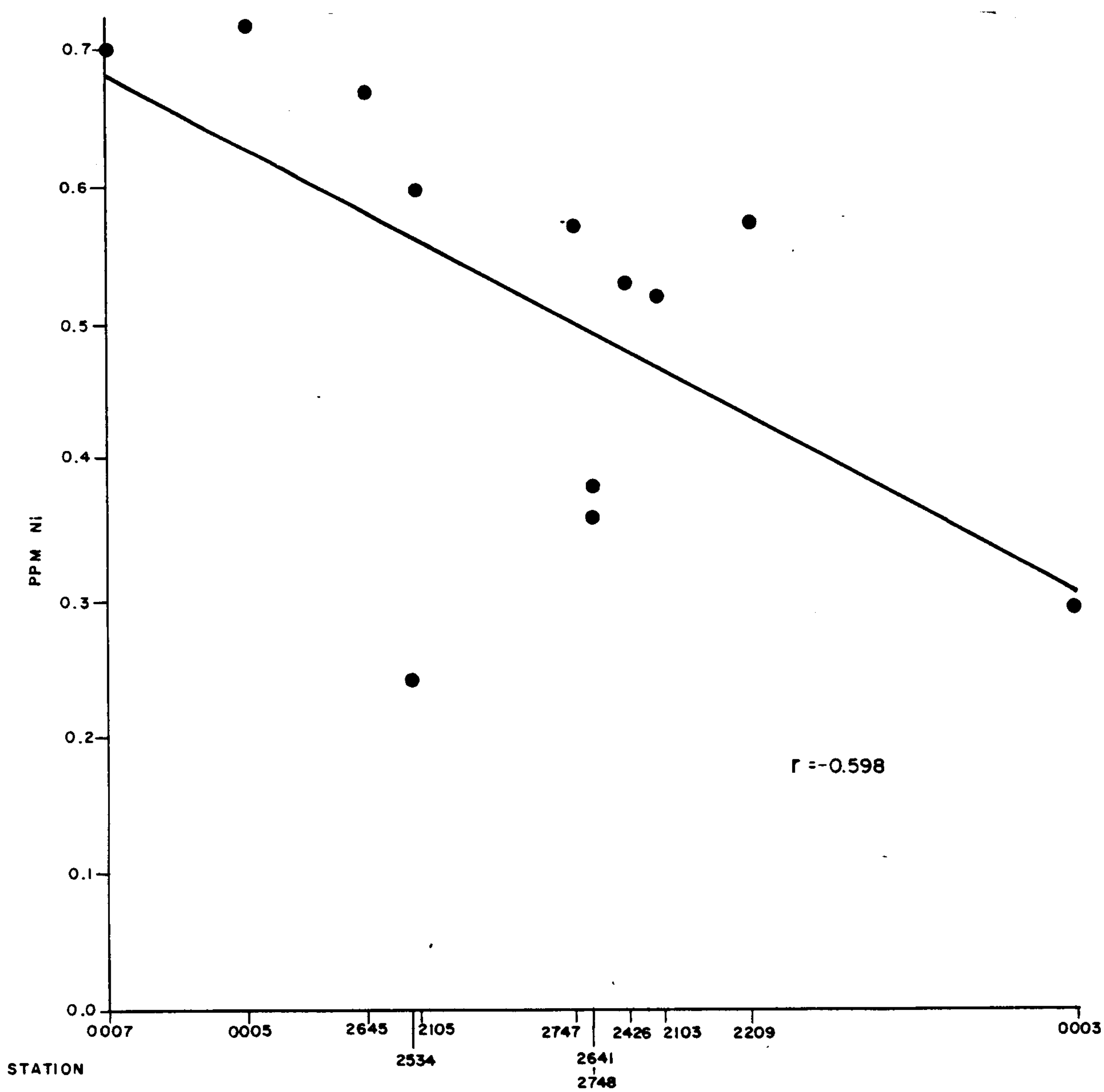


FIGURE 55

MEAN Ni IN SYACIUM VS STATION
BRAY CURTIS Q MODE

in Volume II, Chapter 6), indicating that these two metals behave counter to the others in sediment tissue partitioning. Cu and Ni also behaved similarly (and opposite of the other metals) in their seasonality.

To assess the probable effect of diet on tissue trace metal distribution, a combined ordination of macroepifauna and Syacium was generated (Figure 56). As with Figure 53, the spatial array of points in Figure 56 represents the similarity of tissue trace metal burdens (7 metals pooled) here for each species (all individuals of each species from all tissues and locations pooled), and classes of feeding types and major phylogemetic groups have been enveloped. The fish specimens all group together and show very little variation in either component axis relative to the invertebrates. They are also "near" the shrimp group, shrimp comprising a major part of the diet of Syacium (Topp and Hoff, 1972). The analysis indicates that both feeding type and phylogeny are major factors in tissue trace metal concentrations. Johnson (Volume II) also examined the trends in metals in shrimp to determine if the patterns seen in Syacium tissues could be caused by changes in the tissue burdens of their prey. In five species of shrimp (including three identified by Topp and Hoff, 1972, from the stomach contents of Syacium) Ba and Cd both declined by about a half from summer to winter just as they do in Syacium. Cu and Ni do not show any periodic pattern in these shrimp, and their variation in Syacium cannot be separated from the geographic/diet/time combined variance.

Johnson made estimates of tissue turnover rates in Syacium to determine the probability of short-term (days) changes in diet or in brief exposure to water column changes in metals affecting body burdens of trace metals. The rates are set on a relative scale and show Cd and Cu to have the highest turnover rates, V and Zn to be about ten times slower, and the remainder to be 20 to 40 times slower.

Summary

Trace metal levels in the Dusky Flounder, Syacium papillosum, are low throughout the MAFLA area. Natural variation is about equal to analytical variation in each metal, and variations are shown for specific metals in time and location. Locational variations are strongly associated with local "availability" of trace metals in sediments, and appear to be diet related. There are between-metal differences in residence time which vary mmore than 30-fold, and which control the extent to which short-term perturbations in the trace metal environment would be expressed in fish tissue. Cd and Cu would be expected to show effects of environmental availability most rapidly and Ba and Cr least rapidly.

Usefulness of Demersal Fish Trace Metals as a Monitoring Tool

Trace metals have been shown to be associated with offshore activities of man, including oil and gas development activities. The current levels of trace metals in Syacium tissues in the MAFLA area are very low, and a sound baseline now exists. Figure 57 shows the number of specimens required to detect various levels of change in tissue trace metals in Syacium for all metals examined except Cd and Pb (too many values were less than detectable levels). A tripling of tissue levels in any metal could be

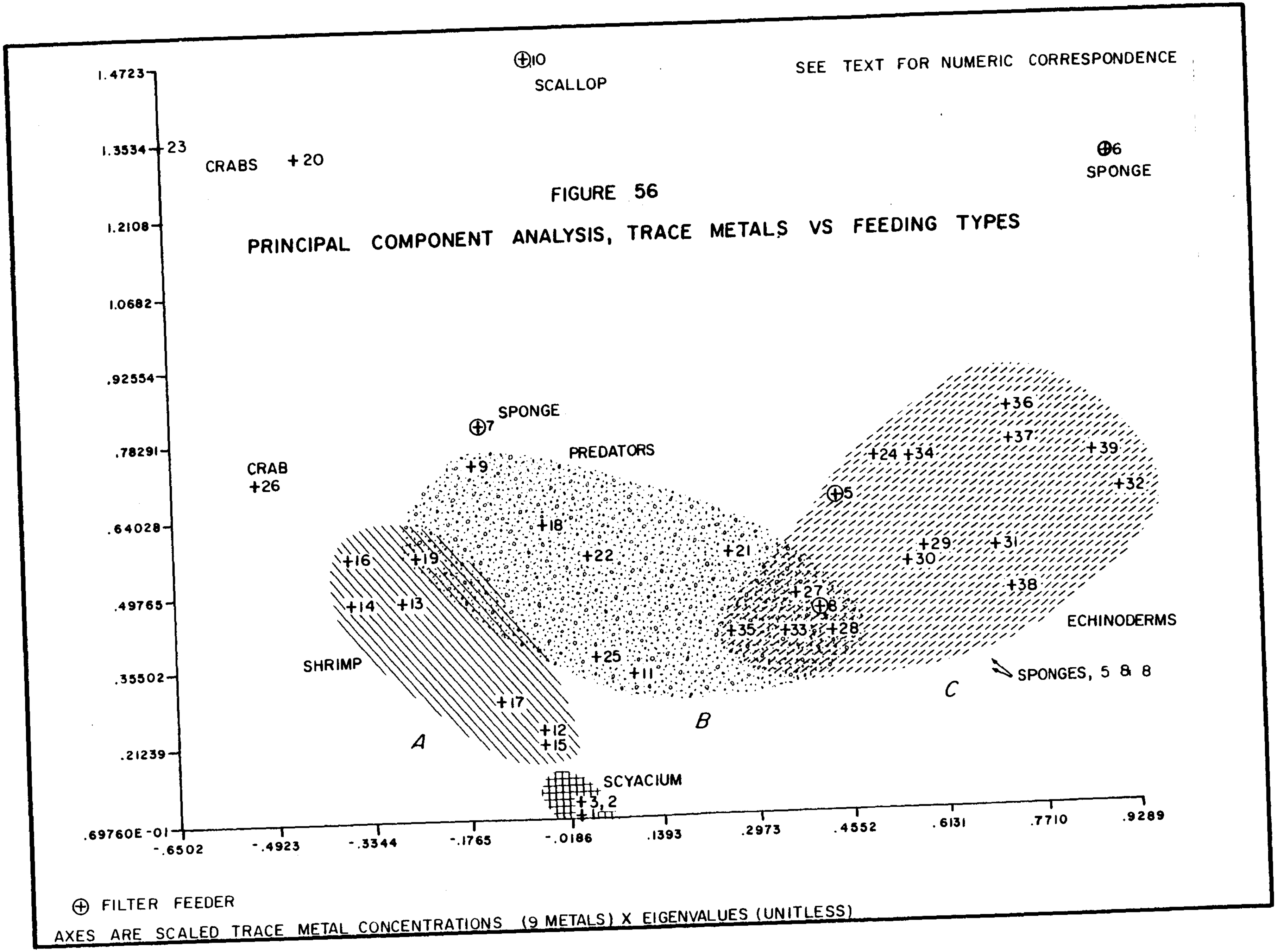
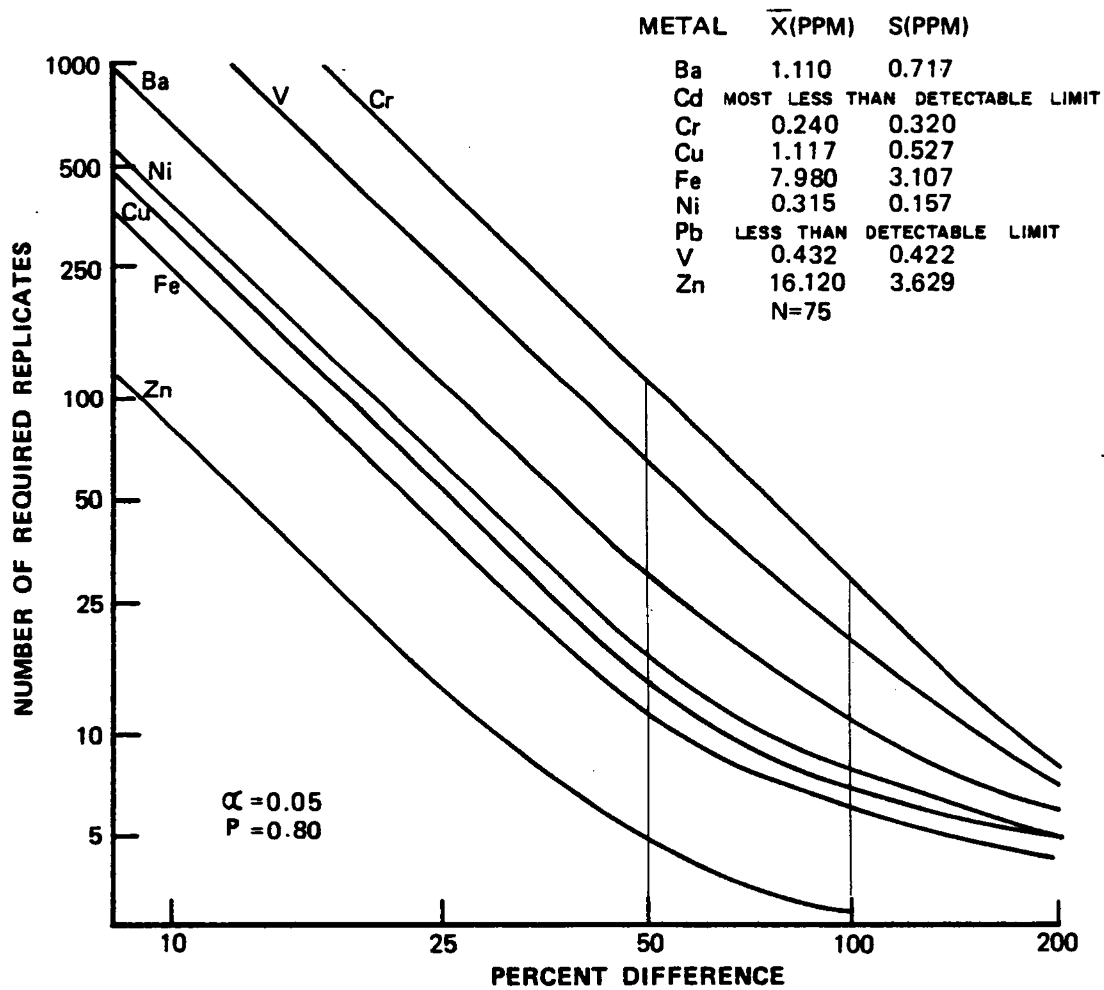


FIGURE 56
PRINCIPAL COMPONENT ANALYSIS, TRACE METALS VS FEEDING TYPES
SEE TEXT FOR NUMERIC CORRESPONDENCE
SCALLOP
CRABS
SPONGE
CRAB
PREDATORS
SHRIMP
ECHINODERMS
SPONGES, 5 & 8
SCYACIUM
A
B
C
1.4723
1.3534
1.2108
1.0682
.92554
.78291
.64028
.49765
.35502
.21239
.69760E-01
-.6502
-.4923
-.3344
-.1765
-.0186
.1393
.2973
.4552
.6131
.7710
.9289
⊕ FILTER FEEDER
AXES ARE SCALED TRACE METAL CONCENTRATIONS (9 METALS) X EIGENVALUES (UNITLESS)



MINIMUM DETECTABLE DIFFERENCE (%) BETWEEN TWO SAMPLES OF *SYACIUM PAPILLOSUM*

FIGURE 57

detected with 10 or fewer specimens, and a doubling (except Cr) with about 25 or less. Syacium is available in such abundances throughout most of the MAFLA area in less than 200 m depths, and the present levels of metals are such that any significant metal pollution event would be likely to produce large increases in tissue levels if the metal were available to the tissues. As a result, it appears that demersal fish trace metals are a useful monitoring tool. As with demersal fish hydrocarbons, it is recommended that a wider variety of demersal fish, and especially larger, longer-lived predators, be added to the data bank.

Trace Metals in Macroepifauna

Introduction

As with the macroepifaunal hydrocarbons, the principal functions of the trace metal studies in macroepifauna were to broaden the scope of the trace metal study to include a variety of feeding types, to examine food web connections to the demersal fish, to aid in the development of a monitoring program, and to establish principals which may aid in interpreting the hydrocarbon data. In addition, different species of invertebrates are known to concentrate specific metals far beyond environmental levels (see, for instance, Riley and Segar, 1970). It is important to delineate which species have natural high extreme values before the oil and gas development activities begin so that those values are not incorrectly ascribed to the development. In addition, species which concentrate particular elements may be used to monitor metals whose usual concentrations in the environment are below analytical detection limits.

The species analyzed are listed above in Table 14. Where sufficient tissue was available, the same individuals were split to form pools of equivalent tissue for separate hydrocarbon and trace metal analyses. Analytical variability is described above in the introduction to the demersal fish trace metal section, and a rationale for the selection of metals analyzed is provided in the introduction to the marine chemistry section.

The literature review by SUSIO (1973) lists no tissue trace metal studies, and the final report for the 1975/76 program (SUSIO, 1977) also cites no prior work in the Gulf. The data base for the 1977/78 program is discussed in the introduction to the macroepifaunal hydrocarbons section. More samples could be run for trace metals than for hydrocarbons, however, because a smaller sample size could be used.

Results and Discussion

Figures 58 through 61 show the mean concentrations of each trace metal by major taxonomic group (see Johnson, Volume II, Chapter 6, and Shokes, Chapter 7), with single standard deviation bars superimposed. Total concentrations were generally low (compare with Horowitz and Presley, 1977; Segar et al., 1971; and Riley and Segar, 1970; SUSIO, 1977), and each metal is reviewed briefly below.

Cadmium values ranged from <1 to >130 ppm with most values around 1 ppm. Molluscs had the highest values (mean ~13 ppm) with significant

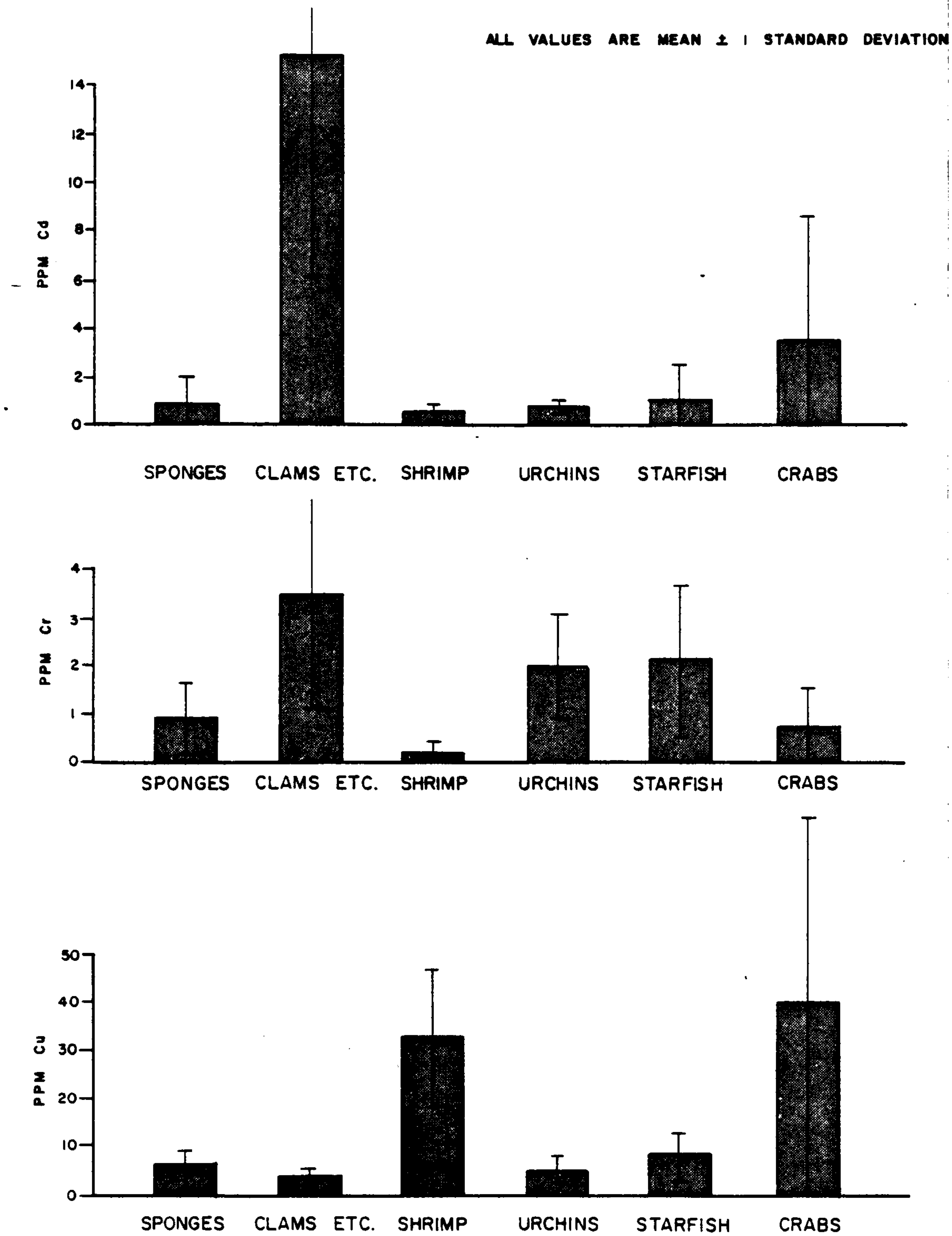


FIGURE 58

DISTRIBUTION OF TRACE METALS BY MAJOR TAXONOMIC GROUP
CADMIUM, CHROMIUM AND COPPER

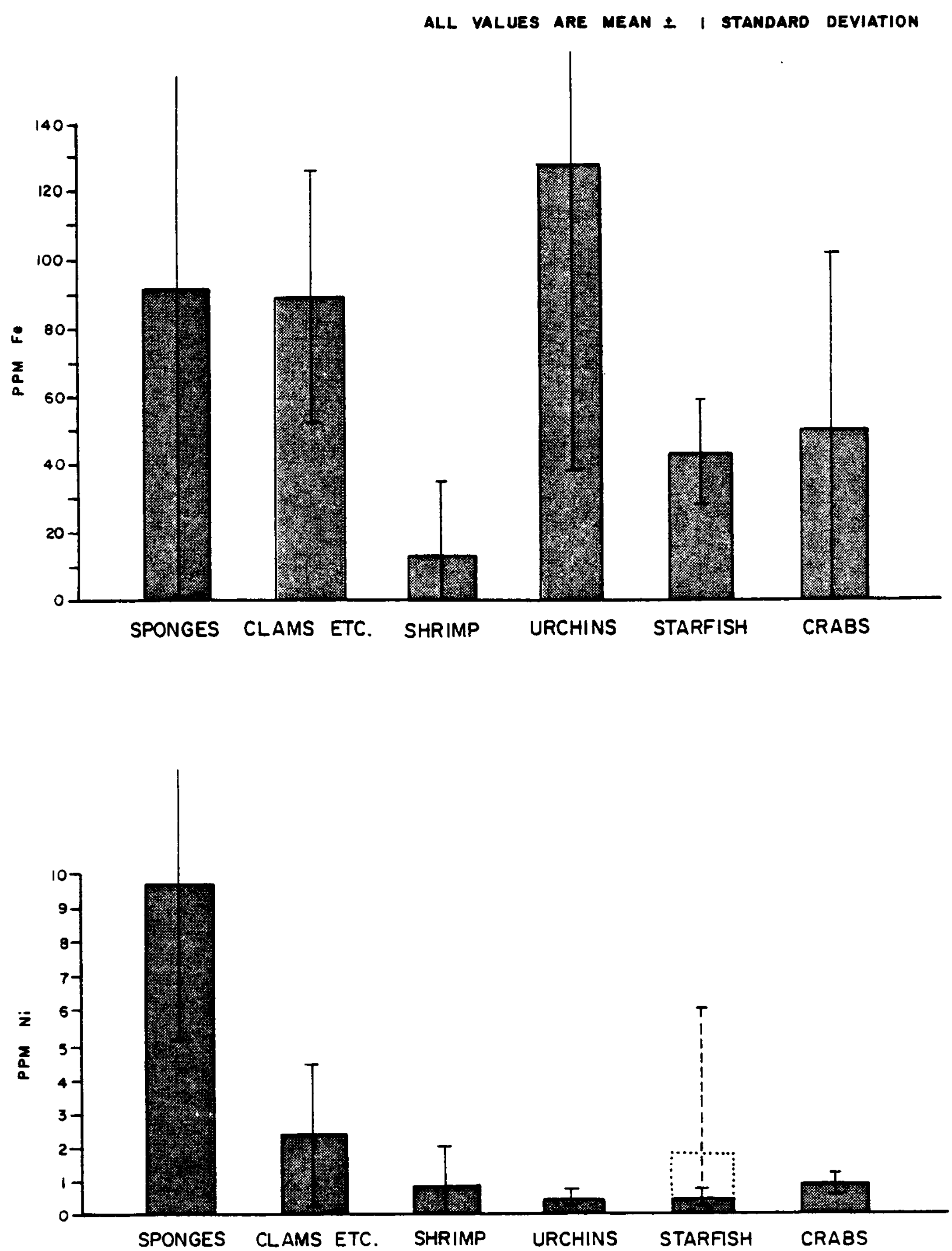


FIGURE 59

DISTRIBUTION OF TRACE METALS BY MAJOR TAXONOMIC GROUP
IRON AND NICKEL

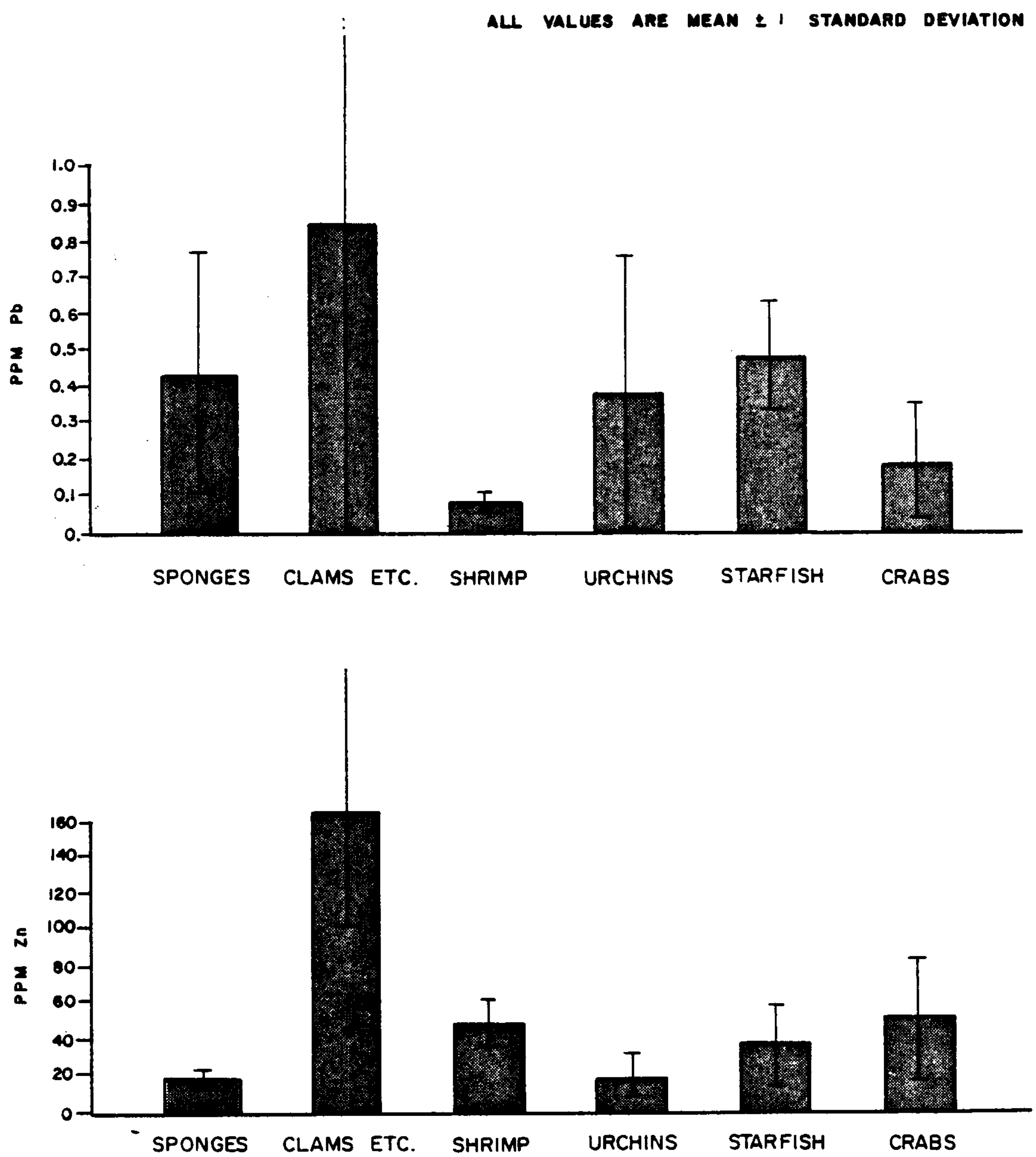


FIGURE 60

DISTRIBUTION OF TRACE METALS BY MAJOR TAXONOMIC GROUP
LEAD AND ZINC

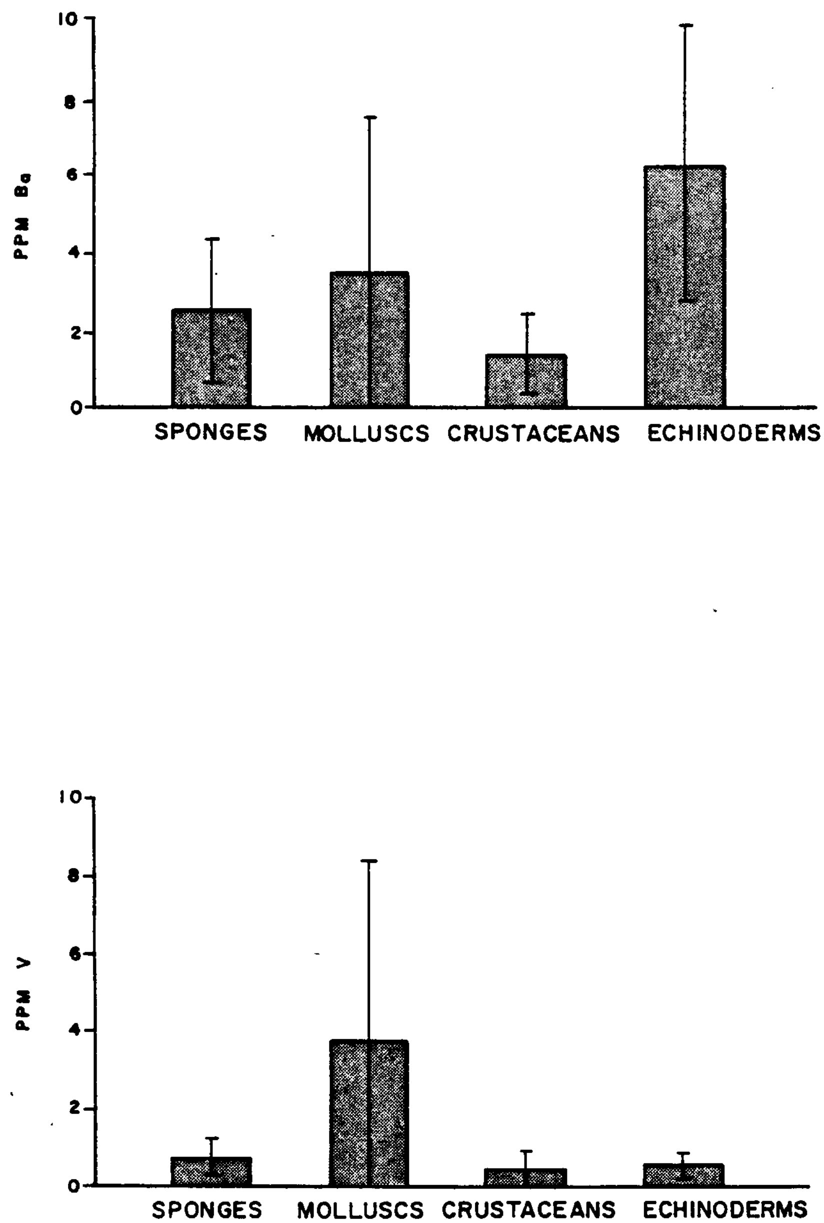


FIGURE 61

DISTRIBUTION OF BARIUM AND VANADIUM BY PHYLUM influence from the scallop Aequipecten glyptus (mean 66 ppm). Scallops are known to concentrate cadmium (Segar et al., 1971) and the general mollusc values compare favorably with the 1975/76 MAFLA data. All the other values were comparable to (crabs and echinoderms) or lower than (sponges and shrimps) the 1975/76 data. The lower values, where comparable, were similar to those of Horowitz and Presley (1977) and Shokes (1978). Except for the molluscs and crabs, the values generally fell in the range of MAFLA sediment trace metal values (see below, and Trefry, Volume II, Chapter 3). Most values were higher than the average crustal abundance of cadmium of 0.2 ppm (see Trefry, Volume II).

