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NORTHWESTERN GULF OF MEXICO TOPOGRAPHIC FEATURES STUDY

FINAL REPORT

TO THE

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF LAND MANAGEMENT

OUTER CONTINENTAL SHELF OFFICE

NEW ORLEANS, LOUISIANA

CONTRACT NO. AA550-CT7-15

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CHAPTER I

INTRODUCTION

AND

OBJECTIVES

INTRODUCTION

AND

OBJECTIVES

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Thomas J. Bright
Richard Rezak

In 1977-78 studies were performed under the BLM contract on the nine topographical features (banks) listed in Table I-1 and depicted in Figure I-1. Detailed bathymetric charts were produced for all but the East Flower Gardens Bank, which was mapped in 1976 (see Figures I-2 through -10).

TABLE I-1

Topographic Features (Banks) Studied During 1977-78
Under BLM Contract

Banks	Nearest Coastal Pass	Range (Nautical Miles)	Bearing
Bouma	Sabine Pass	122.0	142.0
Bright	Sabine Pass	112.0	164.5
Claypile	Sabine Pass	83.4	191.5
East Flower Garden	Sabine Pass	106.7	173.0
18 Fathom	Sabine Pass	122.0	146.5
Ewing	Sabine Pass	176.0	121.0
Parker	Sabine Pass	141.3	136.0
Sonnier	Sabine Pass	106.7	136.5°
Sackett	Burwood (Southwest Pass)	21.0	205.0°

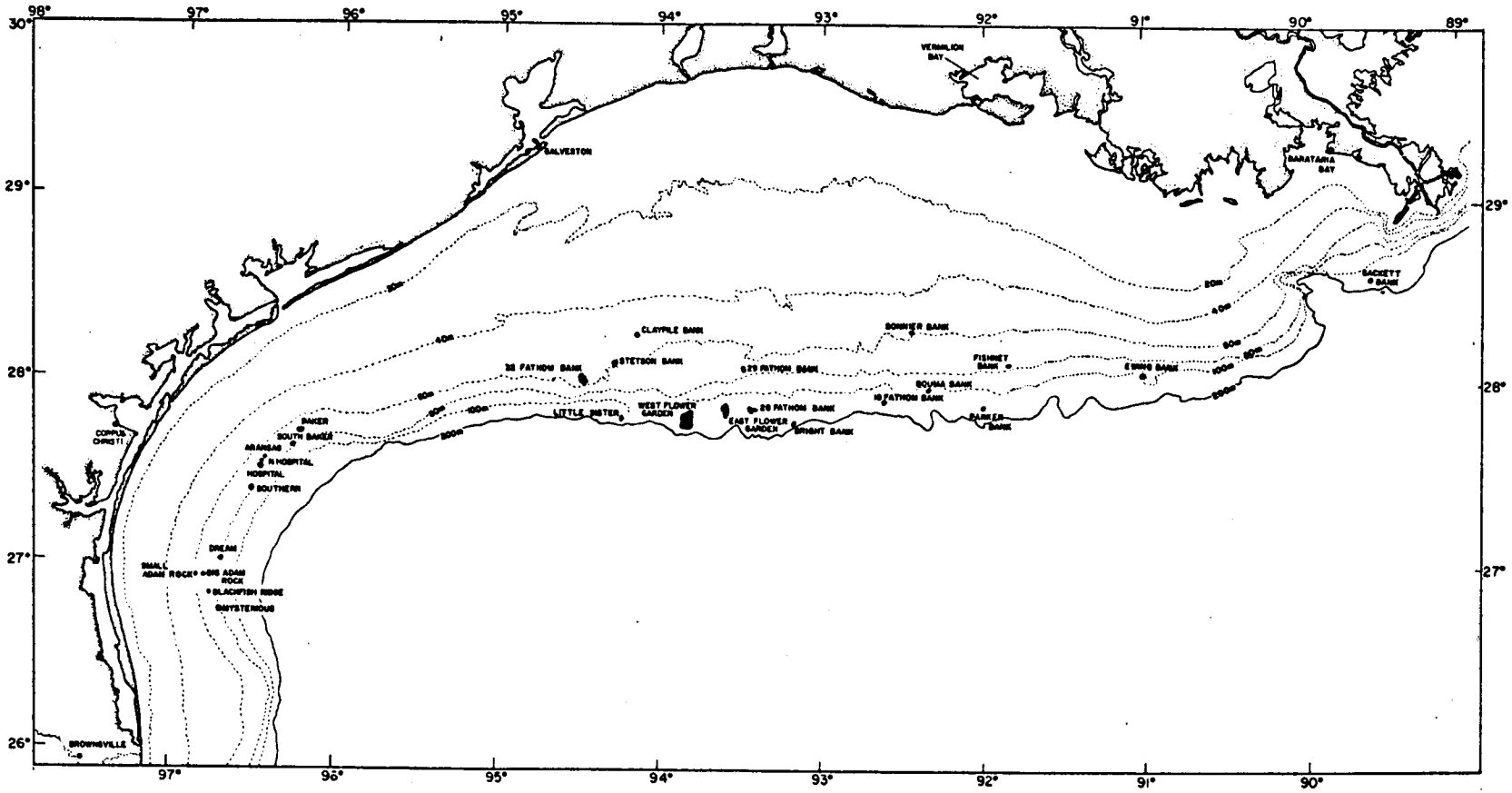

Figure I-1. Fishing banks and reefs of the Outer Continental Shelf of the northwestern Gulf of Mexico.

Descriptive reconnaissance studies were completed in 1977 for Bouma, Bright, Ewing, Parker, Sackett, Sonnier and 18 Fathom Banks. The reconnaissance studies include the geology and biology of the banks as observed from the submersible. In addition, at the East Flower Gardens, Sonnier, Bright and Sackett Banks, the study included: the size distribution and mineralogy of the surrounding sediments; hydrography in the vicinity of the banks; chemical analyses of sediments and selected faunal components for trace metals and heavy molecular weight hydrocarbons; chemical analyses of the water column for nutrients, dissolved oxygen, and low molecular weight hydrocarbons; and temperature, salinity, transmissivity and current velocity profiles of the water column.

A monitoring study was initiated within the living coral portion of the East Flower Gardens Bank. Through the use of long and short term time lapse camera systems, the spread of pathological conditions and the effect of physical damage to reef coral was observed. The brine lake discovered in 1976 was visited and further observations of this phenomenon were made.

Also at the East Flower Gardens, a study of very near-bottom current magnitude and turbulence was made using dye emission apparatus observed from the submersible.

The study of the distribution of reworked fossil coccoliths on the South Texas Outer Continental Shelf initiated during 1976 was continued, and has resulted in a much more detailed map of the transport pathways of suspended sediment.

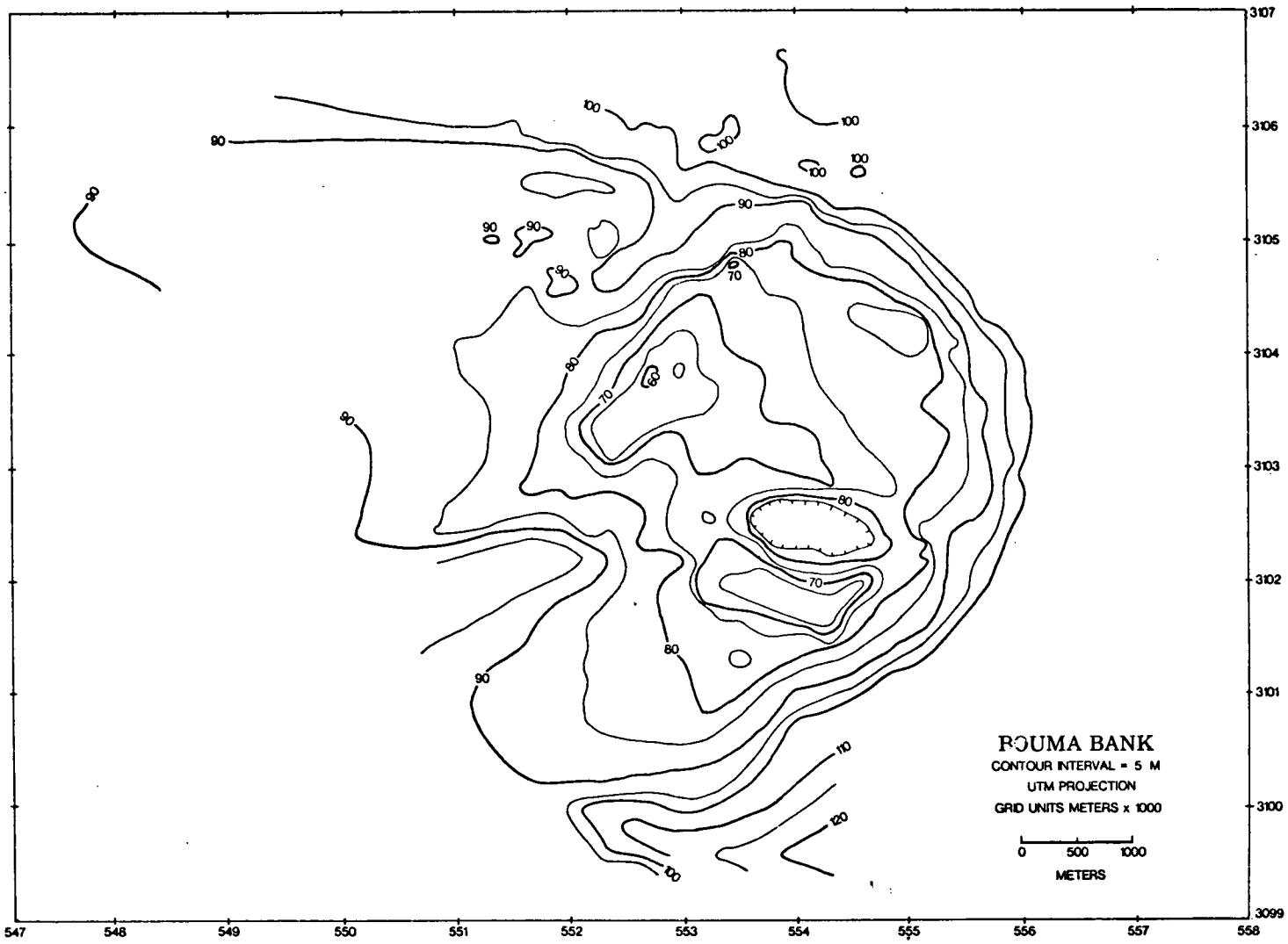

Figure I-2. Bathymetric map of Bouma Bank.

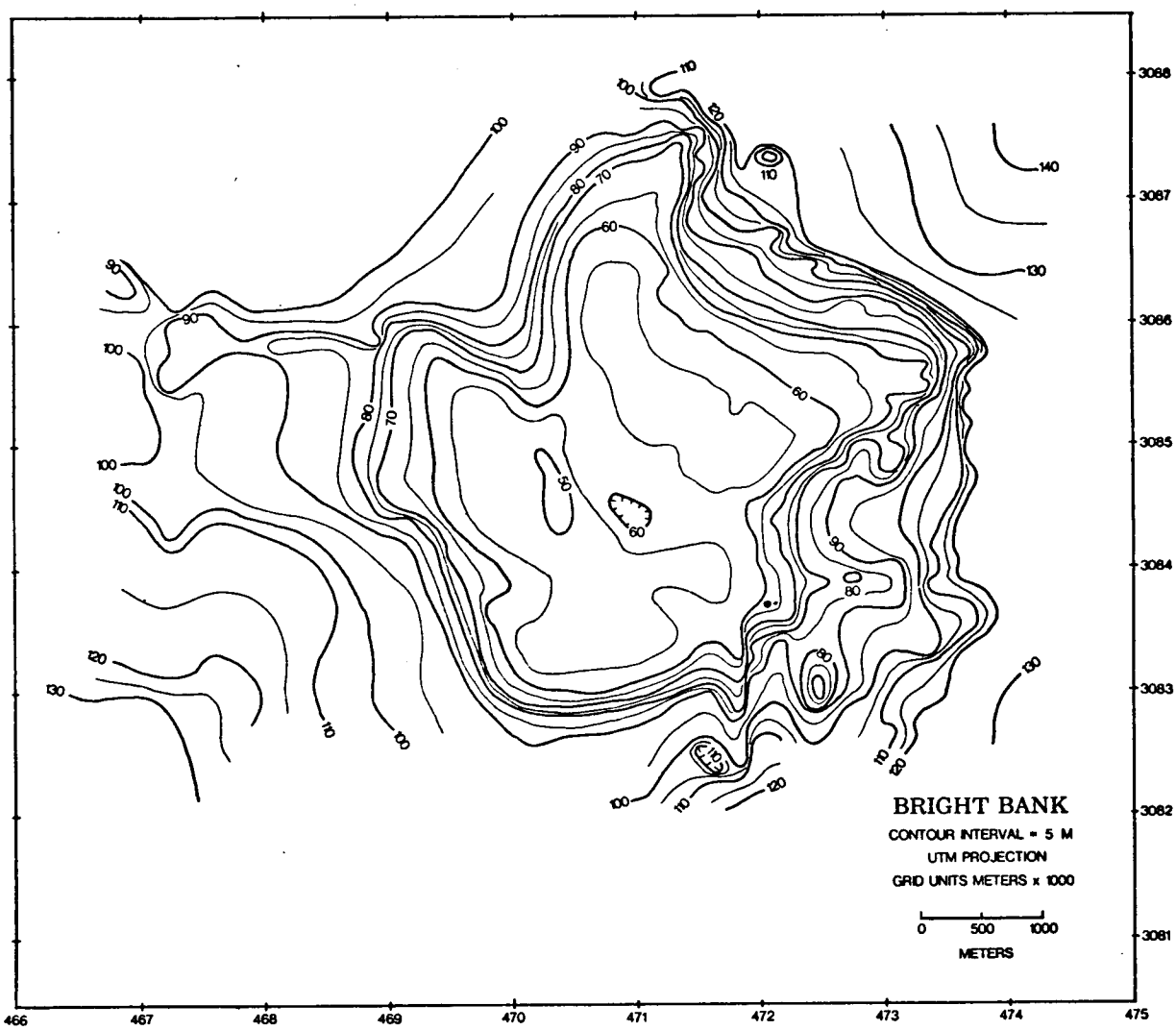

Figure I-3. Bathymetric map of Bright Bank.

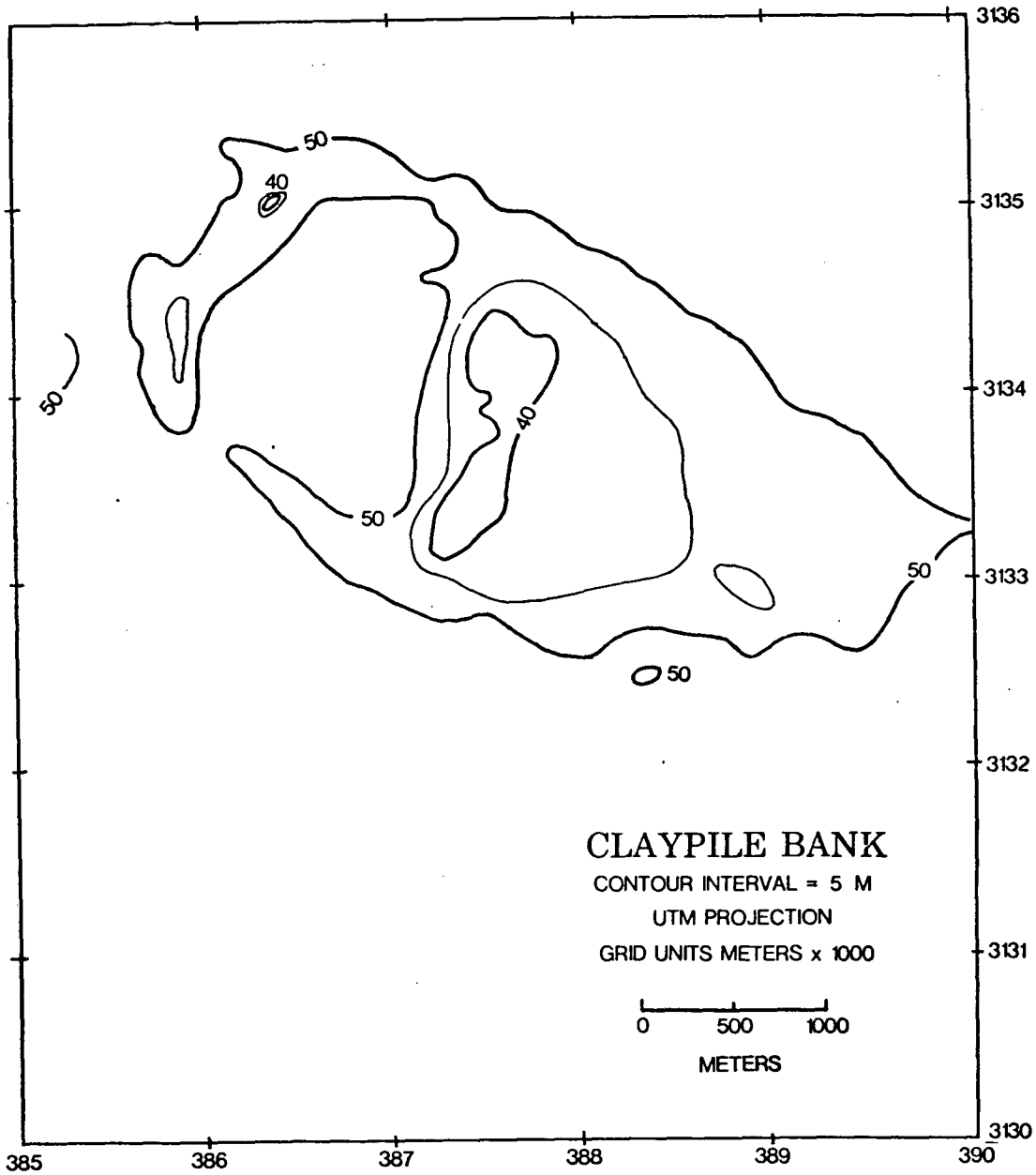

Figure I-4. Bathymetric map of Claypile Bank.

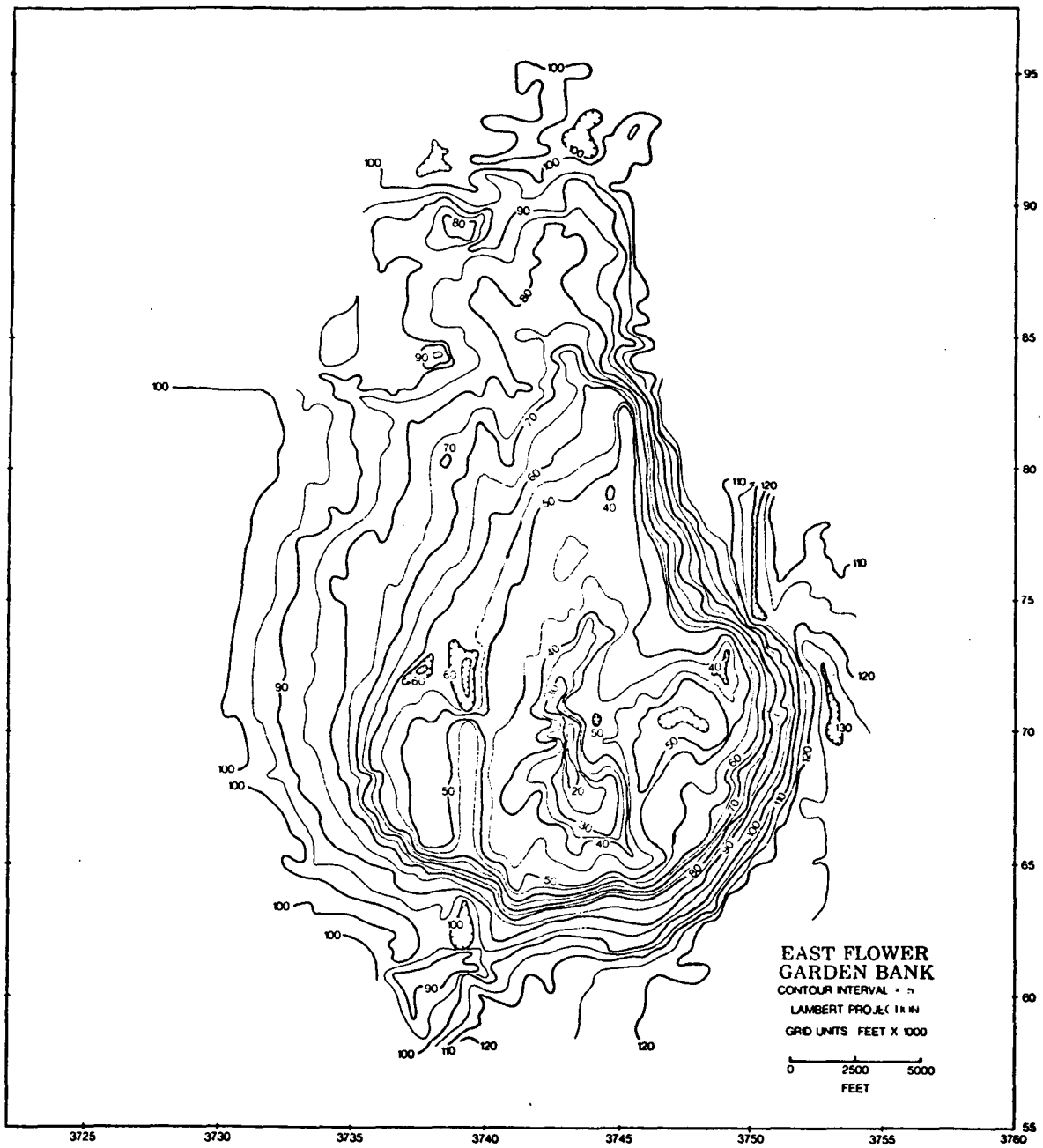

Figure I-5. Bathymetric map of East Flower Garden Bank.

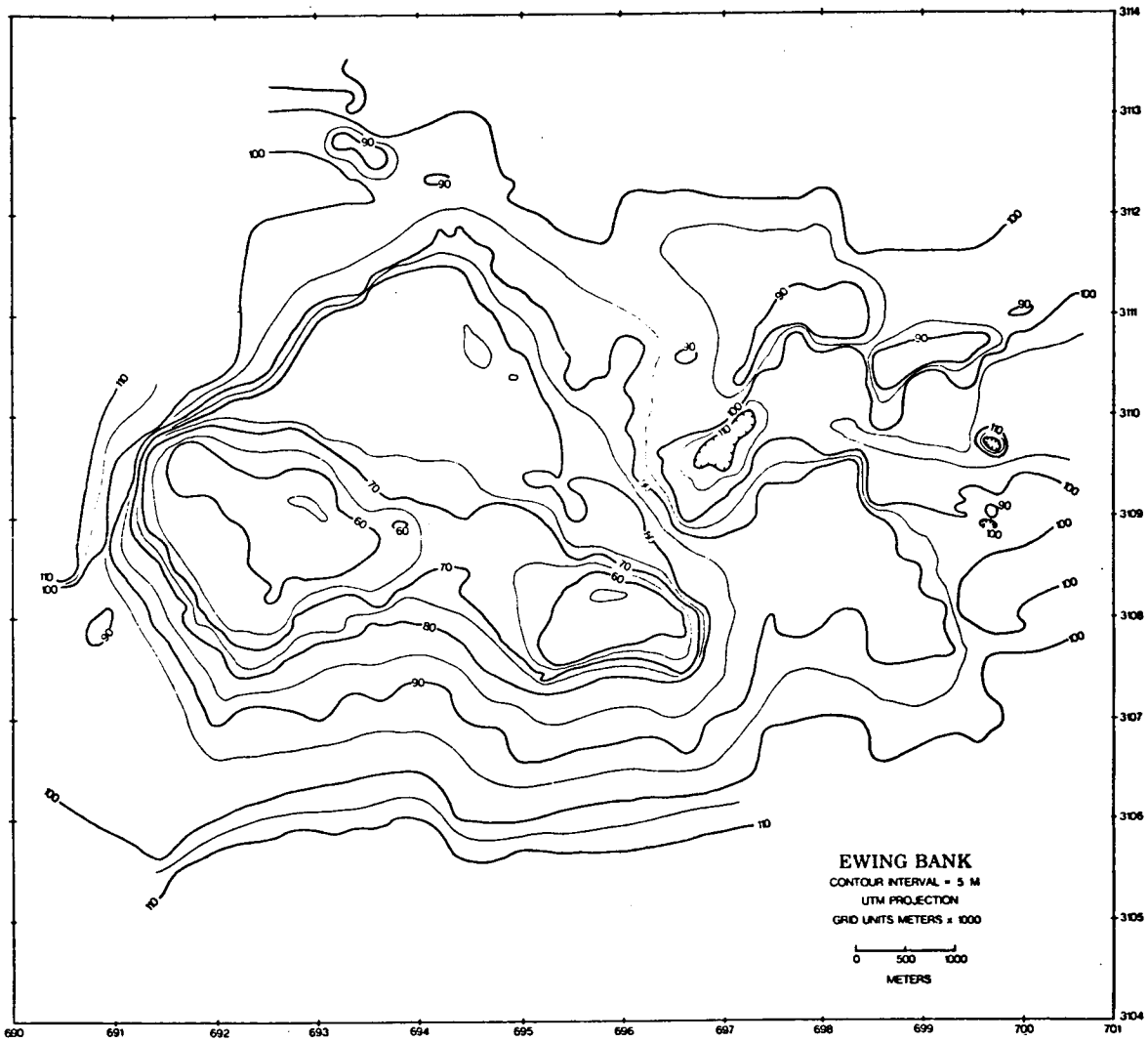

Figure I-6. Bathymetric map of Ewing Bank.

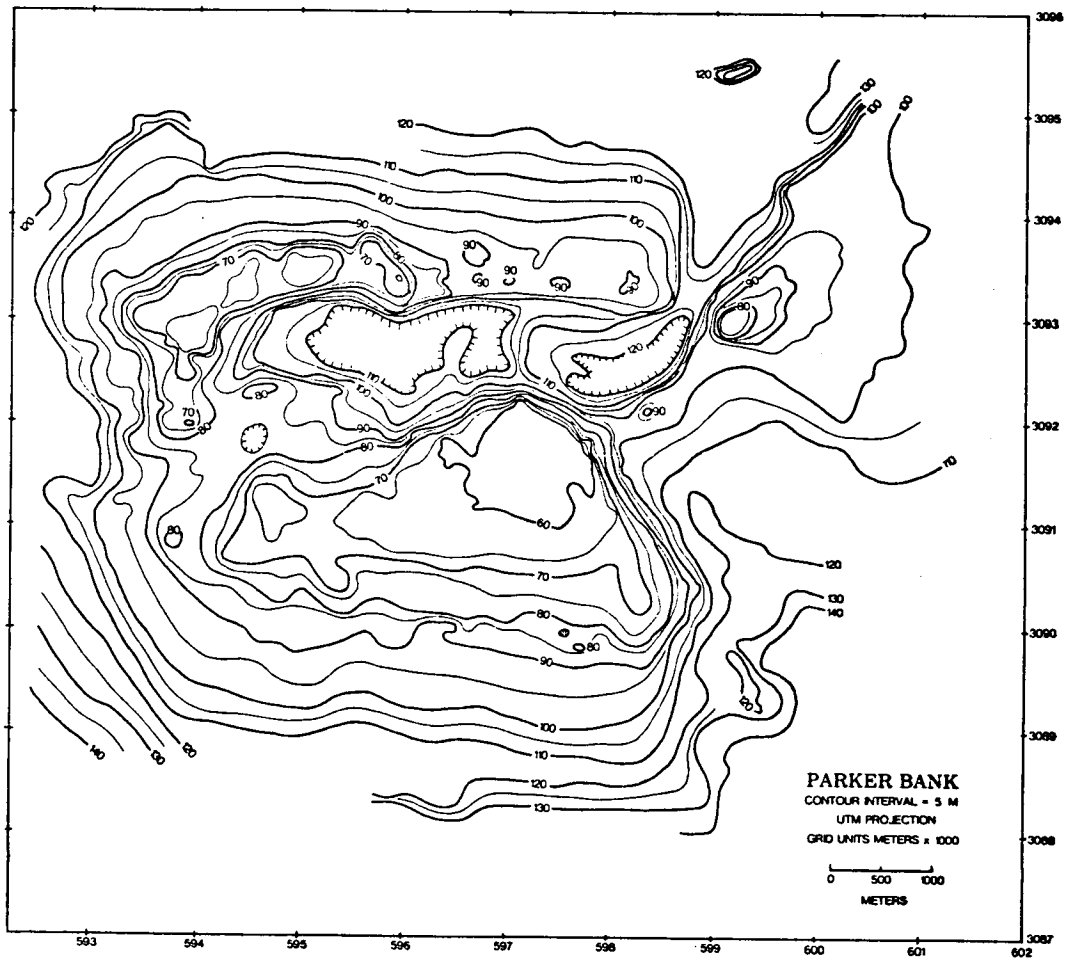

Figure I-7. Bathymetric map of Parker Bank.

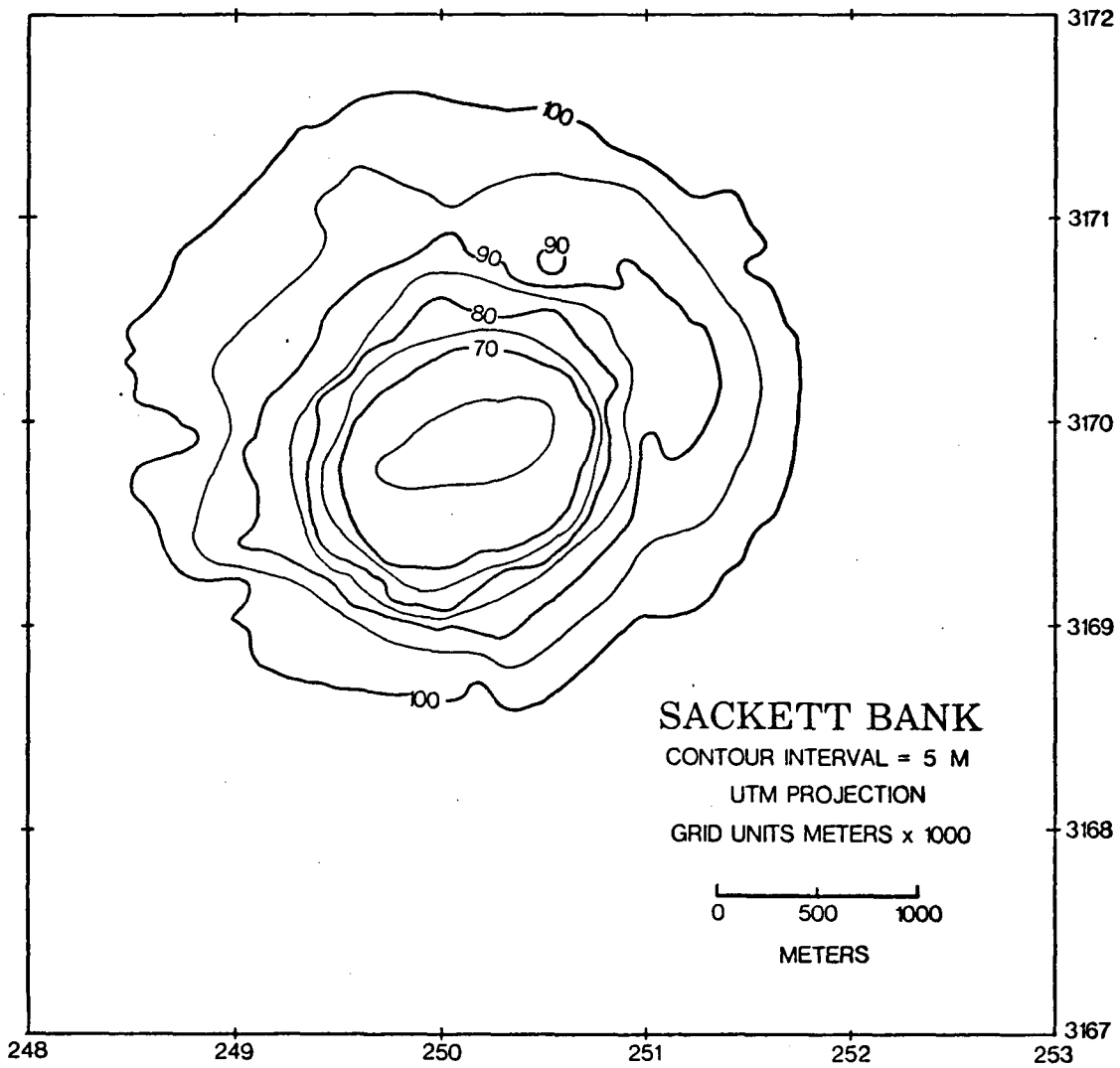

Figure I-8. Bathymetric map of Sackett Bank.

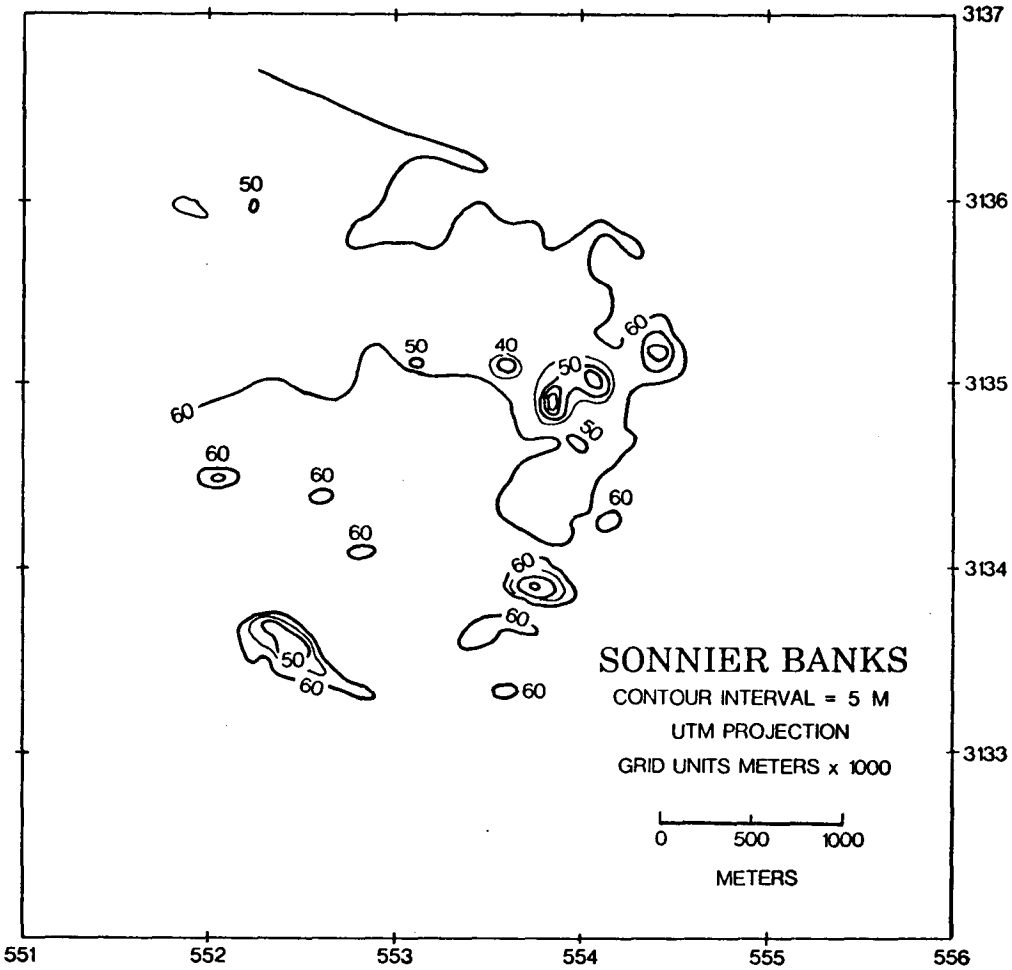

Figure I-9. Bathymetric map of Sonnier Banks.

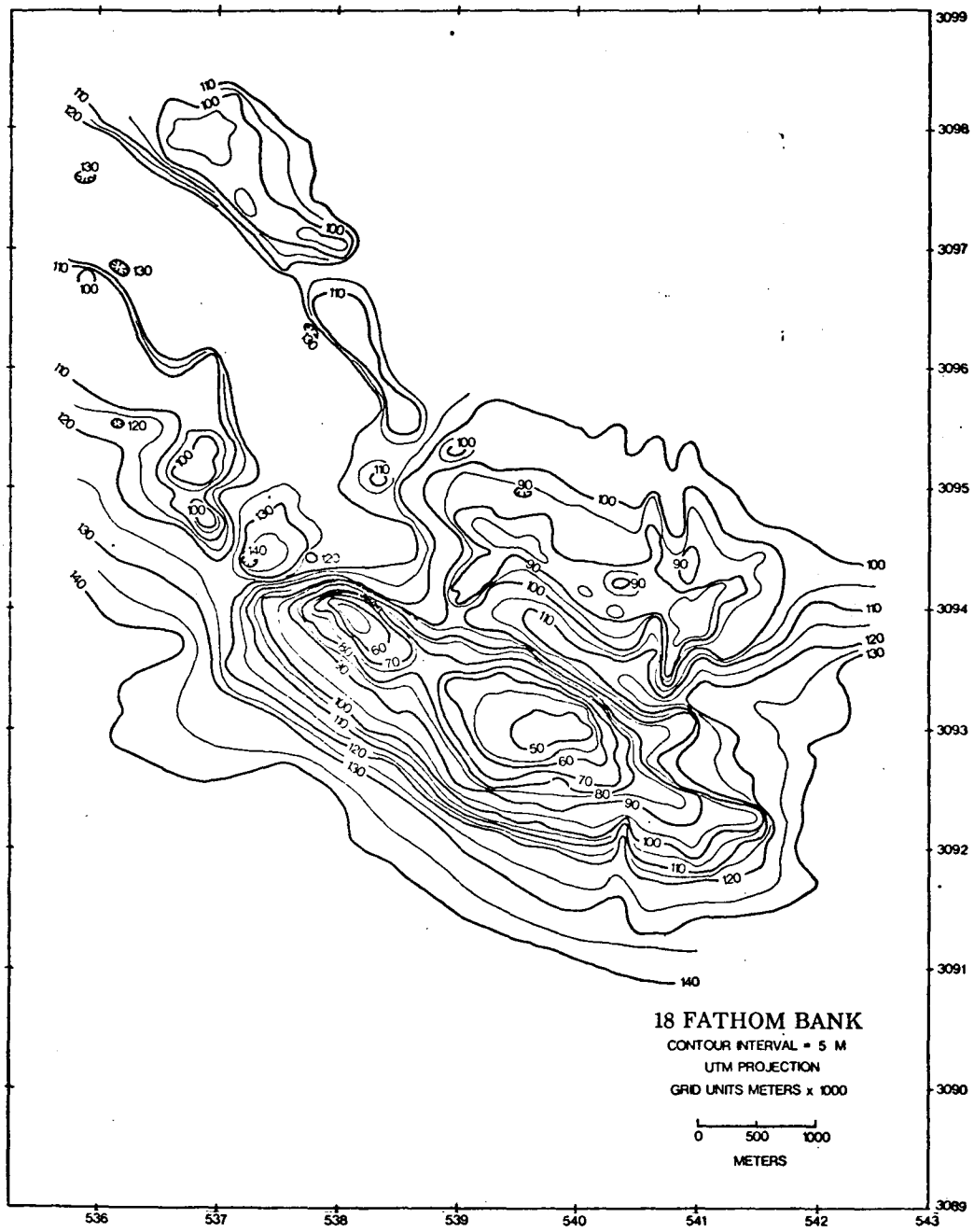

Figure I-10. Bathymetric map of 18 Fathom Bank.

CHAPTER II

FIELD METHODS

FIELD METHODS

Compiled By

Richard Parker

Thomas J. Bright

INTRODUCTION

The field effort for this project was divided into four phases. As originally planned there were to be a mapping phase, a sampling phase, a submersible phase and a monitoring phase. The mapping phase and a portion of the sampling phase were conducted on board the lease vessel M/V DECCA LOCATOR, chartered from Decca Survey Systems, Inc. at Freeport, Texas. Due to mechanical problems with the lease ship and our own shipboard equipment, a portion of the sampling phase was completed aboard the R/V GYRE during the submersible phase. The winter seasonal sampling was started aboard the M/V DECCA PROFILER (Profiler, Inc., Freeport, Texas) and finished on the R/V LONGHORN (University of Texas Marine Science Institute, Port Aransas Marine Lab, Port Aransas, Texas). The monitoring phase used several ships, including the M/V CHIP IV (The Dive Shop, Galveston, Texas) the R/V LONGHORN, The R/V GYRE (in conjunction with the submersible cruise) and the M/V CHERAMIE BO-TRUC #25 (Cheramie Bros., Inc., Golden Meadows, Louisiana). The specifications of these vessels can be found in Table II-1. Cruise dates are in Appendix A, Table II-1.

PHASE I - MAPPING CRUISE

Under sub-contract with Decca Survey Systems, Inc. of Houston, Texas, Bathymetric surveys were conducted at Bouma, Bright, Claypile, Ewing, Parker, Sackett, Sonnier and 18 Fathom Banks.

The navigation for all portions of this phase was provided by Decca Survey Systems, Inc. and positions were recorded on magnetic cassette tape. Decca also provided the 7kHz EDO Western subbottom profiling system, EDO side scan sonar system and Atlas-Deso digital recording PDR system.

TABLE II-1

Specifications of Ships Used During the 1977-78 Study Period

Vessel	Length	Beam	Special Equipment
M/V DECCA LOCATOR	33.5 m	7.6 m	"A" Frame, 2 winches
R/V GYRE	53.1 m	11 m	2 "A" Frames, hydraulic crane, STD winch, coring winch, hydro winch, submersible handling system
M/V DECCA PROFILER	33.5 m	7.6 m	"A" Frame, winch
R/V LONGHORN			Hydraulic crane with winch
R/V DIAPHUS	6.1 m	1 m dia.	2 passenger submersible, with depth capacity 366 m, 409 kg payload
M/V CHIP IV	23 m	4.6 m	
M/V CHERAMIE BO-TRUC #25	51 m	11.5 m	

Leg I of the bathymetric cruise (designated 77DL3) began on 17 May 1977 and ended on 26 May 1977 with Leg II beginning the same day. Leg II ended on 3 June 1977.

POSITIONING

The positioning was provided by Decca Survey Systems, Inc. Decca utilized a Lorac receiver operating in the hyperbolic mode, with the receiving antenna located 18.9 m from the stern of the vessel.

Lane counts were acquired at fixed production platforms, and were tracked on an analog recorder. Closed lane count traverses were made between the lane count tie points (platforms) and the designated work areas. During the bathymetric cruises, the data from both the Lorac receiver and PDR were coupled into a PDP 1105 computer through a Texas Instrument Silent 700 ASR. This data was recorded on magnetic tape every 20 meters distance on track lines and plotted on a Houston Instruments Complot Model DP-3-1 every one minute immediately after completion of the work area. Table II-2 presents the direction, number and spacing for survey lines on each bank.

During surveying, the vessel's position was continuously monitored with course corrections for the pre-plotted track lines being relayed to the helmsman via a left-right indicator. This indicator was coupled with the computer and indicated the vessel's position to within 3 meters of track line.

The on-board plotted survey areas were contoured during each leg so that sampling sites could be determined prior to the start of Leg III. Final bathymetry was prepared by Decca on mylar charts.

TABLE II-2

DATA ABOUT DIRECTION AND DISTANCE OF SURVEY LINES

BANK	DIRECTION & DISTANCE APART OF REGULAR SURVEY LINES			DIRECTION & NUMBER OF TIE LINES		TOTAL KILOMETERS OF LINES
Ewing	N-S	47	300 m	E-W	4	239.1
Parker	N-S	33	300 m	E-W	3	223.2
Bright	N-S	27	300 m	E-W	6	166.1
Bouma	N-S	23	300 m	E-W	4	131.9
18 Fathom	N-S	39	300 & 150 m	E-W	2	131.1
Sackett	N-S	23	150 m	E-W	3	76.0
Claypile	N-S	20	300 m	E-W	4	66.8
Sonnier	N-S	18	300 & 150 m	E-W	5	64.8

BATHYMETRY

The bathymetry was accomplished through the use of a Atlas-Deso PDR System operating at 210 kHz. The transducer is hull mounted and was 2.1 m below the surface. This unit utilizes a dry paper recorder and was coupled with an Atlas-Edig digitizer. The digitizer unit gives a visual reading of depth accurate to ± 1 cm. This unit was also coupled with the on board computer and depths were recorded on magnetic tape every 20 m along the ship's track.

During a portion of the bathymetric survey a hull mounted EG&G Boomer Unit was utilized for the purpose of verifying Atlas records and for gathering high-resolution data in order to delineate the structures that are responsible for the banks. This system was powered by an EG&G Model 231 Triggered Capacitor Bank operated at 400 joules. The signal was processed through a Del Norte Model 502A signal processor operated at a 270 - 500 kHz band pass. The data was then recorded on an EDO Western Model 550 recorder at ½ second continuous sweep and 20 scale lines full scale with a line density of 150 lines per 2.54 cm. Side scan sonar records were utilized to verify topographic features of the surveyed banks.

SIDE SCAN SONAR

The unit utilized was an EDO Western Model 606 side scan sonar system. The Model 602 towed fish operated at a frequency of 100 kHz with a pulse width of 100 microseconds. Peak output is 126 decibels, reference 1 microbar at 1 m. The horizontal beam width is 1.3° at -3 decibels. The tow fish was operated in the 10° down vertical beam orientation.

The Model 606 recorder, utilizing dry electrosensitive paper, was operated in the combined side scan and subbottom profile mode. This mode provides a 23.3 cm side scan display and a 23.5 cm subbottom profile display. The side scan was operated in the 200 m per side range with 25 m scale line interval. The subbottom profiler used in conjunction consisted of a Model 248c Transceiver and a 7 kHz hull mounted transducer. This system was also operated in the 200 m scale using 25 m scale lines.

BENCHMARKS AND BUOYS

Benchmarks were made of 55 gallon oil drums filled with concrete. On completing a survey of each bank, benchmarks were placed as close to the highest topographic relief as was possible. Each benchmark had approximately 3 m of polypropylene line attached. Table II-3 presents the location of benchmarks in Loran A coordinates, degrees latitude and longitude, and UTM grid system.

FINAL CHARTS

Decca Survey Systems, Inc. prepared the charts through the use of the magnetic tape data acquired on Legs I and II.

Depth contours are presented in 2 m intervals except where relief requires a 5 or 10 m interval, with data presented from mean sea level, and prepared at a scale of 1 cm = 120 m. Each survey trackline is numbered and has an arrow indicating direction of traverse. Depths are indicated along these traverses at 1 minute intervals. These charts also include latitude and longitude, UTM grid, lease block numbers and boundaries, and bench mark locations.

TABLE II-3

Bench Mark Locations

BANK NAME	UTM IN METERS (cm 93) X	UTM IN METERS (cm 93) Y	GEOGRAPHIC COORDINATES LATITUDE	GEOGRAPHIC COORDINATES LONGITUDE	LORAN A 3H2	LORAN A 3H3
18 Fathom	539,752	3,093,049	27° 57' 48.47"N	92° 35' 45.04"W	2674.06	3249.66
Claypile	388,094	3,134,150	28° 19' 49.15"N	94° 08' 29.72"W	3538.56	3330.36
Bauma	552,644	3,103,784	28° 03' 35.73"N	92° 27' 51.47"W	2603.65	3288.36
Sonnier	553,849	3,134,500	28° 20' 13.73"N	92° 27' 02.23"W	2601.23	3384.09
Ewing	697,006	3,109,235	28° 05' 43.87"N	90° 59' 41.37"W	1796.19	3316.80
Parker	597,280	3,091,550	27° 56' 49.10"N	92° 00' 40.08"W	2352.61	3261.16
West Cameron 656	470,301	3,084,639	27° 53' 16.09"N	93° 18' 06.26"W	3044.72	3180.38

BANK NAME	UTM IN METERS (cm 87) X	UTM IN METERS (cm 87) Y	GEOGRAPHIC COORDINATES LATITUDE	GEOGRAPHIC COORDINATES LONGITUDE	LORAN A 3H2	LORAN A 3H3
Sackett	250,124	3,169,888	28° 38' 00.89"N	89° 33' 21.56"W	1112.69	3424.77

PHASE II - SAMPLING CRUISES

The sampling effort during this study included three seasonal and one summer sampling cruise. The first seasonal (Spring-Summer) cruise to the East Flower Gardens and Sonnier Banks was conducted in conjunction with the summer sampling cruise, which was scheduled to visit Bright, Parker and Sackett Banks. This cruise was called Leg III of 77DL3, as the same ship (the M/V DECCA LOCATOR) was used and the only break was for mobilization. During the sampling portion a portable van was placed on board for use as a wet lab for the chemist and biologist. A 1.8 m x 2.5 m refrigeration van was also placed on board for storage of samples. Mobilization for Leg III began on 6 June 1977 with the cruise departing Galveston, Texas on 9 June 1977 and ending on 22 June 1977. Demobilization took place on 23 and 24 June 1977. All sampling was completed with the exception of Sackett Bank and the gravity core operation on Sonnier Bank.

The second seasonal (Fall) cruise to the East Flower Gardens Bank was scheduled to occur along with submersible cruise on the R/V GYRE. In addition, because of the problems encountered during the summer sampling cruise, Sackett Bank had to be sampled. The sampling took place on Leg I of the submersible cruise, 77G10, which started 9 September 1977 and ended 21 September 1977.

The third seasonal (Winter) cruise to the East Flower Gardens Bank was scheduled to go out in January-February of 1978. Cruise 78DP1 on the M/V DECCA PROFILER did go out 15 February to 22 February, but a combination of bad weather, ship equipment failure and scientific

equipment failure diminished the value of the time spent at sea. Therefore a cruise was undertaken aboard the R/V LONGHORN 14 March - 16 March, 1978. Water column measurements were taken at the four primary stations and bottom sediment samples were taken at two of the four before bad weather terminated the cruise.

SAMPLING DEVICES UTILIZED

During Leg III operations all cores and grabs were taken with a gravity core and Smith-McIntyre sampler. The gravity corer unit utilized had an approximate weight of 136.1 kg and was equipped with a 7.6 cm diameter X 3.0 m long barrel. Plastic core liners were placed in the barrel and upon obtaining a sample these liners were extruded and capped. The cores were then measured and placed upright in the refrigeration van. All benthic and bottom sediment samples were acquired through the use of the Smith-McIntyre sampling device which has a weight of approximately 90.7 kg. This device collects an undisturbed sample of approximately .0125 cubic meters.

Transmissometry data were taken through the use of a Martek 1 meter folded path transmissometer and accompanying depth sensor. Salinity, temperature and depth data were acquired through the use of a Martek Mk III system. Both systems were coupled to a Martek EDP digitizer and all data was recorded on magnetic tape. The EDP also provided an automatic print-out of all incoming data. All salinity and temperature data were checked at the surface and near bottom using Nansen bottles with reversing thermometers.

A Hydroproducts profiling current meter Model 960 complete with a

gasoline engine powered winch and on deck electronic readout was employed to measure the water velocity from the sea surface to the bottom. In addition, the sensor unit was sometimes deployed to a particular depth and the velocity changes with time measured.

Water column samples were taken at surface and mid-depth with 5 l Niskin bottles and at near bottom with 30 l Niskin bottles. Subsamples were taken for dissolved oxygen, nutrients and low molecular weight hydrocarbons from all water samples, then samples were filtered on board the vessel.

The macronekton (primarily snapper and grouper) samples were obtained with standard sport fishing tackle consisting of rods and reels. Bait used was either squid or cut fish.

SAMPLING PROCEDURES

After the ship was anchored on station, sampling followed the same sequence at all stations at all banks on all cruises. The sequence was divided into three sections, which were performed in the following order: 1) water column measurements, 2) water sampling and 3) bottom sediment sampling. All banks sampled had four primary stations at which all three sections were performed. In addition, the East Flower Gardens Bank had eight secondary stations, at which only section one was performed. The station locations can be found in Table II-4.

Water Column Measurements

Within section one, the procedure was to first place the

TABLE II-4

Sampling Station Locations at Each Bank

BANKS & STATION	UTM in meters X	Y	LAT	LONG	WATER DEPTH (m)
East Flower Garden		(Lambert Coordinates in Feet)			
1	3,759,665	78,285	27°56'09"N	93°32'58"W	118
2	3,753,970	76,216	27°55'51"N	93°34'02"W	119
3	3,729,280	67,191	27°54'33"N	93°38'42"W	104
4	3,724,596	65,658	27°54'20"N	93°39'35"W	99
5 (77DL3, 78,DP1)	3,740,830	94,283	27°58'56"N	93°36'19"W	105
(77G10)	3,744,627	90,128	27°58'13"N	93°35'39"W	87
6 (77DL3, 78DP1)	3,741,573	88,302	27°57'56"N	93°36'14"W	91
(77G10)	3,743,987	96,286	27°50'16"N	93°35'43"W	99
7	3,733,606	72,735	27°55'30"N	93°37'51"W	85
8	3,727,603	73,650	27°55'38"N	92°38'57"W	103
9	3,744,419	65,815	27°54'13"N	93°35'54"W	39
10 (77DL3, 78DP1)	3,747,325	62,989	27°53'43"N	93°35'23"W	98
(77G10)	3,745,252	64,422	27°53'59"N	93°35'46"W	
11	3,751,609	58,916	27°53'01"N	93°34'38"W	129
12	3,758,677	51,931	27°51'49"N	93°33'23"W	158
Bright					
1	472,479	3,086,787	27°54'26"N	93°16'47"W	119
2	469,888	3,085,930	27°53'58"N	93°18'21"W	87
3	469,306	3,084,002	27°52'55"N	93°18'43"W	82
4	472,203	3,084,254	27°53'04"N	93°16'57"W	70
Sonnier					
1	552,294	3,135,651	28°20'51"N	92°27'59"W	60
2	553,006	3,134,563	28°20'16"N	92°27'33"W	62
3	554,263	3,133,540	28°19'42"N	92°26'47"W	61
4	554,517	3,135,921	28°21'00"N	92°26'37"W	62
Parker					
1	593,934	3,093,880	27°58'06"N	92°02'42"W	92
2	596,263	3,092,749	27°57'28"N	92°01'17"W	118
3	598,513	3,091,100	27°56'34"N	91°59'55"W	105
4	594,179	3,089,776	27°55'52"N	92°02'34"W	104
5	598,452	3,094,022	27°58'09"N	91°59'56"W	
Sackett					
1	249,314	3,161,633	28°37'52"N	89°33'51"W	83
2	250,482	3,170,740	28°38'27"N	89°33'09"W	84
3	250,156	3,131,029	28°38'38"N	89°33'21"W	86
4	251,148	3,170,342	28°38'16"N	89°32'44"W	85

transmissometer in the water for calibration, then hand lower it to the bottom and raise it back to the surface. Transmissivity values and depth were logged automatically on magnetic tape and printed on fan fold strips by the EDP every second, but were also read and written down every meter of depth on the way down. These data were used to determine the depth and number of the 30 l Niskin bottles to use in section two. Then the STD was placed in the water for calibration, hand lowered to the bottom and raised back to the surface and taken out. Salinity, temperature and depth also were logged by the EDP and by hand. The profiling current meter was lowered by winch in 10 m increments until it reached the vicinity of the bottom at which time the rate was decreased. At some stations the current meter was then lowered to a pre-selected depth and the readout monitored by one person for the duration of the station.

Water Samples

A transmissivity change near the bottom was an indication of the presence and thickness of a turbid layer at a station. The indicated thickness was used to determine whether one, two or three 30 l Niskin bottles would be deployed at the bottom of the hydrocast for water samples. A Secchi disc was used to determine the depth of the photic zone. After these parameters had been set, a cast was made consisting of the 30 l Niskin(s) and two 5 l Niskins: one at the surface and one at one-half the photic zone depth. After retrieval, subsamples were

taken from the two 5 l Niskins and the bottom 30 l Niskin for dissolved oxygen, nutrients and low molecular weight hydrocarbons. Approximately one liter subsamples were also taken from the 30 l Niskins for size analysis of the suspended material after which the water was filtered for mineralogy determinations. A second cast was taken at each station consisting of two Nansen bottles (surface and near bottom) with reversing thermometers attached for calibration of the STD. This cast was the only water sample to be taken at secondary stations as well as primary.

Bottom Sediment Samples

After the water column work was finished, sampling with the Smith-McIntyre grab was started. The two "seasonal" banks, East Flower Gardens and Sonnier, required up to 10 grabs per station because of the infauna sampling while the three "summer" banks required only four. The first six grabs at a seasonal station were subsampled for sediment texture, then sieved using filtered, pumped seawater through 6.35, 1 and 0.5 mm sieves for macroinfauna. The seventh grab was subsampled using six cores for meiofauna, then subsampled for sediment texture, mineralogy, trace metals and high molecular weight hydrocarbons (HMWHC). Grabs eight through ten were subsampled for total carbonate, total organic carbon, del C^{13}, sediment texture, trace metals and HMWHC. Each grab was subsampled directly from the sampler before another sample was taken. The last sample taken was a gravity core, if required, after which the current meter was brought back on board and the anchor weighed.

Fish for Chemical Analyses

Snappers of the species *Lutjanus campechanus* and *Rhomboplites*

aurorubens were collected by hook-and-line at the banks at night at special stations. All specimens were labeled, double bagged in polyethylene bags, frozen, and delivered to be analyzed for trace metals and high molecular weight hydrocarbons.

PHASE III - SUBMERSIBLE CRUISE

Biological and geological descriptions were made on Bright, Bouma, Ewing, Parker, Sackett, Sonnier, 18 Fathom and East Flower Garden Banks. The submersible cruise, 77G10, was broken into two legs, the first of which left Galveston 9 September and returned 21 September. Leg II left 28 September and finished 1 October. Surface geology, epifauna and groundfishes were assessed visually using a submersible. Observations were documented on videotape and 35 mm color photographs. Sampling of epifauna was accomplished primarily through the use of the submarine's manipulator arm. Specimens were either frozen or preserved in 10 percent buffered formalin or 95 percent ethyl alcohol. Epifauna and groundfish samples are listed in Table II-2 of Appendix A. In addition, bottom water currents around East Flower Gardens Bank were observed by recording dye emission patterns from the submersible.

SUBMERSIBLE

The submersible utilized during this project was the DR/V DIAPHUS owned and operated by Texas A&M University, Department of Oceanography. It was built by Perry Submarine Builders, Riviera Beach, Florida in 1974. This vessel is 6.04 m in length with a 265.8 m depth capability. The DIAPHUS carries one pilot and one observer on a 180 man hour life support capacity. The pilot controls the progress of the submersible while looking out of a conning tower, while the observer and all photographic equipment utilize the forward

91.4 cm hemispherical viewport.

For all sampling purposes this submersible was equipped with a four position hydraulic manipulator arm and a wire mesh collection basket. Bottom sediment samples were taken utilizing a small scoop type sampler constructed of 6.35 cm clear Lexan pipe. For the dive at the brine pool location on the East Flower Garden the submersible had an additional system added which included a temperature probe and hose attached to the manipulator arm. The hose was then run through the submersible bulkhead and valved so that water samples could be collected in situ.

For photographic purposes the submersible was equipped with the following cameras and lights:

A Benthos Model 3980 flood light was utilized for all photography when available light was too low for photographic use.

A Burns and Sawyer 175 watt spot light for general lighting and photography.

A Sony Video system was utilized for general documentation on all dives. This system consisted of an AVC 3400 T.V. camera, an AV 3400 T.V. recorder and a 18 cm monitor. Power for the system was supplied from the main batteries of the submersible. The camera, aimed through the main viewing port, was mounted on a bracket although it was easily detached for hand held use (See Appendix A, Table II-3).

A Bauer Royal 8 E Makro Super 8 mm movie camera was also utilized on most dives. This camera had a time lapse rate of 1 frame/second and was bracket mounted. The film utilized was Kodak Ektachrome EF 7242, film speed ASA 160.

Hand held 35 mm photos were taken with a Nikon FTN and 55 mm lens. The films used for this camera were Kodachrome 64, KR 135-36, film speed ASA 64, and Kodak Ektachrome, EH 135-36, film speed ASA 160 (See Appendix A, Table II-3).

Submarine Transects

Submarine transects were selected at each bank on the basis of topography and geological sampling. After launch , the submarine proceeded on the surface to the desired dive site and submerged. Upon reaching the bottom it followed a predetermined course using the gyrocompass. Tracking of the submarine from the anchored ship was accomplished by taking visual bearings and radar ranges on a two foot diameter tether buoy attached to the submarine by a light polypropylene line. In sea conditions not favorable to radar, a 4.3 meter rubber ZODIAC boat was sent to the position of the tether buoy to provide a larger "target" for the radar. Course corrections were conveyed to the submarine from the ship through the underwater telephone (UQC). A maneuvering board plot of the submarine's position relative to the stationary ship was kept during each dive. Dives made using the DR/V DIAPHUS are summarized in Appendix A, Table II-4.

PHASE IV - MONITORING OF THE EAST FLOWER GARDENS BANK

SCIENTIFIC DIVING

Self contained underwater breathing equipment (SCUBA) was used on the shallowest parts of the East Flower Garden Bank. During SCUBA dives, observations were documented photographically using a NIKONOS II underwater camera and SUBSEA strobe light. Divers selectively gathered certain biological specimens.

TIME LAPSE PHOTOGRAPHY

Four long term time lapse camera systems (LTTL) were designed for continuous monitoring of selected locations in the vicinity of the study site. A 35 mm Canon AE-1 still camera equipped with a Canon Powerwinder and 50 mm lens was used in each system along with a Minolta XL-400 Super 8 mm movie camera. These cameras have automatic metering which assured accurate remote exposures. The systems were designed to remain in the field for 60 days. The Canon AE-1 exposed one frame every 48 hours, enabling a roll of 36 exposure Kodak Kodachrome 64 color slide film to last a maximum of 72 days. The Minolta XL-400 was set in the "single frame" mode and an exposure was taken every 30 minutes. A roll of Kodachrome 40 Super 8 mm movie film contains 3600 frames, more than enough to last 60 days at this exposure rate. The subject-to-lens focal distances were predetermined according to the selected site.

The timing of the exposures was controlled by eight intervalometers, one for each camera in the 4 systems. These intervalometers, adjustable from 1 minute to 99 hours, were designed and built by Mr. Paul Boatright of Oceanography International Inc., College Station, Texas. The intervalometers triggered the Canon AE-1 cameras via a solenoid plunger attached to a cable release which was mounted over the shutter release button. The intervalometers activated the Minolta cameras through an electrical contact. The duration of activation of the intervalometers is adjustable from less than one second (for single frame exposures) to approximately 15 seconds. The units are each powered by 4 Gates model 0800-0071 6 volt, 5 amp-hour rechargeable batteries

wired in parallel, giving a total of 6 volts and 20 amp-hours. The intervalometers were designed to require 7-10 amp-hours over a 60 day period.

The cameras, intervalometers and battery packs were mounted on a tray which was designed to slide into an underwater housing. This housing was made from 10" 6066-T aluminum alloy seamless pipe. This alloy is commonly used in marine equipment because of its corrosion resistant properties. A half-inch plate of this alloy was welded onto one end of the cylinder. The o-ring sealed viewport was fabricated from 1" plexiglas. An organometallic polymer (OMP) was painted on as an optically transparent anti-fouling agent. This material was given to us by the Department of the Navy, Naval Ship Research and Development Center, Bethesda, Maryland. The OMP was very effective for approximately 6 weeks at the thickness which it was applied. After this period, slow deterioration of its effectiveness was evidenced by thin diatom films beginning to accumulate on the glass.

Tripods to accommodate the camera housings were fabricated from 2" iron pipe. The legs were adjustable by sliding a 1.5" pipe up into the 2" legs of the tripod and locking them in position with a set screw. Twenty pound lead rings were fitted onto the legs to add weight and increase stability. The housings were attached to the tripods by two chains which cradled the cylinder. A Galvalum-III sacrificial anode was affixed to the rear leg of each tripod to inhibit the corrosion of the entire system. It also added weight. The anodes were obtained from Cathodic Protection Services, Houston, Texas.

The LTTL systems presented several functional difficulties. After evaluating the first set of 35 mm photographs taken over a 60 day

period, we concluded that 2 of the intervalometers had not functioned on a precise 48 hour schedule. The units were all turned on at 1200 hours to insure maximum sunlight for all exposures. Two of the sets showed sequences of exposures where every third frame would be well exposed and the other two would be too dark, indicating the exposure was taken at night. This showed that the timers were out of synchronization. The other two systems showed all frames well exposed. The units could not be deployed until the 2nd cruise (August, 1977) due to a problem with the 35 mm camera shutter release system.

To ascertain changes in the corals as subtle as we now know them to be, fine photographic resolution is required. The first set of photographs demonstrated that these systems were unable to obtain this resolution. The 4 LTTL cameras were originally trained on (1) Colpophyllia sp. head which harbored white epithelial pigments, (2) an artificially damaged area on a Montastrea cavernosa head, (3) a knoll of Madracis sp. interspersed with growths of soft algae, and (4) an area selected to monitor fish activities. Due to the questionable accuracy of the intervalometers, it was difficult to date events seen on the photographs. However, the systems recording the damaged M. cavernosa head and the Madracis sp. algae knoll both appeared to operate accurately. They recorded the shifts in their orientation, presumably caused by the passage of two hurricanes in late August and early September as occurring approximately 14-16 days after their deployment. This agrees with the actual time between their deployment and the hurricane. After discovering the disorientation of the cameras on the September, 1977 cruise, we relocated them at their original position.

Short term time lapse (STTL) systems were also used during the study. These systems consist of a Minolta XL-400 Super 8 mm movie camera in an Ikelite housing. A Vivitar Model 102 strobe unit, in another Ikelite housing, was connected to the camera. A 6 volt dry cell battery was wired into the strobe to supply the extra power necessary to provide the required number of flashes. Both housings were then attached to a tripod. The camera's built-in intervalometer was set to expose one frame every 24 seconds. The STTL systems operate over a 24 hour period. However, we generally set the cameras out during afternoon dives and picked them up on the following morning dives, concentrating on nocturnal periods.

The STTL systems functioned satisfactorily. The only difficulties encountered involved focusing and orienting the camera on the required subject. Occasionally the tripod would slip during the session and consequently disorient the camera. However, overall the system worked well. Data gathered on nocturnally active grazing organisms and coral behavior using STTL systems proved quite valuable and are discussed in greater detail in the following sections.

SELECTED PHOTOGRAPHIC STATIONS

Twenty specific subject stations were selected for repetitive, seasonal photography to generate data on variations in rates of coral tissue regression, mortality and growth on the reef. These sites were established on the June, 1977 cruise and all were located in the vicinity of the BLM Reef Monitoring Site (see Figure VII-1a). Three additional stations were added during the September, 1977 cruise to monitor the fate of three coral heads apparently affected by the passage

of hurricanes Anita and Babe.

These stations were marked by placing a galvanized spike as near to the area of interest as possible without disturbing live coral tissue. A small float was then numbered appropriately and attached to the marker nail by a short length of nylon cord.

Nikonos underwater cameras fitted with 35 mm lenses were used with Subsea Products Mark 50 strobes to take the photographs. Kodak "Kodachrome 64" color slide film was used. To insure a constant focal distance from subject to camera for each photograph, a 1.2 m x 0.3 cm aluminum rod was attached to the camera bracket. The end of this rod could be gently placed on the substratum and the picture taken. To facilitate the location of each site and insure that the repetitive pictures at each site were taken at approximately the same orientation on each trip, black and white prints were made from the slides taken on the June cruise. These prints were laminated into an underwater book to be used on location by the photographer. A map was also made on underwater paper which was carried by the photographer to locate the sites. It is appropriate to mention here that underwater time at 26 m depth is one hour per diver per day maximum. Therefore, maximum efficiency must be obtained when working at these depths. On each cruise, every effort was made to locate and photograph each of the study sites. However, occasionally one to several were missed on a cruise. On the March 1978 cruise, only 12 stations were photographed. Hazardous conditions such as high seas and the presence of large predatory sharks dictated that this effort be terminated prematurely. The results of these photographic stations are given in the Appendix at the end of Chapter VII.

The same Appendix gives the results of a set of photographic stations located at two additional sites, designated CSA-A and CSA-B, on the East Flower Garden Bank. These two sites were established in September 1977 as a part of an environmental impact report for Mobil Oil Co. by Continental Shelf Associates, Inc. Similar techniques were used to mark and photograph the individual sites, except that a Nikon F Camera was used with a Nikon 50 mm macro lens, all in an underwater case. Kodak "Kodacolor 100" color slide film was used. This camera-film combination yielded much more satisfactory results than the system used on the BLM monitoring stations.

CHAPTER III

MEASUREMENTS WITHIN IN WATER COLUMN

PART ONE

CURRENT MEASUREMENTS AND DYE DIFFUSION STUDIES

Principal Investigator

David W. McGrail

Contributors

David Huff
Stacy Jenkins

PURPOSE

The research described in this section was designed to provide a definition of the "nepheloid layer" as it exists on the Texas continental shelf. That is, the purpose of the study was to develop an understanding of the constituents of the layer, why it occurs where it does, and what causes its variability in time and space. In order to accomplish this goal an investigation was launched to study the processes which initiate and modify the turbidity in the shelf waters.

The work carried out under this contract consisted of three integrated parts. Foremost among these parts was the seasonal monitoring of temperature, salinity, transmissivity and current structure around the East Flower Garden Bank. This provided valuable, however sparse, information on the long term variability of the measured parameters. The second part of the study, carried out during the September seasonal sampling cruise, was the dye emission study. This was accomplished from the submersible DR/V DIAPHUS using a 3 m high dye emitting stand emplaced from the R/V GYRE. Its purpose was to examine the short term phenomena, such as turbulence, and their relationship to the turbidity in the water column. The third part of the work was comprised of a single visit reconnaissance of Sackett, Bright, Parker and Sonnier Banks. At each of these banks at least four stations were occupied to measure the distribution of temperature, salinity, transmissivity and current velocity with respect to depth. The third portion of the study provided, therefore, a measure of the spatial

variability of the measured parameters.

SIGNIFICANT FINDINGS

It is quite clear from the work done this year that the nepheloid layer is an integral part of the bottom boundary layer (BBL). The amount of suspended sediment and its penetration height above the bottom is a function of the local sediment type and the intensity of the turbulence present, and degree of stratification of the water column. The reason for this relationship is rather straightforward.

When water flows over a bounding surface, it adheres to the surface by means of molecular friction (viscosity). This produces a very thin layer near the bounding surface in which there is a sharp velocity gradient wherein the velocity drops from the mean speed of the flow to zero at the bottom. The adherence to the bottom causes a momentum transfer to the material on the bottom in the form of tangential stress. That is, the flow pulls on the bottom material in a plane parallel to, and in the direction of, the flow. If this shearing stress exceeds the shear strength of the bottom material (sediment in the case of interest) the flow will cause erosion and begin tearing pieces of material from the bottom. Viscosity is, however, an inefficient mechanism for momentum transfer in water and laminar flow (nonturbulent) is rarely capable of exerting sufficient stress on the bottom to cause any erosion.

As a matter of fact, laminar flow is rarely, if ever, observed in the marine environment. Rather, the adherence of the water at the bottom causes deformation of the flow over the bottom leading to the

formation of turbulent eddies in a layer above the bottom which is thicker than the laminar boundary layer.

These eddies carry high velocity water from relatively high up in the water column down on to the bottom thereby transferring momentum with orders of magnitude more efficient than mere molecular attractions. Turbulent boundary layers are, therefore, much more efficient in applying sufficient stress on the bottom to erode the sediment and entrain it in the flow. The height to which the sediment can be lifted depends on the intensity of the turb lence and its vertical distribution. As long as the upward flowing limb of a turbulent vortex applies a greater force to the sediment than the acceleration of gravity, the sediment will continue to rise. So the penetration height of the sediment depends on the frequency of occurrence of upward flowing vortex limbs and the vertical velocities they possess.

If intensity of turbulence were directly related to the velocity of the mean flow, the job of the sedimentologist would be simple. He would merely have to measure the bottom stresses exerted by flows with various velocities and the shear strengths of various sediments in order to know whether the sediment would be eroded and how high above the bottom it could be carried if it were eroded. Unfortunately there is no direct relationship between the mean current velocity and intensity of turbulence. Things such as bottom roughness, presence or absence of stratification, water temperature, superposition of waves on the mean flow, and history of the flow all influence the intensity of the bottom turbulence.

It was found that at all of the banks stratification played two important roles. In the first place, it caused the extinction of

turbulence outside of a thin (5 m - 20 m) boundary layer. This could be seen from the existence of a layer mixed with respect to temperature and salinity which extended from the sediment/water interface up to the onset of a sharp thermocline. In stratified waters the turbulent eddies must do work in displacing waters of different densities as they transport momentum. When the eddies are sufficiently intense to cause the displacement, the water becomes homogenous with respect to temperature and salinity. Away from the bounding surface, the eddies are less intense and reach a point where they can no longer mix the water. At stations where both turbidity and the mixed layers were present, the turbidity did not extend above the mixed layer. The reason is quite clear ; the extinction of turbulence by the stratification precludes the transport of sediment up beyond the top of the mixed layer.

At some stations near the banks there were isolated spikes of turbidity and mixed layers separated from the bottom mixed layer by clear, stratified waters. This is related to the second effect of stratification. In this case the top of the bank represents a new bounding surface well up in the stratified waters. Rapid flow over the bank leads to the formation of a narrow mixed layer. More importantly the presence of the bank induces internal waves much akin to the riffles that form over rocks on the bottom of a fast flowing stream.

These internal waves have very little surface expression, but rather, are manifest in the vertical displacement of isotherms and presence of a layer at the height of the bank where the velocity undergoes minimum and maximum inflections. Where the waves impinge on the bottom they stir up the sediment and it becomes entrained in the flow over the bank. The sediment appears as a spike in the trans-

missivity profile on the downstream side of the bank in such a case. This was observed at the East Flower Garden Bank particularly.