Chromium values were less variable, with values ranging from <1 to about 15 ppm and an average about 2 ppm. Molluscs again had the highest values ($\bar{x} = 3.4 \pm 2.3$). Values in crustaceans and molluscs were comparable to the 1975/76 MAFLA data. Sponges were lower by about a factor of 4 and echinoderms higher by about a factor 2 or 3. Since Segar et al. (1971) list their echinoderm values as all BDL (below detection limits), Johnson cautions that the 1977/78 echinoderm values should be viewed with caution, but they were well within the range of MAFLA sediment values (2-47 ppm) and an order of magnitude or more below average crustal abundance (Trefry, Volume II).

Copper ranged from about 1 to 200 ppm, with a mean of about 15 ppm. Highest values were found in crustaceans (shrimp and crabs), which use copper as a constituent of their blood pigment (hemocyanin; see, for instance, Prosser and Brown, 1950). The crabs Iliacantha subglobosa and Paguristes spinipes, for example, had mean copper concentrations of 140 and 120 ppm, respectively. Overall the values compare well with the 1975/76 results, and with results from the western Gulf of Mexico (Horowitz and Presley, 1977), the north central Gulf (Shokes, 1978) and the southeast Atlantic coast (Windom and Betzer, 1978). Except for the crustaceans, the values fell in the range of the MAFLA sediment results and were an order of magnitude less than average crustal abundance (Trefry, Volume II). For crustaceans the values regularly exceeded mean crustal abundance and often exceeded MAFLA sediment values by an order of magnitude.

Iron values varied from <10 to >500 ppm, with a mean about 70 ppm. These values were comparable to the 1975/76 data for molluscs, and lower by a factor of 2 to 5 for the other groups. At these lower levels they generally agreed with the values of Horowitz and Presley (1977). The low values for shrimp ($\bar{x} = 10 \pm 18$) agreed generally with other studies, and at more than an order of magnitude less than the sediment minimum value (420 ppm; Volume II, Chapter 3) showed that the tissue samples have been well isolated from both ingested and adhering sediments. Overall the tissue iron concentrations were one to two orders of magnitude below MAFLA sediment values and two to three orders below mean crustal abundance.

Except for a few isolated values from single specimens of sponges, nickel values ranged from <1 to about 30 ppm, with a mean of 2.5 ppm including the sponges, and less than 1 ppm excluding the sponges. The sponges also had the highest values during the 1975/76 MAFLA analyses (mean and range about 2 times 1977/78 values). The crustacean and echinoderm data agreed well with 1975/76 data and the molluscs, while still second in rank were an order of magnitude lower in nickel in 1977/78 samples. Overall the values were in general agreement with comparable studies, generally lower than sediment levels and two orders of magnitude less than mean crustal abundance (Volume II, Chapter 3). Two sponge values of 50 and 150 ppm were in the range of crustal abundance. The remainder were half or less of that value and not more than twice maximum sediment values.

Lead values ranged from <0.1 to about 2 ppm, with a mean <0.5 ppm. Many values were BDL. Mollusc values were comparable to 1975/76 MAFLA data, with all others lower by about a factor of 3. They were also comparable to or lower than the values reported by Segar et al. (1971), Horowitz and Presley (1977) and Shokes (1978). Lead in sediments was about an order of magnitude higher, which in turn was about half of mean crustal abundance.

Zinc ranged from about 5 to 500 ppm, and had a mean of about 50 ppm. Molluscs had the highest values ($x = 164 \pm 64$). Molluscs are known to concentrate zinc, with reported values for whole soft tissues ranging from 90 to 990 ppm (Segar et al., 1971). Zinc was not measured in the previous MAFLA program. For the other groups, the data were similar to other comparable studies (see Johnson, Volume II, Chapter 6), and were comparable to both MAFLA sediments and mean crustal abundance.

Barium values ranged from <1 to >50 ppm, with a mean <4 ppm. Highest values were found in echinoderms and molluscs, both of which secrete heavy $CaCO_3$ shells. Shokes (Volume II, Chapter 7) indicates that barium is frequently substituted for calcium in exoskeleton formation. Barium was not reported in the 1975/76 final report, and order of magnitude changes (improvements) in sensitivity of analysis make other comparisons of questionable utility (see Shokes, Volume II, Chapter 4).

Vanadium concentrations ranged from <0.1 to about 20 ppm with a mean of about 1.5 ppm. The results compare well with the 1975/76 MAFLA data. Shokes (Volume II, Chapter 6) notes that all the high vanadium values were from molluscs collected along the 40 m contour on the west Florida sand sheet.

Molluscs had the maximum values for 5 of the 9 metals analyzed (Cd, Cr, Pb, V, Zn) and appear to have specific affinities for cadmium and zinc. Nickel values, in general, in sponges may reflect trapped sediments (range <1 to $\sim$20 for all but seven sponge specimens compared to a range of <1 to 16 for sediments). However, the high values ($\bar{x} = 50 \pm 38$) are strongly indicative of bioconcentration. Crustaceans show a definite affinity for copper, with shrimps showing the minimum means in six other metals (Ba, Cd, Cr, Fe, Pb, and V).

Variability in trace metals of pooled (by time or by location) macroepifauna occur in both short-term time (months) and geographically. However, sample size at single station and single seasons for each species is too low to separate the effects. Both may be related directly to diet, as indicated in Figure 56, above, where the combination of feeding type and phylogenetic group accounts for most of the variability in trace metals of MAFLA demersal fish and macroepifauna.

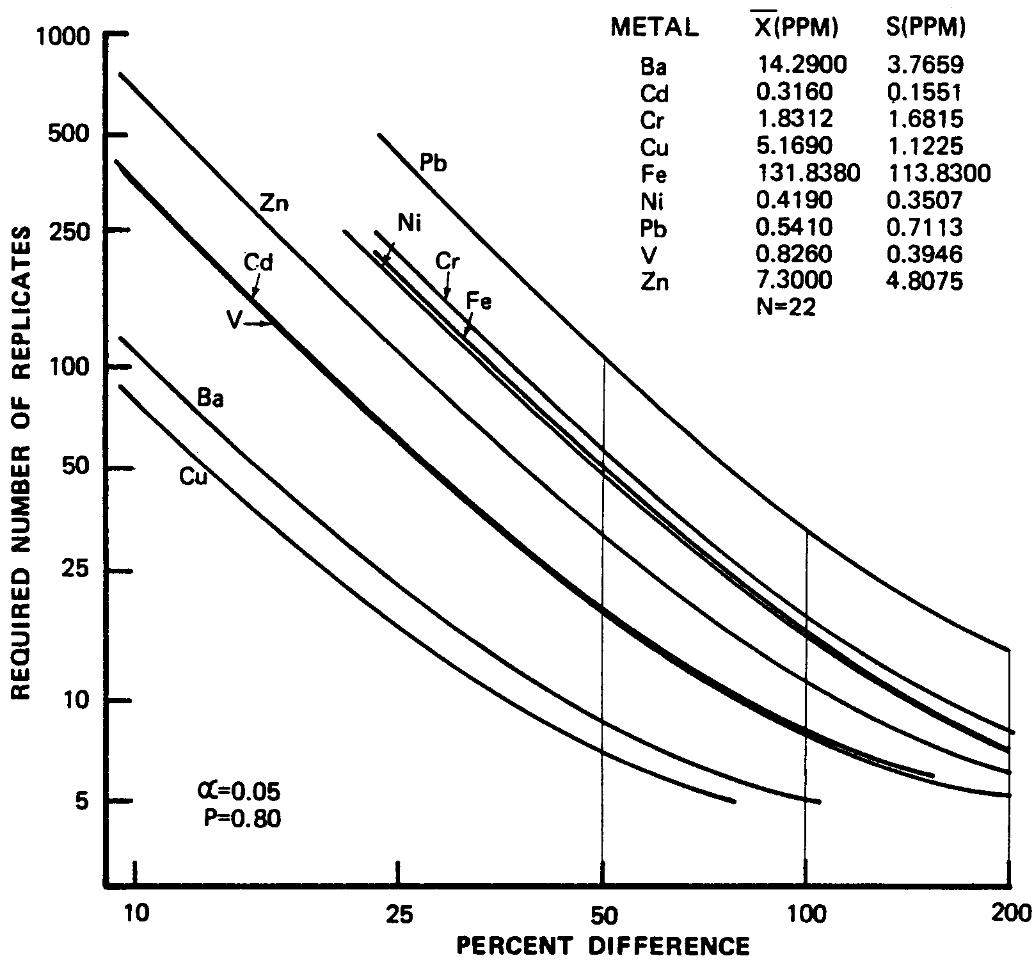
Summary

Trace metals in macroepifauna from the MAFLA area are generally comparable to or lower than values from the western and northern Gulf of Mexico, or from the south Atlantic OCS. They are also generally lower than the values from the 1975/76 MAFLA program. Zinc and (reliable) barium data are reported for the first time. The data base, especially in terms of numbers of species analyzed, has been significantly widened. Short-term variations, species variations and geographic variations in levels are apparent in the data, but sample size for individual species at stations is too small to differentiate between the three. Diet is an apparent major source of those variations.

Usefulness of Macroepifaunal Trace Metals as a Monitoring Tool

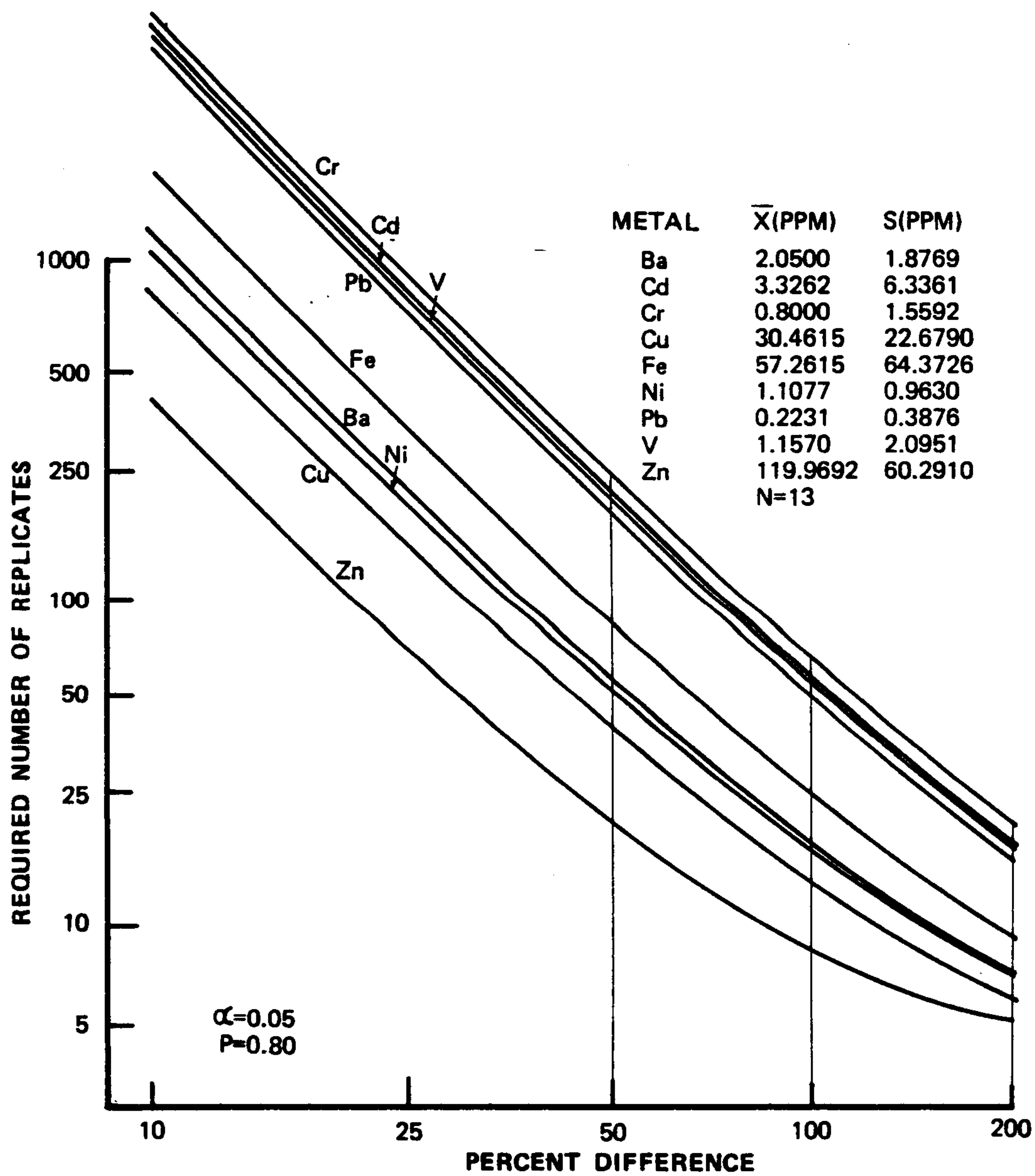
The data base for histochemistry of macroepifauna on the Dames & Moore Data Tape, as pointed out in the hydrocarbon discussion, is now very extensive, and includes all trophic levels except primary producers. Its breadth has led to a weakness in low numbers of replicates for most species. However, for the eight species shown in Figures 62 through 69, sufficient replication was made to allow calculation of minimum sample size curves. These curves indicate the minimum number of specimens required to detect a specified level of change in the tissue burden of any trace metal analyzed (and above detection limits). For all of these, the data base to determine locations of probable occurrence of each species in sufficient numbers is on the data tape. For instance, at the level of sampling used to collect macroepifauna (see Marine Biology results, below) the average return from four seasons of sampling (summer 76-winter 78) was in excess of 100 individuals for Clypeaster ravenelli at Station 2426, inshore of the major proposed lease area between 200 and 400 m off Transect IV. Reference to Figure 62 indicates that that would be enough to detect a 50% change in all metals but lead and a 75% change in all metals. A tripling of metal levels in any of these species would be detectable with a sample size of 25. Johnson (Volume II, Chapter 6) speculates that the baseline values are so low that such increases would be likely to result from a pollution event, and would still be below levels which would be injurious to the species.

Figures 70 through 72 are the minimum sample contour "surfaces" of all nine metals and these eight species for 50%, 100%, and 200% changes in tissue burdens, respectively. While their complexity indicates that both species and metals behave independently in their variance, the surface "sinks" to one which indicates that 10 specimens of any species will detect a tripling of Ba, Cu, Fe, Ni, or Zn, and all metals for all species are at or below the "sample size = 25" plane. It can also be seen that Pseudoceratina crassa, a sponge, requires the fewest specimens to detect the most metals at any level. Lastly, the general sinking of the plane with increasing percent change and the fact that for nearly every species and every metal, a 25-specimen sample will detect a doubling of tissue burdens indicates that many other species of macroepifauna will prove equally useful once their sample size in the data base becomes large enough to calculate a nest of curves for the metals. Inclusion of macroepifaunal trace metal studies in a monitoring program is recommended. Collection of more individuals from the same stations over a period of time will measurably increase the value of the existing data base.



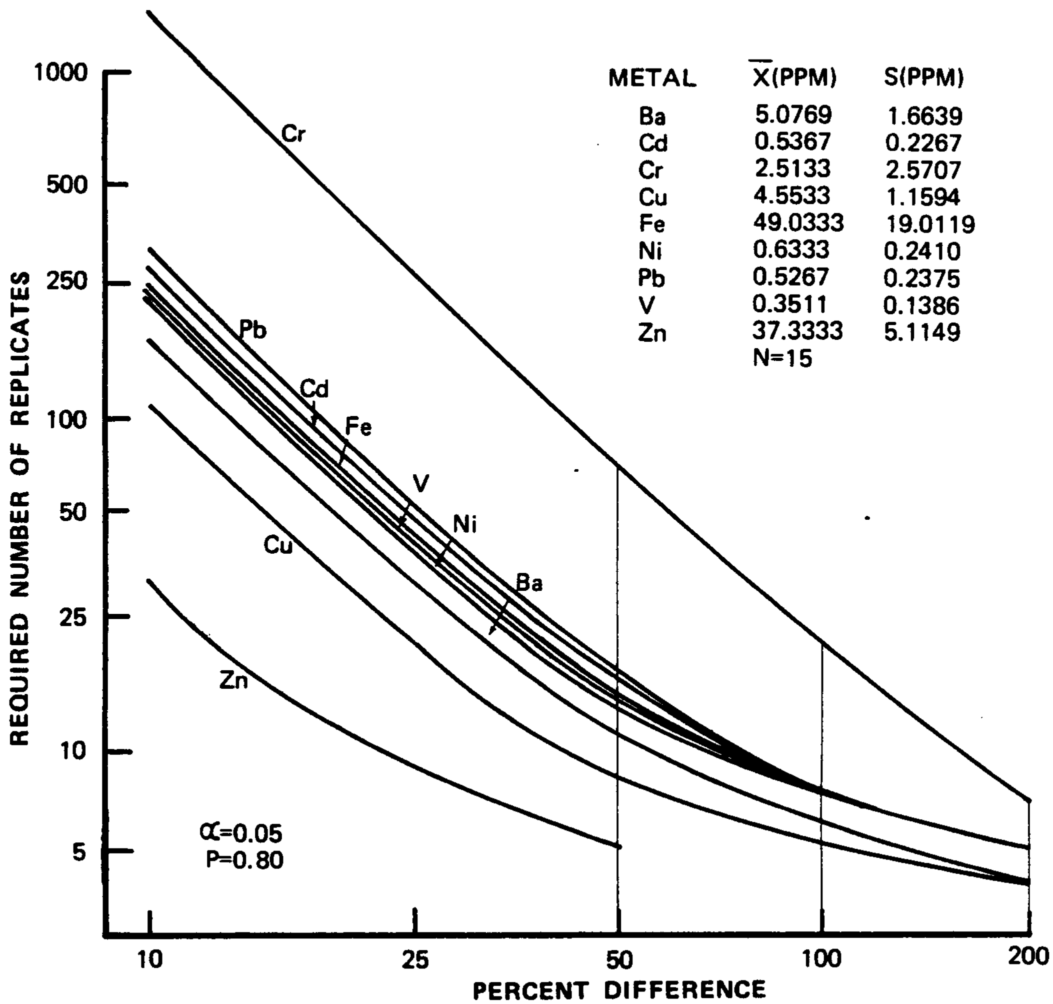
MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
CLYPEASTER RAVENELLI
8153010104

FIGURE 62



MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
ACANTHOCARPUS ALEXANDRI
6186020301

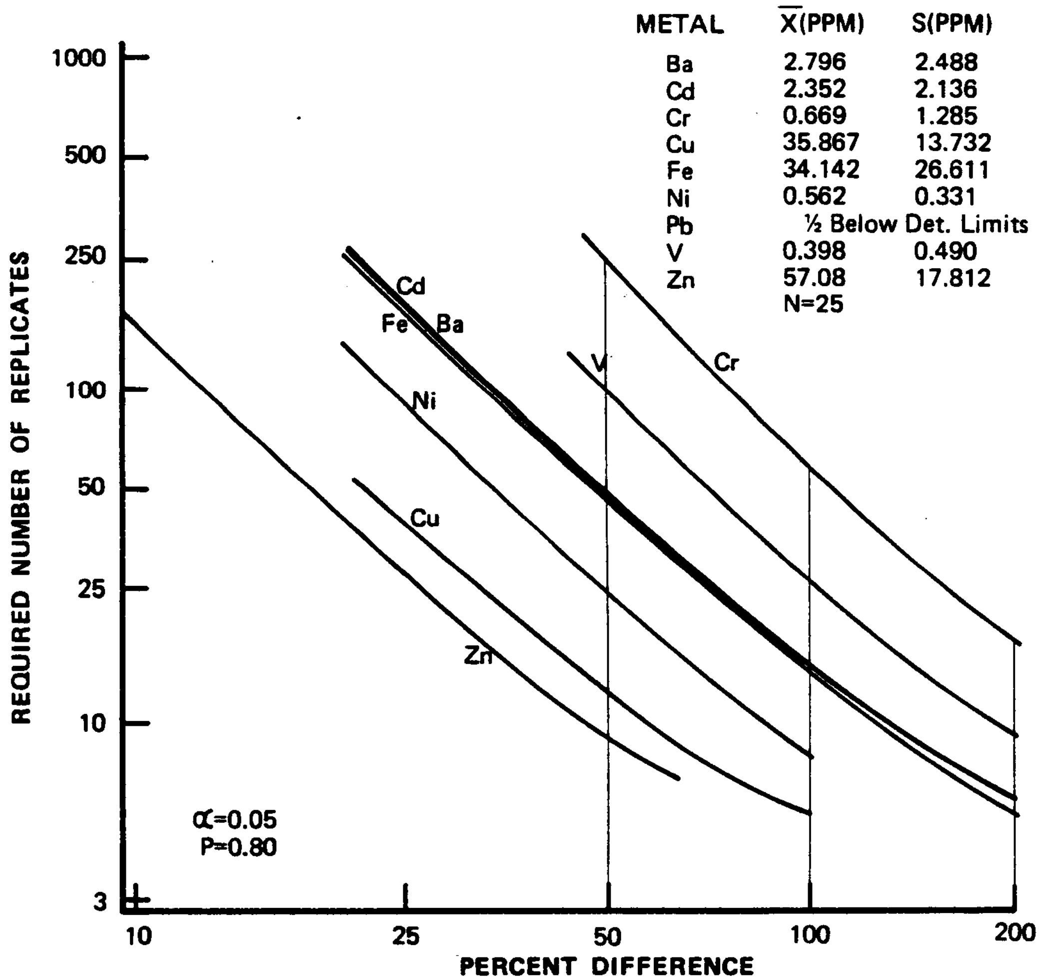
FIGURE 63



METAL	$\overline{X}$(PPM)	S(PPM)
Ba	5.0769	1.6639
Cd	0.5367	0.2267
Cr	2.5133	2.5707
Cu	4.5533	1.1594
Fe	49.0333	19.0119
Ni	0.6333	0.2410
Pb	0.5267	0.2375
V	0.3511	0.1386
Zn	37.3333	5.1149
	N=15	

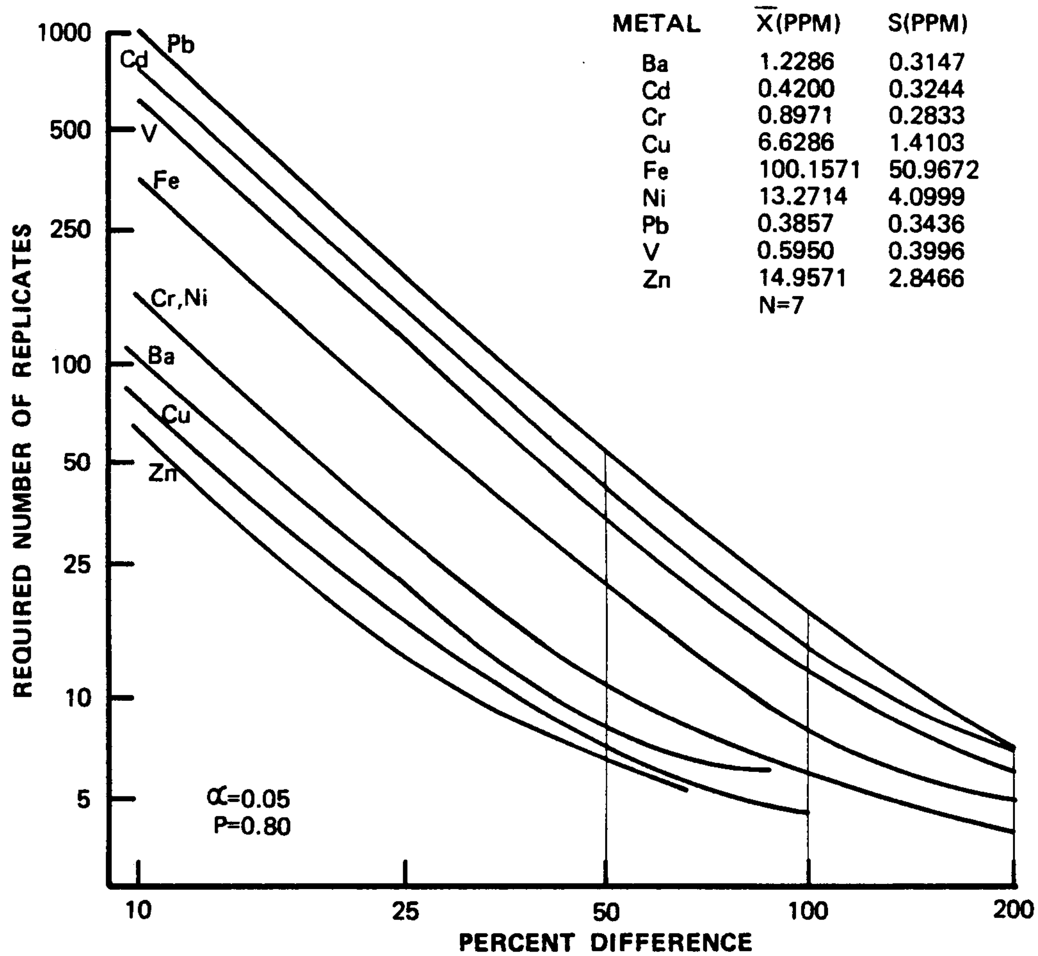
MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
ASTROPORPA ANNULATA
8125030101

FIGURE 64



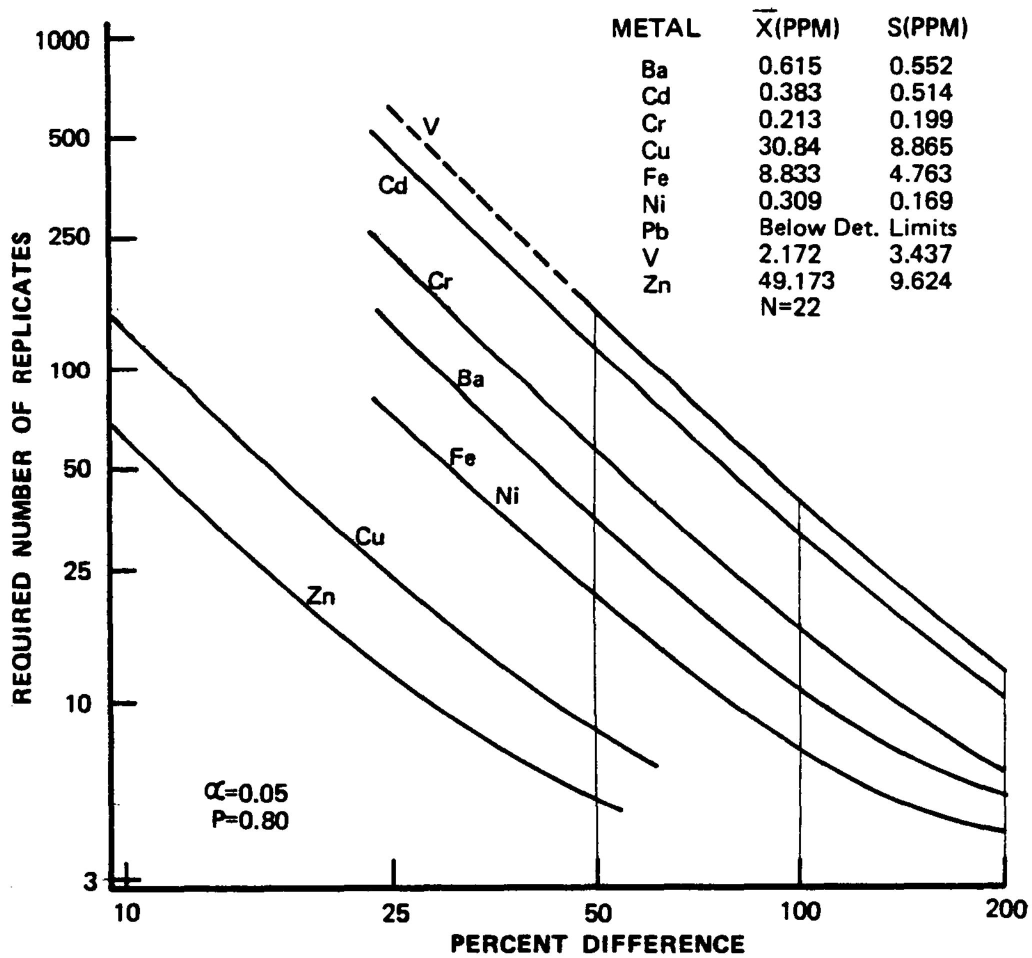
MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
PORTUNUS SPINICARPUS
6187013601

FIGURE 65



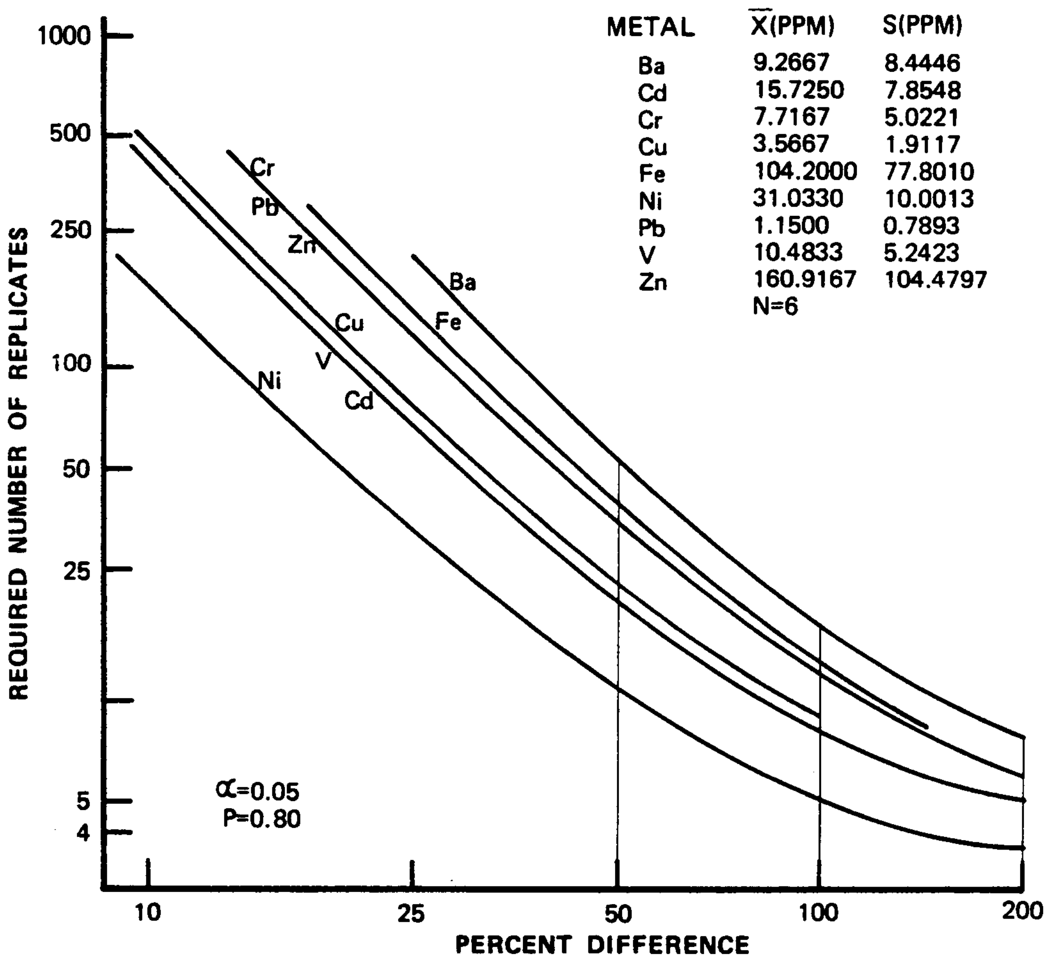
MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
PSEUDOCERATINA CRASSA
3662010101

FIGURE 66

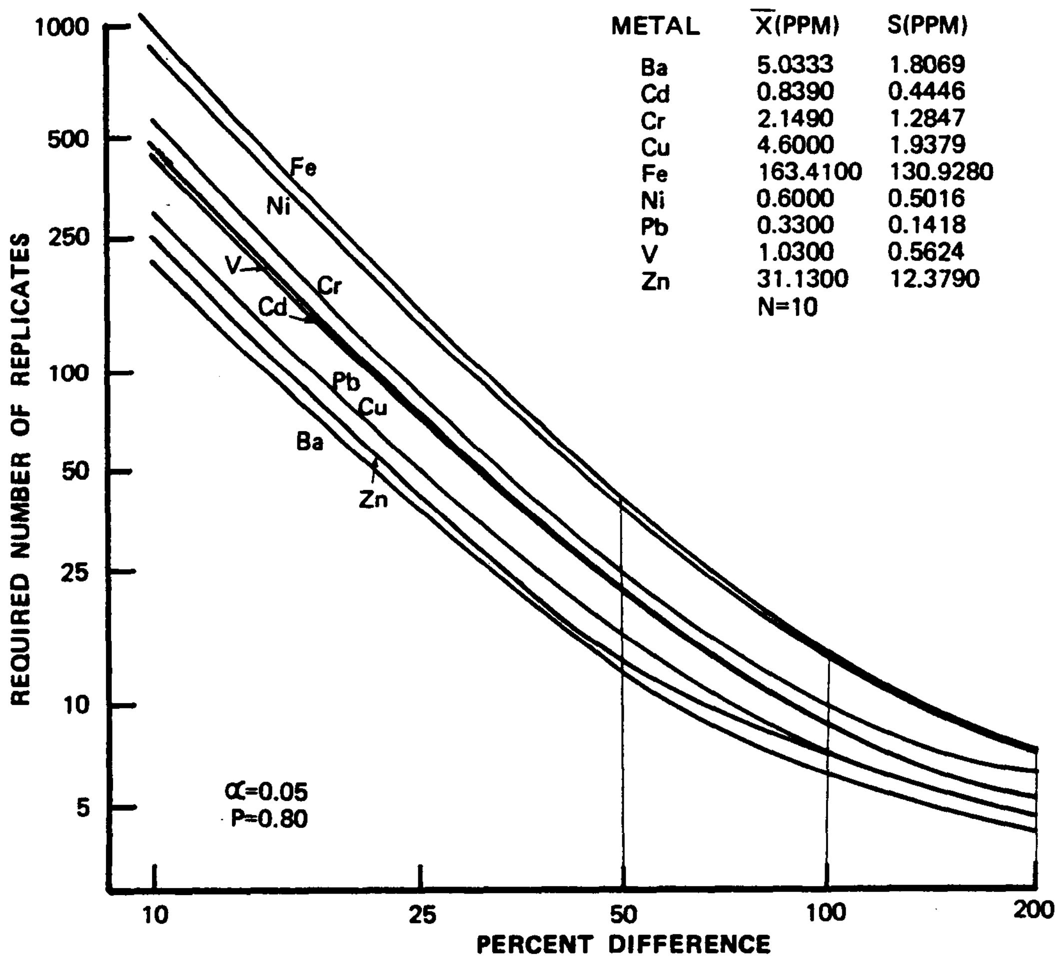


MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
SICYONIA BREVIROSTRIS
6177030101

FIGURE 67

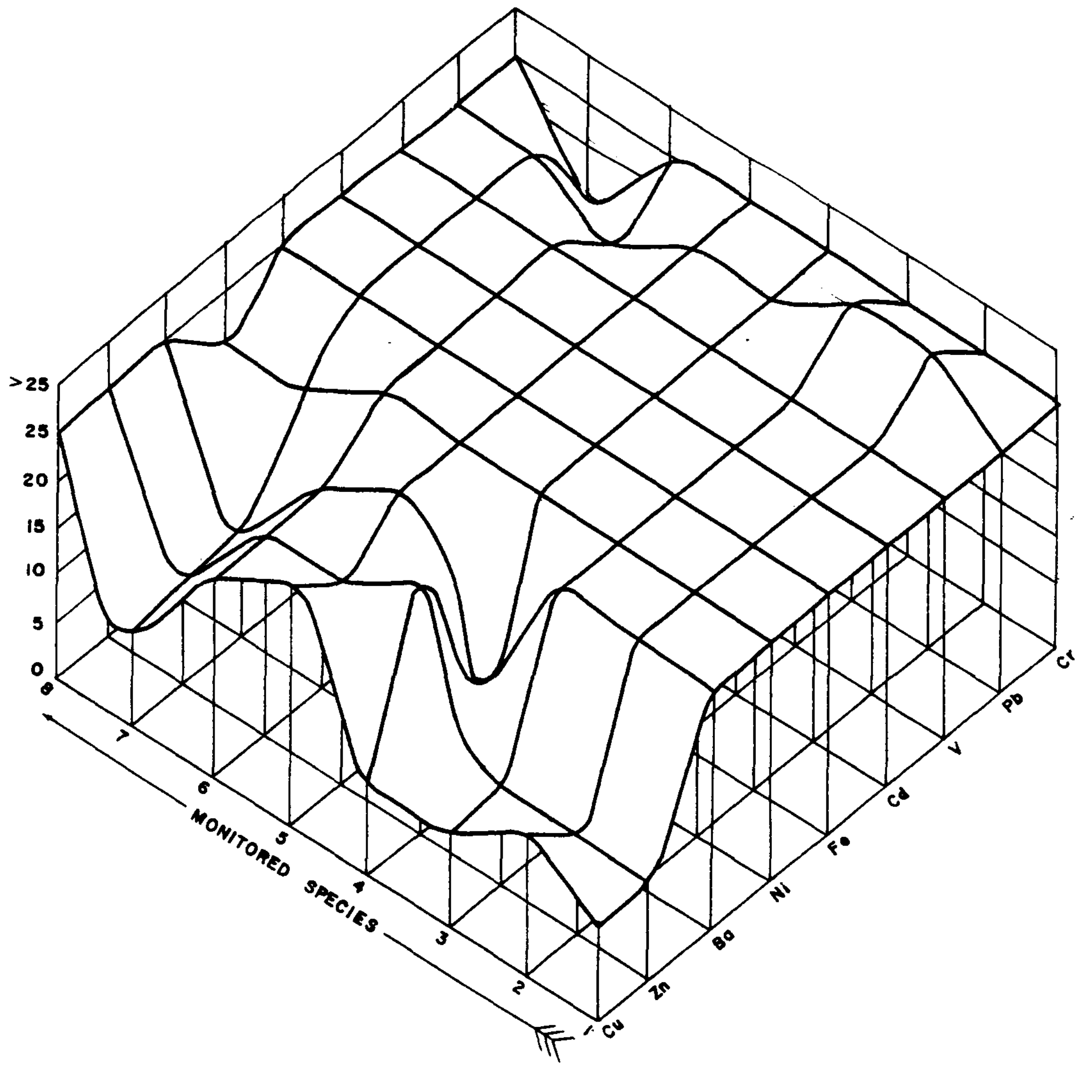


MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
<u>SPONDYLUS AMERICANUS</u>
5509070101
FIGURE 68



MINIMUM DETECTABLE DIFFERENCE (%)
BETWEEN TWO SAMPLES OF
STYLOCIDARIS AFFINIS
8138010201

FIGURE 69

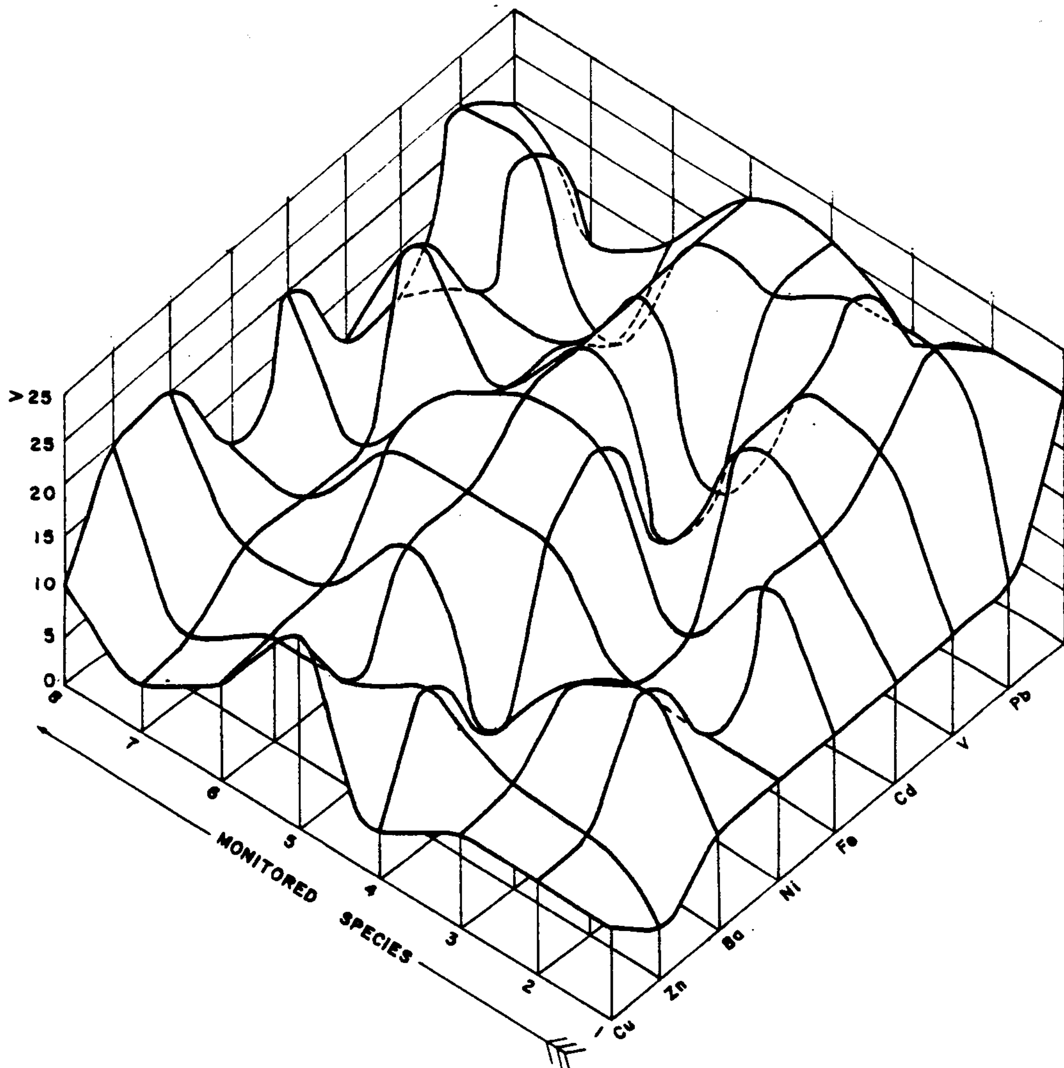


MONITORED SPECIES

1. ACANTHOCARPUS ALEXANDRI
2. PORTUNUS SPINICARPUS
3. SICYONIA BREVIROSTRIS
4. CLYPEASTER RAVENELLI
5. ASTROPORPA ANNULATA
6. STYLOCIDARIS AFFINIS
7. PSEUDOCERATINA CRASSA
8. SPONDYLUS AMERICANUS

FIGURE 70

NUMBER OF SPECIMENS REQUIRED TO DETECT A 50% DIFFERENCE IN ANY METAL FROM ANY MONITORED SPECIES

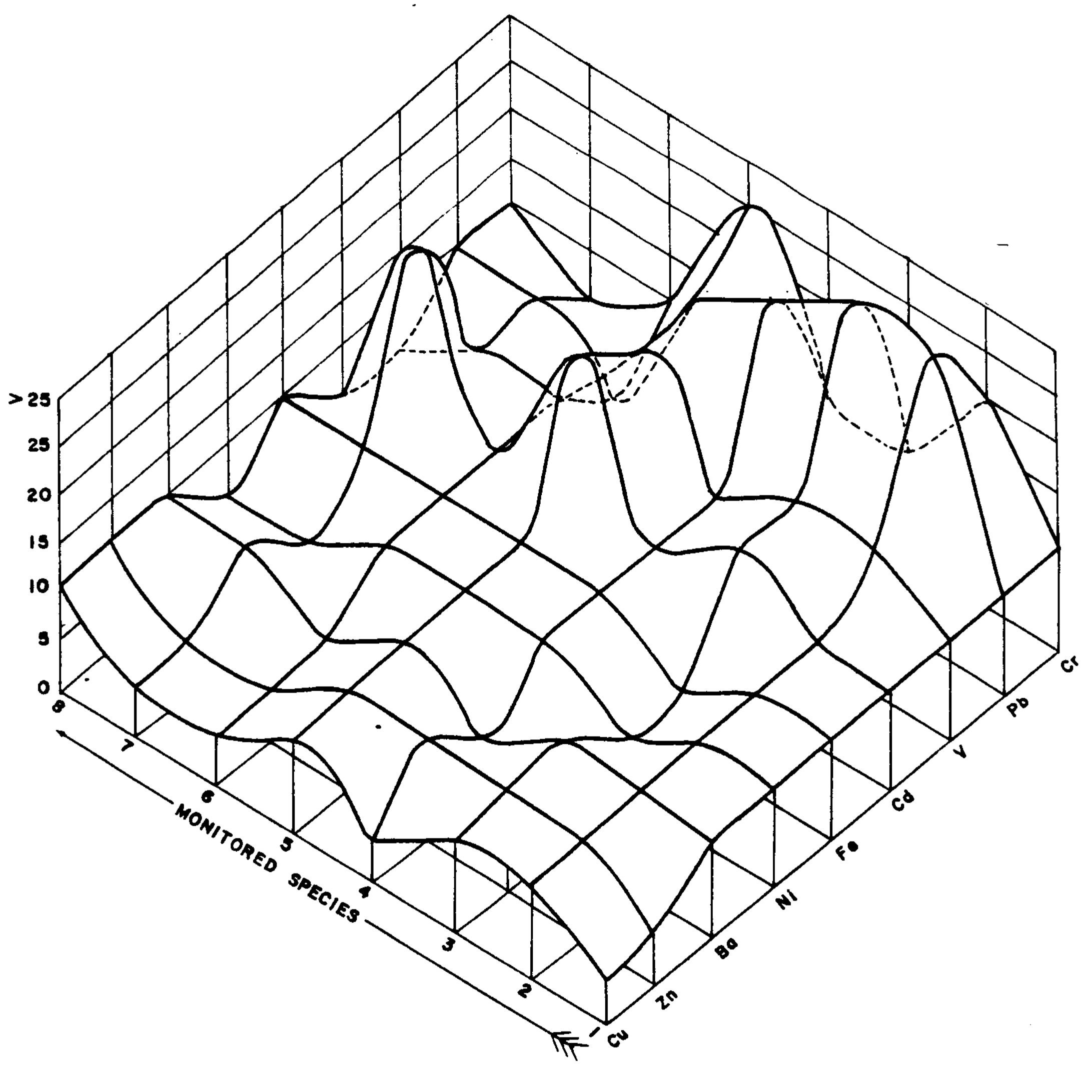


MONITORED SPECIES

1. ACANTHOCARPUS ALEXANDRI
2. PORTUNUS SPINICARPUS
3. SICYONIA BREVIROSTRIS
4. CLYPEASTER RAVENELLI
5. ASTROPORPA ANNULATA
6. STYLOCIDARIS AFFINIS
7. PSEUDOCERATINA CRASSA
8. SPONDYLUS AMERICANUS

FIGURE 71

NUMBER OF SPECIMENS REQUIRED TO DETECT A 100% DIFFERENCE IN ANY METAL FROM ANY MONITORED SPECIES



MONITORED SPECIES

1. ACANTHOCARPUS ALEXANDRI
2. PORTUNUS SPINICARPUS
3. SICYONIA BREVIROSTRIS
4. CLYPEASTER RAVENELLI
5. ASTROPORPA ANNULATA
6. STYLOCIDARIS AFFINIS
7. PSEUDOCERATINA CRASSA
8. SPONDYLUS AMERICANUS

FIGURE 72

NUMBER OF SPECIMENS REQUIRED TO DETECT A 200% DIFFERENCE IN ANY METAL FROM ANY MONITORED SPECIES

Trace Metals in Sediments

Introduction

As with the sediment hydrocarbons, studies of sediment trace metals provide a longer time-integration than the study of water column or tissue trace metals. Trace metals are known to be scavenged by organic detritus, by clay particles, and by organisms which may deposit the metals in exoskeletons (Trefry and Shokes, Volume II, Chapters 3 and 4). All of these mechanisms provide for the relatively rapid transport of metals from the water into the sediments. The general function of trace metal studies is described in the introduction to the marine chemistry section (and see preceding trace metal sections).

Holmes (1973) review of the northern Gulf is the only comparable study of sediment trace metals in the MAFLA region prior to the BLM studies. The data from the 1975/76 study have been merged with the current data for metals where techniques are comparable (Cd, Cr, Cu, Fe, Ni, Pb), and this report addresses all data available from 1975-1978. Sediment trace metal samples have been collected by box-core from six transects (21XX-26XX in Figure 1) during that entire period. In the summer of 1976 Tansect VII (27XX) was added, and in the summer of 1977 Transect IX (29XX) was included. All of these locations were sampled on a seasonal (3) basis in 1975/76 and 1977/78. During the summers of 1976 and 1977 six supplementary stations were sampled between transects (28XX). All stations were sampled by single samples from single box-cores in the seasonal sampling, and, in addition, each station was sampled with five additional replicates (one from each of five extra box-cores) at least once during the program to establish very small-scale geographic variability.

The principal changes in the 1977/78 program from the prior work (in addition to the added stations and the replicate sampling) were:

- Addition of zinc as an analyzed metal;
- Modificaton of the barium methodology to produce reliable barium data for the first time in the program (see Shokes, Volume II, Chapter 4);
- Addition of weak acid (1 N HNO_3) leaching step to assess "bioavailability".

During the 1977/78 program 364 weak acid leaches and 105 total dissolutions were performed. Analytical variation was in the realm of 5 to 13% for most metals, and up to about 20% on cadmium and lead when their levels were below average.

Results and Discussion

Trace metals in MAFLA sediments were generally low, with no evidence in any samples of metal pollution (Trefry, Shokes; Volume II). All metals except cadium were depleted relative to mean (continental) crustal abundances (Table 17 and Volume II, Chapter 3). Cadmium had its maximum at

TABLE 17

RANGE OF TRACE METAL VALUES FOR MAFLA SEDIMENTS[1]

	MAFLA SEDIMENTS				AVERAGE CRUSTAL ABUNDANCE[2]
	MAXIMUM	(STATION)	MINIMUM	(STATION)	
Cd	0.33[3]	(2957)	0.01	(2856)	0.2
Cr	47	(2638)	2	(2856)	100
Cu	8	(2536)	0.3	(2318)	55
Fe	23,000	(2638)	420	(2856)	56,000
Ni	16	(2536)	0.4	(2318)	75
Pn	16	(2638)	0.6	(2318)	20
Zn	66	(2638)	0.8	(2102)	70
Fines[4] (%)	73	(2536)	1	(2856)	--
TOC[5] (%)	1.1	(2535)	<0.01	(2853,56)	--

[1]Data from Trefry, Volume II, Chapter 3

[2]Taylor (1964) and Turekian and Wedepohl (1961)

[3]All values in ppm, total dissolution

[4]Grain size -62 μm

[5]Total organic carbon

Station 2957, on the 180 m contour on the southernmost transect where it associated with high $CaCO_3$ (>90%) and moderate amounts of fine sediments (c. 20% of sediments less than 63 m diameter).

All of the metals tended to follow a similar pattern of increasing concentration offshore and to the north and west. Figure 73 illustrates this trend with the values of copper. The independent variables responsible for this trend were percent fines (especially clay minerals) and total organic carbon (TOC) both of which scavenge metals (Trefry, in Volume II), such that increased metal concentrations are associated with increasing percent fines and TOC. Table 17 indicates that all the maxima (total dissolution) except cadmium were located at two stations (2638, 2536) which both have >70% fine sediment and >0.4% TOC (see Figures 4 and 8 in the geology discussion above). Similarly, all the minimum values were from three stations (2856, 2318, and 2102) which all have <5% fines and < 0.1% TOC. Distance from shore (therefore from terrigenous, i.e., riverine and airborne sources) and depth (less current and surge winnowing) may also affect this distribution.

Cadmium and barium showed some deviation from the general pattern. Figure 74 provides mean Cd contours for the 1977/78 data (all trends in 1977/78 follow those described for 1975/76, in SUSIO, 1977). The general offshore increase still prevailed, but two anomolies showed up. The maxima were in the southern offshore stations and at Stations 2531 and 2533. High values ($\geq$0.15) were all high $CaCO_3$ stations (84-98%) with <50% fines ($\bar{x}$ = 20% for 10 stations 2957, 2958, 2106, 2746, 2212, 2313, 2531, 2533, 2643, 2645). Trefry (Volume II, Chapter 3) speculates that the calcium carbonate is the causative variable. Figure 5 in the geology section, shows that the middle of Transect V has an anomolously high set of $CaCO_3$ values, and the cadmium concentrations also reflect that anomaly. Similar associations between barium and $CaCO_3$ were reported by Shokes (Volume II, Chapter 4), who reported that barium is substituted for calcium by organisms producing $CaCO_3$ exoskeletons.

Cluster analysis of stations indicated five regional divisions of the MAFLA sediments on the basis of their metal concentrations. Regions I and II (Figure 75) formed a cline of offshore sediments with increasing fines and decreasing $CaCO_3$ from south to north and with most metals having higher concentrations in I than II (except Cd). Region III was composed of generally coarser sediments (the MAFLA sand sheet and West Florida sand sheet of Doyle; see Figure 12, above, and Volume II, Chapter 2), with high $CaCO_3$ and lower metal values of quartz sands and decreasing metals.

Variability between replicate samples at stations and analytical variability were low (<20% of means), and variability between seasons was also low. Figure 76 shows that eight stations had significant inter-season variability in more than one metal over the course of the study. The two Middle Grounds changes probably reflected small-scale geographic differences in sediments (see geology discussion, above, and macroinfauna, macroepifauna discussions, below). The variations of Stations 2640, 2528, 2419, and 2207 may have been true seasonal shifts related to varying inputs from the nearby coastlines (Mississippi River/Mobile Bay, Panama City, St. Johns River, Tampa Bay, respectively). The geographic variation in metal levels shown in

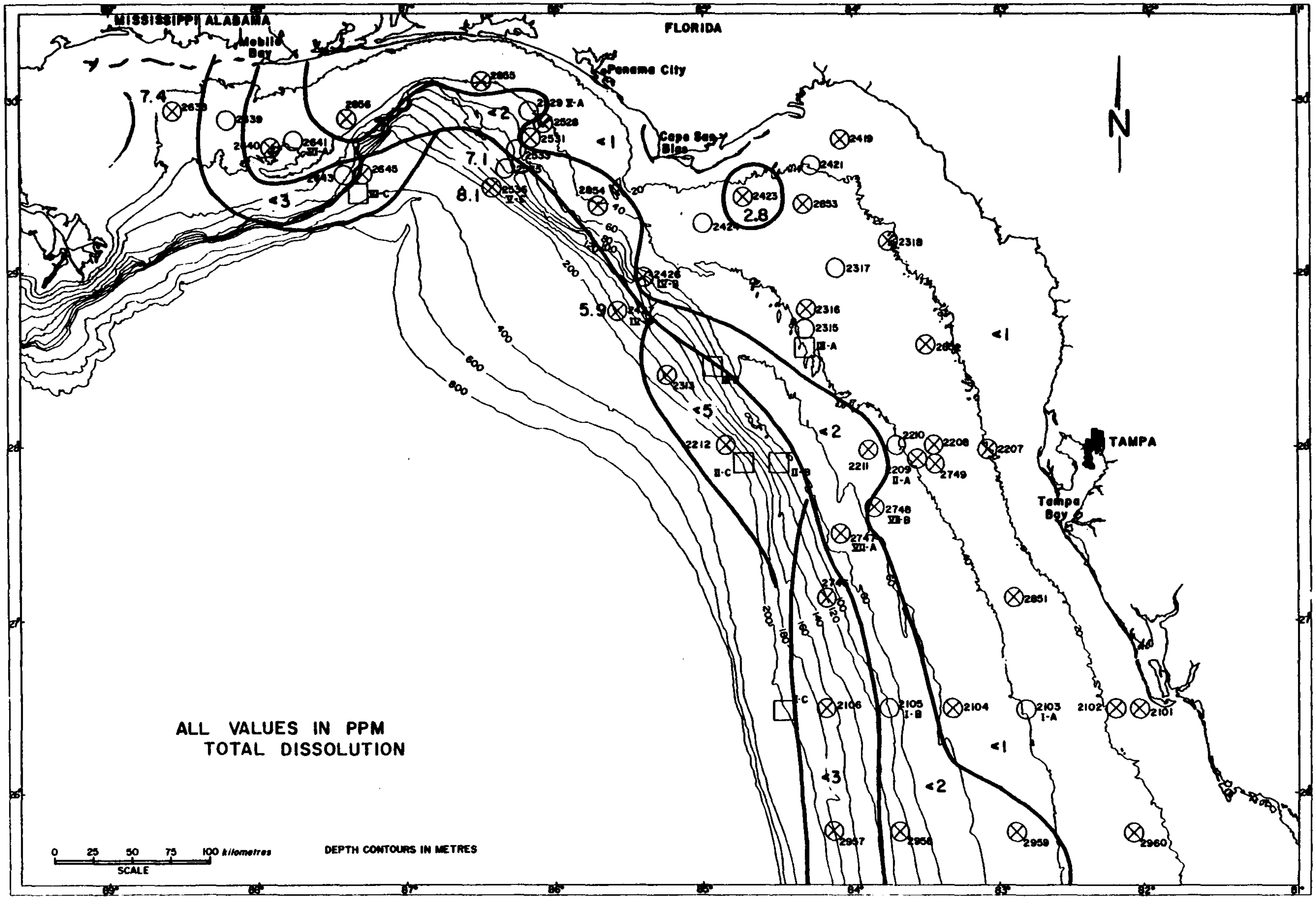


FIGURE 73
TYPICAL SEDIMENT TRACE METAL TREND (Cu)