Topographic excitation is only one way that internal waves are generated on the continental shelf in the Gulf of Mexico. Some appear to have a tidal origin. These are caused by break up of the barotropic tide on the shelf edge. The waves of this type seem to travel as packets with large amplitude, relatively low frequency waves at the head of the packet and low amplitude, high frequency waves at the tail of the packet. These waves affect the whole water column and contribute large quantities of turbulence to the bottom boundary layers. This, in turn, leads to intermittent suspension of dense clouds of sediment as the waves pass over the bottom.

IMPLICATIONS FOR MANAGEMENT

The nepheloid layer is a transient feature in a state of almost constant change. It does, however, represent sediment trapped near the bottom by stratification of the water column. An artificial turbid layer such as the effluent of drilling mud from a rig could be expected to behave in much the same manner. That is, once shunted to the bottom it would be unlikely to rise again to the level of the living reefal communities on the East Flower Garden or other banks. Dumped on the surface, this effluent might travel long distances before sinking to safe depths. The variability of directions and speed of the surface currents suggest that it is unwise, therefore to permit surface dumping near these banks.

DATA ANALYSES AND INTERPRETATIONS

East Flower Garden Bank Monitoring and Boundary Layer Experiments

Studies at the East Flower Garden Bank dealing with currents and suspended sediment were comprised of two complementary portions, a seasonal monitoring program and a set of short term, *in situ* boundary layer experiments.

The seasonal monitoring effort at the East Flower Garden consisted of 3 cruises to the Bank. On each cruise, profiles of temperature, salinity, transmissivity and velocity were to have been obtained at 4 primary and 8 secondary stations distributed around the bank as shown in Figure III-1. This sampling was done in June and September, but on the first station of the February cruise, the winch for the profiling current meter system seized, preventing acquisition of any velocity profiles. The other parameters were measured but because of the importance of the velocity profiles, a second effort was made to obtain all of the data again in March. All 4 primary stations were profiled completely before the gasoline engine on the current meter winch failed utterly. In spite of the loss of velocity data for the winter season at the 8 secondary stations, considerable information about, and understanding of, the physical processes controlling currents and sediment dispersal in the vicinity of the East Flower Garden Bank were gained during this work.

Conditions Observed During June

Salinity Distribution

Salinity data, because of its constancy, provided very little

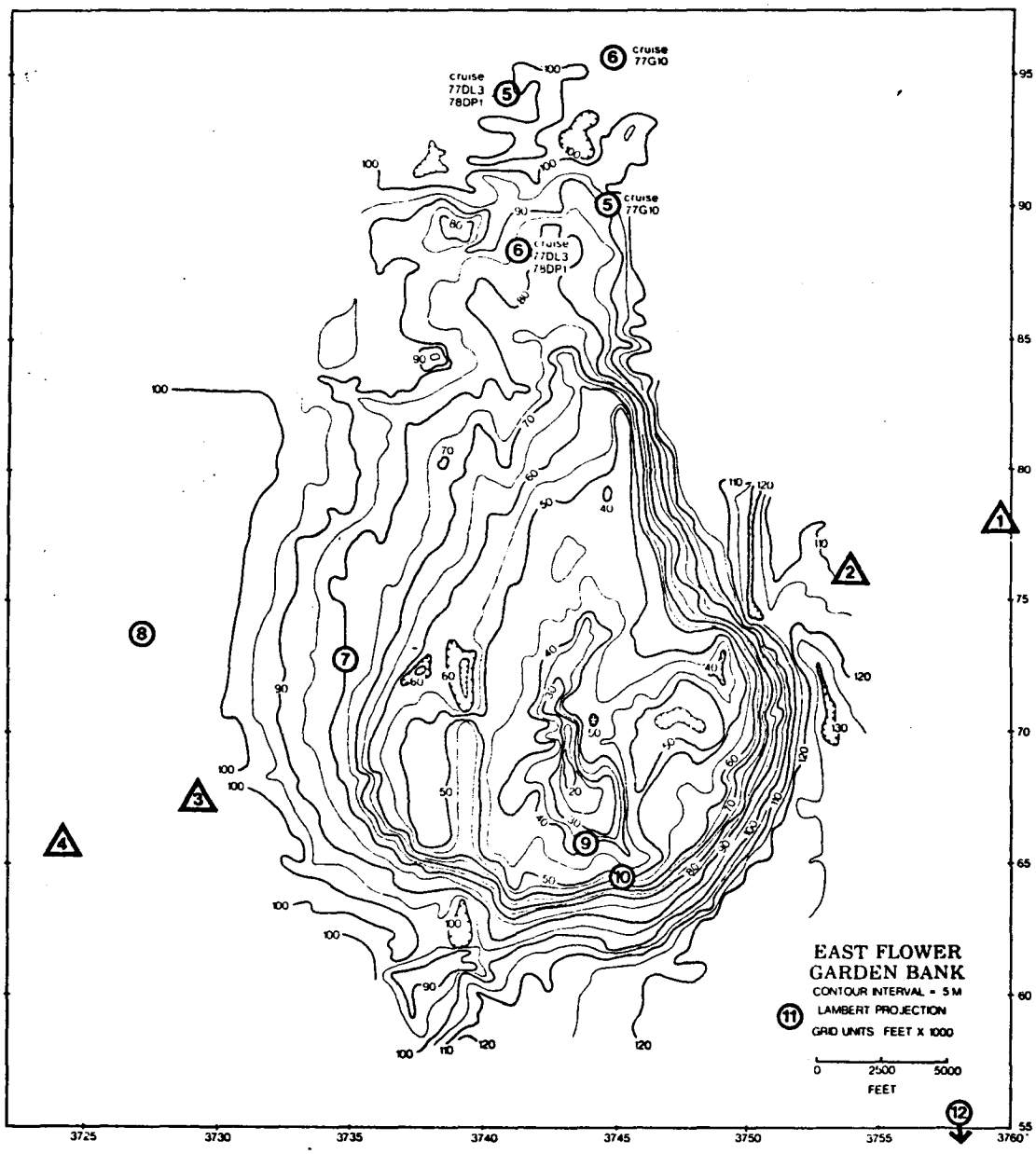

Figure III-1. East Flower Garden Bank with station locations. Triangular symbols represent primary stations, circles represent secondary stations.

useful information regarding the dynamics of the flow in the vicinity of the East Flower Garden Bank in June. The total salinity range over all stations was from 35.55% to 36.64%. The variation in density accounted for by the salinity gradient at any given station constituted substantially less than 10% of that induced by temperature differences. Salinity data for this period are therefore presented in Appendix A, Table III-1 without further discussion.

Temperature Distribution

The data at all 12 stations were to have been collected over a short period so that a quasisynoptic picture of the conditions at the bank could be developed. In June however, problems with equipment and weather intervened and the data were collected in three batches. Station 1, 5 and 6 were occupied during the period from the 10th through the 11th of June, Station 2 was occupied on the 14th of June and the remainder of the stations were occupied between the 16th and 18th of June. Rather than diminish the value of the data, this temporal distribution of the sampling afforded the opportunity to observe the response of the water column to the passage of a small storm and its subsequent recovery from the storms effects.

Prior to the storm, the upper unit of the water column consisted of a layer ≈ 15 m thick possessing a weak thermal gradient from ≈ 28°C at the surface to ≈ 27.2°C at the base. This was an unusual condition since even light winds ordinarily mix the surface waters sufficiently to create a thin isothermal layer. The existence of the gradient at the surface is probably a Spring phenomenon. During this period there is a very large differential between

atmospheric and oceanic temperature and it appears that heat conduction through the interface slightly exceeded the convective mixing from wind induced turbulence.

Prior to the occupation of station 2 a late Spring storm moved over the East Flower Garden Bank producing strong local winds and seas in excess of 2.5 m. This vastly increased surface mixing and rendered the upper water column isothermal to a depth of 18.4 m. It also reduced the surface temperature to 27.5°C. By the 16th of June, when station 3 was occupied, the surface temperature had increased to 27.84°C and the weak thermal gradient had been reestablished. This gradient persisted throughout the remainder of the June sampling period.

Below the surface layer, the water column was characterized by a strong thermocline with a vertical gradient of approximately 0.16°C/m. Though the thermocline exhibited considerable variability in thickness from station to station, at most stations it terminated between 40 m and 60 m. This depth range corresponds to that of the major breaks in slope on the East Flower Garden Bank.

Profiles of the water column beyond the base of the thermocline exhibited a variety of structures from nearly isothermal at some stations to stairstep-like units at others. At the base of almost every station was an isothermal layer created by turbulent mixing in the boundary layer.

Transmissivity

Transmissivity is an indirect measure of the amount of suspended particulate material in the water column. During June, the

upper 60 m of the water column were remarkably free of suspended particulates by this measure. The surface waters registered 80% transmissivity or more indicating that a minimal amount of planktonic biota were present at that time. Below 10 m the transmissivity generally increased to ≥ 85%.

At most stations there was a slight increase in turbidity around 55 m to 60 m as shown by a decrease in transmissivity from 85% or more to 80% or slightly less. Station 3 on the southwest side of the bank possessed a strong isolated spike in transmissivity with a reduction to 63% at approximately 60 m. The suspended particulates causing the reduction in transmissivity at this location appear to have washed off the surface of the bank because measured flow at that depth was to the west-southwest. A very much attenuated diminution of transmissivity occurred at the same depth in station 4. This suggests that either most of the material had come out of suspension at that distance from the bank or the mean flow direction had changed since measured flow at 60 m was to the northeast in station 4. An isolated turbid layer was also found between 63 m and 80 m at station 5. Flow between 60 m and 70 m at station 5 was to the northwest, again suggesting that the particulate material was being transported off the East Flower Garden Bank, as can be seen from Figure III-1.

Isolated layers of increased turbidity were also observed at stations 11 and 12 but these occurred below 80 m and were associated with isolated flow ranging in direction from south-east to southwest. Again this suggests that the bank is the source of the suspended material. These particular turbid layers were also isothermal (see

Appendix A, Table III-1).

At the base of the transmissivity profile of every station there was a decrease in transmissivity in a relatively thin layer adjacent to the bottom. In most stations the turbidity did not reduce transmissivity beyond 70% indicating rather low concentrations of suspended particulates. A true nepheloid layer, characterized by a nearly logarithmic decrease of transmissivity with increasing depth to values of 50% or less, occurred at only three stations, 1, 2, and 5.

At station 1 (Fig. III-2) the inflection point in the transmissivity profile marking the top of the nepheloid layer occurred at 82 m. This corresponded exactly with an inflection in the temperature profile marking the transition from a moderate gradient of 0.036^{o}C/m to very weak gradient of 0.008^{o}C/m. From 83 m to 91 m the transmissivity gradient was 3.1%/m. Between 91 m and 100 m the transmissivity gradient decreased to 1.02%/m then increased below 100 m to 3.1%/m once again. The inflection in the transmissivity profile at 100 m corresponded in depth with the point at which the temperature profile became completely isothermal and probably represents the top of the active boundary layer.

The transmissivity profile in the nepheloid layer at station 2 (Fig. III-3) was found to be a complex series of irregular steps terminating in a 6 m thick layer which was well mixed with respect to turbidity. Between 75 m and 91 m the transmissivity decreased from 88.5% to 81.0% in 3 distinct steps. The real top of the nepheloid layer, marked by a drop in transmissivity of 6% in less than 1 m

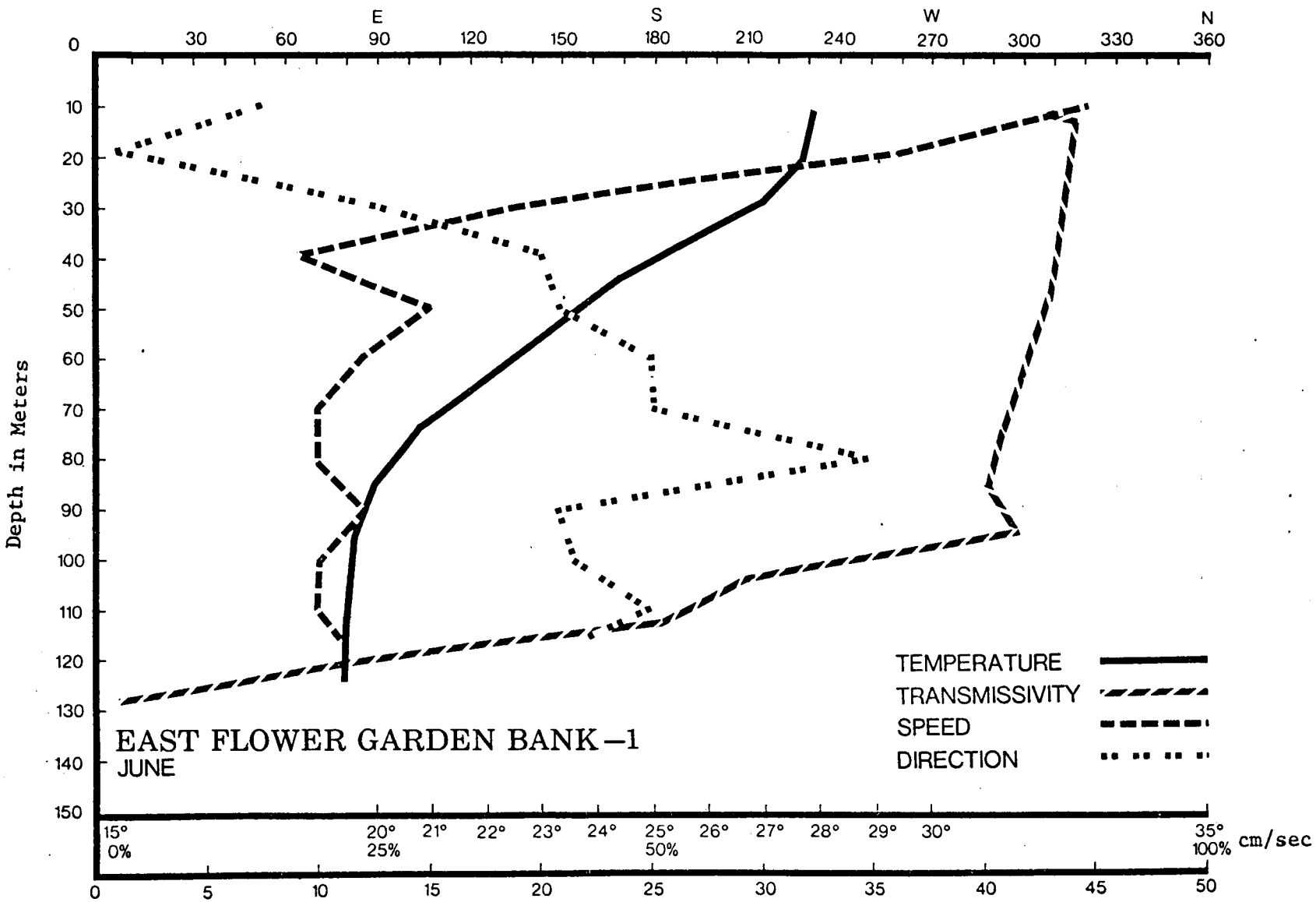

Figure III-2. Superimposed vertical profiles of temperature, transmissivity, and current velocity at station 1.

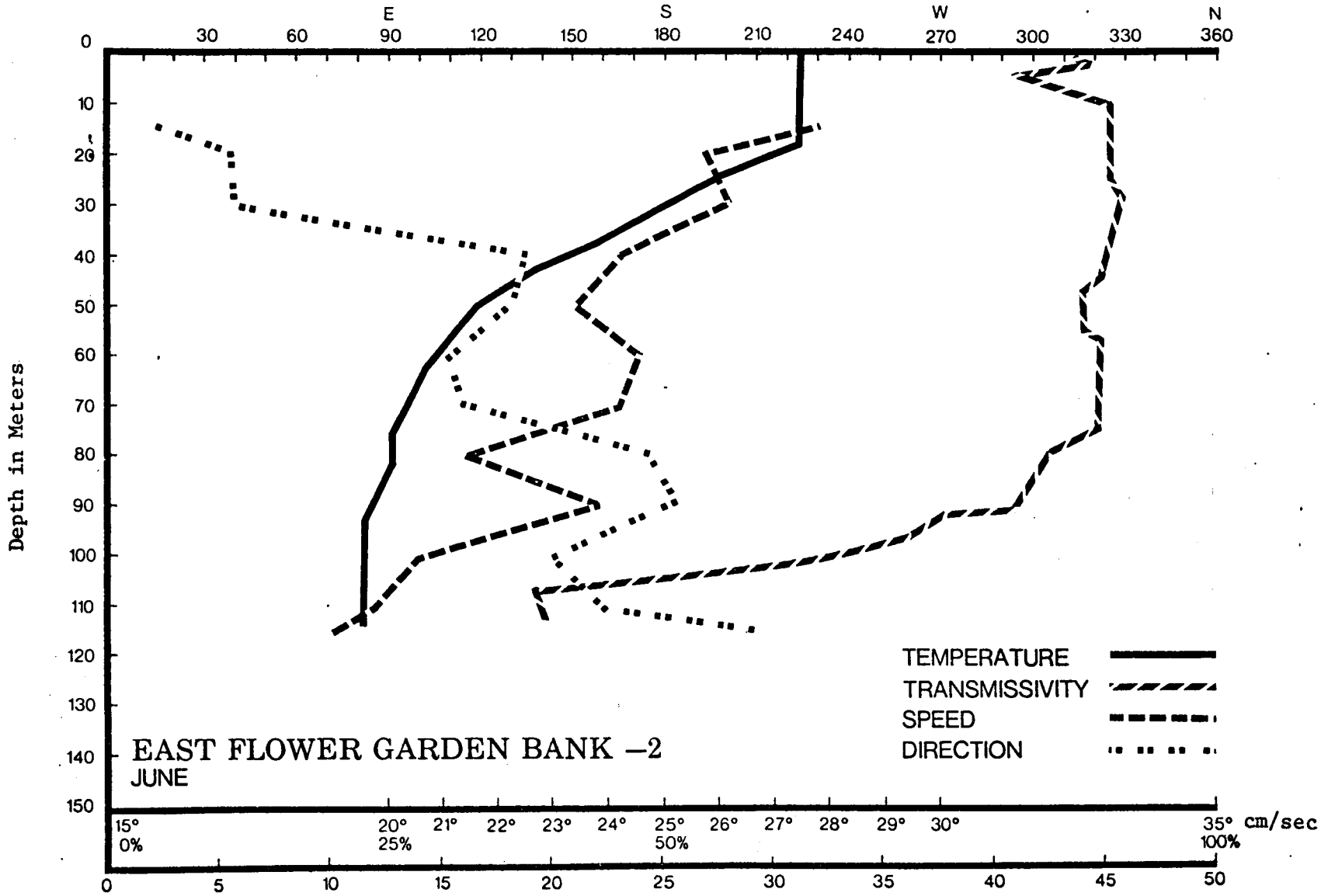

Figure III-3. Superposition of temperature, transmissivity and velocity profiles at station 2.

coincided in depth, 91 m, with the top of a completely isothermal layer at the base of water column. The structure of the transmissivity profile within the isothermal layer suggests that the process responsible for mixing the water with respect to temperature was no longer acting uniformly throughout the layer. If it had been, one would have anticipated a uniform, monotonically decreasing transmissivity gradient all the way to the bottom. This profile may represent material coming out of suspension after the previously mentioned storm.

The profiles from stations 3 and 4 (Figs. III-4 and III-5) are shown for contrast. Notice that the weak turbid layer (minimum transmissivity > 70%) at station 4 coincides in depth and thickness with an isothermal layer at the base of the water column. Similarly, the bottom nepheloid layer at station 5, though stronger (minimum transmissivity < 50%), also coincides with a thermally mixed layer at the base of the water column. The transmissivity profile at station 5 also resembles that at station 2 in that it does not decrease all the way to the bottom but rather reaches a minimum approximately 4 m above the bottom, then becomes constant with increasing depth.

Velocity Distribution

Vertical profiles of the current velocity were made at each station by means of a savonius rotor and vane type instrument. This was lowered in 10 m increments starting at 10 m below the surface and proceding to the lowest metre of the water column. The profile was not started at the surface because of the magnetic influence of the ship and because of contamination of the velocity signal by surface

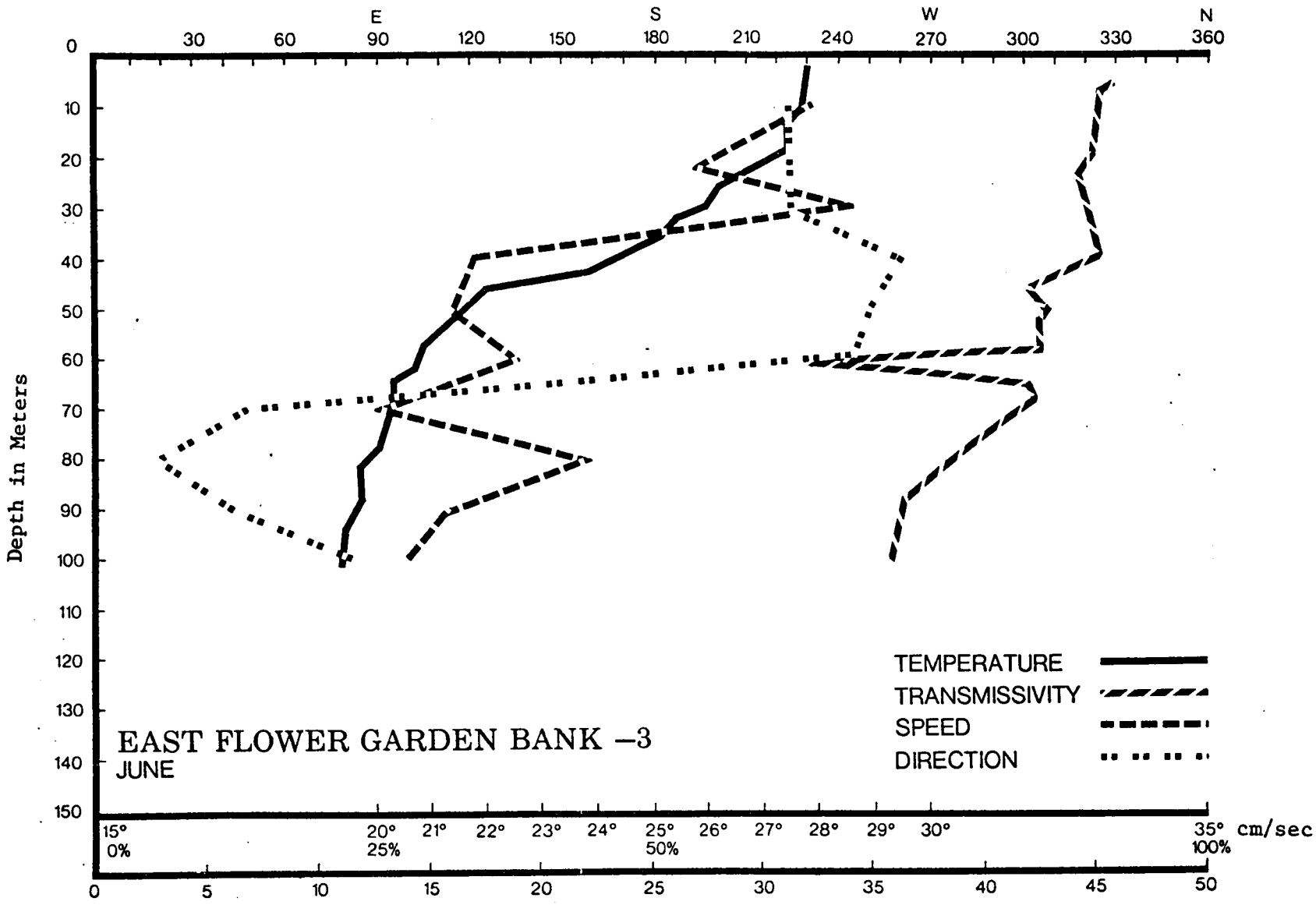

Figure III-4. Superposition of temperature, transmissivity and velocity profiles at station 3.

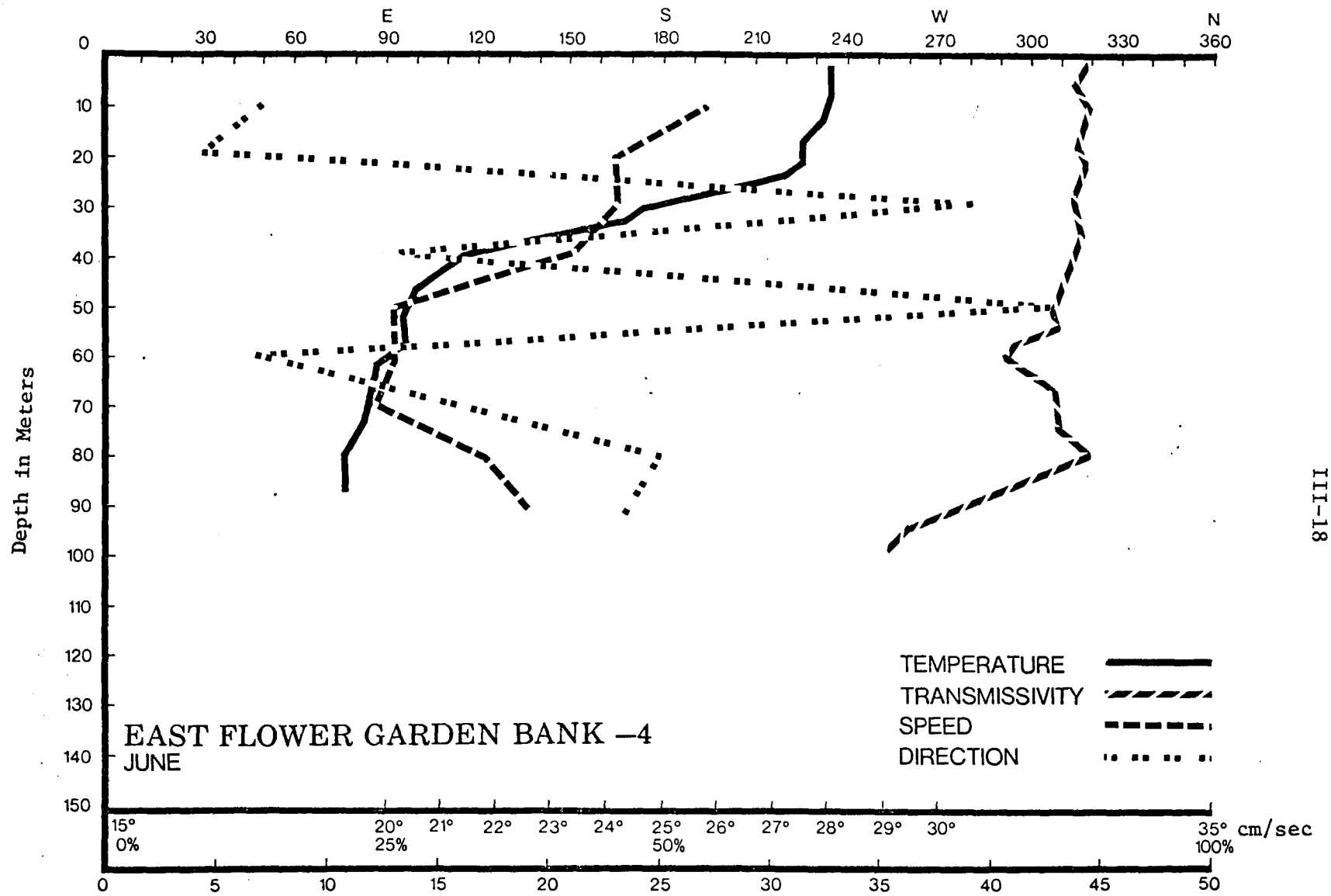

Figure III-5. Superposition of temperature, transmissivity and velocity profiles at station 4.

gravity waves.

The velocity structure of the water at the East Flower Garden Bank was highly variable in both time and space. For example, stations 1, 2, 4, 6 and 9 had currents at the 10 m depth flowing to the east or northeast at an average speed of 30 cm/sec whereas stations 3, 5, 10, 11, and 12 recorded flow to the west or northwest at an average speed of 24 cm/sec at that depth. The remaining two stations 7 and 8, recorded flow to the southeast at 27 cm/sec and to the southwest at 32 cm/sec respectively at the 10 m depth. Near bottom flow displayed somewhat more variability in both speed and direction as shown in Appendix A, Table III-1. The depth dependence of the velocity profiles and their clear relationship to subtle variations in the temperature profiles (Figures III-2 through III-6) indicate that the flow had a strong baroclinic component to it in June. That is, the currents were, at least in part, driven by pressure gradients set up by disequilibrium in the field of mass. If the currents had been principally barotropic, that is driven by elevation of the sea surface, the velocity would have been depth independent (constant with respect to depth) outside of the boundary layers at the surface and bottom. In these layers momentum exchange in the vertical direction caused by turbulence and molecular viscosity lead to steep velocity gradients. At the surface the flow must adjust to wind stresses and at the bottom the fluid adheres to the sediment reducing the velocity to zero at, or just below, the interface.

In addition to the profiles, short time series current measurements were made at several stations when time permitted. The longest

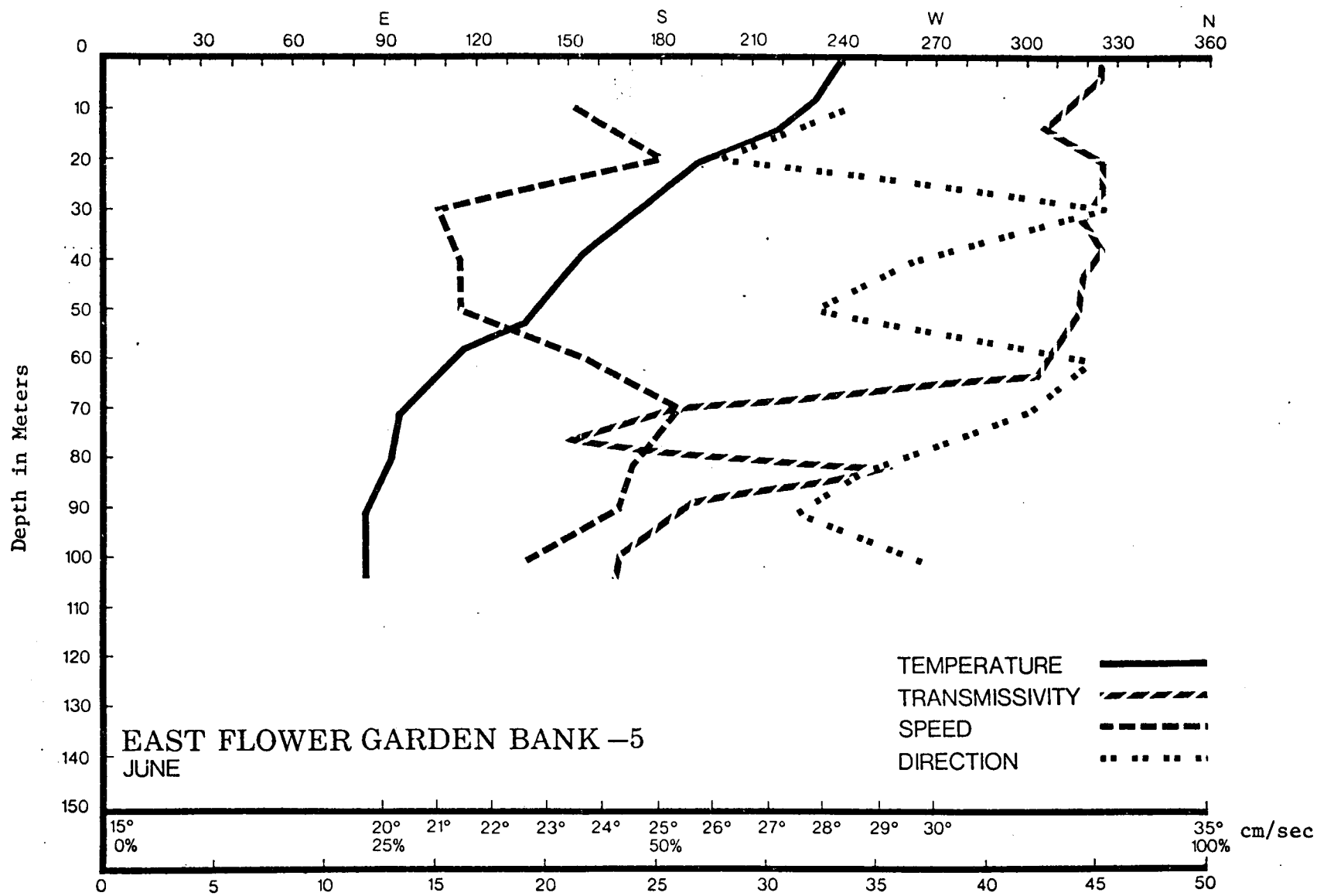

Figure III-6. Superposition of temperature, transmissivity and velocity profiles at station 5.

of the measurements were made at station 1 and lasted almost 2 hours. The current meter was suspended at a depth of 92 m throughout that period. In the initial profile, the velocity at 90 m was 12 cm sec^{-1} toward 150°. During the time series it varied from a minimum of 5 cm sec^{-1} toward 315° to a maximum of 43 cm sec^{-1} toward 265°. Over the nearly two hour period, flow was recorded in every sector except that between 316° to 44°. Most of the high velocity flow was toward the southwest (240°-260°) and most of the low energy flow was toward the south or southeast.

The interesting thing about these changes in speed and direction is that they were not completely random but rather occurred with some rythmicity. The peak to peak intervals ranged from 11 min to 27 min with an average of 17.8 min. This lies well beyond the longest period of wind driven surface waves and the observations were made well below the depth of influence of all but the most intense of storm waves.

It appears far more likely that these rythmic changes in the flow were caused by the passage of internal waves. These are waves that ride the density interfaces in the water column in analogy to the surface gravity waves that exist at the air sea interface. Since the density contrasts within the water column are much smaller than that between water and air, less work is required to displace internal interfaces so internal waves may have very large amplitudes. They also tend to have long wave lengths and low frequencies when compared to surface gravity waves. The highest stable frequency for an internal wave is its natural frequency. That is the frequency at which a parcel of water would vibrate about its equilibrium position if displaced.

This is the Brunt-Vaisala frequency given by

$$N = \left\{ -\frac{g}{\rho_o} \frac{\partial \rho}{\partial z} \right\}^{\frac{1}{2}} \quad \text{(Turner, 1977)}$$

where: g = acceleration of gravity

ρo = average density

$\frac{\partial \rho}{\partial z}$ = vertical density gradient.

For the average gradient at station 1 the Brunt-Vaisala frequency was 7.9×10^{-3} sec^{-1}. That translates to a period of 13.2 min which is very close to that of the observed oscillations.

At station 2 the current meter was suspended at 50 m. During the downcast the speed at 50 m was 21 cm sec^{-1} toward 130° and on the upcast it was 24 cm sec^{-1} toward 116°. The predominant direction of flow was toward the southeast. Again there was a rythmicity to the flow with speed variations peaking every 13 min to 17 min. The effect of the internal waves at station 2 appears to have been modulation of a rather steady southeasterly flow.

Evidence of the presence of internal waves in the other profiles lies in the multiple minima and maxima in the speed trace, particularly in the 40 m to 70 m range (Figures III-2 through III-6). It appears likely from this information that at least some of the internal waves were being locally generated through interaction of the flow and the topography of the East Flower Garden Bank itself.

It should be noted that in the only profile, station 1 (Figure III-2), which possessed a monotonic decrease in transmissivity all the way to the bottom, the current velocity was actually increasing toward the bottom. Such a condition would favor erosion through increased turbulence and upward diffusion.

Conditions Observed During September

Salinity Distribution

The small variations of salinity observed in September rendered that data as valueless in interpreting the hydrodynamics around the East Flower Garden Bank as the salinity data acquired in June. Therefore the vertical salinity measurements made in September appear in Appendix A, Table III-2, without further discussion.

Temperature Distribution

Though Hurricane Babe passed to the east of the East Flower Garden Bank only 10 days prior to the beginning of the September sampling cruise, there were no discernible features in the thermal data that could be attributed to the storm. This is surprising in view of the evidence of energetic flow and environmental stress that Dr. Bright reported from his monitoring studies at the crest of the bank, which were carried out during the same cruise. It would appear that either the effects of the storm were insufficient to have penetrated to very great depths or that the thermal structure of the water column was reestablished with surprising rapidity. Since the storm's closest approach to the monitoring site was never less than 125 nautical miles, the first explanation seems more plausible than the second.

In general, the waters around the bank were characterized by a nearly isothermal surface mixed layer with temperatures exceeding 28.5°C. This mixed layer extended to depths of from just less than

30 m to greater than 35 m. At most stations this isothermal layer gave way abruptly to a smooth thermocline with a strong gradient on the order of 0.26°C m^{-1} which extended down to between 40 m and 50 m. Below this depth there existed considerable station to station variability in the vertical temperature profiles. All stations possessed a decrease in vertical thermal gradient, but in some the decrease was marked by steplike breaks whereas in others it was marked by a slight inflection in the profile.

Unlike the June profiles, only station 3 exhibited a completely isothermal bottom boundary layer. This might be accounted for by a more northerly trend in the bottom flow at most stations which would bring cooler water up slope and maintain a gentle gradient even in the presence of turbulence. Significantly, the bottom flow at station 3 was to the southwest (195° True) at the time of station occupation.

The temperature distribution around the East Flower Garden Bank was contoured by station and appears in Figure III-7. No horizontal distances are implied by the station locations along the horizontal axis. The isotherms are dashed where the data were missing due to instrument malfunction. Where the data are present, however, it is obvious that there is a strong topographic response of the thermal field to the presence of the bank. The thermocline at the base of the mixed layer is evident in the close bundling of the isotherms in the range from 23°C to 28°C.

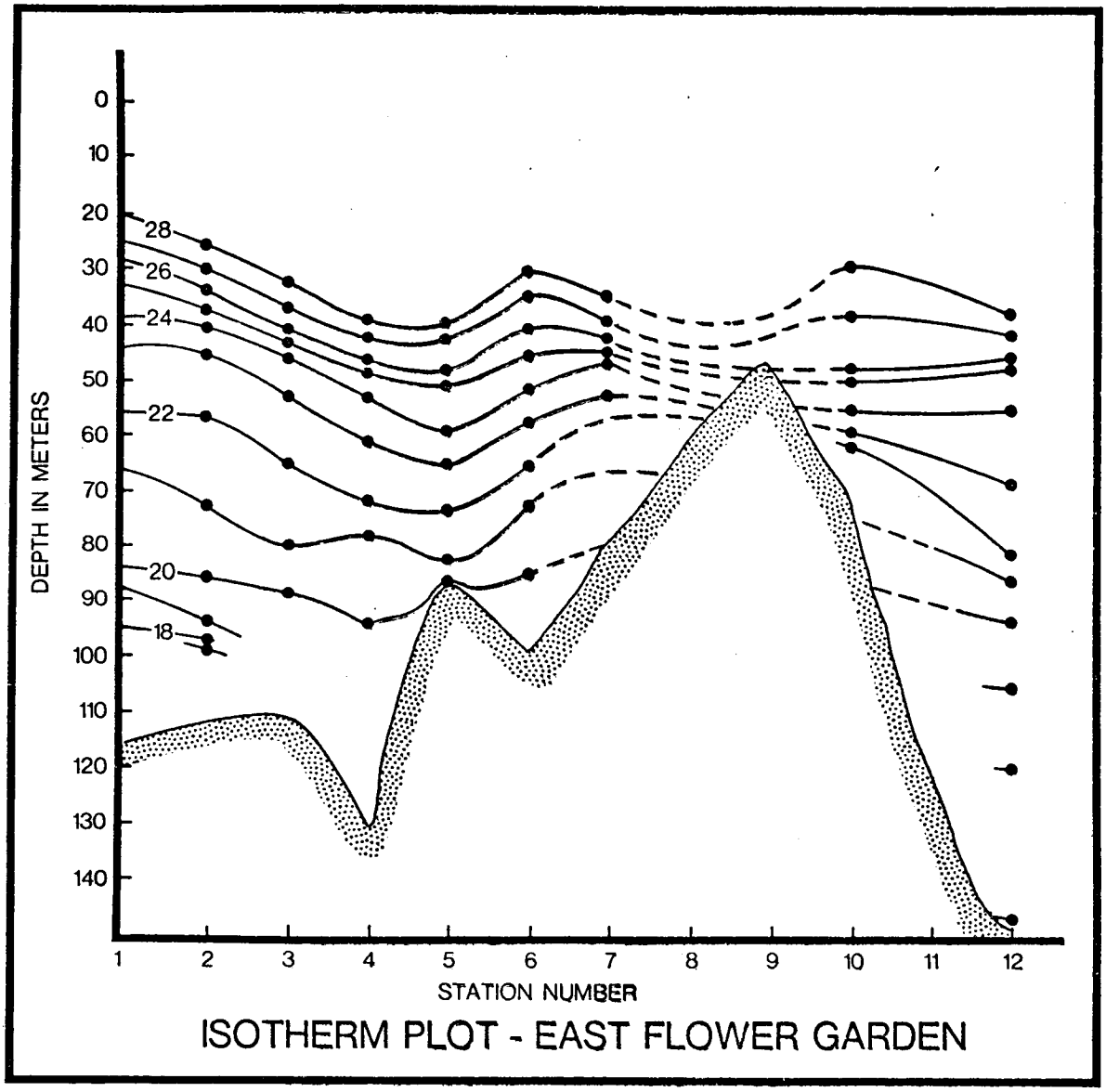

Figure III-7. Vertical distribution of temperature during September 1977. Stipled area represents bottom. Numbers along the horizontal axis are stations.

The step structures which appear in the lower portion of many of the stations' temperature profiles could reasonably be formed by two mechanisms. The steps may either have been formed as the water of that depth flowed over the surface of the bank indicating turbulent mixing or, they may have been formed as local patches, mixed by the breaking of internal waves over and around the bank. These patches of relatively mixed water would then have been advected along in the mean flow. Ample evidence for both causal mechanisms was observed in both the velocity profiles and boundary layer experiments.

Transmissivity Distribution

In addition to the change in the thermal structure at the base of the water column observed between June and September, there was a marked difference in the transmissivity profiles. Overall, the bottom water was clearer in September than in June with no significant nepheloid layer recorded at any station. This turned out to be somewhat misleading, however, because the first boundary layer experiment, located in just over 110 m of water near station 1, was characterized by an intense turbidity throughout its duration. The subsequent boundary layer experiments, though carried out in clearer water at shallower sites, also revealed considerable temporal variability in the amount of suspended material in the water column near the bottom.

There was evidence of near bottom turbidity at stations 1, 2, and 6, but the minimum transmissivity did not fall below 50%. As in

June, the uppermost portion of the turbid layer did, in no case, extend above 80 m.

At several stations there was a slight decrease in transmissivity between 40 m and 60 m on the order of 5% m^{-1} to 10% m^{-1}. This decrease appears to be correlated with the steplike structures in the temperature profiles. In view of that, and the direction of flow at 40 m to 60 m in those stations, it may reasonably be inferred that the increased turbidity arises from resuspension of detritus on the bank itself.

These variations in transmissivity were superimposed on a background level of 80% m^{-1} to 85% m^{-1} in the clearest waters.

Velocity Distributions

One of the shortcomings of taking velocity profiles is that it takes a finite amount of time to lower the instrument and record the flow. Variations in velocity recorded as a function of depth may in fact, therefore, be a partial function of time. This is particularly true in an energetic system. In order to gauge the extent to which this problem affected the velocity profiles taken in September, two checks were made. In the first, the temporal variation of the velocity at a fixed depth was measured at several locations and in the second, the velocities were recorded at selected depths on both the down and up cast. It was found that at Dive site 6, for example, the near bottom velocity varied from 4 cm sec^{-1} to 30 cm sec^{-1} in speed and from 110°T to 235°T in direction

over a two hour period. These variations were not completely random but occurred at a period of from about 9 minutes to 12 minutes. There was also a long term decrease in the mean speed from 16 cm sec^{-1} to 11 cm sec^{-1} over the two hours of observation. The comparison of downcast and upcast records indicated a similar scatter of data.

The value of this data, therefore, resides in the trends revealed by the whole set and in the relationship of the profiles to the thermal structure of the water column. It should not be viewed as either an instantaneous representation of the velocity distribution at each station or representative of long term conditions.

The most striking feature in the September velocity profiles is the presence of multiple speed maxima accompanied by large directional shears. The most prevalent oscillations in the current speed and direction bracket the strong thermocline between $\sim$ 30 m and 50 m. This structure of the velocity profiles, in conjunction with the quasiperiodic nature of the time series observations, confirm the presence of internal waves implied by the thermal structure shown in Figure III-7. The sharp local, vertical velocity gradients below the thermocline also serve to explain the steplike nature of some temperature profiles. Such intense velocity shearing causes the development of turbulence which, in turn, causes local mixing of the water column.

With few exceptions, surface flow observed in September was toward the east or southeast. Mid-depth flow was primarily to the northwest, but near bottom flow was highly variable in both speed and direction.

The general picture is that of a principally baroclinic long term flow field perturbed by internal waves in a rather broad frequency band from several cycles per hour to a few tenths of a cycle per hour.

Conditions Observed in February

A failure of the current meter winch on the first station of the February cruise precluded acquisition of any velocity data during this period.

Salinity Distribution

As in the June and September data, the uniformity of the salinity around the East Flower Garden Bank observed in February makes it of little value in interpreting the processes taking place. The salinity data may be found in Appendix A, Table III-3.

Temperature Distribution

The various stations exhibited considerable variability in the thickness of the surface mixed layer. This may be due to the passage of a cold front during the cruise, which was attended by high winds and heavy seas. At stations 1 and 2 (see Figure III-1 for location) the mixed layer, with a temperature of approximately 18.4°C, extended to approximately 75 m depth. From 75 m to ∿ 87 m there was

a weak thermocline at these two stations below which the water was rather well mixed with respect to temperature.

In contrast to the mixed layer of the first two stations, that at station 3 extended to 100 m and that at station 4 extended to ∿ 95m. These latter two stations are approximately the same relative distances from the bank as the first two and are in very nearly the same depth of water. It is presumed therefore that additional mixing caused by the storm experienced during the cruise caused this depression of the lower boundary of the mixed layer.

Stations 5 and 6 on the northern flank of the East Flower Garden Bank were completely isothermal to a depth of nearly 60 m. At station 5 the water between the bottom of the mixed layer and 82 m possessed an extremely weak thermal gradient. Between 82 m and 87 m a weak thermocline was observed which gave way to much more weakly stratified water which extended to the bottom. Within the lowest 2 m to 3 m of the station the water was isothermal. Below the mixed layer at station 6 the temperature profile exhibited a steplike structure. Between ∿58 m and 61 m there was a weak thermocline, between 61 m and 68 m the water was isothermal, and below that there was a second thermocline.

Stations 7 and 8, on the western side of the bank, exhibited a thicker isothermal surface layer. At station 7, located in 85 m of water, the mixed layer extended to within 5 m of the bottom. Below 80 m there existed only very weak stratification. The water was isothermal to a depth of 86 m at station 8 followed by a rather well developed thermocline from there to about 94 m. From 94 m to

the bottom at 107 m the water was very well mixed and suggestive of a bottom boundary layer.

Station 9 in 45 m of water and station 10 in just under 100 m of water were both isothermal top to bottom. Stations 11 and 12, which together with 9 and 10 form a southeastward trending transect on the southern margin of the bank, were well mixed from the surface to approximately 103 m. Below this depth station 11 was rather well stratified all the way to the bottom at 131 m. Station 12, on the other hand, exhibited a somewhat steplike thermocline between 103 m and 121 m where a bottom mixed layer was encountered.

Transmissivity Distribution

A nepheloid layer was observed at every station which was located in water of 100 m depth or greater but none was encountered at the shallower stations. As observed during both June and September, the top of the nepheloid layer did not extend above approximately 80 m. In some cases the turbid layer was trapped below the weak stratification but in others it extended up to the base of the surface mixed layer. The inference made here is that even during the winter, when stratification is at a minimum and local wind forcing is at a maximum, resuspension of the bottom sediment does not extend above 80 m in the vicinity of the East Flower Garden Bank.

Conditions Observed in March

Only the four primary stations were occupied in March because the gasoline engine on the current meter winch threw a rod on station 4 and the weather deteriorated to full gale conditions.

Salinity Distribution

The salinity data for this sampling effort appear in Appendix A, Table III-4.

Temperature Distribution

The temperature profiles obtained in March were significantly different from those obtained the previous month. At stations 1 and 2 the upper 5 m possessed a rather strong thermal gradient. This appears to have been eradicated in the other two stations by the rising wind stress. In both stations 1 and 2 the water was weakly stratified to a depth of approximately 90 m. At station 1 the weak stratification gave way to a bottom mixed layer below ∿ 91 m. Between 89 m and 102 m at station 2, the temperature profile was steplike with an isothermal layer from there to the bottom.

The temperature profiles at stations 3 and 4 were nearly identical to each other. From the surface to 60 m the profiles assumed a subtle S shape with a rather weak thermocline between 50 m and 60 m forming the tail of the S. Between 60 m and 82 m, the water at station 3 was isothermal. Below that the water exhibited some weak stratification. There were two isothermal layers separated by weak thermoclines in the zone between 61 m and 76 m at station 4. From 76 m to the bottom at 99 m the water was isothermal at this station.

Transmissivity Distribution

In the transmissivity profiles from stations 1 and 2 it is clear that a plankton bloom was in progress. This is not quite so obvious in the profiles from stations 3 and 4. This could be due to the patchiness of the bloom or its dispersal under the increasingly stormy conditions experienced. A nepheloid layer was observed at all 4

stations. At stations 1 and 2 the bottom turbid layer was rather thick with a somewhat diffuse upper boundary at 80 m to 90 m. The turbid layer at stations 3 and 4 exhibited a very sharp onset within the lowest 7 m of the water column. The sediment appears to have been undergoing active resuspension at all of the stations during the period of observation.

Velocity Distribution

The velocity profiles from each station are distinct. This is probably due in part to surface gravity wave contamination in the records of stations 3 and 4. The surface flow at stations 1 and 2 was to the east and northeast, respectively. At station 1 the flow between 50 m and 70 m swung from east to west. Below 80 m the flow was to the southwest. Surface flow at station 1 had a speed of approximately 10 cm sec^{-1} with near bottom flow of 3 cm sec^{-1} to 4 cm sec^{-1}.

The flow at station 2 veered from northeasterly at the surface to southeasterly at the bottom. The surface speed at that station was 20 cm sec^{-1}, which dropped rather steadily to 1 cm sec^{-1} at 110 m, then increased to 9 cm sec^{-1} within 1 m of the bottom.

The surface flow at station 3 was to the southeast at 10 cm sec^{-1}, swinging to the south and increasing to 23 cm sec^{-1} at 20 m depth. Between 40 m and 60 m the flow was to the northwest at 7 cm sec^{-1} to 12 cm sec^{-1}. From there to the bottom the flow was westerly with speed decreasing monotonically.

At station 4 the current veered from southerly flow of 20 cm sec^{-1} at the surface to 1 cm sec^{-1} to 2 cm sec^{-1} westerly flow near the bottom.

Boundary Layer Experiments at the East Flower Garden Bank

In situ boundary layer flow visualization experiments were carried out at 3 sites on, and proximal to, the East Flower Garden Bank in September. These experiments were interspersed, in time, with the September sampling program so that the data from each effort complimented that of the other.

At each site of the boundary layer experiments, a dye emittor stand 3 m in height was lowered to the bottom. Three dye emittors were gimbled on a taut wire attached to a standoff at the top of the stand and a leg at the bottom of the stand. These emittors were filled with fluorescent dye, fixed on the wire by means of a brass collar, and their height above the leg recorded before the stand was set in place. The emittors consisted of hollow cyclinders with a small aperture in front and an emitting tube extending to the rear from the upper after section. A small diameter rod, 1 m long, with a fin on the end was inserted into the lower after section to orient the emittor in the flow. The rod was also marked every 10 cm to facilitate scaling of the flow.

After the emittor stand was set from the ship, it was located by means of the DRV DIAPHUS and observations initiated. The flow visualization was recorded on super 8mm color movie film and black

and white video tape for quantitative analysis.

The first experiment was dive 77-6 of the DRV DIAPHUS and will hereafter be referred to as dive 6. Location of the experiment with reference to local topography is shown in Figure III-8. As shown in that figure, the local bathymetry trends northeast-southwest in the vicinity of the dive site. Dive 6 was conducted at this site on the 17th of September.

A velocity profile was obtained 3 hours before initiation of the submersible observations. At the time of the profile the surface water was flowing to the southeast at 12 cm sec^{-1} in opposition to a 10 knot wind from the southeast. The magnitude of the current velocity increased with depth to a maximum of nearly 37 cm sec^{-1} at 20 m with no appreciable change in direction. It is generally held that the surface speed of a wind generated current is 3% - 4% of the wind speed. That assumption is in relatively good agreement with this set of observations since the wind speed was approximately 500 cm sec^{-1} and the speed deficit of the surface current was $\sim$ 25 cm sec^{-1}. It is probable that the southeasterly flow was initiated by the N to NW winds of the previous day.

The near bottom flow recorded by the profiling current meter was to the south at 20 cm sec^{-1}. It should be noted that the lowest reading taken on the station was $\sim$ 3 m above the bottom.

A transmissivity profile was obtained at the same time as the current profile. The surface waters had a transmissivity of nearly 85% m^{-1} decreasing to 80% m^{-1} at 50 m. Between 50 m and 90 m the transmissivity fluctuated between 78% m^{-1} and 85% m^{-1}. The flow in this depth range was to the ESE or from the direction of the bank.

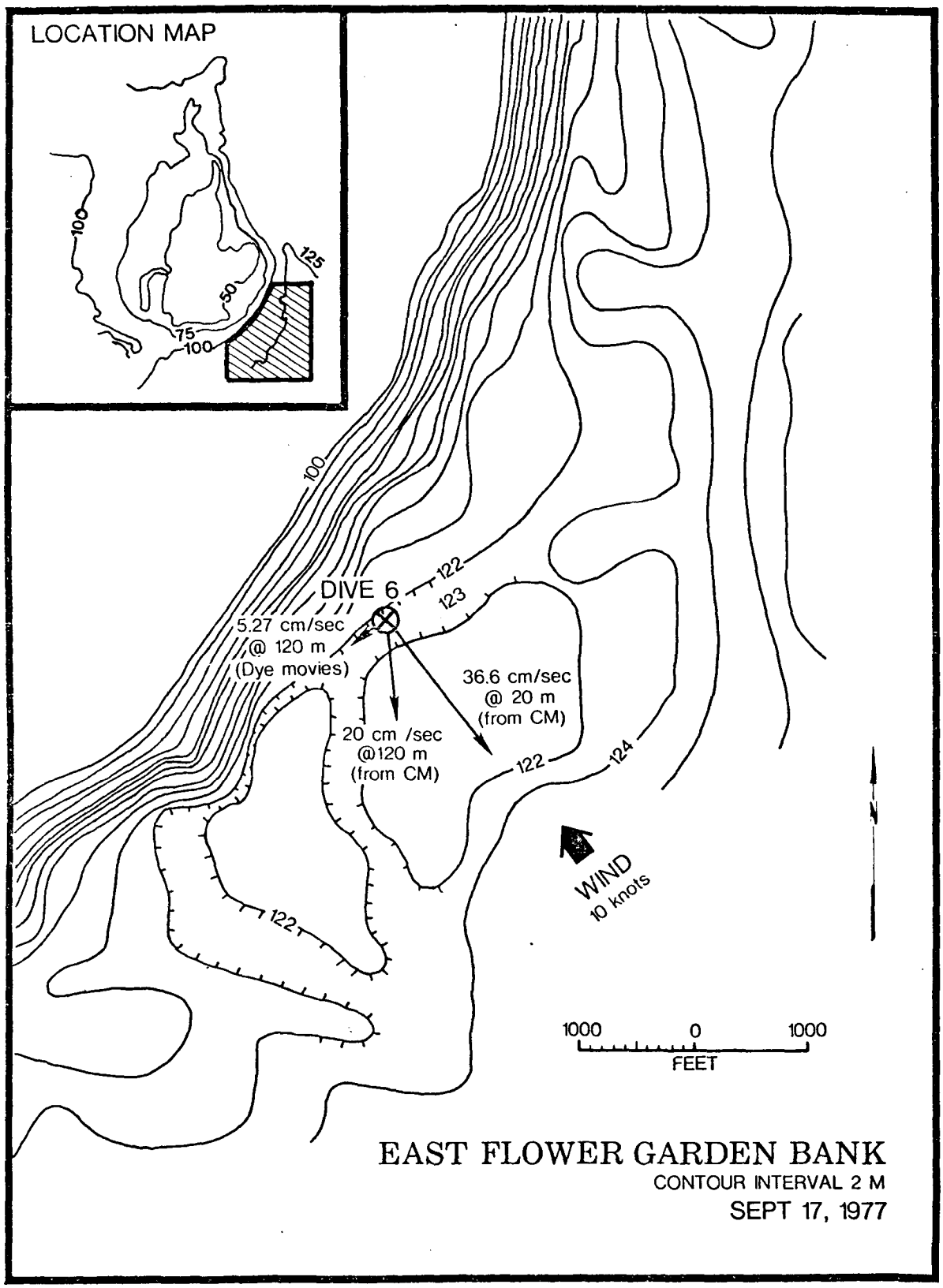

Figure III-8. Location of first flow visualization experiment.

These fluctuations may, therefore, represent detritus swept from the bank. At 103 m there was a sharp inflection in the profile at the top of a turbid layer. Between 103 m and 123 m the transmissivity decreased from 80% m^{-1} to 62% m^{-1}.

Sediment samples were obtained at the dive site from the submersible by means of short plastic tubes. A textural analysis revealed that the sediment consisted of approximately 6% sand, 48% silt and 46% clay. Observations from the submersible indicated that this fine sediment was easily mobilized from a surface layer a few millimeters thick. Below this layer the sediment was very cohesive and not easily resuspended.

A surface buoy was tethered to the dye emittor stand both to mark the location and allow recovery of the stand. The DRV DIAPHUS was piloted to the buoy on the surface. The dive was then initiated with descent to the emittor guided by the polypropylene tether line. The subtle variations of transmissivity between 50 m and 90 m recorded by the transmissometer were either below the threshold of visual detection or no longer present at the time of the dive. The top of the turbid layer was rather diffuse so that the impression of the observer was that of a gradual increase in turbidity with depth below 100 m. At the bottom (123 m) the turbidity was so intense that only the bottom dye emittor was clearly visible at a horizontal distance of between 1 m and 2 m. The suspended material consisted of both very fine particulates which gave the water a hazy appearance and a large quantity of particles big enough to be readily visible to the naked eye. Some of the latter were attached to the bottom of slender tube like gelatinous organisms which appear to be

salps.

The flow at the lowest emittor, 65 cm above the bottom, was relatively low during the whole dive averaging 6 cm sec^{-1} to 8 cm sec^{-1} early in the dive and decreasing to 4 cm sec^{-1} to 6 cm sec^{-1} toward the end. Throughout the dive the flow was to the southwest parallel to the general trend of the isobaths. The average speed of the near bottom current over the whole dive was just over 5 cm sec^{-1}. The instantaneous horizontal velocity varied from -4.4 cm sec^{-1} (northeasterly flow) to 14.2 cm sec^{-1}. Instantaneous vertical velocities ranged from +5 cm sec^{-1} (up) to -4 cm sec^{-1} (down) with an average over the whole dive of +1.3 cm sec^{-1}. These velocity fluctuations were used to calculate the shear stress using

$$\tau_{xz} = \rho \, \overline{u'w'}$$

where

$$u' = \overline{u} - u$$

$$w' = \overline{w} - w$$

$\overline{u}$ = average horizontal velocity

u = instantaneous horizontal velocity

$\overline{w}$ = average vertical velocity

w = instantaneous vertical velocity.

The shear stresses provide information about the vertical transport of horizontal velocity. The more intense the turbulence the greater the magnitudes of u' and w' and thus the larger τ_{xz}. Averaged over the whole experiment, τ_{xz} was 1.8 dynes cm^{-2}. However, the 2.5 sec time averaged τ_{xz} (5 values) ranged from -7.3 to 16.2 dynes cm^{-2}. Throughout the experiment the rotation of the vortices made visible by the dye was clockwise when looking normal to the flow, downstream to the right. This is equivalent to saying that the velocity of the

flow decreased with increasing proximity to the bottom.

From the information available at this site it was not possible to determine whether most of the suspended sediment constituting the nepheloid layer was being advected from some distant location or was being locally eroded. It seems likely that both processes were contributing to the turbidity but the relative proportions was indeterminate.

Because of the difficulties encountered in recording the flow visualization in such turbid water, the second experiment was moved to a shallower location on the southwestern flank of the bank (Figure III-9). Two dives were made to this site on the 18th of September. The first, dive 7, lasted from 1005 to 1301 and the second, dive 8, lasted from 1358 to 1732. The bottom at the dive site sloped gently ($< 2^{o}$) to the southwest and was composed of a carbonate sand with less than 10% clay.

A transmissivity profile was obtained just prior to the dive. It showed that near bottom transmissivity was 78% m^{-1} to 80% m^{-1} which is relatively clear.

Six STD profiles were also taken at this site. One profile was made just prior to dive 7 and the remaining 5 were all taken during dive 8. In addition, near bottom current velocities were recorded from the ship every 3 minutes, except during the launch and retrieval of the submersible.

Upon first sighting of the dye emittor on dive 7 it could be seen that there was about a 15° spread in direction between the top and bottom emittors. The flow was generally southeasterly with the flow at the bottom emittor more easterly than that at the

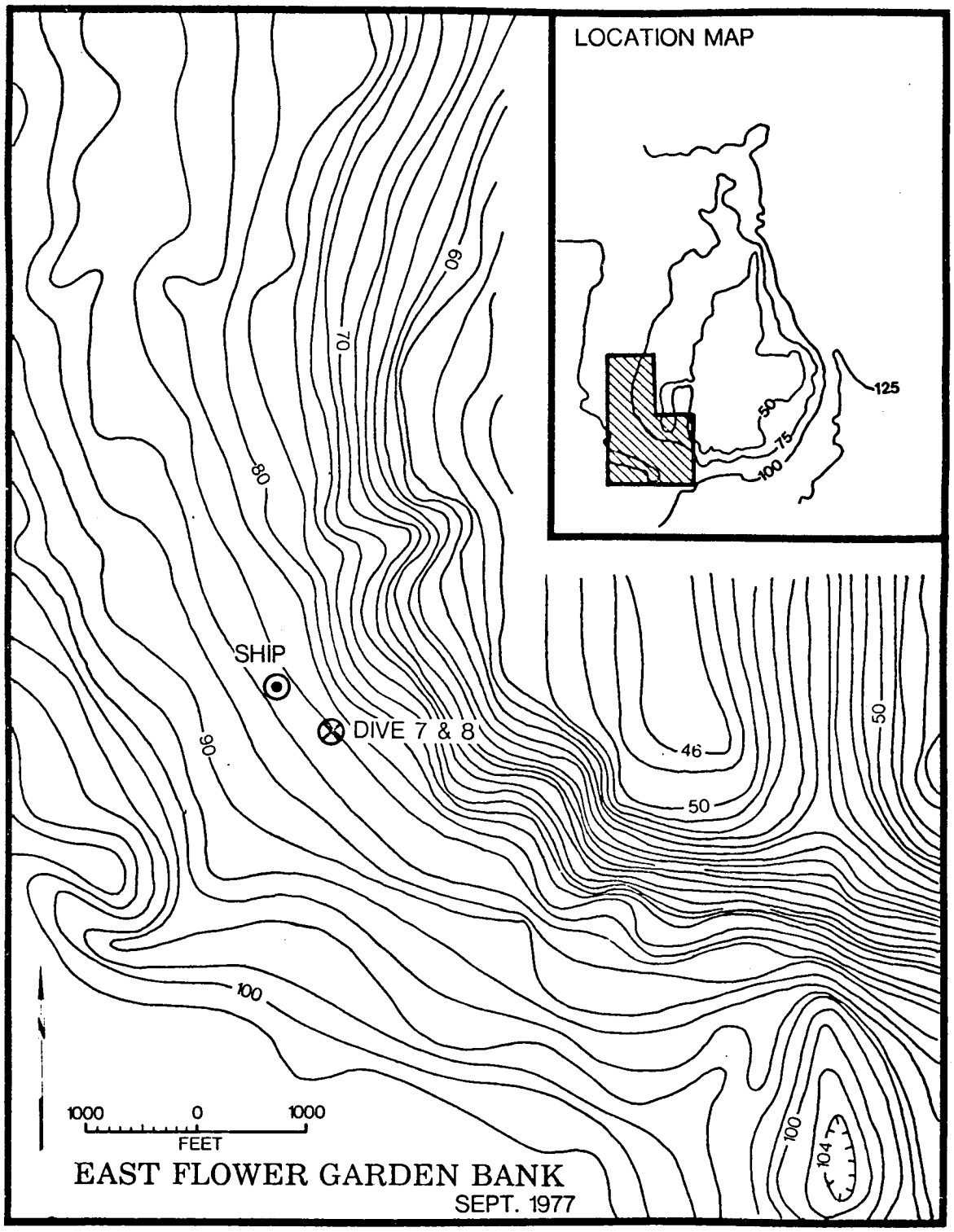

Figure III-9. Location of second flow visualization experiment. Contour interval 2 m.

top. Shortly after the submersible touched down on the bottom, the bottom emittor swung to the southwest then the middle emittor turned and finally the top emittor turned to a more southerly direction. So in the first instance, there was a left hand downward spiral to the flow, facing downstream, then it switched to a right handed downward spiral. During the period of the dive at intervals of 15 to 20 minutes the flow would turn upward starting at the bottom emittor and progressing up, then resume the horizontal flow and finally turn sharply downward starting at the top emittor and progressing down. As a prelude to the start of the sequence, the flow at the bottom would accelerate so that it was faster than that above. This caused a reversal of the shear near the bottom and rapid diffusion of the dye. Just before the termination of dive 7 the current underwent a 180° shift starting at the bottom. This shift was accompanied by a great increase in the scale of turbulence present and a decrease in the clarity of the water.

Throughout dive 8 the flow was generally to the northwest though it exhibited some fluctuations to the north and northeast.

At the beginning of dive 8 the speed of the current 90 cm above the bottom (middle emittor) varied from 6.9 cm sec^{-1} to 8.6 cm sec^{-1} with an average of 8.1 cm sec^{-1}. The flow at 68 cm above the bottom (bottom emittor) for the same period varied in speed from 6.6 cm sec^{-1} to 11.9 cm sec^{-1} with an average of 7.6 cm sec^{-1}. This represents a typical boundary layer flow, decreasing in mean speed toward the bottom with increasing turbulence. During a period of reversed shear, the average speed at the middle

emittor was 9.7 cm sec^{-1} with a range of 8.6 cm sec^{-1} to 11.1 cm sec^{-1}. The mean speed at the bottom emittor during this event was 13.1 cm sec^{-1} with a range of 11.2 cm sec^{-1} to 15.2 cm sec^{-1}. By the middle of the dive the speed of the flow peaked. At the top emittor (∿ 2 m above the bottom) the mean speed was 19.9 cm sec^{-1}, at the middle emittor it was 16.7 cm sec^{-1} and at the bottom emittor it was 14.5 cm sec^{-1}, all toward the northeast.

Figure III-10 is a plot of the depth of selected isotherms versus time from the 5 STD casts taken during dive 8. The maximum vertical excursion, 11 m, is exhibited by the 23.5°C isotherm. Most undergo at least 6 m of vertical displacement over the ∿ 3.5 hour period. It should be noted that the isotherms above 50 m appear to be out of phase with those below 50 m.

The near bottom current meter time series (Figure III-11) spans the time of the two dives. It shows primarily southerly flow ∿ 2 m above the bottom with velocity decreasing in time until approximately 1430 when the flow reversed. It then increased in speed to a maximum of ∿ 25 cm sec^{-1}. There also appears to be a rather periodic fluctuation in the magnitude of the velocity vectors, particularly after the reversal, with a frequency of 1.1 to 1.25 cycles per hour.

The evidence from the current meter record and STD casts suggest that a major internal deformation, either wave or bore, passed through the area of observation causing a reversal of flow near the bottom. It appears that this same reversal was observed at the dive site about 90 minutes earlier than at the ship. Since the distance between the dive site and anchorage was approximately 220 m, the internal wave was propagating to the northeast at a speed of

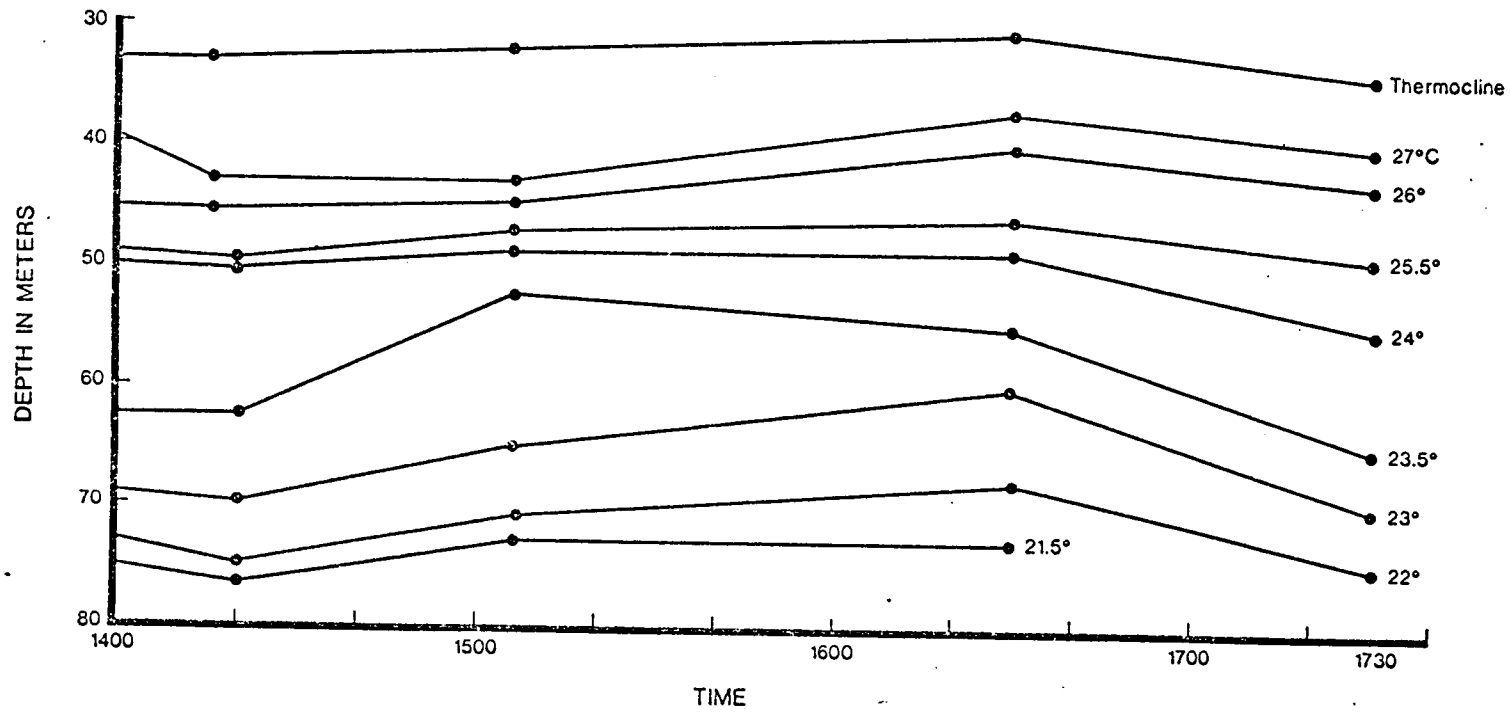

Figure III-10. Plot of isotherms from Dive 8.

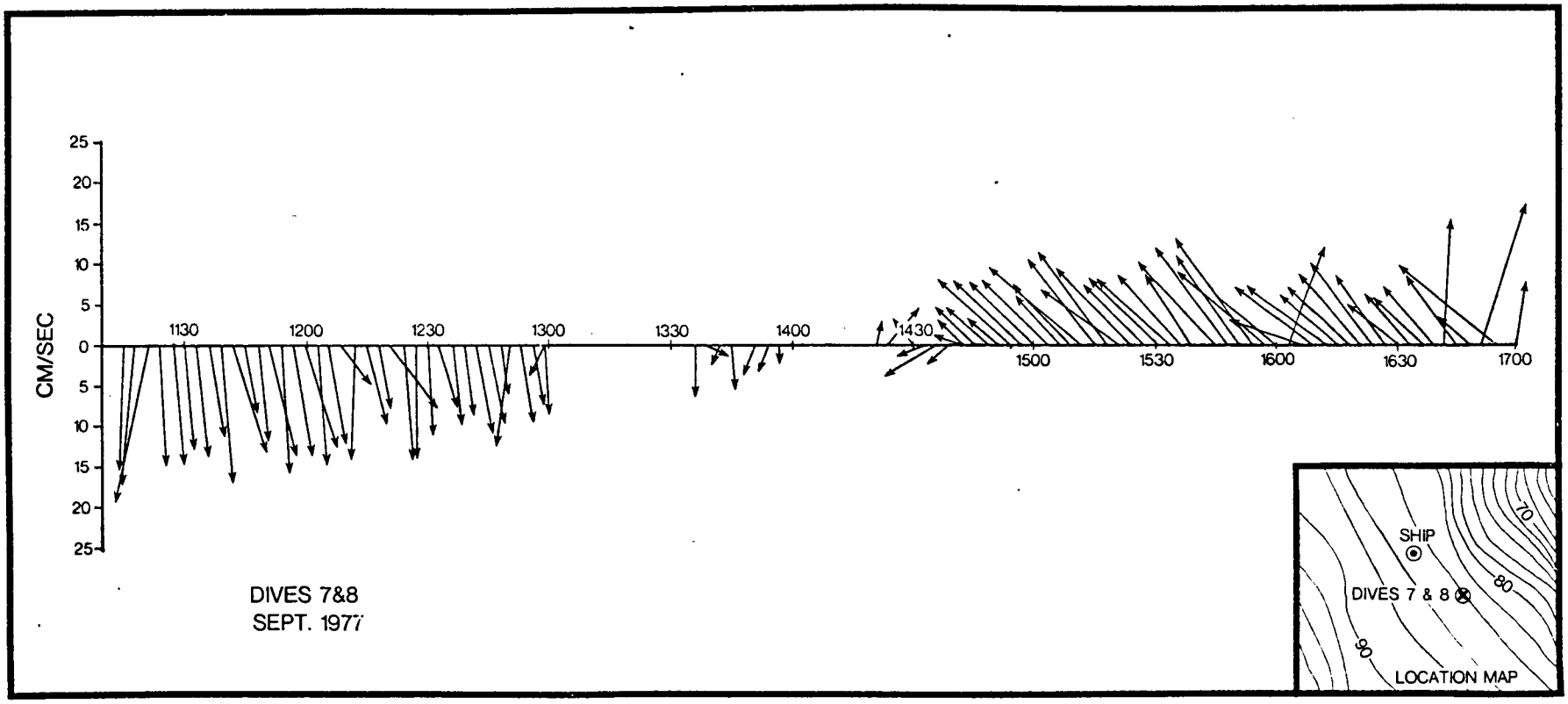

Figure III-11. Current velocity time series at ship's position for dives 7 and 8. Times are indicated along the horizontal axis. Arrows point in direction of flow and length is proportional to the speed.

4 cm sec^{-1}. Superimposed on this major event were higher frequency oscillations which were also probably internal waves.

The third experiment was carried out at the northwestern tip of the East Flower Garden Bank (Figure III-12). Again two dives, 12 and 13, were made to the site. On the first dive it had been planned that a weighted bag of dye would be placed on the bottom and punctured so that very near bottom flow could be observed. The bag was accidentally punctured and dislodged from the manipulator arm of the submersible just before descent to the emittor was begun. As the submersible approached the bottom it could be seen that the dye from this bag had spread out in a thin ($\sim$ 20 cm) layer approximately 5 m above the bottom. It could also be seen that long crested small amplitude waves were deforming this surface for as far as it could be observed. By hovering in the layer it was possible to see that mixing across this layer was negligible.

The observations from the submersible at this site duplicated those made in dives 7 and 8. The major reversal occurred at the termination of dive 13 and was accompanied by rapid vertical flow, large scale turbulence and great increase in the concentration of suspended sediment in the water column. Since the dive site was above the level at which the nepheloid layer is usually found, it is believed that the decreased transmissivity was due to local resuspension of the fine fraction in the predominately carbonate sand at the site.

From these observations it is believed that internal waves contribute significantly to turbulence in the benthic boundary layer over the continental shelf in the northern Gulf of Mexico. These

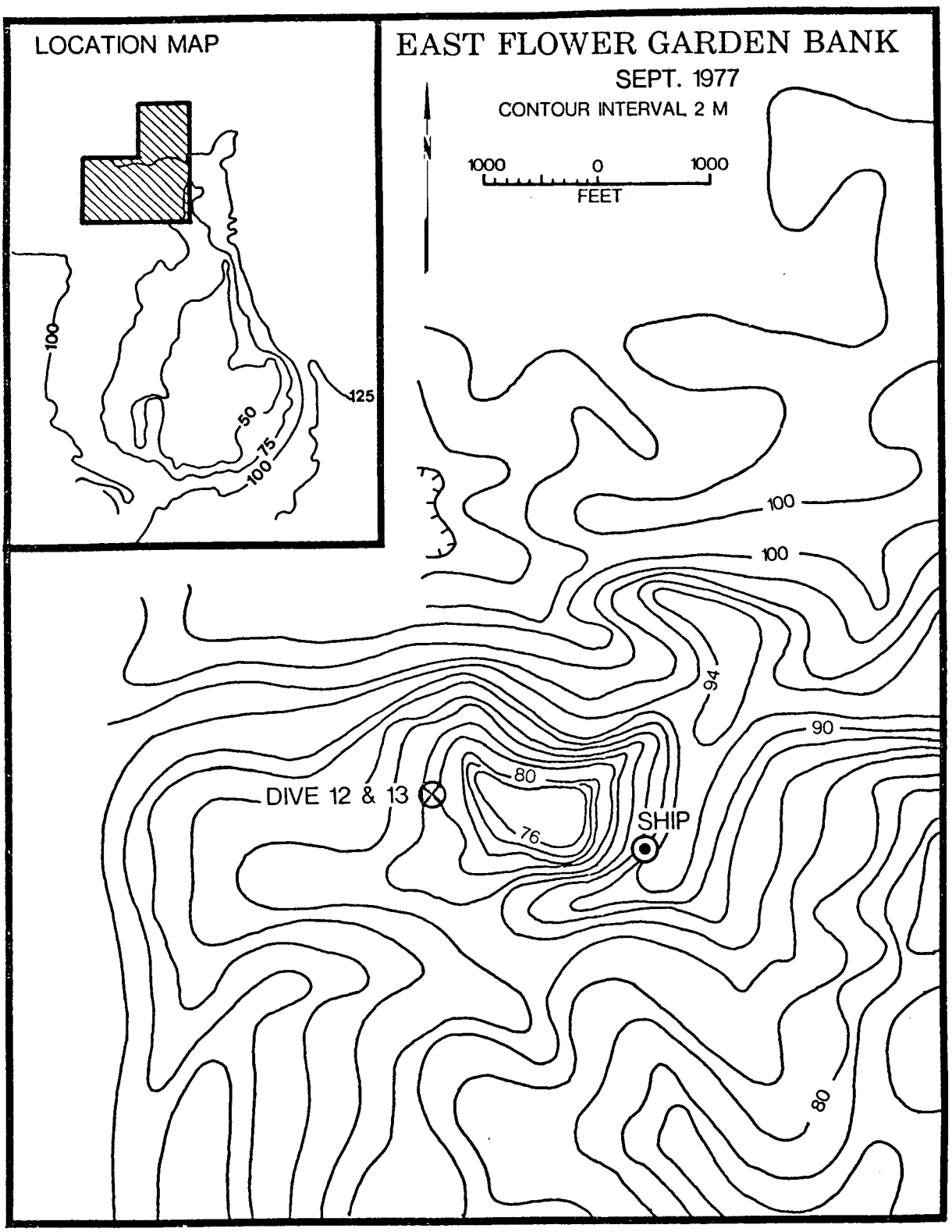

Figure III-12. Location for the third flow visualization experiment.

waves may originate from: breakup of the barotropic tide at the continental slope; interaction of flow and topography in the presence of stratification; impulsive changes in wind stress or triad resonnance with paired surface gravity waves. In the last mode of formation, internal waves are fed energy when two sets of surface gravity waves propagate through an area with a small angular difference in their direction of propagation. Under these conditions the surface waves interact at long wave lengths and create oscillations of the thermocline.

Reconnaissance Sampling at Sonnier Banks

Station locations for Sonnier Banks are shown in Figure III-13. At each station an STD cast, a transmissivity profile and a current velocity profile were obtained. Sampling on these banks was accomplished in June. Profiles of velocity, temperature and transmissivity for stations 1 through 4 are shown in Figures III-14 through III-17, respectively. All of the data obtained at these stations appear in tabular form in Appendex A, Table III-5.

The area surrounding the base of these banks was enveloped in a nepheloid layer varying in thickness from 10 m to 18 m. This turbid layer appears to have been trapped below the main thermocline at all 4 stations. The presence of near bottom velocity maxima at stations 1, 3 and 4, the marked station to station variation in the shape of the temperature profiles and the sharp directional shear of the current at $\sim$ 40 m at all stations indicate that internal waves were active during the sampling. Considering the high near bottom velocities observed, it is very probable that the fine sediment was

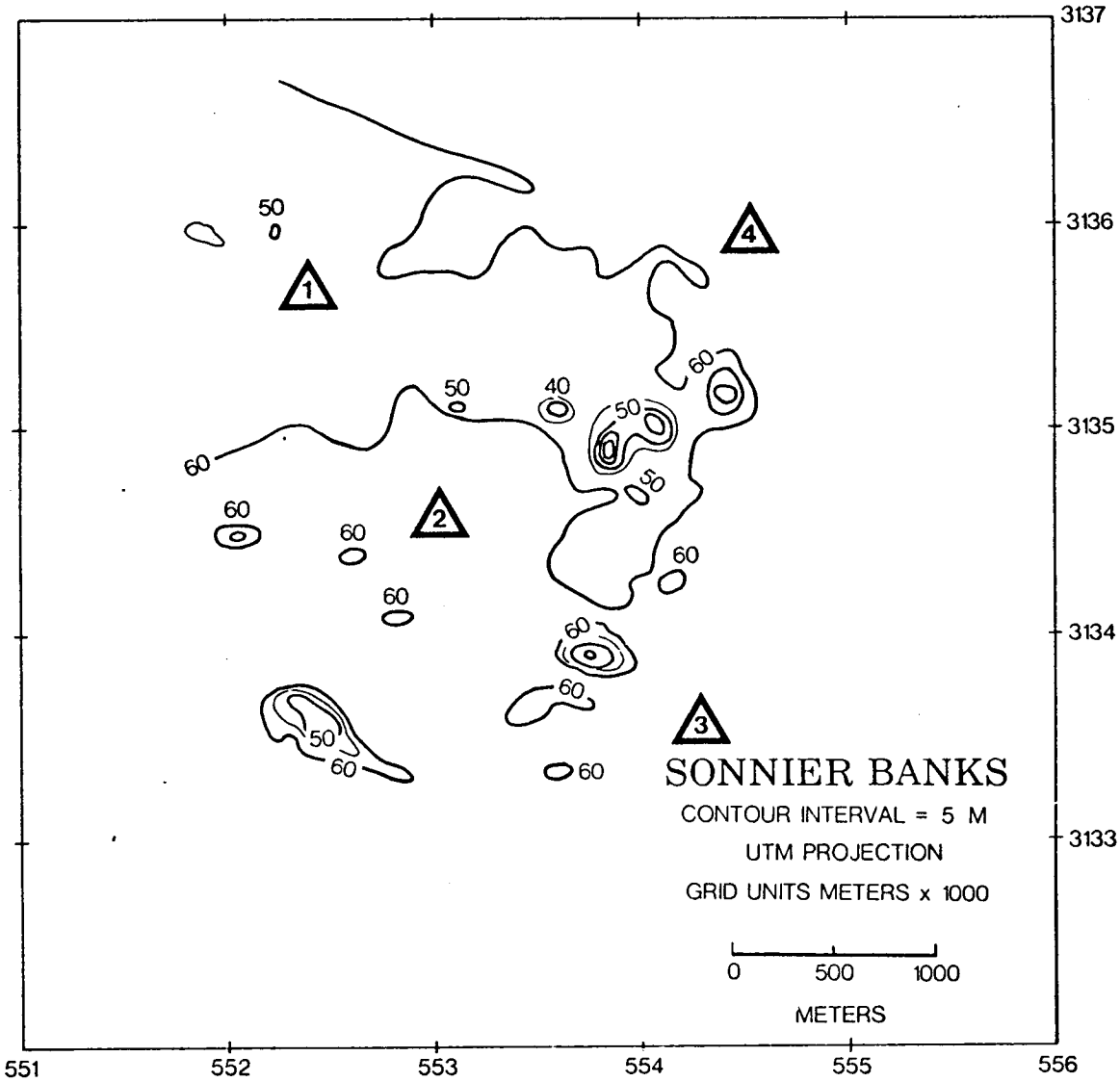

Figure III-13. Sampling station locations for Sonnier Banks.

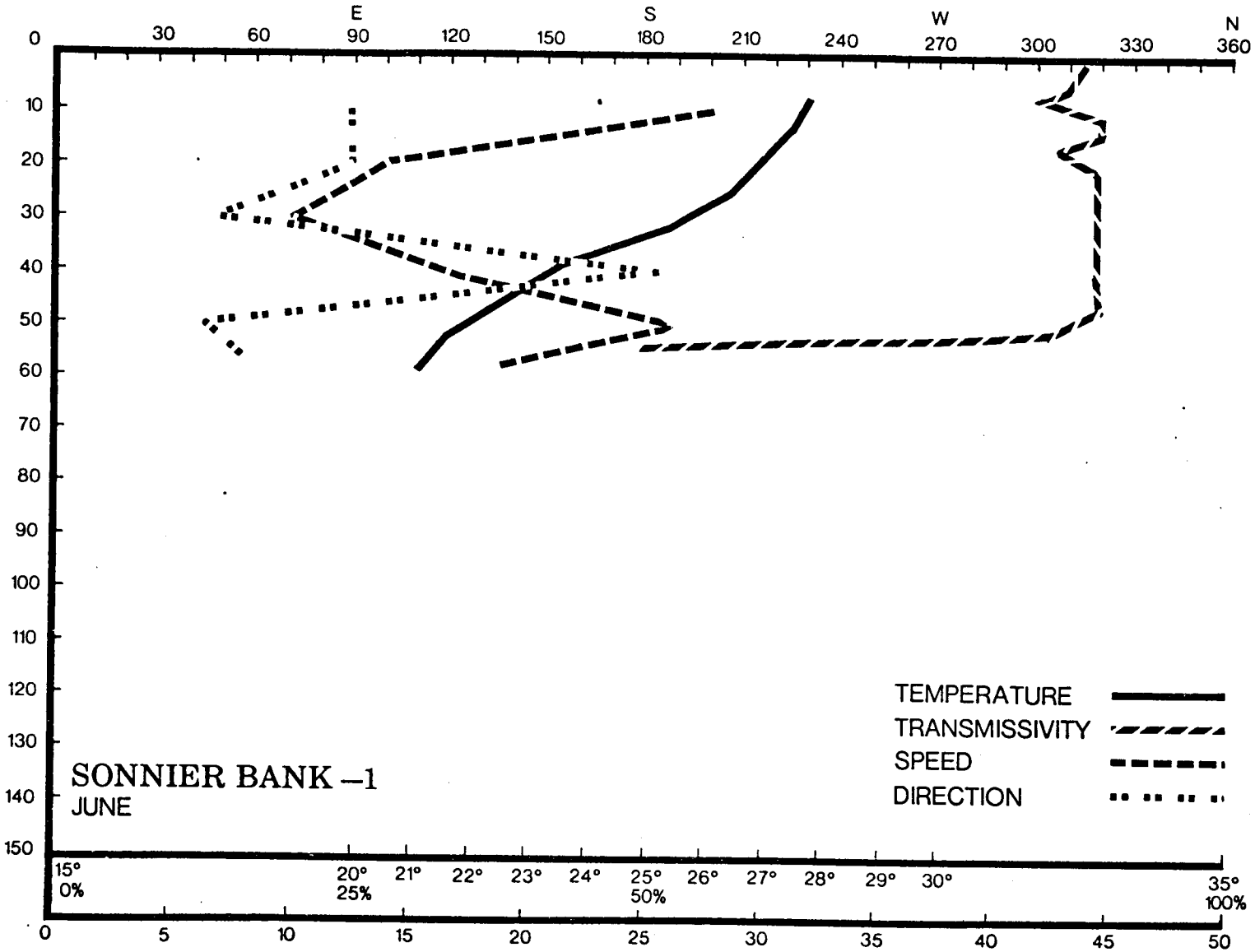

Figure III-14. Superposition of temperature, transmissivity and velocity profiles for station 1.

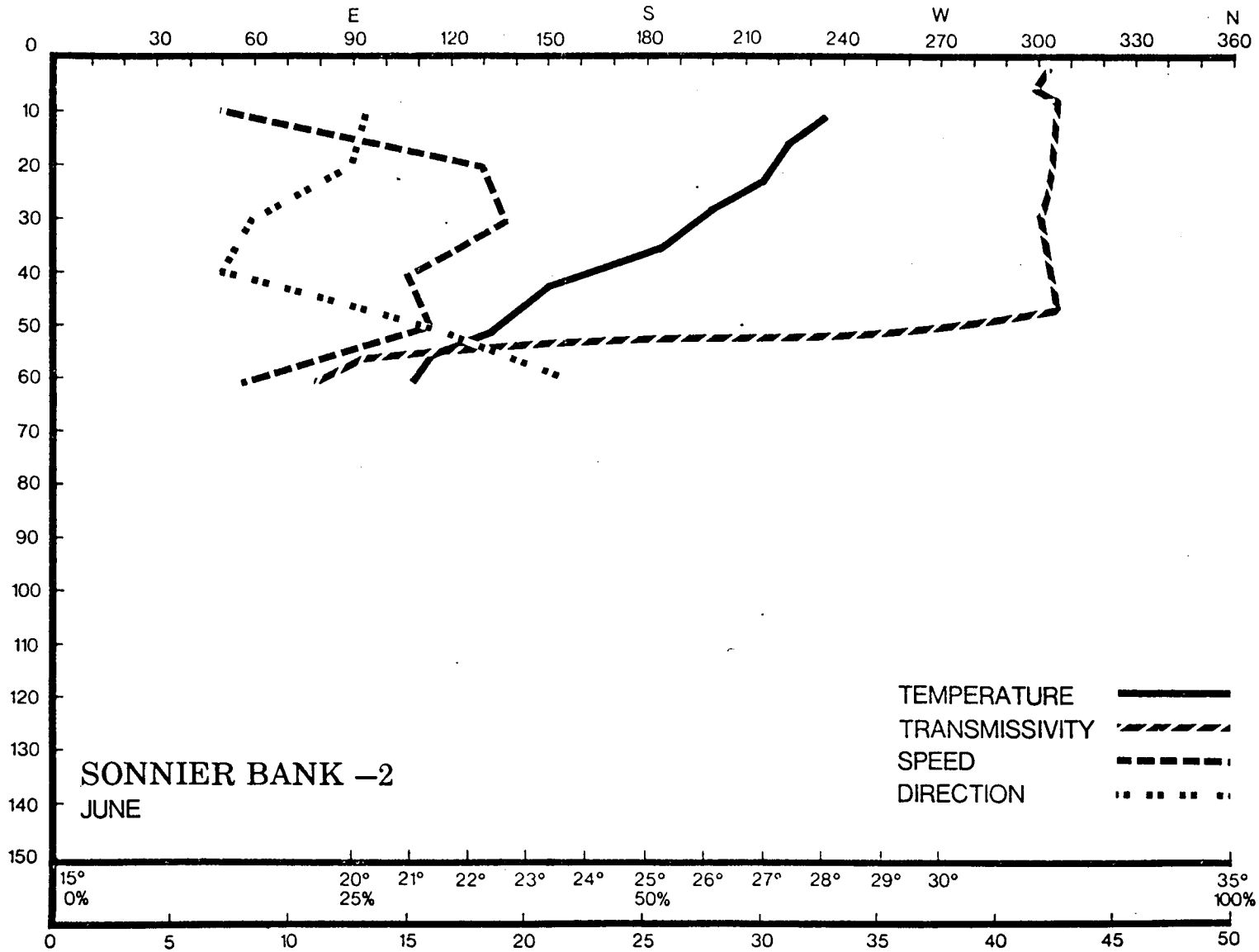

Figure III-15. Superposition of temperature, transmissivity and velocity profiles for station 2.

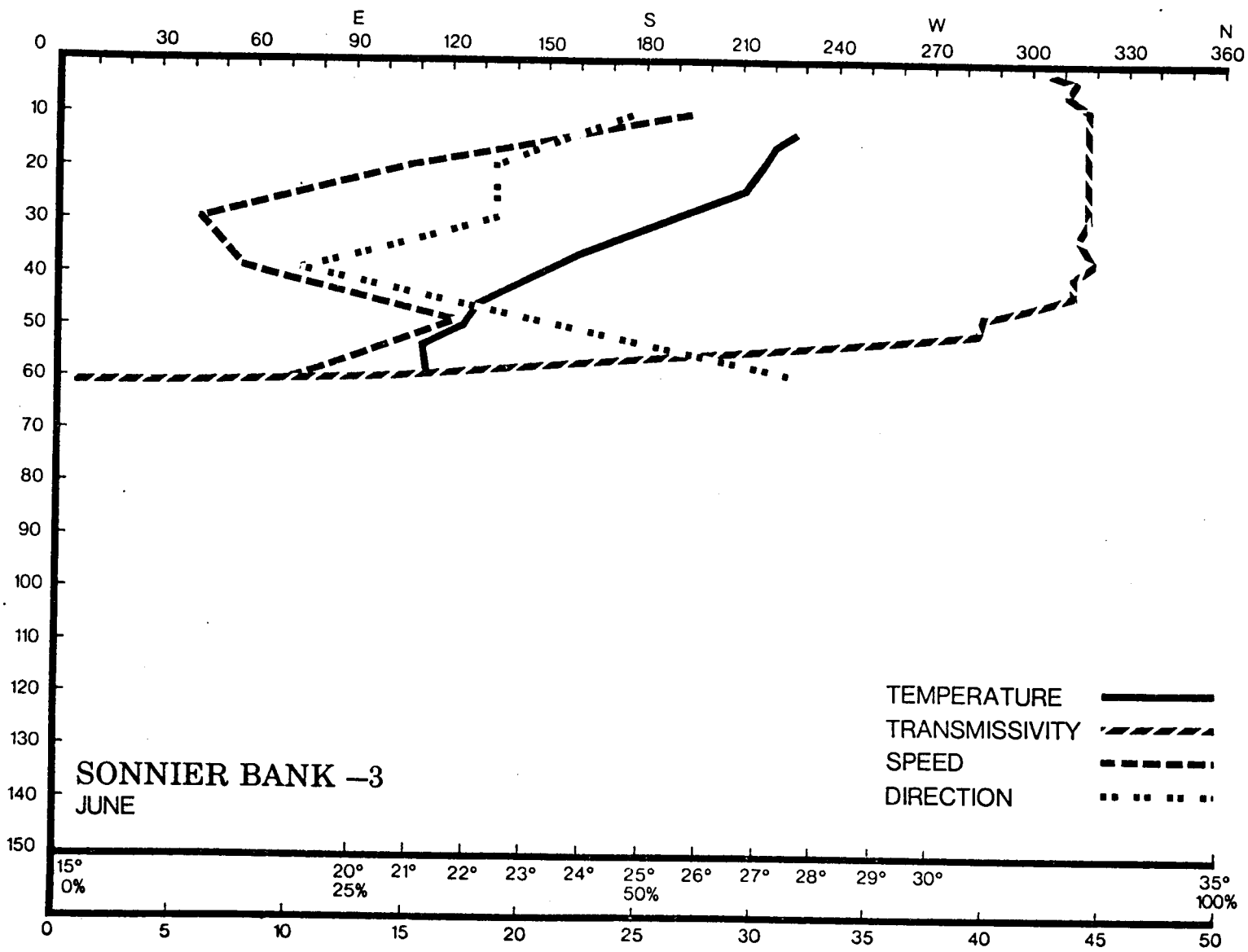

Figure III-16. Superposition of temperature, transmissivity and velocity profiles for station 3.

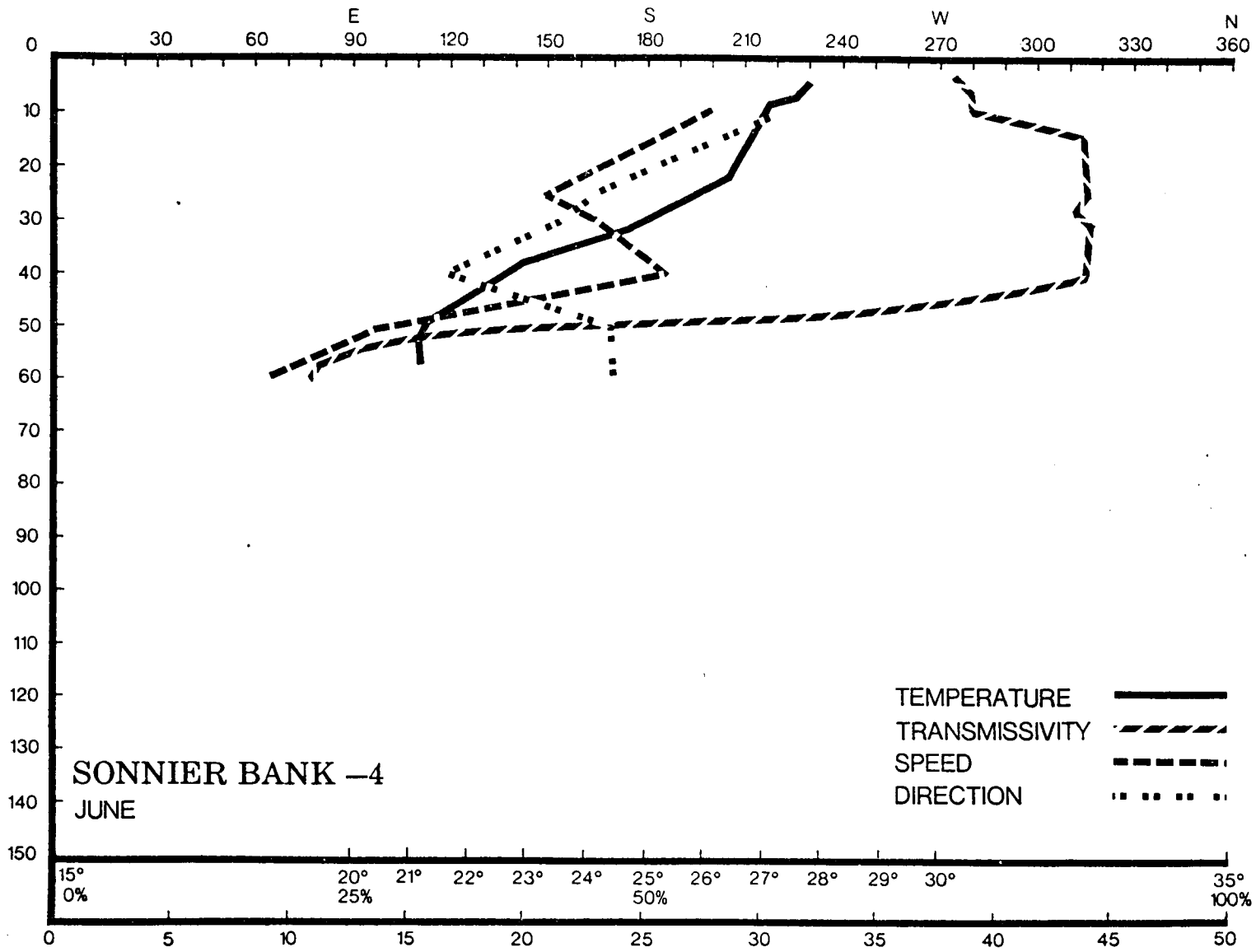

Figure III-17. Superposition of temperature, transmissivity and velocity profiles for station 4.

being actively resuspended into the nepheloid layer during the sampling period.

Reconnaissance Sampling at Bright Bank

Four sampling stations were also occupied at Bright Bank (Figure III-18) on the June cruise. The only significant nepheloid layer was encountered at station 1 (Figure III-19). That is the only station at this bank which was in water deeper than 100 m. The top of the turbid layer was found at 91 m. The second deepest station, 2, had a spike in the transmissivity (increase in turbidity) between 82 m and 88 m (Figure III-20) which appears to have been fine material resuspended from the bank locally. The vertical distribution of all measured parameters except salinity are shown in Figure III-19 through III-22. All of the velocity profiles have sharp directional changes at approximately 60 m with multiple subsurface velocity maxima. From this, the steplike structure of the temperature profiles below the thermocline and the vertical displacement of the isotherms from station to station (Figure III-23), it is inferred that a complex set of internal waves were present at this bank during the sampling. It appears from the location of the critical layer (zone of rapid vertical shear) that these waves are topographically induced by the bank interacting with the flow. The vertical distribution of transmissivity at these 4 stations is shown in Figure III-24. All of the water column data collected at these stations are given in Appendix A, Table III-6.

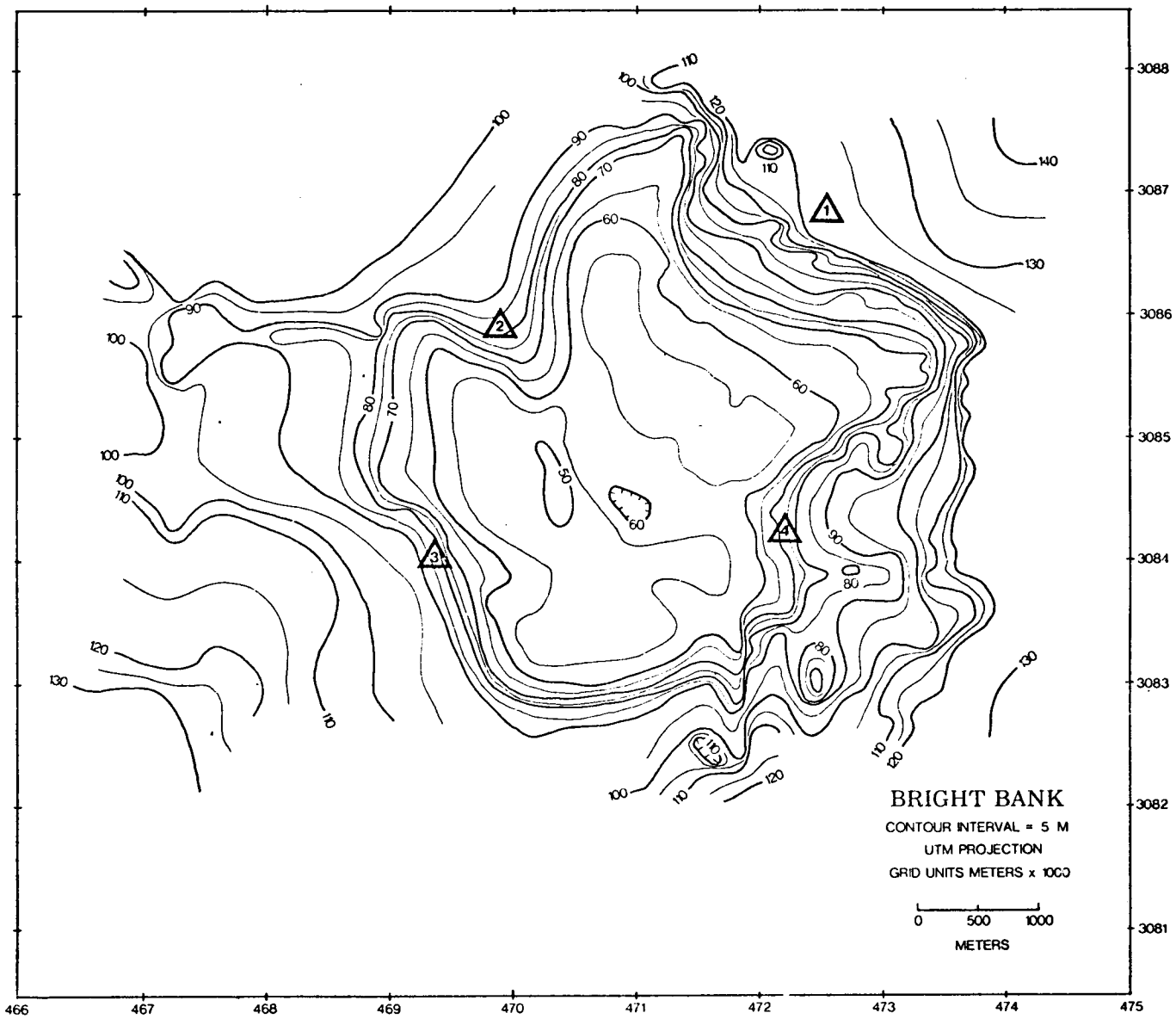

Figure III-18. Location of the sampling stations on Bright Bank.

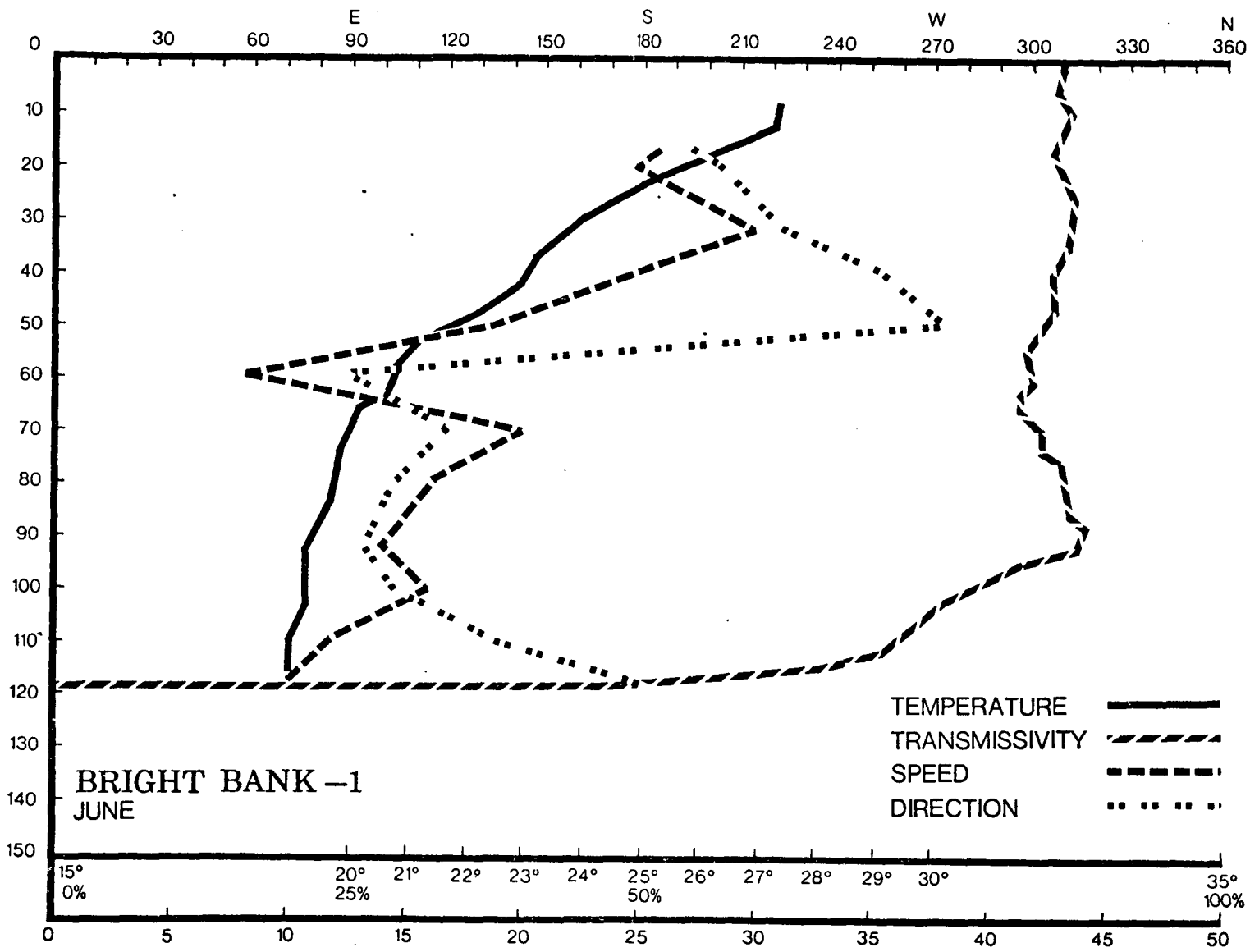

Figure III-19. Superposition of temperature, transmissivity and velocity at Bright Bank station 1.

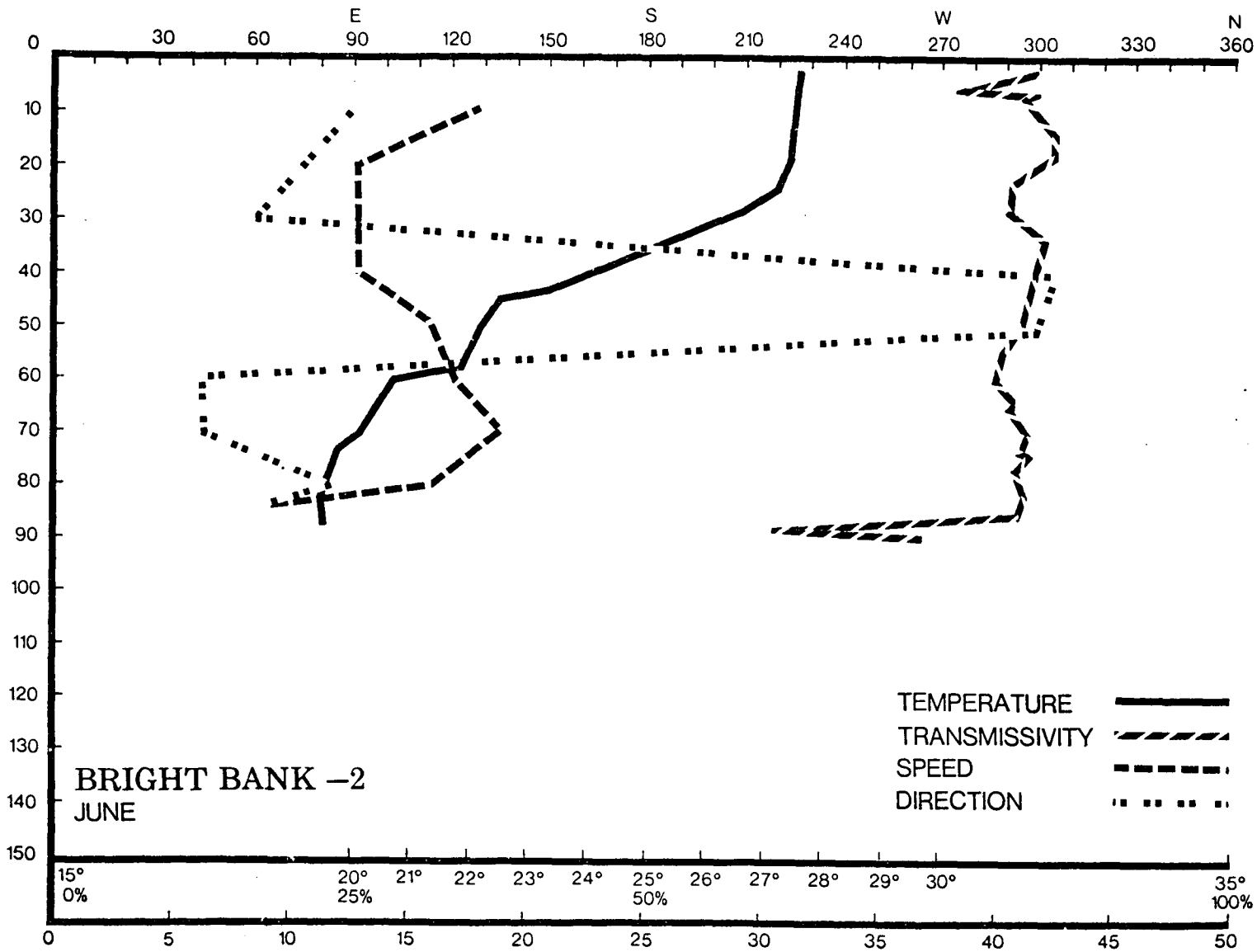

Figure III-20. Superposition of temperature, transmissivity and velocity at Bright Bank station 2.

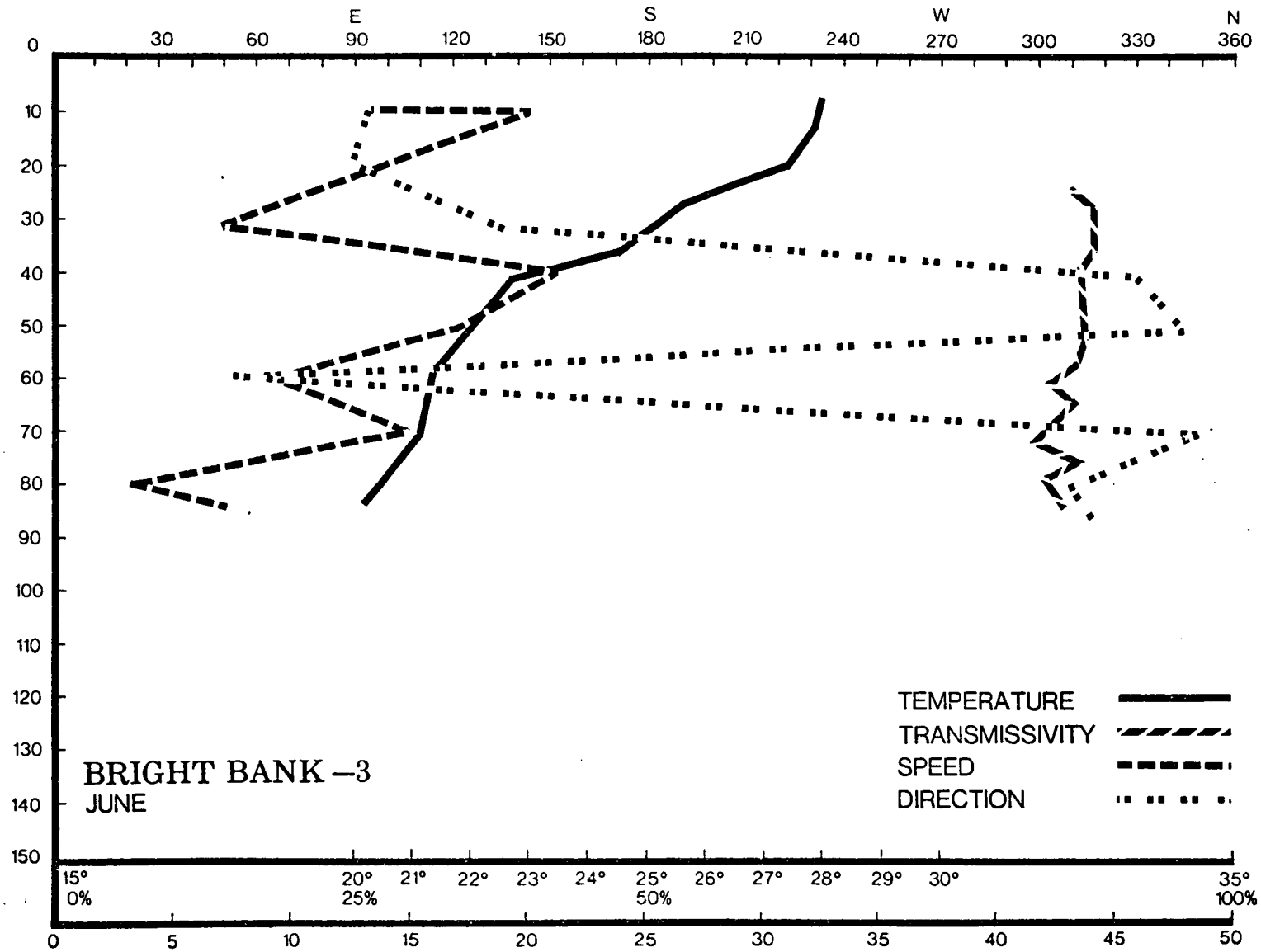

Figure III-21. Superposition of temperature, transmissivity and velocity at Bright Bank station 3.

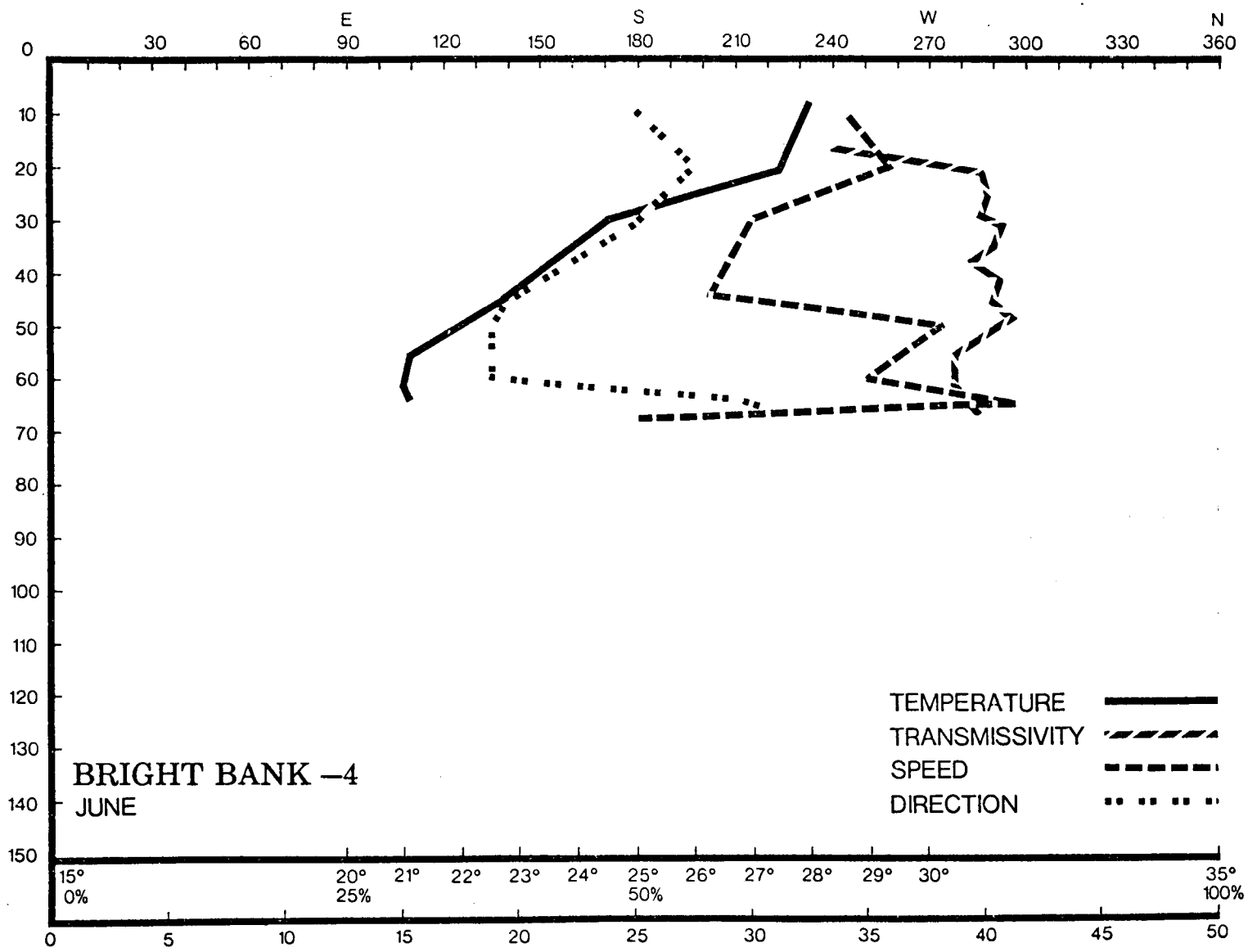

Figure III-22. Superposition of temperature, transmissivity and velocity at Bright Bank station 4.

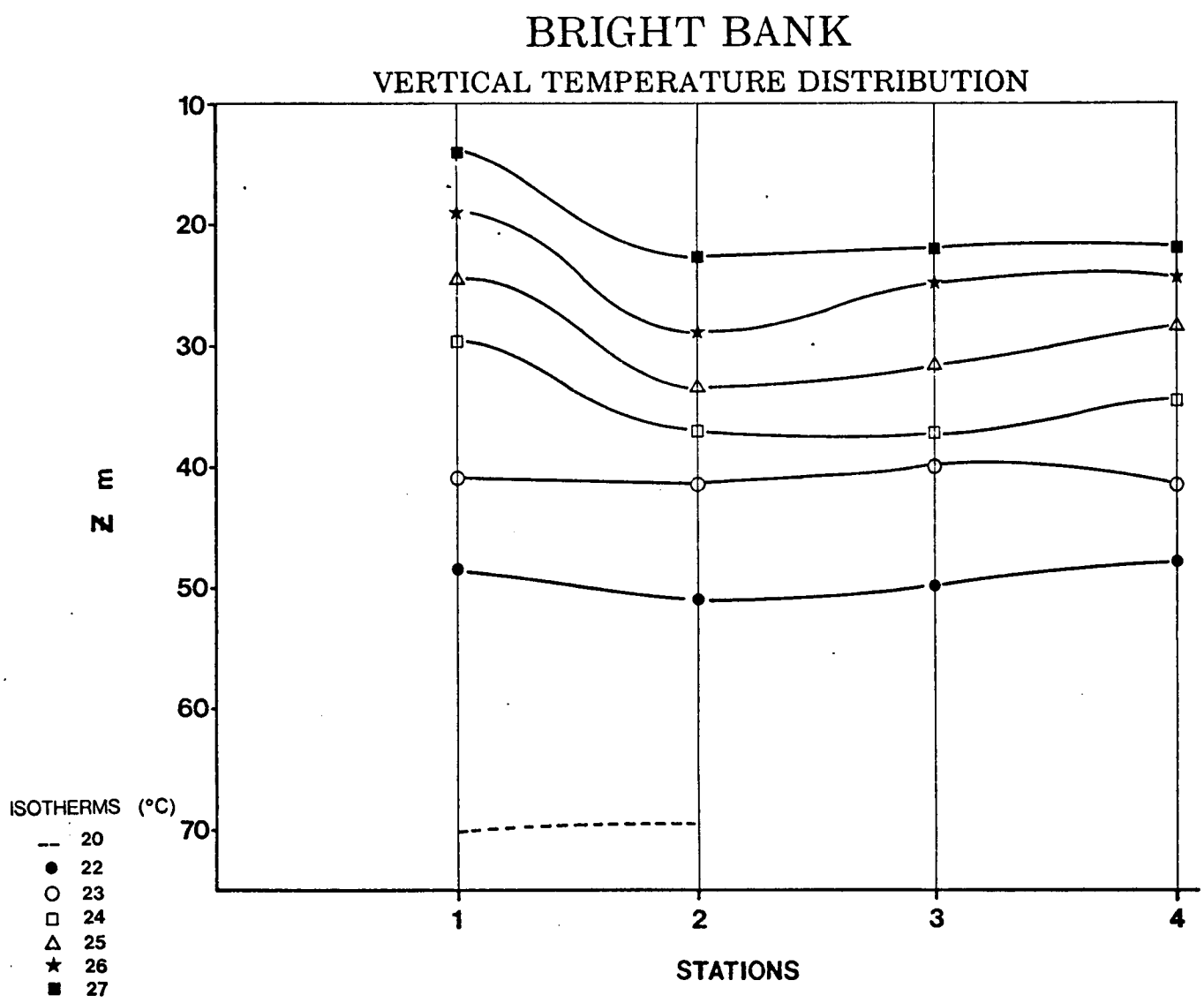

Figure III-23. Vertical temperature distribution at Bright Bank.

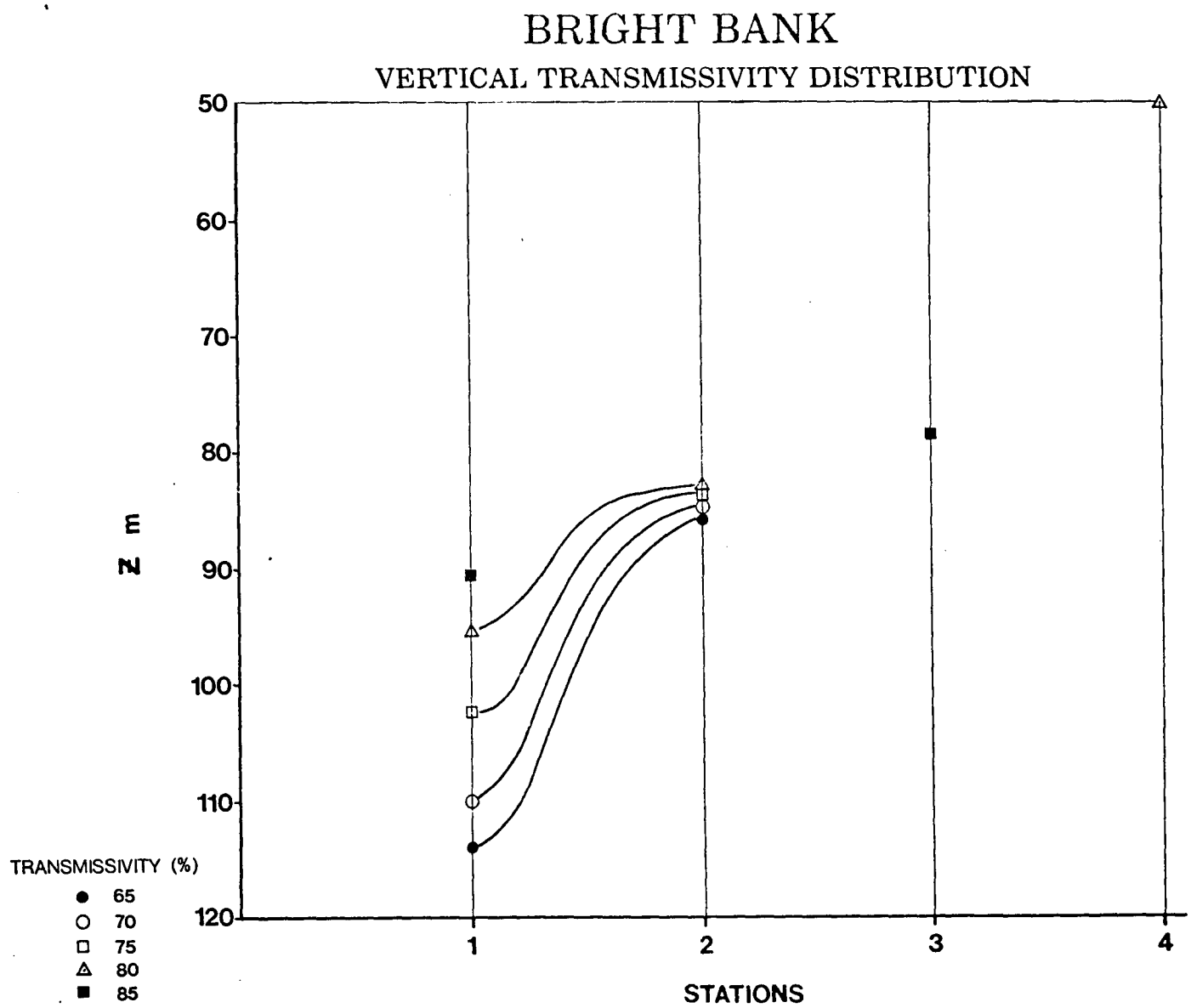

Figure III-24. Vertical transmissivity distribution at Bright Bank.

Reconnaissance Sampling at Parker Bank

Locations of the sampling stations occupied at Parker Bank are shown in Figure III-25. All of the water column data obtained at these sites appear in tabular form in Appendix A, Table III-7. The profiles of velocity, temperature and transmissivity at stations 1 through 4 are shown in Figures III-26 through III-29 respectively. The only significant nepheloid layer observed at any of these stations was located in the central trough (station 2). Surface flow was to the east at every station except 3. At station 3 the flow was southerly to a depth of ∿ 90 m at which it turned sharply to the east. In general the bottom flow seemed to conform to the isobaths of the bank. The westerly flow below ∿ 90 m at station 2 apparently represents an eddy like flow into the trough probably separated from the northern area of the bank. Again the distribution of temperatures and nature of the velocity profiles suggest the presence of internal waves.

Reconnaissance Sampling at Sackett Bank

Unlike the reconnaissance sampling at the other banks, which was done in June, that at Sackett Bank was carried out in September. Because this bank lies very near the mouth of the Mississippi River, the surface salinities ran off the lower scale of the STD. This lens of fresh water extended to approximately 20 m depth. All of the water column data collected at the sites shown in Figure III-30 appear in tabular form in Appendix A, Table III-8. The vertical distribution of all measured parameters except for salinity for Sackett Bank stations 1 through 4 are shown in Figures III-21 through III-34.

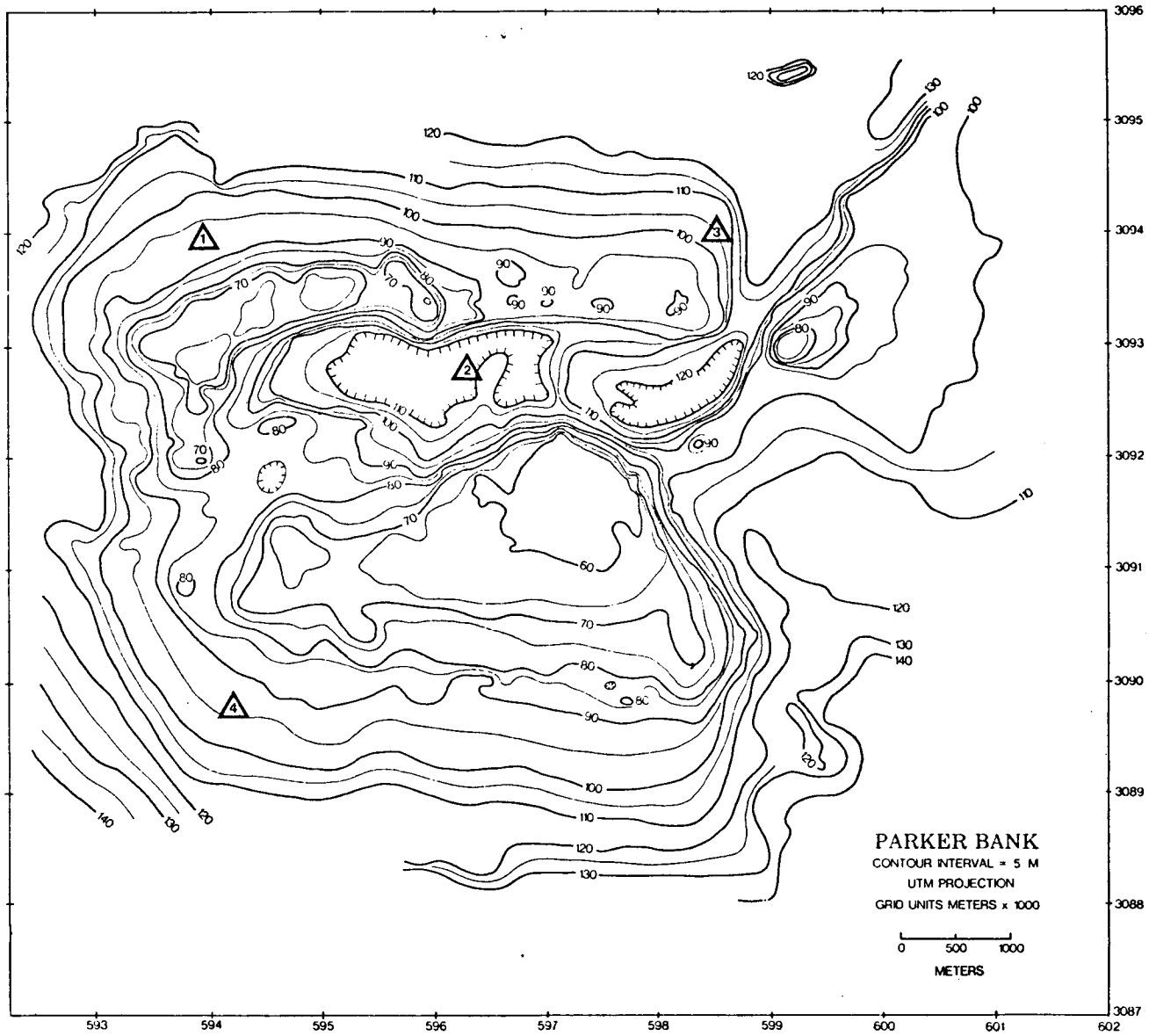

Figure III-25. Location of the sampling stations at Parker Bank.

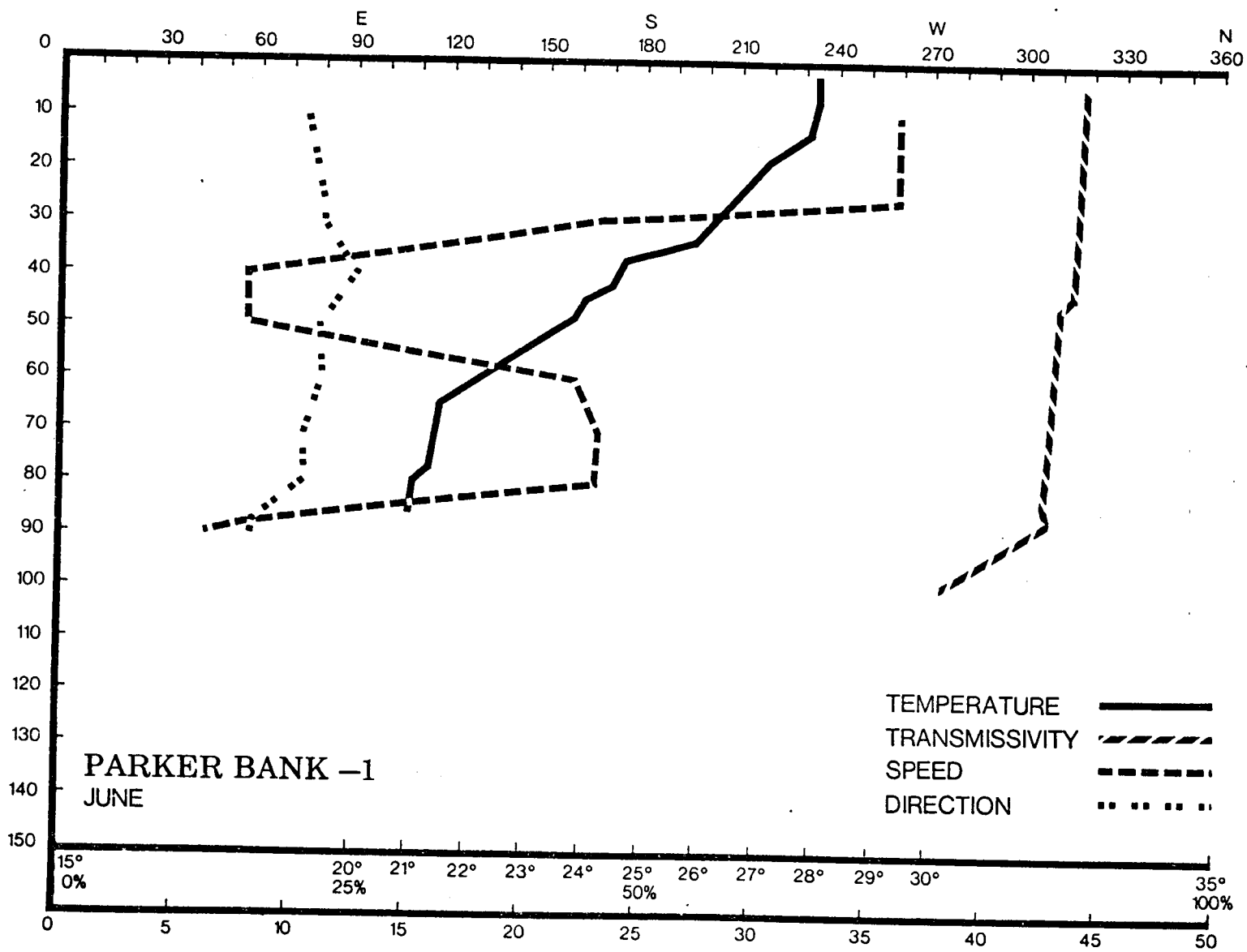

Figure III-26. Superposition of temperature, transmissivity and velocity at Parker Bank station 1.

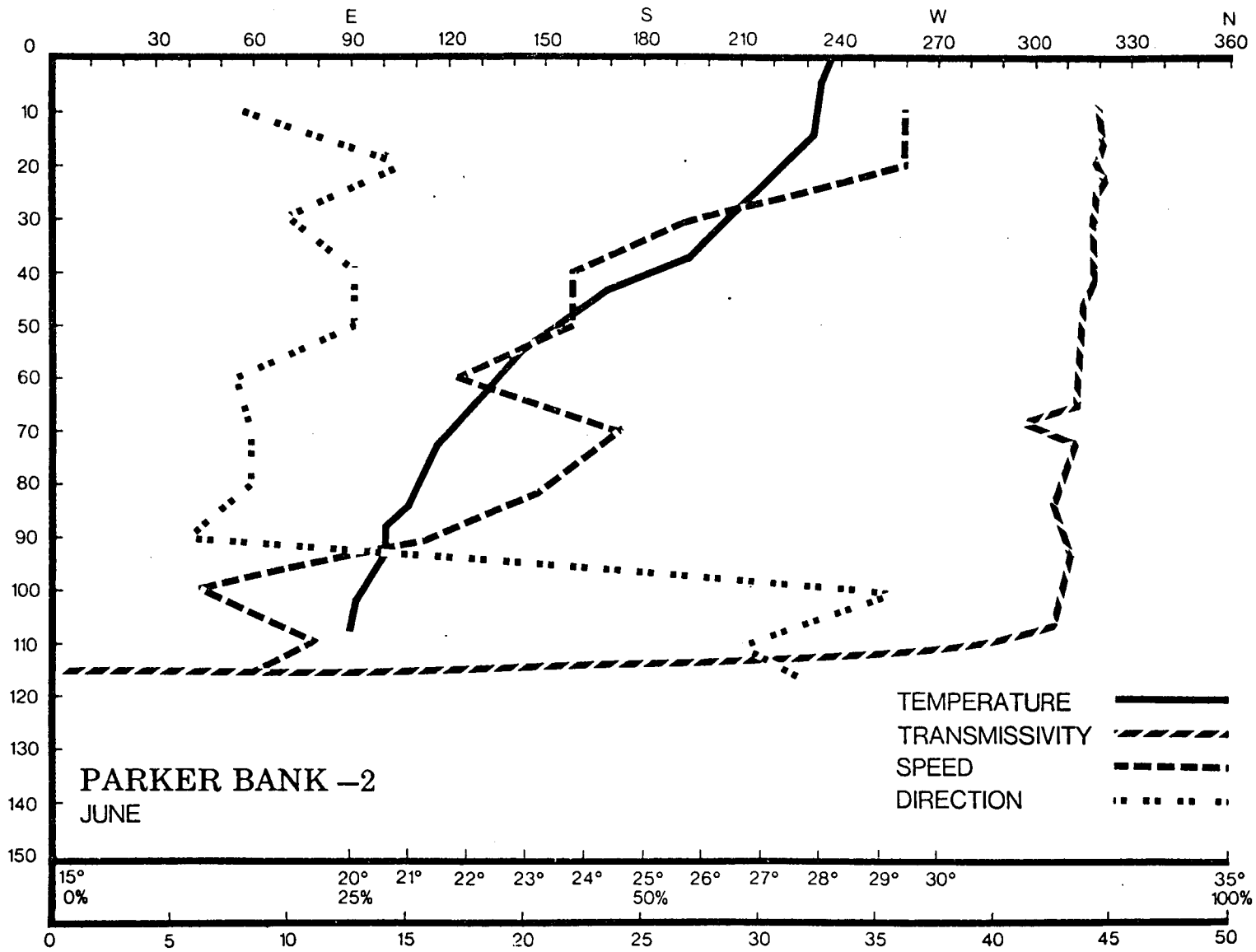

Figure III-27. Superposition of temperature, transmissivity and velocity at Parker Bank station 2.

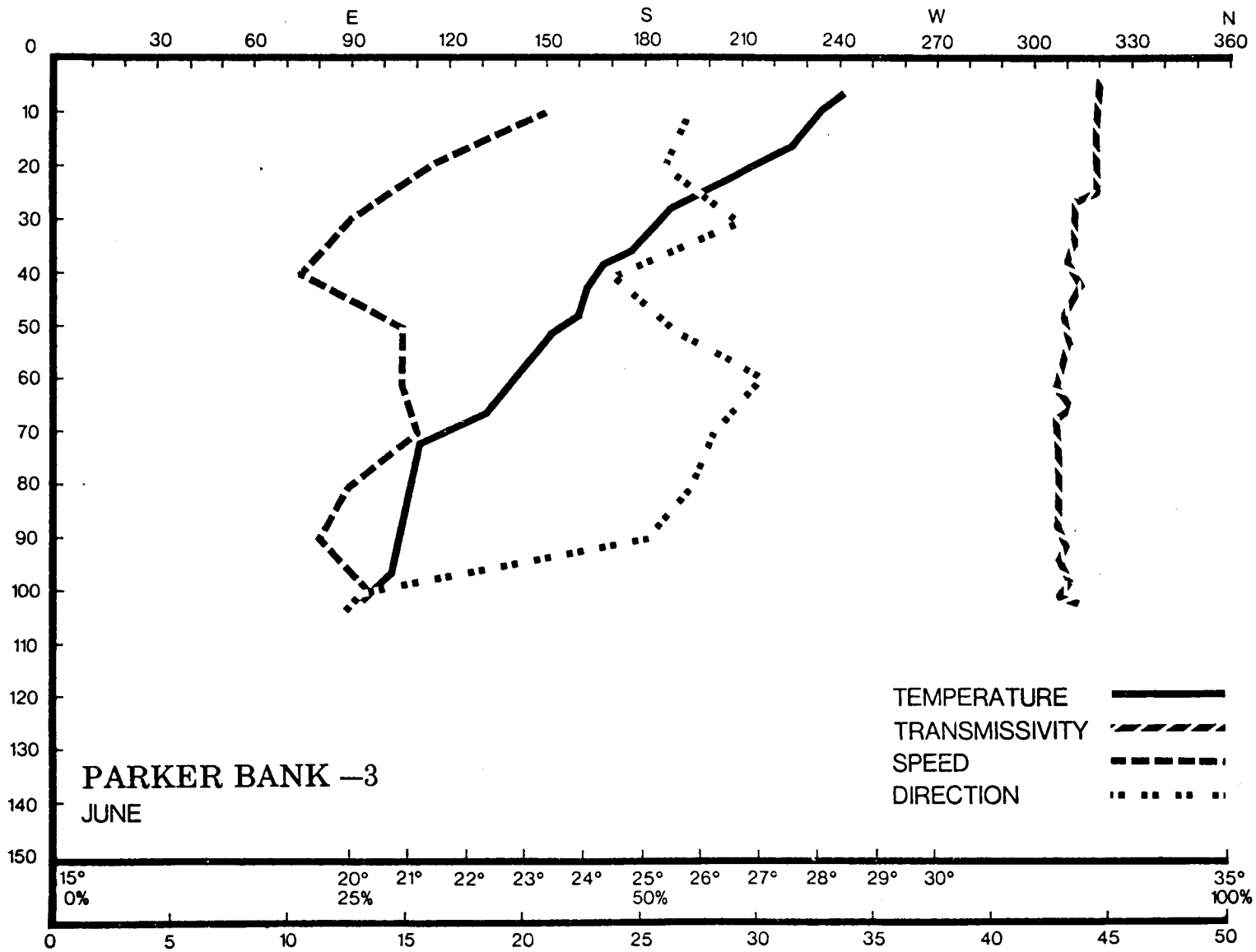

Figure III-28. Superposition of temperature, transmissivity and velocity at Parker Bank station 3.

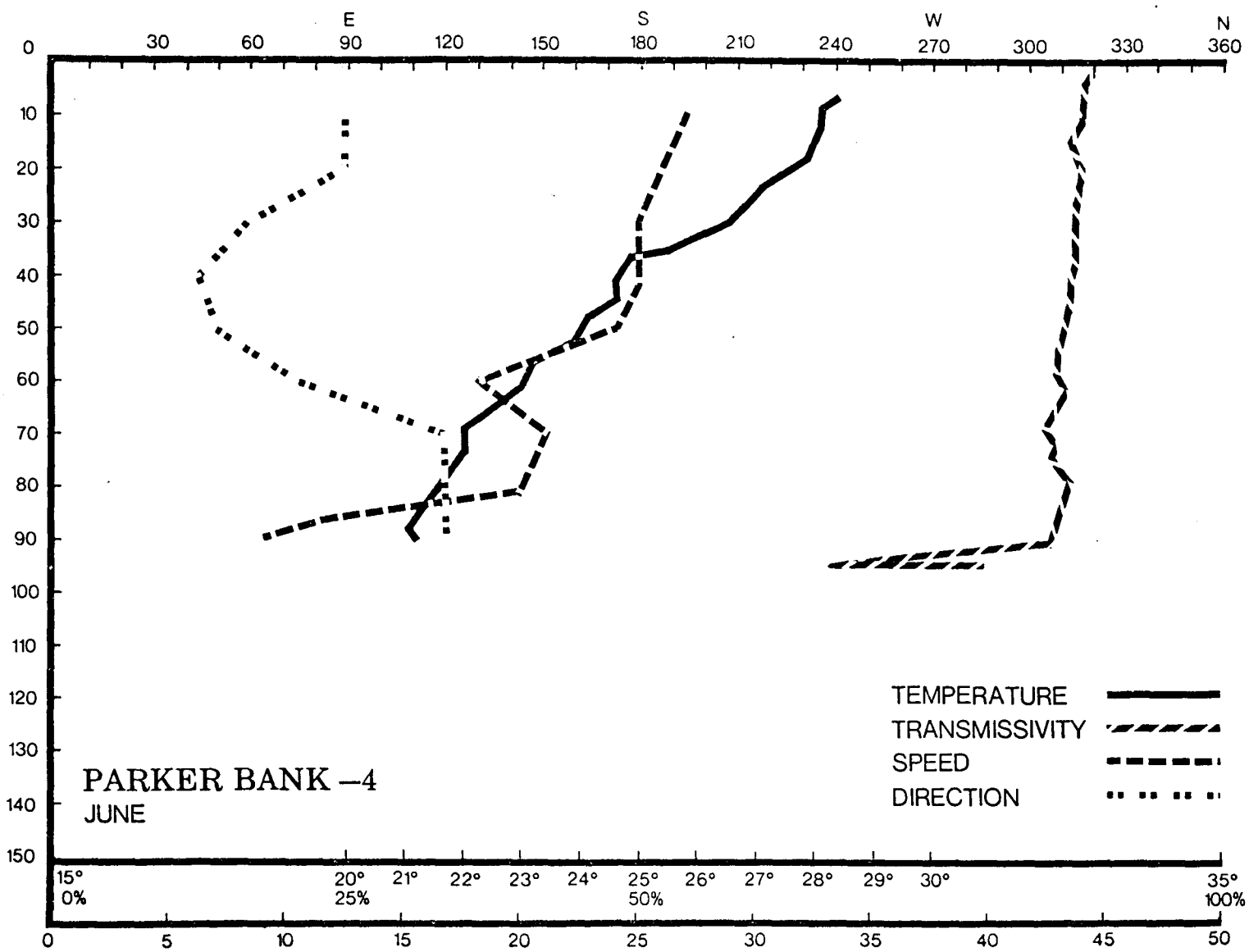

Figure III-29. Superposition of temperature, transmissivity and velocity at Parker Bank station 4.