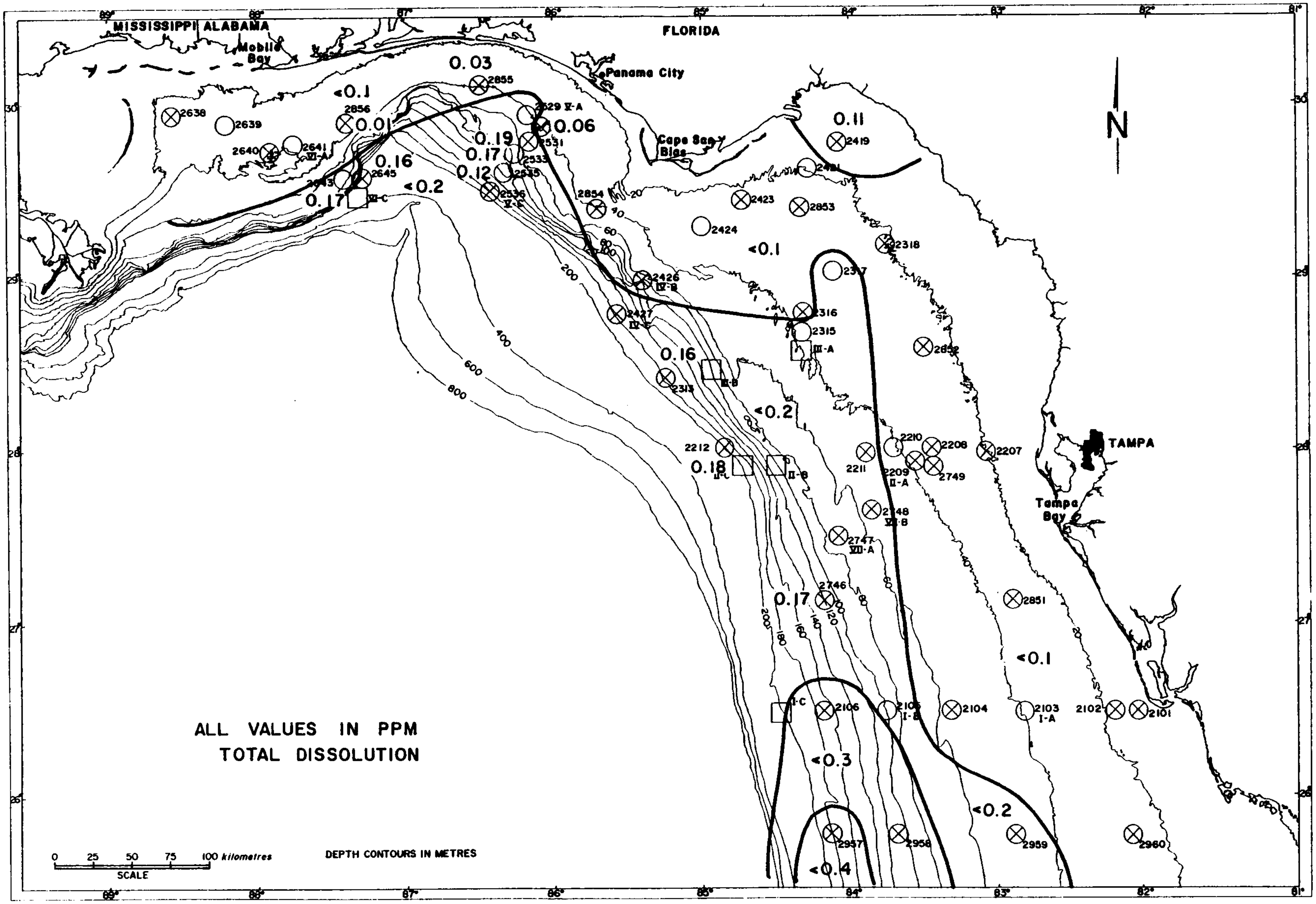


FIGURE 74

CADMIUM DISTRIBUTION IN THE MAFLA AREA

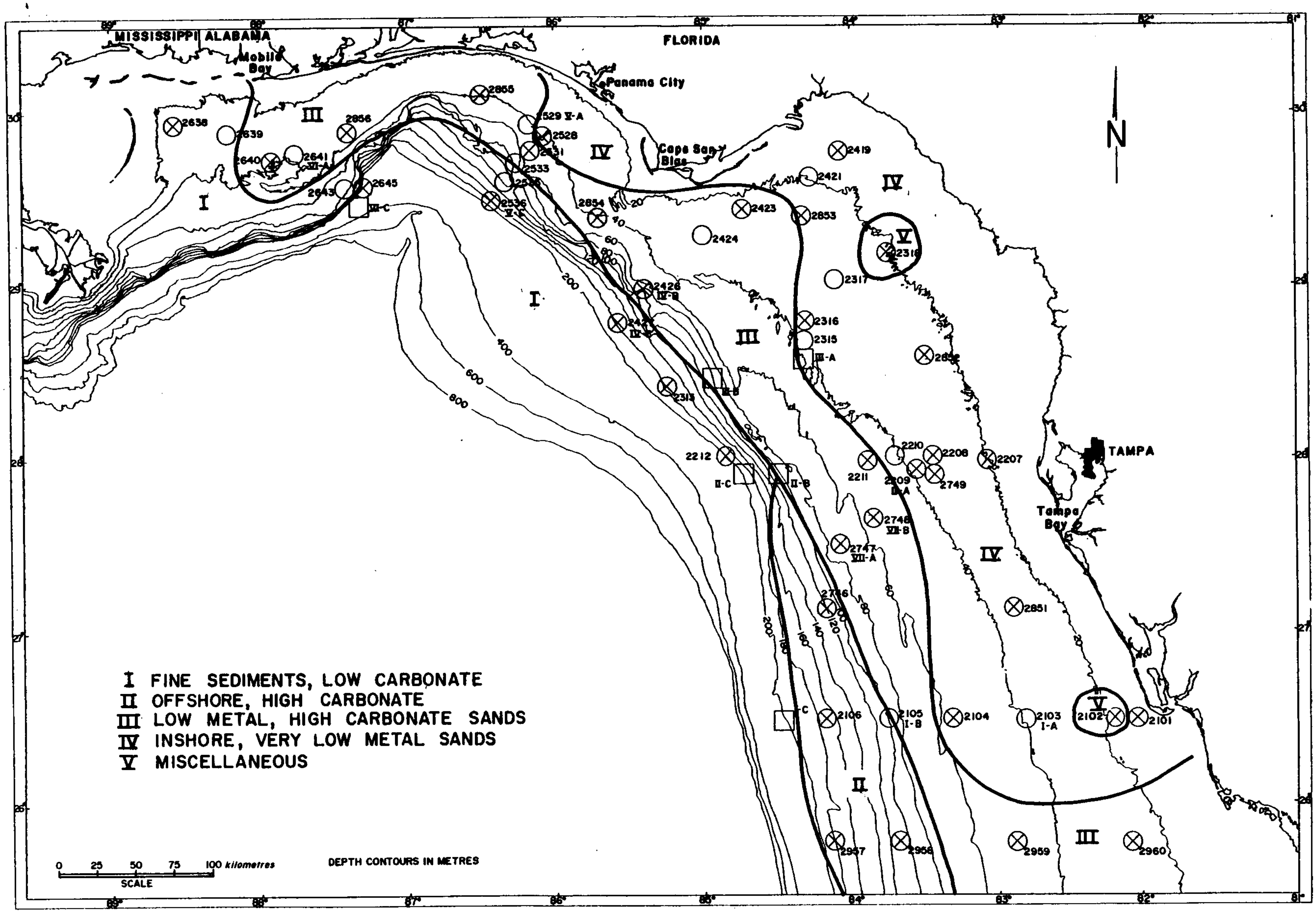


FIGURE 75

STATION CLUSTERS BY TRACE METAL SIMILARITY

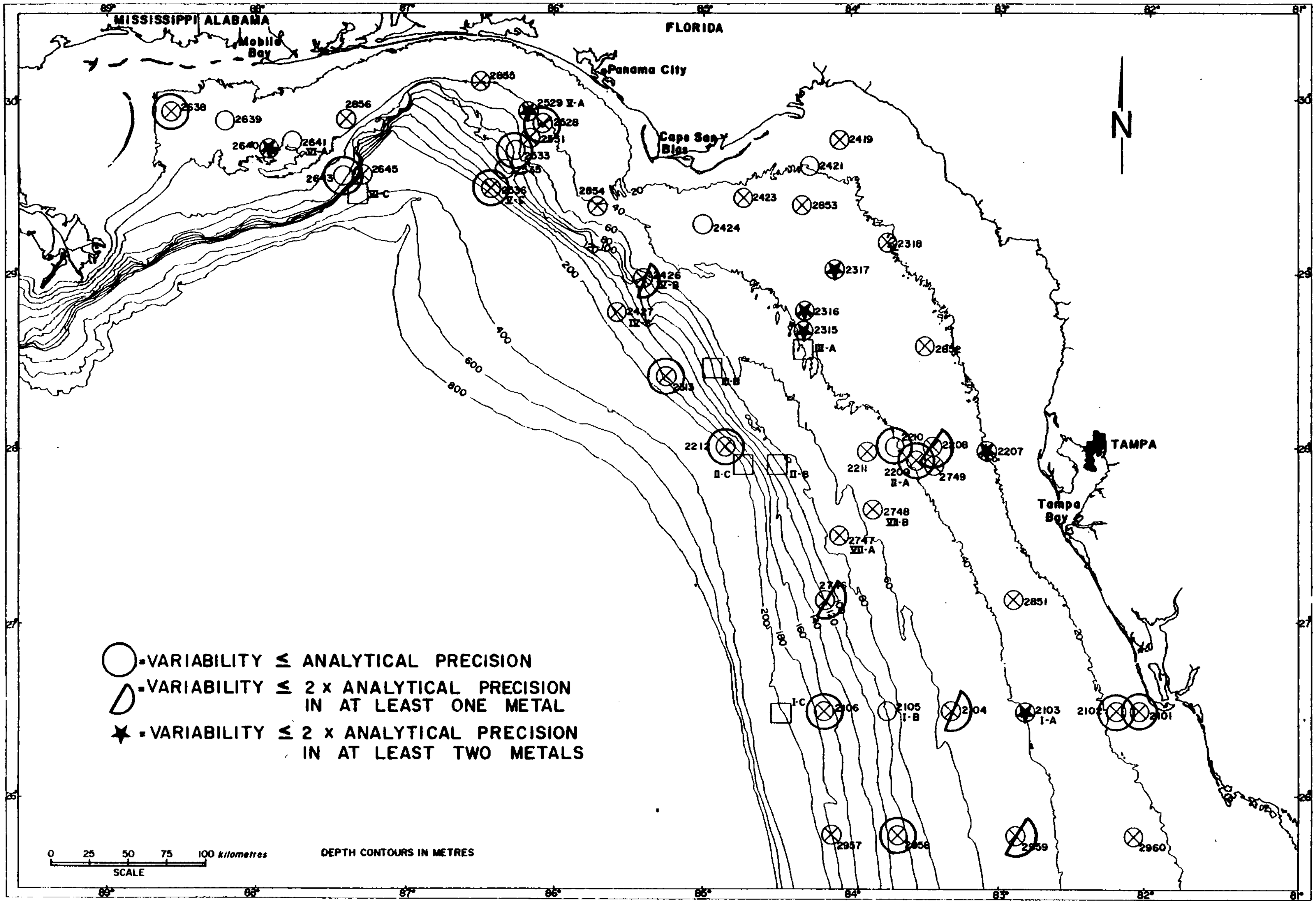


FIGURE 76

RELATIVE TEMPORAL VARIABILITY IN SEDIMENT TRACE METALS

Figures 73 and 74 above for Cu and Cd were well in excess of analytical error, and were thus real.

The range of variability seen for these metals (see Trefry, Volume II, Chapter 3) was low for coastal waters, and these data were from total dissolutions. To attempt to assess how much of these metals could become accessible to organisms which ingested them, a weak acid extraction was performed on most samples. Due to the high amounts and high variance in $CaCO_3$ in MAFLA sediments, it was necessary to use 1 N HNO_3 for this purpose (not as "weak" as most invertebrate gut levels which have pH values of 4 to 8; Barnard, 1973; Gates and Travis, 1969). In general, about 60% of the total dissolution quantities were removed by this partial leach. It tended to be nearly 100% in high (>90%) $CaCO_3$ sediments and near 10% in high clay sediments. Thus, the low total metal levels were still conservative when considering availability of these metals to organisms (excluding considerations of specific enzymatic attack).

A similarity matrix was constructed by Trefry (Volume II, Chapter 3) to inspect covariance. It confirmed what the trends suggested, that all of the metals except Cd and Ba were strongly inter-related, and they were, in turn, connected strongly with TOC and fine sediments. In addition, barium and cadmium (and chromium) showed strong affinities to $CaCO_3$ distribution.

Usefulness of Sediment Trace Metals as a Monitoring Tool

Sediment trace metals show very low analytical error levels relative to most parameters in the MAFLA studies program, and the casual mechanisms for observed distributions were generally demonstrated by the work carried out between 1975 and 1978 under BLM. The levels, and especially the "bio-available" levels were low for coastal areas, with no signs of any metal pollution. Trefry (Volume II, Chapter) demonstrates that metal:iron ratios can be used to predict expected metal levels for all metals, and that by placing "error windows" around the slope of the ratio line, outlying values can be visually picked out. Such outliers when above predicted intervals will signal pollutant input at levels well below their potential for adversely affecting the biota (see macroepifauna trace metals discussion, above, and Johnson, Volume II, Chapter 6). In addition, a complete data base with reliable metal values now exists for the sediments, and a relationship between the sediment levels and demersal fish levels has been established (demersal fish trace metals discussion, above, and Johnson in Volume II). For these reasons it is strongly recommended that sediment trace metals be made a part of any OCS oil and gas development-related monitoring program.

ORGANIC CARBON

Introduction

Particulate organic carbon (POC) and dissolved organic carbon (DOC) are both measures of living and nonliving carbonaceous material which derive from biogenic, anthropogenic, and petrogenic sources. With proper calibration, measures of POC and DOC may provide sensitive indicators of increasing relative amounts of anthropogenic and petrogenic hydrocarbons to naturally occurring biogenic levels. Boehm discusses an analagous scheme using total organic carbon (TOC) in sediments in Volume II, Chapter 10 and see sediment hydrocarbon discussion, above. (The treatment of TOC in sediments is given in the geology section of this volume and in Chapter 2 of Volume II; this section will deal only with POC and DOC.)

Average DOC concentrations in Gulf of Mexico coastal waters at depths less than 200 m were reported by Fredericks and Sackett (1970) to be in the range of 0.58 to 2.35 $mgC \cdot \ell^{-1}$ with an average of 1.08 $mgC \cdot \ell^{-1}$. POC concentrations in the same depth range and area were reported by the same investigators to be from 0.022 to 1.911 $mgC \cdot \ell^{-1}$ with an overall average of 0.214 $mgC \cdot \ell^{-1}$. Their data points were mostly in the northwestern and central Gulf coastal waters. The most complete study of DOC and POC distribution to date in the MAFLA survey area was the previous BLM study of Knauer and Aller (in SUSIO, 1977). They analyzed samples for DOC and POC three times a year at each of 15 stations distributed along four offshore transects on the continental shelf of the northeast Gulf of Mexico from Pascagoula, Mississippi to Tampa, Florida. Sampling periods were summer and fall 75, and winter 76. According to their report, POC reached the highest concentrations during the summer and winter and was at a minimum in the fall. DOC exhibited low levels during the summer and fall and was maximum in the winter. POC was found to be much more variable than DOC. Levels of POC seemed to be closely related to phytoplankton standing stocks, but DOC could not be related to any measured parameter.

This 1977/78 study was an extension of Knauer and Aller's investigation of DOC and POC levels in the MAFLA survey area. The samples were taken in fall 77 and winter 78. The emphasis in this study was on the variability of organic carbon with time at a few stations. Forty DOC and POC samples were collected on the fall (DM II) cruise and 160 on the winter (DM III) cruise.

Results and Discussion

The results of the POC and DOC analysis and a more detailed discussion are given by Jeffrey in Volume II, Chapter 26. The means and ranges of POC and DOC for the summer 77 and winter 78 cruises are shown on Figure 77.

The concentrations of DOC at the four stations during November 1977 were remarkably uniform and low. The corresponding POC values were also low for coastal water, but somewhat more variable than the DOC. The DOC and POC levels of the fall 77 water samples correspond reasonably well with Knauer and Aller's (1976) data. The range of DOC values for their September/October 1975 survey was 0.196 to 1.30 $mgC \cdot \ell^{-1}$, and the range of POC concentrations was 0.049 to 0.116 $mgC \cdot \ell^{-1}$.

The POC levels from winter 78 were seen to be as much as five times as high as the fall values at the same station. The DOC levels showed a great deal more variability than did the fall data, and also showed an increasing trend from the southern part of the MAFLA to the northern part; both mean values and ranges tended to increase.

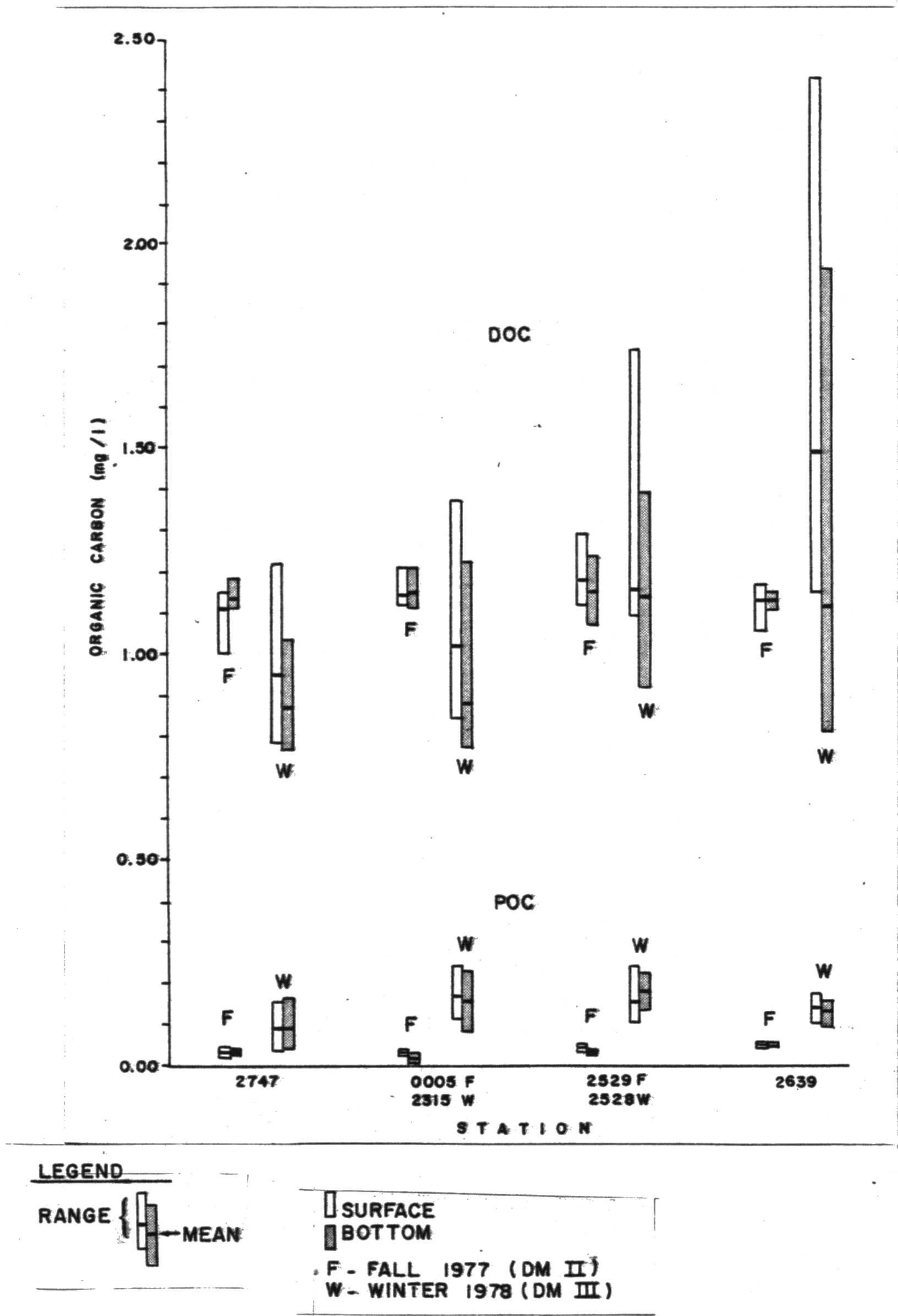


FIGURE 77

MEANS AND RANGES OF POC AND DOC VALUES
FALL 1977 AND WINTER 1978

The higher means and ranges of the winter 78 data were believed to reflect (1) the increased river runoff, particularly in the north, (2) greater mixing of the water column by wind waves resulting in more resuspension of bottom materials containing organic carbon, and (3) the effects of an observed plankton bloom during the time of the winter cruise.

Even in light of the variability seen in the data set, the values are very low in an absolute sense and are representative of truly oceanic conditions.

Usefulness of POC and DOC Analyses as Monitoring Tools

Measurement of POC and DOC is a relatively simple task, both in the field collection of samples and their subsequent analysis, and is not as prone to contamination problems as is the case with hydrocarbons and trace metals. POC and DOC values, determined in concert with characteristically biogenic hydrocarbon peaks, has the potential for being a relatively cost-effective way to detect additions of petrogenic hydrocarbons to the marine system. We recommend its continued inclusion in monitoring studies.

Furthermore, changes in the levels of POC and DOC are relatively easy to demonstrate with replicate sampling programs due to their relatively low natural variability. Figure 78 shows the number of replicates required to detect a given percent differences in POC and DOC concentrations. For example, a 50% difference in POC levels can be detected with fewer than 20 replicate samples, and a 10% difference in DOC by as few as 10 samples.

RESULTS AND DISCUSSION: MARINE BIOLOGY

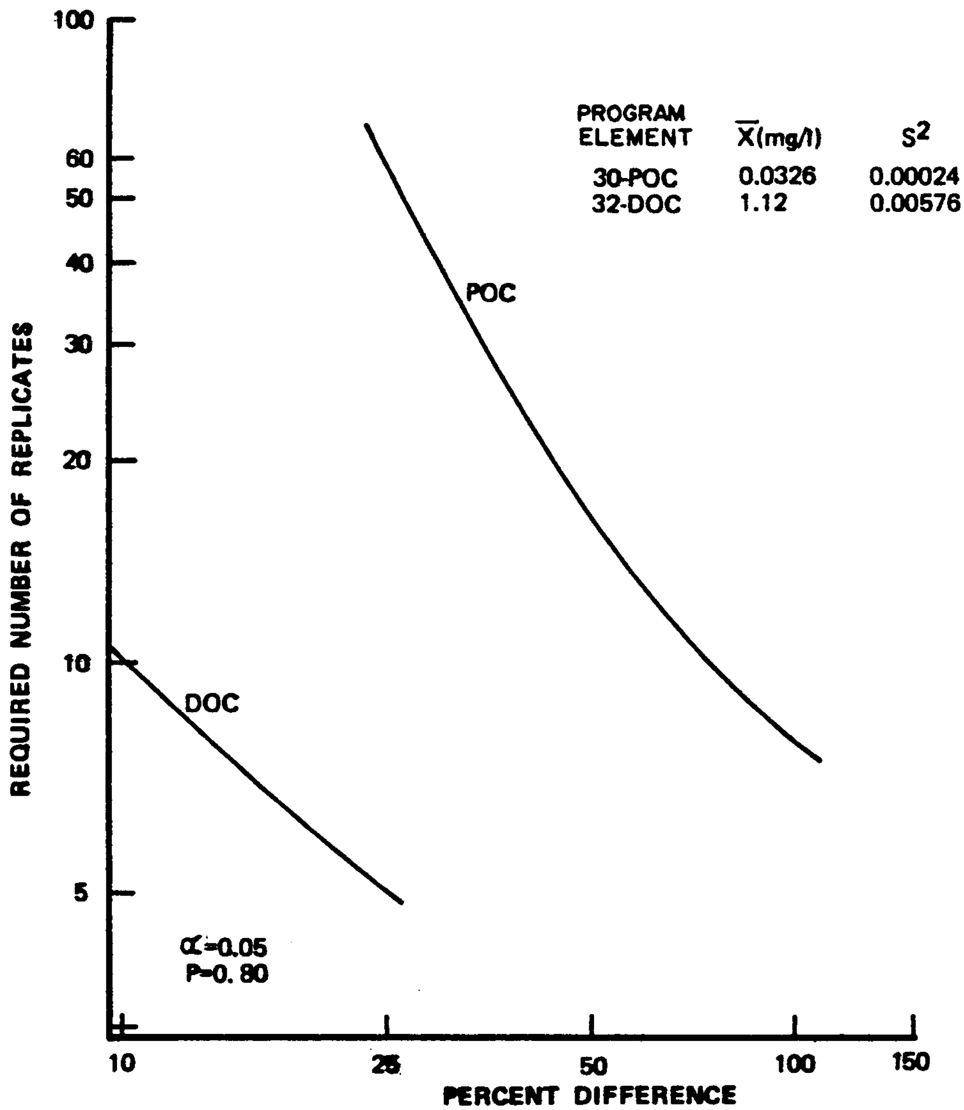
FUNCTION OF THE MARINE BIOLOGY STUDIES

Marine biological parameters form the second major dependent variable group studied in the MAFLA program. They not only complement the studies of tissue chemistry (see previous section on trace metal and hydrocarbons of animal tissues in the MAFLA region), but provide two important additional baseline needs:

- Community description (faunal associations), and
- Tissue health (histopathology).

Each of these is needed to assess potential environmental impacts of oil and gas development, to set restrictions (including prohibition) on development in specific areas, to design realistic monitoring programs, and to provide background for comparison with data collected during and after development of OCS resources.

Histopathology (the study of irregularities in cell/tissue formation) studies indicate the general health of organisms involved, and, as petroleum hydrocarbons may produce such irregularities under some circumstance, these studies provide the link between the marine chemistry and marine community characterization studies. They have been performed on a wide variety of



MINIMUM DETECTABLE DIFFERENCE (%) BETWEEN TWO SAMPLES OF POC/DOC

FIGURE 78

macroepifaunal invertebrates from each of the seven transects sampled by dredge and trawl.

Assessing the community structures of the marine sedimentary faunas of the MAFLA area included studies of ATP, foraminifera, meiofauna, macroinfauna, macroepifauna, demersal fish, zooplankton and neuston. The data set and definition of each of these is provided generally here, and more specifically within the discussion of each work element.

ATP (adenosine triphosphate) is a biochemical molecule used for "storing" easily accessible energy within all living organisms. Its ease of use in cells as an energy source also makes it highly degradable. Thus, its abundance in sediments is a measure of the amount of living biomass (most often microbial). Levels would be expected to increase rapidly under conditions that favor bacterial blooms, and to decrease under conditions of acute toxicity (see Cooksey, Volume II, Chapter 11).

Foraminifera are an order (a taxonomic level) of single-celled organisms which produce or aggregate an exoskeleton, often of calcium carbonate, but also occasionally of quartz sand grains or other materials. They are often very abundant in sediments, and their skeletons commonly persist over geological time. Due to their relatively short generation times (usually less than months; Hall, 1953) and sensitivity to environmental stresses, comparisons of live and dead individuals rapidly show the effects of some environmental perturbations. Their species-specific associations with various habitat conditions also allow them to be used as indicators of long-term (geologic time) changes or consistency in environmental conditions (see Bock, Volume II, Chapter 12).

Meiofauna are small (here operationally defined as passing through a 0.5 mm screen) animals that live among sediment particles. Several phyla are included in this group, most notably the nematodes (round worms). They tend to have short life spans (less than months; Barnes, 1963), and they typically do not have planktonic larvae (see Ivester, Volume II, Chapter 13).

Macroinfauna include members of many phyla that live in sediments. In the MAFLA program they are operationally defined as those organisms which are collected by box-core and which are retained on a 0.5 mm mesh. They tend to have life spans on the order of months and typically have planktonic larvae (Barnes, 1963). The macroinfauna form the basis of the food chain for many predators in the benthic environment, and most of them process sediments in their feeding (Barnes, 1963). They are, therefore, directly influenced by sediment pollutant bioavailability, and are a pathway for sediment pollutants to fishes and macroepifauna (see Reish, in Minutes, first quarterly meeting, Dames & Moore, 1977c). The three most abundant groups of macroinfauna in the worlds' oceans (in order) are typically polychaetes, crustaceans and molluscs (Hedgpeth, 1957). That sequence holds for the MAFLA area as well (see Volume II, Chapters 14-16).

Macroepifauna also include members of several animal phyla; abundant members usually include molluscs, crustaceans and echinoderms. Where sufficient solid substrate exists (loose rock, reefs, or the exoskeletons of other animals), sponges and corals may also be abundant. This portion of the marine fauna normally lives on the surface or in the immediate near-surface of the substrate. The macroepifauna include many commercially harvested shellfish, and include the food sources of many demersal fish. Their varied feeding types allow assessment of sources of pollutants by analyzing different species from this group for tissue chemistry. In the MAFLA program they are operationally defined as the invertebrates collected by dredge or trawl (see Hopkins, Volume II, Chapter 17).

Demersal fish are fish that live in association with the bottom, living buried in it, resting on it, or swimming in close proximity above it. Most demersal fish are predators. This position at or near the top of food webs allows determination of the extent of biomagnification of pollutants. Most trawl-collected commercial fish fall into this segment of the benthic fauna. In the MAFLA program they are operationally defined as any fish collected by dredge, trawl or box-core (see Shipp and Bortone, Volume II, Chapter 19).

Zooplankton are the animal portion of the plankton. They are free floating species which are characterized by having limited motility relative to the (horizontal) movement of the water mass they are immersed in. As a result, their gross movements are dictated more by the currents than by their own swimming (as opposed to the fishes and squids). In the MAFLA program they are operationally defined as the animals retained in a 202 μm mesh plankton net (see Caldwell and Maturo, Volume II, Chapter 27).

The neuston are a subset of the zooplankton that live in the upper few centimetres of the water column. Most of the species found in zooplankton collections are also found in neuston collections, although some species are specialized for this near-surface existence.

Both neuston and zooplankton contain many filter feeders which would be exposed to surface and water column pollutants immediately following the pollutant input. They process large volumes of small particulates, producing three forms of generally faster sinking products (fecal pellets, shed skeletons, dead individuals), and through the vertical migration of some species they actively transport materials into and out of the sediments. In addition, these two groups contain temporary water column inhabitants which are the eggs and larvae of infaunal, epifaunal and demersal fish species. Thus, they constitute a fraction of the fauna which can be rapidly exposed to pollutants and has both food and life history connections to the benthos (see Collard, Volume II, Chapter 28).

General data set descriptions for each of the descriptive ecology groups follow:

- Macroinvertebrate histopathology, from dredge and trawl samples on seven transects
- ATP, from box-cores at all infaunal stations
- Foraminifera, from box-cores at all infaunal stations
- Meiofauna, from box-cores at all infaunal stations

- Macroinfauna, from box-cores at 29 replicated seasonal stations, 13 non-replicated seasonal stations and 6 replicated summer 76, summer 77 stations.

- Macroepifauna, from dredge and trawl samples on seven transects

- Demersal fish, from dredge and trawl samples on seven transects

- Zooplankton, from abbreviated time series samples at one station (Florida Middle Grounds) over a five day period, summer 76, winter 78

- Neuston, from abbreviated time-series samples at four water column stations at the same times as zooplankton.

The biology of the MAFLA region is extensively reviewed by SUSIO (1973), and is summarized in BLM, 1978. Recent literature is also discussed in the 1975/76 SUSIO (1977) final report sections on biology, and in Chapters 11 through 19, 27, and 28 of Volume II of this report. The remainder of this section of Volume I is arranged in the order that the work elements are discussed above.

HISTOPATHOLOGY

Introduction

Begun as part of the BLM/MAFLA field studies in 1974, the histopathology effort has examined the tissues of macroinvertebrates from 20 stations from depths of 40 to 200 m spread over Transects I to VII (see Figure 1). The connection of tissue pathologies to pollutants, including petroleum hydrocarbons, is discussed by Blake in Volume II, Chapter 18. He points out that lethal effects on many marine animals may occur at levels as low as 1 to 10 ppm of aromatic hydrocarbons (see Moore and Dwyer, 1974 for a review), and that sublethal effects have been observed at levels as low as 10 ppb. Sublethal effects may include the production of abnormal formations in both somatic (body) and gonadal (reproductive) tissues and may cause tissue degradation and sloughing.

Results and Discussion

The distribution of collection locations of 73 species used for histopathological examination are given in Appendix A, Table 1. The table includes 6 sponges, 24 corals, 22 molluscs, 16 crustaceans and 5 echinoderms. They include specimens from all seven dredge/trawl transects and from all depths.

From all sectioned animals, 14,732 microscope slides of different tissues were prepared. Each slide contained one or more serial sections. Examination of all of these slides showed no occurrences of pathology. Moreover, there were very few incidents of internal parasites. Blake (Volume II, Chapter 18) concludes that the macroepifauna of the eastern Gulf of Mexico can be stated to be healthy, and the MAFLA region pristine in comparison with other shelf areas.

Boehm (Volume II, Chapter 10) indicates the outer ends of Transects IV and V as having sediment hydrocarbons which are qualitatively indicative of petroleum hydrocarbon input. Bieri (Volume II, Chapter 9) finds the clearest case of tissue petrogenic input in mid Transect V in the winter 78 demersal fish samples. The inner end of this transect also shows relatively (within the MAFLA area) high trace metal variability (Trefry, Volume II, Chapter 3) and the outer station has the maximum nickel value for the region (also high percent fines, high TOC and low $CaCO_3$), and generally high trace metal values over all. However, none of these trends shows up in the macroepifauna (Bieri, ibid; Johnson, Volume II, Chapter 6; Shokes, Volume II, Chapter 7), and winter collected filter feeders and mixed deposit feeder-predators collected from mid Transect V in winter 78 also show no pathologies. Further, both the infauna and epifauna (see below, this section) in mid Transect V are biologically similar to other stations in their associations, and have relatively high species variety and persistence, both indicative of good community health. Thus, even in the area where the greatest likelihood for extant condition pathologies from petrogenic or trace metal inputs, the biota sampled show no signs of tissue abnormalities, and the communities there are healthy.

Usefulness of Histopathology as a Monitoring Tool

Histopathology has to be highly recommended as a monitoring tool in the MAFLA area. For macroepifauna the occurrence of pathologies is not statistically discernable from zero, and thus the perfect base for "before and after" studies exists. A wide variety of species from all depths in all areas has indicated the extent of this pristine condition, and many common species are included in the current data bank (20 of the 50 most abundant macroepifauna; see macroepifaunal section, below, and Volume II, Chapter 17). The cost of this work is relatively low in return for the directly interpretable results (approximately $50,000 for the 1977/78 histopathology work element).

Histopathology studies on fishes are absent from data collected to date in this program, and are an obvious discrepency. Shipp and Bortone (see Volume II, Chapter 19) made an effort to report apparent external malformaties of fish, but that effort is not in any way comparable to a fish histopathology study. Such data should be included in a monitoring program.

MICROBIAL BIOMASS

Introduction

Unicellular organisms, including the bacteria, some algae and protozoans, make up the smallest size class/life span segment of marine benthic communities. At typical sizes of less than 63 μm in greatest dimension, they are smaller than the meiofauna. They usually have life spans (or division times) on the order of hours to days (Hall, 1953). The foraminifera (covered in the next section) are a special set of microorganisms which are distinguished by their relative ease of counting and identification.

Marine microorganisms include primary producers and decomposers (Hedgpeth, 1957). In the latter role they have been associated with petroleum hydrocarbons, and petrophyllic (oil-loving) bacteria have been noted to increase in abundance in the vicinity of natural or introduced oil (Pierce et al., 1975). In the former role they contribute to the base of food webs.

Adenosine triphosphate (ATP) is a biochemical produced in all living organisms to store energy for use in energy consuming metabolic activities in cells. It degrades very quickly upon the death of cells, and thus is used as a means of discriminating between TOC and living organic carbon (live biomass). The measurement of ATP to estimate microbial biomass was developed by Holm-Hansen and Booth (1966), and has been used in that manner in this report. The extent to which the data reflect actual microbial biomass levels is discussed below.

The data set treated in this report covers only the three benthic cruises of the 1977/1978 MAFLA study. Methodological problems with the procedure used in the 1975/76 program make intercomparisons of questionable value (see below). Samples for microbial biomass determination were collected during all three seasons at 42 box-core stations, and at 6 supplemental stations during summer 77. Triplicate or quadruplicate subsamples of about 2 cm^3 volume were taken from a single box-core at each station.

Prior studies in the Gulf reviewed by Cooksey (Volume II, Chapter 11) includes only the BLM work by LaRock (SUSIO, 1977). That work in turn shows no prior studies in the MAFLA region.

Limitations on the Data

Microorganisms are usually treated in ecological studies as a class of organisms with group, rather than species-specific characters. Traditional means of quantifying them are either extremely laborious (direct count methods) or are dependent upon the success of matching culture media to specific survival requirements of the entire sampled microbial community (plating methods; see Cooksey and Paul, Volume II, Chapter 11). Just as oceanographers have gone to measures of cell pigments to quantify phytoplankton standing crops, marine bacteriologists have determined an empirical relationship between microbial biomass and ATP, a relatively simply measured cell characteristic. Limitations of the method are described here.

Causes of variability in the data come from three sources other than the true natural variability of microbial biomass:

- The extent to which the assay assumptions hold true
- The extent to which non-microbes are included in the sample
- The extent to which analytical variability can be controlled.

For the first, the assumptions listed by Cooksey and Paul are paraphrased here with comments on the validity of each: (1) ATP is ubiquitous in living material and absent in non-living material; both conditions appear to hold in sediments, but Cooksey (Minutes, third quarterly meeting, Dames & Moore, 1978e, Appendix A, page A-8) reports evidence of the second half not holding in the water column, (2) the ratio of ATP to organic carbon is a single constant; Holm-Hansen's (1969) empirical relationship of 250:1 for carbon to ATP has been shown to vary from at least 40:1 to 220:1 in marine bacteria (Bancroft el al., 1976), (3) ATP levels do not change with environmental conditions; Cole et al. (1967), have shown cyclic oscillations in ATP in cultures of microbes with changes in growth and changes in culture conditions, and (4) the extraction procedure is efficient and no significant changes in ATP levels occur from the time of sampling to time of analysis; recoveries of spikes ranged from about 1 to 50% and averaged less than 20%.

Regarding the second source of variation, it must be understood that the ATP measured is non-selectively drawn from all living tissue in the 2 cm^3 sample, not just from microorganisms. A single polychaete or infaunal crustacean in a sample (as occurred in at least one replicate of a sample this year, Cooksey and Paul, personal communication) may produce an ATP reading which would greatly overestimate microbial biomass of that sample. Thus, the measurements are, in fact, estimates of total living biomass, including microorganisms, meiofauna and macroinfauna.

Analytic variation ranged from 1 to 80% of means of summer samples and 1 to 50% of means of fall and winter samples following approval of a change in methodology. For a thorough review of the current methodology see the third quarterly report, Appendix D (Dames & Moore, 1978e). The tests carried out in developing that methodology and in illucidating the problems of the prior methodology are detailed in the first quarterly report, Appendix C (Dames & Moore, 1978c). Briefly, shipboard extration before freezing led to excessive loss of ATP, sulfate ion interference in samples and absence in standards produced high estimates of ATP, and variations in end point pH caused by using a fixed amount of acid in an array of sediments varying from less than 10 to more than 90% $CaCO_3$ resulted in varying extration efficiences. Adoption of the new methodology reduced mean variability between replicates from more than 30% to less than 20%, and increased percent recovery of spikes from about 5% to more than 10%.

In sum, estimating microbial biomass by the ATP method is more efficient than counting and more accurate than plating, but the data should be viewed with caution. In this report the values discussed are amounts of ATP, not of living carbon. These comparisons remove the variability of conversion discussed in assumptions (2) and (3), above.

Results and Discussion

The distribution of ATP values in the MAFLA area during the 1977/78 sampling year can be viewed as having exhibited three kinds of geographic patterns: distribution of annual means, distribution of seasonal means and distribution of interseason variability. All three patterns are displayed in Figure 79.

ATP values ranged from single measurements (as opposed to replicate) lows of less than 50 to more than 3500 $ng \cdot m\ell^{-1}$, and inspection of Figure 79 suggests a level of about 500 $ng \cdot m\ell^{-1}$ is typical. Offshore (150-200 m) means tended to be low, and mid-transect values tended to be highest. The distributions of high values did not follow sediment grain size patterns

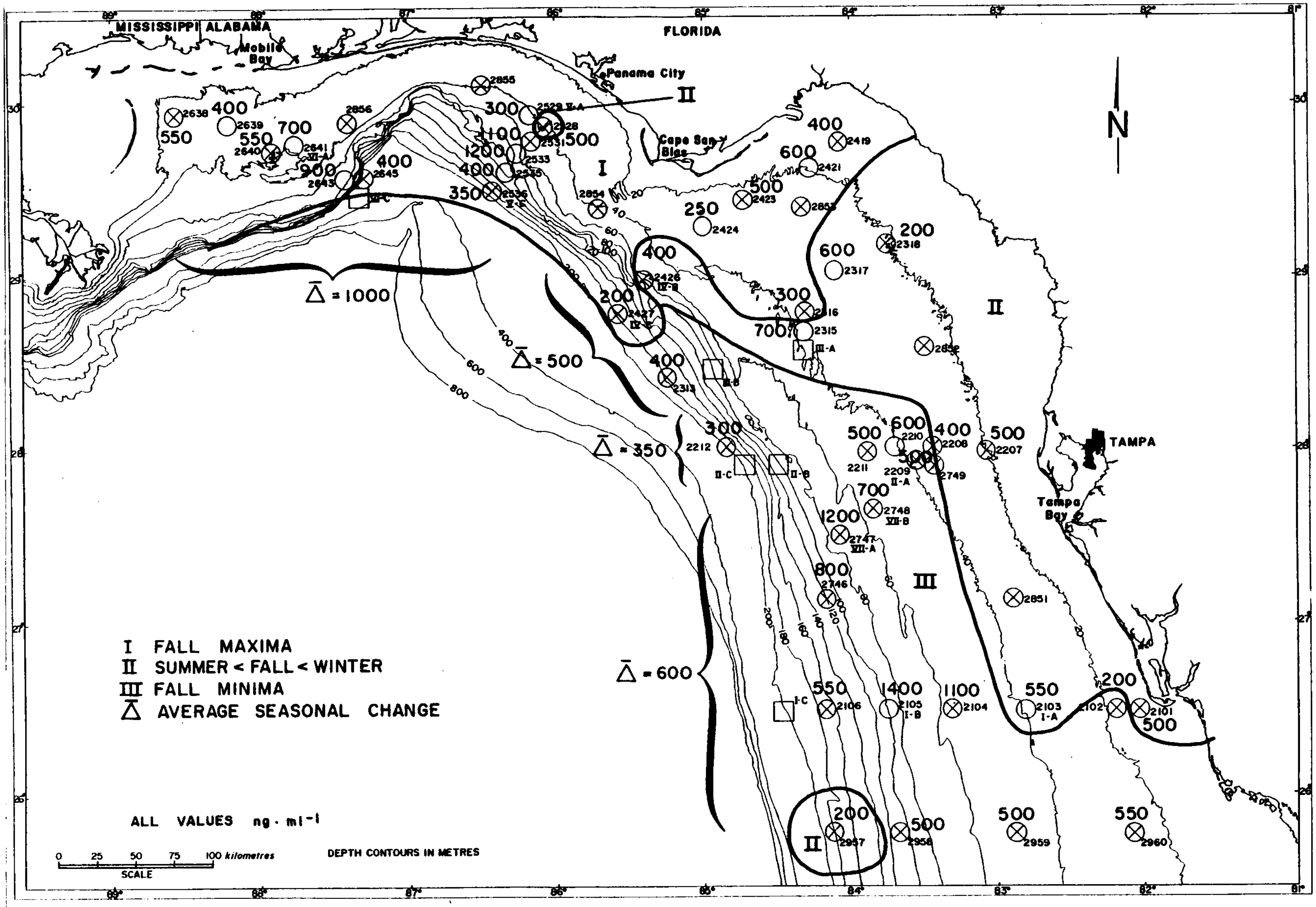


FIGURE 79

DISTRIBUTION OF ATP MEANS AND SEASONALITY

(Cooksey, Volume II, Chapter 11), nor did they match distribution of meiofaunal or macroinfaunal abundance (see those sections, below). There was not a direct correlation between ATP values and TOC (Cooksey, Volume II, Chapter 11), but all high ATP values (means > 1000 ng · $m\ell^{-1}$) fell in the window of TOC values > 0.1% and < 0.3% (see Geology discussion above and Figure 8).

Knauer and Ayers (1977) indicated that ATP values increase with increasing TOC until the refractory (difficult to break down) organic carbon becomes the dominant remaining fraction. TOC values generally increased offshore (Figure 8), and the incidence of residual petrogenic hydrocarbons in fine, offshore (100-200 m) sediments was also relatively frequent (see Marine Chemistry section, above and Figure 41). Thus, the distribution of ATP may have been following the concentrations of biodegradable TOC.

Distribution of seasonal means fell into three patterns which were geographically relatively coherent (Cooksey, Volume II, Chapter 11, and see Figure 79). Group I stations all fell into the north and west portions of the study area (Transects IV-VI). They were characterized by having all maxima. For most of these stations a single standard deviation from the mean of the fall value did not overlap the standard deviation of the means of summer and winter values, and for several there was no overlap at two standard deviations (indicative of significant differences of means at the 95% confidence level).

Group III stations were southerly and offshore, and were characterized by having fall means as minima. Group II had the least well defined area geographically, occurring inshore on Transects I-III, and with isolated single stations in each of the midsections of Groups I and III. Group II stations were characterized by having their mean ATP values increase through the year from summer to winter.

Seasonality can also be viewed by observing the distribution of changes in ATP means values between seasons (as opposed to direction, as above). Such a set of observations is also displayed in Figure 79. It shows that seasonal variation was highest in Transects V and VI (average change in means at all stations between adjacent seasons about equal to 1000 ng · $m\ell^{-1}$) and lowest in Transect III (average change approximately 350 ng · $m\ell^{-1}$). The fact that seasonal variation ranges from about half to more than the combined seasonal maximum mean in each set of transects is indicative of the most salient conclusion that can be drawn from the ATP data, that short-term variation was very high. Since essentially none of the conclusions drawn from this year's study (Cooksey, Volume II, Chapter 11) agreed with those of the 1975/76 study (LaRock, in SUSIO, 1977) and since there were a number of questions of credibility of prior data due to methodological problems, the patterns observed here can only be said to exhibit short period variability, rather than seasonality (no repetition of patterns in seasons over years).

Conversion of ATP to carbon at the high conversion of Holm-Hansen (250 x ATP = carbon) indicated that only a very small amount of the TOC at any station was accounted for by living biomass (from less than 0.01% to 5% of TOC). A rough approximation was that microbial (as qualified) biomass accounted for about one-quarter of one percent of sediment TOC.

Usefulness of ATP as a Monitoring Tool

Studies by Pierce et al. (1975) and Hood et al. (1975) both showed changes in microbial composition in the presence of petroleum (shift toward petrophyllic types) but no change in overall microbial abundance. Problems in non-indicative variability (laboratory methodology at the state-of-the-art, and invalid conversion assumptions) coupled with high natural short-term field variability, and the question of whether even a serious oil-related incident would induce a detectable alteration in microbial biomass, make ATP a very poor candidate for a monitoring program. Microbial monitoring of abundance of petrophyllic types by other methodologies would be a useful monitoring tool.

FORAMINIFERA

Introduction

The foraminifera (forams) are a taxonomic subgroup of the single-celled animal phylum Protozoa. They have a complex life cycle which includes a prolonged asexual stage and a less common sexual stage. They are distinguished by use of extensions of the cell wall and included plasma for motility and feeding and by production or aggregation of a skeleton, most often of calcium carbonate.

Although most forminifera are less than 1 mm in diameter, extant species include members with sizes on the order of 1 cm and extinct species reached sizes an order of magnitude larger. The skeletons they produce may persist over geologic time, and in some parts of the world's oceans their skeletons ("shells") comprise the major source of sediments (Trask, 1955; and see Doyle, Volume II, Chapter 2, in reference to West Florida slope sediments).

Historically the connection between foraminiferal studies and petroleum development has been in paleontological investigations to determine areas of probable oil-containing rock. In the context of the MAFLA studies, forams are the smallest size class of animals examined to describe and characterize existing benthic environments. Their relatively short generation time (average about 40 days; see, for instance, Hall, 1953) allows them to develop relatively tight environmental requirements while their dispersal mechanisms (Bock, 1969) make them available as settlers over wide geographic areas. In this manner they have become useful as characterizers of specific environmental conditions, including being indicators of environmental stress (see Bock, Volume II, Chapter 12). In addition, the persistence of skeletons (which are the basis for taxonomic identification in forams) allows comparison of the present environmental condition with those of the recent (geologic) past.

Prior studies in the northern and western sections of the MAFLA area have been common (Lankford, 1959; Ludwick and Walton, 1957; Parker, 1954; Phleger, 1954, 1955, 1960; Walton, 1964), but the shelf fauna off the west Florida coast was studied only limitedly before the BLM/MAFLA work. West Florida studies include those of Bandy (1956) and Parker (1954).

Bock has been the Principal Investigator for the MAFLA studies from 1974 through the present (see Bock in SUSIO, 1975, 1977 and in Volume II, Chapter 12). The differences in the basic sampling programs between contracts is reviewed in Methods, above. The data set for foram studies in the 1977/78 program consisted of paired replicate subsamples from two box-cores at each of 29 stations on 8 transects which were sampled by replicate box-coring seasonally, and from 6 supplemental stations between transects in the summers of 1976 and 1977. In addition, a pair of replicate subsamples were collected from each of 13 stations sampled by a single box-core seasonally (see Figure 1). Recent live and dead forams were collected from the top 3 cm of each 15 cm deep subsample (about 15 cm^3 of sediment from a surface area of about 5 cm^2), and recent (geologic) past foram assemblages were collected from the bottom 3 cm.

Results and Discussion

More than 400 species of foraminifera have been identified from MAFLA area sediments between 1974 and 1978. Defining major dominant species as those which have at least 5% of the total live individuals at any station, Bock (Volume II, Chapter 12) reported that this class of forams has increased from 24 species at the end of the 1975/76 program to more than 50 as a result of 1977/78 counts.

The number of species, number of individuals, and ratio of live to dead individuals all tended to increase in an offshore direction. The connection of the last two traits is related to grain size with increases in foram numbers and percent live corresponding to decreases in grain size. Thus, abundance and live/dead ratio also increased in a northerly direction (see Bock, Volume II). Although TOC followed the same trend (see Figure 8 above) no other biological distributions did. Meiofauna, macroinfauna and macroepifauna all decrease in species variety and numbers of individuals from inshore to offshore (refer to Figures 81, 83, and 85 below). The trend suggests a positive effect of percent fines on foram distribution which is contrary to its effect on other animal groups. The effect of fine sediments on forams may have been related to either or both of habitat stability and increased food availability (Bock, Volume II, Chapter 12; and see also Figures in Fausak, Volume II, Chapter 21 or above, Figures 31 and 32). In addition, Trefry (Volume II, Chapter 2) speculates that the relatively high concentrations of trace metals in offshore, high carbonate sediments may be a result of scavenging of these metals during carbonate skeleton formation by forams, such that areas of higher foram skeleton deposition would show trace metal acccumulations (especially barium).

Foram community associations (after Bock, Volume II, Chapter 12) are shown in Figure 80. The 100 to 200 m association was characterized by a dozen species in six genera (Table 18), and was continuous along the MAFLA outer shelf. One additional dominant, Brizalina subaenariensis, was present in abundance only at Station 2536.

The inner portion of the West Florida Shelf contained a second major association which was characterized by the habit of forams in this area of attaching themselves to sand grains. Asterigina carinata was indicative of this zone, the other dominant species (Table 18) being ubiquitously distributed over the MAFLA shelf, but showing the attached habit only within this

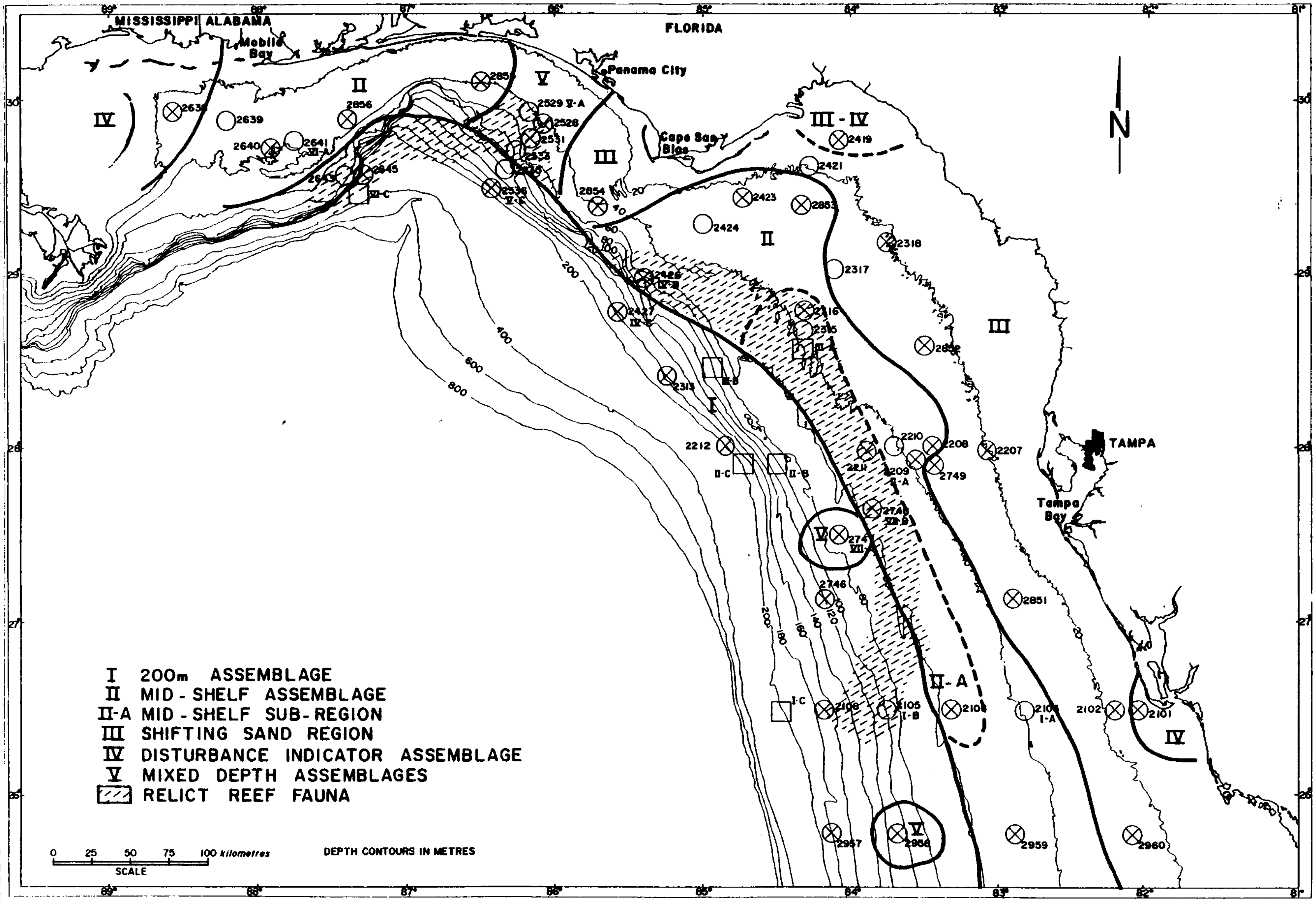


FIGURE 80

FORAMINIFERAL ASSEMBLAGES IN THE MAFLA REGION

TABLE 18

CHARACTERISTIC FORAMINIFERA OF THE MAFLA AREA

Species	FAUNAL GROUPS (see Figure 80) I	II	III	IV	V
Ammonia beccarili (S)*				X*	
Amphistegina gibbosa (R)*	X	X			X
Archais angulata (G)*				2419*	2747
Asterigerina carinata		2103,2104	X(A)*	2419	
Brizalina goessii	X				
B. lowmani	X				
B. subaenariensis					2536
Cassidulina curvata	X				X
C. subglobosa	X				X
Cibicides concentricus	X				
C. floridanus	X	2103,2104	X(A)		2534
Elphidium galvestonense				2638	
Hanzawaia strattoni		2103,2104	X(A)	2101,2419	
Lenticulina orbicularis (R)	2643,2645				
Neoconorbina orbicularis		2104,2211			
Nonionella atlantica (D)*				2638	
N. opima (D)				2638	
Peneroplis carinatus					2747
Planorbulina mediterranensis	2746				
Planulina ariminensis	X				
P. exorna		X			2748
P. foveolata	X				
Quinqueloculina lamarchiana		2103,2104			
Remaneica sp. A				2101	
Rosalina columbiensis	2105	2103,2104	X(A)	2101	
R. concinna		2103,2104	X(A)	2101	
Siphonia pulchra	X				
Uvigerina flintii	X				
U. peregrina	X				

*X = Characteristic of the association
S = Stress indicator species
G = Sea grass indicator species
A = Attached to sand grains
2XXX = Station numbers within cluster where characteristic
R = Reef indicator species
D = Mississippi Delta indicator species

shallow, inshore environment. Bock concluded that the attachment habit is used to provide additional weight to keep the formas from being swept away from the area.

Between these two associations on the West Florida Shelf and appearing again in the Mississippi-Alabama transition zone was a third foram assemblage. This mid-shelf association was linked with medium to coarse sediment, and was characterized by the species Planulina exorna as a dominant.

The stress indicator species Ammonia beccarii characterized three small, discontinuous regions, the westernmost station (2638; and 2637 of the 1975/76 survey, see Table 3), and the two shallow, inshore stations, 2419 in the northeast corner and 2101 in the southeast. Station 2638 is under the influence of Mississippi River runoff, and has salinity (low) and siltation stresses. It also stood out as a separate faunal association in the macroinfauna (see below). Bock (Volume II, Chapter 12) indicated a clear transition onto the adjacent shelf to the west which was also apparent in the meiofauna (see next section, and Ivester, Volume II, Chapter 13), the macroinfauna (below), the fishes (Volume II, Chapter 19), and the sediments (below, and Volume II, Chapter 2).

Station 2419 had the highest combined range of bottom temperature and salinity in the area (Figures 27 and 28, above), and is under the influence of terrestrial source sedimentation as indicated by leaves and twigs in the sediment samples (Vittor, Minutes second quarterly meeting, Dames & Moore, 1978b, Appendix A). It also had the lowest recorded bottom temperature and salinity during the 1977/78 program (9.8°C and 33.7°/oo; see Fausak, Volume II, Chapter 21; letter Dames & Moore to PIs dated August 16, 1978; Dames & Moore Data Tape). Both the polychaetes and molluscs among the infauna showed a relationship between the western stations and the northeast corner stations (Volume II, Chapters 14 and 15).

Station 2101 was the shallowest (<10 m) and nearest shore (<10 km; c. 5 mi) station sampled in the 1977/78 program. It had the summer maximum bottom salinity value for the MAFLA area (36.5°/oo), and both its temperature range (Δ = 13.6°C) and temperature maximum (>28°C) were high for its latitude (see T and S references, previous paragraph).

A fifth distributional area for forams in the MAFLA region (Figure 80) was along Transect V, where the occurrence of indicators of oceanic conditions and deeper water were found well up onto the shelf. Bock (Volume II, Chapter 12) ascribed this distributional anomaly to oceanographic circulation patterns related to the Loop Current and to the DeSoto Canyon. Stations 2747 and 2958 also showed a mixed depth assemblage of forams, but in the opposite direction, i.e., shallow water species were found at these outer shelf stations in 50 to 100 m depths, respectively. Station 2747 also showed this shallow water faunal affinity in the macroepifauna (see below). In the macroinfauna, seasonal transitions between stations in this zone and the mid-shelf zone were also apparent (Figure 84, below).

Within the mid-shelf region was a linear subregion paralleling the 50 m contour from Station 2104 to the Florida Middle Grounds. It was characterized by having the foram species Neoconorbina orbicularis as a codominant species along with Planulina exorna.

Superimposed over these areas was a relict reef associated fauna (Figure 80). This fauna had a much more varied dominant fauna among the relict fauna than the living, indicating the once wider spread presence of active reefs along the present 50 to 100 m contour throughout the MAFLA area. These species when dominant in the living fauna were found in the Florida Middle Grounds near the existing active reefs of the MAFLA shelf.

Seasonal variability in species composition was uncommon among dominant foram species. Changes in abundance with season tended to be inshore decreases. Although all the dominant species in the 1975/76 survey were still present in this survey, the relative abundance of the once very abundant Hanzawaia strattoni has decreased, while several other species have increased to become dominants.

Usefulness of Foraminifera as a Monitoring Tool

Because of their relative ease of identification at the species level (compared with other protozoa or the meiofauna), presence throughout the area, regionality and established use as indicators, the forams appear to be an excellent sediment community monitoring tool. As a result of this study a thorough taxonomic, descriptive abundance and distributional baseline on the forams in the MAFLA area now exists. Indications from similarity of replicates are that single samples from each box-core are adequate to characterize both species variety and abundance (low very-small-scale variability among dominants; see Bock, Minutes second quarterly meeting, Dames & Moore, 1978b).

MEIOFAUNA

Introduction

The meiofauna are composed of infaunal animals of several phyla, including protozoans, coelenterates, flatworms, nemertean worms, nematodes, gastrotrichs, kinorhynchs, annelid worms, and arthropods, as well as others. They are characterized by their small size (between 63 and 500 m) which allows them to live among or on single sand grains. The meiofauna include the larvae (by this program's definition, at least) of macroinfaunal species, but permanent (i.e., whole life span) meiofauna either lack larvae or have benthic larvae (Ivester, Minutes third quarterly meeting, Dames & Moore, 1978e). Thus, like the forams, they have been able to evolve specific habitat requirements, and would be expected to reflect disturbances to the local environment relatively rapidly (see, for instance, Marcotte and Coull, 1974).

Meiofauna are typically very abundant in marine sediments, with densities averaging about $10^6 \cdot m^{-2}$. Nematodes and harpacticoid copepods usually comprise the most abundant groups (see Ivester, Volume II, Chapter 13). The meiofauna may comprise as much as five times the food supply to higher levels of benthic food webs as do the macroinfauna (Gerlach, 1978) and may be abundant under conditions which macroinfauna find unfavorable (McIntyre, 1968).