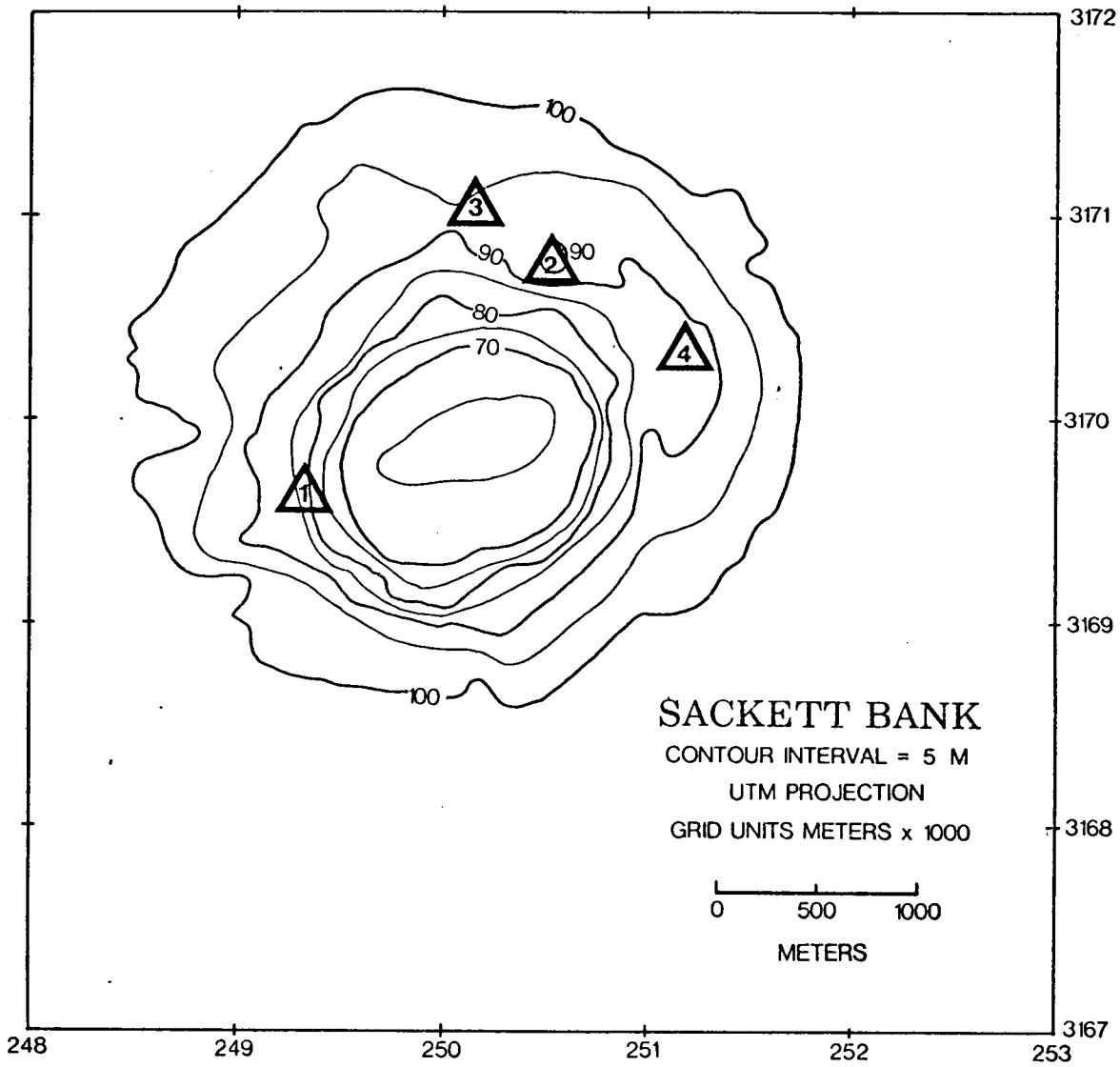

Figure III-30. Location of sampling stations at Sackett Bank.

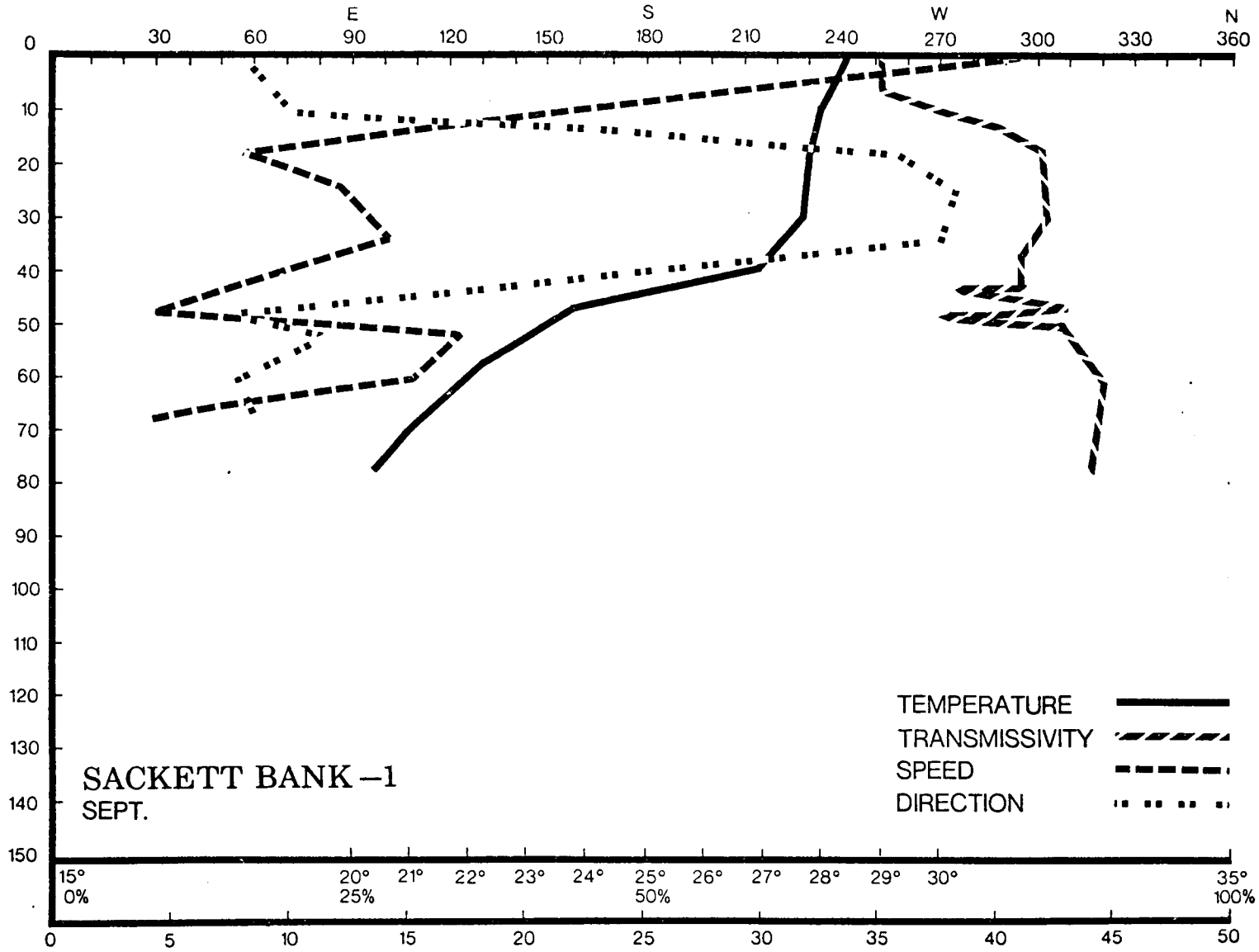

Figure III-31. Superposition of temperature, transmissivity and velocity at Sackett Bank station 1.

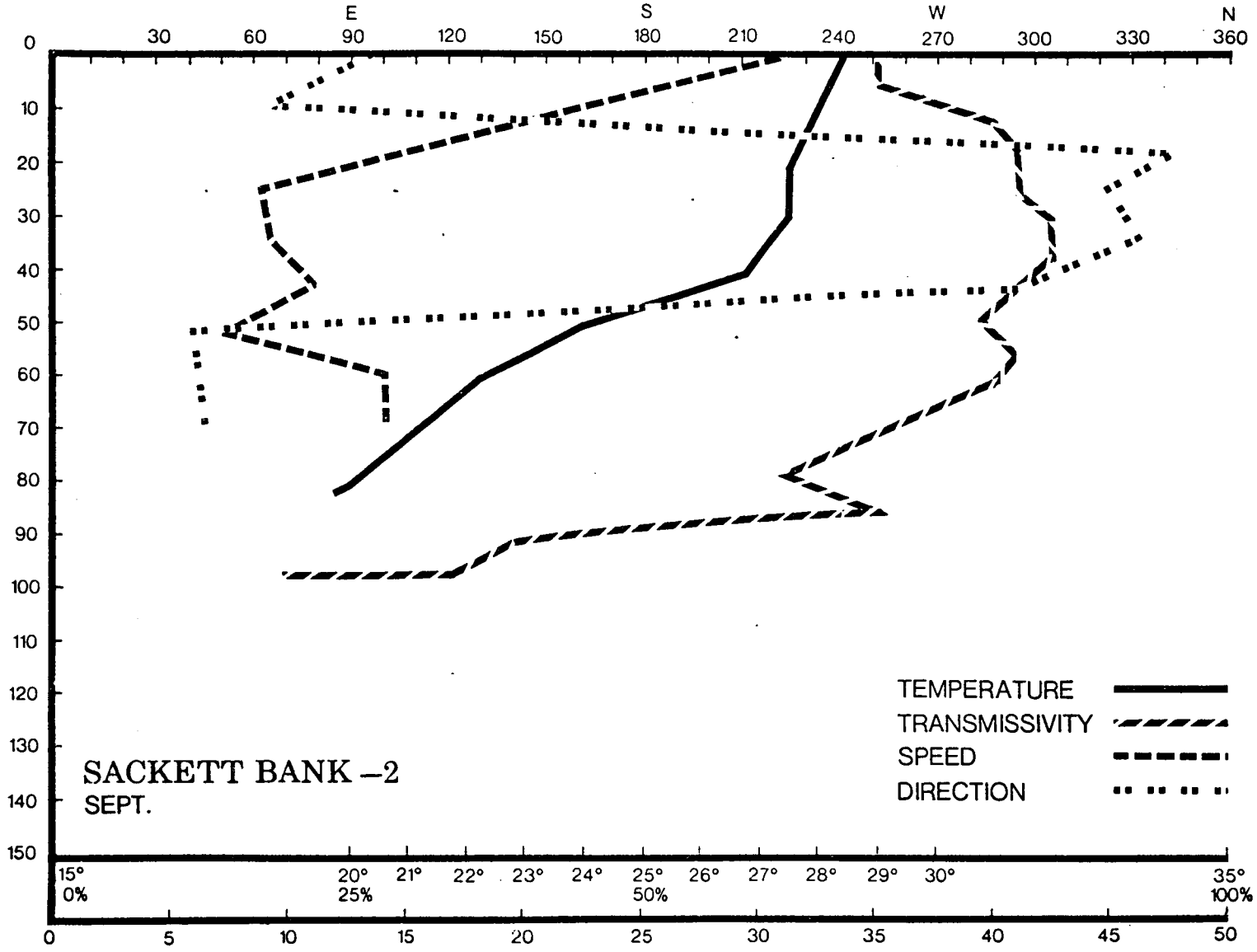

Figure III-32. Superposition of temperature, transmissivity and velocity at Sackett Bank station 2.

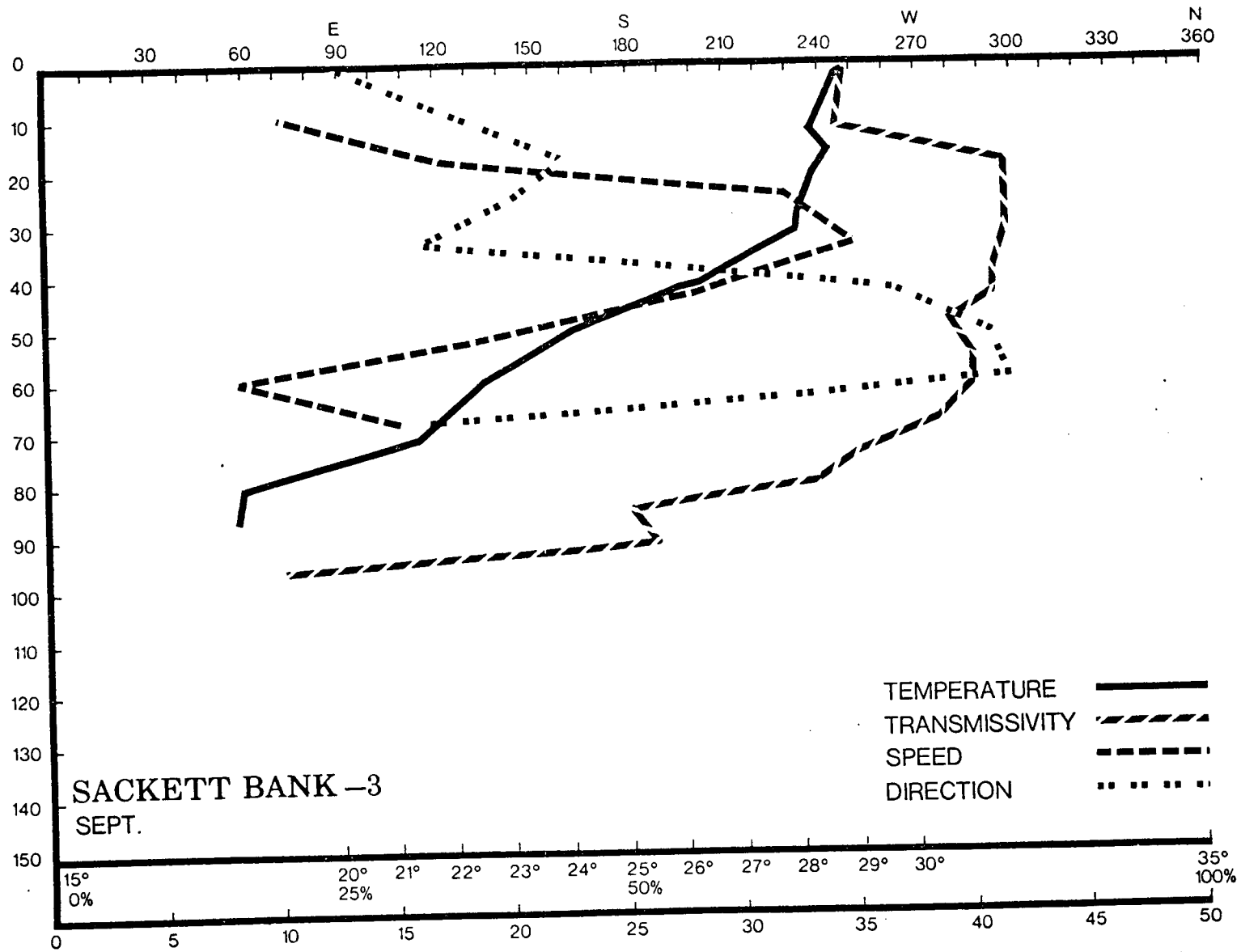

Figure III-33. Superposition of temperature, transmissivity and velocity at Sackett Bank station 3.

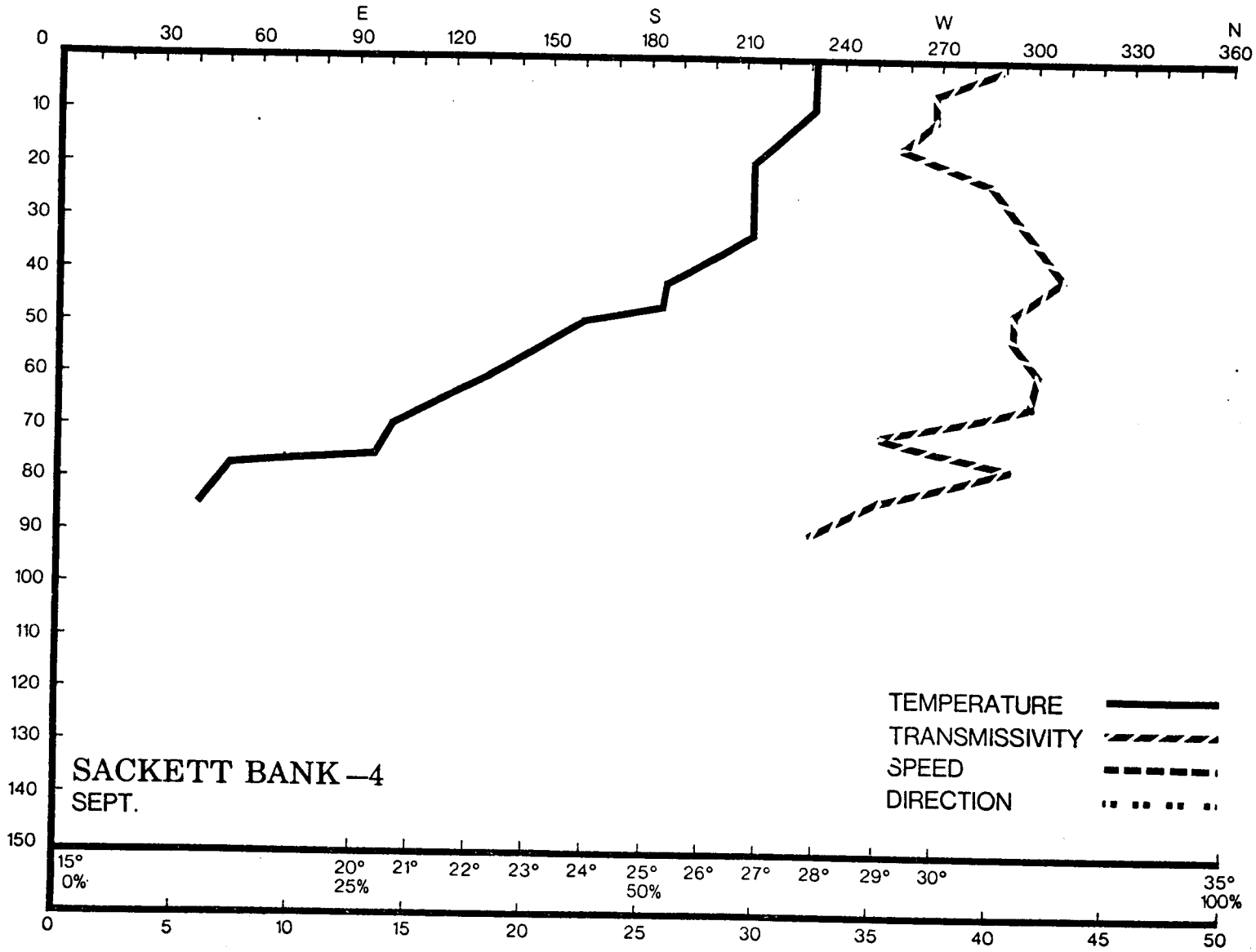

Figure III-34. Superposition of temperature, transmissivity and velocity at Sackett Bank station 4.

All of the velocity profiles (station 4 is missing because of an instrument malfunction) indicate a very strong directional shear at the base of the fresh water lens and a second one through the thermocline. The surface flow was to the east or northeast at the surface swinging to the west or northwest between ∿ 20 m and 50 m. Below 50 m the flow swung back to the east or northeast. The deeper stations, 2, 3 and 4 encountered a nepheloid layer with a poorly defined upper limit near 70 m. The surface layer also showed depressed transmissivity due to suspended material.

PART TWO

DRIFT BOTTLE STUDIES

WEST FLOWER GARDEN

Russell E. Putt
Thomas J. Bright

INTRODUCTION

In 1971 a baseline study of the West Flower Garden Bank was initiated by the Flower Garden Ocean Research Center, a division of the Marine Biomedical Institute of Galveston, Texas. As part of that effort, a drift bottle program was conducted to gather data concerning movements of surface waters from the bank. Particularly, we wished to examine to what extent surface carried materials released at the Flower Gardens are transported to near shore areas, and to evaluate seasonal variations in outer continental shelf surface currents in the Northwestern Gulf.

PROCEDURE

Coded recovery information cards were placed within "Pepsi" soft drink bottles which were then capped and sealed with parrafin. Numbers of these unweighted drift bottles were released from the West Flower Garden Bank during each of eight cruises, beginning in October 1971 and continuing through September 1972. Recoveries of bottles were recorded when enclosed cards were returned bearing information as to recovery site and date. A total of 950 bottles were released during the study, of which 385 or 40.5% were recovered. Insofar as the numbers of bottles dropped per cruise varied, recoveries are presented herein as percentages of the total numbers of released bottles recovered per cruise.

RESULTS

Bottles were recovered as far south as Mexico and as far north as Louisiana. Despite large areas of rarely visited and sparsely inhabited

coastline, seasonal recoveries as high as 55% were obtained in June, 1972. Recovery percentages were larger during the warmer months, as might be expected due to increased recreational beach use. Recoveries also appeared concentrated in areas of pronounced beach utilization. (i.e. Galveston, Corpus Christi, etc.)

The recovery range was divided into the following four areas: Tiger Point, Louisiana to Galveston, Texas (area 1), Galveston to Port O'Connor (area 2), Port O'Connor to Baffin Bay (area 3) and Baffin Bay to Boca San Rafael, Mexico (area 4) (Figure III-1).

Examination of the sequential records shown in Figures III-1 to -8 reveals a very neat progression of the zones of maximum recovery from the south-central area 3 in October 1971 to southernmost area 4 in January 1972, back to south-central area 3 in February and March 1972 to north-central area 2 early in May 1972 to northernmost area 1 in late May and June 1972 and then back again to north-central area 2 in September 1972. This rather orderly pattern of seasonal change in net drift direction appears to be directly correlated with similar changes in the predominant (resultant) wind patterns as measured at Corpus Christi, Texas for monthly periods immediately following releases of the drift bottles.

The minimum number of days between release and return of a drift bottle was 19 days. Time intervals between releases and first recoveries of bottles varied from 19 to 44 days (Table III-1), the former recovery being made at Galveston, Texas and the latter at Matamoros, Mexico at the mouth of the Rio Grande River. These first recovery data indicate that surface transit of floating debris from the West Flower Garden to various points on the Texas-Louisiana coast may occur within a time

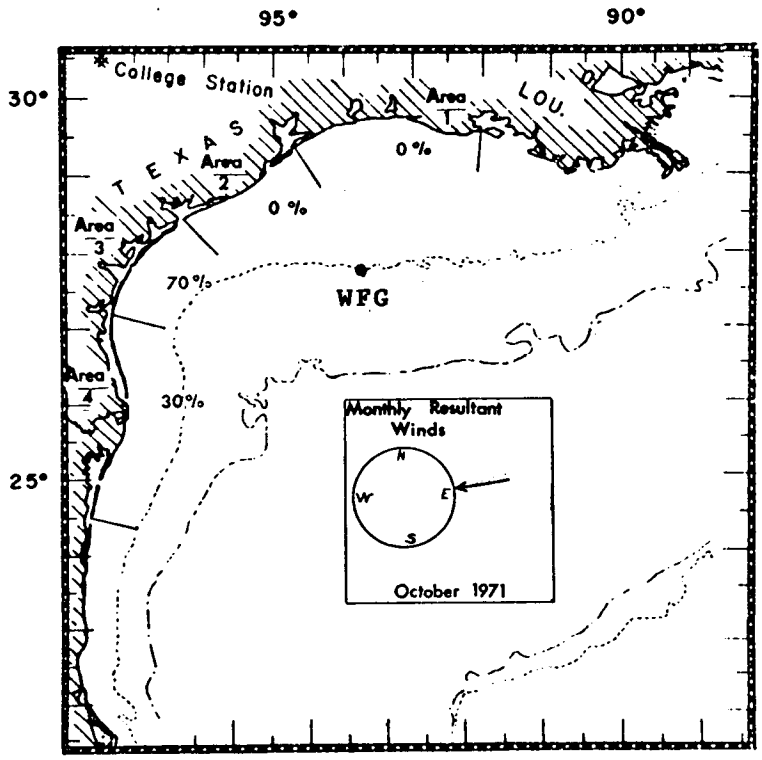

Figure III-35. Distribution of drift bottle returns for October, 1971 releases.

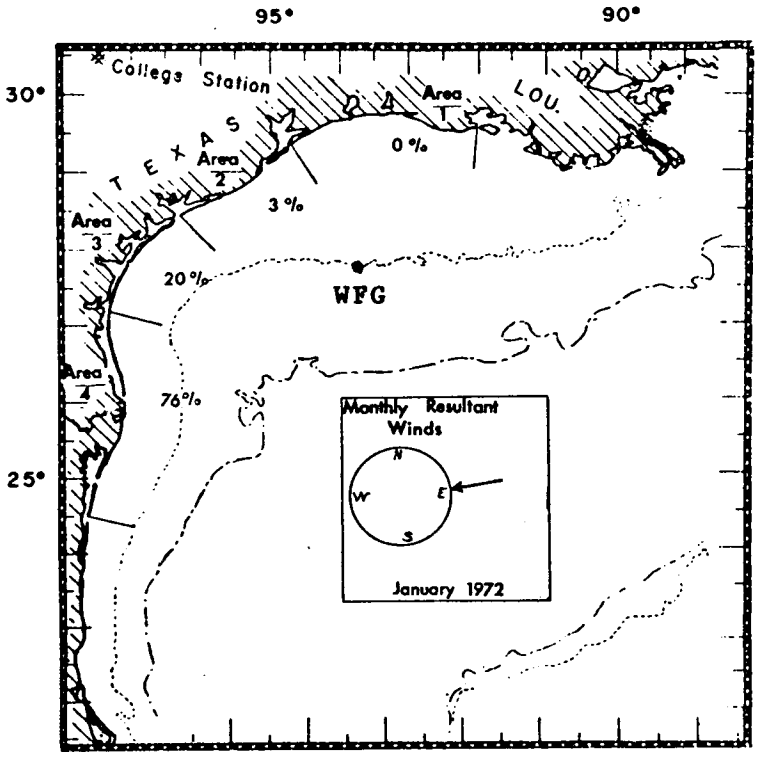

Figure III-36. Distribution of drift bottle returns for January, 1972 releases.

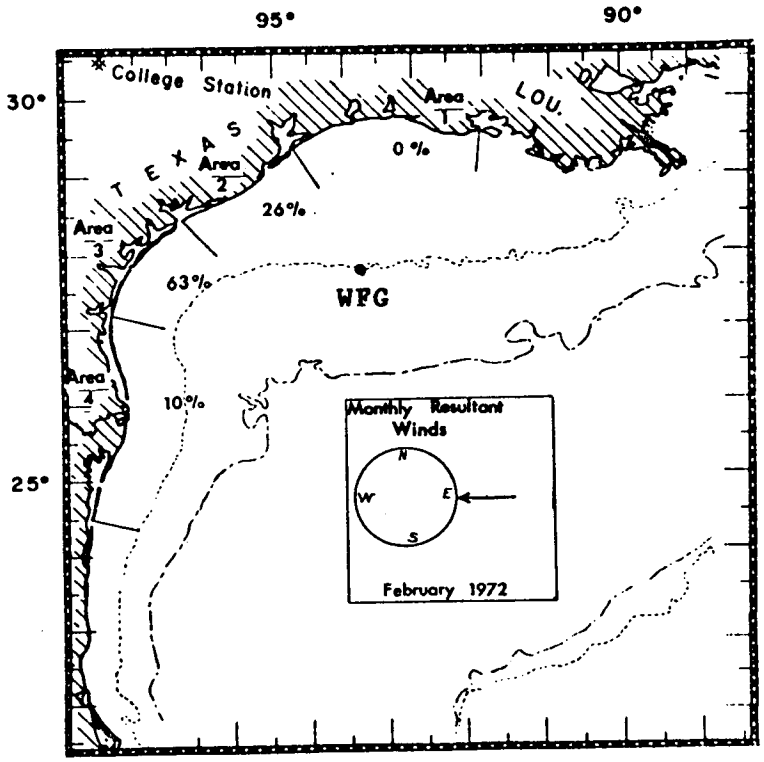

Figure III-37. Distribution of drift bottle returns for February, 1972 releases.

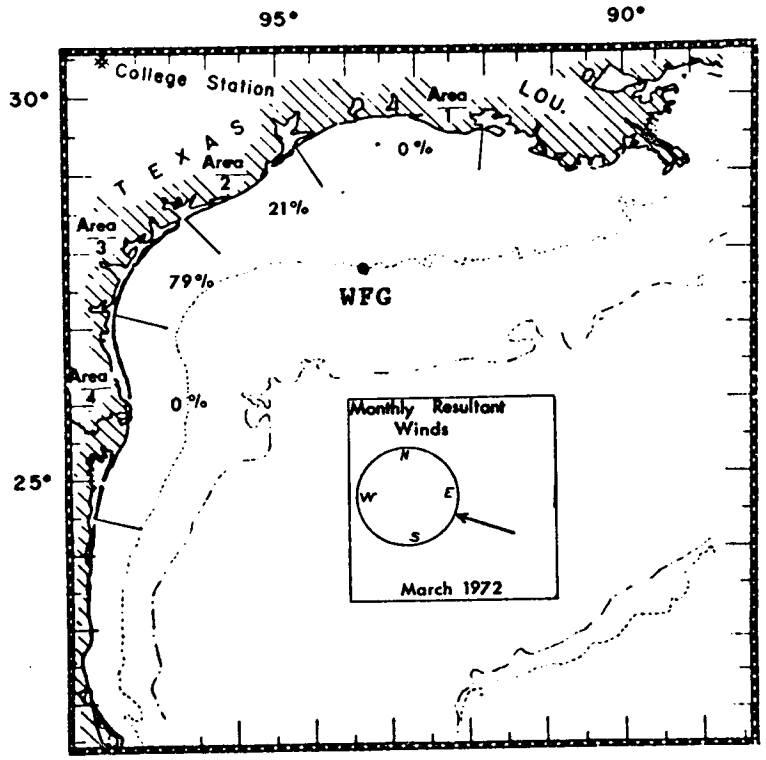

Figure III-38. Distribution of drift bottle returns for March, 1972 releases.

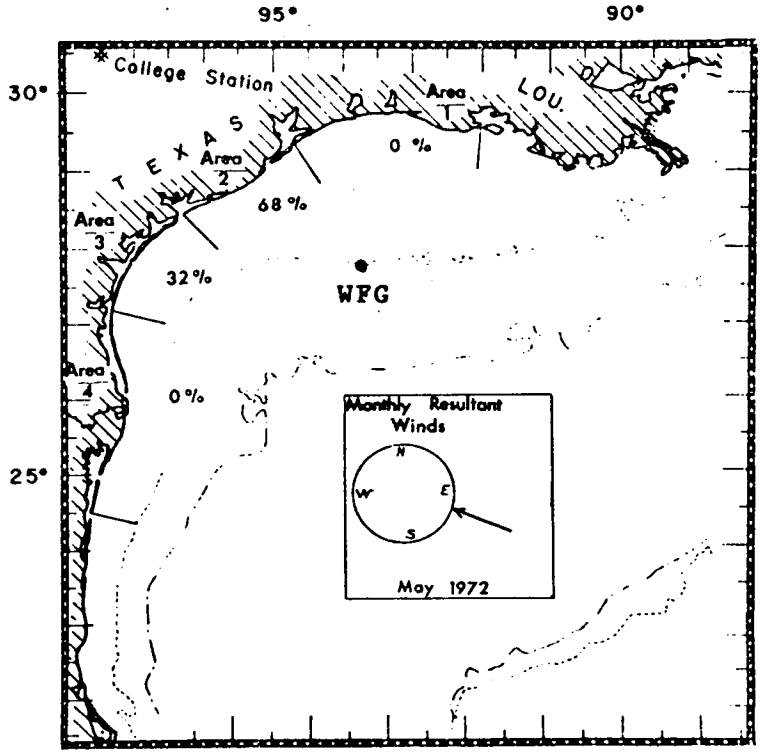

Figure III-39. Distribution of drift bottle returns for May 7, 1972 releases.

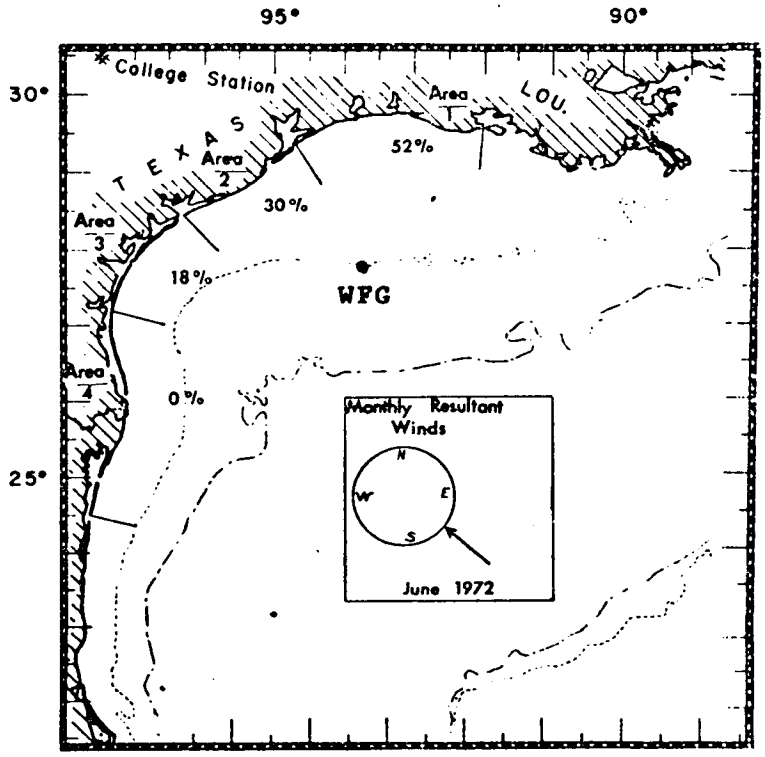

Figure III-40. Distribution of drift bottle returns for May 24, 1972 releases.

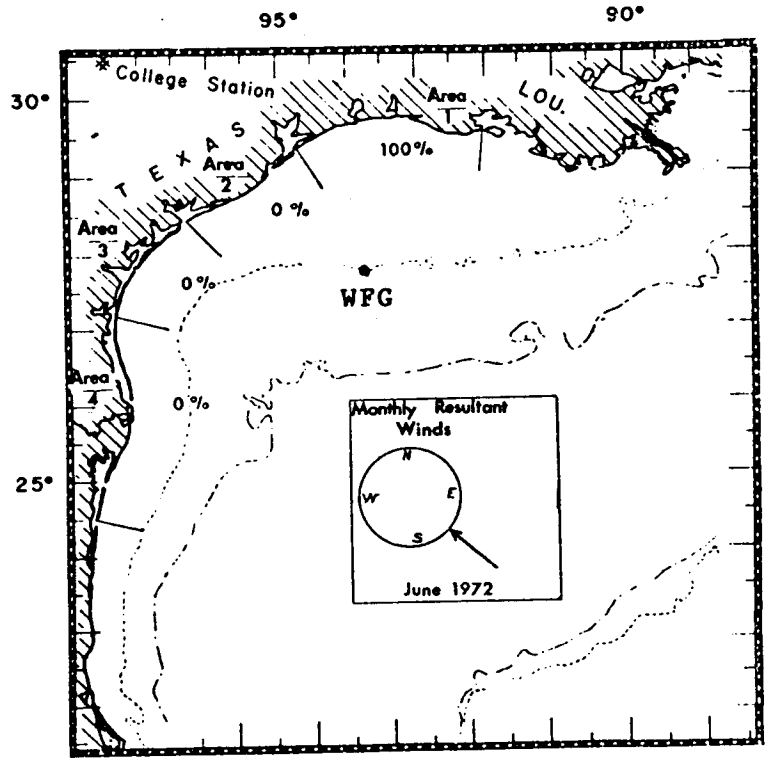

Figure III-41. Distribution of drift bottle returns for June, 1972 releases.

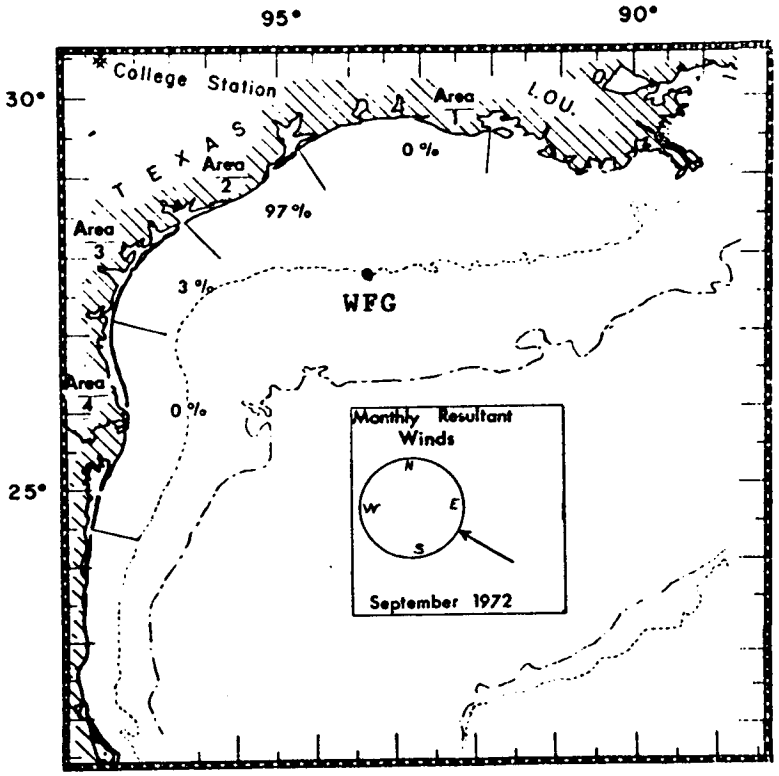

Figure III-42. Distribution of drift bottle returns for September, 1972 releases

TABLE III-1

FIRST RECOVERIES OF WEST FLOWER GARDEN DRIFT BOTTLES

Release Date	Date of First Recovery	No. of Days from release to 1st Recovery	Recovery Location	No. of Miles from Release to Recovery Site
October 9, 1971	November 12, 1971	3	Port Isabel, TX	230
January 14, 1972	February 27, 1972	44	Matamoros, Mex.	240
February 27, 1972	March 23, 1972	26	Matagorda Isl., TX	175
March 25, 1972	April 22, 1972	28	Sargent, TX	130
May 7, 1972	June 2, 1972	25	Freeport, TX	120
May 24, 1972	June 19, 1972	26	Port Aransas, TX	200
June 10, 1972	July 14, 1972	34	Bolivar, TX	120
September 1, 1972	September 20, 1972	19	Freeport, TX	120

period of 2 to 5 weeks depending on seasonal wind and surface current conditions.

CONCLUSIONS

The data indicate a strong correlation between the drift of floating objects released at the West Flower Garden and monthly resultant wind patterns at Corpus Christi, Texas and that such objects could be expected to reach nearby coasts in a matter of several weeks. There may be a basis here for a simple method of predicting the behavior of an oil spill if one should ever occur at the Flower Gardens, either as a result of drilling or the grounding of a supertanker on the shallow reefs.

CHAPTER IV

DESCRIPTIVE GEOLOGICAL RECONNAISSANCE STUDIES

PART ONE

GEOLOGY AND SEDIMENTOLOGY

Principal Investigator

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Contributors

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Frank Irwin
Richard Parker
Bob Tompkins
Wei Wang
Celia Watson

INTRODUCTION

This chapter describes the bottom conditions at and in close proximity to the banks investigated under this contract. Descriptions of the physiography of the banks are based upon the bathymetric surveys and submersible observations. The sediments are characterized by: 1) clay mineralogy, 2) grain-size distribution, (3) total carbonate percent, 4) bulk mineralogy, and 5) particle type identification of the coarse fraction. Cores taken from the sediment apron surrounding the banks have been described and radiographed. The extent of geological effort on the banks is given in Table IV-1. No mapping was done at the East Flower Garden as this already had been completed. Samples were not taken at Claypile, 18 Fathom, nor Ewing Banks. In addition to the five banks observed on geological dives, tapes of Bouma, 18 Fathom Lump, and Sackett Banks made during biological dives were reviewed for their geological content. See Figure I-1 for the bank locations.

PHYSIOGRAPHY

GENERAL

All of the banks investigated during the present contract are associated with shallow subsurface salt structures. All except Sonnier Bank are shelf edge banks. Sonnier is a mid-shelf bank

Table IV-1

Geological Effort on Banks

BANK	MAPPING	SAMPLING	SUBMERSIBLE
East Flower Garden		x	x
Claypile	x		
Bright	x	x	x
18 Fathom	x	3rd Priority	
Bouma	x	x	
Sonnier	x	x	x
Parker	x	x	x
Ewing	x	3rd Priority	x
Sackett	x	x	

composed primarily of Tertiary bedrock while the shelf edge banks are primarily Pleistocene to Recent coral algal reefs. Bathymetric charts of the banks mapped for the present study have been drafted at a scale of 1:12,000. (See Figures 1 through -14.)

PERSPECTIVE DIAGRAMS

In order to create a better visual image of the bank physiography, computer produced perspective diagrams were constructed. An attempt was made to preserve the interpretation of the manually drawn contour maps. This was accomplished by digitizing contour lines at irregular closely spaced points. This data was then converted to a form compatible with the SYMAP program.

SYMAP is a computer program which portrays quantitative data in a map form. Data consist of coordinate locations of randomly spaced points and, for the present study, the elevations of the bank at these points. Other data specify the map size, the contour interval, and the symbols which represent the intervals. SYMAP interpolates between data points in order to find the elevation of the bank at regularly spaced grid points. The program then determines the contour interval to which each grid value belongs and assigns each point the appropriate contour symbol. A map which consists of these symbols is then printed.

The concept, overall design and mathematical model was developed in 1963 by Howard T. Fisher (Northwestern Technological Institute). It was programmed by Mrs. O. G. Brown of the Northwestern University

Computing Center. Since then many changes have been made in the program. Our study used version number 5. Many of these changes were accomplished by Robert A. Russel and Donald S. Shepard at the Laboratory for Computer Graphics and Spatial Analysis, Harvard University.

The printer type contour maps were produced and checked for conformity with the manually produced charts. The gridded contour values from these maps were then fed from tape into the SYMVU program.

SYMVU is a computer program which plots three dimensional displays of data. It was developed by Frank J. Rens, under the direction of Prof. Howard T. Fisher, at the Laboratory for Computer Graphics and Spatial Analysis, Harvard University. The data from SYMAP was later used by SYMVU in order to obtain perspective views of the banks. Plotting was performed by using a Systems Engineering Laboratory plotter. The diagrams are included as Figures IV-15 to -28. Captions on the diagrams require definition. Azimuth refers to the direction the observer is facing when viewing the bank. Altitude refers to the height of the observer in degrees relative to the crest of the bank. Width and Height are arbitrarily chosen figures that control the scale of the diagram. The vertical scale on the right side of the diagram is a depth scale after foreshortening.

DESCRIPTION OF BANKS

Claypile (Figures IV-1 and -2)

This feature is approximately 4000 m long and 2100 m wide, trending in a northwest-southeast direction. Local relief is about 17 m. The crest of the bank is a north-south oriented ridge that

divides the bank into two parts: 1) a gentle southeastern slope and 2) a northwestern basin that is circumscribed by steeply dipping Tertiary bedrock. The basin appears to be due to a salt spine at that location that was dissolved during Late Pleistocene subaerial exposure of the bank. Collapse of the overlying bedrock created the basin. No sampling nor geological submersible observations were conducted at Claypile. However, T. J. Bright (pers. comm., 1978) has stated that the steeply dipping Tertiary beds resemble the siltstones and claystones observed at Stetson Bank.

Bright (Figures IV-3 and -4)

Bright Bank is approximately 6300 m wide in an east-west direction and 5800 m wide in a north-south direction. Local relief is 70 m. The crest of the bank at between 50 and 55 m is a broad surface of very low relief. Scattered over this surface are outcrops of Pleistocene (?) reef rock. The relief on the reef rock appears to be 45 to 60 cm. The rock is jointed and large areas of coarse sand, coral and algal nodules lie between the joint blocks.

Three lineations on the bank appear to be fault controlled (Figure IV-3). A north-south lineation at grid coordinates 472 x 3082 to 3083.5 may represent a radial fault. Another possible radial fault lies between grid units 467 and 470 at 3086. The steep scarp which lies between grid units 3086 to 3088 and 470.5 to 473 is a peripheral fault.

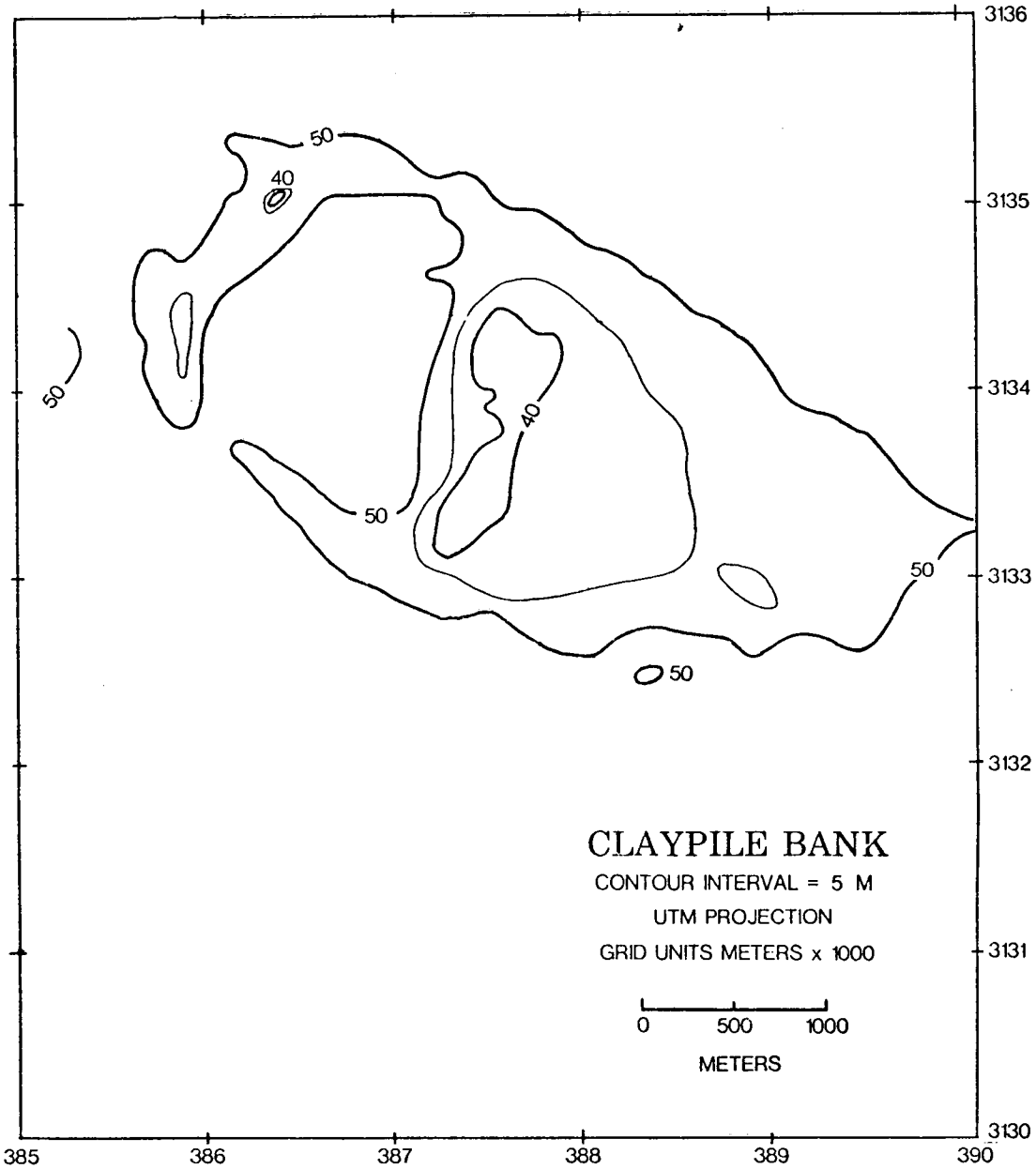


Figure IV-1. Bathymetric map of Claypile Bank.

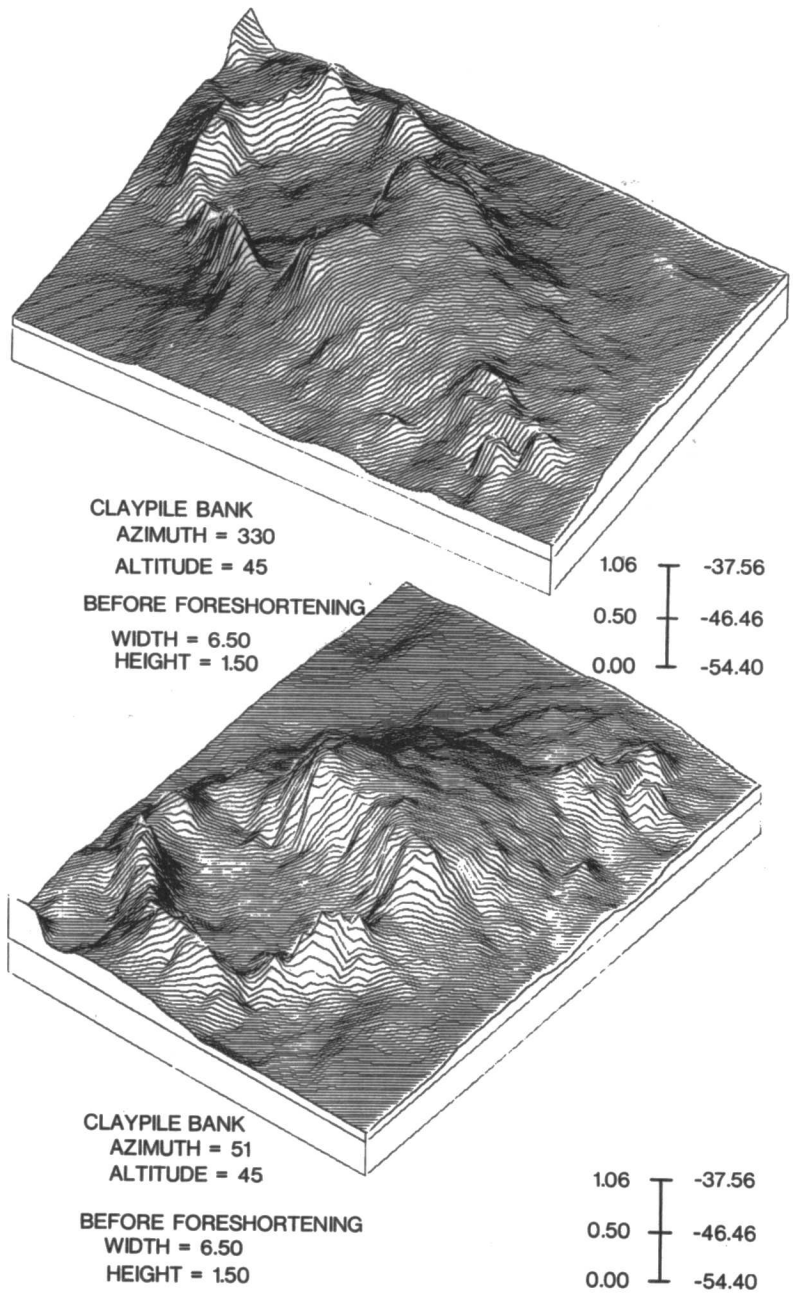


Figure IV-2. Three dimensional perspective views of Claypile Bank: 330° and 51° azimuth.

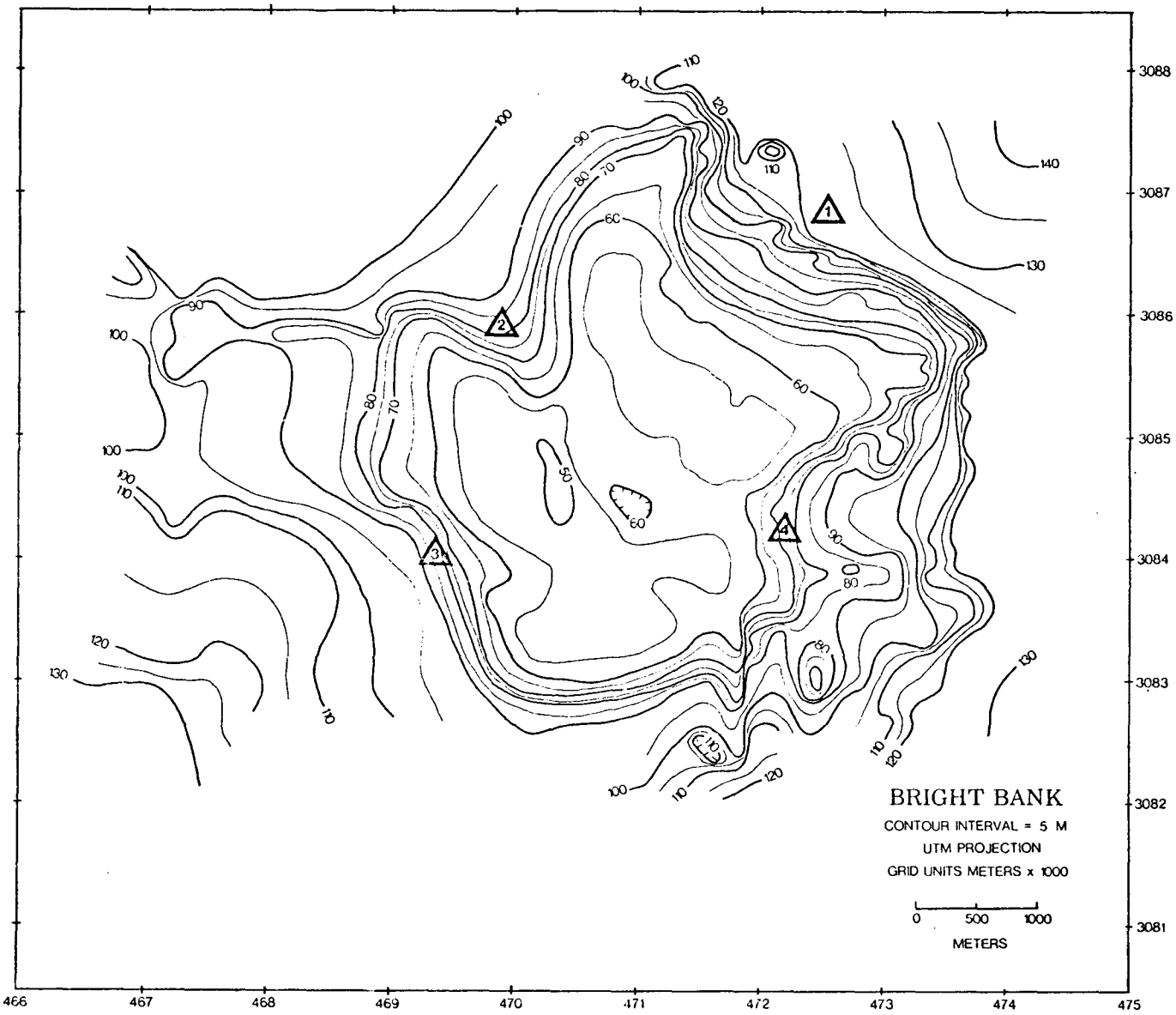
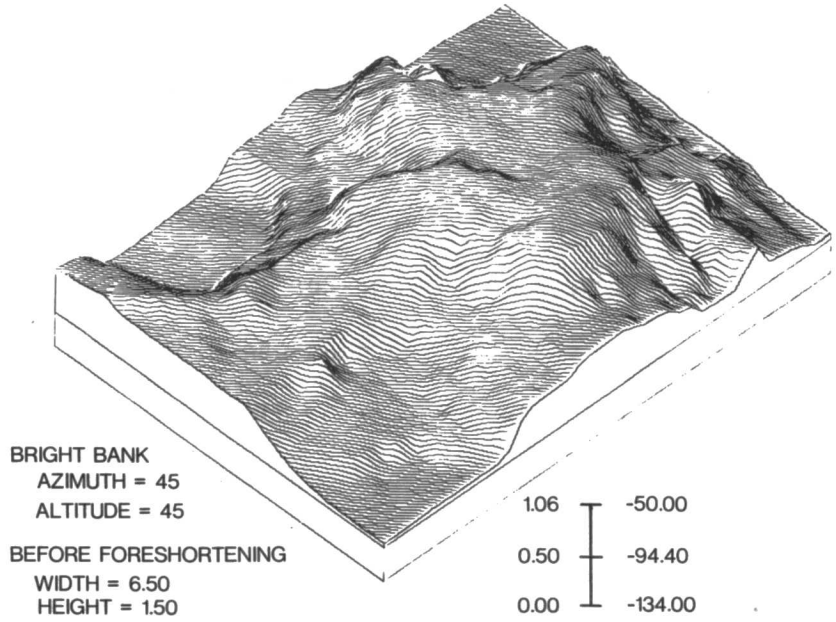


Figure IV-3. Bathymetric map of Bright Bank showing sampling station locations.



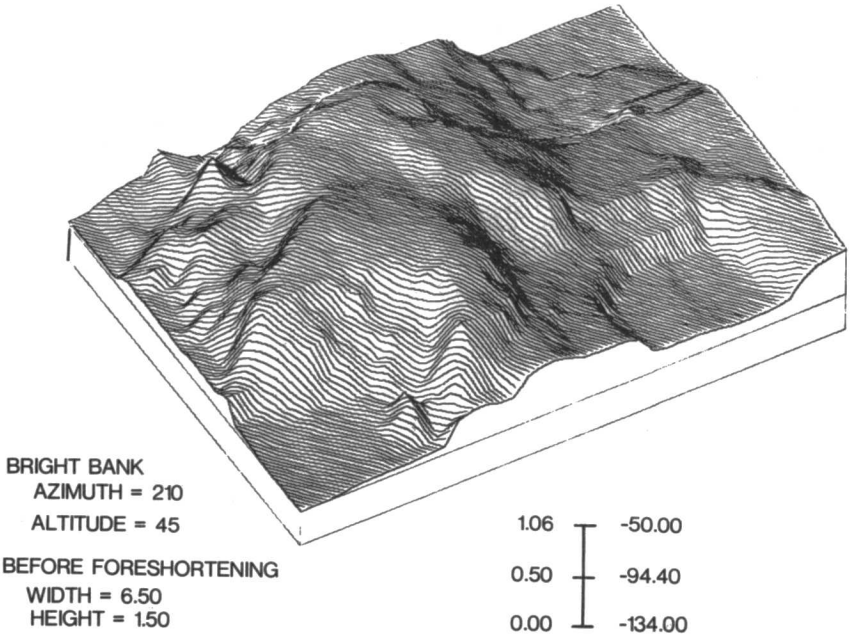


Figure IV-4. Three dimensional perspective views of Bright Bank: 45° and 210° azimuth.

18 Fathom (Figures IV-5 and -6)

This feature is an arcuate pair of northeast-southwest trending ridges separated by a valley. The bank appears to be a small part of a large salt dome that lies to the southwest. Local relief is about 90 m with the crest of the southeastern ridge lying at a depth of about 50 m. The northwestern slope of the outer ridge is considerably steeper than the southeastern slope giving the impression of a resistant Tertiary formation dipping steeply away from the salt dome. The inner ridge is less resistant and has much lower relief. The valley between the two ridges represents a Tertiary unit that was easily eroded during Late Pleistocene exposure. A breech through both ridges at grid coordinates 538 x 3094 may represent a Pleistocene drainage feature (Figure IV-5).

A drowned fringing reef was encountered during one of the submersible dives. The reef appears as a massive ledge. Its crest lies at a depth of 78 m and its base is at 90 m (see Figure VI-2). The upper surface of the reef was covered with knobby protuberances about 60 cm high. These protuberances appear to be the same as those seen on Southern Bank (Bright and Rezak, 1977) and are interpreted to be intertidal erosional features. Cutting through the reef at right angles to its trend are several large channels filled with sand. These are interpreted to be surge channels between reef buttresses.

The face of the reef has a very sharp overhang about 2 to 3 m thick and about two meters wide. In one location a chimney was found to penetrate the overhang. The overhang may have been caused by the outward growth of an emergent reef community or it could be a disso-

lution feature such as are commonly seen in carbonate rocks that are exposed at sea level. All evidence points to this reef having been formed at or near sea level.

Bouma (Figures IV-7 and -8)

Bouma is a nearly circular bank about 5800 m wide in an east-west direction and about 5500 m in a north-south direction. Maximum relief is 47 m. There are two major peaks on the bank, one at grid coordinates 522.8 x 3104 and the other at 554 x 3101.5. Their crests lie at 60 m and 65 m respectively. To the north of the 65 m peak, a large depression signals the early stages of collapse of the crest of the bank. The rough topography on the northwestern and northern sides of the bank (Figure IV-7) indicates that those parts of the bank have already collapsed and the peaks in those areas are partially buried beneath Recent sediments. Three valleys are located on the north, southwest, and south sides of the bank. They appear to be erosional features but are most likely structurally controlled.

Sonnier (Figures IV-9 and -10)

The name has been changed to the plural form as there are eight separate banks or peaks associated with this salt dome. The peaks are nearly conical features with a maximum relief of about 30 m. Each peak consists of steeply dipping Tertiary sandstones, siltstones and claystones. The strike of the bedding planes on the one peak that was observed from the submersible varies from 300 to 330° and the dip varies from 45 to 90°. The constancy of the strike within

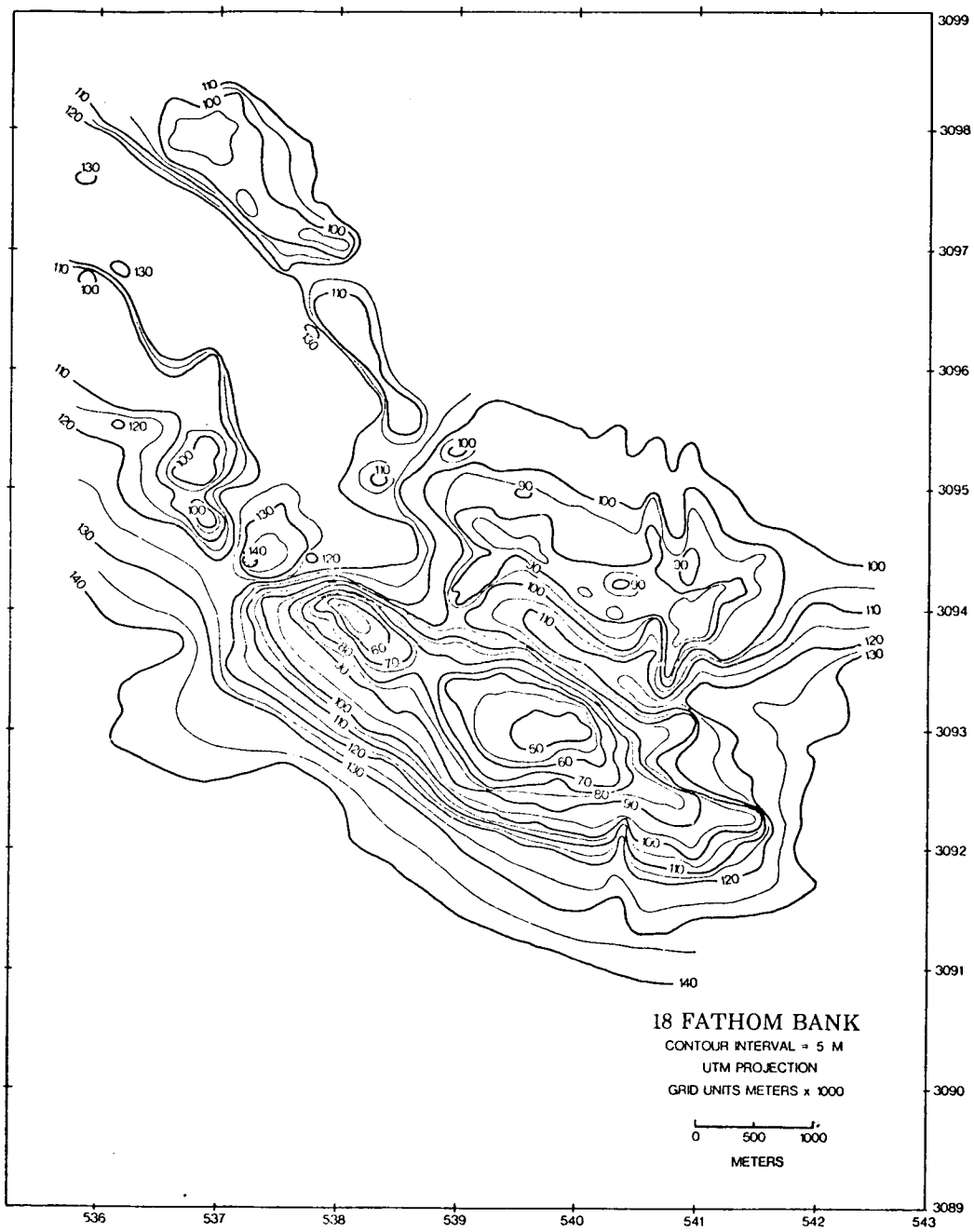


Figure IV-5. Bathymetric map of 18 Fathom Bank.

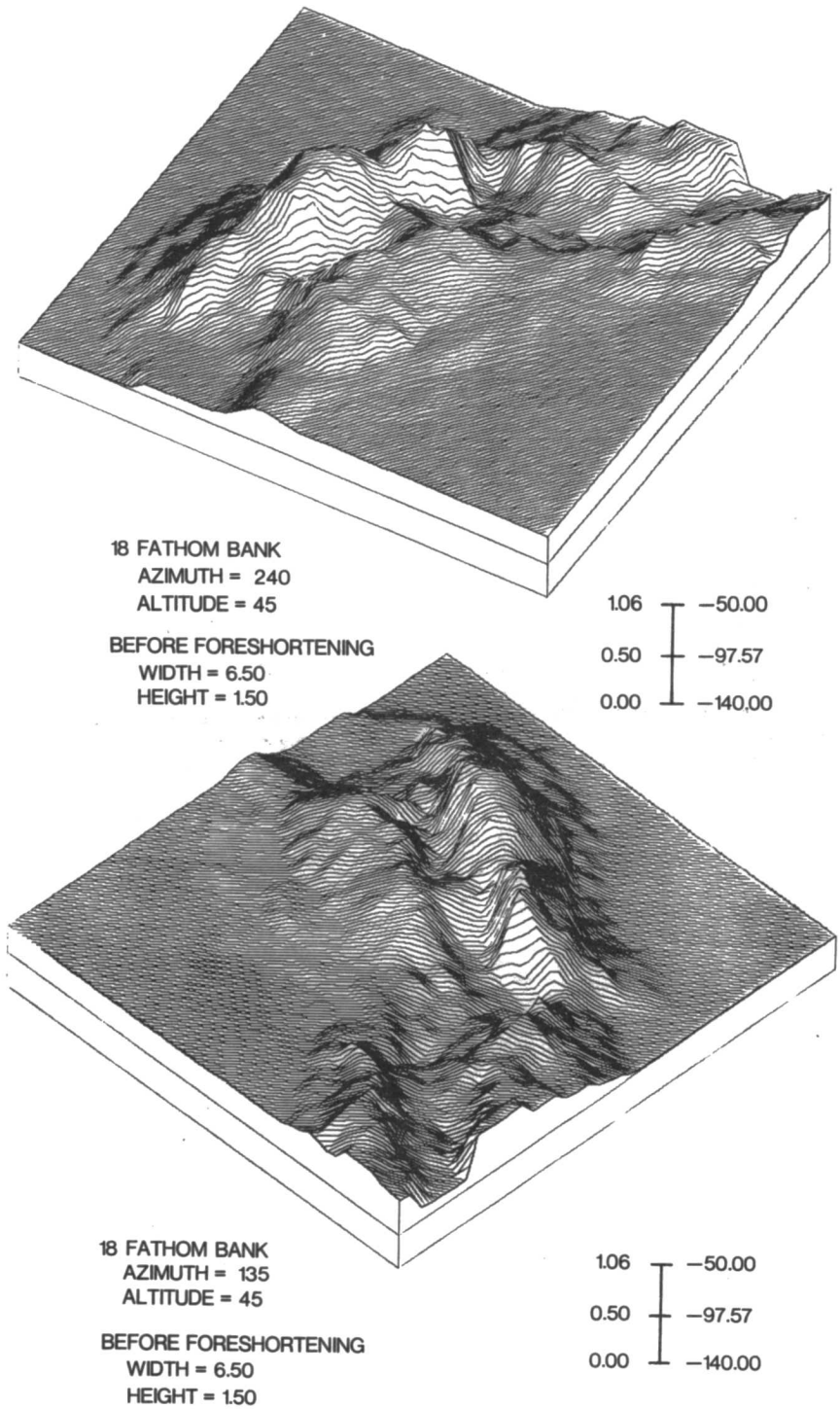


Figure IV-6. Three dimensional perspective views of 18 Fathom Bank: 240° and 135° azimuth.

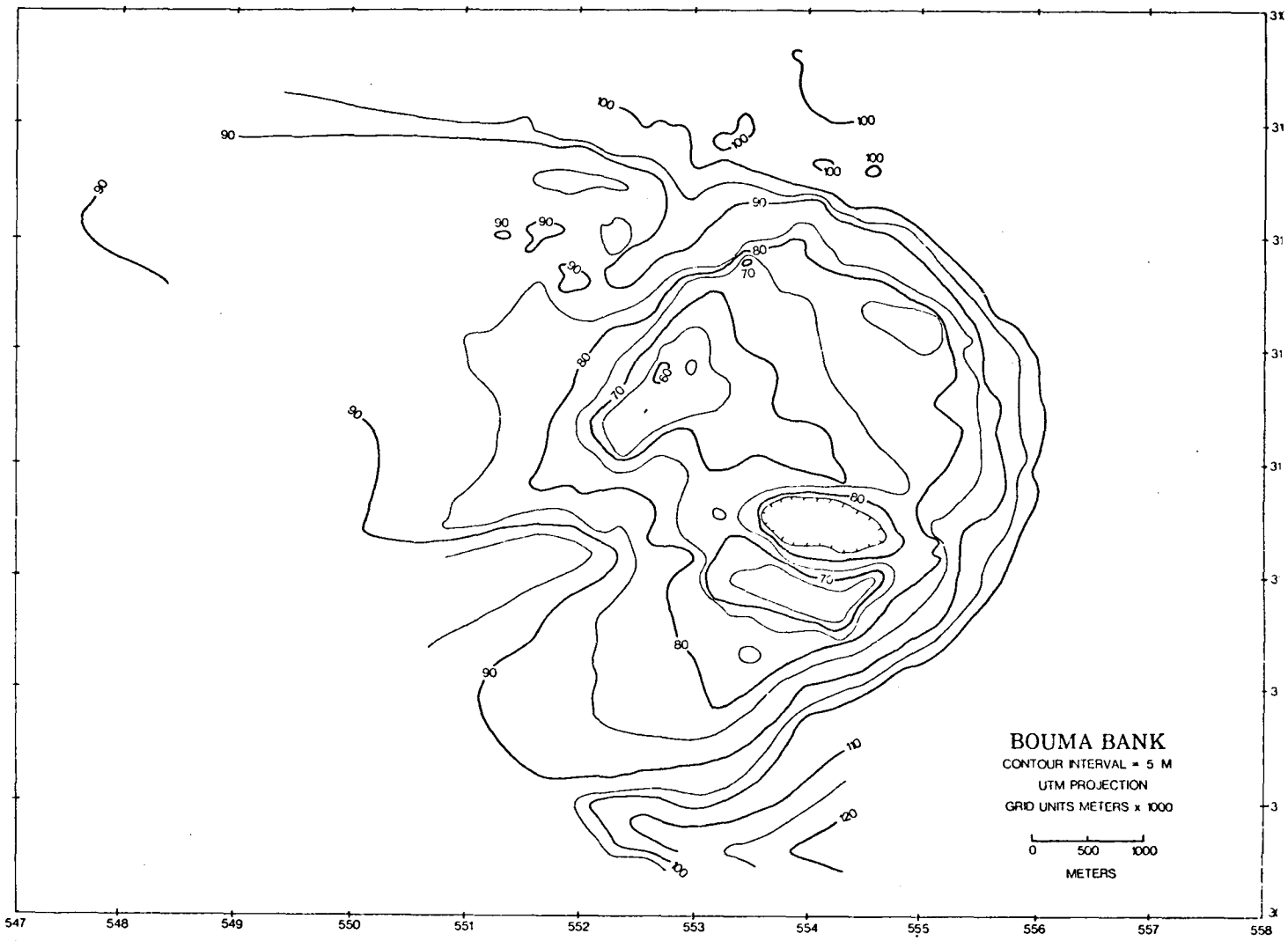


Figure IV-7. Bathymetric map of Bouma Bank.

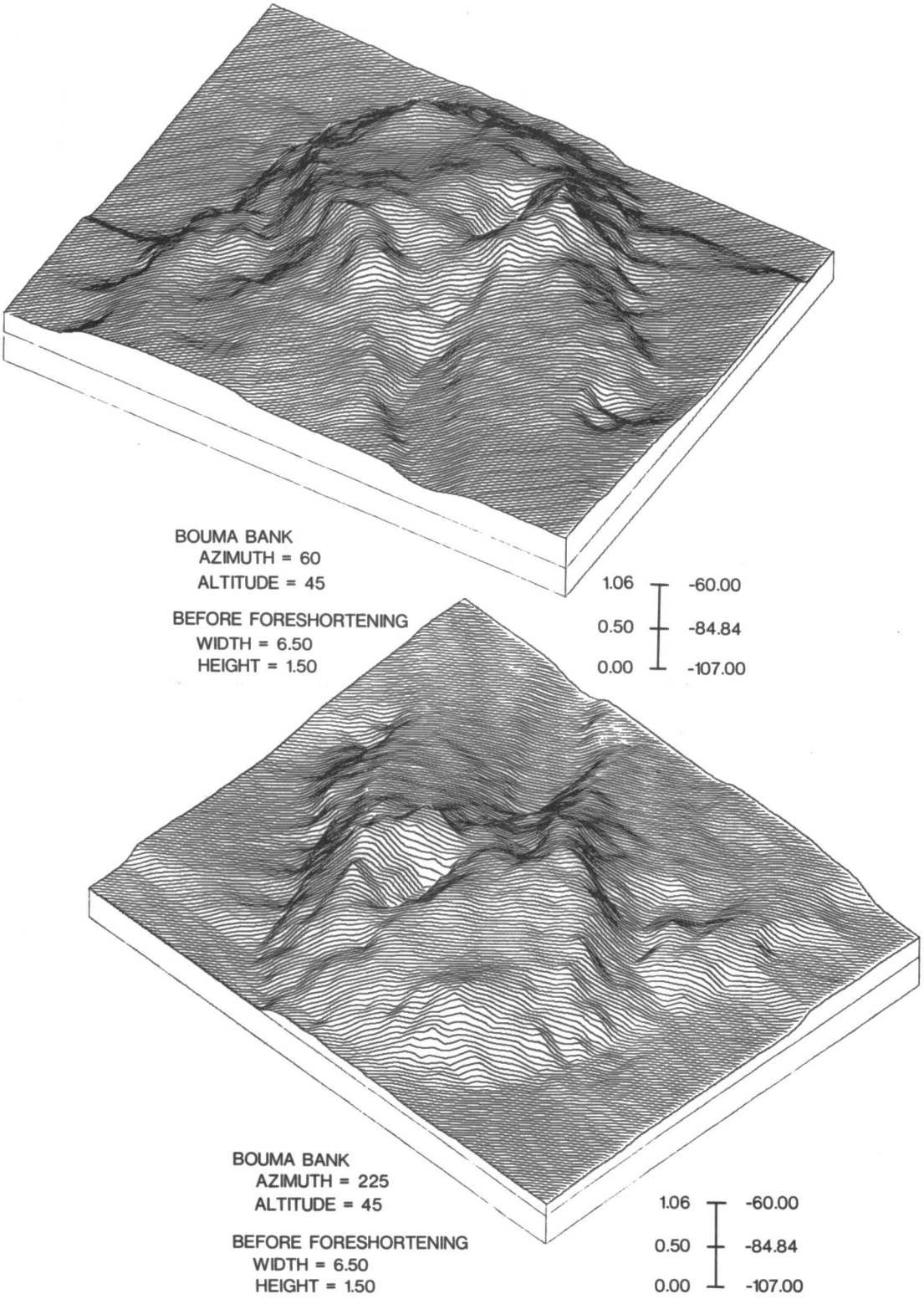


Figure IV-8. Three dimensional perspective views of Bouma Bank: 60° and 225° azimuth.

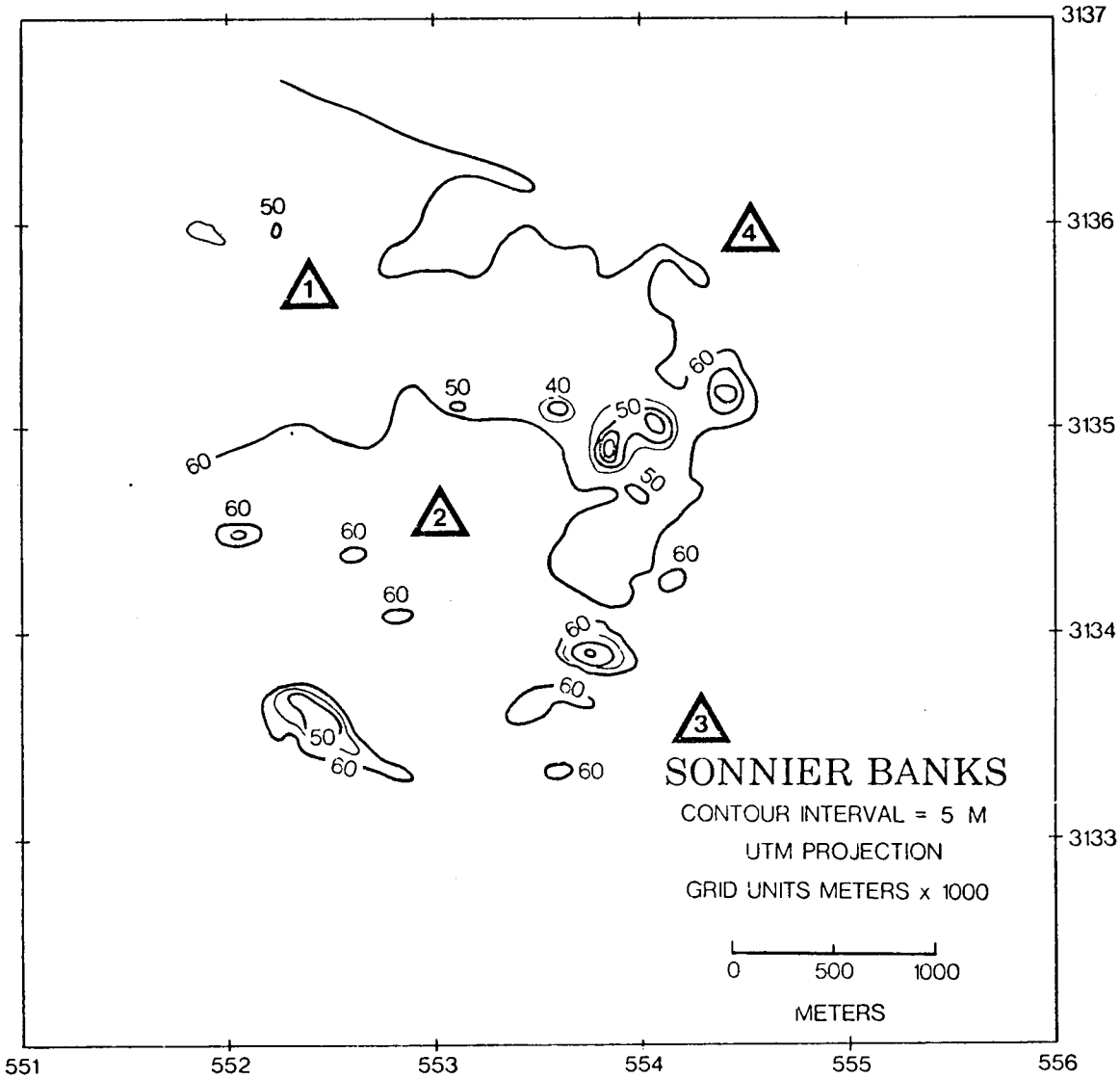
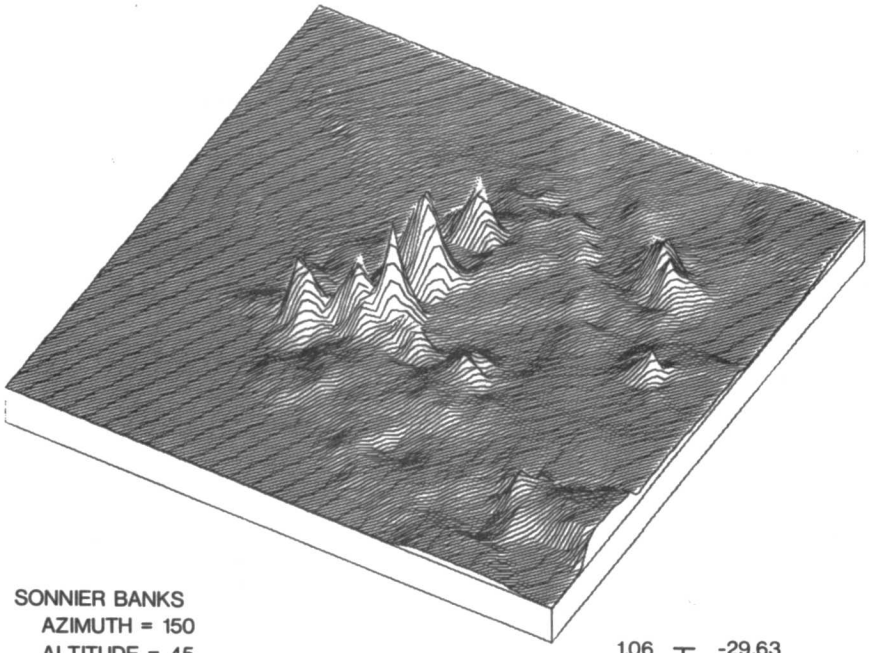


Figure IV-9. Bathymetric map of Sonnier Banks showing sampling station locations.



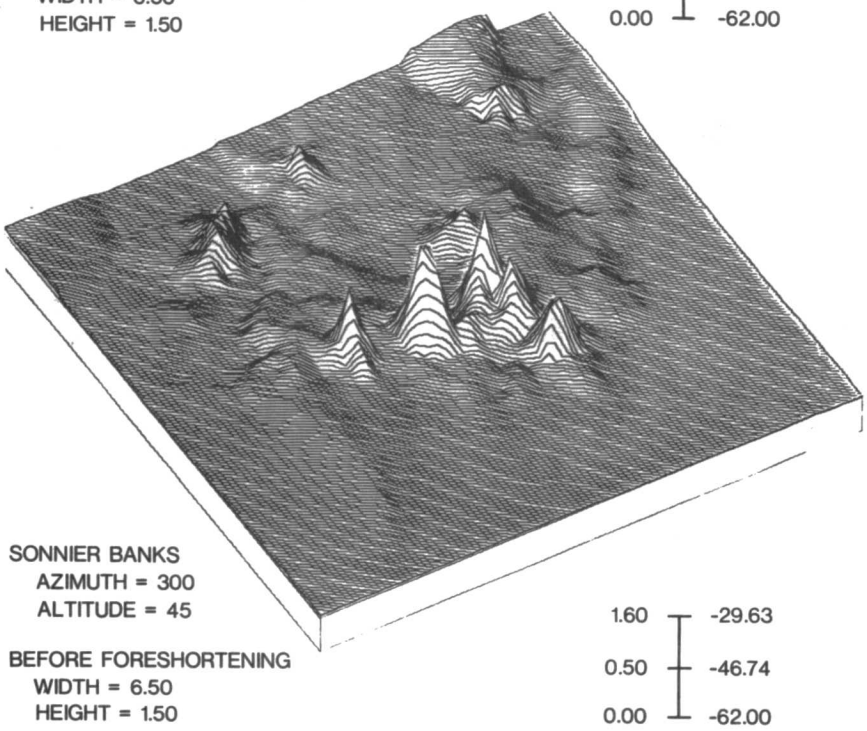


Figure IV-10. Three dimensional perspective views of Sonnier Banks: 150° and 300° azimuth.

a single peak and the arrangement of the peaks leads to the conclusion that each peak represents an individual fault block caused by the collapse of the beds overlying the salt along radial and annular faults.

Parker (Figures IV-11 and -12)

This feature is nearly circular and has a diameter of 7000 m in an east-west direction and 5500 m in a north-south direction. The maximum relief on the bank is 73 m. The highest peak is at 57 m and is located in the east central part of the bank. A broad, deep valley cuts into the bank from the east and trends westward almost to the western limit of the bank. This valley must have been eroded during a Late Pleistocene low sea level stand. Its original outlet was towards the southeast across the 100 meter sill at grid coordinates 599 x 3092 (Figure IV-11). A later outlet developed towards the northeast across the 110 meter sill at grid coordinates 598.8 x 3093.2.

Two submersible transects on the western crest of the bank revealed no Tertiary bedrock. Pinnacles in that area are patch reefs of Pleistocene coralgal rock. The surrounding areas are covered by coralline algal pavements and the normal bank sediments of the northwestern Gulf of Mexico.

Ewing (Figures IV-13 and -14)

Ewing Bank is roughly triangular in shape and extends for 7700 m in an east-west direction and 6500 m in a north-south direction.

Maximum relief is about 61 m with two high peaks at about 55 m. The peaks lie at grid coordinates 692.6 x 3109 and 696 x 3108 (Figure IV-13). A broad triangular shaped terrace at 80 m depth lies on the north side of the bank. Another broad terrace at 90 m depth lies just to the east of the eastern peak. These terraces may have been caused by wave action. However, the surrounding topography is so rough that late collapse features seem to dominate the physiography of the bank.

No Tertiary bedrock was observed on this bank. It appears to be a normal shelf edge bank with a typical hard bank community occupying the crest of the bank.

Sackett (Figures IV-15 and -16)

This feature is nearly circular and has a diameter of about 3000 m. The crest is broad and relatively flat at a depth of 63 m. The relief on the bank is 45 m. The crest of the bank is mainly algal nodules with scattered drowned patch reefs up to 3 m high and 12 m in diameter. At a depth of 73 m there is an outcrop of Tertiary claystone. The surface of the bedrock has been bored by clams and looks like the claystones that occur on Stetson, Claypile and Sonnier Banks.

This appears to be a relatively young bank that may have begun its growth during the last rise in sea level. There is no evidence of collapse such as we have seen at Sonnier, Claypile, 18 Fathom or the West Flower Garden Banks.

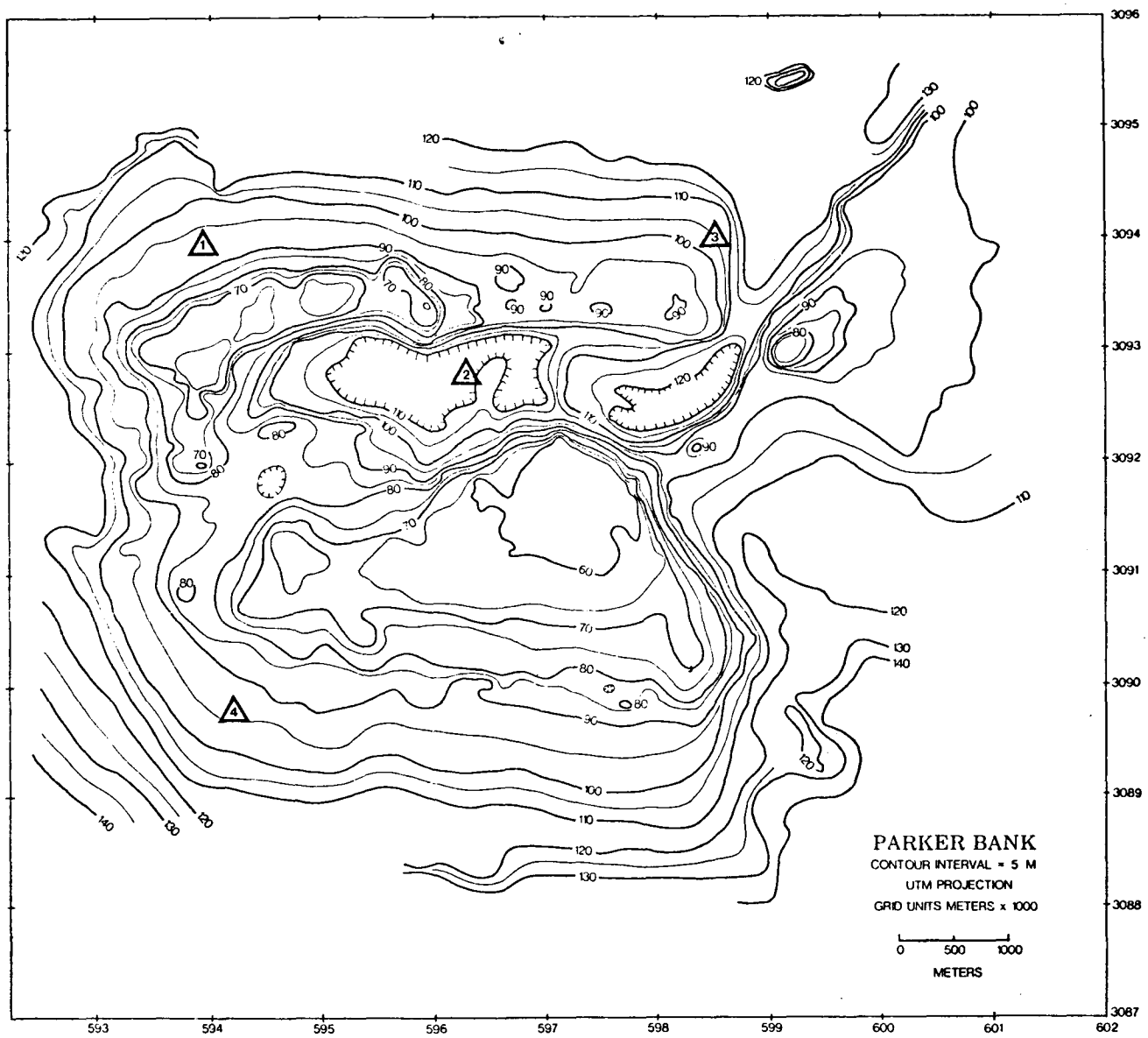


Figure IV-11. Bathymetric map of Parker Bank showing sampling station locations.

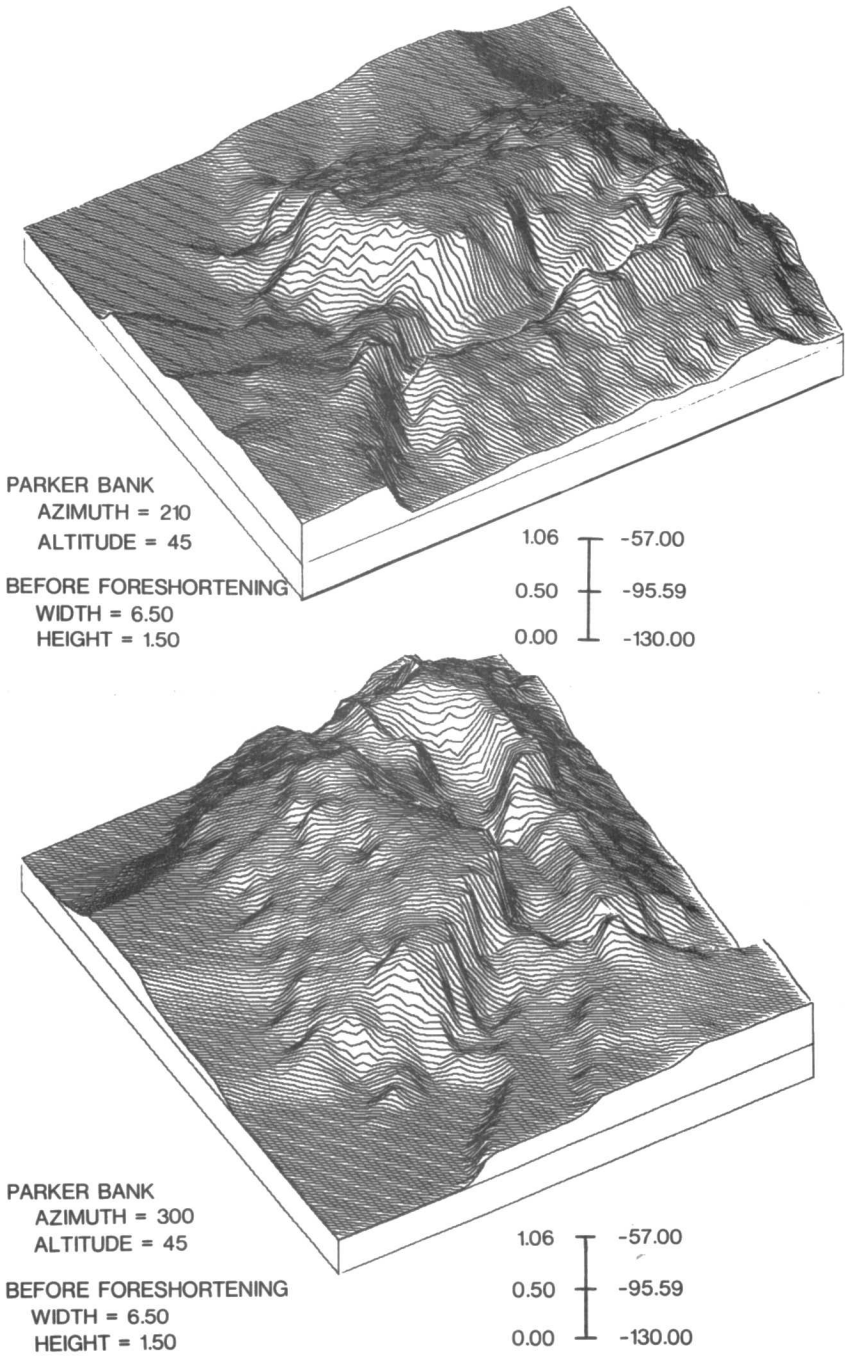


Figure IV-12. Three dimensional perspective views of Parker Bank: 210° and 300° azimuth.

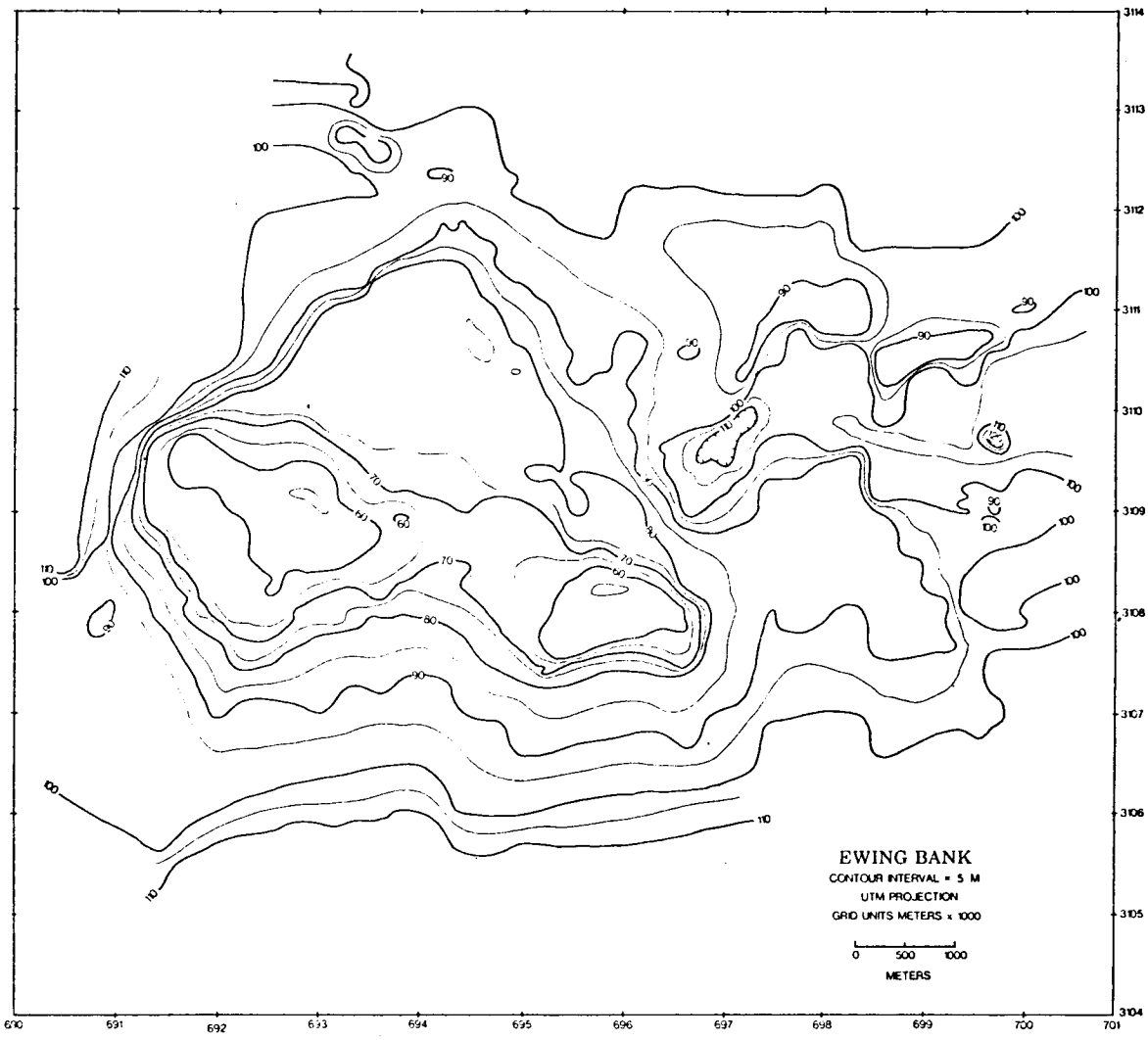


Figure IV-13. Bathymetric map of Ewing Bank.

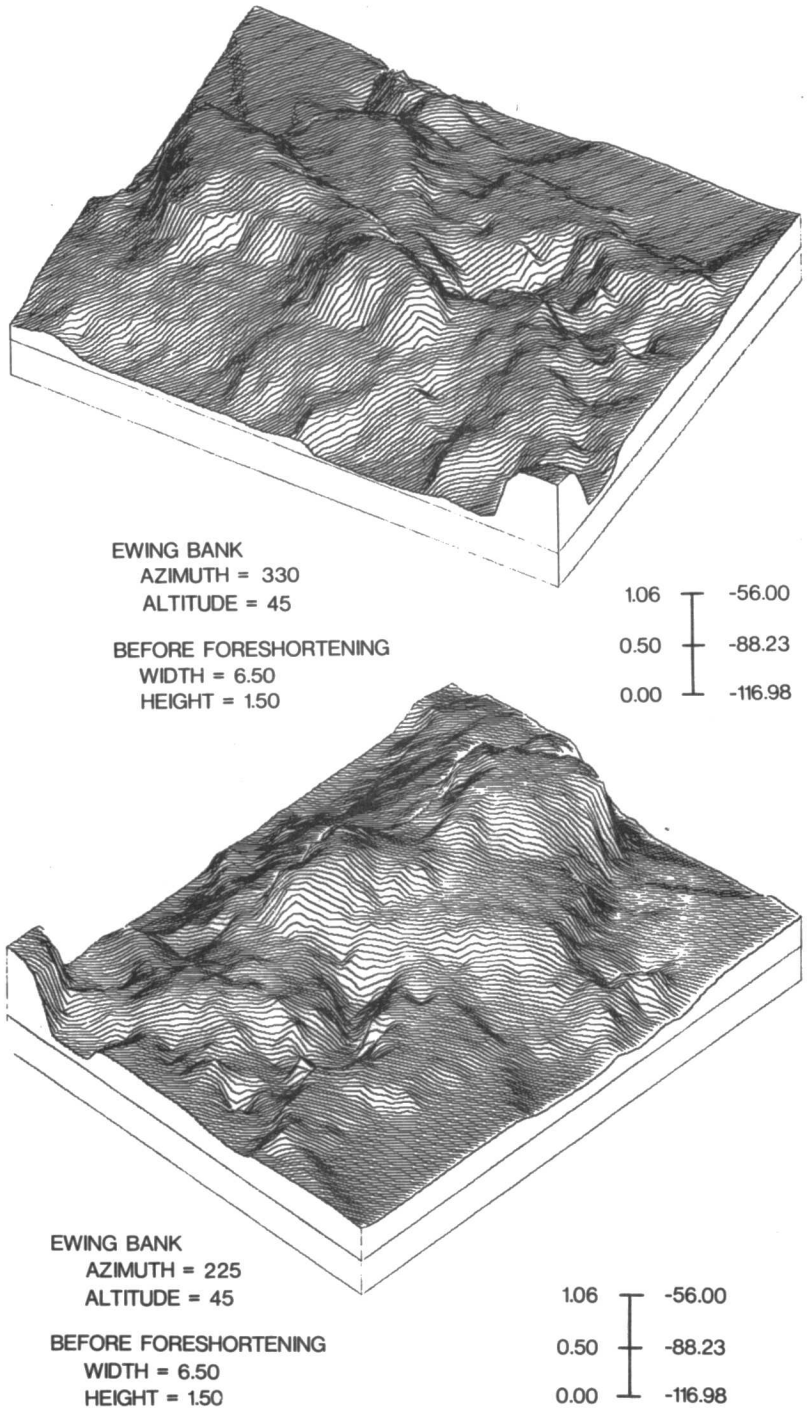


Figure IV-14. Three dimensional perspective views of Ewing Bank: 330° and 225° azimuth.

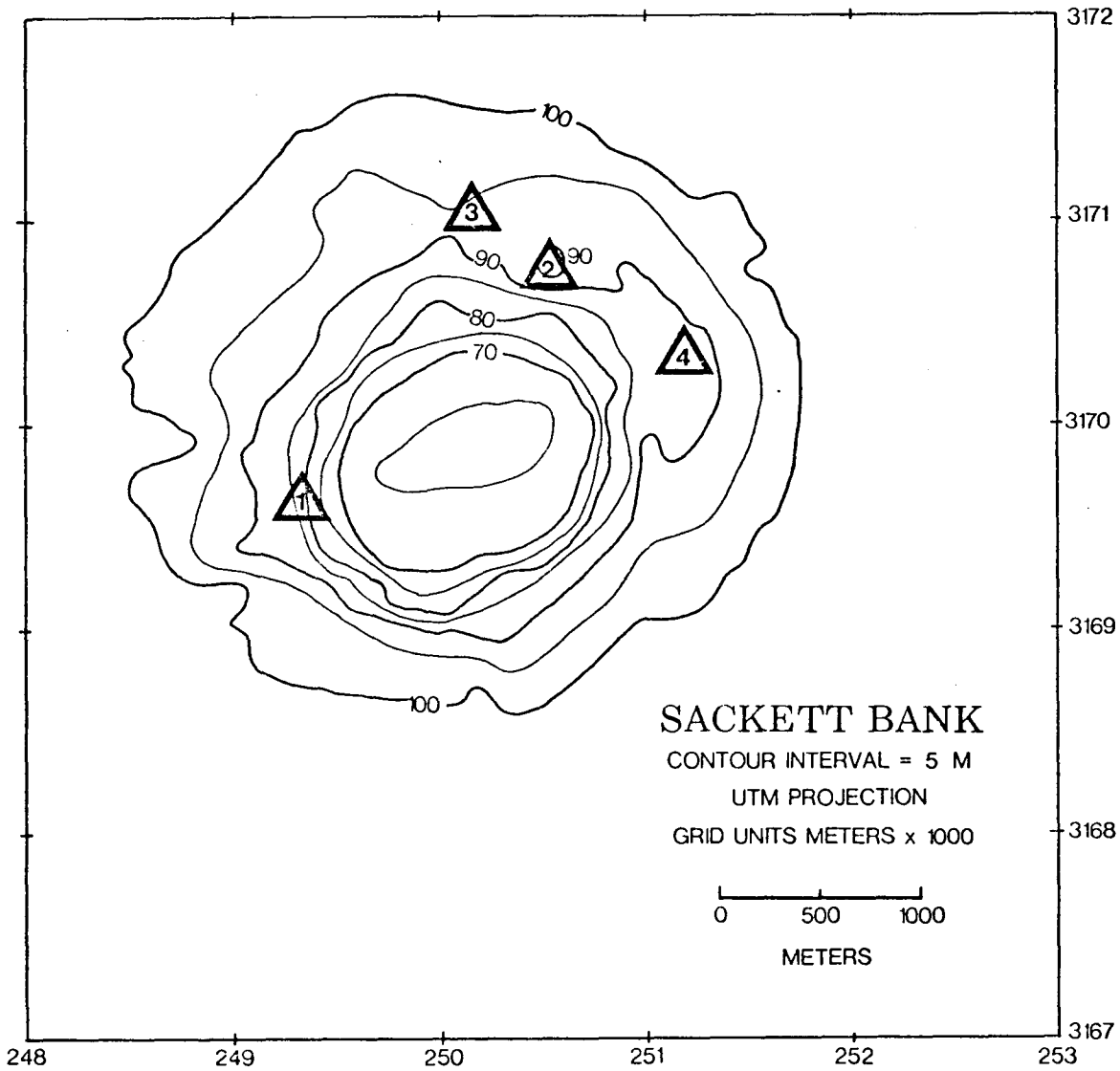


Figure IV-15. Bathymetric map of Sackett Bank showing sampling station locations.

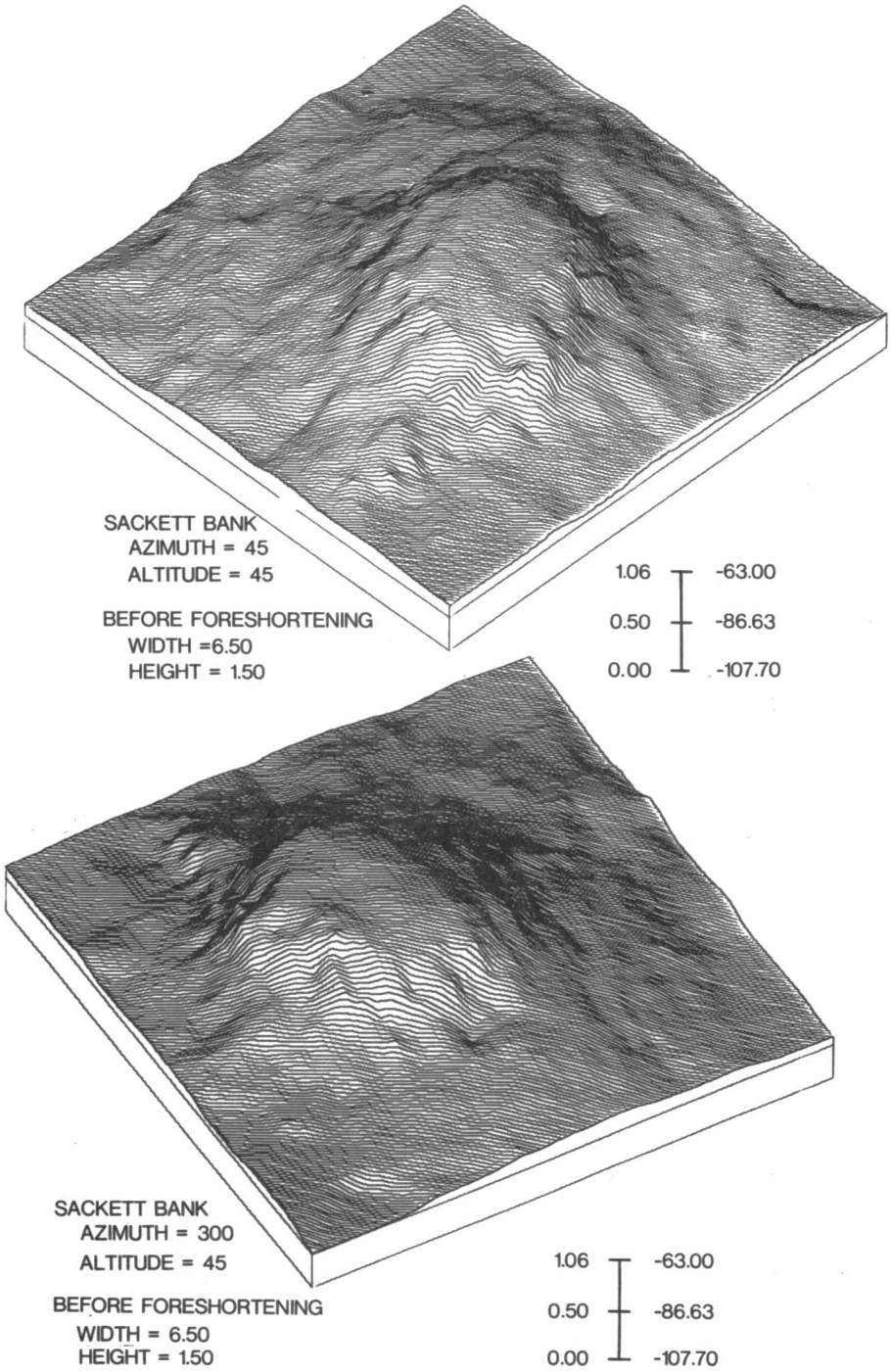


Figure IV-16. Three dimensional perspective views of Sackett Bank: 45° and 300° azimuth.

CLAY MINERALOGY OF BOTTOM SEDIMENTS

CLAY MINERAL ANALYSIS PROCEDURES

Samples prepared for clay mineral analysis were dispersed in deionized water overnight. The clay fractions (< 2 μm) were separated from bulk sample by treating with 1 ml of 2.5 m NH_4OH to disperse the sample before centrifuging for 2 minutes at 1000 R.P.M. The remaining suspended sediment fraction (< 2 μm) from this process was decanted from each centrifuge bottle and continuously collected in a one gallon polyethylene bottle. Approximately ten to twelve centrifuge cycles were required to collect the entire clay fraction.

Two oriented clay slides, one Mg-glycerol saturated and one K-saturated, were prepared on ceramic tiles for each sample (Carroll, 1970; Gibbs, 1971; Huang et al., 1975). To minimize any experimental variation, a 35 μm clay film was prepared for each sample by placing appropriate amounts of clay suspension onto the tiles. Acid treatment to dissolve the carbonate minerals was not necessary, because the 25°C X-ray scan showed no visible masking of the clay mineral assemblage.

One set of X-ray diffractograms was obtained from each of the above two oriented clay slides. The Mg-glycerol saturated clays were subject to X-ray analysis after each consecutive step of drying in air at 25°C and then heating at 110°C for 12 hours. The K-saturated clays were subject to X-ray analysis after each consecutive step of drying in air at 25°C and then heating at 110°C for 12 hours, at 300°C for 4 hours, and at 550°C for 1 hour.

X-ray analysis was carried out on a Phillips Norelco diffractometer, operating at 35 Kv and 20 mA, a scanning speed of 1° 2θ per minute, and a chart speed of 30 inches per hour. A 1° beam slit, with a 0.003 inch receiving slit, was used for the entire scan (2° to 35° 2θ).

MINERAL IDENTIFICATION CRITERIA

Illite is used as a group name here to include all clay mineral constituents of "mica-type" structure in argillaceous sediments (Grim et al., 1937). Basal reflections of illite are approximately 10, 5, and 3.3Å. Illite peaks in these samples, for the most part, show extremely well crystallized reflections, with relatively well developed [(002) Miller Index] resolution. An example of peak spacing can be seen in Figure IV-17.

Kaolinite is difficult to differentiate from chlorite by using X-ray diffraction techniques (Johns and Grim, 1958; Griffin, 1962), because the d-spacings of kaolinite (001) and chlorite (002) are both at 7.2Å, and kaolinite (002) and chlorite (004) coincide at 3.5Å. However, kaolinite was identified by using both the (001) and (002), occurring at 7.15 - 7.20Å and 3.52 - 3.58Å, respectively, which collapse to an amorphous state after heating at $550^{o}C$ for 1 hour. Biscaye (1965) suggests that the 3.52 - 3.58Å reflection should be examined carefully to resolve this identification problem, but samples with the abundance of kaolinite found in this study did not need such resolution.

Chlorite identification was resolved by the following criteria:

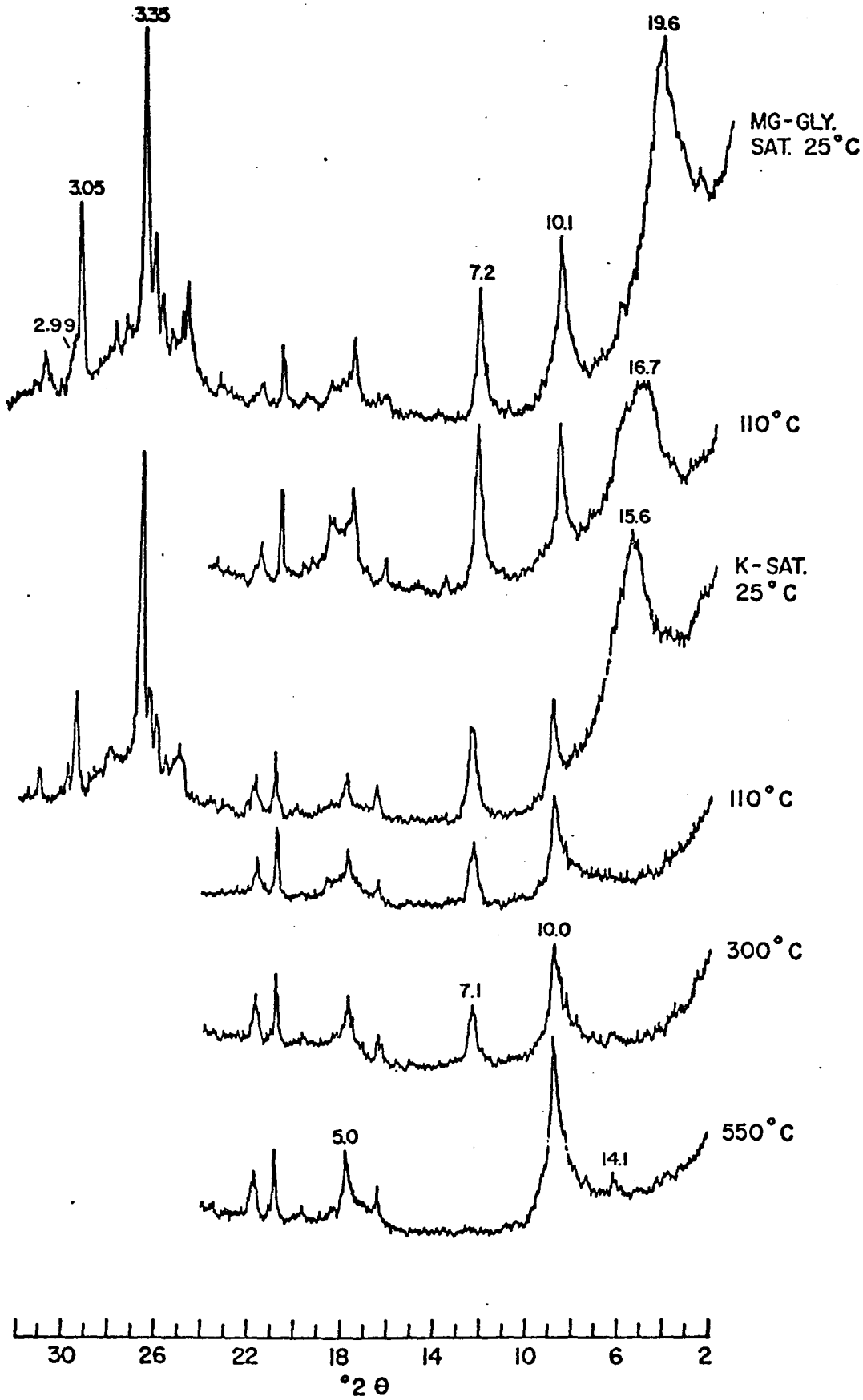


Figure IV-17. Typical X-ray Diffractogram of the < 2 μm fraction of bottom sediments from the Texas-Louisiana outer continental shelf.

(1) Characteristic basal reflections at 14.1 - 14.5, 4.75, and 3.54Å for the (001), (003), and (004) respectively. Since the (002) coincides with the (001) of kaolinite at 7.15 - 7.20Å, the (002) of chlorite can only be used after the sample is heated at 550°C for 1 hour, when kaolinite is in an amorphous state.

(2) The 14Å reflection will be intensified after being heated at 550°C (Brindley, 1961). Since chlorite occurred in such small amounts, true identification of this mineral was accomplished after the 550°C treatment for the (001) and (002).

Smectite is a group of clay minerals characterized by a basal reflection which expands to 19.6Å (001) and 9.8Å (002) when saturated with magnesium and glycerol. The (001) reflection collapses to 10Å after being heated at 550°C. The large abundance of this mineral allows for simplified identification.

The non-clay minerals of the clay-sized fraction were identified in the following manner: Identification of quartz was primarily from the characteristic diffraction array between 2.99 - 3.05Å. There was a distinction made for these samples between high and low magnesium calcite (2.99 - 3.01Å and 3.03 - 3.05Å respectively).

Numerous semi-quantitative estimation techniques have been proposed to determine abundances of clay minerals. These methods include the comparison of peak area, peak intensity, and chemical analyses (Johns et al., 1954; Jackson, 1956; Biscaye, 1964; Carroll, 1970; Griffin, 1971). No universal procedure has been adopted by clay mineralogists. The relative clay mineral percentages of this study were determined by measurement of the (001) peak area using a planimeter.

The Mg-glycerol saturated samples were used to determine the relative amounts of illite. These separate measurements at 25°C were to differentiate the illite (001), which was overlapped by the smectite (002) on the Mg-glycerol saturated sample. The relative abundance of kaolinite was determined by the difference in the intensity of the 7.15 - 7.20Å reflection on the Mg-glycerol saturated diffraction patterns at 25°C and heated at 550°C for 1 hour. The non-clay minerals of this fraction were identified from both diffractograms, since they are not affected by the treatment.

CLAY MINERAL RESULTS

Table IV-2 lists the percent smectite, illite, kaolinite, and chlorite for the clay (< 2 μm) fraction of the bottom sediment. Smectite is the dominant clay mineral in all samples, ranging from 56% to a high of 74%. Illite is next in abundance, ranging from 16-28%. Kaolinite varies from 8 to 19% and chlorite occurs in trace quantities in all samples except Parker Bank sample 1-1, Sonnier Banks sample 2-8, and Bright Bank sample 3-1 where it was not detected.

SEDIMENT SIZE

PROCEDURE FOR GRAIN SIZE ANALYSES

The procedures for grain size analysis are the same as those used for Contract AA550-CT6-18. A Coulter Counter, Model TAII is used for the sediment fraction finer than 0.062 mm and a Woods Hole type Rapid Sediment Analyser is used for the sediment fraction coarser than 0.062 mm.

TABLE IV-2

Mineralogy of Clay Fraction (< 2 μm)

Bank & Sample	Smectite	Illite	Kaolinite	Chlorite	Others
East Flower Garden					
1-7	67	21	11	T	L-Mg calcite
2-8	71	19	11	T	L-Mg calcite
3-8	68	21	12	T	L-Mg calcite
4-8	63	23	14	T	L-Mg calcite
Parker					
1-1	56	28	16	-	L-Mg>>H-Mg calcite
2-8	71	20	8	T	L-Mg>>H-Mg calcite
3-8	69	20	11	T	L-Mg>>H-Mg calcite
4-8	58	26	16	T	L-Mg>>H-Mg calcite
Sonnier					
1-8	74	18	9	T	L-Mg calcite
2-8	63	24	14	-	L-Mg calcite
3-8	69	19	12	T	L-Mg calcite
4-8	74	16	10	T	L-Mg calcite
Bright					
1-1	65	23	12	T	L-Mg>>H-Mg calcite
2-1	Not enough for clay fraction.				
3-1	56	25	19	-	L-Mg>>H-Mg calcite
Sackett					
1-1	68	20	12	T	L-Mg calcite
2-1	65	22	13	T	L-Mg calcite
3-1	69	19	11	T	L-Mg calcite
4-1	71	20	9	T	L-Mg calcite

T = Trace

The sample pre-analysis preparation procedures are as follows:

(1) Approximately 50-60 g of sediment is placed into a 1 liter jar.

(2) Add 5 ml of hydrogen peroxide every 15 minutes up to a total of 30 ml.

(3) Allow to react overnight.

(4) Fill jar with distilled water and again allow to sit overnight or until the water is clear.

(5) Pour off supernatant.

(6) Add 15 ml of 40% sodium hexametaphosphate to sediment slurry.

(7) Wet sieve through a 230 mesh sieve, collecting the fine material in a 1 liter column.

(8) Dry coarse fraction and sift through 230 mesh sieve again. Add the pan fraction to the fines. Weigh coarse fraction.

(9) Take a 20 ml aliquot, dry and weigh. The weight of the sample equals the weight of solids in beaker minus .12 g (the sodium hexametaphosphate) x 50.

(10) The coarse fraction is placed into a labeled envelope and saved for the Rapid Sediment Analyzer (RSA).

(11) The fine fraction is now ready for analysis using the Coulter Counter.

The Coulter Counter procedures were modified from those used by the U.S.G.S. laboratory at Corpus Christi, Texas.

The RSA procedures are as follows:

(1) Sieve the coarse fraction using a 10 mesh (2 mm) sieve to separate the sand from the gravel.

(2) Weigh material retained on sieve.

(3) Split the sand fraction repeatedly, using a microsplitter to obtain an appropriate size work sample (1 - 3 g when possible).

(4) Turn on the electronics and allow to warm up to 20 minutes, then zero amplifier.

(5) Fill water column until flush with top edge of tube before calibration and each analysis. Record water temperature.

(6) Calibrate using Ottawa Sand (1 Ø size).

(7) Care must be used to minimize all shock waves in support and air due to walking, doors closing, etc.

(8) Spread sample evenly over the central portion of the moistened entry plate; avoid clumping grains.

(9) Turn on recorder pen and chart, using a chart speed of 10"/min.

(10) Gently close plate and start a stop watch to begin timing.

(11) Mark time of closing on chart and after 95 seconds change chart speed to 2"/min or 1"/min (depending on sample).

(12) Continue monitoring chart for about 5 mintues until the curve reaches the baseline.

(13) Terminate analysis and label chart.

Interpretation of the RSA data consists of the following:[1]

(1) Mark the following three points on the pressure curve:

(a) Introduction time (T_o) - first major pressure deflection (usually downward),

(b) 0% inflection point,

[1] Modified from G. L. Shideler, 1976, personal communication.

(c) 100% termination point (minimal pressure).

(2) Draw baseline from termination point parallel with graph paper grid.

(3) Using the size-fall time overlay, make the overlay's baseline coincident with the drawn baseline. Vertically align the "0" time line of overlay with the introduction time (T_o) mark on the graph paper. Tape down the graph paper and overlay.

(4) Place a Gerber scale perpendicular to the baseline at the 0% inflection point, and divide it into 100 increments. Using a straight-edge, read off the cumulative % for each half-phi size and record on data sheet (nearest 0.5%). Use the size value immediately preceding the 0% inflection point as the 0% size. If the 4.0ϕ size value occurs at less than 100%, consider it as the 100% size value. If the curve terminates prior to 4.0ϕ, consider the half-phi value immediately prior to termination as the 100% size value.

GRAIN SIZE PARAMETERS

A program for use of the Amdahl 470 V6 was written by S. Helwick to combine the RSA and Coulter Counter Data, as well as the weight of gravel, and compute the gravel/sand/silt/clay percentages, median, mean, standard deviation, skewness and kurtosis. The statistical grain-size parameters were calculated using both the graphic method and method of moments. Calculations for the method of moments were taken from Carver, 1971. The results of the method of moments calcu-

lations are listed in Appendix A, Tables IV-1 to -7. Graphic statistical parameters were calculated as follows:

Median Diameter - That diameter corresponding to the 50 percent mark on the cumulative curve. The measure determines that size in which half of the particles are coarser than the median and half are finer. The Graphic Mean corresponds very closely to the mean as computed by the methods of moments. It is computed by the formula

$$\text{Graphic Mean} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where ϕ is a logarithmic transformation of the Wentworth Scale. The Inclusive Graphic Standard Deviation is a measure of sorting and is determined by the formula

$$\text{Standard Deviation} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6} .$$

This formula includes 90 percent of the distribution and is considered to be the best overall measure of sorting.

Folk, 1974 (p. 46) has suggested the following verbal classification scale for sorting:

Values less than .35ϕ, very well sorted

.35 - 0.50ϕ, well sorted

.50 - 0.71ϕ, moderately well sorted

0.71 - 1.00ϕ, moderately sorted

1.0 - 2.0ϕ, poorly sorted

2.0 - 4.0ϕ, extremely poorly sorted.

Inclusive Graphic Skewness is a skewness measure that is geometrically independent of the sorting of the sample. It measures the degree of asymmetry as well as the "sign" of the curve. This determines whether a curve has an asymmetrical tail to the left or right. The following

formula is used to determine the Inclusive Graphic Skewness SK_I:

$$SK_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + 095 - 2\phi 50}{2(\phi 95 - \phi 5)}.$$

Graphic Kurtosis is used to determine the departure of the frequency from that of the normal probability curve. It is determined by the formula:

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}.$$

The value of this parameter is open to question as most sediments do not have a normal distribution curve but are bimodal or polymodal. Folk (1977, personal communication) feels that there is some value to the parameter and that it should be calculated for each analysis.

DISTRIBUTION OF GRAIN SIZE PARAMETERS

All of the results discussed in the following paragraphs are syntheses of data from 4 to 10 analyses at each station. The intermediate data for these analyses is presented in Appendix A, Tables IV-1 to IV-7. Due to wind and sea conditions, there was a certain amount of ship drift during sampling, so that the sample sites for each station may vary. However, for the majority of stations, the results from each samples display little variation. In most cases, the deviation of results of one sample out of six does not affect the general classification assigned to the sediment, i.e., degree of sorting, skewness, kurtosis, and sediment classification. Another parameter used in the following discussions is the Mode, which is the most frequently occurring particle diameter in a sample. It may be read directly from a size frequency curve or a histogram. Modes and sediment

classification are given in Table IV-3.

East Flower Garden Bank

Four stations were sampled at the East Flower Garden Bank on a seasonal basis. Stations 1 and 2 are on the sediment apron to the east of the bank. Stations 3 and 4 are on the sediment apron to the southwest of the bank (Figure IV-18). The location of these stations was based upon a suspicion that net transport of sediment across the bank is from east to west. Stations 1 and 2 are on a muddy bottom with less than 10% sand and gravel. Station 3 samples average about 80% carbonate sand and Station 4 is classified as a muddy sand. Both stations 3 and 4 show a considerable variation in the amount of gravel. As both pairs of stations are almost equidistant from the bank, the presence of mud to the east and muddy sand to the southwest indicates that little or no skeletal debris is shed from the bank towards the east but considerable amounts are shed towards the southwest.

Sonnier Banks

Stations 1 and 2 are to the east. Station 3 is to the south and Station 4 is to the north of the main complex of peaks (Figure IV-9). The sediments at Stations 1 and 2 are muddy, sandy, granular gravel. At Station 3 the sediment is a slightly granular mud and at Station 4 it is a mud with less than 10% sand and gravel.

At Station 2, several cobble size lithoclasts were washed out of the macroinfauna grabs. These consist of claystone and siltstone that has been eroded from the Tertiary bedrock exposed in the peaks. Again the transport direction seems to be from east to west.

TABLE IV-3

Sediment Modes and Classification

BANK	STATION	MODES			CLASSIFICATION
		Primary	Secondary	Tertiary	
East Flower Garden	1	Clay			Mud
	2	Clay			Mud
	3	Medium Sand	Fine Sand	Clay	Muddy Sand
	4	Medium Sand	Fine Sand	Clay	Muddy Sand
Sonnier	1	Grandule	Coarse Sand	Clay	Muddy, sandy, granular gravel
	2	Grandule	Coarse Sand	Clay	Muddy, sandy, granular gravel
	3	Clay	Fine Sand	Coarse Silt	Slightly granual gravel
	4	Fine Silt			Mud
Bright	1	Clay	Very Fine Sand		Sandy mud
	2	Medium Sand	Coarse Sand		Granular sand
	3	Very Fine Sand			Slightly granular sand
	4	Algal nodule			Mud
Parker	1	Coarse Sand	Granular	Clay	Granular sand
	2	Very Fine Sand	Fine Sand	Silt	Slightly granular mud
	3	Medium Sand	Very Fine Sand	Clay	Granular, muddy sand
	4	Medium Sand	Very Fine Sand		Slightly granular, muddy sand
Sackett	1	Very Coarse Sand	Silt		Slightly granular, sandy mud
	2	Very Coarse Sand	Silt		Slightly granular, sandy mud
	3	Very Coarse Sand	Clay		Slightly granular muddy sand
	4	Clay	Very Coarse Sand	Coarse Silt	Slightly granular, sandy mud

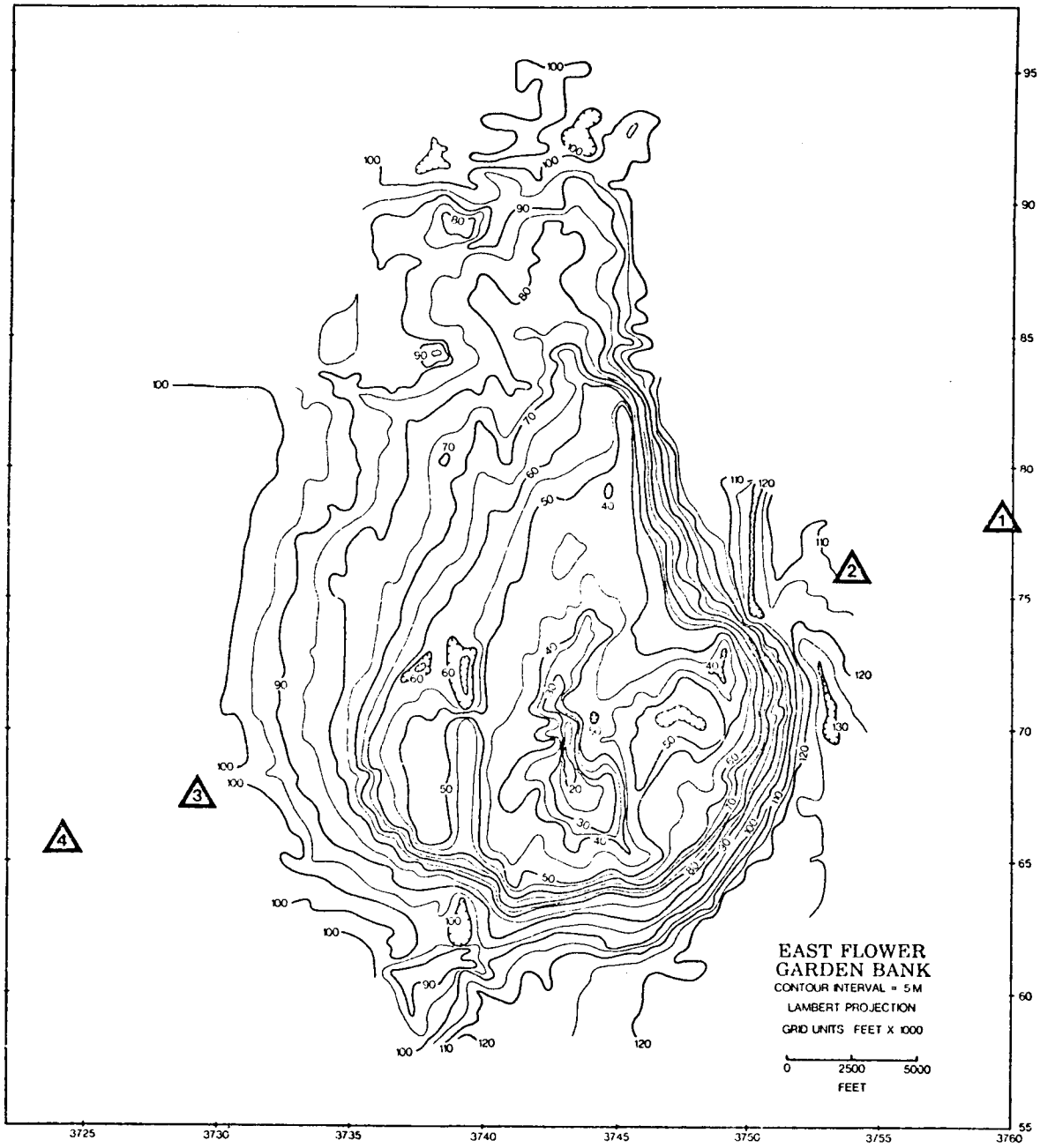


Figure IV-18. Bathymetric map of the East Flower Garden Bank showing four primary sampling stations.

Bright Bank

Of the four stations at Bright Bank (Figure IV-3), Station 1 is on the sediment apron to the northeast of the bank and the rest are on the bank proper. The off-bank sediment at Station 1 is a sandy mud. The three on-bank stations vary from slightly granular sand to a cobble gravel. The cobble gravel consists of coralline algae nodules while the slightly granular sand represents the *Amphistegina* sand facies.

Parker Bank

All four stations are located within the bank proper (Figure IV-11). Stations 1 and 3 are on the northern flank of the bank in mainly sandy sediments. Station 2 is in a basin in the east-west valley that cuts into the bank is a slightly granular mud. Station 4 is on the southern flank of the bank and there the sediments are slightly granular, muddy sand. No estimates of transport direction can be made from the available sediment texture data.

Sackett Bank

All four stations are located on the bank proper (Figure IV-15). Stations 1 and 2 both have a slightly granular sandy mud sediment. Stations 2 and 4 on the northeast and east side of the bank are characterized by a slightly granular sandy mud. The increase of mud on this side of the bank may be due to the fine sediment being supplied to the bank from the mouth of the Mississippi River.

CARBONATE ANALYSES

TECHNIQUES

Total Carbonate

$CaCO_3$ percentage in the sediment was determined using the Scheibler method described by Bouma (1969). One-half gram of sample, along with 5 ml distilled water and 7 ml HCL (25%) in a small plastic beaker, is placed in a bottle and sealed. After mixing the acid and the sample by shaking them for 20 minutes, the volume of gas evolved is measured in a water-filled buret connected to the bottom by plastic tubing. Accuracy may be checked by duplicate sample analysis, allowing no greater than 10 percent $CaCO_3$ difference in the results.

Sand-sized Carbonate Mineral Analysis (X-ray Diffraction)

Samples for the greater than 63 μm fraction were separated from the silt and clay fraction during the clay preparation by sieving the silt through a 63 μm sieve after the clays were extracted. This sand-sized fraction was dried at 100°C, finely ground, packed randomly into aluminum holders, and analyzed by X-ray diffraction. The major minerals that made up the assemblage were identified by the following characteristic peak criteria: (1) Quartz: 4.26, 3.35Å; (2) Calcite: 2.99, 3.05Å (Distinction can be made for low or high magnesium calcite by the reflection position within this range.) (3) Aragonite: 3.40, 3.27, 2.70Å. Examples of these spacings are presented in Figure IV-19.

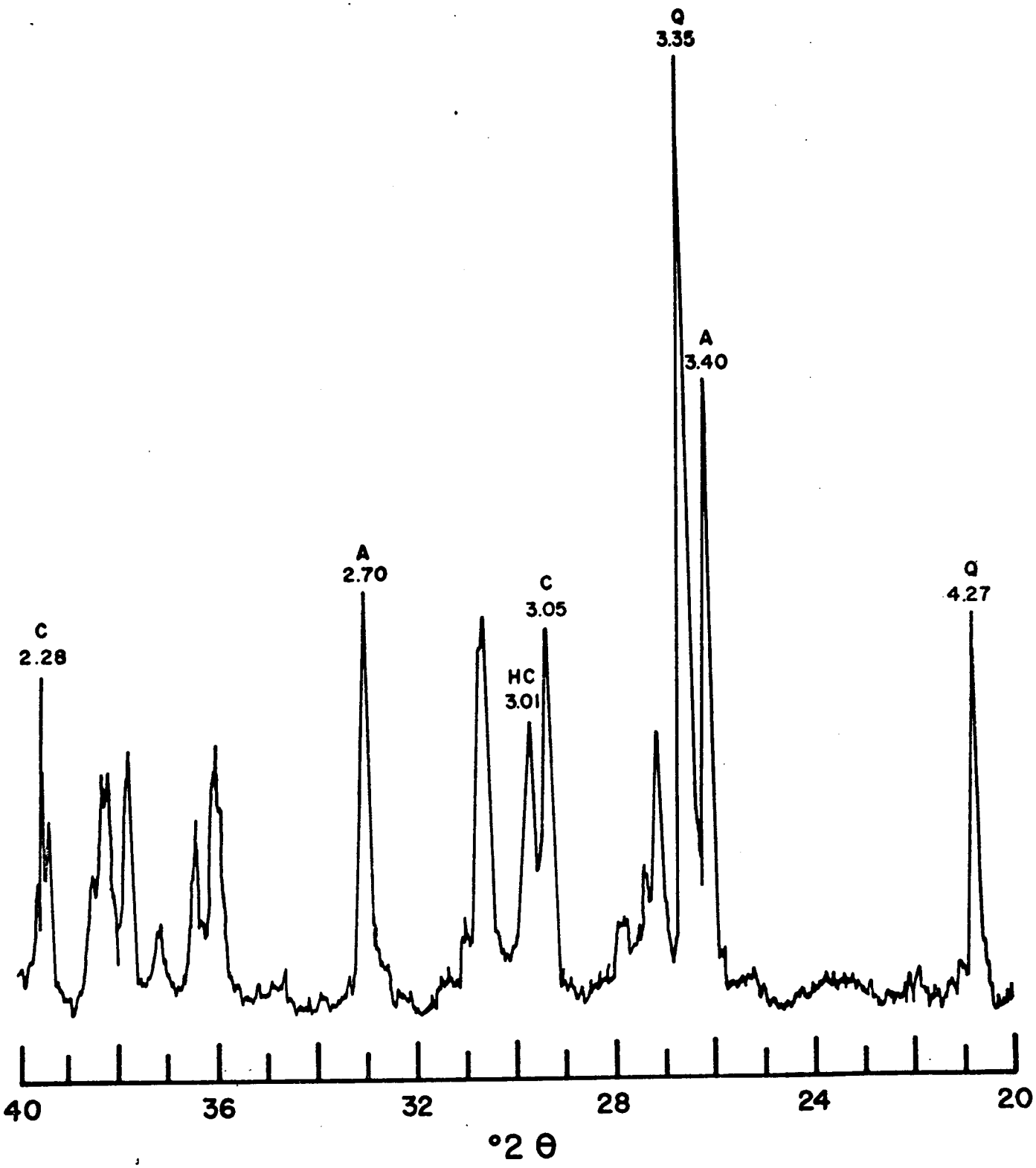


Figure IV-19 Typical X-ray diffractogram of the > 62 μm (sand) fraction of bottom sediment from the Texas-Louisiana outer continental shelf. A = Aragonite, C = Calcite, HC = High MG Calcite, Q = Quartz.

Particle Type Identification

The coarse fraction from each surface sediment sample was split until a sample of approximately 200 grains was obtained. These were then dispersed on a tray and examined using a Bausch and Lomb binocular light microscope. Two hundred grains were identified using nine compositional parameters based on relative abundance in the samples. These include: quartz, benthic foraminifera, planktonic foraminifera, echinoderms, molluscs, coral, algae, lithoclasts and miscellaneous. The miscellaneous category included not only heavy minerals and unidentified skeletal fragments, but also identifiable skeletal fragments not applicable to other categories, such as bryozoans, diatoms, and sponge spicules.

RESULTS

Total Carbonate Analysis

The percent of calcium carbonate in surface sediment samples varies from 11.97 to 100. Various samples were analyzed twice to determine accuracy and the percentages were found to be valid (Appendix A, Table IV-8).

Summary of Carbonate X-Ray Analysis

Sonnier Banks are the only anomalous banks with respect to coarse fraction mineralogy (Table IV-4). The abundance of quartz and low Mg calcite almost to the exclusion of all other carbonate minerals is due to the age of the bedrock which supplied most of the coarse fraction to the sediment. The abundance of low Mg calcite is most cer-

TABLE IV-4

Sand-Sized Carbonate X-Ray Analysis (> 62 μ)

BANK & SAMPLE	MINERALS (in decreasing relative abundance)
East Flower Garden	
1-7	low-mg calcite>quartz>>high-Mg calcite>>aragonite
3-8	high-mg calcite>low-mg calcite>quartz>aragonite
4-8	quartz>>high-mg calcite>low-mg calcite>aragonite
Parker	
1-1	high-mg calcite>low-mg calcite>aragonite
2-1	low-mg calcite>high-mg calcite>aragonite
3-1	high-mg calcite>low-mg calcite>aragonite
4-1	high-mg calcite>low-mg calcite>aragonite
Sonnier	
1-8	quartz>low-mg calcite
2-8	quartz>low-mg calcite
3-8	quartz>>low-mg calcite (trace aragonite)
4-8	quartz≈low-mg calcite
Bright	
1-1	low-mg calcite>>high-mg calcite>quartz>aragonite
2-1	high-mg calcite>low-mg calcite>aragonite>quartz
3-1	high-mg calcite>low-mg calcite>aragonite>quartz

Symbols

> = greater than
>> = much greater than
≈ = nearly equal to

tainly due to extensive subaerial exposure of the banks and resultant alteration of the carbonate minerals to low-Mg calcite.

Summary of Particle Type Identification

The counts for all samples are included in table form (Appendix A, Table IV-8).

SEDIMENT CORES

Only six cores were taken from five coring stations due to a malfunction of the coring apparatus. The cores were split, visually described, and radiographed. The information is included in the data summary, Appendix A, Table IV-9. The tan to brown sediment at the surface of Sackett Bank cores 1, 2 and 4 represents an oxidized zone. This zone is not present in core 3, possibly due to slumping of the sediment at this site and exposure of non-oxidized sediment. The two cores from the single station at the East Flower Garden do not provide sufficient information for interpretation.

PART TWO

CLAY MINERAL ANALYSIS

OF

SUSPENDED SEDIMENT

Authors:

Richard Rezak

Robert E. Tompkins

INTRODUCTION

The requirements of this and previous study efforts included the determination of the mineralogy of the suspended material. There has been, for some time, a suspicion that the results obtained from these determinations have been inconclusive and non-correlative with any other data. This suspicion resulted in a small study of the effect of concentration of suspended material on observed mineralogy. The results of this study are presented here.

Within the last decade there has been an increased interest in determining the relationship between the distribution, concentration, and composition of suspended particulate matter and bottom sediment composition in the world oceans and estuaries (Jacobs and Ewing, 1969; Pierce *et al.* 1972; Biggs, 1977). Comparison of these two sediment reservoirs can be useful in studying provenance, transportation and final deposition of fine-grained sediment (Jacobs and Ewing, 1965 and 1969).

The study of oceanic suspended sediment presents a concentration problem because only a few milligrams of material are normally recovered from tens of liters of deep ocean water. Whether such small quantity samples will yield the same relative abundances of clay minerals by x-ray diffraction as larger samples has prompted several studies (Gibbs, 1965; Stokke and Carson, 1973; Peterson, 1976).

Beer *et al.*(1974) designed a prototype deep pump filtration system, with unlimited depth capability, that can sample large enough volumes of water to collect a maximum of 20 mg per lowering. The principle of this system has merit, but with the high costs of ship board time, the number of casts to properly sample low concentrations in deep sea

locations might be prohibitive. Since Niskin casts are usually thought to obtain enough suspended sediment from the nepheloid layer to analyze by x-ray diffraction, this less expensive sampling method has been used extensively.

Laboratory preparation for clay mineral analysis after sample collection has received considerable attention. Stokke and Carson (1973) examined several methods to prepare bottom sediment clay samples and found, using the suction on ceramic tiles method, that the calculated clay mineral ratios remained the same down to dilutions of 0.655 mg/cm^2. This dilution is still a considerably higher "on-filter" concentration than normally found in a nepheloid layer. Tucholke (1974) found an artificial depletion of smectite in dilute-on-filter concentrations (less than 1.6 mg/cm^2) of clay-sized fractions prepared on silver filters. He also found an artificial enrichment of illite, with kaolinite and chlorite remaining relatively constant below an on filter concentration of 1.6 mg/cm^2. Peterson (1976) goes a step further and presents data on background radiation caused by various filters that can be used in suspended mineralogy analysis. This is extremely important with low concentrations, since the thickness of the clay film may allow x-ray penetration to the filter medium. Peterson concludes that Selas Flotronics silver filters are the best for x-ray analysis because they yield the least background, are the most weight stable, and are resistant to chemicals used for suspended mineralogy analysis (i.e. acetone, ethylene glycol, and glacial acetic acid).

During the course of analyzing suspended sediment for clay mineralogy for the South Texas Outer Continental Shelf, Topographic

Features Study of the Department of Oceanography at Texas A&M University, the authors became concerned over the accuracy of x-ray diffraction mineralogy of sediment suspensions having very low concentrations. We devised a series of experiments using dilute bottom sediment concentrations of the clay fraction (< 2 μm) of sediments from three separate geographic areas and a laboratory mixed standard having different relative abundances of clay minerals. The primary purpose of the experiments was to determine the effects of on-filter concentrations on the apparent relative abundance of the clay mineral species. Tucholke (1974) described the results of a sample with the abundance ratios illite > chlorite > smectite > kaolinite that was diluted to yield artificial depletions and enrichments of certain clay minerals. As far as we know, this is the only published record of reliable data on x-ray analysis of diluted samples. There is a need to look at samples rich in smectite or kaolinite, in addition to Tucholke's illite-rich sample, to see how each mineral reacts to dilutions at varying relative abundances.

METHODS

Samples were taken from 1) cores near Kodiak Island, Alaska, 2) the Orca Basin (26°55'N, 91°20'W), and 3) East Flower Gardens Bank (27°55'N, 93°31'W) on the NNW Gulf of Mexico continental margin. The clay fraction (< 2 μm) of the samples was separated from the bulk sediment by dispersing with 1.0 ml of 2.5 M NH_4OH and centrifuging for 2 minutes at 1000 R.P.M. The remaining suspended fraction (< 2 μm) was decanted from each centrifuge bottle and continuously collected until the suspension became clear. In addition, an artifically mixed standard clay suspension

was prepared in the laboratory by weight percent in the ratio of smectite 4, chlorite 3, illite 2, and kaolinite 1. Concentrations of each of the four samples were determined by drying and weighing 15 ml aliquots in preweighed aluminum dishes. Each sample was vacuum-sedimented onto a Selas silver filter (0.45 μm pore size and 25 mm diameter) under controlled conditions. In order to intensify the clay peaks and to prevent differential settling of particles, a controlled unit of suspended sample was introduced at approximately 4 minute time intervals. The filter was washed with deionized water to remove any residual salts. Twenty-five dilutions were made of each sample, ranging in on filter concentrations from 0.069 mg/cm^2 to 12.47 mg/cm^2, by taking microliter aliquots of the original and adding deionized water to bring the volume up to 10 ml. This allowed the desired dilution with ample volume to promote homogeneity within the layered silicates on the filter.

One set of five x-ray diffractograms was obtained for each sample by analyzing the sample after each of the following consecutive treatments: (1) air dried at 25°C untreated, (2) glycolation at 25°C, (3) heating at 110°C for 12 hours, at 300°C for 4 hours, and at 550°C for 1 hour. X-ray analysis was carried out on a Phillips-Norelco diffractometer, using Cu $K\alpha$, nickel-filtered radiation, operating at 35 Kv and and 20 mA, a scanning speed of 1° 2θ per minute, and a chart speed of 30 inches per hour. A 1° beam slit, with a 0.003 inch receiving slit, was used for the entire 2θ scan (2° to 35° 2θ).