Crezee (in SUSIO, 1977) lists no prior work on the meiofauna of the MAFLA/OCS, and his report provides the regional comparative data used by Ivester in this program (Volume II, Chapter 13). Ivester believes that differences in the data base between programs arise from laboratory methodologies, and not from real environmental differences, and has, therefore, based most of her interpretations on the 1977/78 program results. General trends have held up, and are discussed in terms of the period 1975/1978 (meiofauna are not reported from the 1974 program; SUSIO, 1975).

The data base for the 1977/78 program consists of paired replicate subsamples from each of three box-cores at 29 stations seasonally and from six supplemental stations in summer 77. In addition, a pair of subsamples was collected from the single box-core from each of 13 stations seasonally.

Results and Discussion

Sample densities of meiofauna ranged from a low of $65 \cdot 10\ cm^{-2}$ (Station 2533) to $3952 \cdot 10\ cm^{-2}$ (Station 2207). Figure 81 shows station means (all seasons, all replicates) for 1977/78 samples. Densities decreased with increasing distance from shore on all transects, and had comparable ranges on all but Transect V. These trends and overall densities agreed with meiofaunal studies in other comparable areas (see review by Ivester, Volume II, Chapter 13).

The anomalously low values along Transect V probably reflected sediment conditions. The meiofauna tended to have high densities in medium to fine sediments with moderate to high (~30-85%) carbonates (Ivester, Volume II, Chapter 13). The inner stations on Transect V (2528-33) had about 60% or more of their sediments as coarse sands or greater. The outer stations (2535, 36) were not atypical in densities for their depths. Note in Figure 81 that the inner Transect V stations belonged to a cluster (sediment association) of stations (Q-mode, grand station means 1974-78, grain size only) which included a number of midshelf stations from east of Cape San Blas. The range of meiofauna densities for those five stations on the West Florida Shelf was $192 \cdot 10\ cm^{-2}$ to $534 \cdot 10\ cm^{-2}$, with a mean of 389 ± 289 (2 SD). All the meiofaunal densities of inshore Transect V fell within the 95% confidence limits (2 SD) of the mean of those five stations, and thus were not statistically different from them. Similarly, note that all three of the inshore Transect VI high values had the same sediment cluster assignment, and that they grouped (by sediment classification) with other high density ($>1000 \cdot 10\ cm^{-2}$) stations on the West Florida Shelf.

Relative to the other inshore stations on Transect VI, Station 2638 had an anomalously low density. This station showed signs of stress from the foram faunal composition (see above, and Volume II, Chapter 12), and fell out faunally from the remainder of Transect VI in the macroinfauna (see below). Its sediment type (Figure 81) was like that of the outer stations on Transect V; it had 70% fines (clay + silts) and less than 20% $CaCO_3$.

The taxomonic composition of these faunas was dominated by nematodes (70% of all sample specimens identified). Nematode worms dominated all stations, all seasons, all years except for a single station in the 1975/76 survey. Copepods (mainly in the order Harpacticoidea), were the next most

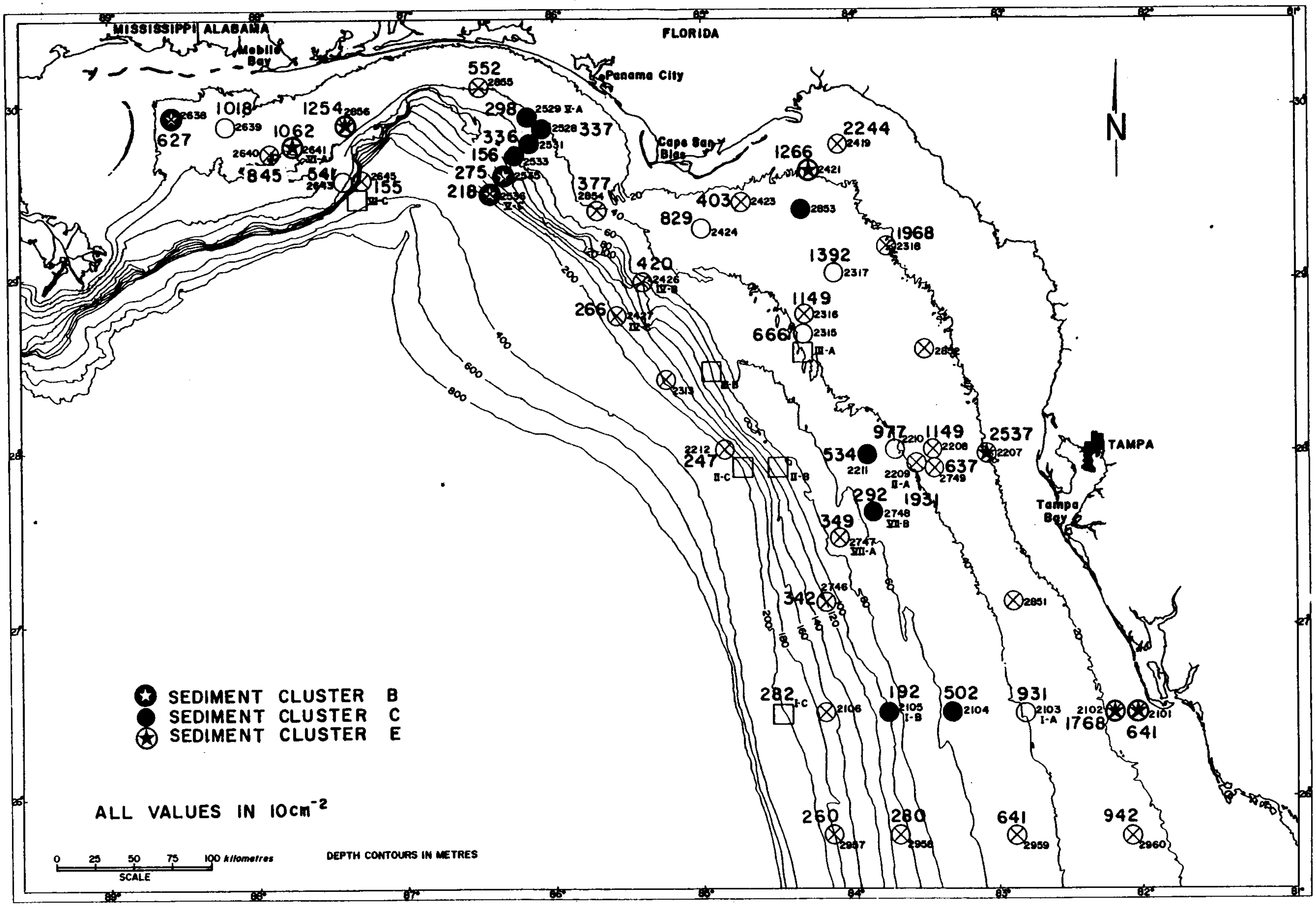


FIGURE 81

MEAN MEIOFAUNAL DENSITY 1977/1978

abundant faunal group ($\bar{x}$ = 14%) with one sample containing almost 52% copepods. Other phyla made up the remainder, with only the polychaetes approaching 5%.

Figure 82 shows the results of cluster analysis of the 1977/78 meiofauna, with each season treated independently within the single similarity matrix. A different, but similarly complex, set obtained for the 1975/76 data (see figures in Volume II, Chapter 13). These clusters were based on the most general level of taxonomic identification (mostly phyla), and root transformations were applied to try to equalize the variability. It is probable that finer level identification, though needed to make good community association conclusions, would produce more complex patterns.

Several conclusions about general meiofaunal distributions can be drawn from these cluster analyses:

- o Meiofauna group associations tend to be very localized
- o Temporal continuity is very low
- o There is no compelling geographic pattern to the groups.

The first of these is probably related to the combination of the lack of free swimming larvae for dispersal and the close discrimination among sediment types in an area which has much fine scale variation in its sediment patterns (see geological variation discussion, above).

The low temporal continuity is not "seasonality," because the patterns do not revert to type for similar seasons (see figures in Volume II, Chapter 13). Overlaying the six seasons produced almost every possible set of proximity associations. The 1975/76 cluster were somewhat more localized and less complex than the 1977/78 set, and had a stronger within-transect orientation. Temporal variability was also shown in accounting for times of maximum abundance. Of 36 stations sampled over six seasons (S,76; F,75; W,76; S,77; F,77;, W,78), the yearly maxima were each strongly biased toward one season. For the 1975/76 year, 22/36 maxima occurred in summer 75; in 1977/78, 22/36 maxima occurred in fall 77 (12 each season would be expected if only chance were involved). The deviation from expectation is indicative of non-random causation of high meiofaunal densities, but their non-synchroneity between years (May-July 1975; November 1977) indicates that the event was nonseasonal.

Reference to Figure 82, or to figures in Volume II, Chapter 13 shows that clusters within seasons or years had no more tendency to follow than to run perpendicular to depth contours, this despite the clear depthwise trend in overall density and in predominance of meiofaunal counts by two taxonomic groups. This lends further strength to the conclusions that meiofaunal distributions are non-predictable in time or geography. Four pairs of stations, 2102-2103, 2138-2419, 2208-2209, 2207-2208 (but not 2207-2209) were found in the same cluster in five out of six sets of samples (with varying other added stations). These are all within the 40 m contour, and all are adjacent stations on the same transect except 2318-2419 which are of the same sediment cluster (Q-mode, grand station means, grain size only).

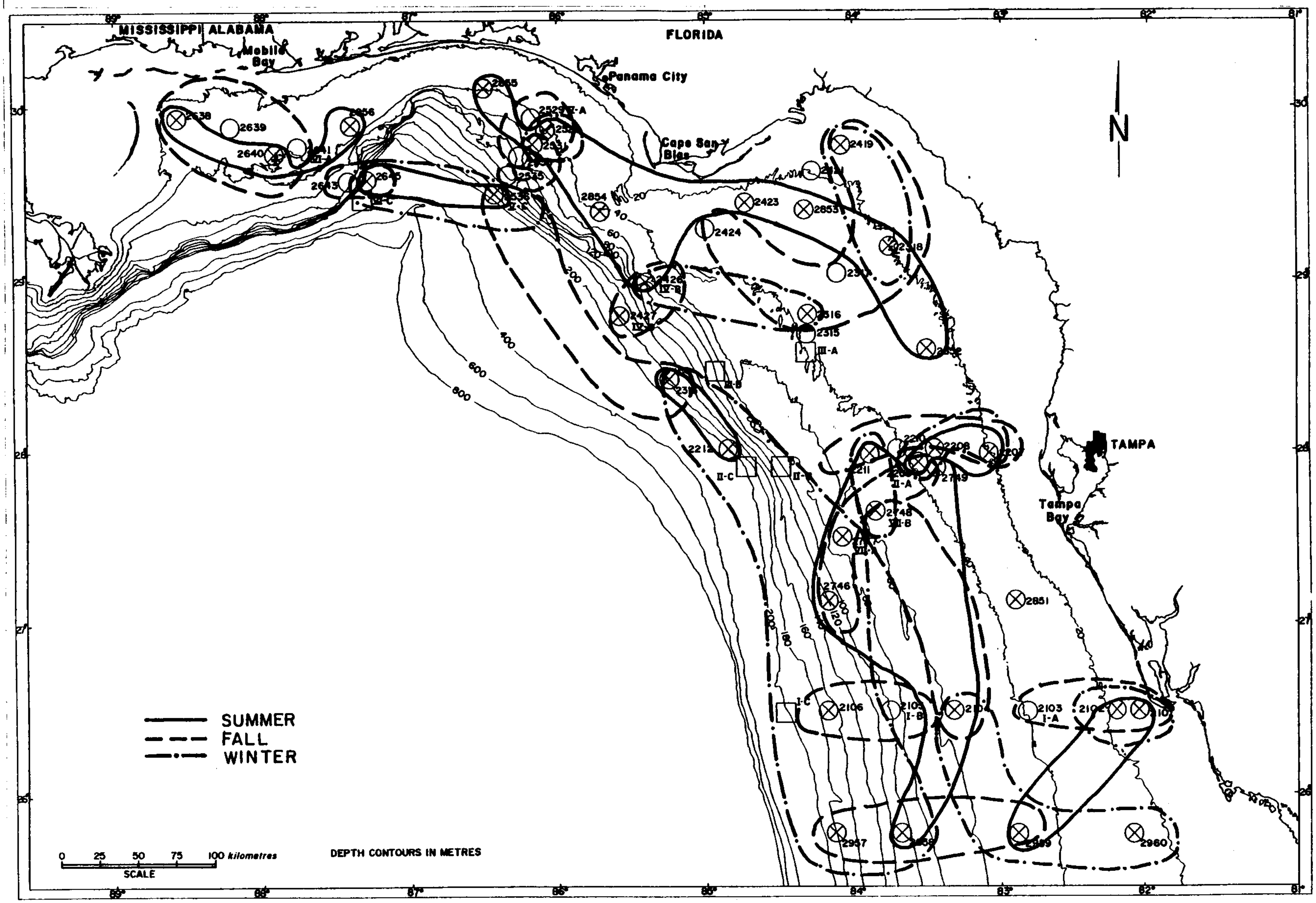


FIGURE 82

MEIOFAUNAL SIMILARITY BETWEEN STATIONS 1977/1978

Usefulness of Meiofauna as a Monitoring Tool

On theoretical grounds the meiofauna should be at least as good a monitoring tool as the forams, having similar life spans, sizes and localized environmental requirements. They live for the most part in the immediate surface of marine sediments (Ivester, Volume II, Chapter 13), and should be exposed to environmental perturbations quickly. Local extinctions would take longer to recover due to their lack of planktonic larvae, and thus a less than immediate after-event sampling would still have a good chance to catch the change in community structure. However, even using root transformations and counting taxa at very general levels, both of which should reduce variability, a picture of rapid and non-regular temporal and spatial variability in meiofaunal associations emerges. Moreover, to use the meiofauna properly in a monitoring program, species level identifications (rather than ordinal and higher) should be made. Dames & Moore estimated that to mount a monitoring program of the 1977/78 baseline study scale for species level meiofauna determinations would cost $200,000 to $300,000 for the laboratory work alone, if the expertise could be brought to bear on this highly diverse, understudied and taxonomically relatively difficult (relative to forams and macrofauna) group. From only 9 of the 48 stations sampled (all geographically close together) and looking only at the nematodes, 46 genera from 30 families were identified. Further analysis at the generic level within the time and budget were not possible in this program.

Although total densities could be arrived at with expenditures similar to those in this program, the PI (see Ivester, Volume II, Chapter 13) cautioned that such data are not indicative of environmental conditions. She cites examples in which total densities are non-reflective of composition from the relatively proximate station pairs 2211-2749 and 2209-2210. In the first pair the total densities were similar, but nematodes dropped from 74% of the sample at 2211 to 48% at 2209. On the other hand, Station 2209 had nearly twice the mean density of Station 2210 (see Figure 81), but the gross composition were nearly identical (84.4% nematodes, 6.9% copepods vs 84.4% nematodes and 9.4% copepods).

We cannot conclude that meiofaunal analysis in the MAFLA OCS would be a cost effective monitoring tool at the present state-of-the-art.

MACROINFAUNA

Introduction

The macroinfauna comprise those organisms that are greater than 0.5 mm in least dimension (do not pass a 0.5 mm screen) and live in the sediments. In the MAFLA program they are restricted to those collected by box-core (as opposed to the macroepifauna, which were collected by dredge or trawl). Aside from the operational difference between infauna and epifauna applied here, the infauna tend to be smaller (size measured on the order of millimetres) and to have shorter life spans (on the order of months; see Barnes, 1963; see macroepifauna, below). In addition, most of the infauna live buried in or at least intimately involved with the surface sediment layer, while most of the epifauna live on and above the surface. Because the two elements are composed of a broad overlap of the same taxonomic groups, there is some overlap of coverage of species between the two sections.

The macroinfauna analyzed in detail in the MAFLA 1977/78 program included the molluscs, crustaceans and polychaetes. These three groups usually dominate shelf sediments in temperate and tropical waters in numbers of species and in abundance (Hedgpeth, 1957). During the 1975/76 program the infaunal crustaceans were not analyzed. Therefore, the primary synthesis effort of this study was aimed at the data from the 1977/78 program. The separate accounts of the polychaetes and molluscs include analysis of data back through the inception of the program.

In contrast to the meiofauna and forams, which preceded this section, the majority of the macroinfauna have planktonic larvae (Barnes, 1963). This attribute allows them to disperse over distances much greater than that which the adult may cover in a lifetime. At the same time, their intimate involvement with the sediments has led to their larvae becoming evolved to select suitable habitats on the basis of both the texture and chemical quality of surface sediments with which they come in contact (Thorson, 1956). As a result, the macroinfauna should tend to show more general trends than the meiofauna, and also show the effects of disturbances to sedimentary habitats.

Infaunal studies in the eastern Gulf of Mexico are reviewed in the BLM sponsored literature search of the MAFLA area (SUSIO, 1973). In that volume Collard and D'Asaro site three summary monographs that cover infauna of the region: Galtsoff (1954), Hedgpeth (1953), and Pequegnat and Chase (1970). These studies, as does the review of Colalrd and D'Asaro, deal with both the infauna and the epifauna, and the latter group tend to dominate early reviews.

Blake describes a series of eastern Gulf collections by dredge of molluscs (Blake, Volume II, Chapter 14), but points to the lack of quantitative data in the region prior to the BLM/MAFLA surveys. Major reviews of the polychaetes of the offshore eastern Gulf listed by Vittor (Volume II, Chapter 15) are those of Bault (1969), Hartman (1951) and Perkins and Savage (1975). Again, all of these lack the scope and quantification of the current MAFLA program. Heard (Volume II, Chapter 16) reviews the diverse literature on the taxonomy of eastern Gulf crustaceans. These include Chase (1972) for shrimps, the series (1918-1937) by Rathbun on crabs, Richardson (1905) on isopods, and Culpepper and Pequegnat (1969) on amphipods.

Prior MAFLA studies on molluscs and polychaetes are reviewed in Volume II by Blake (Chapter 14) and Vittor (Chapter 16). The work of Heard (Chapter 15) in Volume II is the first comprehensive, quantitative analysis of infaunal crustaceans in the MAFLA region. The 1974 sampling program sampled a wide array of stations in the summer only, with little replication (see Tables 2 and 3 in Methods, above; and refer to SUSIO, 1975). The 1975/76 program collected replicate (usually 7) box-cores along six transects (21XX-26XX in Figure 1) as well as some single samples, all seasonally. The summer 76, and the 1977/78 program collected nine replicates (covering approximately 0.6 m^2 of surface area in total) for infauna at "primary" stations (see Figure 1), and single samples seasonally at "secondary" stations. In addition, "supplemental" stations with locations between transects were replicate sampled in the summers of 1976 and 1977. The summer 76 survey covered all the transects shown in Figure 1 except Transect IX (29XX) which was added in the current contract.

The majority of the following discussion is based on a merging of the three major infaunal groups into a single data set (the taxonomic division by PIs being an ecologically artificial one) for synthesis purposes. In setting up the merged data for analysis, 100 of the approximately 1,250 different species level identified groups were utilized. It is typical for marine benthic communities to have large numbers of rare or infrequently occurring species (see, for instance, Sanders, 1968). These low density species do not tend to influence multivariate analyses and even with common species, methods such as cluster analysis become inefficient when treating matrices exceeding 120-150 independent (R-mode) variables (see Volume II, Chapter 29).

The species treated in this systhesis were the most abundant overall, or proportionately within their phyla (see below, Results and Discussion), and the least abundant of these had densities such that on the average one individual would be found in an area four times the size of this page when sampling those stations where the species were recorded to have occurred. It is unlikely that species with densities lower than that would impact the analyses discussed below. Each PI provided identification and abundance data on all species, however, and those data are contained on the Dames & Moore Data Tape, and in condensed form in the PIs' final reports (Blake, Heard, Vittor; Volume II, Chapters 14-16). In addition, each taxonomic group is treated in summary fashion in the discussion below.

Results and Discussion

General

To reduce the data base of more than 1,200 species level identified macroinfauna to a level which could be efficiently handled by multivariate analysis without loosing information of importance to associations analysis, two sets of 100 species were created. The first was the 100 most abundant species. This list contained 87 species of polychaetes, 10 crustaceans, and 3 molluscs. To determine whether this overwhelming influence of the polychaetes was masking associations mediated by crustaceans and molluscs (relatively abundant within their taxonomic group, but of lower overall abundance than any of the 87 species of polychaetes in the first list of 100) a second list was made. In the second list, the number of species level identifications in the 1977/78 data base in each of these three taxonomic groups was used to generate a ratio which would provide a list of 100 species with proportionate (to species number) representation of there three major groups. This second list had 60 species of polychaetes, 28 crustaceans and 12 molluscs. Since cluster analysis of stations did not differ in any marked way between the two data sets only one data set was required for analysis, and all further discussion in this section concerns the 100 most abundant species (the first list).

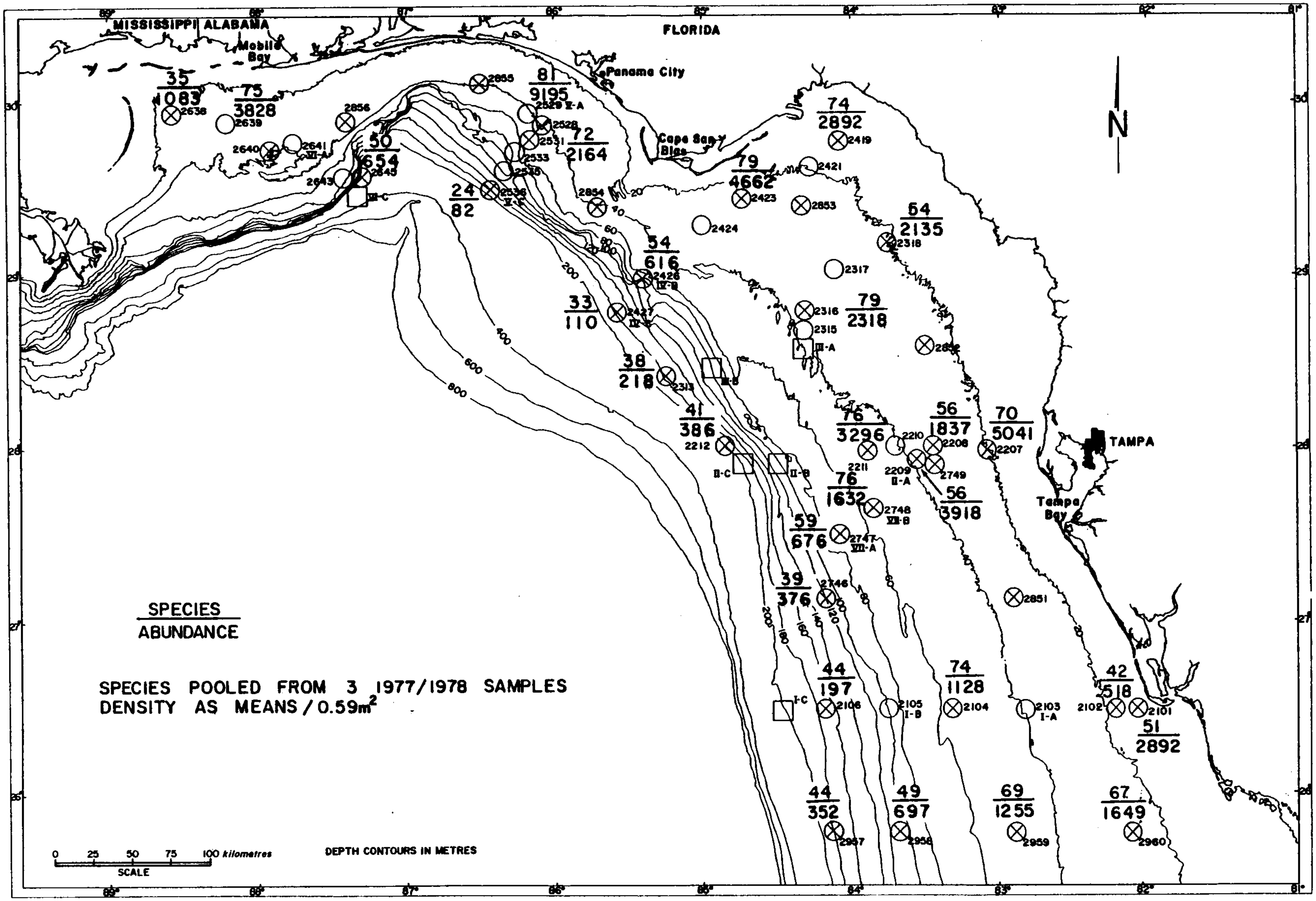


FIGURE 83

SPECIES VARIETY AND MEAN DENSITY FOR MACROINFAUNA

Species Variety and Abundance

Figure 83 shows the distribution of numbers of species (of the 100 most abundant; cumulative over 3 seasons) and of abundance (mean of 3 seasons as density below 0.59 m^2) of the pooled macroinfauna. There were no latitudinal trends either in numbers of species or in density. Average number of species per transect ranged from 53 to 61 with a mean of 57 $\pm$ 5 (confidence intervals as 2 SD, or about 95% confidence limits on mean), and average density per transect ranged from 988 to 2,640 with a mean of 1,970 $\pm$ 1,101. Highest densities were nearshore and lowest offshore as they were for meiofauna (above) and macroepifauna (below). For most transects the greatest species variety was at mid-transect stations, in the 30 to 60 m depth range.

Station 2528 had the most species (81/100) and the highest density ($9195 \cdot 0.59\ m^{-2}$), and that density was nearly twice the next highest value ($4662 \cdot 0.59\ m^{-2}$ at Station 2423). At the other end of that transect, Station 2536 had the lowest number of species (24/100) and the lowest density ($82 \cdot 0.59\ m^{-2}$).

In general, density decreased with a combination of increasing percent fine sediments (see Figure 4, in Geology, above) and increasing depth. The outer ends of Transects IV and V (mean density of $96 \cdot 059\ m^{-2}$) had greater than 50% fines and were near the 200 m contour in depth. Contrarily, the inner end of Transect V (density of $9195 \cdot 0.59\ m^{-2}$) was composed mainly of coarse sands and gravel (see discussion in Meiofauna, above). To see the separate effects of depth and grain size, first compare Stations 2638 and 2640, which are at equivalent depths. The former station had less than half the variety and density of the latter, and had 71% fines compared to only 4% at 2640 (grand station means, 1974-1978). The effect of depth may be seen by comparing Station 2638 with 2536. They had about the same concentration of fines, but Station 2638 is in about 20 m of water and 2536 in about 200 m. The former had greater variety and an order of magnitude greater density. The mid-shelf high variety may have been a result of the relatively greater stability of the habitat (lower temperature and salinity ranges; higher winter temperatures, lower summer temperatures, and no measured major salinity anomalies; see section on physical oceanography, above) compared with inshore stations, and lower percent fines and shallower depths than the >100 m assemblages.

The 100 most abundant species were relatively ubiquitous in distribution with nearly three quarters of them being present at more than half of the stations, and only 6/100 present at less than one quarter of the stations. The 10 most abundant all had average densities greater than 20 individuals (normalized to 0.59 m^2) per station per sampling period, and total sample sizes in the 1977/78 program of about 1,500 to 3,000 individuals. The next 20 had average densities per occurrence greater than 10, and ranged from about 650 to 1,400 in total sample size. The remaining 70 ranged from sample sizes of less than 200 to about 600, with most having average densities of less than 10 per occurrence. A density $10 \cdot 0.59\ m^{-2}$ is equivalent to about one individual on each section of bottom equal to twice the size of this page; the most dense species would have about 100 individuals in the same space. At Station 2529 that species would share the same space with about 1,000 other individuals of 70 different species (discounting meiofauna, forams and macroepifauna). At Station 2536, a total of 10 individuals would be found in that two-page space.

Species Associations

When cluster analysis was applied to either the 100 most abundant species or the 100 proportional (to species number) species, seven species associations are defined (Figure 84). The clusters followed depth contours, with the four principal clusters representing faunas along approximate contours of 200 m, 100 m, 40 m and 20 m. Isolated inshore stations were separated in the northwest (2638) and southeast (2101-2102, and 2960).

Table 19 lists the general descriptive characteristics of each cluster. The 200 m cluster had significantly lower densities than all other clusters, and significantly less variety than the 20 m and 40 m clusters, The 100 m cluster also had significantly lower density then the 20 m and 40 m clusters. Although the mean density of the 20 m stations was more than 65% higher than the mean density for the 40 m cluster, the variance of both sets was sufficiently high that the means cannot be said to be significantly different. Similarly, the mean variety (number of species) was not distinguished between these two clusters.

Several diversity indices were calculated for each data set (see Volume II, Chapter 29). The Shannon-Wiener data are presented in this analysis because that index tends to be sensitive to species in the lower half of the abundance distribution of a data set. Analysis sensitive to these species out of a pool such as the 100 most abundant (which are also generally ubiquitous in distribution) is more likely to be able to distinguish between cluster diversities. Reference to Table 19 indicates that even with such selection, most of the clusters cannot be distinguished on the basis of diversity. However, the 20 m cluster had significantly lower diversity than the 40 m cluster.

As with the general trends of density and variety discussed above, the probable sources of cluster differentiation were percent fines and depth. Cluster V, containing only Station 2638, the westernmost box-core station, had more than 70% fines, while all the inshore stations in the 20 m cluster (IV) had less than 10% fines (grand station means, 1974-1978). Cluster VII had significantly lower density than other 20 m stations (in Cluster IV), but was otherwise similar. It had higher $CaCO_3$ content than other 20 m stations in Cluster IV (>98% compared to a range of 11 to 52%) but the sediment type grouped with other Cluster IV stations in the sediment associations testing. No evident explanation for its separation could be determined, although its position was the most southerly of inshore stations.