Standard criteria were used to identify each of the clay minerals present. Illite was designated by the 10Å (001), 5Å (002) and 3.3Å (003) basal reflections, which were not affected by glycolation or

heating treatment through 550°C. Kaolinite is difficult to differentiate from chlorite by using x-ray diffraction techniques (Griffin, 1962; Johns and Grim, 1958), because the d-spacings of kaolinite (001) and chlorite (002) are both at 7.2Å, and kaolinite (002) and chlorite (004) coincide at 3.5Å. However, kaolinite was identified by using both the (001) and (002) reflections, occurring at 7.15 - 7.20Å and 3.52 - 3.58Å, respectively, and which collapsed to an amorphous state after heating at 550°C for one hour. As kaolinite was an obvious constituent of these samples, identification of relative abundance was made by comparing the (001) reflections (7.15 - 7.20Å) at 25°C and 550°C. Chlorite identification was resolved by characteristic basal reflections at 14.0Å (001), 4.75Å (003), and 3.54Å (004). The 14Å peak will be slightly intensified after being heated at 550°C, but identification is insured by no change in d-spacing through this heating treatment. Smectite is characterized by a basal reflection of about 12.5Å untreated, expanding to 19.6Å when saturated with glycerol at 25°C, with a gradual collapse in d-spacing, through the heating treatments described, to approximately 10Å at 550°C.

RESULTS

The minimum on filter concentration that permits consistent mineralogical analyses varies as a function of the original relative abundance of each clay mineral, as shown in Figures IV-20, -21, -22, and -23. The Alaskan sample with no smectite, as shown in Figure IV-20, gradually changes from a low on filter concentration (0.069 mg/cm^2) with no positive x-ray recognition of minerals to a consistent mineralogical

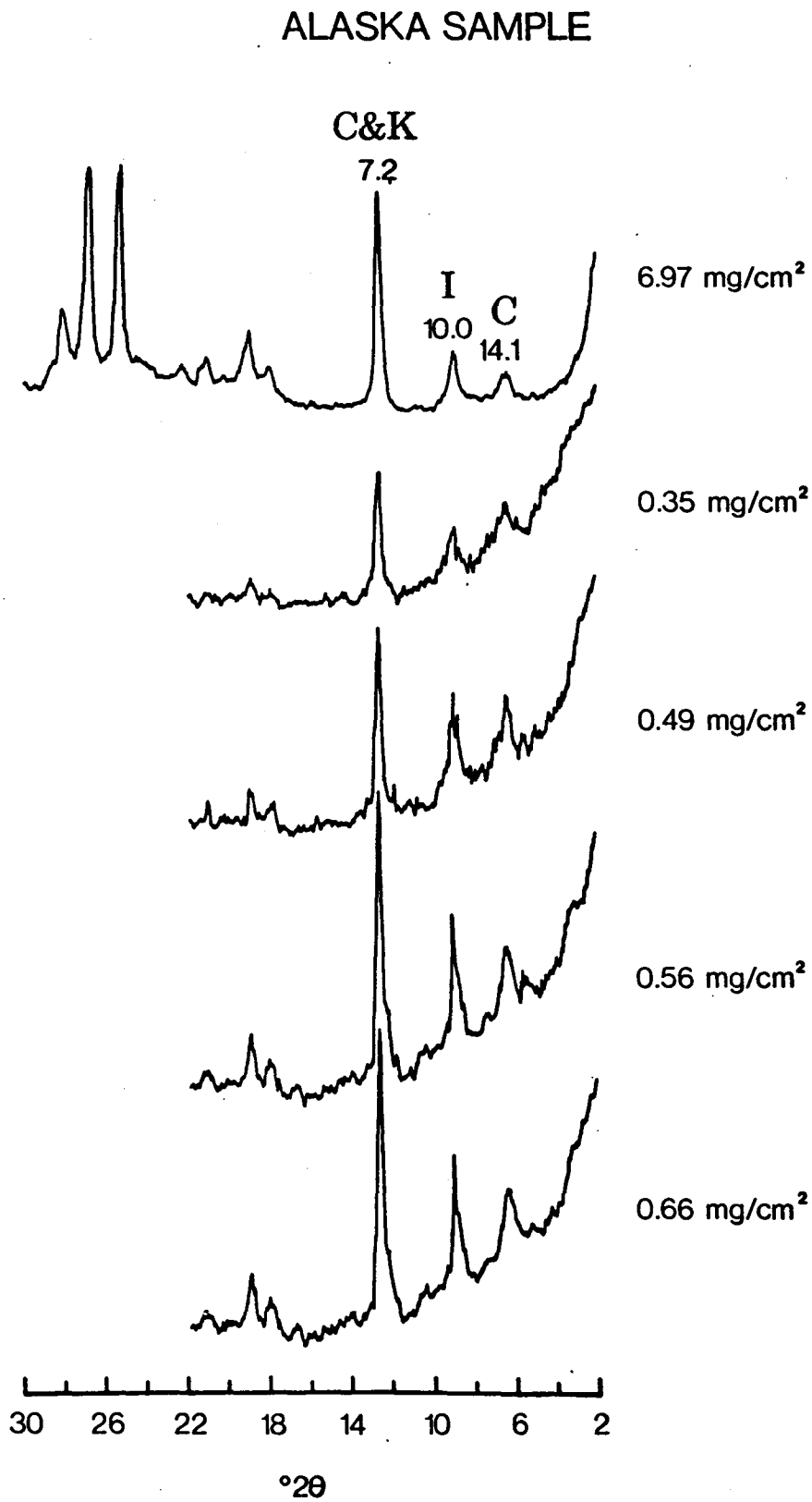


Figure IV-20. Diffractograms of filtered, bottom sediment concentrations in a gradational sequence to a consistent mineralogic analysis. Original on-filter concentration is given at the top as a reference (kaolinite illite chlorite, no smectite). C:chlorite; I:illite;K:kaolonite.

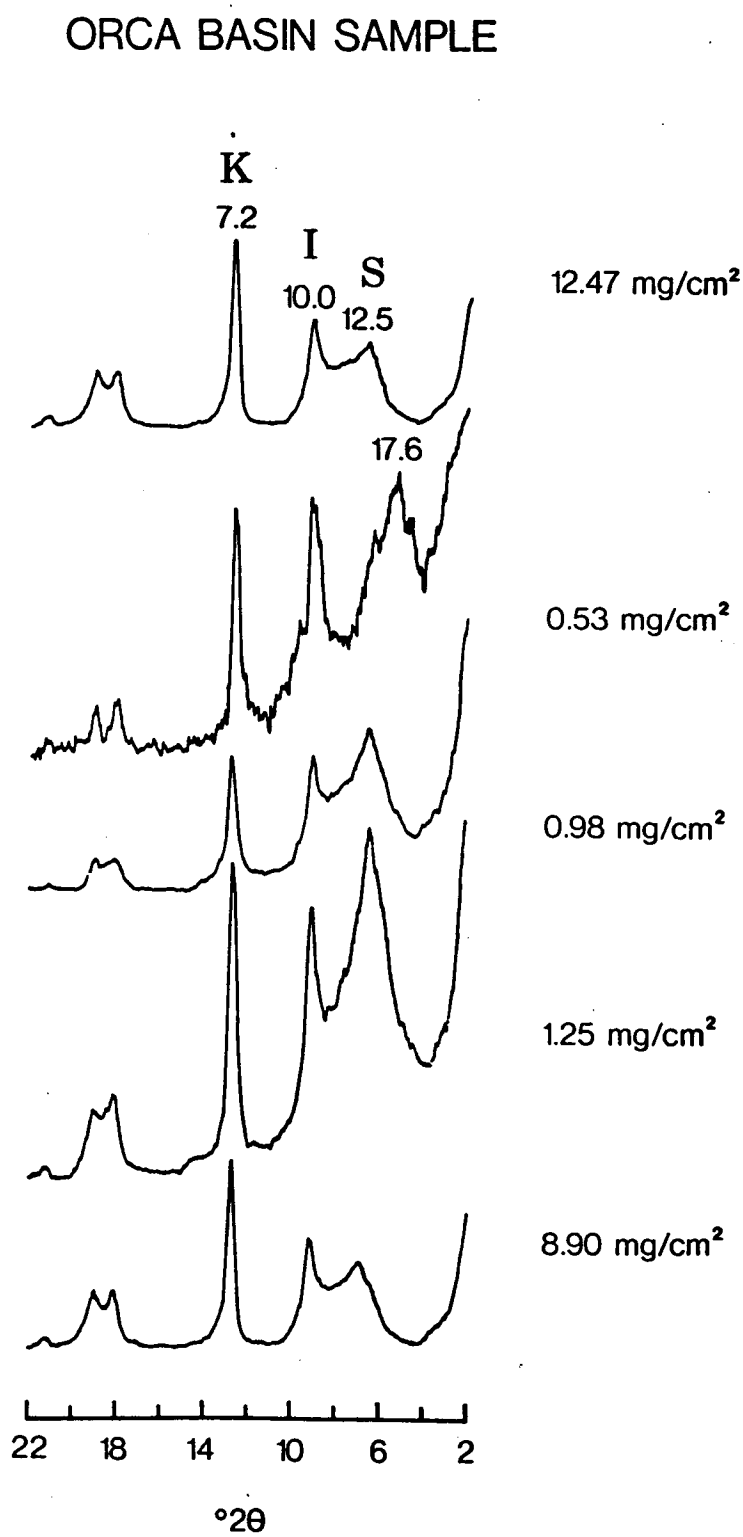


Figure IV-21. Gradational sequence to a consistent mineralogical analysis with intermediate amounts of smectite. Original on-filter concentrations is referenced at the top. S:smectite; I:illite; K:kaolinite.

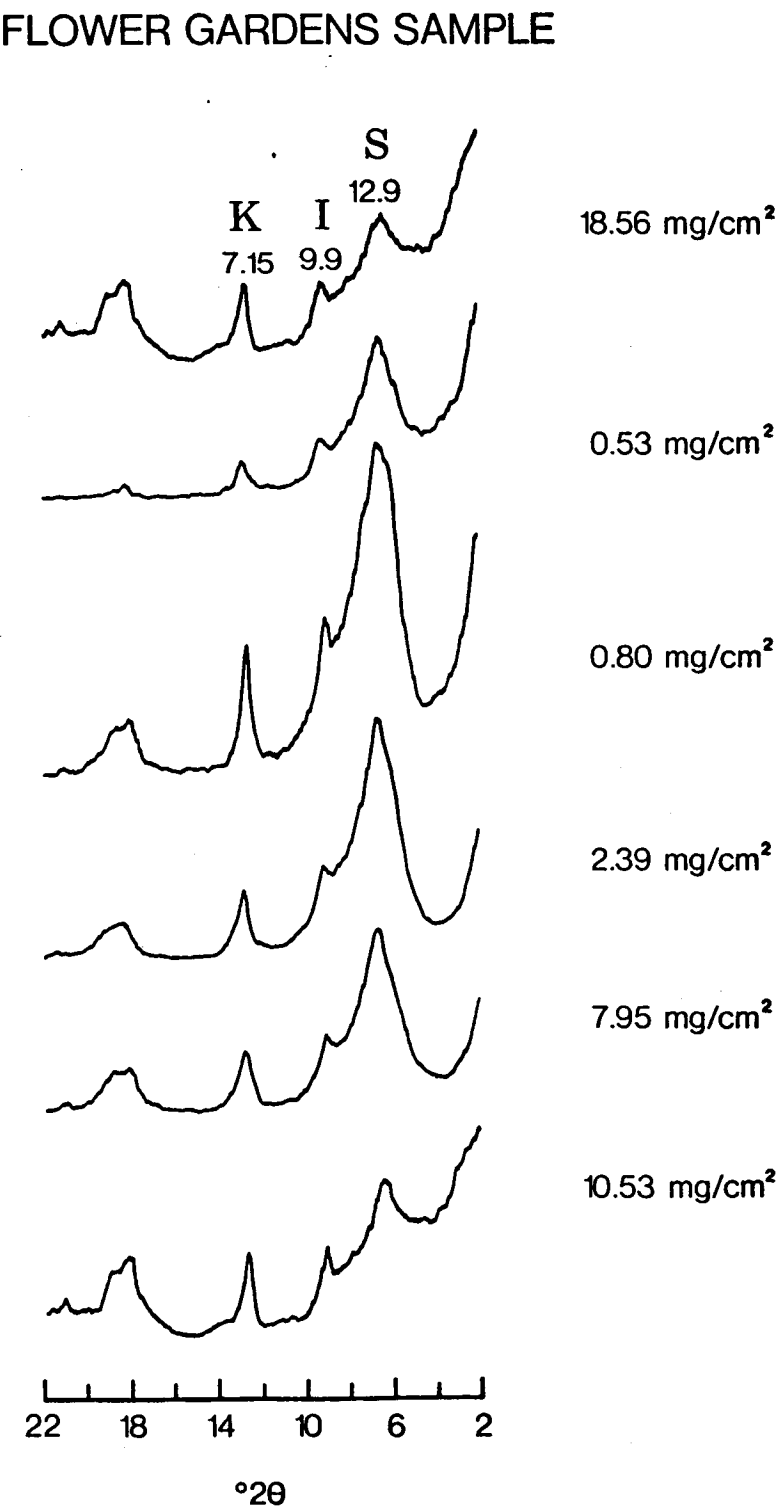


Figure IV-22. A smectite-rich on-filter concentration sequence that depicts the pronounced irregularies due to the original mineralogical composition. The original on-filter concentration is given as a reference at the top. S:smectite; I:illite; K:kaolinite.

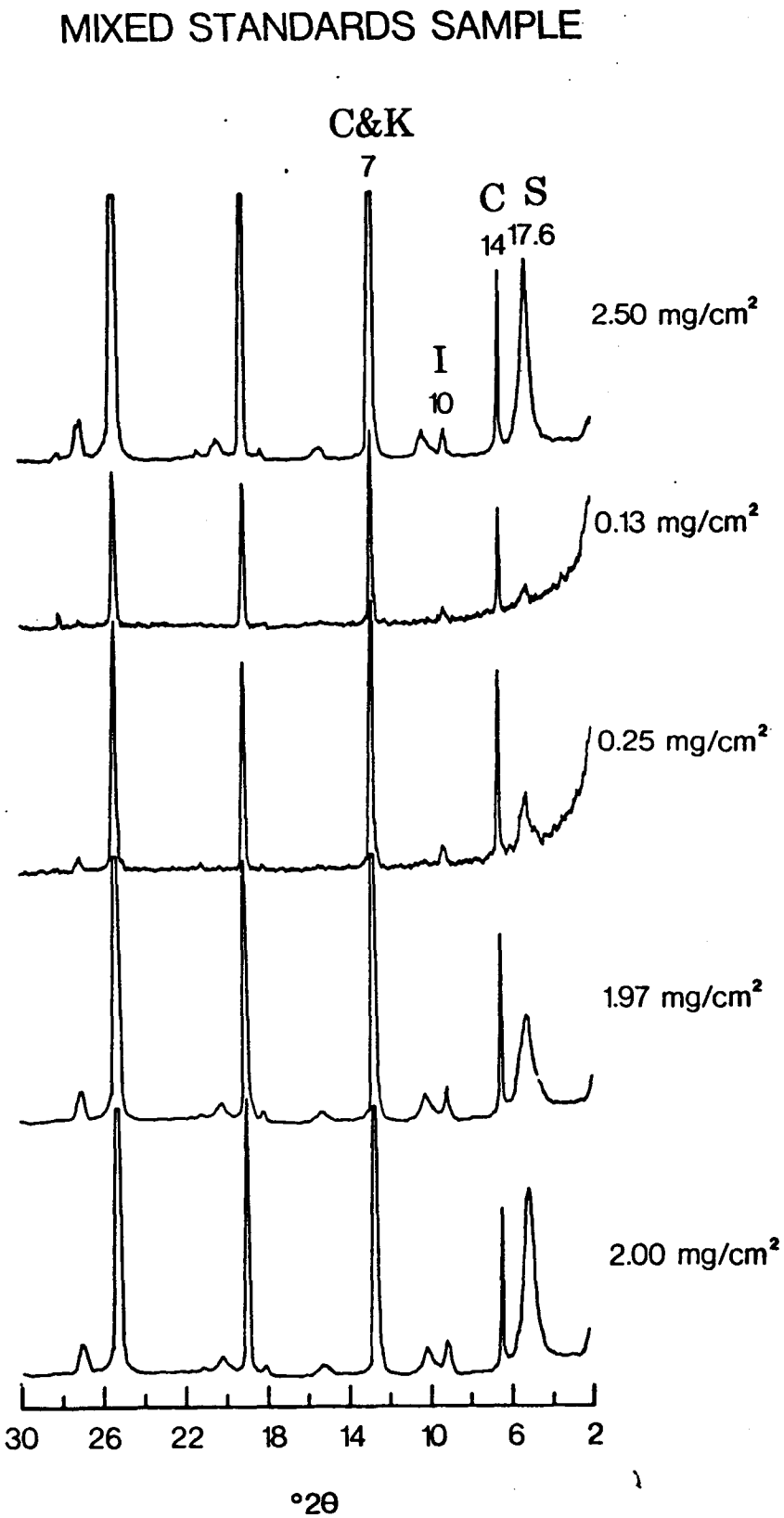


Figure IV-23. Gradational sequence of the laboratory mixed clay suspension in a weight ratio of smectite 4, chlorite 3, illite 2, and kaolinite 1. Original reference sample is given at the top. S:smectite; C:chlorite; I:illite; K:kaolinite.

analysis at 0.56 mg/cm^2 and higher (see Table IV-5). Dilute suspensions of the Alaskan clay mineral suite show an artificial depletion of illite and kaolinite relative to chlorite, below an on filter concentration of 0.56 mg/cm^2, at which point, the relative abundances match those of the original sample. Duplicate samples of the significant on filter concentrations were run to insure the validity of these results. Although the artificial depletion of illite is rather subtle, due to its relatively small abundance in this sample, it certainly cannot be overlooked as a major concentration artifact of a sample with that mineralogical composition (see Table IV-6).

Samples that contain intermediate (Orca Basin) or large amounts (East Flower Garden Bank) of smectite require a higher on-filter concentration to produce consistent analyses (see Table IV-5). Artifical depletion of kaolinite and enrichment of smectite is evident in dilute suspensions that contain intermediate amounts of smectite, as shown in Figure IV-21. There is a consistent enrichment of smectite between 0.53 and 1.25 mb/cm^2, at which point, smectite begins to decrease towards the original relative abundance and kaolinite and illite attain a consistent ratio. The diluted samples match the original composition at a concentration of 8.90 mg/cm^2. See Table IV-6.

The artificial enrichment of smectite is further displayed by the East Flower Garden suspensions (see Figure IV-22). With smectite existing in larger quantities than in the Orca Basin, the apparent increase in smectite is greatly enhanced. Dilute suspensions of this sample show an artificial depletion of both kaolinite and illite relative to the enrichment of smectite below an on-filter concentration

Table IV-5. Dilutions of different clay mineral suites.

SAMPLE	ON-FILTER CONCENTRATIONS (mg/cm^2)	TOTAL WEIGHT USED ON 1.6 cm SILVER FILTERS (mg)
Alaska		
original	6.97 (1.4 mg/ml)	14.00
A-8	0.35	0.70
A-11	0.49	0.98
A-14	0.56*	1.12
A-17	0.66	1.33
Orca Basin		
original	12.47 (3.58 mg/ml)	25.06
O-7	0.53	1.07
O-12	0.98	1.97
O-15	1.25	2.51
O-19	8.90*	17.90
East Flower Garden		
original	18.56 (5.33 mg/ml)	37.31
E-7	0.53	1.07
E-11	0.80	1.60
E-15	2.39	4.80
E-18	7.95	15.98
E-19	10.53*	21.17
Mixed Standard		
original	2.50 (1 mg/ml)	5.00
M-5	0.13	0.25
M-8	0.25	0.50
M-14	1.97	3.95
M-16	2.00*	4.00

* Lowest on filter concentration to produce consistent analyses.

Table IV-6. Calculated clay mineral composition (%)

SAMPLE	SMECTITE	CHLORITE	ILLITE	KAOLINITE
Alaska				
original	-	16	27	57
A-8	-	29	29	43
A-11	-	24	31	45
A-14	-	18	26	55
A-17	-	16	28	56
Orca				
original	28	-	34	38
O-7	33	-	31	36
O-12	46	-	29	25
O-15	46	-	26	28
O-19	29	-	33	38
East Flower Garden				
original	53	-	17	30
E-7	75	-	14	11
E-11	74	-	14	12
E-15	61	-	20	19
E-18	60	-	21	19
E-25	54	-	17	29
Mixed Standard				
original	41	31	18	10
M-5	**T	*P	T	P
M-8	26	47	T	26
M-14	37	33	11	19
M-16	40	31	14	10

* major constituent present in sample, but too small to calculate

** minor constituent present in trace amounts

of 10.53 mg/cm^2. This is a highly concentrated sample (21.17 mg total weight) and may pose a sampling problem in areas of low suspended sediment concentration. See Table IV-6.

The standard mixed sample consisting of smectite, chlorite, illite and kaolinite in the ratio by weight of 4:3:2:1 respectively showed an apparent depletion of smectite relative to the other minerals in dilute suspensions. Consistent mineralogical ratios were reached at a concentration of 2.00 mg/cm^2. See Table IV-6.

DISCUSSION

The influence of low on filter concentration on mineral species ratios in x-ray diffraction studies of clayey sediments has not been adequately treated in the published record. The mineralogy of the North Atlantic sample used by Tucholke (1974) is not similar in composition to any of the four samples used in the present study. His sample contained such a small amount of smectite, that an artificial depletion of this mineral, with decreased concentration of the suspensate, should be expected. Comparison of relative amounts of illite in analyses conducted during the present study and Tucholke's analysis (1974) illustrates how relative abundance alters results in dilute suspensions. Tucholke recorded an apparent enrichment of illite. No enrichment of illite was apparent in our experiments with four samples that contained much smaller amounts of illite.

Particle segregation might be used to account for the apparent enrichment of smectite in the Orca Basin and East Flower Garden samples. To preclude any bias due to differential particle settling,

duplicate samples were prepared by instantaneous filtration, thereby permitting no time for any particle segregation. The diffractograms from the two separate preparations were essentially identical.

Another possible explanation might be found in the techniques used for concentrating samples. Stokke and Carson (1973) showed that the suction on ceramic tile method, the principles of which were used in our experiments, is the most reliable (along with smears) for sample reproducibility. Therefore, the diffractograms of the original samples in our experiments are the best possible representations of mineralogical composition.

Particle orientation and sample thickness may be important factors in the artificial enrichment of smectite in dilute samples such as those from Orca Basin and the East Flower Garden. We feel that interpretation of the effects of dilution on the apparent clay mineralogy of a sample must await a detailed study of the effects of dilution on individual clay minerals combined with electron microscopy to observe the orientation of the minerals on the filters. This kind of study may reveal the nature of the decrease in basal reflection.

CONCLUSIONS

Examination of dilute suspensions of three different bottom sediment clay fractions (< 2 μm) and a laboratory mixed standard sample show relative mineral abundances different from the original sample. The on filter concentration required to obtain consistent mineralogical analyses varies as a function of the original relative abundance of

each clay mineral. An Alaskan sample consisting of large amounts of kaolinite with smaller amounts of illite and chlorite (no smectite) shows an artificial depletion of illite and kaolinite relative to chlorite at concentrations below 0.56 mg/cm^2, above which consistent mineralogical analyses are attained. Samples that contain intermediate and large amounts of smectite show artificial depletion of kaolinite and enrichment of smectite in low concentrations of suspended sediment. A higher concentration is required to obtain consistent x-ray diffraction analyses of these samples, i.e. samples from Orca Basin (8.90 mg/cm^2) and East Flower Gardens (10.53 mg/cm^2).

Results of the present study are different from those of Tucholke (1974) but we feel that this is a function of the nature of the original samples rather than the technique. Smectite was not a major constituent in the < 2 μm fraction used in his study. Therefore, the concentration observed by Tucholke (1974) as the minimum for consistent composition (1.6 mg/cm^2) must be used only for suspensates of similar mineralogical composition. The minimum on filter concentrations of suspended sediment for varying mineralogical composition must be considered prior to analysis; otherwise erroneous and misleading results will be obtained.

CHAPTER V

SUSPENDED SEDIMENT DISPERSAL - FOSSIL COCCOLITHS

SUSPENDED SEDIMENT DISPERSAL - FOSSIL COCCOLITHS

Principal Investigator

Stefan Gartner

INTRODUCTION

In the 1976-77 project year a study was initiated to evaluate the usefulness of calcareous nannofossils as natural tracers for the dispersal of fine grained sediments. The rationale for the initial study is given in detail in the 1976-77 South Texas Topographic Features Study, Final Report to BLM (Bright, Rezak, et al., 1978) and will be outlined here only briefly.

Coccoliths and related calcareous nannoplankton remains are contributed to the sediment as a steady rain of particles over the entire continental shelf area. These particles are produced in great number, by algae in the photic zone and, although they are quite small - 1 to 10 μm - they are distinctive in appearance and, therefore, can be readily identified. Age characteristic nannofossils are found in nearly all marine sediments, including most notably the wide belt of Cretaceous chalk that is found in a wide belt around the Gulf of Mexico. Streams and rivers flowing over the outcrop areas erode the soft and friable nannofossil bearing sediments and transport them to the Gulf of Mexico along with other fine grained detrital sediments. These sediments enter the Gulf of Mexico at a series of point sources along the coast where the rivers enter the Gulf, or where the various bays and estuaries open to the Gulf. Because of their small size coccoliths and other nannofossils are moved essentially as part of the suspended load, being placed in suspension by waves, and dispersed across the continental shelf by prevailing currents.

As these fossil coccoliths are dispersed their numbers are also

constantly being diluted by the contribution of modern coccoliths that are produced in the overlying water column, so that at any point on the continental shelf the ratio of redeposited coccoliths to modern coccoliths will reflect the relative proportion of the detrital sediment contribution. The variations in this proportion in turn will reflect the pathways of sediment dispersal. Thus, a high proportion of redeposited specimens would reflect a relatively high amount of detrital contribution; and a tongue of high proportion of redeposited specimens extending across the continental shelf would indicate dispersal direction of detrital sediment.

In a surface sediment sample even the uppermost millimeter may represent several tens of years of sedimentation, owing to mixing by burrowing organisms and other agencies. The relative abundance of redeposited nannofossils in surface sediments, therefore, represents the integrated effect of detrital sediment dispersal over a period of years. In suspended sediment samples, on the other hand, the proportion of redeposited nannofossils will depend entirely on their proportion in the parent sediment. If the suspended sediment originated on the sea floor in the immediate area where it was taken, then the proportion of redeposited nannofossils will reflect this; if, on the other hand, the suspended sediment originated in an area where the proportion of redeposited nannofossils is different, this will be readily apparent. Moreover, given sufficient sampling density, it should be possible to determine the direction of movement of suspended sediment at a particular time.

The justification for the study ultimately is to provide a means

of predicting the fate of particulate pollutants that might be introduced to this area through the activities of man.

SUMMARY OF PREVIOUS WORK

During the 1976-77 contract year suspended sediment distribution and dispersal as indicated by redeposited fossil coccoliths was examined in three ways. First, the distribution of redeposited fossil coccoliths was mapped in the surface sediments of the South Texas continental shelf, using 44 surface sediment samples (Gartner, 1978). The resulting map shows that in the northernmost part of the study area onshore transport of fine silt and clay size particles prevails, while immediately to the south of this is a pronounced band characterized by offshore transport, due east and diagonally across the continental shelf. In the central region of the South Texas continental shelf there is an area where dispersal seems relatively slow and uniform over a large area, and in the southernmost region a broad tongue extends offshore in the region just north of the mouth of the Rio Grande.

The second aspect of the study was to determine the ratio of "redeposited" coccoliths in the suspended sediment over the South Texas continental shelf during three different seasons and at three different depths, using samples from some 28 stations. This part of the study met with only limited success because most of the water samples yielded no coccoliths, fossil or modern, and indeed some yielded no carbonate particles at all. The latter led to suspicion that much of the carbonate in the suspended sediment was dissolved

by the unbuffered preservative used on the sample on board ship, a suspicion that seemingly is borne out by data obtained during the 1977-78 contract year.

The third aspect of the first year's study was to determine the distribution of redeposited fossil coccoliths in the surface sediments around several topographic highs on the South Texas continental shelf as well as in the suspended sediment over the banks. Both parts of this study yielded useful data. Anomalously high numbers of redeposited fossil coccoliths were found in surface sediments around these topographic highs, particularly on their southeast side. This is interpreted as either representing sediment transport parallel to the Gulfward margin of the banks, or exposure of relict late Pleistocene sediments caused by non-deposition or erosion in this area. Significantly the proportion of redeposited fossil coccoliths in the suspended sediment over the topographic highs indicates that these sediments did not originate on or in the immediate vicinity of these highs, but rather, that the continental shelf near the topographic highs was the most probable source for the suspended particles.

STUDY PROGRAM FOR 1977-78

The study program for 1977-78 consisted of two parts. First the map of the distribution of redeposited fossil coccoliths and other calcareous nannofossils on the South Texas continental shelf was to be refined by the additional study of 44 coretop samples from this area. The map prepared during the first year's study suggested that pathways in sediment transport may be so sharply limited as to escape detection with the original grid of samples. Therefore, all

additional available samples over the area were analyzed, thereby reducing the distance between adjacent samples to about half that in the initial study (Figure V-1). The second part of the study program consisted of determining the distribution of redeposited coccoliths in the suspended sediment over the South Texas continental shelf, but making a special effort to insure that carbonate was not dissolved in these samples by the addition of a buffer that would lower the pH of the sample. Since the previous year's study had indicated that appreciable amounts of suspended sediment containing the coccolith size fraction (1-10 μm) were present consistently only in near bottom suspended sediments, only these samples were examined. The samples were taken at the same stations as during the previous year, and during three seasons (November, 1976, March, 1977, and June, 1977).

SAMPLE PREPARATION

Sample preparation techniques for this study were essentially the same as were developed and used for the 1976-77 study, with only one minor change in the filtering of suspended sediment samples, designed to facilitate counting of coccoliths.

(1) Bottom Sediments

Core top samples were prepared as follows: a small amount of sediment was suspended in 1 to 2 ml of water to which were added two drops of polyvinyl alcohol solution (PVA). This suspension was thoroughly mixed and spread onto a cover glass. The suspension was dried on a warming plate, thereby depositing a uniform layer of sediment on the cover glass, and which was held to the cover glass by a thin film of polyvinyl alcohol. The dry cover glass was mounted on

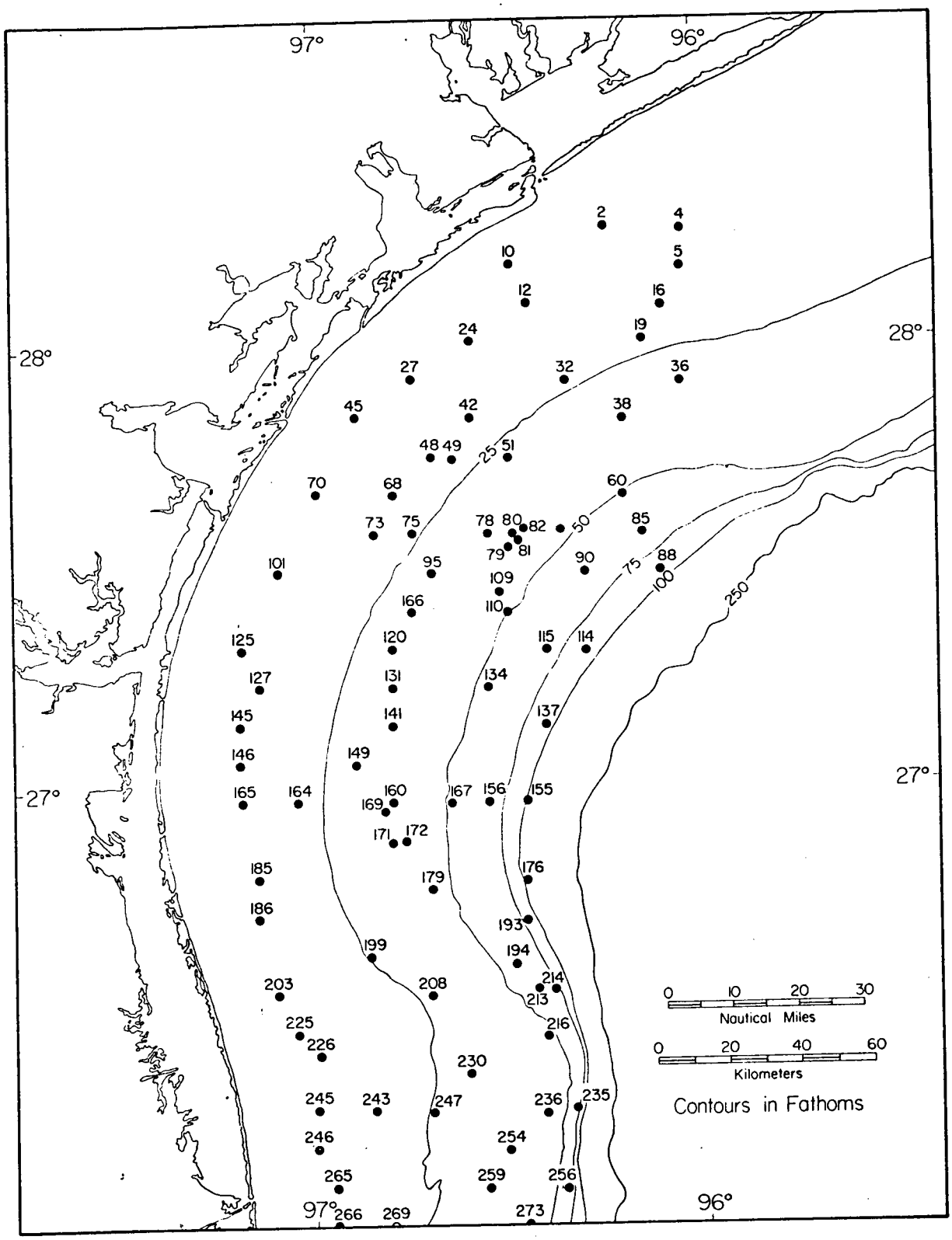


Figure V-1. Location map of coretop samples used to construct suspended sediment dispersal map.

a glass slide with Caedex, a synthetic resin.

(2) Suspended Sediments

To prepare suspended sediment for microscopic examination a 47 mm diameter Millipore filter with 0.8 μm pore size was masked so all filtrate was deposited on a rectangular area measuring 20 mm by 28 mm. Half of a one liter water sample was filtered onto this area. If the amount of suspended sediment was very small, the filter was again masked, this time in such a way as to expose ¼ of the area on which sample had been filtered previously. The remaining suspended sediment was then filtered onto this area. (The ratio of suspended sediment on the two parts of the filter is 1:5, and this allows for a relatively wide latitude of concentration in the water sample without appreciably increasing the difficulty of making counts on the filtrate.)

The filter was rinsed of salt by drawing about 50 ml of distilled water through the filter after the water sample. The filter and sediment were then dried at low temperature (100 to 110°F). The rectangular portion of the filter containing the suspended sediment was trimmed, mounted on a glass slide with immersion oil (refractive index = 1.515) and covered with a cover glass. The immersion oil rendered the filter transparent and allowed study of the suspended sediment in transmitted light.

STUDY TECHNIQUES

Abundances of reworked and of modern coccoliths were determined by counting the number of specimens within a given area. Counts were made at 1000X magnification in cross-polarized light. Because the

indigenous modern forms were generally much more abundant than reworked Cretaceous species, especially in samples taken towards the edge of the continental shelf, the count for indigenous modern species could be made on one or two fields. In these samples a much larger area had to be scanned to get a count of the reworked Cretaceous species.

After the counts were made the values were normalized for an equal area. The ratio of total coccoliths to reworked coccoliths was determined from these normalized values. The total coccolith number was used rather than that of indigenous modern species so that the ratio could not be less than 1, even if only reworked coccoliths were encountered, and all of the ratios are presented by number ranging from 1 to ∞. Samples containing no redeposited species yield a ratio of ∞; samples containing one or more redeposited speciments yielded number from 1 to about 65000. These ratios represent a very large spread and cannot be visualized or represented on a map readily. Therefore, ratios were reduced to exponential values of powers of ten. Thus ratios ranging from 1 to 10 are represented by the exponent 1; ratios between 10 and 100 are represented by the exponent 2; ratios between 100 and 1,000 are represented by the exponent 3; ratios between 1,000 and 10,000 (including ∞) are represented by the exponent 5. When reduced to exponential values the ratios can be readily plotted and visualized for interpretation.

RESULTS AND INTERPRETATION

The data resulting from this study are presented in tabular form in Appendix A Tables V-1 to -4. The same data are also plotted

on maps on Figures V-2 to -5. As in the previous year's study the exponential values to base ten of the ratios are plotted on the maps and contoured.

SURFACE SEDIMENTS

Figure V -2 represents the relative abundance of redeposited coccoliths, almost exclusively Cretaceous species, in the surface sediment of the South Texas continental shelf. The greatest concentration, represented by the number 1, is along the coast line. The lowest concentration, represented by the number 5, is found in samples from the continental shelf and slope. Intermediate concentrations extend in more or less parallel bands, sometimes approximately parallel to the coast, elsewhere trending across the shelf.

The general pattern of distribution of redeposited nannofossils as established during the previous study remains after the new data have been incorporated (Compare Fig. V-15 in Gartner, 1978 and Figure V-2 in this report). One notable and significant difference is that the more closely spaced samples in the current study have revealed the presence of a narrow tongue of high concentration of redeposited coccoliths extending from offshore of Port Aransas to the south-southeast diagonally across the continental shelf and the upper continental slope. The shoreward end of this tongue merges with the shoreward end of an equally pronounced but somewhat broader tongue extending nearly due east from Port Aransas diagonally across the shelf. Thus, these two tongues of high concentration of redeposited coccoliths are nearly at right angles to one another, and are separated by a broad area of significantly lower concentrations. In the southern part of the study area the previously constructed map is not altered

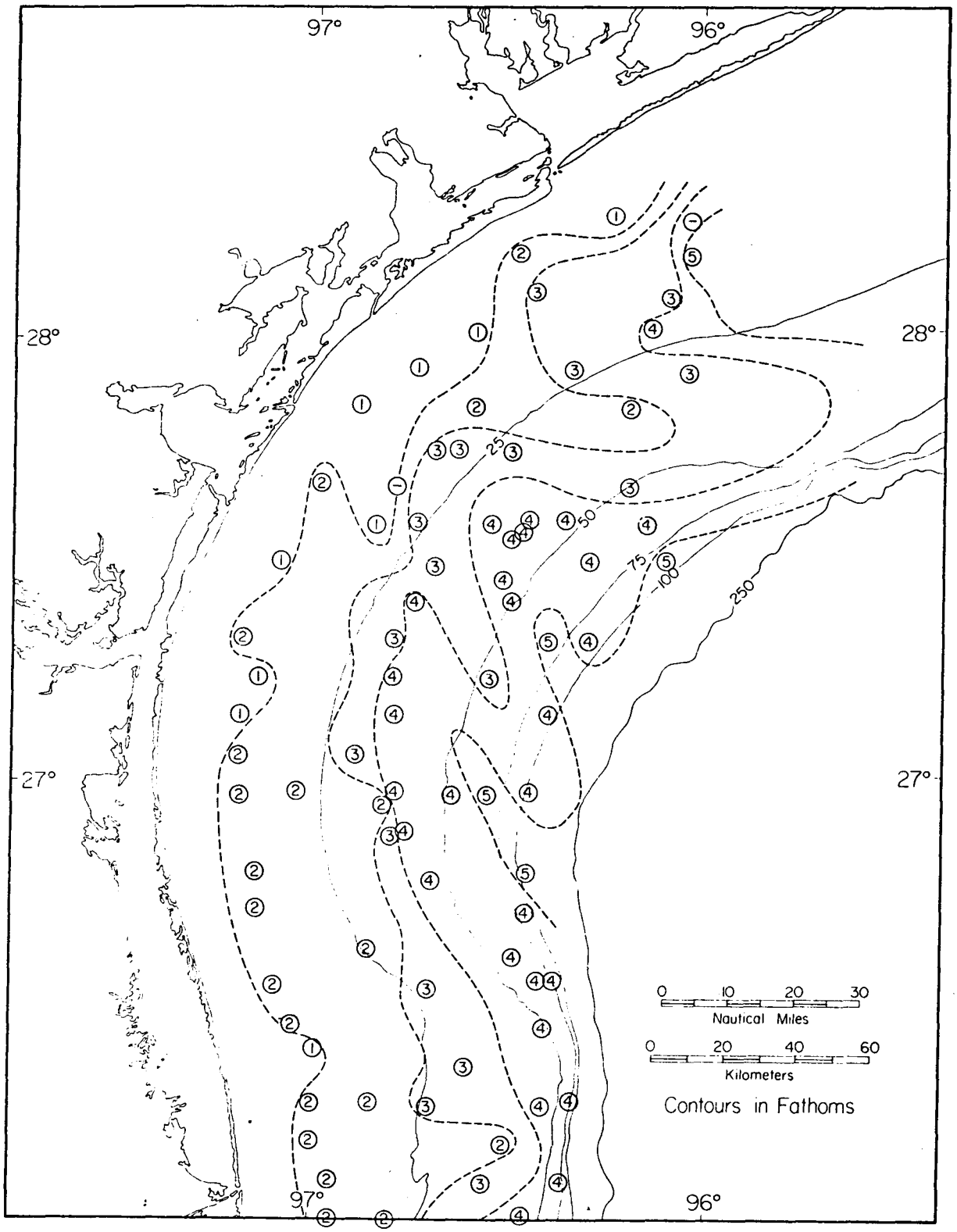


Figure V-2. Suspended sediment dispersal pattern indicated by the relative abundance of redeposited fossil coccoliths in suspended sediment. For explanation see text.

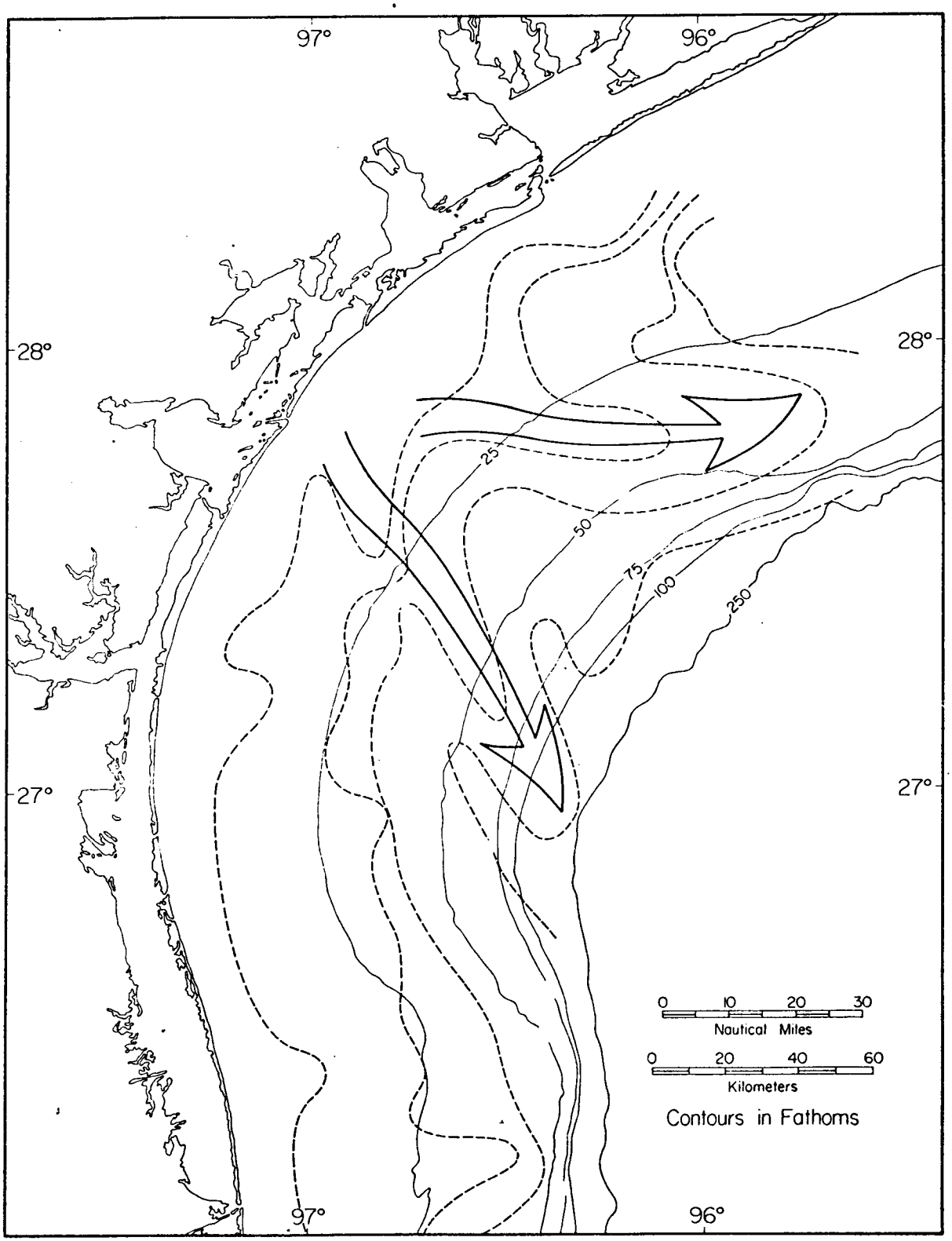


Figure V-3. Inferred direction of seasonal suspended sediment transport based on redeposited coccoliths.

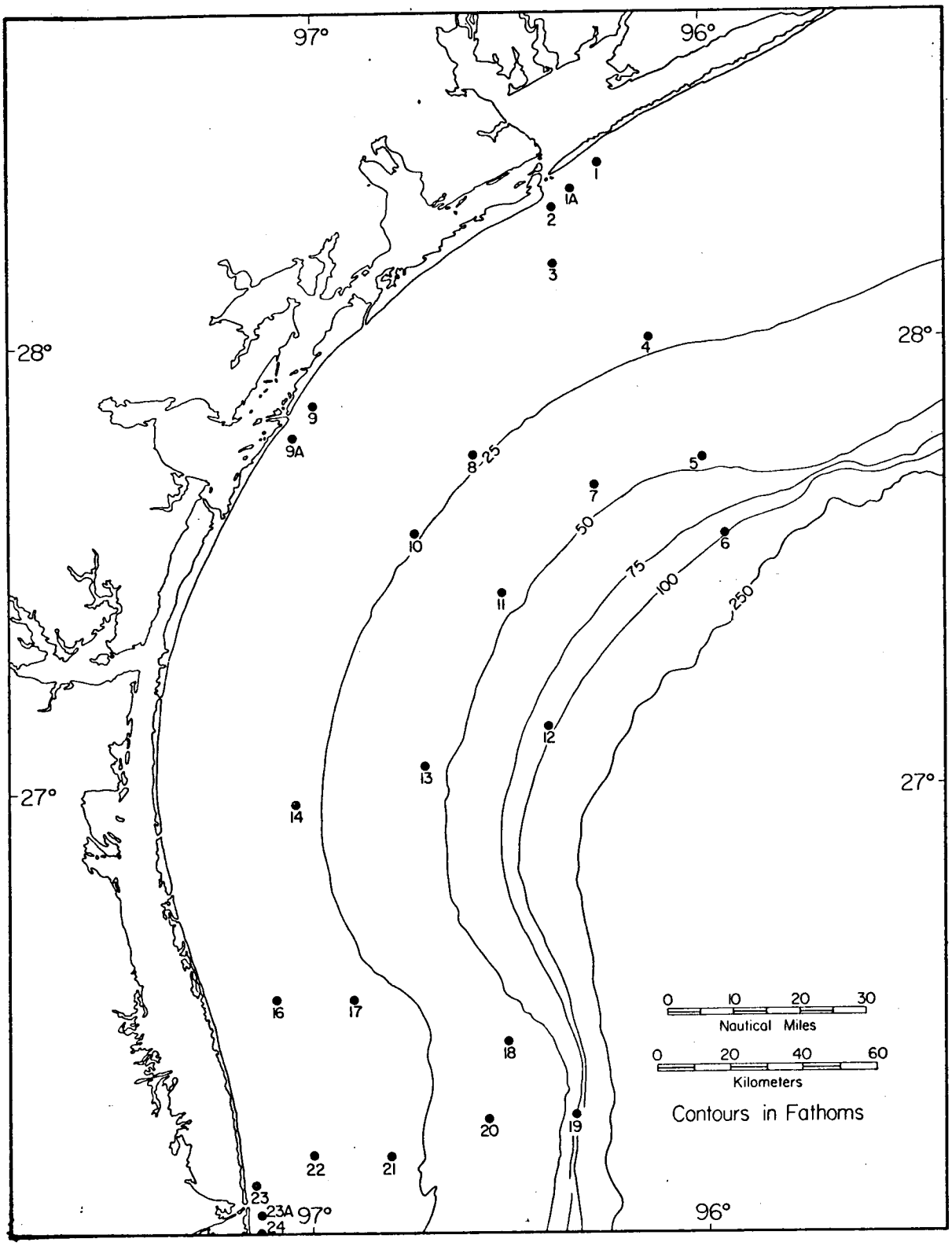


Figure V -4. Water column suspended sediment sampling stations.

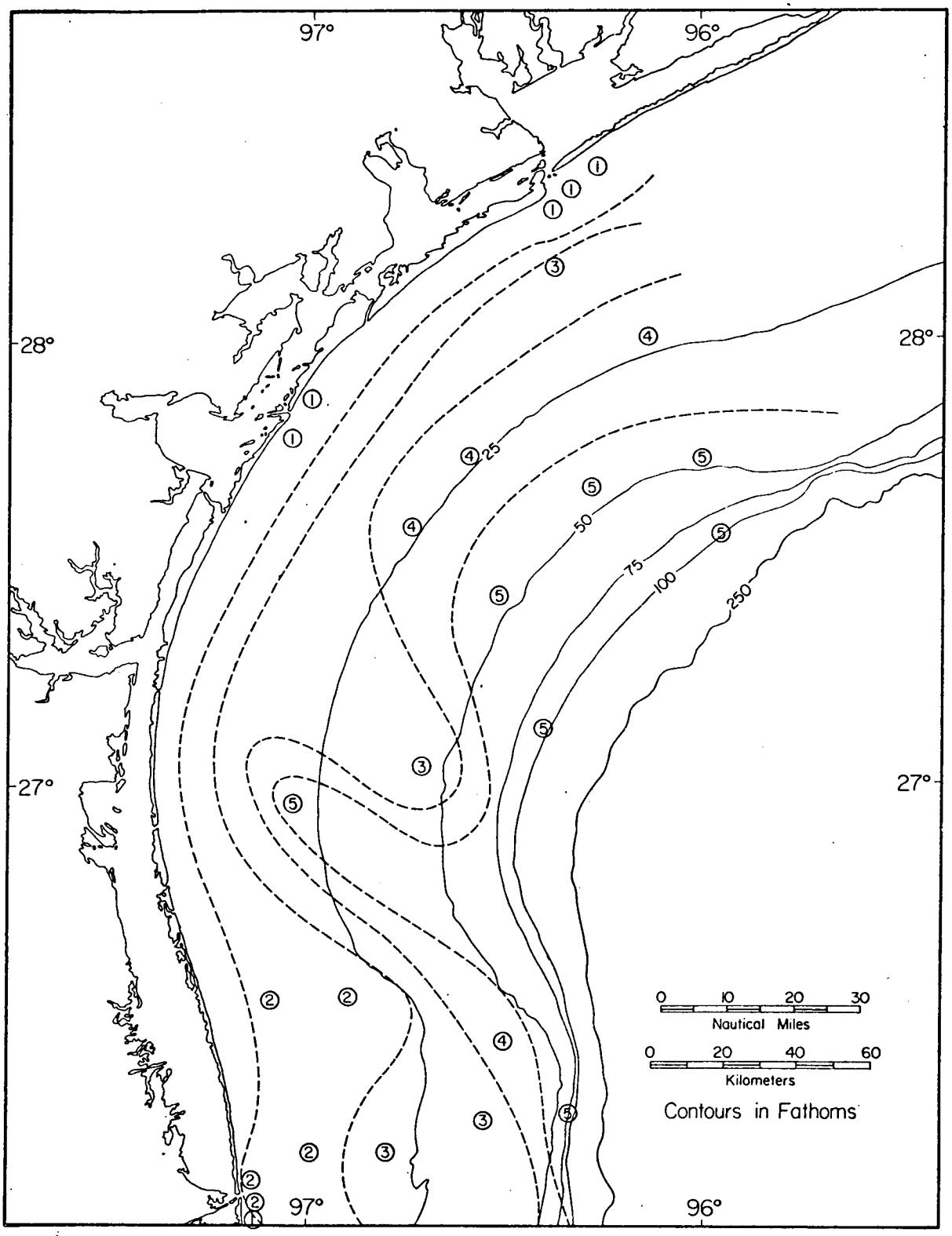


Figure V-5. Relative abundance of resuspended fossil coccoliths in near bottom water samples, November, 1976.

significantly by the new data. A broad bulge of slightly higher concentration is associated with the mouth of the Rio Grande, and locally higher concentrations of redeposited species may be found.

The most interesting and intriquing aspect of the distribution of redeposited fossil coccoliths is in the northern half of the study area. Curray (1960) and van Andel (1960) inferred offshore transport of sediment, more or less at right angles to the coast line, and centered near the mid part of the study area. Their conclusion was based largely on surface sediment texture. Shideler (1976, 1977) made a more detailed analysis of surface sediment texture over this area, but ventured only a general statement regarding sediment dispersal. He concluded that the "Palimpsest and modern mud sediments of the respective northern and central provinces appear to be encroaching southward onto relict deposits of the southern ancestral Rio Grande delta. . ." (Shideler, 1977). The data from this study suggest that in the northern half of the South Texas continental shelf there are two pathways by which fine grained detrital sediments (fine silt and coarse clay size particles) are dispersed across the continental shelf, and that these pathways are indicated by the tongues of high concentration of redeposited fossil coccoliths (Figure V-3).

Previously (Gartner, 1978) the data were interpreted in terms of the inferred shelf water circulation (Berryhill et al., 1975), compiled from surface salinity data. Inferred current directions are represented on maps at approximately monthly intervals. In the northernmost part of the South Texas continental shelf the current direction is to the west-southwest nearly throughout the year. This agrees well with the low concentration of redeposited fossil coccoliths

in the area south of Matagorda Bay since the prevailing current direction would result principally in an onshore transport. Immediately to the south of this area and due east of Port Aransas a north and eastward flow dominates from mid-March through September, and this flow coincides rather closely with the sediment transport direction inferred from the eastward extending northern tongue of high concentration of redeposited fossil coccoliths.

The second tongue, which extends south-southwest from the Port Aransas area, is not as readily explained by the inferred currents. It should be pointed out, however, that this tongue lies completely between shelf transects from which the data were taken for the inferred circulation. It is, therefore, highly likely that evidence for seasonal currents moving southward from offshore of Port Aransas may not be obvious. The limited data used in the current studies (Berryhill, et al., 1975) are interpreted to indicate the presence of an eddy at irregular times in the area of ths south-southeasterly extending tongue of highly concentrated redeposited fossil coccoliths. It is not at all obvious how such an eddy would relate to the sediment transport direction suggested by the redeposited coccoliths. Rather, the sediment data would lead to the expectation that, seasonally at least, a sharply defined current flows from offshore or Port Aransas to the south-southeast, possibly driven by the convergence of two currents flowing more or less parallel to the shoreline. It might be speculated further, on the basis of the position and orientation of the two tongues that the resulting offshore current depends on whether the southwestward flow in the north or the northward flow in

the southeast dominate.

SUSPENDED SEDIMENTS

The data from suspended sediment samples were treated in the same manner as the data from surface sediment samples. Figure V-4 indicates the stations at which suspended sediments for this study were taken. Figures V-5 to -7 are plots of these data for the three seasonal cruises, contoured as in Figure V-2. The first seasonal sampling cruise was in November, 1976 (Fig. V-5). The values for this season are all relatively low, though quite real. Fossil coccoliths derived from Cretaceous sediments were present in nearly all of the suspended sediment samples, with highest values being encountered at stations near the coast. In the northern part of the study area the contours run parallel to the coastline and are rather closer to the coast than might be expected from the position of corresponding contours for surface sediments. In the mid part of the study area two stations, numbers 13 and 14, yielded anomalous values. It is possible that only one of these values is significant. For example, if station 14 is eliminated the general trend of the contours continues smoothly to the south. However, the data points are too few to justify discarding any one value as spurious. In the southern part of the study area a broad, somewhat irregular bulge extends out onto the continental shelf. A likely interpretation of the data is that relatively little suspended detrital sediment entered the Gulf of Mexico along this stretch of coast during this period of time, since there are no obvious concentrations in the vicinity of passes through the barrier islands. Nor does it seem likely that the bottom had been stirred up

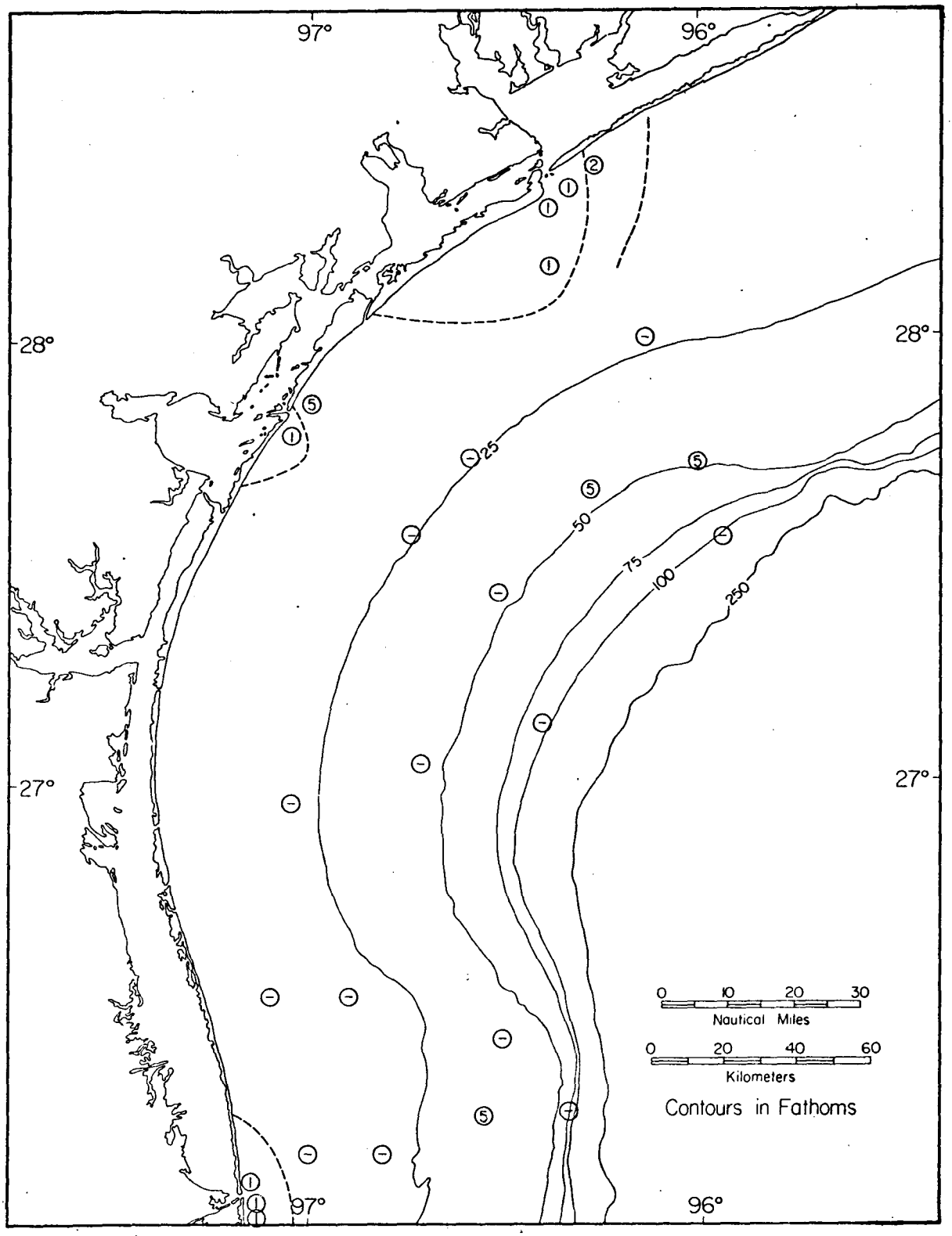


Figure V -6. Relative abundance of resuspended fossil coccoliths in near bottom water samples, March, 1977.

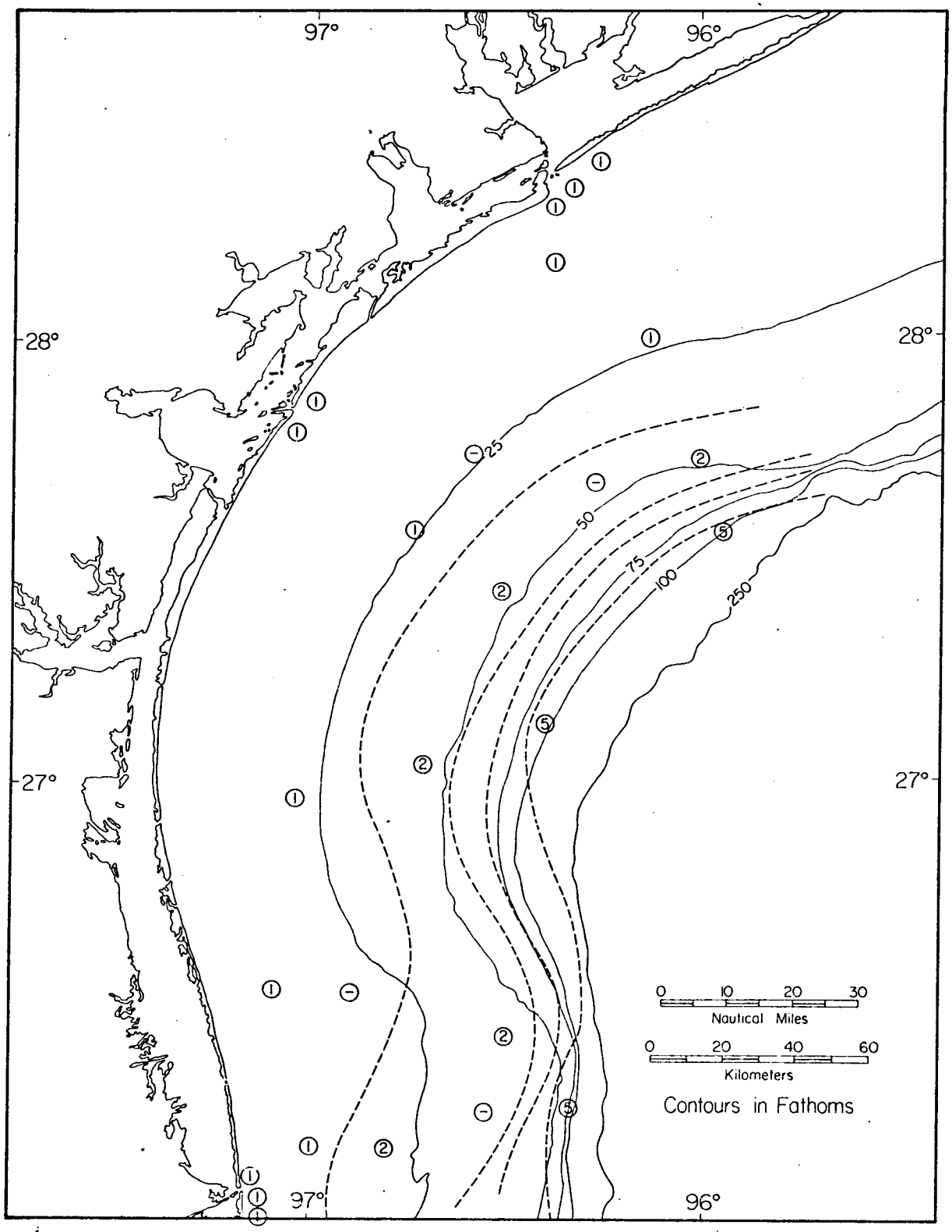


Figure V-7. Relative abundance of resuspended fossil coccoliths in near bottom water samples, June, 1977.

greatly just prior to sampling. Most probably the Cretaceous nannofossils present in suspension originated for the most part in shallow areas near shore, and significant numbers were transported offshore only in the southern part of the South Texas continental shelf.

The second seasonal sampling was done in March, 1977, and the samples taken at this time yielded virtually no suspended coccoliths, except in the vicinity of the entrance to Matagorda Bay (Pass Cavallo), Aransas Pass, and Brazos Santiago (Fig. V-6). The obvious interpretation is that little or no turbulence occurred for a period of time preceeding this sampling cruises that would have caused any resuspension of fine sediment anywhere on the South Texas continental shelf.

The third seasonal sampling was done during June, 1977, and at this time high concentrations of Cretaceous coccoliths occur rather far out on the continental shelf (Fig. V-7). Half of a bulge seems to be discernible directly offshore from Pass Cavallo and a broad bulge is present north of the mouth of the Rio Grande. This latter bulge can, in a general way, be associated with a similar bulge in the the redeposited coccolith concentration in the surface sediment, but it may well be associated also with run off from the Rio Grande and northeastward transport of suspended sediment.

A further speculation is offered here based on the combined data from surface sediment and suspended sediment. The very sharp bulges in concentration of redeposited fossil coccoliths in the surface sediment indicate that pronounced dispersal of suspended sediment can and does occur on the South Texas continental shelf. Moreover, the pattern is related to the current regime over the area. That this

pattern is not apparent in any of the three seasonal sample sets, even though two of the sample sets contain significant numbers of fossil Cretaceous coccoliths, may be explained either by the fact that the density of sampling stations during the seasonal sampling was not nearly as great as the density of surface sediment samples. Alternatively the currents responsible for dispersal of the suspended sediments are ephemeral, though probably quite intense, and simply are not present at the time the sampling was done for suspended sediment.

CHAPTER VI

DESCRIPTIVE BIOLOGICAL RECONNAISSANCE STUDIES

DESCRIPTIVE BIOLOGICAL RECONNAISSANCE STUDIES

by

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INTRODUCTION

Descriptions of the zonation, structure, species composition and relative population levels of epibenthic biotic communities occupying seven outer continental shelf topographical features in the northwestern Gulf of Mexico were derived from data and samples taken using the Texas A&M Research Submersible in September, 1977. Submersible transects were run on the 18 Fathom, Bright, Bouma, Parker, Ewing, Sackett and Sonnier Banks.

Biotically, the banks fall into three categories. 18 Fathom, Bright, Bouma, Parker and Ewing Banks are shelf-edge features supporting active, diverse, reefal communities dominated by anthozoan corals and/or coralline algae. Sackett Bank, possibly because of its close proximity to the Mississippi River and the probable chronic stress associated with variations in turbidity and salinity due to the river outflow, is not occupied by extensive, thriving coral or coralline algal communities, although drowned remnants of previously active coralline algal reefs are present and small populations of coralline algae occur as scattered nodules and crusts. Sonnier Bank is a mid-shelf structure comprised of siltstone outcrops encrusted with populations of hydrozoan fire coral, sponges and other epifauna similar to that found on Stetson Bank (see Bright et al. 1978).

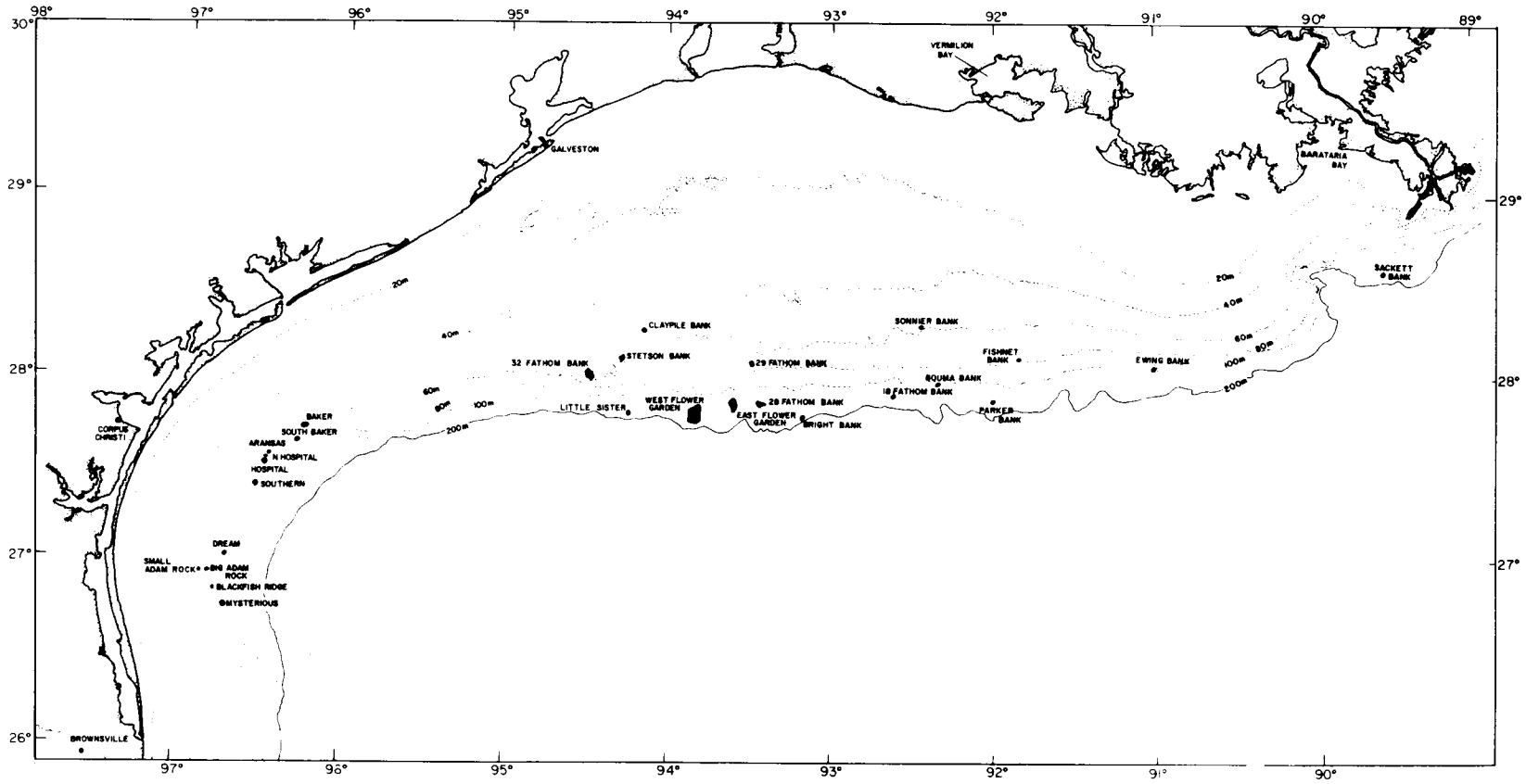


Figure VI-1. Major topographical features on the Texas-Louisiana Outer Continental Shelf.

18 FATHOM BANK

18 Fathom Bank (27°58'N, 92°36'W) is a topographical feature with a comparatively shallow crest depth (43 m)(Fig. VI-1). Of the shelf-edge carbonate banks west of the Mississippi Delta, only the East and West Flower Garden Banks have shallower crests. Like the Flower Gardens, the uppermost part of 18 Fathom Bank is occupied by coral reefs, coralline algal reefs, algal nodules, leafy algae and a diverse array of attached and mobile invertebrates and fishes (Fig. VI-2) (Tables VI-1a and VI-1b).

The coral reefs of 18 Fathom Bank are unique, occurring in patches between 43 and 47 m depth (Figs. VI-2, 3, 4). Biologically, they are much less diverse than the Flower Garden reefs. Only 4 types of coral seem to be important reef builders, compared to 10 or so at the Flower Garden. At the crest of 18 Fathom Bank, the coral *Stephanocoenia* sp. forms crusts and rounded heads which may be 1.5 m in height. Smaller heads of *Stephanocoenia* sp. were seen on coralline algal reef patches, ledges and hard bottoms down to a depth of 54 m. The fire coral, *Millepora* sp., is very conspicuous above 54 m depth, encrusting on coralline algal reefs and other hard substrata. *Montastrea cavernosa* occurs in the same depth range, primarily as flat crusts up to 1 m or so in diameter. This encrusting growth of a coral which typically forms large massive heads occurs under conditions of chronically low light levels, which reduce the efficiency of carbonate skeleton production by the coral. Nearly identical platter-like growths were also seen at the crest of Bright Bank. Not all of the *Montastrea cavernosa* colonies at 18 Fathom Bank were

Figure VI-2a. **18 FATHOM BANK**

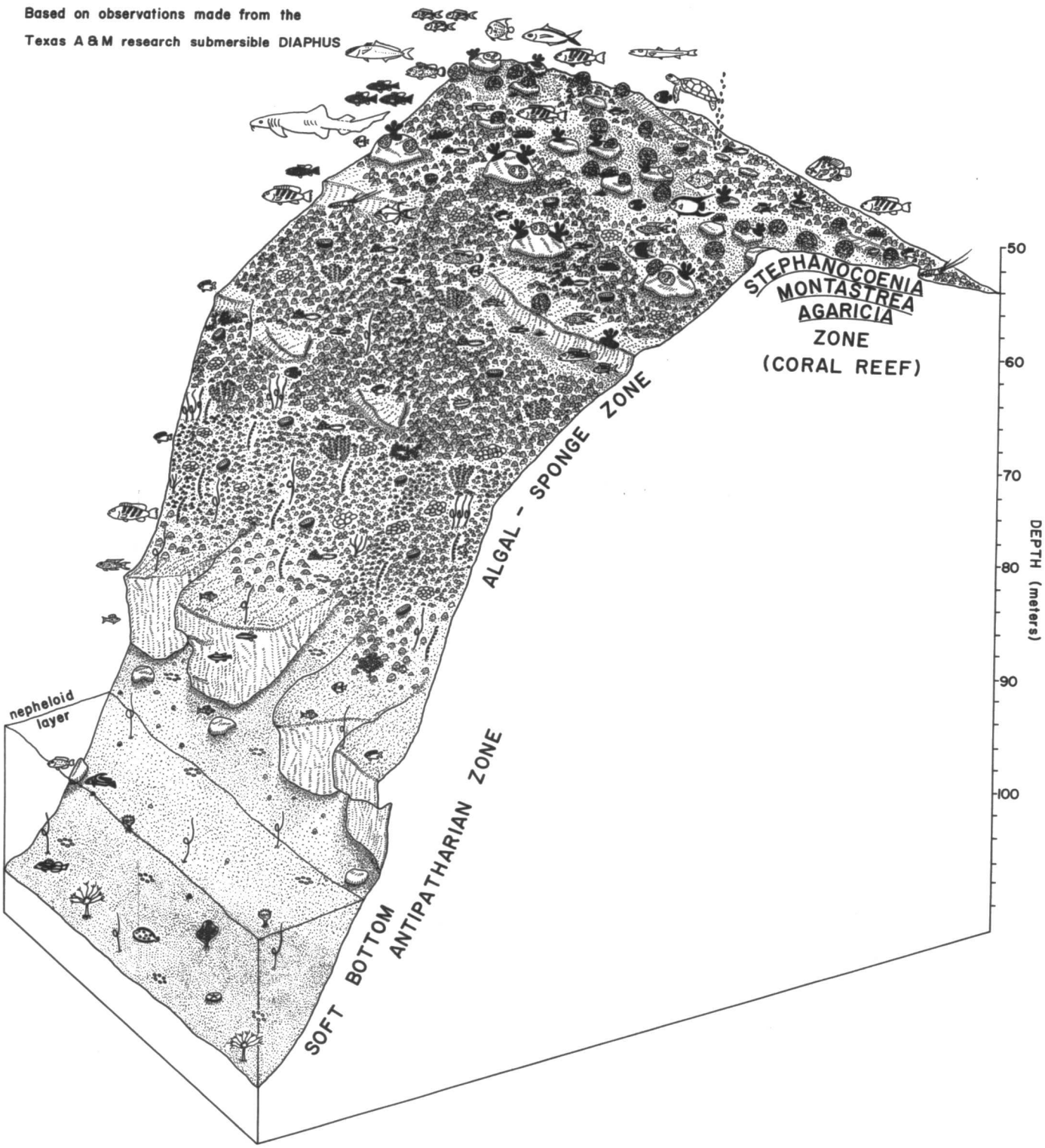


Figure VI-2b. Legend for Figure VI-2a.

- patterned burrows
- gas seep
- coralline algal nodules
- carbonate rubble
- coralline algal reef
- Oxysmilia (solitary coral)
- Madracis (coral)
- Millepora (Fire coral)
- Stephanocoenia, Montastraea cavernosa, Agaricia — corals
- saucer shaped Agariciid
- Cirripathes (Thorny coral)
- Antipathes (Thorny coral)
- Elisellid (sea whip)
- Nidalia (octocoral)
- plume-like hydroid
- leafy algae
- Lobophora (algae)
- Halimeda (algae)
- Agelas (sponge)
- Clypeaster (sand dollar)
- Diadema (Black urchin)
- Paramuricid (sea fan)
- Vermetidae (worm shell)
- Spondylus americanus (American thorny oyster)
- Panulirus argus (Spiny lobster)
- Equetus punctatus (Spotted drum)
- Liopropoma (basslet)
- Balistes vetula (Queen triggerfish)
- Xanthichthys ringens (Sargassum triggerfish)
- Lutjanus campechanus (Red snapper)
- Pseudupeneus maculatus (Spotted goatfish)
- Caranx ruber (Bar jack)
- Holacanthus ciliaris (Queen angelfish)
- Holacanthus tricolor (Rock beauty)
- Pomacanthus paru (French angelfish)
- Triglidae (sea robin)
- Pleuronectidae (flounder)
- Priacanthidae (bigeye)
- Paranthias furcifer (Creolefish)
- Chromis cyaneus (Blue chromis)
- Chromis enchrysurus (Yellowtail reeffish)
- Mycteroperca (grouper)
- Bodianus pulchellus (Spotfin hogfish)
- Thalassoma bifasciatum (Bluehead)
- Holocentrus (Squirrelfish)
- Ginglymostoma cirratum (Nurse shark)
- Centropyge argi (Cherubfish)
- Sphyraena barracuda (barracuda)
- Canthigaster rostrata (Sharpnose puffer)
- Epinephelus adscensionis (Rock hind)
- Epinephelus cruentatus (Graysby)
- Epinephelus inermis (Marbled grouper)
- Seriola dumerili (Amberjack)
- Chaetodon sedentarius (Reef butterflyfish)
- reef fish A
- turtle

encrusting. A few medium sized massive heads were seen, one at 54 m depth. Such heads occur on the East Flower Garden Bank at the same depth. A species of the coral genus Agaricia occurs as crusts and small masses on the coral reefs and coralline algal reefs on 18 Fathom Bank down to at least 49 m depth.

In recognition of the unique nature of these coral reefs, the depth range wherein sizeable colonies of hermatypic corals of the genera Stephanocoenia, Montastrea and Agaricia are abundant has been designated the STEPHANOCOENIA - MONTASTREA - AGARICIA ZONE. It is pointed out, however, that coralline algal reefs are probably at least as widespread within the zone as are the coral reefs.

The coral and coralline algal reefs at the top of 18 Fathom Bank harbor a population of reef fishes which is more diverse (more species present) than those found on the shelf-edge banks having deeper crests (Table VI-1b). On the other hand, fish diversity is less on reefs at 18 Fathom Bank than at the East and West Flower Garden Banks. When we examined 18 Fathom Bank, in September 1977, populations of Scamp, Mycteroperca phenax and Red snapper, Lutjanus campechanus were present around the reefs.

In general, from the standpoints of coral, fish, algae and invertebrate populations, the shallowest reefs at 18 Fathom Bank are comparable to deep coral reefs reported from 43 to 55 m depth at the East Flower Garden (Bright et al., 1976). The deep East Flower Garden reefs are formed primarily by Montastrea cavernosa, Diploria spp., Colpophyllia sp., Agaricia sp. and Millepora sp. Heads of Stephanocoenia sp. are also frequent at these depths on the

East Flower Garden Bank. It appears, therefore, that because of its shallow crest depth, 18 Fathom Bank has been colonized by a population of reef building corals which is similar to the population of corals occupying the deepest coral reefs found at the Flower Gardens. This overlap of comparable coral reef communities from one bank to another, and the nearly perfect correlation of their depth distribution, is significant evidence that depth related factors, probably light penetration, largely control the distribution of biotic communities on the upper portions of the clear-water, shelf-edge carbonate banks in the northwestern Gulf of Mexico. That the influence of such factors may be offset by proximity to the Mississippi River will be discussed in relation to Sackett Bank.

An interesting feature of the substratum immediately adjacent to the reef patches at the crest of 18 Fathom Bank is the presence of large ripple marks (Fig. VI-3). These are widespread on the coarse carbonate sand bottom and are on the order of 2 m or so in wavelength and a few cm deep. Presumably they are produced by wave action, possibly during storms. Notably, however, there was a substantial current at the crest of 18 Fathom Bank when the submarine explored the area.

Away from the reef patches, between 45 and 76 m depth, the bottom is generally covered with coralline algal nodules. The nodules become less abundant below 76 m depth and are not significant below 82 m depth. The portion of the bank dominated by living coralline algal nodules, large populations of leafy algae and sponges (45 to 76 or so m depth) is designated an ALGAL-SPONGE ZONE (Fig. VI-2). The biotic community associated with the algal nodules is probably

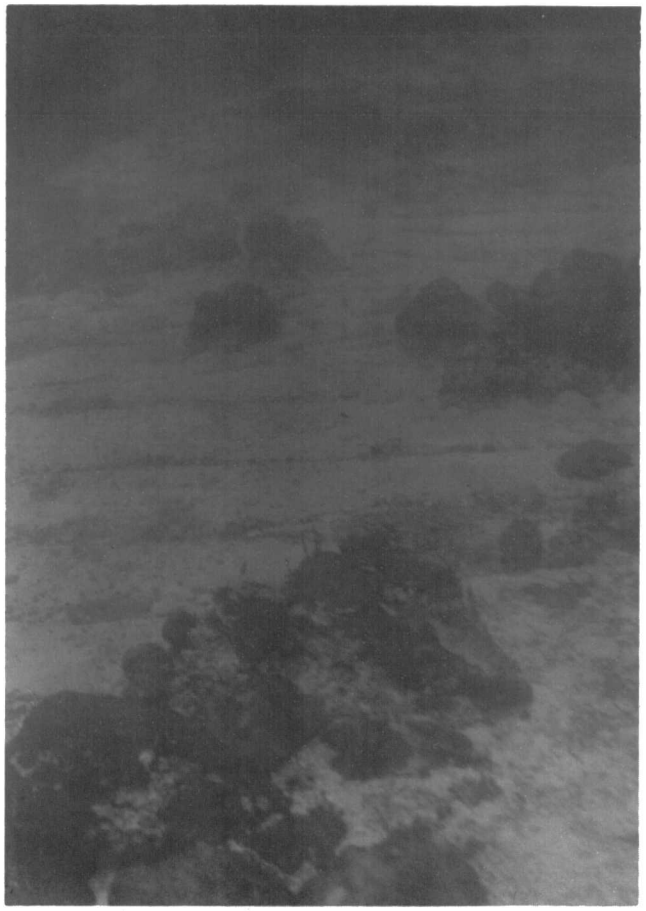


Figure VI-3. 18 Fathom Bank. Coral reef at crest of bank (43-47 m depth). Live coral heads are dark in coloration. Note the large ripple marks in carbonate sand.

Figure VI-4. 18 Fathom Bank. Reef patch at 45 m depth, showing live Stephanocoenia sp. coral heads (dark) and substantial crusts of the fire coral Millepora sp., at top of reefrock in foreground.

the most diverse on the bank in terms of invertebrates and algae.

The leafy algae population is large everywhere in the ALGAL-SPONGE ZONE. Lobophora variegata is the most abundant leafy alga, in places covering 70 to 80 percent of the bottom, overgrowing the coralline algal nodules. Localized patches of other types of leafy algae may be very profuse, with large standing crops of Brown algae, Caulerpa sp. and others (Fig. VI-5). Halimeda sp. was collected at 76 m depth.

Abundant populations of small hermatypic corals are associated with the nodules. Numerous branching colonies of Madracis sp. were seen among the nodules and on hard substratum between 50 and 65 m depth. The saucer-shaped agariciid, so abundant on other shelf-edge banks in the northwestern Gulf, is here in large numbers between 47 and 63 m depth. Skeletal material produced by these two corals undoubtedly contributes very significantly to the carbonate sediment on 18 Fathom Bank.

In the lowermost portion of the ALGAL-SPONGE ZONE, a very large population of elisellid sea whips (octocorals) has developed (62-73 m depth). Also, at these depths, substantial clusters of vermetid gastropod tubes were encountered. Spondylus americanus (American thorny oyster) is abundant among the algal nodules throughout the zone, particularly around 55 m depth. Burrows of the Sand tilefish (Malacanthus plumieri) are quite frequent on the nodule covered bottom.

Large coralline algal reefs up to 2.5 m in height and 6 m or so in diameter occur on the algal nodule platform between 46 and 48 m. North of the bank's crest, these reefs are spaced 30 to 50 m apart. They are actively growing, with extensive covers of living coralline algae. Millepora sp. and the sponge Agelas dispar are abundant on the

Figure VI-5. 18 Fathom Bank. Patch of leafy algae at 51 m depth dominated by an unidentified large-bladed Brown alga. This alga is abundant on many of the Outer Continental Shelf banks in the northwestern Gulf.

Figure VI-6. Sea turtle at 50 m depth near a ledge at 18 Fathom Bank. This turtle is either Caretta sp. (loggerhead) or Lepidochelys sp. (ridley).

algal reefs. Heads of Stephanocoenia sp. and Montastrea cavernosa are present, along with a significant population of Spondylus americanus. Fishes congregating around the algal reefs are the same types as were seen on the nearby coral reefs.

The area of the bank which bears coral reefs and large coralline algal reefs (43-48 m depth) is bounded to the north and south by carbonate ledges (Fig. VI-2), the tops of which are at 48-49 m depth and the bases of which are at 53-59 m depth. These ledges are heavily encrusted with coralline algae and are occupied by the same types of corals, sponges, invertebrates and fishes described above for the large coralline algal reefs. The bases of the ledges are bordered by bands of bare carbonate sand, indicating a substantial amount of localized bioturbation. A significant population of the common black urchin Diadema sp. occurs on the ledges and Spiny lobsters, Panulirus sp., live along the undercut bases of the ledges. A natural gas seep was seen at one point on one of these ledges, and a sea turtle was encountered (Figs. VI-2, 6).

A second-level terrace of sorts occupies the bank between the base of the aforementioned ledge and another smaller ledge at 62 m depth (Fig. VI-2). On this second-level terrace the bottom is covered with coralline algal nodules, Lobophora variegata, other leafy algae, sponges and the typical ALGAL-SPONGE ZONE biota. A robust, basketball-shaped tethyid sponge is fairly abundant around 55 m depth. The Spondylus americanus population is particularly large among the algal nodules, as is that of the coral Madracis sp. An alga which appeared to be Sargassum sp. was seen attached to the bottom here and on the crest of the bank (see Table VI-1a).

The small ledge at 62 m marks a substantial increase in slope of the bottom. It also marks the depth at which the cover of larger coralline algal nodules begins to thin out and give way to smaller nodules, rubble and a very substantial cover of Lobophora variegata. At around 68 m depth and deeper, the Lobophora has a yellowish-white coloration rather than the typical reddish brown. Nevertheless, between 68 and 70 m depth this alga covers almost 90 percent of the bottom in places. Lobophora variegata was not seen below 79 m depth. Large antipatharians (Cirripathes sp.) were seen from 58 m depth downward and were most abundant from 68 to 80 m depth.

From 80 m depth, a large, spectacular carbonate ledge drops vertically ten meters (Fig. VI-2). This ledge marks the edge of the bank in the area examined. It also marks the downward transitions from constructional, clear water communities, dominated by coralline algae and coral, to the deep water bank-edge community typical of the flanks of shelf-edge carbonate banks in the northwestern Gulf of Mexico. The top of the ledge has a significant cover of encrusting coralline algae, and a scattering of rather large coralline algal nodules. The lower sides of the ledge support less living coralline algae, and smaller carbonate structures near the base of the ledge are more-or-less "drowned" (without substantial crusts of living coralline algae). Fishes associated with the large ledge are typical of similar habitats at similar depths on other banks in the region (Chromis enchrysurus, Reef fish A, Bodianus pulchellus, Chaetodon sedentarius, Holocentrus sp., Liopropoma sp.). A number of Scamp (Mycteroperca phenax) frequent the ledge.

From the base of the ledge downward, the substratum grades from

fine carbonate sand and rubble to sand and silt which is easily stirred up (indications of a nepheloid layer were detected near the base of the ledge and deeper). This deep, soft bottom is occupied by antipatharian whips (Cirripathes sp.),paramuricid sea fans with numerous very small crinoids clinging to them, the small octocoral (Nidalia occidentalis),large solitary corals which appear to be (Oxysmilia sp.),sand dollars (Clypeaster sp.), and other deep-water forms generally not found in the shallower clear-water communities.

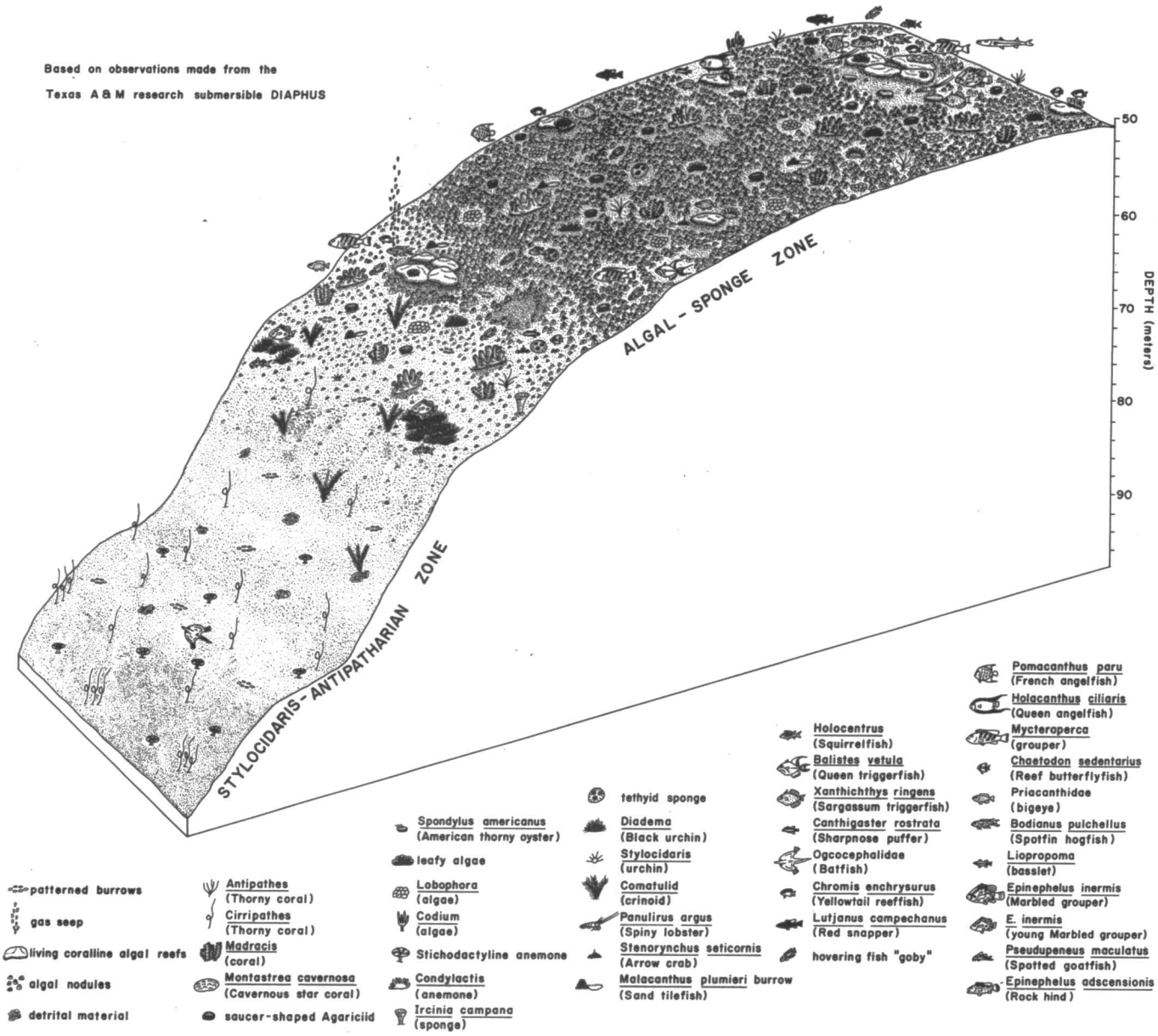
18 Fathom Bank is extremely interesting biotically and ecologically. The coral reefs at its crest parallel the deepest coral reefs found at the Flower Gardens. Their presence implies the possibility that any of the shelf-edge carbonate banks in the northwestern Gulf could become future sites for coral reef development, providing the reef-building activities of the deeper-living coralline algae continue to decrease crest depths of the banks in the coming centuries.

It seems critical, therefore, that the productivity and constructional capabilities of coral and coralline algal populations on these banks not be interfered with. 18 Fathom Bank must be included in the group of shelf-edge topographical features classified as first priority from an environmental standpoint.

BRIGHT BANK

Bright Bank (27°53'N, 93°18'W) is a shelf edge carbonate topographical feature occupied by clear-water benthic communities similar to those comprising the ALGAL-SPONGE and ANTIPATHARIAN ZONES of 28 Fathom Bank and the Flower Garden Banks (Fig. VI-1,7; Tables VI-2a, 2b)

Figure VI-7. **BRIGHT BANK**



(Bright et al. 1976, 1978). The dominant epibenthic organisms on the upper protion of Bright Bank (52-68 m depth) are coralline algae. Within this range (ALGAL-SPONGE ZONE) algal nodules and living coralline algal reefs are conspicuous and abundant (Fig. VI-7). The reefal structures are typically boulder-like, 1.5 m or less in height and 1 or 2 m in diameter. They occur singly or clustered into reef patches of various sizes. Some reef patches are 50 m or more in diameter and attract a variety of reef fishes and large mobile invertebrates (Table VI-2b). Natural gas seeps were detected adjacent to some of these structures.

In addition to the healthy and active populations of frame-building coralline algae (Lithothamnium and Lithophyllum), several species of leafy algae are abundant on the reef patches (Tables VI-2a, 2b; Fig. VI-8). A large blade-like Brown alga and Caulerpa racemosa are particularly conspicuous and probably provide a large amount of primary nutriment for grazing fishes and invertebrates. Montastrea cavernosa, a reef-building coral, occurs on the coralline algal reefs near the bank's crest (Fig. VI-8). At such depths, however, the species grows in flat, encrusting plates of less than 1 m diameter, and it is probably not a substantial contributor to substrate production.

The existence of a significant population of spiny lobsters is indicated by two sightings of Panulirus sp. at a reef patch near the crest of the bank (52 m depth)(Fig. VI-10). The lobsters seen were large adults. It is doubtful that population levels are presently large enough to be considered "exploitable" from a fishery standpoint. The most frequently seen crustacean in the ALGAL-SPONGE ZONE was the

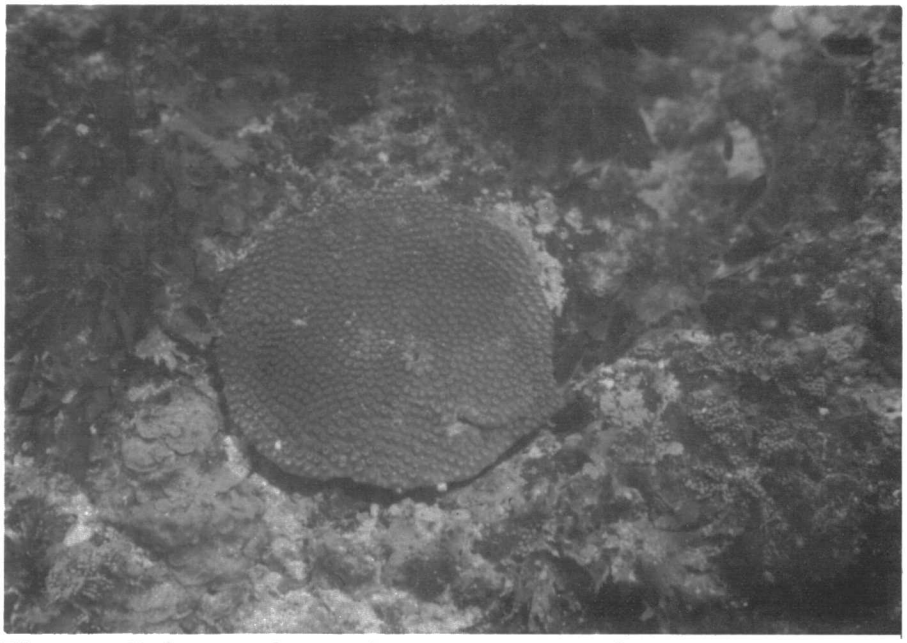


Figure VI-8. Bright Bank. Flat crust of the coral Montastrea cavernosa at 52 m depth. The crust is approximately 1 m in diameter. Abundant growths of the large-bladed Brown alga occur in the upper left and lower right, along with the grape-like masses of Caulerpa and what appears to be an adherent Padina-like alga in the lower left.

Figure VI-9. Bright Bank. Lobophora variegata almost totally covering algal nodules in Algal-Sponge Zone. Saucer-shaped Agariciid coral in center (approx. 8 cm diameter).

Arrow crab (Stenorynchus seticornis).

As at most of the other shelf-edge carbonate banks in the northwestern Gulf of Mexico, the predominant conspicuous fishes around reefs in the ALGAL-SPONGE ZONE are Chromis enchrysurus (Yellowtail reeffish), Chaetodon sedentarius (Reef butterflyfish), Bodianus pulchellus (Spotfin hogfish) and Mycteroperca phenax (Scamp). Surrounding the reef patches,there are usually localized bands of bare to rubble-strewn coarse carbonate sand. These are undoubtedly due to the bioturbating activities of fishes and invertebrates frequenting the reefs.

Away from the coralline algal reef patches the upper bank's surface is covered primarily by coralline algal nodules on top of carbonate sand. Areas where the nodules are less abundant or missing occur here and there within the ALGAL-SPONGE ZONE. A large population of leafy algae is associated with the coralline algal nodules. The large blade-like Brown alga, Caulerpa sp., and other varieties are abundant. In places, Lobophora variegata becomes almost totally dominant, overgrowing the nodules entirely (Fig. VI-9). These patches of Lobophora can be rather large (10 m or more in diameter). Lobophora variegata is undoubtedly the most abundant leafy alga associated with the nodules and may cover 30 to 50% of the bottom near the top of the bank.

Two sightings of the alga Codium taylori at 54 m depth are significant insofar as this is a species which was not known to occur in the Western Atlantic until the 1950's. It was possibly introduced from Europe, arriving here attached to the hull of a ship (Kinbury, 1969). What appeared to be attached Sargassum sp. was observed and

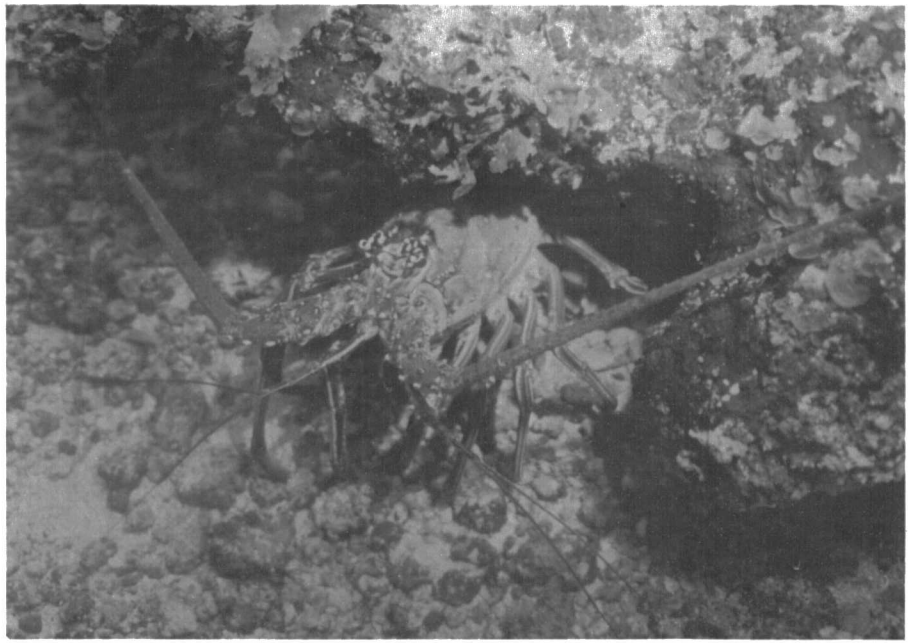


Figure VI-10. Spiny lobster, Panulirus sp., at 52 m depth on Bright Bank.

Figure VI-11. Bright Bank. "Herd" of large urchins, Diadema sp., at 68 m depth. The fishes shown exhibited a preference for a position above the Diadema "herd".

photographed at 59 m depth. No sample was taken, however, and the photograph was not definitive, so the identification is questionable.

Judging from observed standing crops of leafy and coralline algae within the ALGAL-SPONGE ZONE of Bright Bank and other shelf-edge carbonate banks, benthic primary production above 70 m depth on these structures must be phenomenal.

Stony coral populations among the algal nodules are substantial down to 62 m depth. Atypically, a significant percentage of these colonies were upside-down when we observed them in September 1977. Upon turning some of them upright, they were found to still have healthy coloration, indicating that they had only recently been disturbed, possibly by the passage of hurricanes Anita and Babe several weeks earlier. Small branching colonies of Madracis sp. are abundant throughout the ALGAL-SPONGE ZONE, especially at 61-63 m depth. The agariciid and Madracis sp. undoubtedly contribute significant amounts of carbonate sediment to the bank's substratum and thereby are important constructional elements of the benthic community. Other noteworthy benthic coelenterates occupying the ALGAL-SPONGE ZONE are two large anemones (Condylactis sp. and another unidentified species), stichodactyline anemones and the branching throny coral Antipathes sp.
dactyline anemones and the branching thorny coral Antipathes sp.

Branching, encrusting and massive sponges are abundant sub-dominant components of the ALGAL-SPONGE ZONE community, competing for space on reef patches and the nodule terrace, and supplying micro-habitats for numerous mobile invertebrates and fishes (Table VI-2a). As at the other banks, Neofibularia sp. is probably the most widespread

large sponge. A spherical, tough, orange, tethyid sponge, generally about 15-20 cm in diameter, was conspicuous because of its relative abundance at Bright Bank (Fig. VI-7).

Molluscs are conspicuously represented in the ALGAL-SPONGE ZONE by a sizeable population of Spondylus americanus (American thorny oyster) above 63 m depth. A pen shell (Atrina sp.) was seen at 63 m depth, star shells (Astraea sp.) at 55 m depth, and a Lion's paw (Lyropecten sp.) at 59 m depth.

The Sand tilefish (Malacanthus plumieri) constructs large burrows throughout the ALGAL-SPONGE ZONE, and in the process piles up mounds of nodules and rubble which may be 1 m in height. From the standpoints of abundance and large-scale bioturbation, this fish is rather important. More frequently seen, however, was a small burrowing fish very similar in habit to Burrowing fish C, which is common in ALGAL-SPONGE ZONES on other banks we have studied. We were unable to collect a specimen to use in making a reliable identification, and have therefore designated the fish "Hovering fish D".

At about 65 m depth the algal nodule cover begins to decrease, and the nodules are more or less gone at 70 m depth. The transition of the substratum with increasing depth below the ALGAL-SPONGE ZONE is distinct, as follows:

65-69 m depth: Coarse carbonate sand. Number of small nodules and rubble decrease with increasing depth.

69-70 m depth: Very shallow and broad ripple marks in carbonate sand. Leafy algal detritus

in depressions.

70-74 m depth: Carbonate sand with scattered coralline algal rubble and leafy algal detritus. Tracks and trails, burrows, mounds.

74-76 m depth: Nearly total carbonate sand bottom with abundant leafy algal detritus, tracks and trails, burrows, mounds.

77-95 m depth: Fine carbonate sand, tracks and trails, burrows, mounds.

The occurrence of large amounts of leafy algal detritus in the upper SOFT BOTTOM-ANTIPATHARIAN ZONE is an important indication of the probable contribution of the benthic primary producers higher on the bank to the nutriment of surrounding soft-bottom communities.

Changes in benthic community composition with depth are interestingly reflected by the echinoderm populations on Bright Bank. Suspension feeding comatulid crinoids are generally abundant wherever hard substratum of any type occurs, nodules and rubble are sufficient. On the other hand, the several conspicuous species of bottom feeding echinoids (urchins) and asteroids (starfish) appear to be distributed on the bank in clearly defined depth and substratum related bands. In the ALGAL-SPONGE ZONE above 65 m depth, most of the echinoids sighted were smaller individuals of a species of Diadema. These were associated primarily with the coralline algal reefs. Between 64 and 70 m depth, algal nodules gave way to carbonate sand and rubble. In this transition zone spectacular "herds" composed of hundreds of very large Diadema sp. were seen at 68 and 69 m depth (test diameters over 12 cm). These "herds" were moving across the sand and rubble bottom

stirring up clouds of fine sediment (Fig. VI-11). Schools of small fish swam above the urchins. Among the urchins were several fishes which resembled yound Marbled groupers. Feeding on the bottom around the periphery of each "herd" were several Spotted goatfishes (Pseudupeneus maculatus). At 73 m depth, a significant population of asteroid starfishes was observed on the fine grained carbonate sand bottom. The small urchin Stylocidaris sp. began to appear on the fine sand bottom at 80 m depth and increased in abundance downward to a very substantial population below 85 m depth (approximately one urchin per square meter of bottom).

Bright Bank harbors a diverse and highly productive clear-water benthic community comparable to those of other shelf-edge carbonate banks of similar depth in the northwestern Gulf of Mexico. From the standpoint of environmental protection, it should be considered one of the highest priority Outer Continental Shelf biotopes.

BOUMA BANK

Bouma Bank (28°02'N, 92°27'W) is a shelf-edge topographical feature bearing clear-water carbonate reefal communities dominated by coralline algae. The upper portion of the bank is covered with large coralline algal nodules on top of coarse carbonate sand (Fig. VI-1, 12, 13). Between 62 and 65 m depth the nodule cover is 80-90% in places. It decreases to 15-20% at 68 m depth, 10-15% at 72 m depth, and is nil below 75 m depth. In addition to the nodules, actively growing coralline algal reef patches and ledges occur from the crest of the bank to at least 70 m depth (Fig. VI-14). Small,

Figure VI-12. **BOUMA BANK**

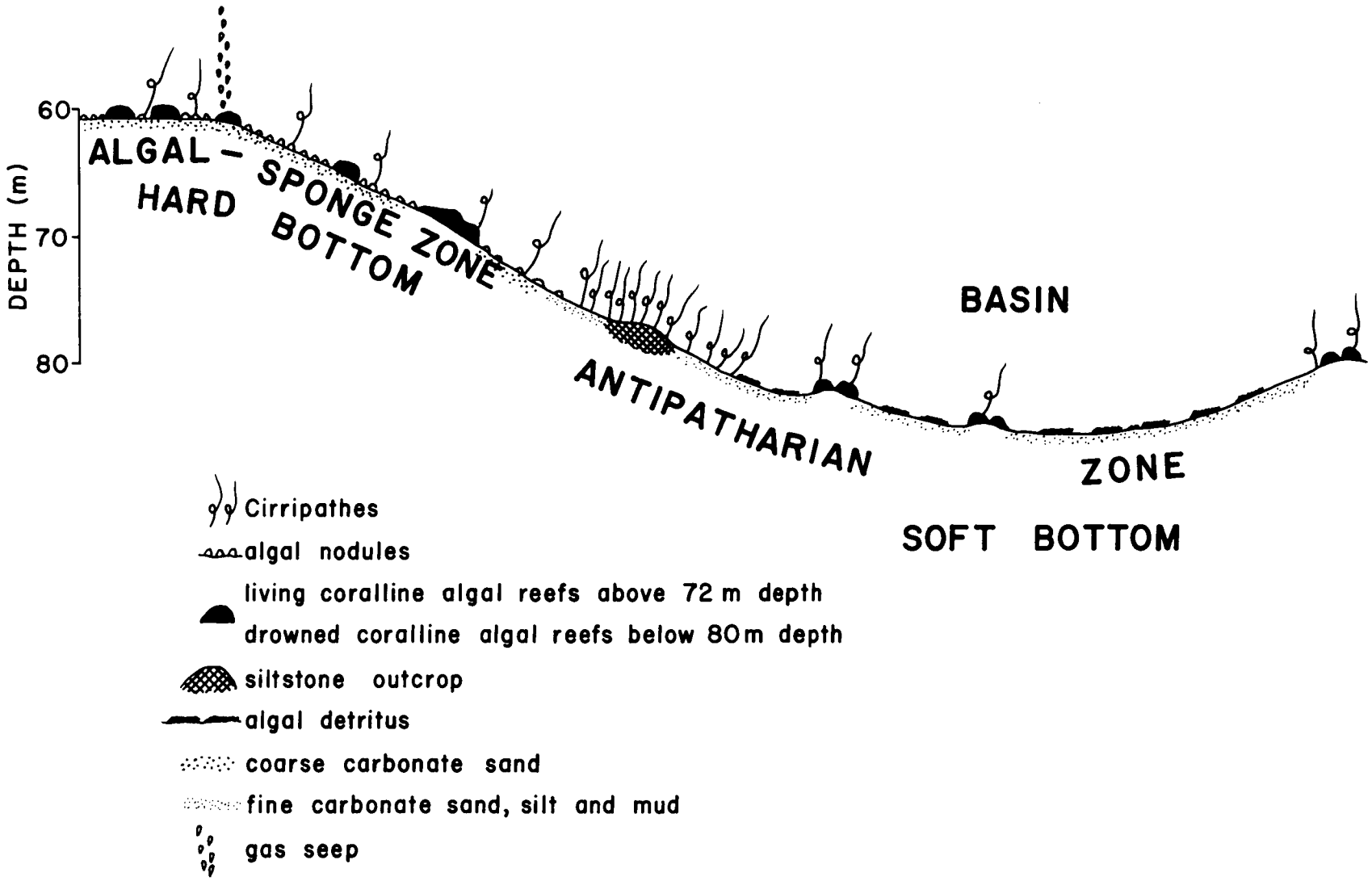


Figure VI-13. The anemone Condylactis sp. on large algal nodules near the top of Bouma Bank.

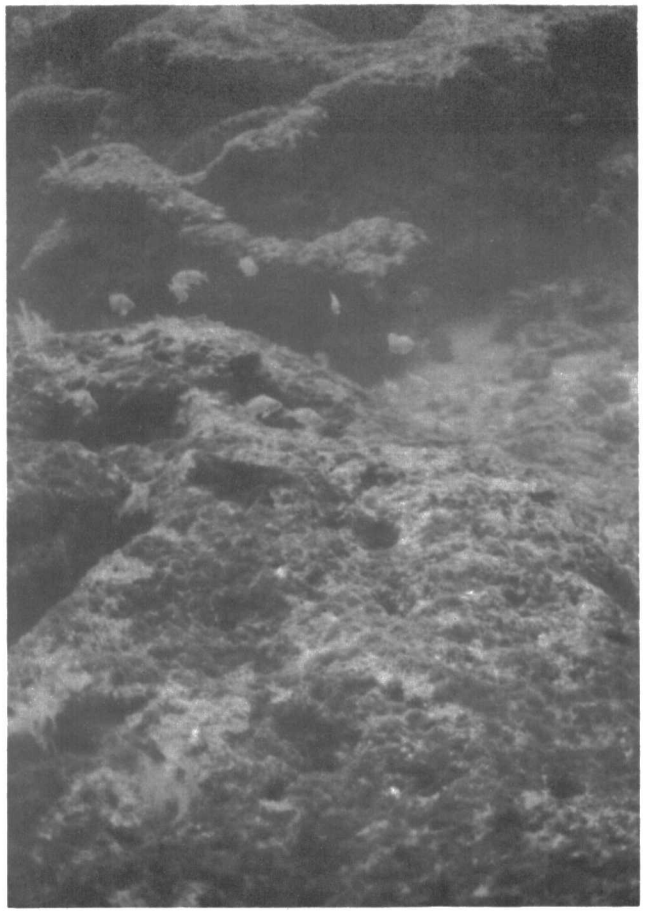


Figure VI-14. Reefrock ledge at 68 m depth on Bouma Bank. "Reef fishes A" hovering above the ledge.

drowned, reefal structures occur at greater depths but live coralline algal cover on them is comparatively slight. Flatish crusts of coralline algae occur on the sand and over groups of nodules in places above 68 m depth.

Biotically, the part of Bouma Bank dominated by coralline algal populations is a typical ALGAL-SPONGE ZONE, with a community composed of plants, invertebrates and fishes found in corresponding zones at the Flower Garden , 28 Fathom, 18 Fathom, Ewing, and Parker Banks(Tables VI-3a, 3b). Whereas the species composition of all the ALGAL-SPONGE ZONE communities on all the banks listed is basically the same, differences in relative abundances of some of the more conspicuous species are apparent from bank to bank. Bouma Bank has especially large populations of gorgonocephalan basket stars and the anemone, Condylactis sp. (Fig. VI-13). The average size of the algal nodules themselves is unusually large. Most are the size of the largest nodules encountered on the other banks. This may account for the fact that the populations of Yellowtail reeffish, Chromis enchrysurus , and Cherubfish, Centropyge argi, appear to be greater on Bouma Bank above 65 m depth than is generally the case on other banks (such small fishes may utilize the larger nodules as cover more effectively than they would smaller, more closely packed nodules).

Leafy algae populations on the crest of Bouma Bank do not appear to be as substantial as those found on some of the other banks, though considerable amounts of Caulerpa sp. and Microdictyon sp. are associated with the nodules. From 63 to 65 m depth the large-bladed Brown alga encountered on most of the shelf-edge banks is abundantly attached to many of the nodules. Leafy algae populations are undoubtedly

subject to seasonal variations and are rather ephemeral. Such is strongly indicated by massive accumulations of loose algal detritus on the lower flanks of the bank and in a basin ("hole") on the bank's southeastern quarter (Fig. VI-12, 15)(see chart of Bouma Bank). This algal detritus was seen in piles and large boluses covering approximately 5% of the bottom in the basin. One of the boluses was 10 m long, 3 m wide and 1/6 m high. It is possible that the sparsity of leafy algae on the top of Bouma Bank in September 1977 was due to its being torn up and washed downslope in late August and early September by wave action associated with the passage of hurricanes Anita and Babe. In spite of the apparently small amount of leafy algae on the very crest of Bouma Bank at the time we examined it, it is obvious that the bank supports an extremely productive population of benthic plants. These, in turn, must contribute substantial amounts of food to epibenthic and infaunal communities on and adjacent to the bank.

Natural gas seeps were encountered in the ALGAL-SPONGE ZONE at 62 and 68 m depth. At 68 m depth, a seep issued from a reefal ledge which was almost totally encrusted with coralline algae. Except for white patches several centimeters in diameter at the points of gas emission, there was no visually detectable difference in the coralline algal crusts at the seeps when compared to crusts some distance away. This apparent lack of significant deleterious effects of such natural gas seepage on surrounding biota is typically the case here and at other banks we have examined.

Around coralline algal reefs at 67 m depth we observed a congregation of hundreds of large squirrelfishes (either *Holocentrus rufus* or *H. ascensionis* or both). The concentration of these fishes

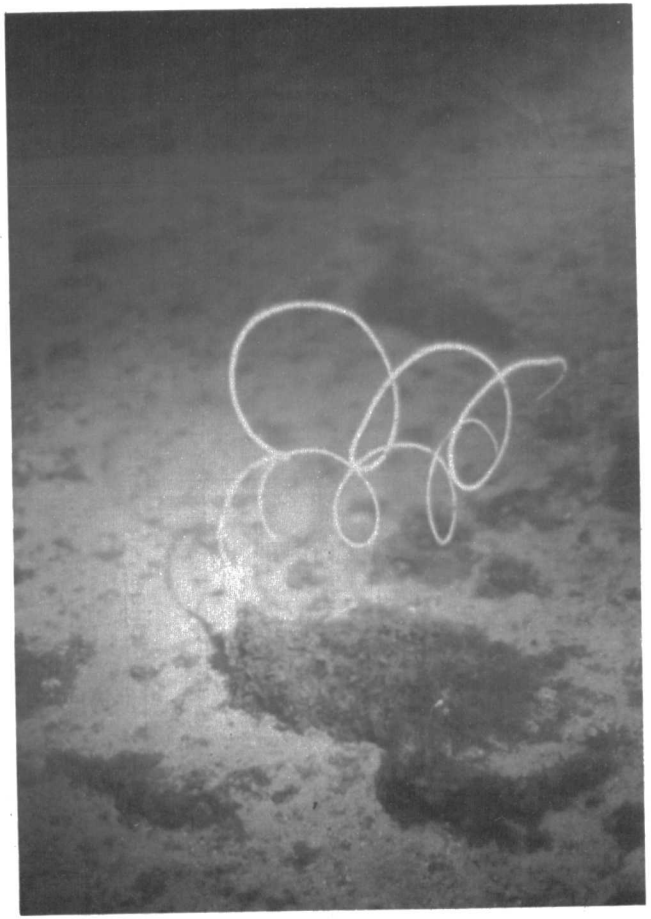


Figure VI-15. Cirripathes sp. and algal detritus on sandy bottom at 80 m on Bouma Bank.

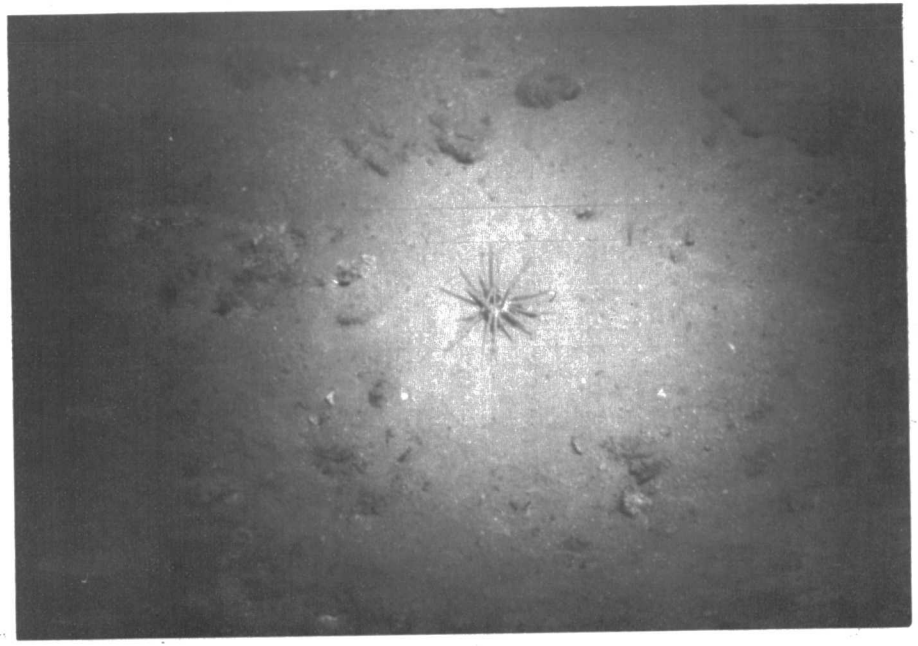


Figure VI-16. The urchin Stylocidaris sp. on soft bottom at Ewing Bank, approximately 90 m depth.

was larger than we have previously seen and it is possible spawning was involved, though there were no clear manifestations of such behavior.

There are very few algal nodules at 75 m depth; the bottom is a mixture of sand, a substantial amount of shell material and easily stirred fine sediment. The percentage of fine sediment increases with increasing depth. A siltstone outcrop was encountered at 77 m depth. It is possible that much of the fine non-carbonate sediment found in the basin and on the lower flanks of this and other shelf-edge banks is derived *in situ* as a result of disintegration of underlying siltstone and claystone rocks.

Drowned carbonate reef patches covered with thin veneers of fine sediment occur on slight rises at 79, 82, 83 and 84 m depth in the basin. The reefal structures are generally less than 1 m in height and a few meters across. Small amounts of live coralline algae, less than 5% cover, are present on these structures. They also house populations of sessile and mobile invertebrates and fishes typical of the ANTIPATHARIAN ZONE (*Cirripathes* sp.; *Neofibularia* sp.; comatulid crinoids; bigeye, *Priacanthus* sp.; Yellowtail reeffish, *Chromis enchrysurus*; Cubbyu, *Equetus umbrosus*; Bank butterflyfish, *Chaetodon aya*; Reef fish A; basslets, *Liopropoma* sp.; and Red snapper, *Lutjanus campechanus*).

The predominant, conspicuous benthic invertebrates occupying the surrounding soft bottom are *Cirripathes* sp. and several species of echinoderms (Fig. VI-15, 16). A very large population of small comatulid crinoids occurs between 80 and 82 m depth. These organisms frequently form "tufts" on the aboral (upper) surfaces of sand dollars,

Clypeaster sp., which are common, along with the urchin Stylocidaris sp., around 80 to 82 m depth. The starfish Narcissia trigonaria is conspicuous from 75 to 82 m depth. Below 82 m depth the soft bottom is generally devoid of large, conspicuous epifaunal organisms in the part of the basin examined.

Bouma Bank should be classified, along with 28 Fathom Bank and other similar features, as a first priority bank for purposes of environmental protection.

PARKER BANK

Parker Bank (27°57'N, 92°00'W) was not examined directly by the author from the submersible. However, video tapes made during a geological reconnaissance dive were reviewed and form the basis of the following description.

Above approximately 75 m depth, the bank is occupied by coralline algal nodules and leafy algae with large populations of comatulid crinoids, sponges, Cirripathes sp. and other invertebrates and fishes typical of the ALGAL-SPONGE ZONES found at similar shelf-edge banks in the northwestern Gulf of Mexico. Sand tilefish burrows (Malacanthus plumieri) are conspicuous on the upper part of the bank.

Coralline algal reefs of substantial size occur near the top of the bank, and carbonate ledges were observed in the vicinity of 73 m depth. Large schools of Creolefish (Paranthias furcifer) congregate around the algal reefs, along with numerous groupers (Mycteroperca spp.), Reef fish A, Chromis enchrysurus, and other resident bank fishes.

Between 73 and 80 m depth, the algal nodule cover thins considerably

and is replaced by coarse carbonate sand and rubble. At 84 m depth the bottom is mostly fine carbonate sand with numerous burrows and ripple marks. The sediment grades to an easily stirred soft mixture of fine carbonate sand, silt and mud at 87 m depth.

Parker Bank is undoubtedly a shelf-edge carbonate feature bearing clear-water reefal communities dominated by coralline algae above 80 m depth. It should therefore be classified along with 28 Fathom Bank as a first priority bank from the standpoint of environmental protection.

EWING BANK

Ewing Bank (28°06'N, 91°00'W) is a typical northwestern Gulf of Mexico shelf-edge carbonate bank harboring clear-water reefal communities similar to those occupying 28 Fathom Bank (Fig. VI-1, 17; Tables VI-4a, 4b)(Bright et al. 1978). The dominant organisms above 70 m depth are coralline algae, nodules of which cover most of the upper part of the bank. Small, growing, coralline algal reef patches of low relief occur here and there on the bank's upper platforms and at ledges.

The nodules are underlain by coarse carbonate sand which becomes the predominant sediment below 70 m depth. A severe break in slope about 72 m depth is marked by a ledge of algal reefrock, components of which extend down to 80 m. Below this ledge, the sediment becomes finer, grading to a silty mud around 100 m depth.

The ALGAL-SPONGE ZONE at Ewing Bank (56-70 m depth, approximately) is typical, and basically the same as those described for the Flower

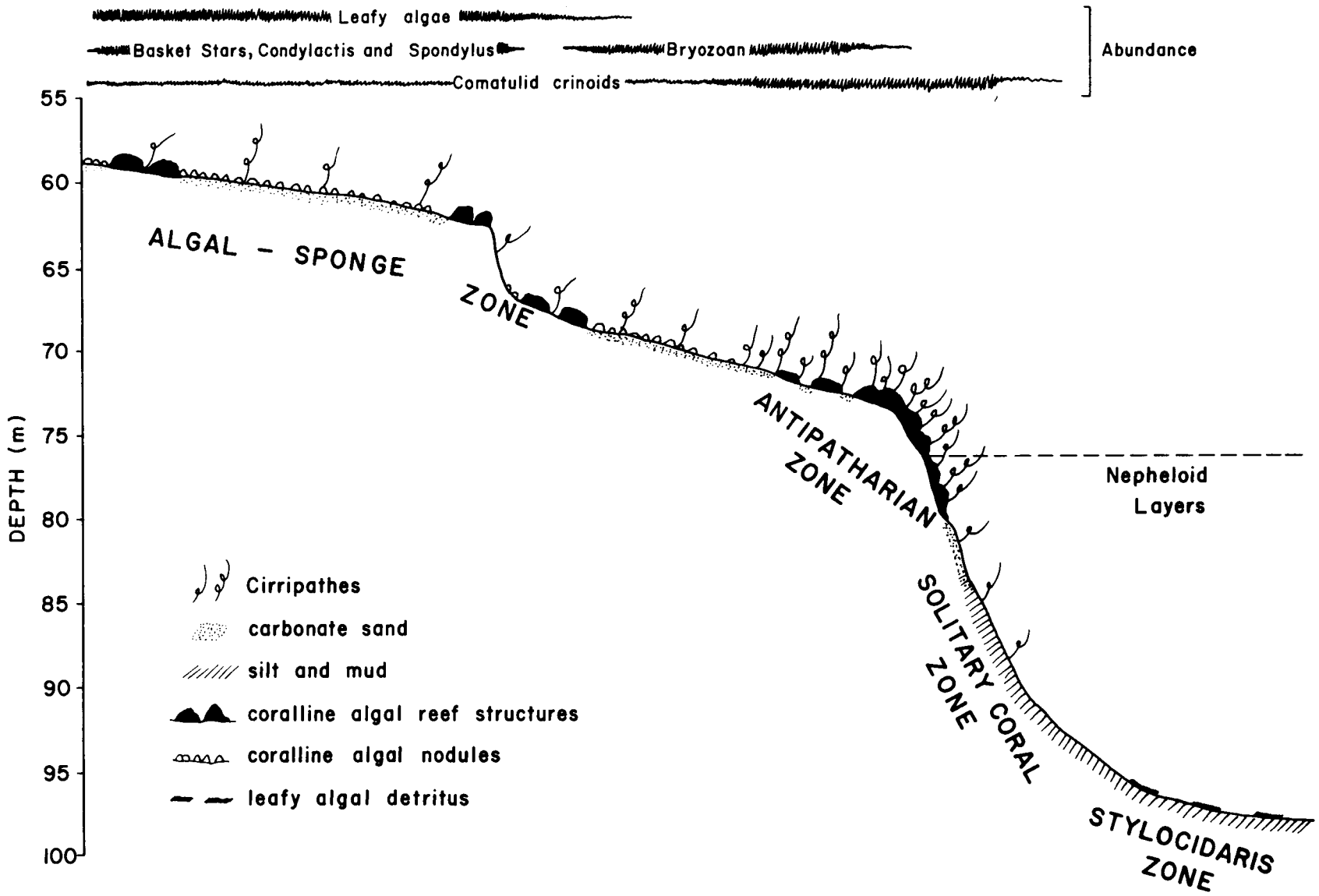


Figure VI-17. EWING BANK

Garden , 28 Fathom Bank, 18 Fathom Bank, Bright Bank, Bouma Bank and Parker Bank. The ALGAL-SPONGE ZONE communities on all of these banks are comprised of basically the same array of organisms and are dominated by coralline algae, with leafy algae and sponges as co-dominant groups. On the other hand, within limits, the benthic communities on the various banks differ somewhat in terms of relative abundance and distribution of certain significant species. For example, as at Bouma Bank, Condylactis sp. (large anemones), large gorgonocephalan basket stars, Spondylus americanus (American thorny oyster) are exceptionally abundant on the upper terrace of Ewing Bank (56-60 m depth). Above 58 m depth there is a substantial population of the "Hovering fish D" which occurs also at Bright Bank, but has not been seen at 28 Fathom Bank or the Flower Garden Banks.

A transition to a deep-water epibenthic community is apparent below 67 m depth. On the 67 to 72 m depth terrace, algal dominance is diminished and an abundant population of tubular, branching bryozoans (Stylopoma sp.) is conspicuous. Comatulid crinoids and antipatharians (Cirripathes sp.) are only moderately abundant above 70 m depth, but they become very numerous from 70 and 80 m depth downward.

Bank-to-bank variations in species composition and relative abundances within these deep-water communities are apparent. For example, both Ewing and Bright Banks have sizeable populations of the urchin Stylocidaris sp. (Fig. VI-16) on their deeper flanks but

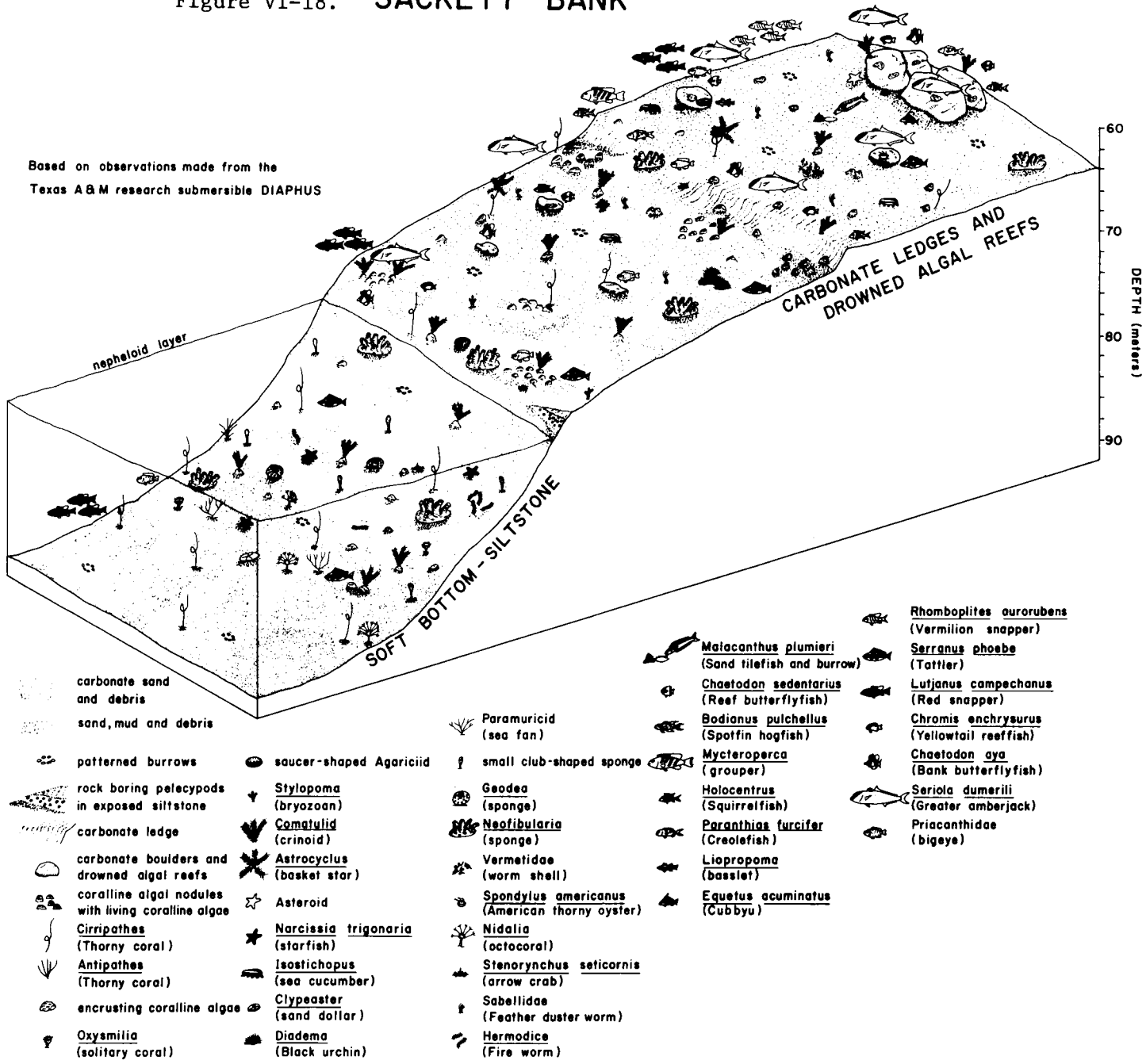
Stylocidaris was not encountered at 28 Fathom Bank. Large solitary coral populations were detected only at Ewing and 28 Fathom Banks, and not at Bright or Bouma Banks. Other examples such as these can be derived by comparing the lists of species collected and observed at the various banks (Tables VI-1 - 6; Bright et al. 1976, 1978). Whether such apparent interbank differences in community structure are real or not is questionable. None of the banks has been explored in full, and only small segments of the deeper biotic communities can be described using the data generated so far. Lateral variations in epibenthic community structure are likely. If lateral variability per bank is great, it is probable that bank-to-bank variability will turn out to be smaller than it appears at present.

Ewing Bank is a typical shelf-edge carbonate bank bearing highly productive and diverse clear-water reefal communities. Coralline algal reef building is active above 70 m depth. From the standpoint of environmental protection, Ewing Bank should be considered one of the highest priority Outer Continental Shelf biotopes.

SACKETT BANK

Sackett Bank (28°38' N, 89°33' W) (Fig. VI-1) is a shelf-edge topographic feature capped by carbonate sediments, including sand, debris, algal nodules, rock ledges and drowned algal reefs (Fig. VI-18). Whereas these sedimentary components are basically the same as those comprising the substrata of the other shelf-edge carbonated banks, they exist in very different proportions on the upper parts of Sackett Bank. Biotic communities, though composed of species found commonly on the other shelf-

Figure VI-18. SACKETT BANK



edge banks in the northwestern Gulf, are much less diverse, and less abundant than are those of the other banks. In terms of community structure, the epibenthic biota of Sackett Bank seem to occupy a position somewhere between those of the South Texas Fishing Banks (such as Southern and South Baker Banks) and those of the other shelf-edge carbonate banks in the northwestern Gulf of Mexico (such as 28 Fathom and Ewing Banks) (Tables VI-5a, 5b).

The topmost part of Sackett Bank (64-65 m depth) is rather flat and sandy, with carbonate rubble, a few scattered coralline algal nodules and drowned coralline algal reef patches. On this upper terrace, limited amounts of live coralline algae occur on the reef patches, tops of pieces of rubble and nodules. However, the present degree of carbonate production by coralline algal populations on Sackett Bank does not appear to be substantial.

Some of the drowned reef patches are quite large, up to 3 m high and 12 m across (the largest seen by us crest at 61 m depth). All are covered with thin veneers of fine, easily stirred sediment and harbor surprisingly sparse populations of epibenthos and fishes. The primary invertebrates clinging to or encrusting the drowned reefs are comatulid crinoids, encrusting sponges, *Diadema* sp. (urchin), *Cirripathes* sp. (antipatharian), *Spondylus americanus*, the saucer-shaped agariciid and small patches of coralline algae. Fish are not particularly abundant on the drowned reefs, though the following types are frequent: *Chromis enchrysurus* (Yellowtail reeffish), *Bodianus pulchellus* (Spotfin hogfish), *Equetus umbrosus* (Cubbyu), *Seriola dumerili* (Greater amberjack), *Priacanthus* sp. (bigeye), *Serranus phoebe* (Tattler), *Apogon* sp. (cardinalfish), *Chaetodon*

sedentarius (Reef butterflyfish), Chaetodon aya (Bank butterflyfish), Paranthias furcifer (creolefish) and Reef fish A. These are generally the same species seen over the entire upper portion of the bank above 73 m depth. The population of Chaetodon aya seemed large in comparison to other banks examined. Schools of Vermilion snapper (Rhomboplites aurorubens)were seen near the drowned reefs.

The predominantly sandy bottom occupying most of the upper platform of the bank above 65 m depth, houses a relatively depauperate assemblage of macroepifauna compared to those occurring at similar depths on other shelf-edge banks in the northwestern Gulf. Clusters of burrowing sabellid polychaete worms are, however, rather abundant. Comatulid crinoids are frequent on rubble and nodules and the population of the sponge Neofibularia nolitangere is significant. Diademid urchins and the large sea cucumber Isostichopus sp. are conspicuous.

Small mounds of "tangled" vermetid gastropod tubes were seen on the upper terrace (64 m depth)(Fig. VI-19). These organisms were observed also on 18 Fathom Bank. They may be important contributors to carbonate sediment on Sackett Bank.

Burrows produced by the Sand tilefish, Malacanthus plumieri, are interesting in terms of what they may indicate concerning the nature of the surficial sediments covering the top of Sackett Bank. These conical burrows of about 1 m in diameter were seen in what appeared to be basically sandy bottom with some rubble and few nodules. Adjacent to the apparently sandy burrows, however, were piles of algal nodules, presumably removed from the burrows by the fishes during

Figure VI-19. Mass of vermetid gastropod tubes at 65 m depth on Sackett Bank.

Figure VI-20. Siltstone outcrop at 73 m depth on Sackett Bank. Note holes in bedrock, presumably due to the activities of rock boring pelecypods. A sea robin fish was seen in the large hole.

construction. This would imply that, even though the visible sediment surface is mostly sand, there are significant amounts of coarse material and dead algal nodules buried just beneath. Considering this, and the fact that fair-sized drowned reefs are present on the uppermost part of the bank, it is speculated that in the past Sackett Bank must have supported a rather active reef-building community dominated by coralline algae.

Actually, living coralline algal nodules are more abundant near the base of small carbonate ledges and on low mounds on a 67-73 m depth terrace bordering the upper platform (Fig. VI-18). The carbonate ledges, 1 to 2 m high, separate the upper platform from the terrace in places. The ledges are generally of relatively gentle slope with algal nodules scattered on them. Near their bases, nodules extend sparsely for some distance out onto the terrace (Fig. VI-18). Populations of epibenthos and fishes are somewhat more diverse and abundant on and adjacent to these ledges than is the case for the shallower drowned reefs. Crinoids, sponges, diademid urchins, sabellid worms and the same types of fishes listed above for drowned reefs occur on the ledges and among the nodules. Large groupers appeared to prefer the ledges.

The substratum of the 67-73 m depth terrace is basically a rubble strewn sandy bottom with significant amounts of silt and clay. Very few algal nodules were found on the central part of the terrace. Clusters of them occur more frequently on small mounds toward the break in slope around 70-72 m depth. Sabellid worms are

abundant on the terrace, and in general the conspicuous soft bottom epifaunal populations are similar to those on the upper platform except for some significant additions. The antipatharian, Cirripathes, becomes abundant near the outer margin of the terrace. Basket stars are associated with Cirripathes. Substantial populations of the same very large Diademid urchin seen at Bright Bank were observed on the central part of the terrace at Sackett Bank.

At approximately 72 m depth the slope increases considerably. At this depth also we encountered a small outcrop of siltstone similar in appearance to the rocks at Stetson and Sonnier Banks, and to the outcrop seen in the basin at Bouma Bank (Fig. VI-18). These rocks are generally rather soft, and probably disintegrate rapidly where they are exposed directly to water. Chips and fine sediment obviously derived from the bedrock were seen around the base of the outcrop (Fig. VI-20). Holes in the exposed rock at Sackett Bank are identical in appearance to holes in the outcrops at Stetson Bank, where they are considered to be produced by rock boring pelecypods. The occurrence of siltstone outcrops at mid-shelf banks such as Stetson and Sonnier, and the less conspicuous occurrence of similar outcrops on deeper parts of the shelf-edge carbonate banks is interesting. One might speculate that the substantial carbonate reefal communities on the shelf-edge banks have developed on, and almost totally overgrown or buried, a basic substratum of upthrust siltstone. In all cases, the unconsolidated sediments on the flanks of the shelf-edge carbonate banks grade outward from coarse carbonate sand to mixtures of sand, silt and clay and finally to a fine mud. A 1 m deep grouper hole in

the soft mud bottom at 90 m depth at Sackett Bank was observed to have siltstone at its bottom. It would be interesting to know what percentage of the fine sediment surrounding these banks is derived from disintegration of underlying siltstone and claystone rock.

When Sackett Bank was explored with the submersible, the top of the nepheloid layer was roughly coincident with the break in slope at 72-74 m depth. A substantial change in the composition of the benthic epifaunal community is apparent between 73 and 76 m depth. The comatulid population becomes "tremendous"; Neofibularia sponges are abundant, and surprisingly white rather than the normal reddish brown; fire worms, Hermodice sp., are exceedingly numerous; Asteroid starfishes, particularly Narcissia trigonaria and Astropecten-like forms, are conspicuous; Cirripathes sp. become somewhat more abundant; the globular white sponge Geodea sp. and a small yellow club-shaped sponge appear as major constituents of the soft-bottom community. These conditions persist to at least 85 m depth. In addition, at around 80 m depth, Antipathes sp. (a branching antipatharian), Nidalia occidentalis (a curious octocoral), small paramuricid sea fans and a large solitary stony coral resembling Oxysmilia sp. are found. The paramuricids, Nidalia, and the large solitary coral are abundant down to around 88 m depth. Interestingly the large polyps of Nidalia are contracted and inconspicuous above 83 m depth but well expanded below 85 m depth.

Below 90 m depth almost nothing was visible on the mud surface, the conspicuous epifaunal organisms having nearly disappeared. However, holes 20 cm to 1 m wide and deep were seen. One contained a large eel, and a grouper occupied another. A school of Red snapper,

Lutjanus campechanus, was cruising near the bottom.

The fact that the epibenthic communities on the upper part of Sackett Bank are poorly developed compared to those on shelf-edge banks to the West makes Sackett Bank very interesting ecologically. Its topography, depth and location would seem to favor development of clear-water carbonate reefal communities, were it not for the proximity of the Mississippi River. Indeed, the presence of large drowned coralline algal reefs and large numbers of dead algal nodules buried under carbonate sand indicates that a substantial, active reef building community existed on the bank some time in the past, dominated by coralline algae.

The small population of living coralline algae existing on the bank suggests that environmental conditions do not now altogether preclude limited carbonate substratum production. It is hypothesized, however, that the conditions of water quality, hydrography and turbidity associated with Mississippi River outflow are responsible for limiting the contemporary development and growth of substantial carbonate reefal communities at Sackett Bank.

Such communities, which are basically dependent on photosynthetic organisms require adequate levels of light throughout the year (even corals require light to support useful symbiotic plants in their tissue). The water overlying Sackett Bank was much more turbid when we observed it than the water above any of the other shelf-edge banks. The upper 10 m of the water column (above the thermocline) was very green and contained an enormous amount of organic matter in the form of plankton and seston (floating non-living organic material, often mucus-like). At the thermocline (approximately 10 m depth) we observe large "sheets"

of mucus-like white organic matter. Mucus "strands", accompanied by very large zooplankton populations, extended down past 30 m depth. All this suspended material, substantially the result of enormous phytoplankton and zooplankton productivity, effectively blocks out much of the downwelling light, even though the water between the organically turbid surface layers and the bottom nepheloid layers may be quite clear. It is possible, therefore, that the benthic reefal communities of Sackett Bank are held in check by the tremendous productivity of nutrient rich near-surface marine waters in the vicinity of the Mississippi Delta. Long term observations of light penetration, salinity, temperature, nutrients, suspended organics and water column productivity at Sackett Bank and Ewing Bank (the closest shelf-edge bank supporting substantial ALGAL-SPONGE ZONE populations) could reveal much concerning the environmental factors limiting development of clear-water carbonate reef-building communities in the northwestern Gulf of Mexico.

The structure and abundance of biotic communities at Sackett Bank is intermediate between those described for shelf-edge carbonate banks (such as 28 Fathom Bank) and South Texas fishing banks (such as Southern Bank). Living coralline algae populations at Sackett Bank are more substantial than those found on the South Texas banks. It is difficult, therefore, to fit Sackett Bank into the classification scheme for banks in the northwestern Gulf proposed by Bright et al. (1978). In terms of precautions to be taken to protect Sackett Bank, I would recommend that it be considered a second priority bank, along with Stetson and Sonnier Banks (see Bright et al. 1978, Conclusions).

SONNIER BANK

Sonnier Bank (28°21'N, 92°27'W) has formerly been called Three Hickey Rock by Texas fishermen and sport divers. The bank is composed of siltstone outcrops which extend to at least 53 m depth. Sizeable boulders and debris derived from the bank occur as deep as 58 m. The siltstone rocks exhibit bedding and are perforated extensively with small holes, probably resulting from the activities of rock boring pelecypods. The similarity in the surficial geology of Sonnier Bank and Stetson Bank is notable (Bright et al. 1976).

The epibenthic communities occupying Sonnier Bank are also basically similar to, but better developed than, those found at Stetson Bank (Fig. VI-21, Tables VI-6a, 6b). The crest of Sonnier Bank (20-21 m depth) is almost entirely encrusted with fire coral (*Millepora* sp.) and the sponges *Neofibularia nolitangere* and *Ircina* sp. (Fig. VI-22, 23).

The fire coral population extends downward to 40 m depth, but is severely diminished below the bank's crest. Dead branches and broken pieces of fire coral occur abundantly in the unconsolidated sediment at the bases of the shallower outcrops along with siltstone chips and fine silt and clay-sized particles. The coral must, therefore, contribute significantly to the sediment which is produced on the bank and ultimately transported to the surrounding level-bottom.

Heads of the hermatypic anthozoan coral *Stephanocoenia* sp. were seen at 36, 38 and 41 m depth. None of these heads was over 1 m in diameter. Dead patches on the deepest one possibly indicate periodic mortality and regrowth. *Stephanocoenia* is widespread on the mid-shelf and shelf-edge banks off North Texas and Louisiana. It appears to

Figure VI-21. SONNIER BANK

Figure VI-22. Crest of Sonnier Bank showing near total cover of fire coral Millepora sp., and the sponges Neofibularia sp. and, apparently, Ircinia sp.

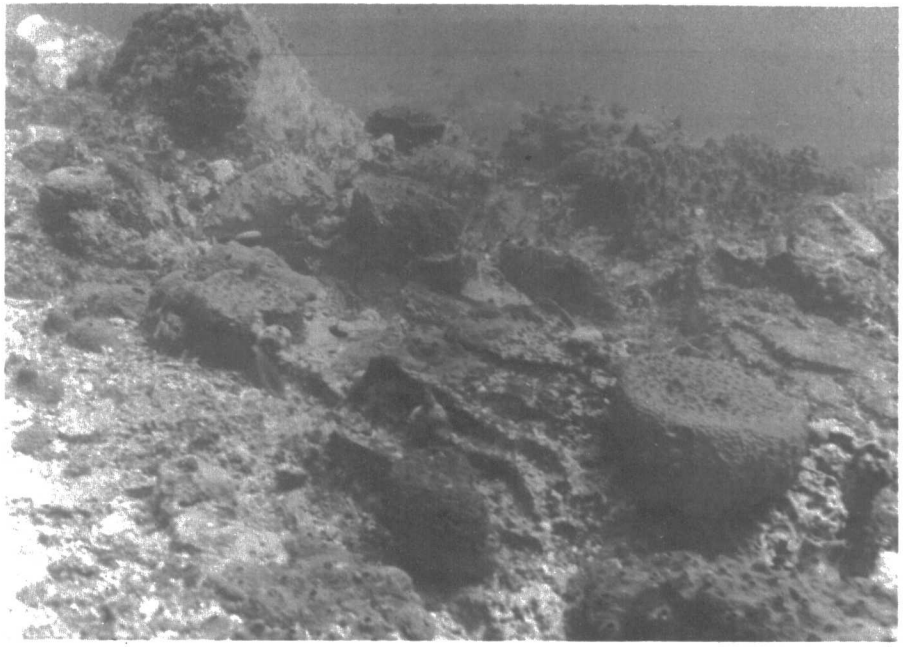


Figure VI-23. Siltstone outcrop at Sonnier Bank, with crusts of Millepora sp., Neofibularia sp. and a black massive sponge which is apparently a species of Ircinia.

tolerate conditions of low light intensity and moderate turbidity better than other types of reef-building corals. The only other stony coral encountered at Sonnier Bank is the saucer-shaped agariciid which seems to be even more tolerant of such conditions than Stephanocoenia sp. and was seen at 52 m depth.