Cluster VI was composed of two stations (2101-2102) with very similar sediment characteristics (grand station means, 1974-1978, cluster of all stations by sediment grain size only). The only other primary, seasonally sampled station with the same sediment characteristics was Station 2207. Station 2102 had an order of magnitude lower density, 40% fewer species and less than one-third the number of characteristic (species occurring in a

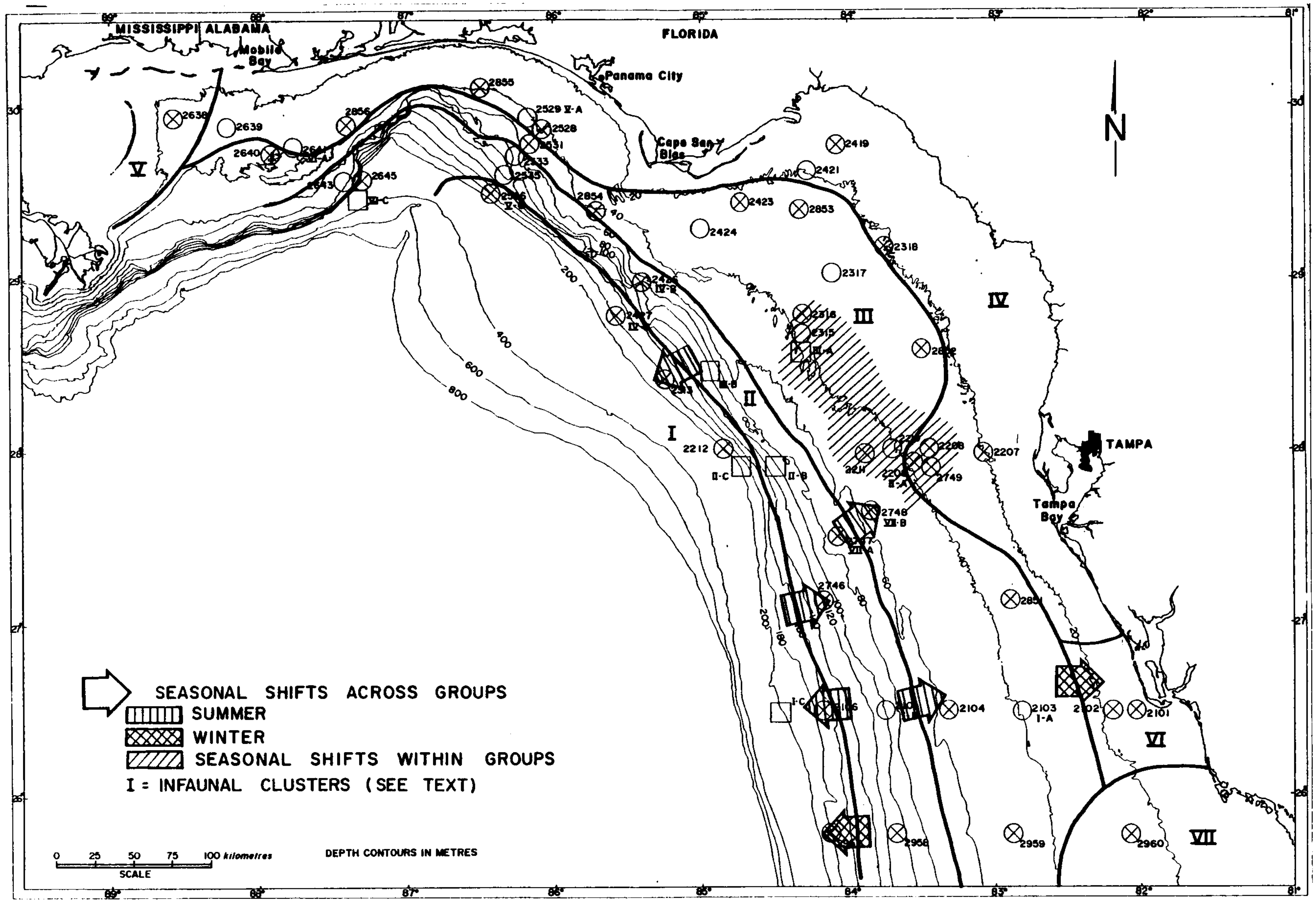


FIGURE 84

MACROINFAUNAL ASSOCIATIONS MAFLA 1977/1978 SURVEY

TABLE 19

MACROINFAUNA CLUSTER CHARACTERISTICS[1]

CLUSTER[2]	N[3]	S[4]	D[5]	C[6]	P[7]
I	224	37	3.09	7	7
(200 m)	±243[8]	±16	±0.44	±9	±10
II	604	50	3.00	15	13
(100 m)	±257	±12	±0.50	±11	±10
III	2535	75	3.57	50	30
(40 m)	±2827	±8	±0.23	±21	±20
IV	4170	65	2.93	40	26
(20 m)	±5886	±22	±0.59	±36	±25
V	1083	35	2.44	13	9
(2638)			one station only		
VI	1705	47	2.35	20	10
(2101-2102)	±2374[9]	±9	±0.98	±8	±6
VII	1649	67	3.43	35	23
(2960)			one station only		

[1]Based on primary stations, 1977/78 data only

[2]See Figure 84

[3]Average density 0.59 m^{-2} per station in the cluster

[4]Average number of species of the 100 most abundant per station in the cluster

[5]Average diversity (Shannon-Wiener) per station in the cluster

[6]Average number of species per station which are characteristic of the cluster

[7]Average number of species per station which are persistent at that station. (See text for definitions of characteristic and persistent.)

[8]95% confidence limits from estimated standard deviation (x2) after Tate and Clelland (1957)

[9]Range

majority of the stations in the cluster) or persistent species (species occurring during most sampling periods over the period summer 75-winter 78) of Station 2207. Although Station 2101 had a density and variety typical of Cluster IV stations, it had lower diversity and less than one-half the characteristic or persistent species of Station 2207.

Bock (Volume II, Chapter 12) indicated that the stress-indicating foram Ammonia beccarii was present at Station 2101. The salinity and temperature range and temperature and salinity maxima were all higher at that station than for the nearest stations in any direction (2960, 2103, 2851). Station 2102 also showed an anomalously low ATP level.

Temporal Variation

Although clear cluster groups can be derived for the macroinfauna, the specific boundaries on the clusters south of Transect IV were not fixed. Figure 84 indicates that there were both within and across cluster shifts with the passage of time, especially in Cluster II and mid-Cluster III. No transgressions across more than one cluster boundary were recorded. Changes in the middle of Cluster III may have been related to concomitant shifts in sediment characteristics (see Table 11 in Geology, above, and related discussion). The principal seasonal changes noted by PIs (see Volume II, Chapters 14-16) were general winter decreases in density and variety.

On a species basis (contrasted to a cluster basis), temporal variation was relatively high in depths less than 100 m. Even when restricting the discussion to the most abundant 100 species, which tended to be less variable in occurrence than rare species, inspection of Table 19 shows that in shallow stations the number of species which were seasonally persistent were about two-thirds of the number which were characteristic of the cluster, and that was about one-half of those which were recorded from the cluster. Thus, about two-thirds of the species present in shallow water clusters tended to be non-persistent through a three-sample data set.

Polychaetes

More than 1,000 polychaete taxa were reported from 1974 through the present from the MAFLA studies. These represent about 750 different confirmed species from nearly 200,000 individuals counted. These species came from 60 families (including all major families); seven of these families were new records for the Gulf and at least 50 new species have been documented from the MAFLA collections. Due to the unprecedentedly large effort in geographic range, depth range and use of quantitative sampling techniques, the known geographic or depth range of nearly every species recorded was changed. The fauna was a mix of cosmopolitan, Caribbean, Carolinian and endemic species, with the first of those being the smallest class and the others about equal at 25 to 30% each.

Crustaceans

Of about 10,500 crustaceans collected by box-core during the three benthic cruises in the 1977/78 program, more than 85% were in sufficiently good condition to identify to the species level. These specimens represented nearly 90 families and 360 species. The orders Decapoda and Amphipoda comprised 72% of the species and 65% of the specimens identified to the species level. New range and depth records were established during this one-year effort for most species, and nearly one-third of the species recorded were new to science.

Molluscs

From 1975-1978 about 330 species of macroinfaunal molluscs have been identified from the MAFLA samples. The snails (Gastropoda) and clams (Pelecypoda) together comprised more than 90% of the species, and were about of equal numbers of species. The fauna was a mix of temperate, tropical and subtropical species. Unlike the polychaetes and crustaceans the molluscs have generally restricted distributions with only eight species occurring in 10% or more of the samples.

Summary

The macroinfauna are dominated in terms of abundance by polychaetes, with 87 of the 100 most abundant species in that taxonomic group. Density of macroinfauna ranged from 82 to 9,195 individuals (standardized to 0.59 m^{-2}, means of stations, 1977/78 sampling program) with a mean of 1,970 $\pm$ 1,101 ($\pm$2 SD). Density maxima were inshore, minima offshore, and most of the distribution appeared related to distribution of sediment fine fractions, density decreasing with increased fines. High species variety was shared in 20 m and 40 m stations, but diversity was higher in 40 m stations. Cluster analysis indicated four major clusters, roughly aligned along the 20, 40, 100 and 200 m contours. Shallow water stations at both south and west extremes were isolated from the central shallow species association. High percentage of fine sediments was the probable causative factor for the separation of the westernmost station. Temporal variation was especially noted in the southern portion of the study area. Changes in sediment patterns at stations over time, winter declines in species variety and abundance, and relatively high (relative to macroepifauna and demersal fish, see below) temporal variability at the species level may all have been causative factors.

Usefulness of Macroinfauna as a Monitoring Tool

The combination of relative stability and relative ease of identification when compared with the meiofauna, and their intimacy with and distributional dependence upon sediment characteristics makes the macroinfauna a prime candidate for use in a monitoring study. The overwhelming dominance of this segment of the fauna by polychaetes does raise the question of whether monitoring any other infaunal group is justified. It appears that the molluscs, particularly, may not be a useful part of the infauna to monitor. Not only do they have the fewest species of the three groups, and the fewest abundant species, but their few abundant species are highly variable in density over time and usually limited to restricted portions of the MAFLA area (see Blake, Volume II, Chapter 14).

MACROEPIFAUNA

Introduction

The macroepifauna include members of every major animal phylum, and of most of the minor phyla. Some of these are entirely or in major part, restricted to attached existences on solid substrates. The species of principal consideration in this report are those that live on the surface or immediately below the surface of sedimentary habitats. In the MAFLA program the macroepifauna were considered to be all the invertebrates collected by dredge or trawl.

Macroepifaunal species tend to be larger (on the order of centimetres) and longer lived (on the order of years) than the meiofauna and macroinfauna. They normally have planktonic larvae (Barnes, 1963) and the motile forms may move significant distances as adults. Although the macroepifauna are probably influenced more by substrate type (Thorson, 1956; Hedgpeth, 1957) than any other local environmental factor, they generally do not have quite the degree of intimate contact with the sediments as have the forams, meiofauna and macroinfauna. On the other hand, their relative longevity and dispersal capabilities make them useful indicators of regional faunal boundaries (Ekman, 1953).

The review of prior eastern Gulf invertebrate ecology studies by Collard and D'Asaro (in SUSIO, 1973) is discussed above in the introduction to the macroinfauna. The same general review works discussed there apply to this discussion. Hopkins (Volume II, Chapter 17) reviewed the literature subsequent to the SUSIO literature study. As with other biological work elements, the macroinvertebrates had received attention in the eastern Gulf prior to the MAFLA program, but primarily inshore, regionally and qualitatively.

The BLM program brought the first comprehensive study of macroepifauna of the eastern Gulf OCS into being with the inception of their 1974 sampling program. From summer 75 through winter 78 the dredge and trawl collections have been along the six transects shown in Figure 1 (21XX - 26XX) with seasonal samples collected through the 1975/76 and 1977/78 years. In summer 76, and thereafter, dredge and trawl samples were also collected along Transect VII (27XX in Figure 1). Samples were generally taken from a pair of dredge tows and a single trawl tow at each station, in each season, but the number of tows was most often dictated by the requirements for samples for macrofaunal or demersal fish tissue chemistry (see above). If the minimum number of planned tows was insufficient, additional tows were made until the Chief Scientist decided that an adequate chemistry sample had been collected. Although no collections by divers were made during the 1977/78 program, samples collected by divers from summer 76 were included in the analyses of this program.

The data base during the 1975/76 year was only on presence and absence indications, i.e., no counts of individuals were made. Therefore, quantitative analyses referred to below are based only on summer 76-winter 78 collections. The station locations and cruise periods for all macroepibenthic cruises covered in this synthesis are listed in Tables 2 and 3 in the Methods section.

Results and Discussion

More than 650 species level identifications from more than 20,000 individuals of macroepifauna were made from the collections of summer 76 through winter 78. As a very rough approximation, that total is equal to an average of about one individual for each 20 m^2 of bottom sampled. For densities in this section an estimate of 6,000 m^2 of sampling area per station each season was assumed using approximate tow lengths (from navigation post plots), sampler dimensions, and an assumed 60% bottom contact efficiency; variance between individual samples in this value probably $\pm$ 100%, and the estimate should be used only with great caution; no refined calculations were possible. Using that same approximation of sample area, the density of macrofauna varied from about $1 \cdot 5\ m^{-2}$ to $1 \cdot 100\ m^{-2}$. Assuming that sample effort was approximately equal at all stations, trends in both abundance and variety can be analyzed. Figure 85 shows total number of species and total numbers of individuals from samples collected at the same location over four sampling periods (June 1976-February 1978). Given equal sampling, it can be seen that the same general trends as seen in the macroinfauna held for the macroepifauna, i.e., "density" decreased with increasing depth, but did not have a latitudinal trend. Similarly, species variety was lowest along the 200 m contour and high along the 40 m contour.

Of the more than 650 species collected, less than 100 had total abundances of 50 or more (less than one per station per sampling period). About 50 species had total abundances of 100 or more. The 25 species which had average abundances at stations where collected, of 10 or greater and which were collected at more than one location are listed in Table 20. Only two of those species occurred at more than half of the 17 regularly sampled dredge/trawl stations, indicating considerably lower ubiquity of distribution among the abundant macroepifauna when compared with the macroinfauna. The top 100 species of macroepifauna were composed of 39 species of crustaceans, 26 echinoderms, 25 molluscs and 10 coelenterates. By comparison from the total list of 660 species, crustaceans accounted for about 39%, echinoderms 14%, molluscs 39%, and coelenterates 8%. The difference indicates that echinoderms tended to be more abundant and molluscs less abundant than would have been expected from an even distribution of densities among taxa. The significance of this table as it relates to histochemical monitoring is discussed briefly below, and in the marine chemistry section above.

To analyze species associations, cluster analysis was applied to all but the very rare species, with 213 species being included in the analysis. Two sets of runs were made. A similarity matrix was constructed using presence-absence data from summer 75 through winter 78, and a second was made using counts of each species from the summer 76 through winter 78. The former is less efficient in discriminating associations, and is especially poor when applied to sets of ubiquitously distributed species. For the macroepifauna it should be reasonably accurate. The latter was used on the smaller data base since no counts were made in the 1975/76 survey.

Both analyses discriminated four associations, three of which followed approximately the 40 m, 100 m, and 200 m contours, and the fourth being located on the Florida Middle Grounds (Figure 86). Table 21 is a summary of the characteristics of the first three clusters. Table 22

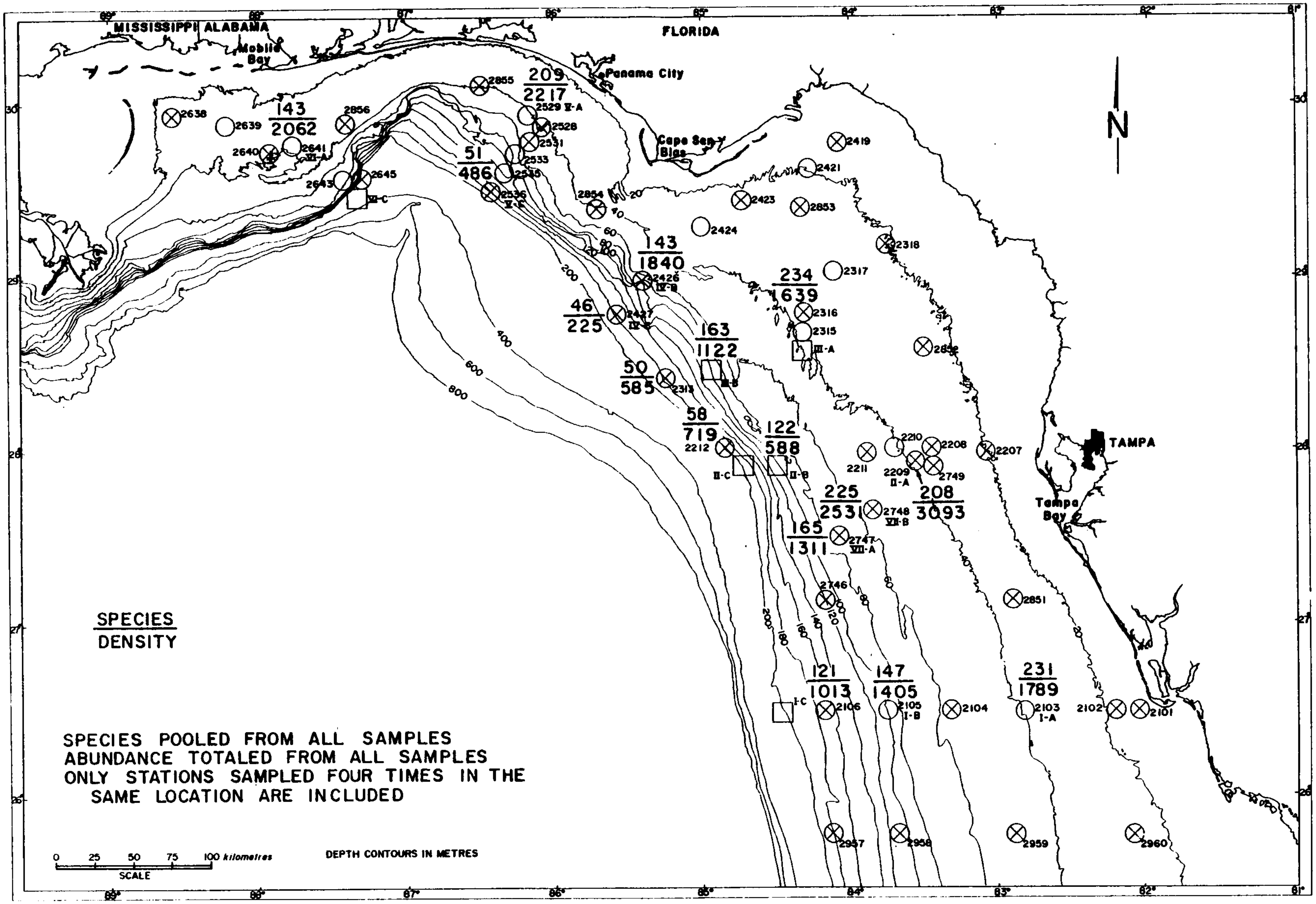


FIGURE 85

SPECIES VARIETY AND TOTAL COUNTS OF MACROEPIFAUNA 1976/1978

TABLE 20

THE 25 MOST ABUNDANT MACROEPIFAUNAL SPECIES*

SPECIES	COMMON NAME	N[1]	N[2]	ST[3]	N/ST[4]	NOTE
Portunus spinicarpus	swimming crab	1222	306	14	22	Pelagic; Chemistry[5]
Loligo pealeii	squid	1188	297	8	37	Pelagic
Vermicularia spirata	attached snail	799	200	6	33	Attached to rocks
Ophiolepis elegans	brittle star	718	180	8	22	
Solenocera atlantidis	shrimp	579	145	8	18	Chemistry
Comactinia meridionalis	crinoid	576	144	4	36	Locally Abundant; Chemistry
Sicyonia brevirostris	shrimp	530	133	11	12	Chemistry
Clypeaster ravenelli	sand dollar	513	128	3	43	Locally Abundant; Chemistry
Dorytheuthis pleii	squid	431	108	8	13	Pelagic
Ophiothrix angulata	brittle star	386	97	6	16	
Astropecten duplicatus	starfish	315	79	7	11	Chemistry
Stylocidaris affinis	sea urchin	314	79	8	10	Chemistry
Parapenaeus longirostris	shrimp	313	78	5	16	Chemistry
Argopecten gibbus	scallop	312	78	3	26	Locally Abundant; Chemistry
Vermicularia knorrii	attached snail	309	77	3	26	Locally Abundant
Synalpheus townsendi	shrimp	307	77	8	10	
Metapenaeopsis goodei	shrimp	307	74	4	19	
Mesopenaeus tropicalis	shrimp	296	74	6	12	Chemistry
Pylopagurus coralinus	hermit crab	281	70	6	12	
Bebryce grandis	soft coral	280	70	3	23	Locally Abundant
Astroporpa annulata	basket star	246	62	6	10	Chemistry
Balanophyllia floridana	hard coral	219	55	5	11	
Clypeaster durandi	sand dollar	162	41	4	10	
Phyllangia americana	hard coral	160	40	2	20	Locally Abundant
Paracyathus pulchellus	hard coral	150	38	3	13	Locally Abundant

*With average occurrence $\geq$10.
[1]Total sample size, all stations, four seasons.
[2]Average abundance per station.
[3]Average number of stations at which the species is found per season (out of 19).
[4]Average abundance per collection.
[5]Used for macrofaunal tissue chemistry.

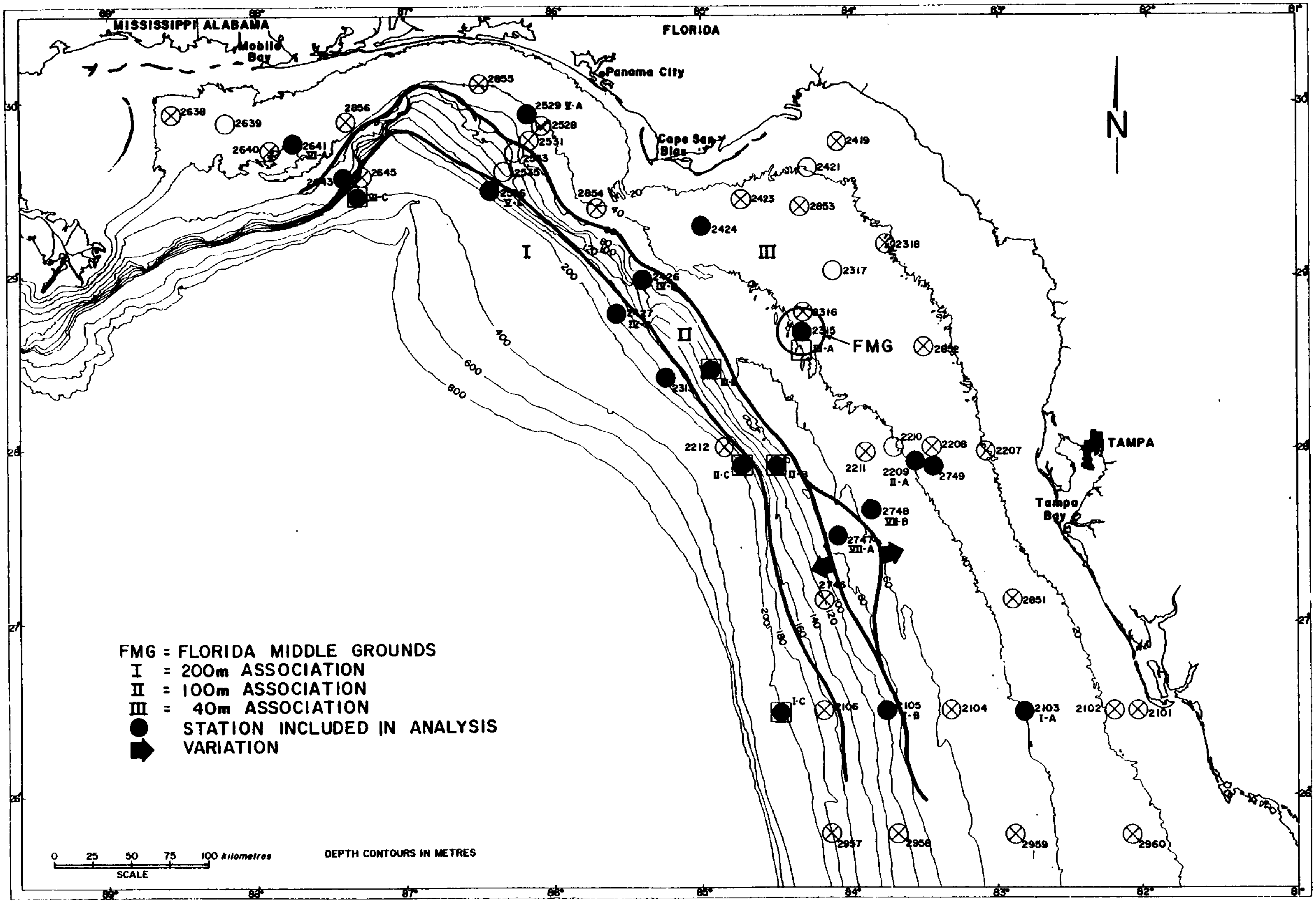


FIGURE 86

MACROEPIFAUNAL SPECIES ASSOCIATIONS, 1975-1978

TABLE 21

MACROEPIFAUNAL CLUSTER CHARACTERISTICS

CLUSTER I

Stations: I-C (2106), II-C (0002), III-C (2313), IV-C (2747), V-C (2536), VI-C (0009)
Depth: 170-190 m
Mean Abundance (±2 Standard Deviations): 660 ± 330
Mean Variety: 65 ± 60
Mean Diversity (Scaled Simpson/Scaled Shannon-Wiener): 0.84 ± 0.13/0 60 ± 0.28

CLUSTER II

Stations: I-B (2105), II-B (0001), III-B (0003), IV-B (2646). V-B (0007), VI-B (2645, 0008)
Depth: 80-110 m
Mean Abundance: 1239 ± 1002
Mean Variety: 144 ± 33
Mean Diversity: 0.89 ± 0.11/0.63 ± 0.21

CLUSTER III

Stations: I-A (2103), VII-B (2748), II-A (2209, 2749), III-A (0005), IV-A (0006), V-A (2529), VI-A (2641)
Depth: 30-50 m
Mean Abundance: 2338 ± 1043
Mean Variety: 203 ± 70
Mean Diversity: 0.94 ± 0.06/0.68 ± 0.12

TABLE 22

MACROEPIFAUNAL STATION STATISTICS

STATIONS	N1	S2	D3	P4	A5
20-50 m					
2103 (I-A)	1789	231	0.97/0.75	37	7
2747 (VII-B)	2531	225	0.93/0.69	42	17
2209 (II-A)	3093	208	0.95/0.68	21	22
2529 (V-A)	2217	209	0.94/0.70	34	16
2641 (VI-A)	2062	143	0.90/0.60	17	13
70 m					
2747 (VII-A)	1311	165	0.96/0.72	24	9
100 m					
2105 (I-B)	1405	147	0.84/0.59	23	10
0001 (II-B)	588	122	0.96/0.75	7	6
0003 (III-B)	1122	163	0.93/0.69	21	8
2426 (IV-B)	1840	143	0.82/0.49	9	12
200 m					
2106 (I-C)	1013	121	0.79/0.52	11	3
0002 (II-C)	719	58	0.70/0.47	13	4
2313 (III-C)	585	50	0.84/0.57	7	3
2427 (IV-C)	225	46	0.96/0.82	3	6
2536 (V-C)	486	51	0.89/0.63	5	2
FMG					
2315 (III-A)	1639	234	0.97/0.75	23	14

[1]Number of individuals pooled over all sampling periods
[2]Nummber of different species, all sampling periods
[3]Diversity, 1-Simpson and Shannon-Wiener (see text)
[4]Persistent, i.e., regular occurrence over time
[5]Acute, i.e., infrequent high abundance

provides individual station statistics for the 16 stations which had four samples at the same location during the summer 76-winter 78 period, including the 70-m transition zone station (2747). Abundance and variety were both significantly less in Cluster I than II, and less in Cluster II than III. The diversity indices are 1-Simpson and Shannon-Wiener. Both were scaled to give relative comparisons (which also makes them evenness indices). The former is sensitive to abundant species and the latter to the less common species (the lower 40%). Large spreads between them indicate steeper abundance vs rank order of abundance curves. The results provide evidence that the three depth associations have equivalent balance of individuals among species, and none of the single station values (Table 22) indicated any measurable stress.

Table 22 also lists the number of persistent (regular occurrence at a station over seven sampling periods) and acute (infrequent high abundance) species at each station. High acute to persistent ratios are indicative of temporal instability. Five of the 16 stations in that table showed relatively high ratios of acutely present species. The only other indication of possible temporal instability was at the depth transition station (2747). Located midway in depth between 40 m and 100 m assemblages, it showed an affinity with the shallow water cluster when abundance was used as a measure, but with the mid-shelf cluster when presence-absence was used. That may have indicated a shift in composition between the 1975/76 survey and the 1977/78 survey, but more probably represented the presence of a large percentage of 100 m species in low abundance at the station with the numerical dominance being held by 40 m species. Cluster analysis, with the three seasonal samples from 1977/78 included separately, did not indicate any marked seasonality. Table 23 lists the species that are uniquely characteristic of each of the clusters. The regular presence of these species in samples from anywhere in the MAFLA region would identify the association being sampled. See discussion by Hopkins, Volume II, Chapter 17, for a more detailed description of these associations.

Hopkins (Volume II, Chapter 17) and Collard and D'Asaro (1973) both concluded that observed distributions were probably the result of a combination of substrate and temperature/salinity relationships. In addition, Hopkins speculated that the richer-than-expected fauna at Station 2529 may have been related to Loop Current supply of tropical and subtropical larvae of Caribbean origin. Several parameters followed the same trends that mark the macroepifaunal associations (decreasing mean grain size, increasing TOC, increasing trace metals and petrogenic hydrocarbons, decreasing ΔT and ΔS, and, of course, increasing depth and distance from shore with transition from Cluster III to Cluster I). There were no nearshore (20 m) stations so the distribution relative to a possible nonrefractory TOC maximum in mid (40-60 m) depths could not be assessed. In conclusion, the macroepifauna follow the same general trends shown for 40 m and deeper in meiofauna, macroinfauna (see above) and demersal fish (below), but opposite of that of the foraminifera (above).

Usefulness of Macroepifauna as a Monitoring Tool

Insufficient quantification of sampling has been done to determine, with any degree of accuracy, the density of any species of macroepifauna.

TABLE 23

SPECIES CHARACTERIZING MACROEPIFAUNAL CLUSTERS

CLUSTER I: Depth 170 to 190 m

Turgurium caribaeum (snail)
Murex beauii (snail)
Aequipecten glyptus (scallop)
Parapenaeus longirostris (shrimp)
Acanthocarpus alexandri (crab)
Myropsis quinquespinosa (crab)
Pyromaia arachna (crab)
Goneplax hirsuta (crab)
Squilla heptacantha (mantis shrimp)

CLUSTER II: Depth 80 to 110 m

Bebryce grandis (soft coral)
Paracyathus pulchellus (hard corral)
Mesopanaeus tropicalis (shrimp)
Iliacantha subglobosa (crab)
Anthenoides piercei (starfish)

CLUSTER III: Depth 33 to 50 m

Chlamys benedicti (clam)
Laevicardium pictum (clam)
Sicyonia brevirostris (shrimp)
Solenocera atlantidis (shrimp)
Scyllarus chacei (slipper lobster)
Pylopagurus coralinus (hermit crab)
Palicus alternata (crab)
Luidia clathrata (starfish)
Ophiolepsis elegrans (brittle star)

Because of that and the difficulty in getting a good measure of dredge or trawl "sampling effort" (i.e., actual area of bottom equivalently sampled) the macroepifauna are a questionable monitoring tool for perceiving subtle changes in environmental conditions. Added to the sampling equipment problem is the relatively low density of most species (about 1:25,000 to macroinfauna) which makes taking closely spaced replicates in sufficient numbers to calculate reasonably low confidence limits very difficult. The greater use of macroepifauna, however, is to provide regional characterizations and general ecological state. For the mid-shelf (40-200 m) from Transects I to VI, this has been well started by the present program.

The macroepifauna are the "first" (in the trophic sense) species group dealt with in this study, which are large enough to be feasible for histochemistry and histopathology use. In the discussion on trace metals above, it has been pointed out that at least one species already monitored was sufficiently abundant throughout the 100 to 200 m depth range to provide a reasonable certainty of determining a doubling of any metal in the tissues of that species with the sample size expected from the macroepifaunal abundance/distribution data. In addition, the theoretically expected link along food web lines from sediments to deposit feeders-infaunal predators appeared to bear up under analysis of the trace metal data, and the very large histopathology data base on invertebrates (see above) indicated absolutely pristine conditions. The inclusion of macroepifaunal ecology as support data for histochemistry and histopthology is as vital as are other independent support variables (e.g., temperature and salinity), and therefore is recommended as a monitoring parameter.

DEMERSAL FISH

Introduction

The demersal fish are those that live in, on, or immediately above (but in close association) the bottom. They are differentiated from the pelagic fish in their close association with the bottom. They tend to find their food (other fish or macroinvertebrates) among the epifauna or infauna, although some may feed on plankton in the water column.

The demersal fish, like the macroepifauna, have relatively large sizes (on the order of centimetres) and long life spans (on the order of years) when compared with the macroinfauna, meiofauna, and foraminifera. They also tend to closely associate with specific habitats (see Shipp and Bortone, Volume II, Chapter 19), but are usually broadly distributed through regions. They usually have planktonic eggs and larvae, and the adults are often highly motile relative to the macroinfauna (see for instance, Lagler, 1962).

The functions of demersal fish ecology in baseline studies include:

- o Delineation of general benthic associations for baseline condition description, impact analysis, and ecological monitoring
- o Assessment of potential commercial or sport fisheries resources

- Establishment of baseline histochemical and histopathological conditions for post-development comparison.

In addition, as predators and often as top carnivores, they represent the upper levels of food webs, and often are the most effective source of species to monitor for bioconcentration of low-level pollutants.

Among the biological groups analyzed during the MAFLA 1974/78 program, the demersal fish were initially the best known (see review of literature by Shipp and Bortone, Volume II, Chapter 19). The principal recent review of the fishes of the Gulf of Mexico outside of the BLM studies is Hoese and Moore (1977). The publications of Nester (1978) and Shipp (1978) also provide recent reviews with information in both partly drawn from the BLM studies.

The MAFLA data base for fishes is based largely on trawl collections. Fishes have been collected by dredge and at least one suspected new species of fish was collected by box-core (see Shipp in Minutes of third quarterly meeting, Dames & Moore, 1978e). The 10 m (mouth diameter) trawls had significantly heavier doors added in the 1977/78 program, and in the latter half of this year a heavier tickler chain was added (see Methods in Shipp, Appendix D, third quarterly report, Dames & Moore, 1978e). Both of these modifications led to the collection of more individuals and more species in this year's MAFLA survey than previously.

Samples were collected along six transects in the 1975/76 program over three seasons. Only presence and absence data were recorded. In the summer of 1976 a seventh transect (27XX in Figure 1) was added. For the 1977/78 program, the same seven-transect plan was maintained for demersal fish collecting. Stations, as for macroepifauna, were spaced roughly along the 40 m, 100 m, and 200 m contours. From summer 76 through winter 78, counts of all individuals were taken.

Results and Discussion

Fishes collected by trawl from May 1974 through February 1978 include about one-half of the species known from the Gulf of Mexico, and nearly all of the demersal fish previously reported from the Gulf. The 292 species collected have been counted, checked for external malformities, measured, weighed, and sex determined for indicative adults. That data base (see Dames & Moore Data Tape) represents a complete baseline for MAFLA shelf demersal fish. Shipp and Bortone (Volume II, Chapter 19) provide a complete species list in an appendix to their final report. The records include several new species and new range and depth records for many species.

R-mode cluster analysis identified several species associations. These groupings represent specific habitats including shallow sand bottoms, deep sand bottoms, and reefs. Table 24 lists these associations.

Q-mode analysis was applied to the total data set using presence-absence data, and to the 1976/78 data set using counts. Both analyses pick out the same station associations. Figure 87 illustrates the demersal fish communities. As with the macroinfauna and macroepifauna, the demersal fish

TABLE 24

DEMERSAL FISH HABITAT ASSOCIATIONS

HABITAT: Shallow sand
INDICATIVE SPECIES:
- *Dasyatis sayi* (Bluntnose Stingray)
- *Eucinostomus gula* (Silver Jenny)
- *Micropogon undulatus* (Atlantic Croaker)

HABITAT: Deep reef
INDICATIVE SPECIES:
- *Holocentrus bullisi* (Deepwater Squirrelfish)
- *Chaetodon aya* (Bank Butterflyfish)

HABITAT: Sponge reef
INDICATIVE SPECIES:
- *Apogon quadrisquamatus* (Sawcheek Cardinalfish)
- *Gobiosoma xanthiphora* (Yellowprow Goby)

HABITAT: Shallow reef
INDICATIVE SPECIES:
- *Hypoplectrus puella* (Barred Hamlet)
- *Evermannicthys spongicola* (Songe Goby)
- *Epinephelus morio* (Red Grouper)
- *Rypticus maculatus* (Whitespotted Soapfish)
- *Astrapogon stellatus* (Conchfish)

HABITAT: Mid-Shelf sand
INDICATIVE SPECIES:
- *Synodus intermedius* (Sand Diver)
- *Centropristis ocyurus* (Bank Sea Bass)
- *Syacium papillosum* (Dusky Flounder)
- *Sphoeroides dorsalis* (Marbled Puffer)

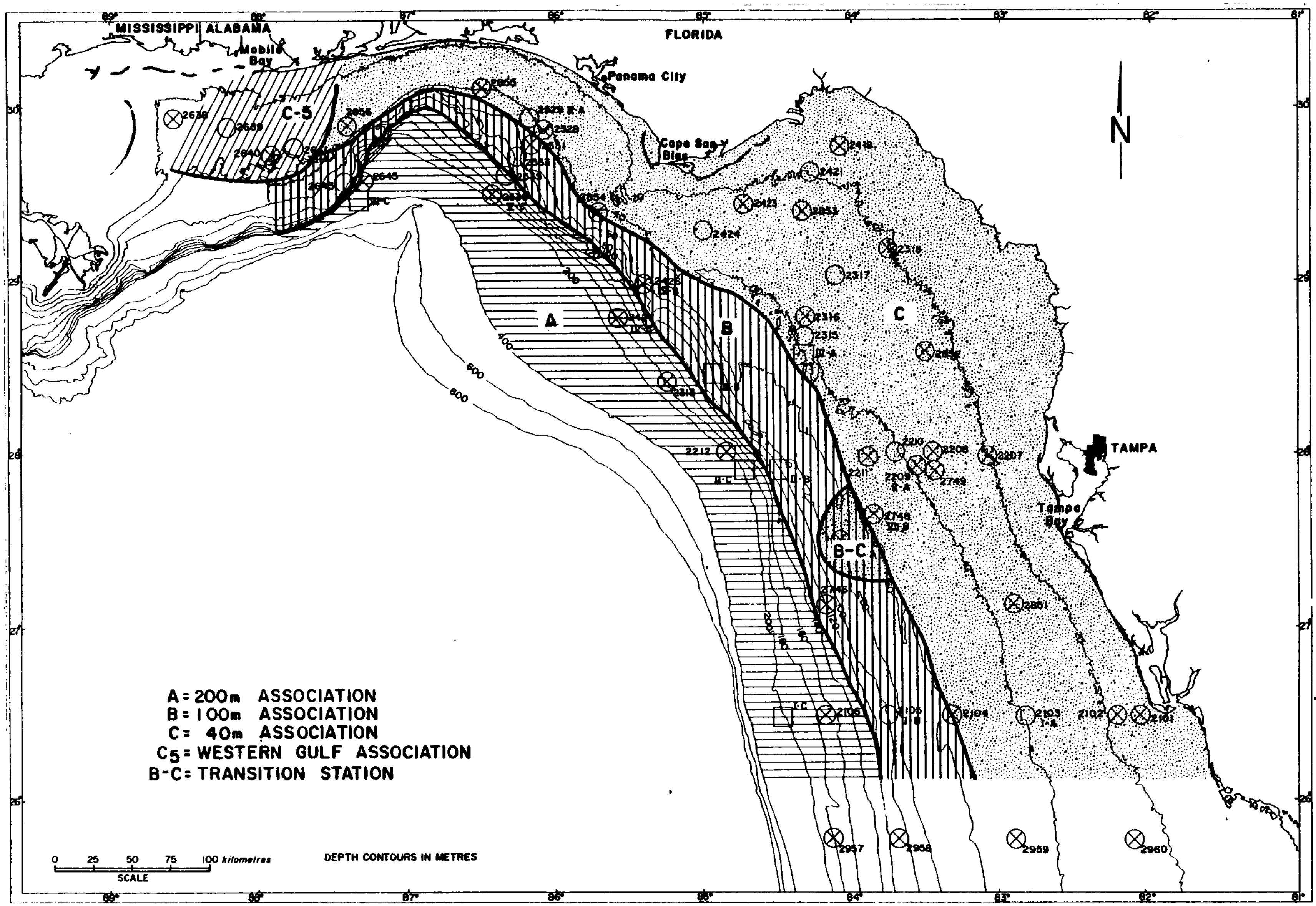


FIGURE 87

MAJOR DEMERSAL FISH ASSOCIATIONS IN THE MAFLA REGION tended to be grouped along depth contours. There were the same three depth-aligned clusters as shown for the macroepifauna at 40 m, 100 m, and 200 m. In the demersal fish the westernmost station was isolated as a subgroup of the 40 m assemblage. The fish fauna there were more nearly characteristic of western Gulf demersal fish associations, and the shelf off Mobile Bay is a transition zone from species associated with predominantly shallow sand bottoms to one associated with predominantly fine sediment bottoms (Shipp, in Minutes of third quarterly meeting, Dames & Moore, 1978e).

The Florida Middle Grounds did not stand out from the cluster analysis of other 40 m stations in most collections, but in two of the seven sampling periods, Stations 2315/0005 were isolated. In other periods they were associated with Stations 2103 and 2529, both of which also exhibit solid substrate elements among the macroepifaunal species. The variability probably represented differences in specific sampling location. From the sediment patterns (see above and Volume II, Chapter 2) it is evident that much small-scale variability in substrate exists, and is particularly acute at the Middle Ground (2315/0005). This was corroborated from diving observations (Dr. Thomas Hopkins, personal communication) made during the 1975/76 MAFLA program. Since the reef at the Florida Middle Grounds is of sufficient vertical relief and strength to rip trawl nets (Cruise Logs, 1977/78 sampling period), the trawl samples were collected at varying distances from the actual reef structure. The area sampled was spread through an area about 2 by 7 km (about 1.3 x 4.4 mi), and it is expected that fish collection within the confines of the reef structure would yield a relatively unique fauna.

Temporal shifts in cluster assignment using presence and absence data (to use the maximum data set) indicted that Station 2747 was a transition station between the 40 m and 100 m assemblages. The same shifting of association at this location was noted in both the macroepifauna and macroinfauna (above). As previously observed, its intermediate depth (70 m) is likely to be the most influential factor in providing an opportunity for aperiodic fluctuations in species dominance. No seasonality was demonstrated in MAFLA demersal fish associations based on either presence-absence or on abundance data.

Usefulness of Demersal Fish as a Monitoring Tool

The demersal fish, like the macroepifauna, are good diagnostic tools for deliniating general biological associations. Certain species are also useful as habitat type indicators. The problems of quantifying trawl collected species has been discussed for the macroepifauna. Unlike the macroepifauna (see Hopkins, Volume II, Chapter 17), the taxonomic state-of-the-art in fish is very advanced. The data base that now exists for the MAFLA area demersal fish is adequate for describing the existing fish communities.

The major void in the demersal fish data base is in histochemistry and histopathology. All the chemical data are for a single species that has ubiquitous distribution and broad diet (see marine chemistry section above, and Volume II, Chapters 6 and 9). There is no way to assess whether this species is characteristic of MAFLA area fish in its histochemistry without a range of other species being tested. It would be especially useful to test species that are higher in food webs and that have longer life spans (e.g., some groupers). There are no fish histopathology data.

Histopathology and histochemistry studies should be integral parts of a monitoring program. The demersal fish community studies are needed to support such studies.

PLANKTON

Introduction

The plankton include all those species in the water column whose general movement geographically is controlled more by the currents than by their own swimming ability (as opposed to the nekton, which includes the fish and squids). The temporary zooplankton (animal plankton) includes the eggs and/or larvae of most macroinfauna, macroepifauna, and demersal fish. The permanent (whole life span) zooplankton is composed of species from many phyla, but copepod crustaceans usually dominate in terms of numbers of individuals and species (Hedgpeth, 1957).

Not only do the plankton contain complete food webs within their associations, but the phytoplankton contribute the vast majority of in-situ primary productivty which reaches benthic communities in the OCS. In addition, they represent a source mechanism for the rapid distribution of contaminants from the water column into the sediments (see Caldwell and Maturo, Volume II, Chapter 27). The neuston (surface zooplankton) would be the first part of the marine ecosystem exposed to surface pollutant inputs. In summary, the health of the plankton community is vital to the health of the ecosystem.

The zooplankton tend to have size ranges on the order of millimetres, and life spans on the order of weeks to months (Raymont, 1963), and are thus comparable in those respects to large meiofauna or small infauna. The short turnover times, varied and aperiodic inputs of eggs and larvae from within and outside the plankton, three dimensionality of distribution, and impact of multiple physical parameters (Dames & Moore, 1977a) including varied currents all tend to make the distribution of zooplankton very patchy (see computer simulation of field studies by Wiebe, 1971), especially offshore Hirota, 1973). Dr. John McGowan (personal communication; lectures at the Scripps Institute of Oceanography) once characterized the extent of the sampling problem by stating that the only way to determine the nature of zooplankton patchiness would be to freeze a cubic mile of seawater and take it apart with an icepick; even then, only that one volume at that one instant would be described. Numbers of replicates from highly varied zooplankton assemblages necessary to detect small differences in composition between areas (or "treatments") run into the hundreds (see for instance, Carpenter et al., 1974). To be able to have even the vaguest idea of the differences between times, locations, seasons or years, simultaneous replicate samples must be collected to assess instantaneous, small-scale geographic patchiness. No such samples have been taken in this program. As a result, the zooplankton and neuston portions of the MAFLA program can only be used to discuss the general qualitative composition of the plankton communities.

Early plankton studies in the eastern Gulf of Mexico were reviewed in SUSIO, 1973. Most studies were inshore and qualitative. Caldwell and Maturo (Volume II, Chapter 27) updated that review. In essence, no offshore replicate sampling has been done in this or other programs over a broad enough area to quantitatively characterize the zooplankton (including neuston) distributions, much less to account for the causes of those distributions.

The plankton program in the current contract consisted of the analysis of limited time-series samples from one station (Florida Middle Grounds, four samples per day for five days) for zooplankton from summer 76 and winter 78. For neuston, four to six samples per day were analyzed from five-day limited time-series collections at four stations (2749, 2315, 2529, and 2639) from winter 78. As with the zooplankton, the neuston data set also included analysis of summer 76 collections.

Results and Discussion

Quantitatively, the neuston data had the greater chance of providing some usable analytical output due to the much greater number of samples. R-mode (species associations) principal components analysis accounted for 66% of the variability with two axes in the summer data, but only 43% in the winter 78. For the better data set, one species, *Paracalanus crassirostris*, was shown to be highly isolated from the remainder of the species. That species was the second most abundant taxon overall (about 41,000 individuals from 73 replicates). To have it behaving in distribution very differently from the remainder was an indication of poorer Q-mode results to follow.

When the sample associations (Q-mode) were run, the summer 76 data showed that less than half the variability in the samples would be accounted for by the first two principal components. That meant that the causes of variation in the sample were coming from so many sources that a major direction could not be discerned. For winter 78 data the first two principal components accounted for less than 30% of the variability. These results were from data sets that were first trimmed to include only the 50 most abundant species and then a fourth root transformation was made to further control the data's inherent variability (all data normalized to length of tow in minutes). These outcomes indicate that the disorder in the data set is so large that further analysis would be fruitless. The data did indicate that one of the two data sets was less ordered than the other (2/78 less than 6/76), and that both were too variable to detect any patterns, much less to attempt to determine the causes of the patterns (or their lack). There was some indication that the northern station near Mobile (2639) was slightly more ordered than the other three.

The numeric data are available for analysis in the Dames & Moore Data Tape, but will not be further discussed here. Qualitatively, the neuston and zooplankton samples contained essentially the same species, the principal difference being the greater abundance and variety of pontellid (a family level taxon) copepods in the neuston. Collard (Minutes, third quarterly meeting, Dames & Moore, 1978e) expressed the opinion that with that exception, there is not a distinct neustonic (upper 1 to 20 cm) community in the MAFLA area. The comparison of species lists confirmed that point.

About 400 different taxa were recorded with about 100 identified to the species level. The list was dominated by copepods, as expected, and Collard (in Dames & Moore, 1978e) reported that essentially every copepod previously reported from the Gulf was included in that list. Caldwell and Maturo (Volume II, Chapter 27) reported that the Florida Middle Grounds' calanoid (a taxonomic order level group) copepods are a cosmopolitan group. The 1976 sample was dominated by shelf species with slope and oceanic species less abundant. The 1978 sample was dominated by slope and oceanic species, with little shelf species influence. The absence of coastal species in either sample would indicate that the Middle Grounds have little influence from coastal waters.

Usefulness of Zooplankton as a Monitoring Tool

The zooplankton hydrocarbon samples (see marine chemistry section, above) were valuable as corroborative of the dissolved and particulate hydrocarbon results, but neither the neuston nor the zooplankton taxonomic studies at the present or at any feasible level are likely to prove useful monitoring tools in and of themselves. Paired, depth stratified, zooplankton tows, with each split between chemical and taxonomic applications, would be useful for monitoring water column hydrocarbons; the taxonomic studies would be for support purposes only.

CONCLUSIONS

GEOLOGY

The MAFLA area is dominated by sands in all but the westernmost and some deep (200 m) stations. The area is roughly divided by the DeSoto Canyon into a prograding, active sedimentary area influenced primarily by the Mississippi River in the west (Mississippi-Alabama Shelf) and the carbonate rich eastern section, which has relatively little sediment input (West Florida Shelf). Clay minerals were used to separate sources of both benthic and suspended sediments. TOC increases offshore and to the north and is associated with percent fines. Temporal stability of sediment types is high, with a few notable exceptions. Small-scale geographic variability is especially high in the mid-portion of the West Florida Shelf, but low elsewhere. All of these factors have major influences on distributions of biota, trace metals, and hydrocarbons. Geological studies of the same general scope are recommended as independent variables to measure in a monitoring program.

PHYSICAL OCEANOGRAPHY

Sea water temperatures both at the surface and bottom in the MAFLA region range from about 9°C to over 30°C and show marked seasonal variation, with winter cooling and summer warming. Salinities vary from less than

$21^{o}/oo$ to over $37^{o}/oo$, with minimum values occurring on the western Mississippi-Alabama Shelf and maximum values on the southern part of the West Florida Shelf. The water column is stratified and exhibits a permanent thermocline which typically lies at depths of 90 to 120 m during the winter, and rises to about 10 to 30 m in the summer. Stratification above the permanent thermocline is generally weak or absent in the southern and central parts of the West Florida Shelf, but becomes very pronounced on the Mississippi-Alabama Shelf where freshwater inflow effects are seen. The West Florida Shelf exhibits the least spatial and temporal variability of physical parameters; the Mississippi-Alabama Shelf shows high variability on very short time and space scales. Physical oceanographic parameters determine, to a large extent, the character of the MAFLA biosphere, and must be included in monitoring programs.

MARINE CHEMISTRY

Hydrocarbons

Water column hydrocarbons appear to be entirely biogenic in source and very low (oceanic) in quantity. No armomatic hydrocarbons were found in either particulate or dissolved phases. Zooplankton also show strong to overwhelming biogenic source indications. The macroepifaunal hydrocarbons are more varied, but still predominantly biogenic. There appear to be four principal sources of variation in epifaunal hydrocarbons: diet, location, species, and season. Sediment hydrocarbons divide the MAFLA area into: (1) an inshore eastern region characterized by entirely biogenic (mostly marine) hydrocarbons; (2) an eastern offshore region characterized by terrigenous (probably Mississippi River source) inputs with mixed biogenic, anthropogenic, and petrogenic hydrocarbons dominating. Demersal fish hydrocarbons follow sediment hydrocarbons very closely, and the connection appears to be diet mediated. Indications of petrogenic contamination were evident in fish collected off Panama City, Florida, where tar balls were also frequently reported. Overall, hydrocarbon analyses in the MAFLA area do not show any signs of significant petrogenic pollution, and means of evaluating future levels are provided. All hydrocarbon parameters are recommended for inclusion in any future oil and gas development related monitoring.

Trace Metals

Sediment trace metals generally increase in concentration to the north and offshore, and tend to be associated with sediment fine fractions, TOC, and, to a lesser extent, $CaCO_3$. Cadmium had its highest values offshore in the south where it was strongly associated with $CaCO_3$. "Weak" acid estimates of "bioavilability" indicate that on the average about 60% trace metals were leached, with nearly 100% for high clay sediments. All values are low, and no signs of metal pollution were observed. Demersal fish and macroepifaunal trace metals showed variations related to diet, location, species, and season, with diet appearing the most important. A strong relationship between demersal fish trace metals and sediment leachable metals was demonstrated. In general, metals in sediments and tissues followed the same patterns as for the 1975/76 year, with reliable barium and zinc data being provided for the first time. Suspended sediment trace metals generally increase toward the source region (Mississippi River), and show some sharp short-term variability. All trace metal studies are recommended for use in monitoring programs, though "zooplankton" trace metals (in reality towed-net total pariculates samples) may not be amenable to variance control.

MARINE BIOLOGY

Most biotic elements show species associations that parallel depth contours and show decreasing abundance in an offshore direction (forams have the opposite trend). Species variety also tends to decrease offshore. Distributions of all groups tend to be highly associated with sediment fine fractions (forams positively; meiofauna, infauna, epifauna, fish negatively). Temporal and geographic variation is very high for meiofauna and ATP, moderate in forams and infauna, and low in epifauna and demersal fish. Species indicative of assemblages are provided. Indications of population stresses are seen in community structure in the westernmost station, the northeast corner and near Sanibel Island (foram stress indicator species and depressed relative density, variety, or diversity). All the stress sources appear to be natural. There were no correlations between high relative chemistry levels and biologic stress. No pathologies were observed in any epifaunal species from a wide variety of species checked. It is concluded that the MAFLA area has a healthy biologic environment and that within that environment, the Florida Middle Grounds are a unique resource. Only the forams and macroinfauna (especially the polychaetes and crustaceans) are recommended for inclusion in a monitoring program for use in measuring subtle environmental changes. Macroepifaunal and demersal fish studies are needed to support histochemistry and histopathology studies. If zooplankton chemistry is included in a monitoring program, zooplankton taxonomy needs also to be included, but high variability and lack of any replication make quantifying zooplankton or neuston samples extremely cost:product inefficient.

RECOMMENDED FUTURE STUDIES

Major deficiencies in the existing data base are:

- Demersal fish histopathology
- Variety in demersal fish histochemistry
- Replication in epifaunal histochemistry
- Sediment-water interface information
- Coastal current data
- Quantification of epifaunal and fish data
- LMW hydrocarbon determinations

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APPENDIX A

HISTOPATHOLOGY SPECIES

TABLE 1

HISTOPATHOLOGY SPECIES COLLECTIONS

		STATIONS																				
		40 m							100 m							200 m						
Species		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
Sponges																						
Cinachyra	75/76			X																		
	76/78																					
Cliona	75/76		X																			
	76/78																					
Geodia gibberosa	75/76					X																
	76/78																					
Guitarra	75/76													X								
	76/78																					
Ircinia campana	75/76			X																		
	76/78																					
Pseudoceratina crassa	75/76			X																		
	76/78	X		X							X											
Corals																						
Balanophyllia floridana	75/76																					
	76/78											X										
Bebryce cinerea	75/76																					
	76/78										X	X										

TABLE 1 (cont'd)

Species (cont'd)		STATIONS 40 m							100 m							200 m						
		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
Cladocora arbuscula	75/76		X																			
	76/78	X	X					X														
C. debilis	75/76		X																			
	76/78																					
Dichocoenia stellaris	75/76			X																		
	76/78			X																		
Ellisella barbadensis	75/76																					
	76/78														X							
Eunicea calyculata	75/76																					
	76/78			X																		
Lophogorgia cardinalis	75/76																					
	76/78			X																		
Madracis decatis	75/76			X																		
	76/78																					
Millepora alcicornis	75/76			X																		
	76/78																					
Muricea elongata	75/76																					
	76/78			X																		
M. laxa	75/76																					
	76/78			X																		
Oculina diffusa	75/76																					
	76/78	X	X									X										

TABLE 1 (cont'd)

Species (cont'd)		40 m I	40 m II	40 m III	40 m IV	40 m V	40 m VI	40 m VII	100 m I	100 m II	100 m III	100 m IV	100 m V	100 m VI	100 m VII	200 m I	200 m II	200 m III	200 m IV	200 m V	200 m VI	200 m VII
O. tenella	75/76																					
	76/78							X														
Paracyathus pulchellus	75/76																					
	76/78																				X	
Phyllangia americana	75/76		X																			
	76/78		X					X														
Placogorgia	75/76																					
	76/78														X							
Porites	75/76			X																		
	76/78			X																		
Scleracis guadalupensis	75/76																					
	76/78										X											
Scolymia lacera	75/76																					
	76/78			X																		
Siderastraea radians	75/76		X																			
	76/78		X																			
Solenastrea hyades	75/76		X																			
	76/78		X					X														
Stephanocoenia michelini	75/76		X																			
	76/78		X	X																		
Villogorgia negrescens	75/76																					
	76/78																					X

TABLE 1 (cont'd)

		STATIONS																				
		40 m							100 m							200 m						
Species (cont'd)		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
Molluscs																						
Aequipecten glyptus	75/76																	X		X		
(scallop)	76/78															X		X	X	X		
A. muscosus	75/76	X	X																			
(scallop)	76/78	X	X			X	X	X													X	
Aequipecten sp.	75/76													X						X		
(scallop)	76/78																					
Anadara sp.	75/76																					
(clam)	76/78																				X	
Arca zebra	75/76		X	X																		
(clam)	76/78																					
Argopecten gibbus	75/76					X	X															
(scallop)	76/78						X															
Callista eucymata	75/76																					
(clam)	76/78									X												
Chama macerophylla	75/76																					
(clam)	76/78	X		X																		
Chama sp.	75/76																					
(clam)	76/78	X		X																		
Chione latilerata	75/76				X																	
(clam)	76/78																					

TABLE 1 (cont'd)

Species (cont'd)		STATIONS 40 m I	II	III	IV	V	VI	VII	100 m I	II	III	IV	V	VI	VII	200 m I	II	III	IV	V	VI	VII
Circumphallus strigillinus	75/76																					
(clam)	76/78									X												
Glycemeris americanus	75/76					X																
(clam)	76/78																					
Laevicardium pictum	75/76		X																			
(clam)	76/78																					
Loligo pealii	75/76				X				X	X	X	X	X	X			X	X	X	X	X	
(squid)	76/78																					
Mercenaria mercenaria	75/76												X									
(clam)	76/78																					
Murex beauii	75/76																X					
(snail)	76/78								X							X	X					
M. cabritii	75/76							X														
(snail)	76/78																					
Ostrea frons	75/76		X	X																		
(oyster)	76/78																					
Pecten raveneli	75/76	X				X																
(scallop)	76/78		X			X	X						X									
Pteria colymbus	75/76			X																		
(clam)	76/78			X																		
Spondylus americanus	75/76			X																		
(clam)	76/78	X	X	X																		

TABLE 1 (cont'd)

Species (cont'd)		STATIONS 40 m							100 m							200 m						
		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
S. ictericus (clam)	75/76																					
	76/78			X																		
Crustaceans																						
Ancanthocarpus alexandri (crab)	75/76																	X	X	X		
	76/78																X	X	X	X		
Calappa angusta (crab)	75/76															X						
	76/78																					
Iliacantha subglobosa (crab)	75/76																					
	76/78								X											X		
Mesopenaeus tropicalis (shrimp)	75/76													X								
	76/78																		X	X	X	
Metapenaeopsis goodei (shrimp)	75/76																					
	76/78					X																
Perapandalus longicauda (shrimp)	75/76															X						
	76/78																					
Parapenaeus longirostris (shrimp)	75/76																					
	76/78															X	X	X	X	X		
Parthenope portalesii (crab)	75/76																					
	76/78													X								
Penaeus duoarum (pink shrimp)	75/76																					
	76/78		X				X	X														

TABLE 1 (cont'd)

Species (cont'd)		40 m							100 m							200 m						
		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
Portunus gibbesi	75/76		X																			
(swimming crab)	76/78		X				X															
P. spinicarpus	75/76	X		X			X		X		X	X										
(swimming crab)	76/78		X	X			X	X	X	X	X	X		X	X	X	X	X	X			
P. spinimanus	75/76																					
(swimming crab)	76/78		X	X				X		X							X					
Sicyonia brevirostris	75/76	X	X	X	X	X	X					X										
(shrimp)	76/78	X	X	X		X	X	X	X	X	X	X		X	X						X	
Solenocera atlantidis	75/76																					
(shrimp)	76/78		X	X		X		X		X						X	X	X	X	X		
Squilla edentata	75/76																				X	
(mantis shrimp)	76/78																					
Stenorhynchus secticornis	75/76	X		X					X					X								
(crab)	76/78	X				X		X	X			X	X		X						X	
Echinoderms																						
Astroporpa annulata	75/76									X				X								
(basket star)	76/78																					
Brissopsis elongata	75/76																				X	
(heart urchin)	76/78																					
Luidia alternata	75/76		X																			
(starfish)	76/78																					

TABLE 1 (cont'd)

		STATIONS																				
		40 m							100 m							200 m						
Species (cont'd)		I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII	I	II	III	IV	V	VI	VII
Lytechinus variegatus	75/76		X																			
(spiny sea urchin)	76/78																					
Ophioderma januarii	75/76					X																
(brittle star)	76/78																					

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.