Encrusting coralline algae occur at Sonnier Bank down to 47 m depth. Populations are moderate above 40 m, becoming sparser with increasing depth.

Populations of fishes and conspicuous, mobile invertebrates are diverse and abundant above 45 m depth, very comparable to populations at Stetson Bank (Table IV-66). Among the more numerous reef fishes are several species of large angelfishes and butterflyfishes (Chaetodontidae), damselfishes (Pomacentridae), Bluehead (Thalassoma bifasciatum), hogfishes (Bodianus spp.), Creolefishes (Paranthias furcifer), Rock hind (Epinephelus adscensionis), groupers (Mycteroperca spp.) and others typical of submerged reefs and banks in the northwestern Gulf (see Table IV-66). Large schools of Vermilion snapper, Rhomboplites aurorubens, were seen above 35 m depth and Red snapper schools, Lutjanus campechanus, were encountered near the base of the bank. A species of Chromis similar in shape, size and habit to C. enchrysurus is extremely abundant above 50 m depth. Chromis enchrysurus, which is abundant on most of the other banks in the northwestern Gulf was not observed at Sonnier Bank in September, 1977.

A sizeable population of the large sea cucumber Isostichopus sp. is present between 35 and 45 m depth. The molt of a spiny lobster, Panulirus sp., was seen at 27 m depth.

A correlation between the depth distribution and abundance of

epibenthic communities and patterns of chronic turbidity at Sonnier Bank is probable. In September, 1977 water turbidity was observed from the submersible to have been greater at Sonnier Bank below 42 m than above, although a highly turbid nepheloid layer was not encountered above 52 m depth. The abundance of Millepora, sponges, coralline algae and most of the other encrusting epifauna is greatly reduced below 40 m depth.

The base of Sonnier Bank lies at approximately 52 m depth. With increasing distance away from the bank, outcrops become smaller and give way to a mud bottom with loose siltstone boulders and cobbles, all covered with veneers of sediment. At 58 m depth, mud is predominant, with a few rocks.

Although certain species which are abundant on the bank extend some distance out onto the surrounding level bottom (Neofibularia nolitangere and Isostichopus sp. were seen down to 54 m depth) benthic communities occupying this turbid water, rock strewn, soft-bottom, differ considerably from those found on the bank. Conspicuous organisms present adjacent to the bank, but not on it, include the antipatharians Cirripathes sp. and Antipathes sp., comatulid crinoids, the sponge Ircinia campana and Burrowing fish C. Abundant burrows, tracks and trails in the mud attest to a substantial population of large infaunal organisms.

Because of the striking similarity in their structure, environment and biota, Sonnier and Stetson Banks should be classed together in terms of measures to be taken in protecting them from possible effects of oil and gas activities. It is pointed out however, that there have already been 9 exploratory wells drilled within 4.6 to 9.2

kilometers of Sonnier Bank (Fig. VI-24). Because they were drilled before any concerted attempts by the federal government to assure protection of fishing bank communities, there were no restrictions on the discharge of effluents such as those currently imposed on drilling activities near such banks. It is therefore assumed that all drill effluents from these wells were discharged at or near the sea surface. Such circumstances must be taken into consideration in assessing the effects of offshore petroleum industry operations on sensitive marine habitats.

In view of the above, it is significant that epibenthic communities at Sonnier Bank appear to be very healthy at present, and there is no evidence of past mass mortalities or large scale deleterious environmental effects attributable to any cause. In fact, the condition of epifaunal populations at Sonnier Bank seemsgenerally better than that of the similar populations at Stetson Bank, around which no drilling had occurred prior to 1975 (we examined Stetson Bank in 1974 and 1976).

We must add the aforementioned to the growing list of observations based on reconnaissance, monitoring and post drilling studies which have failed to demonstrate "real-world" environmental effects of offshore drilling on reefal and fishing bank communities in the northwestern Gulf of Mexico.

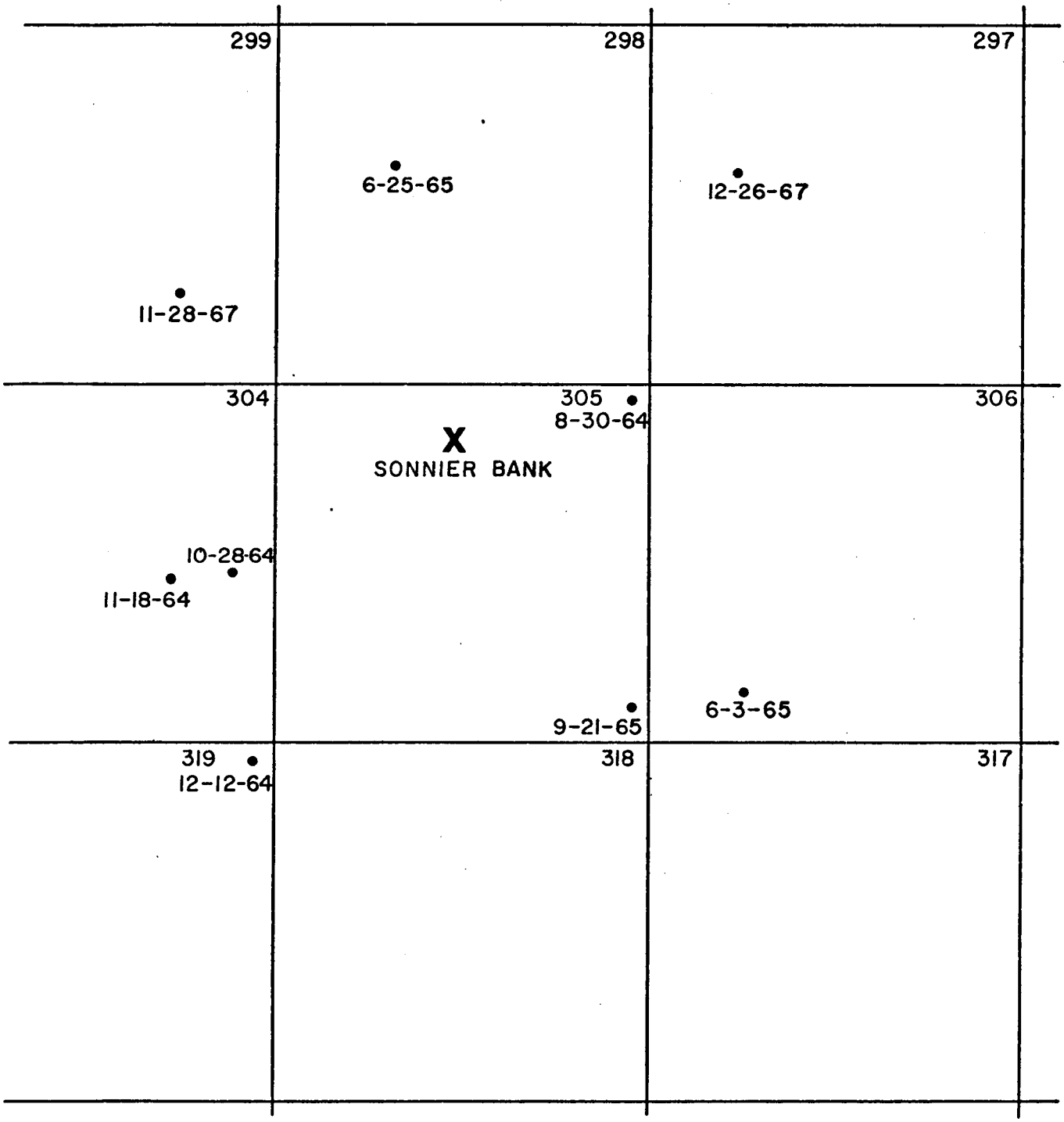


Figure VI-24. Locations and dates of exploratory wells drilled in the vicinity of SONNIER BANK. Information supplied by Continental Oil Company.

SONNIER BANK
VERMILION AREA, SO. ADD.
OFFSHORE LOUISIANA
= 3,000 m
• exploratory wells

TABLE VI-1A

18 FATHOM BANK

Collected Species	Depth (m)	Number
Algae		
Anadyomene stellata	46 - 61	1
Cladophora sp.	46 - 61	5
Lobophora variegata	46 - 61	2
Sargassum hystrix	46 - 61	2
Stypopodium zonale	46 - 61	15
Valonia ventricosa	46 - 61	2
Caulerpa peltata	46 - 61	5
Halimeda tuna	46 - 61	5
Gracilaria sp.	46 - 61	1
Lithothamnium sp.	46 - 61	1
Sponges		
Callyspongia armigera	46	1
Didiscus sp.	46	2
Ircinia strobilina	46	1
I. sp. "a"	46	1
I. sp. "b"	46	1
Spongiidae	46	1
Microscleritoderma sp.	46	3
Myriastra sp.	46	3
Unidentified sp.	46	2
Alcyonaria		
Bebryce cinerea	64 - 91	1
Nicella flagellum	64 - 91	1
Molluscs		
Siliquaria anguillae	46	10
Polychaetes		
Anaitides madeirensis	46	1
Ceratonereis mirabilis	46	2
Chloeia viridis	46	1
Eunice vittata	46	3
Haplosyllis spongicola	46	2

Table VI-1A, cont.

Collected Species	Depth (m)	Number
Terebella pterochaeta	46	1
Typosyllis hyalina	46	1
T. variegata	46	8
Polynoidae	46	1
Crustaceans		
Amphipoda (Gammaridea)	46	5
Synalpheus townsendi	46	2
S. sp. (nr. *longicarpus*)	46	1
Periclimenaeus bermudensis	46	1
Munida simplex	46	1
Goneplacidae sp. A	46	1
Hyas sp.	46	1
Nibilia antilocarpa	46	1
Pilumnus floridanus	46	1
Ophiuroids		
Ophiactis savignyi	46	4
Ophiactis sp.	46	1
Ophiothrix angulata	46	1
Bryozoans		
Celleporaria albirostris	46	1
Cleidochasma contractum	46	1
Entalophora proboscideoides	46	1
Rhynchozoon bispinosum	46	2
Stylopoma spongites	46	1
Trematooecia turrita	46	2
Pycnogonida	46	1

TABLE VI - 1B

18 FATHOM BANK

Observed Species	Depth(m)	Number
Algae		
Coralline Algae	44 - 81	12
Leafy Algae	46 - 54	6
Padina sp.?	46 - 54	3
Valonia sp.	54	1
Caulerpa sp.	47	1
Sargassum sp?	44 - 56	4
Lobophora sp.	56 - 76	9
Pink Branching Algae	44 - 56	1
?*Microdictyon* sp.	69	1
Brown Algae	69	1
Green Filamentous Algae	75	1
Green "Sea-Lettuce" Algae	75	1
Halimeda sp.	76	1
Sponges		
Agelas sp.	44 - 53	8
Tethyid sponge	44 - 62	4
Callyspongia sp.	54	1
Neofibularia sp.	54	1
Barrel sponge	54	1
Tube sponge	44	1
Orange sponge	55	1
Branching sponge	58	1
Verongia sp.	69	1
Hydroids		
"Plume-like" Hydroid	56 - 62	2
Stony Corals		
Stephanocoenia sp.	43 - 54	13
Agaricia sp.	44 - 49	5
Montastrea cavernosa	44 - 54	10
Madracis sp.	52 - 64	8
Millepora sp.	43 - 54	15
"Saucer" agariciids	47 - 69	5
Oxysmilia sp.	94 - 102	3

Table VI-1B, cont.

Observed Species	Depth(m)	Number
Alcyonarians		
Ellisellidae	62 - 73	4
Nidalia sp.	105	1
Antipatharia		
Cirripathes sp.	57 - 105	13
Antipathes sp.	72 - 75	
Molluscs		
Spondylus americanus	43 - 55	6
Nautilus sp.	75	1
Vermetid	~ 62	2
Crustaceans		
Panulirus sp.	53	1
Shrimp	53	1
Cirripeda	54	1
Stenorynchus seticornis	62	2
Hippolysmata grabhami	57 - 62	2
Crinoids		
Comatulids	94 - 102	3
Asteroids		
Starfish	102	1
Echinoids		
Diadema sp.	43 - 53	9
Clypeaster sp.	102 - 105	3
Holothuroids		
Isostichopus sp.	75	1

Table VI-1B, cont.

Observed Species	Depth(m)	Number
Fishes		
Holocanthus ciliaris (Queen angelfish)	44	1
Holocanthus tricolor (Rock beauty)	44 - 53	3
Serranus annularis (Orangeback bass)	42 - 78	6
Holocentrus sp.	42 - 81	7
Xanthichthyes ringens (Sargassum triggerfish)	46	1
Canthidermis sufflamen (Ocean triggerfish)	12	1
Balistes vetula (Queen triggerfish)	44 - 54	4
Equetus punctatus (Spotted drum)	94	1
Priacanthus sp. (Bigeye)	94 - 97	2
Pomacentrus partitus (Bicolor damselfish)	46	1
Caranx ruber (Bar jack)	46	1
Caranx sp.	9 - 54	4
Reef Fish A	81 - 91	3
Flatfish	105	1
Triglidae	105	1
Mycteroperca phenax (Scamp)	44 - 78	8
Mycteroperca sp.	44 - 91	9
Dermatolepis inermis (Marbled grouper)	44 - 47	3
Epinephelus striatus (Nassau grouper)	47	1
E. cruentatus (Graysby)	52 - 53	2
E. adscensionis (Rock hind)	43 - 47	3
Bodianus rufus (Spanish hogfish)	46 - 53	2
B. pulchellus (Spotfin hogfish)	44 - 84	4
Acanthurus sp. (Surgeonfish)	53 - 81	1
Liopropoma eukrines (Wrasse bass)	54 - 84	3

Table VI-1B, cont.

Observed Species	Depth(m)	Number
Striped Parrotfish	54	1
Sparisoma aurofrenatum (Redband parrotfish)	54	1
Sphyraena barracuda (Great barracuda)	6 - 54	4
Elegatis bipinnulata (Rainbow runner)	12	1
Paranthias furcifer (Creolefish)	40 - 47	5
Malacanthus plumieri (Sand tilefish)	44 - 55	6
Ginglymostoma cirratum (Nurse shark)	47	1
Chaetodon sedentarius (Reef butterflyfish)	47 - 84	4
Pseudupenesis maculatus (Spotted goatfish)	53	1
Apogon maculatus (Flamefish)	53	1
Thalassoma bifasciatum (Bluehead)	46 - 47	2
Halichoeres garnoti (Yellowhead wrasse)	47 - 53	2
Calamus sp.	47	1
Chromis sp.	47	2
C. enchrysurus (Yellowtail reeffish)	42 - 69	15
C. cyanea (Blue chromis)	44 - 47	4
Prognathodes aculeatus (Longsnout butterflyfish)	47 - 81	4
Myripristis jacobus (Blackbar soldierfish)	47	1
Lutjanus campechanus (Red snapper)	46 - 47	2
Canthigaster rostrata (Sharpnose puffer)	47 - 84	3
Centropyge argi (Cherubfish)	44 - 61	7
Amblycirrhitus pinos (Redspotted hawkfish)	47	1
Pomacanthus paru (French angelfish)	47	
Reptilia		
Sea turtle	54	1

TABLE VI-2A

BRIGHT BANK

Collected Species	Depth (m)*	Number
Algae		
Codium taylori		5
Lobophora variegata		7
Valonia macrophysa		2
Sponges		
Agelas dispar		1
Callyspongia armigera		1
Gelliodes areolata		1
Haliclonidae		1
Leuconia sp.		2
Spongia barbara		2
Stellata sp.		1
Tethyidae		1
Polychaetes		
Anaitides madeirensis		1
Arabella mutans		1
Chloeia viridis		1
Dorvillea sociabilis		1
Haplosyllis spongicola		96
Harmothoe sp.		3
Vermiliopsis annulata		1
Molluscs		
Siliquaria anguillae		2
Strombus alatus		1
Crustaceans		
Amphipoda (Gammaridea)		4
Isopoda		9
? *Alpheopsis* sp.		-

Table VI-2A, cont.

Collected Species	Depth (m)*	Number
Synalpheus agelas		2
S. barahonensis		2
S. pandionis		7
S. sp. (nr. Hippolytidae)		21
		1
Munida simplex		1
Melybia thalamita		1
Periclimenaeus bredini		3
Ophiuroids		
Ophiactis savignyi		3
O. sp.		6
Bryozoans		
Rhynchozoon sp.		1
Steganoporella magnilabris		3

* All specimens taken from somewhere between 55 and 94 m depth.

TABLE VI-2B

BRIGHT BANK

Observed Species	Depth(m)	Number
Algae		
Lobophora sp.	52 - 70	16
Codium sp.	54	2
Pink Branching Algae	52 - 58	5
Valonia sp.	54 - 62	4
Red-Orange Algae	55	1
Green Algae	55	1
Coralline Algae	52 - 62	8
Padina sp.	52 - 58	7
Caulerpa sp.	52 - 78	4
Branching Algae	53	1
Leafy Algae	52 - 78	15
Large, Flat Green Algae	52	1
Filamentous Algae	52 - 58	2
Sargassum sp.?	58	1
?*Microdictyon* sp.	61	1
Sponges		
Neofibularia sp.	52 - 70	13
Agelas sp.	53	1
Placospongia sp.	52	1
Orange sponge	52	1
Branching sponge	52 - 62	4
Tethyid sponge	55 - 59	5
"Friable" sponge	52	2
Tube sponge	59	1
"Drab-colored" sponge	62	1
Ircinia campana	62	1
Hydroids		
"Plume-like" Hydroids	53	1
Stony Corals		
Madracis sp.	54 - 68	9
Agaricia sp.	54 - 55	2
Saucer-shaped agariciid	54 - 65	17
Montastrea cavernosa	52	

Table VI-2B, cont.

Observed Species	Depth(m)	Number
Antipatharia		
Antipathes sp.	52 - 63	6
Cirripathes sp.	69 - 94	8
Anemones		
Condylactis sp.	52 - 59	10
Brown Branching	51 - 63	5
Stichodactyline	59 - 69	3
Anemone	94	1
Molluscs		
Astraea sp.	55	1
Spondylus americanus	52 - 62	3
Strombus sp.	52	1
Cowry	52	1
Anadara sp.?	52	1
Lyropecten sp.	59	1
Atrina sp.	62	1
Crustaceans		
Stenorhynchus sp.	52 - 64	9
Hermit crab	55 - 61	2
Panulirus sp.	45 - 52	4
Stenopus sp.	59	1
Crinoids		
Comatulid	59 - 69	12
Asteroids		
Starfish	73	2
Echinoids		
Diadema sp.	54 - 69	6
Stylocidaris sp.	80 - 94	5

Table VI-2B, cont.

Observed Species	Depth(m)	Number
Ophiuroids		
Ophiuroids	59	1
Fishes		
Ogcocephalidae (Batfish)	63	1
Eel	63	1
Lutjanus sp.	55	2
L. campechanus (Red snapper)	55 - 59	2
Hovering Fish D	55 - 59	3
Canthigaster rostrata (Sharpnose puffer)	55 - 59	3
Holocentrus sp. (Squirrelfish)	55 - 59	6
Pomacentrus paru (French angelfish)	52 -59	3
Pomacentrus partitus (Bicolor damselfish)	52	1
Eupomacentrus variabilis (Cocoa damselfish)	52	1
Balistes vetula (Queen triggerfish)	52 - 55	4
B. capriscus (Gray tirggerfish)	52 - 55	2
Calamus sp. (Porgy)	55	2
Bodianus pulchellus (Spotfin hogfish)	52 - 59	6
Chromis enchrysurus (Yellowtail reeffish)	51 - 61	14
Serranus annularis (Orangeback bass)	52 - 59	14
Dermatolepis inermis (Marbled grouper)	52 - 53	2
Mycteroperca phenax (Scamp)	52 - 59	8
Epinephelus adscensionis (Rock hind)	52 - 53	4
Chaetodon sedentarius (Reef butterflyfish)	52 - 69	10
Gobiosoma sp. (Goby)	52 - 61	4
Centropyge argi (Cherubfish)	54 - 61	2

Table VI-2B, cont.

Observed Species	Depth(m)	Number
Sparisoma aurofrenatum (Redbank parrotfish)	51 - 54	2
Holacanthus ciliaris (Queen angelfish)	52 - 55	3
Diodon sp.	56 - 69	3
Pseudupeneus maculatus (Spotted goatfish)	59 - 69	6
Apogon sp. (Cardinalfish)	52 - 59	2
Gymnothorax moringa (Spotted moray)	59	1
Sphyraena barracuda (Barracuda)	61 - 62	2
Halichoeres sp. (Wrasse)	61	1
Synodontidae (Lizardfish)	52 - 59	2
Amblycirrhitus pinos (Redspotted hawkfish)	52	2
Seriola sp. (Amberjack)	52	1
Thalassoma bifasciatum (Bluehead)	52	1
Priacanthus sp. (Bigeye)	52 - 61	2
Xanthichthys ringens (Sargassum triggerfish)	52 - 55	3
Liopropoma sp. (Basslet)	52	2
Prognathodes aculeatus (Longsnout butterflyfish)	52	2

TABLE VI-3A

BOUMA BANK

Collected Species	Depth (m)	Number
Algae		
Pocockiella variegata	67	10
Lithothamnium sp.	67	1
Sponges		
Anixellidae sp.	67	1
Prianos sp.	67	1
Sigmadocia sp.	67	1
Polychaetes		
Ceratonereis mirabilis	67	1
Haplosyllis spongicola	67	1
Micropodarke dubia	67	1
Potamilla reniformis	67	1
Spadella sp.	67	1
Sphaerosyllis pirifera	67	1
Tachytrypane jeffreysii	67	3
Trypanosyllis zebra	67	1
Molluscs		
Barbatia domingensis	67	3
Botula fusca	67	1
Chlamys benedicti	67	1
Ischnochiton cf. *papillosus*	67	1
? *Nesta atlantica*	67	1
Siliquaria anguillae	67	4
Vermicularia fargoi	67	2
Bivalve - heavily encrusted	67	1
Crustaceans		
Paranebalia sp.	67	3
Amphipoda (Gammaridea)	67	5
Isopoda	67	6

Table VI-3A, cont.

Collected Species	Depth (m)	Number
Tanaidacea	67	1
? *Alpheopsis* sp.	67	1
Goneplacidae sp. A	67	2
Ophiuroids		
Astrophyton cf. *muricatum*	67	2
Ophioderma phoenium	67	1
Bryozoans		
Celleporaria mordax	67	1
Cleidochasma contractum	67	1
Escharipora stellata	67	1
Smittipora levinseni	67	1
Trematooecia turrita	67	1

TABLE VI-3B

BOUMA BANK

Observed Species	Depth(m)	Number
Algae		
Coralline Algae	61 - 84	21
Leafy Algae	61 - 75	6
Leafy Algal Detritus	75 - 84	10
Caulerpa sp.	61	2
Microdictyon sp.	61 - 67	2
Branching Algae	61	1
?*Padina* sp.	61 - 70	4
Halimeda sp.	64 - 67	2
Sponges		
Neofibularia sp.	69 - 81	3
Encrusting sponge	62	1
Spongia barbara	61	1
Tubular Branching Sponge	61	1
Tethyid sponge	61	1
Ircinia sp.	69	1
Stony Corals		
Madracis sp.	65	1
"Saucer" Agariciid	64 - 71	3
Antipatharia		
Antipathes sp.	61 - 75	4
Cirripathes sp.	61 - 84	43
Anemones		
Condylactis sp.	61 - 67	11
Stichodactyline anemone	61 - 72	4
Anemones	82	2
Molluscs		
Spondylus americanus	61 - 84	3
Busycon sp.	72	
B. egg case	82	1

Table VI-3B, cont.

Observed Species	Depth(m)	Number
Crustaceans		
Hermit crab	72	1
Crinoids		
Comatulids	61 - 83	31
Asteroids		
Narcissia trigonaria	75 - 83	5
Starfish	78	1
Ophiuroids		
Gorgonocephalidae (Basketstars)	61 - 75	6
Echinoids		
Clypeaster sp.	81 - 82	5
Stylocidaris sp.	80 - 82	2
Holothuroids		
Holothuroid	76	1
Fishes		
Chromis enchrysurus (Yellowtail reeffish)	61 - 84	17
Paranthias furcifer (Creolefish)	62 - 67	5
Bodianus pulchellus (Spotfin hogfish)	61 - 72	6
Holocentrus sp. (large)	61 - 73	5
H. sp. (small)	69	2
Mycteroperca phenax (Scamp)	61 - 75	8
Serranus annularis (Orangeback bass)	61	2
S. phoebe (Tattler)	64 - 83	8
Balistes vetula (Queen triggerfish)	60 - 62	2

Table VI-3B, cont.

Observed Species	Depth(m)	Number
Malacanthus plumieri (Sand tilefish)	62	1
Seriola sp. (Amberjack)	61	2
Liopropoma sp. (Basslet)	69 - 83	2
Equetus umbrosus (Cubbyu)	69 - 83	4
Priacanthus sp. (Bigeye)	80 - 84	5
Prognathodes aculeatus (Longsnout butterflyfish)	69	1
Triglidae (Sea robin)	83	2
Eel	81	1
Hovering Fish D	81	1
Burrowing Fish C	80	1
Chaetodon aya (Bank butterflyfish)	80	2
C. sedentarius (Reef butterflyfish)	61 - 84	7
Centropyge argi (Cherubfish)	61 - 69	3
Mulloidichthys martinicus (Yellow goatfish)	69	1
Reef Fish A	69 - 83	8
Lutjanus campechanus (Red snapper)	69 - 83	5
Small "Burrow" Fish	83	1
Holacanthus tricolor (Rock beauty)	67	2
"Tuna"	47	1

TABLE VI-4A

EWING BANK

Collected Species	Depth (m)	Number
Sponges		
Callyspongia armigera	55	1
Diplastrella sp.	55	2
Epallax sp.	55	1
Erybus alleni	55	1
Ircinia sp. "a"	55	2
I. sp. "b"	55	1
Mycale angulosa	55	1
Mycalidae sp.	55	1
Myriastra sp.	55	1
Placospongia carinata	55	1
Ancorinidae sp.	55	1
Unidentified sp.	55	1
Alcyonaria		
Nicella schmitti	55	1
Nidalia occidentalis	55	1
Polychaetes		
Autolytus prolifer	55 - 61	1
Haplosyllis spongicola	55 - 61	13
Trypanosyllis zebra	55 - 61	2
Typosyllis hyalina	55 - 61	1
T. variegata	55 - 61	1
Ceratonereis mirabilis	55 - 61	4
Eunice vittata	55 - 61	2
Harmothoe sp.	55 - 61	1
Podarkeopsis galagani	55 - 61	1
Polypthalmus pictus	55 - 61	2
Tachytrypane jeffreysii	55 - 61	4
Filograna implexa	55 - 61	8
Chloeia viridis	55 - 61	1
Anaitides madeirensis	55 - 61	2
Leocratides filamentosa	55 - 61	2
		1
Nereidae	55 - 61	1
Vermiliopsis annulata	55 - 61	1
Nematoda	55 - 61	1

Table VI-4A, cont.

Collected Species	Depth (m)	Number
Molluscs		
Arca zebra	55	5
Gregariella opifex	55	4
Barbatia domingensis	55	1
B. candida	55	2
Chiton, sp. A	55	1
Limpet, sp. A	55	1
Spondylus americanus	55	1
Vermicularia fargoi	55	2
Crustaceans		
Paranebalia sp.	55	1
Amphipoda (Gammaridea)	55	39
Isopoda	55	12
Tanaidacea	55	2
? *Alpheopsis* sp.	55	1
Synalpheus pandionis	55	1
S. sp. (cf. *disparodigitis*)	55	1
Hippolytidae	55	1
Majidae, sp. A	55	1
Melybia thalamita	55	1
Ophiuroids		
Amphipholis squamata	55	1
Amphiodia pulchella	55	1
Ophiactis savignyi	55	4
Bryozoans		
Aetea truncata	55 - 61	6
Alderina smitti	55 - 61	1
Chorizopora brogniarti	55 - 61	1
Cribrilaria radiata	55 - 61	4
Celleporaria albirostris	55 - 61	2
Mollia patellaria	55 - 61	1
Parasmittina sp.	55 - 61	1
Parellisina latirostris	55 - 61	1
Retevirgula flectospinata	55 - 61	1
Rhynchozoon bispinosum	55 - 61	1
Schizoporella trichotoma	55 - 61	1
Smittipora levinseni	55 - 61	1
Stylopoma spongites	55 - 61	1
Pycnogonida	55	1

TABLE VI-4B

EWING BANK

Observed Species	Depth(m)	Number
Algae		
?*Microdictyon* sp.	58	2
Leafy Algae	58 - 94	4
Brown, Leafy Algae	61	2
Red Algae	58	1
Bushy Brown Algae	67	1
Green Algae	67	1
?"*Ulva*" type Algae	94	1
Coralline Algae	88	1
Sponges		
White	58	1
Tethyid	58	1
Neofibularia sp.	58	5
Demospongia	58	1
Ircinia sp.	58 - 61	4
Barrel sponge	58	1
Agelas sp.	58 - 67	6
Spongia barbara	58	2
Sponges	58	5
Hydroids		
"Plume-like" Hydroids	67	1
Stony Corals		
Madracis sp.	58	1
Oxysmilia sp.	76 - 94	6
"Solitary" coral	94	1
Alyconarians		
Paramuricidae	76	3
Purple Alyconarian	76	1
Alyconarian	58	1

Table VI-4B, cont.

Observed Species	Depth(m)	Number
Antipatharia		
Anthipathes sp.	58	5
Cirripathes sp.	58 - 92	12
Anemones		
Condylactis sp.	58 - 73	18
Stichodactyline	58	1
Anemones	58	1
Molluscs		
Spondylus americanus	58 - 67	9
Lyropecten sp.	67	3
Conus sp.	80	1
Polychaetes		
Sabellidae	58 - 92	2
Crustaceans		
Crab	88 - 94	2
?Anomuran	94	1
Hermit crab	88	1
Crinoid		
Comatulid	58 - 94	10
Asteroids		
Astropecten sp.	98	1
Ophiuroids		
Gorgonocephalidae (Basket star)	58 - 61	3
Echinoids		
Stylocidaris sp.	94 - 95	2

Table VI-4B, cont.

Observed Species	Depth(m)	Number
Holothuroids		
Sea Cucumber	58	1
Bryozoa		
Holoporella sp.	58 - 80	4
Stylopoma sp.	67 - 73	5
Fishes		
Scomboromorus sp. (Mackerel)	0 - 9	2
Seriola sp. (Jack)	9 - 73	3
S. dumerili (Amberjack)	58	2
Chromis enchrysurus (Yellowtail reeffish)	58 - 80	16
Reef Fish A	70 - 80	3
Hovering Fish D	58	7
Acanthurus sp.	58	3
Xanthichthys ringens (Sargassum triggerfish)	58 - 67	5
Balistes vetula (Queen triggerfish)	58	2
Calamus sp. (Porgy)	58 - 61	3
Lutjanus campechanus (Red snapper)	58 - 88	9
Amblycirrhitus pinos (Redspotted hawkfish)	58	1
Paranthias furcifer (Creolefish)	61	2
Dermatolepis inermis (Marbled grouper)	61	1
Synodontidae (Lizardfish)	58	1
Holacanthus tricolor (Rock beauty)	58	2
Gobiosoma sp.	58	2
Centropyge argi (Cherubfish)	58 - 61	5
Serranus annularis (Orangeback bass)	58 - 67	5

Table VI-4B, cont.

Observed Species	Depth(m)	Number
Mycteroperca phenax (Scamp)	58 - 80	10
Malacanthus plumieri (Sand tilefish)	58	2
Holocentrus sp. (Squirrelfish)	58	2
Bodianus pulchellus (Spotfin hogfish)	58 - 76	4
Chaetodon sedentarius (Reef butterflyfish)	58 - 76	9
Pseudupeneus maculatus (Spotted goatfish)	61 - 76	2
Prognathodes aculeatus (Longsnout butterflyfish)	76	1
Equetus punctatus (Spotted drum)	76	1
Halichoeres bivittatus (Slippery Dick)	76	1

TABLE VI-5A

SACKETT BANK

Collected Species	Depth (m)	Number
Sponges		
Epallax sp.	62	1
Geodia gibberosa	62 - 67	2
Ircinia strobilina	62	1
Microscleritoderma sp.	62	1
Stellata sp.	62	1
Ulosa sp.	62	1
Poecilosclerida	62	1
Polychaetes		
Lumbrineris coccinea	62	1
Neanthes acuminata	62	1
Pomatoceros sp. A	62	9
Steninonereis martini	62	1
Trypanosyllis zebra	62	1
Molluscs		
Siliquaria anguillae	67	6
Plicatula gibbosa	67	2
Arca zebra	67	3
Fissurella sp.	67	1
Crustaceans		
Amphipoda (Gammaridea)	62	5
Mysidae	62	1
Tanaidacea	62	2
Munida flinti	62	1
Melybia thalamita	62	1
Ophiuroids		
Ophiactis savignyi	62	1
Bryozoans		
Celleporaria albirostris	62	2
Cribrilaria radiata	62	2
Crisia sp.	62	10
Diaperoecia floridana	62	4

Table VI-5A, cont.

Collected Species	Depth (m)	Number
Disporella fimbriata	62	1
Floridina antiqua	62	1
Mastigophora porosa	62	1
Microporella ciliata	62	1
Reptadeonella violacea	62	1
Schizmopora dichotoma	62	1
Scrupocellaria regularis	62	1
Stylopoma spongites	62	2

TABLE VI-5B

SACKETT BANK

Observed Species	Depth(m)	Number
Algae		
Coralline Algae	64 - 75	8
Drowned Coralline Reefs	61 - 73	18
Sponges		
Neofibularia sp.	62 - 83	19
Orange sponge	64 - 80	3
White Sponge	64	1
Yellow sponge	64 - 73	3
Purple sponge	64	1
Ircinia sp.	72 - 73	2
Geodea sp.	73 - 78	4
Spiny Barrel Sponge	83	1
Yellow-Orange "Tulip" Sponge	81 - 83	2
Stony Corals		
Agaricia sp.	64	1
Oxysmilia sp.	80 - 87	
Oculina sp.	85	1
Alcyonarians		
Nidalia sp.	80 - 87	7
Paramuricidae	87	2
Bebryce sp.	83	1
Small Alcyonarians	83	1
Antipatharia		
Cirripathes sp.	62 - 89	21
Antipathes sp.	80 - 83	5
Anemones		
Pinkish-Orange	64	1
Unidentified Anemone	64	1

Table VI-5B, cont.

Observed Species	Depth(m)	Number
Molluscs		
Cassis sp.	64	1
Lyropecten sp.	64	2
Conus sp.	64	1
Spondylus sp.	64 - 65	1
Vermitid Gastropods	64	3
Busycon sp.	64	1
Polychaetes		
Hermodice sp.	83	1
Sabellidae	64 - 67	6
Crustaceans		
Stenorhynchus sp.	78 - 83	2
Paguridae	64 - 87	2
Anomuran	78	1
Lysmata auboinensis (Scarlet Lady)	64	1
Crinoids		
Comatulid	64 - 87	35
Asteroids		
Narcissia trigonaria	78 - 83	5
Ophidiosteridae	64 - 80	4
Unidentified Starfish	64	1
"Robust" Starfish	80 - 87	3
Ophiuroids		
Gorgonocephalid	64 - 67	4
Echinoids		
Diadema sp.	64 - 72	12
Sand Dollar	80	1
Clypeaster sp.	88	1
Holothuroids		
Isostichopus sp.	62 - 67	4

Table VI-5B, cont.

Observed Species	Depth(m)	Number
Bryozoans		
Stylopoma sp.	71 - 73	2
Fishes		
Serranus annularis (Orange back bass)	64 - 72	4
S. phoebe (Tattler)	64 - 83	14
Mycteroperca phenax (Scamp)	65	1
Chaetodon sp.	75	1
C. aya (Bank butterflyfish)	62 - 73	8
C. sedentarius (Reef butterflyfish)	62 - 67	6
Lutjanus campechanus (Red snapper)	73 - 90	7
Rhomboplites aurorubens (Vermilion snapper)	65	1
Chromis enchrysurus (Yellowtail reeffish)	64 - 73	6
Seriola sp. (Amberjack)	64 - 73	5
Triglidae (Sea robin)	64 - 73	2
Apogon sp.	73	1
A. maculatus (Flamefish)	64	1
Reef Fish A	62 - 65	6
Large *Holocentrus* sp.	65	1
Small *Holocentrus* sp.	64	1
Malacanthus plumieri (Sand tilefish)	64 - 65	2
Sphyraena sp. (Barracuda)	65	1
Acanthostracion sp. (Cowfish)	64 - 80	2
Ogcocephalidae (Batfish)	76 - 80	2
Gymnothorax sp. (Eel)	86	1
Priacanthus sp. (Bigeye)	62 - 90	14
Canthigaster rostrata (Sharpnose puffer)	64 - 67	2

Table VI-5B, cont.

Observed Species	Depth(m)	Number
Gobiosoma sp. (Goby)	67	1
Paranthias furcifer (Creolefish)	62 - 65	4
Bodianus pulchellus (Spotfin Hogfish)	64 - 67	4
Liopropoma sp. (Basslet)	62 - 64	3
Equetus umbrosus (Cubbyu)	64	1
Mulloidichthys martinius (Yellow goatfish)	64	1
Prognathodes aculeatus (Longsnout butterflyfish)	64	1
Halichoeres bivittatus (Slippery Dick)	65	1

TABLE VI-6A

SONNIER BANK

Collected Species	Depth (m)	Number
Sponges		
Agelas dispar	52	1
Agelas sp.	52	1
Terpios fugax	52	1
Unidentified	52	1
Polychaetes		
Harmothoe sp.	52	1
Molluscs		
Arca imbricata	46 - 52	1
Barbatia domingensis	46 - 52	2
Barbatia sp.	46 - 52	1
Cerithium litteratum	46 - 52	1
Cerithium sp.	46 - 52	1
Crustaceans		
Amphipoda (Gammaridea)	54	2
Mysidae	54	1
Synalpheus ?tanneri	47 - 54	2
S. townsendi	47 - 54	9
S. sp. (nr. *longicarpus*)	47 - 54	2
S. sp. (ef. *barahonensis* or *brooksi*)	47 - 54	3
Melybia thalamita	54	2
Goneplacidae sp. A	54	1
Ophiuroids		
Amphipholis squamata	54	1
Ophiactis savignyi	47 - 54	7

TABLE VI-6B

SONNIER BANK

Observed Species	Depth(m)	Number
Algae		
Coralline Algae	38 - 46	3
Encrusting Algae	46 - 47	2
Sponges		
White Sponge	56	1
Tubular Sponge	56	1
Ircinia campana	53 - 54	2
Ircinia sp.	18 - 34	
Unidentified sponge	54 - 55	2
Neofibularia sp.	18 - 53	14
Tubular Branching sponge	47	1
Agelas sp.	37 - 46	4
Encrusting sponge	37	
Hydroids		
"Plume-like" hydroids	40 - 47	3
Stony Corals		
Saucer-shaped Agariciid	52	1
Millepora sp.	18 - 52	7
Stephanocoenea sp.	37 - 41	4
Antipatharia		
Antipathes sp.	47 - 55	2
Cirripathes sp.	55 - 58	4
Molluscs		
Spondylus americanus	37	1
Polychaetes		
Spirobranchus sp.	27 - 52	2

Table VI-6B, cont.

Observed Species	Depth(m)	Number
Crustaceans		
Hippolysmata grabhami	37	1
Panulirus sp.	27	1
Crinoids		
Comatulids	55 - 58	3
Echinoids		
Diadema sp.	34 - 40	3
Holothuroids		
Isostichopus sp.	37 - 54	7
Fishes		
Canthigaster rostrata	37 - 47	3
Paranthias furcifer (Creolefish)	18 - 54	6
Bodianus pulchellus (Spotfin hogfish)	54	2
B. rufus (Spanish hogfish)	43 - 46	2
Epinephelus adscensionis (Rock hind)	27 - 54	3
Mycteroperca sp. (Groupers)	27 - 54	4
M. phenax (Scamp)	37	1
Chaetodon sedentarius (Reef butterflyfish)	24 - 46	6
Pomacentrus variabilis (Cocoa damselfish)	18 - 46	6
Caranx sp. (Jack)	27	1
Seriola sp. (Amberjack)	5 - 37	3
Pomacanthus paru (French angelfish)	27 - 55	3
Burrowing Fish C	54	1
Lutjanus campechanus (Red snapper)	52	1

Table VI-6B, cont.

Observed Species	Depth(m)	Number
Rhomboplites aurorubens (Vermilion snapper)	27 - 43	3
Chromis sp.	18 - 53	8
C. multilineatus (Brown chromis)	37	1
Holacanthus bermudensis (Blue angelfish)	27 - 47	4
Holacanthus ciliaris (Queen angelfish)	27 - 37	2
Holacanthus tricolor (Rock beauty)	27 - 37	2
Clepticus parrai (Creole wrasse)	27 - 47	3
Gobiosoma sp. (Goby)	27 - 37	2
Thalassoma bifasciatum (Bluehead)	27 - 37	2
Pseudopeneus maculatus (Spotted goatfish)	37	1
Acanthurus bahianus (Ocean surgeon)	27	1
Acanthurus sp. (Surgeonfish)	37	1
Holocentrus sp. (Squirrelfish)	34	1
Large *Holocentrus* sp.	37	1

CHAPTER VII

EAST FLOWER GARDEN MONITORING STUDY

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INTRODUCTION

Environmental monitoring at the East Flower Garden is desirable to insure that the condition and health of biotic communities on the bank are not degraded as a result of petroleum development and other commercial, sport and scientific activities. Since 1974, we have used a research submersible to perform yearly reconnaissance transects from the coral reef at the crest of the bank to the edge of the hard bank (Bright et al. 1976, 1978). In June, 1977, a long-term monitoring site (BLM site) was established at 26 m depth on the southeastern side of the coral reef (Fig. VII-1). Two additional reef monitoring sites were established by the consulting firm Continental Shelf Associates (CSA) in the course of a monitoring study for Mobil Oil Company (Continental Shelf Assoc., 1978). We worked closely with CSA during their study and have subsequently utilized their two monitoring stations (CSA sites A and B) (Fig. VII-1).

The submersible reconnaissance observations have resulted in year-to-year comparative assessments of the general health and condition of biotic communities on the bank. Conclusions are based on qualitative judgements made by the principal investigator after direct visual inspection of benthic communities along the reconnaissance transect. No changes in the health and condition of hard-bank communities southeast of the coral reef over the past three years (1974-1977) are apparent from submersible reconnaissance

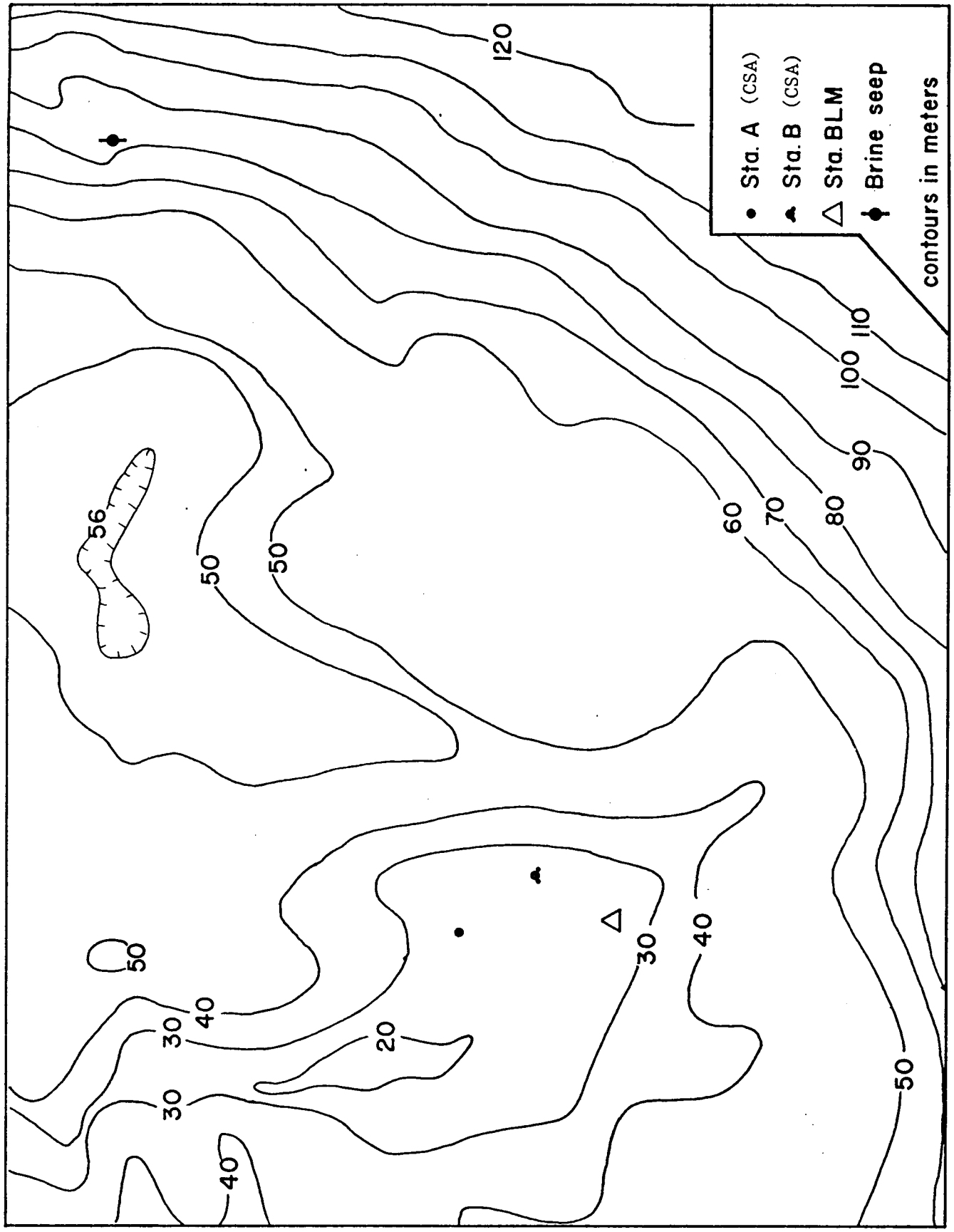


Figure VII-1a. Locations of three East Flower Garden reef monitoring sites (Sta. A, Sta. B, Sta. BLM) and Brine Seep.

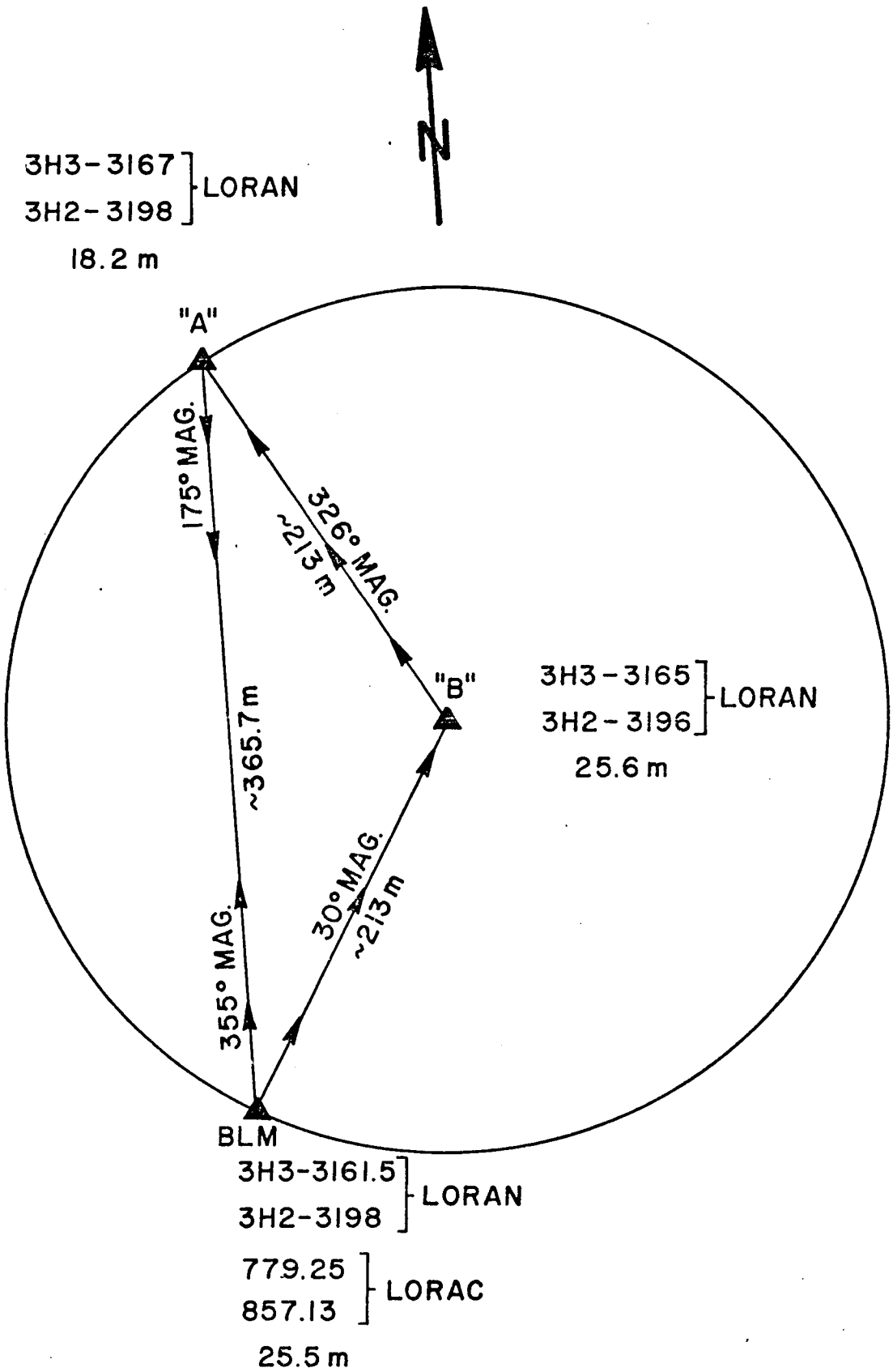


Figure VII-1b. Navigation data and depths for three East Flower Garden Monitoring Sites.

studies.

Research diving techniques using SCUBA are employed at the three reef monitoring sites. Observations on the coral reef are directed toward (1) quantitative estimates of coral populations, and (2) assessment of those natural and man induced environmental processes which affect growth and mortality of the dominant reef building corals and coralline algae. At the East Flower Garden the most significant of these processes are apparently recruitment; encrusting growth; competition for space; coral necrosis; destruction of coral by coralivores, browsers and grazers; effects of hurricanes; and mechanical damage by divers and anchors.

Several years of observation will be required before definitive conclusions can be made concerning population levels of reef building organisms, the rates at which significant processes affecting such organisms proceed, the operational factors governing these processes, and trends in health and condition of corals and coralline algae. The first year's reef monitoring effort has served to focus our efforts while providing a substantial amount of benchmark data concerning localized populations, as well as information concerning short term aspects of the processes under study. Most of the data generated during 1977 and 1978 were derived from photographs and time-lapse motion pictures. Inclusion of the several hundred photographs in this report as basic data is not feasible. Written descriptions of pertinent information in photographs taken at the monitoring sites can be found in the Appendix at the end of this chapter. In the following discussion,

specific subject stations from the BLM monitoring site are referred to as BLM-1,etc. Those stations from the two CSA stations (A and B) are designated CSA-A1, CSA-B2, etc.

CORAL POPULATION ESTIMATES

Nine plotless line transects (Loya,1972) were selected at random on the reef in the vicinity of the BLM monitoring site. The transects were taken by stretching a fiberglass measuring tape across the bottom. Research divers then swam over the length of tape and measured the linear dimensions of each colony of living coral, dead reef rock, zones of competition for space and attached epifauna. The transects were originally intended to be 10 meters each in length. However, the lengths range from 1000 cm to 1500 cm. Transects longer than 1000 cm were obtained whenever extra underwater time was available. A total of 11,287 cm of reef were measured on the 9 plotless line transects (TABLE VII-1). In addition to population data, transects 1-4 give information on corals which are affected by processes such as competition and coral necrosis.

Live coral coverage averaged 62.5% on the transects. It is interesting to compare this percentage with the 30-40% live coral cover reported by Bright *et al.* (1974) for the neighboring West Flower Garden Bank. Bright obtained his data by employing 27 circular quadrats, 3.6 m in diameter, along a 198 m transect line across the reef. Our transects were all taken between 24 and 27 m depth, while the majority of his quadrats were shallower than 26

meters. His data were obtained from the broad, top, central portion of the West Flower Garden reef, while our transect data are restricted to the somewhat deeper southeast edge of the East Flower Garden reef. Recognizing the variability in location and technique between these two sets of data, it is felt that the greater percentage of live coral measured for the reef edge (62.5%) compared to the shallower reef crest (30-40%) is real. Our field observations at both the East and West Flower Gardens have resulted in impressions that live coral cover is greater toward the edge of the reefs (26-31 m depth) than on the reef tops.

Montastrea annularis is the most abundant coral species reported on both the East and West Flower Garden Banks. Our observations show that this species is a strong competitor for living space on the reef. It is often seen in competitive situations where it is killing and overgrowing other coral species (Fig. VII-26; see discussion below). Processes affecting *M. annularis* populations undoubtedly have a major impact on the reef community as a whole.

DESTRUCTIVE PROCESSES AFFECTING CORAL POPULATIONS

Destructive processes resulting in the regression and loss of living coral tissue are commonly seen at the East Flower Garden. During 1977-1978, selected photographic stations established at the BLM and two CSA monitoring sites followed the progress of various coral heads which showed evidence of destructive processes (See Appendix). TABLE VII-2 gives rates of tissue regression observed at the selected photographic stations. These rates represent maximum linear tissue retreat at selected locations along a given colony border. Such re-

gression rarely takes place uniformly along the entire border. It generally occurs along a small segment of the border.

The rates of tissue retreat presented in TABLE VII-2, and those of tissue advancement given in TABLE VII-3, are at best, gross estimates of linear distances vacated or covered by regressing and advancing coral tissue borders. Constraints such as maximum available time working at these depths and the desire to avoid excessive contact with the subject corals dictated that the measurements be made from the photographs and not in the field. Variations in camera orientation between successive photographs can lead to confusion in interpretation of results. Care was taken not to include apparent changes in the corals that possibly resulted from such camera angle variation.

Samples of corals exhibiting typical conditions of mortality were collected and returned to laboratory aquaria for close examination. A particular effort was made to describe the algal population in the immediate vicinity of areas of necrotic coral tissue.

CORAL NECROSIS

Figures VII-2 through 4 (CSA Station A8) show a *Diploria* sp. head which is apparently undergoing a process of mortality frequently affecting the brain corals at the East Flower Garden (*Diploria* spp. and *Colpophyllia* spp.). A zone of tissue necrosis is progressing downward in an irregular band several centimeters wide. The necrosis spreads initially along the tops of the ridges of the brain-line convolutions on the surface of the coral. Green colored filamentous algae are present on these ridges where the living tissue has receded

(Fig. VII-5). The growth of these algae closely follows the progress of necrosis, which leaves the ridges blanched and tissueless. This suggests that the necrosis may be triggered by a chemical agent produced by the algae. Such speculation must be tested by more sophisticated investigation. From the ridges the necrosis spreads into the valleys, eventually resulting in total mortality of coral tissue in the affected area. The newly exposed corallum is rapidly colonized by the aforementioned filamentous algae. In this case, coralline algae and Millepora sp. have also become established on the bare corallum (Figs. VII-6 through 8). Substantial erosion of the carbonate skeleton, as evidenced by the disintegration of the skeletal septa can also be observed in Figs. VII-6 through 8.

Ms. Linda Perry-Plake has generated a description of the surficial algal populations occurring on several necrotic coral samples, as follows:

> "Figure VII-9 shows a head of Diploria strigosa which has experienced the type of mortality described above, mainly on the ridges between individual polyps of the head. The exposed corallum on the underside of this coral head was colonized by the algae Caulerpa vickersiae, Derbesia vaucheriaeformis and crustose coralline forms. Caulerpa exhibits a dual portion thallus, having an erect portion and a stoloniferous portion. The stoloniferous habit enables Caulerpa to vegetatively invade an area and readily colonize it. It is difficult to determine, however, how opportunistic this species is. In addition, a nudibranch was observed apparently grazing on the Caulerpa. Grazing may be an important control on the

extent of algal colonization.

Derbesia was located on only one area of the coral, occasionally integrading into the Caulerpa. Scattered areas were encrusted with patches of coralline algae, probably Lithoporella sp., interspersed among the Caulerpa thalli.

Growing upon areas of recent mortality on the ridges of the small Diploria head were patches of a red filamentous mat (Fig. VII-9). The species composition of this mat included three rhodophytes, Ceramium cruciatum, Polysiphonia denudata and Polysiphonia subtilissima, and one cyanophyte, Oscillatoria sp. The Ceramium, like the Caulerpa, has both prostrate and erect filaments, enabling it to spread across open (dead) areas and anchor at intervals. The two Polysiphonia species are attached erect forms and,with the Ceramium, comprise a skeleton over which the filaments of Oscillatoria become attached. Because of their proximity to the necrotic coral tissue borders, these algae are hypothetically suspect as possible causes of coral tissue regression in brain corals.

A small piece of the fire coral Millepora sp., collected from a large dead colony, was found to harbor the algae Derbesia vaucheriaeformis,Polysiphonia subtilissima and crustose coralline forms. All three species were distributed randomly in scattered patches.

Examination of a fragment of a corallum of predominantly dead Montastrea annularis revealed Caulerpa vickersiae, Derbesia vaucheriaeformis, and the same filamentous algal mat previously described for the small Diploria head. In the

contiguous zone between the Caulerpa and the area covered by the filamentous mat, the mat appeared to be growing over the Caulerpa, possibly causing it to die back.

The coralla described above were collected in March and May, 1978. It appeared that a specific suite of algal species may colonize exposed coral coralla, at least during the spring season. Much more sampling on a seasonal basis is necessary to determine whether the species composition of algal associates changes successionally."

Observations on corals (primarily Montastrea cavernosa) bordered by epifauna and algae covered substratum often revealed a 5mm wide band of living tissue at the border which was dark when compared to the color of the rest of the colony (see Bright et al., 1978; Fig. VII-36). Close examination of this band reveals that the darkness is apparently due to the presence of endolithic algae in the skeletal septa just beneath the living tissue. The algae give the skeletal rock a dark green color. Coral tissue at the colony border may be thinner and apparently harbors less zooxanthellae and pigment, making it somewhat more transparent than the thicker tissue of older, more interior polyps, thereby allowing the dark green coloration of endolithic algae to show through. The dark green alga was sampled and preliminary identification indicates that it is Ostreobium sp., a green filamentous algae found commonly within the skeletal framework of many hermatypic corals.

While examining these dark borders, it was noticed that the coral tissue here did not appear to be as firmly attached to the skeleton as it did on older polyps. The tissue could easily be lifted

away from the septa. The significance of this observation is unknown. We hypothesize that the dense population of endolithic algae in the skeleton might be affecting the attachment mechanism of the coral tissue, possibly even causing the tissue to recede. However, Dr. Karen Lukas, an expert on such algae, informed us that in her experience, "when a portion of the corallum is exposed, due to death of coral tissue, borers colonize the dead area and Ostreobium is crowded out. It therefore would not be to the advantage of the Ostreobium to induce the recession of the coral tissue." Tissue sections from corals exhibiting these darkened borders were examined by both transmission electron microscopy and conventional light microscopy. No discernable differences between the apparent microstructure of these and normal tissues were observed.

Boring barnacles commonly inhabit heads of living coral. These barnacles often occur in great numbers in coralla of Montastrea annularis, M. cavernosa, and other species on the reef. They bore into the skeletal carbonate just underneath the living tissue. A small ovoid aperture 1-2 mm across is all that is not covered by coral tissue. However, an area approximately 1 cm in diameter of the coral tissue surrounding the aperture is often discolored, apparently due to reduced zooxanthellae density in this tissue. We have often seen areas around the barnacle apertures colonized by filamentous algae. Where this occurs, the barnacles have obviously contributed to the reduction of living coral tissue. A specimen of M. annularis was collected that had boring barnacles present over a recently exposed area of bare corallum. The remnant tissue on the head appeared to be in a retreating phase. It is possible that the presence of these

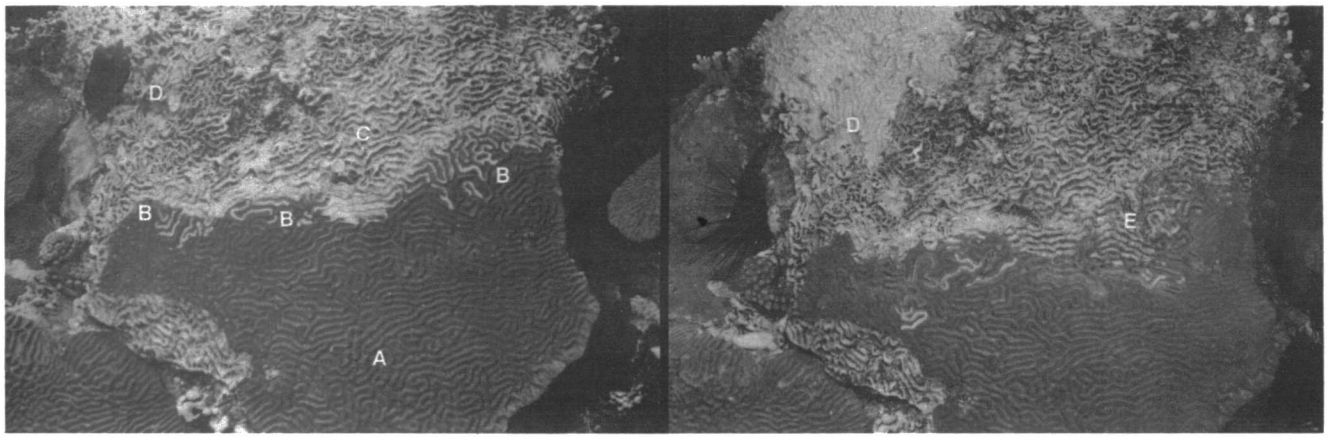


Figure VII-2. September, 1977. CSA Station A8. Necrotic and dying Diploria sp. head. Present on the head are areas of healthy tissue (A), a zone of fatal disease (B), encrusting coralline algae (C), and encrusting fire coral, Millepora sp. (D).

Figure VII-3. December, 1977. CSA Station A8. Approximately 130 cm of Diploria sp. ridges have died since September. Mortality of coral tissue at (E) has spread from the ridges to the valleys, exposing corallum which has subsequently become covered with filamentous green algae. Millepora sp. has grown nearly 2 cm at (D).

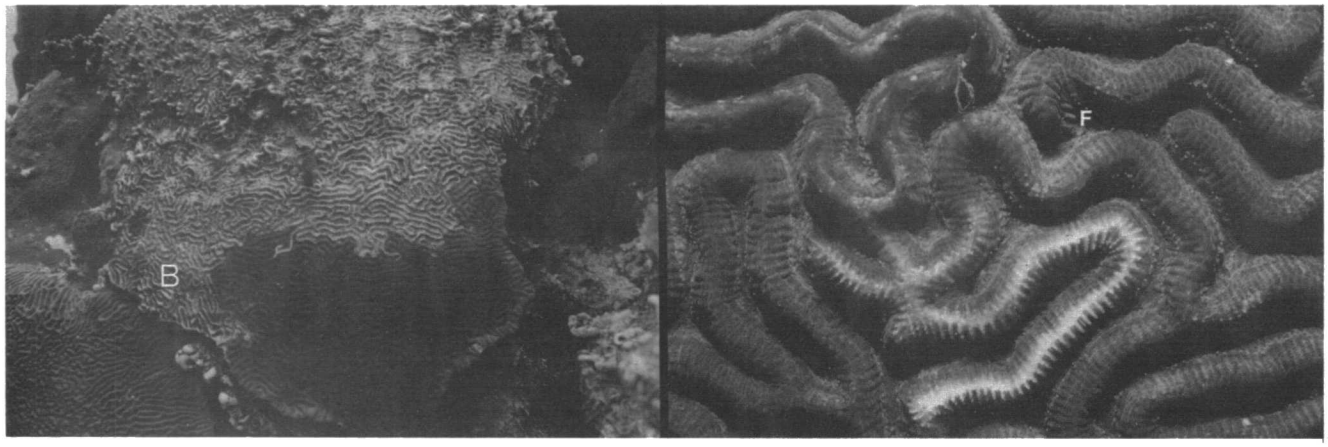


Figure VII-4. May, 1978. CSA Station A8. Substantial mortality has occurred at (B) since December. Millepora sp. has grown 1-2 cm.

Figure VII-5. (Detail on Figures VII-2 - VII-4) CSA Station A8. Necrotic tissue on tops of ridges of Diploria sp. White ridge tops (center) are sites of most recent tissue degradation. As coral tissue disintegrates, the bare corallum is occupied by algae (upper left).

barnacles facilitated the decline of the coral tissue. To what extent the presence of these barnacles results in damage to coral tissue and necrosis is not yet known.

CORALIVORES, BROWSERS, GRAZERS

Coralivores, algal grazers and browsers are important factors affecting coral populations. Coral predators such as fishes of the families Scaridae and Chaetodontidae, the urchin Diadema antillarum, and the the polychaete worm Hermodice carnuculata, are all abundant at the East Flower Garden Bank. A coral crab, Carpilius corallinus, from the East Flower Garden has been observed devouring corals in aquaria. Figures VII-10 and 11 show a before-after sequence demonstrating the destruction of an area of Diploria sp. caused by an unknown coralivore. Figure VII-12 shows a head of Porites sp. which was observed being browsed upon by a Stoplight parrotfish, Sparisoma viride; note the toothmarks left on the corallum. Figure VII-13 depicts a Montastrea annularis head which has been partially destroyed by an unknown coralivore which appeared to have been operating in a distinct "territory." These damaged areas are quickly colonized by algae and epifauna. Substantial areas of live coral cover are consequently lost in a short time due to coralivores. Such areas may or may not be recolonized by corals. There is no doubt that damage inflicted by coralivores is a major factor in reducing live coral cover on the reef.

Grazers and browsers feeding on algae which have colonized exposed areas on coral heads also affect the coral populations. Figures VII-14 through 16 show how these grazers may decimate localized popu-

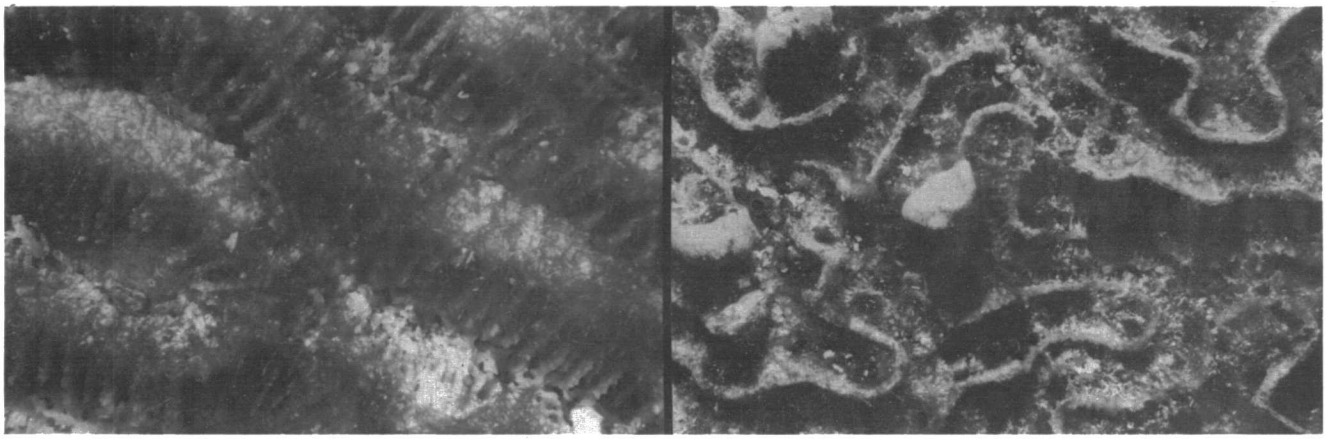


Figure VII-6. CSA Station A8. As necrosis spreads the coral tissue in valleys disintegrates and is replaced by algae. Erosion of corallum septa commences shortly after death of coral tissue. Small remnant of live coral tissue can be seen in one of valleys (left center).

Figure VII-7. CSA Station A8. Occupation of corallum after death of coral by filamentous algae is followed by rapid erosion of corallum surface and invasion by coralline algae (here seen growing as globular masses on top of eroded ridges).

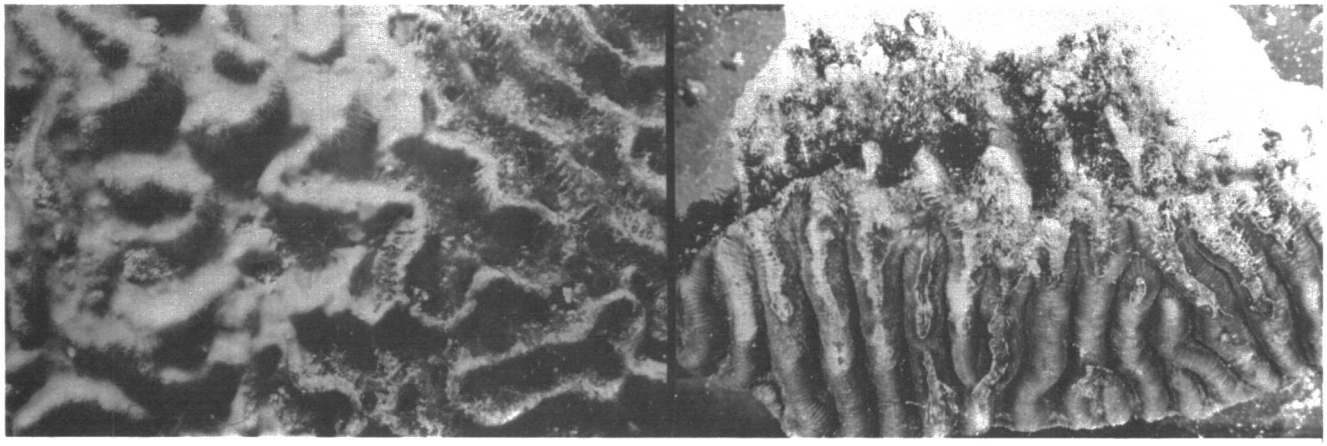


Figure VII-8. CSA Station A8. The algae and eroded corallum may subsequently be overgrown by crusts of fire coral Millepora sp. (upper left).

Figure VII-9. Diploria sp. showing ridge mortality. Algae colonize the ridges left exposed by dying coral tissue.

lations of algae. Figure VII-14 shows a moderate population of filamentous green algae on an exposed corallum in September, 1977. By October, the algal mat had become quite thick. In December, the exposed corallum showed no evidence of any filamentous algae, which apparently had been grazed down by herbivores.

Time lapse 8 mm movies taken of borders between live coral tissue and algal covered reef rock have demonstrated nocturnal grazing activity of hermit crabs (Paguridae) and the sea urchin, Diadema antillarum. These organisms move back and forth along the reef rock close to the living coral, apparently feeding on algae and epifauna. This repeated activity close to the coral can cause incidental damage to coral tissue. We observed one instance where Diadema urchin spines stabbed into coral tissue, causing a wound from which an unknown material oozed. This material ran down the surface of the head in the depressions between the polyps. Another time lapse movie showed a Diadema moving over the tissue of a coral head. This coral exhibited possible stress behavior, viz., failing to expand tentacles for feeding during the observational period. This may have been due to the continued irritation created by the urchin activity. During a night dive at the East Flower Garden, the author observed hundreds of these urchins feeding on the reef, which suggests that numerous instances of coral-Diadema contact occur. The extent of damage caused by these interactions is unknown.

EFFECTS OF HURRICANES ANITA AND BABE

On August 30 and September 4, 1977 the centers of hurricanes Anita and Babe moved through the northwestern Gulf within 125 miles of the

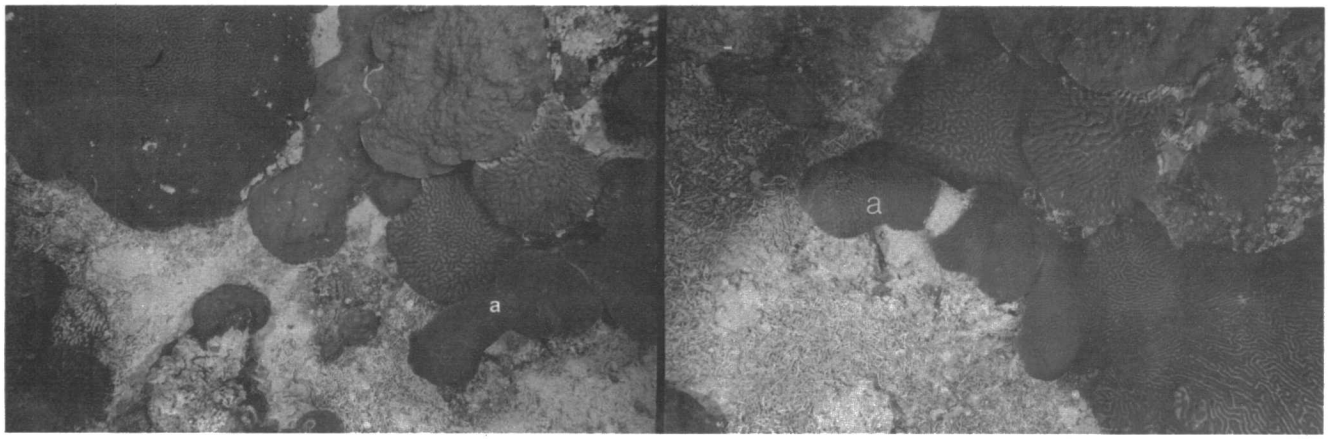


Figure VII-10. CSA Reef Monitoring Site B, September, 1977. Note healthy Diploria sp. head at (a).

Figure VII-11. October, 1977. Same head (a) shown in Figure VII-10 has been severely damaged since September, possibly by a coral eating crab or fish (coralivore).

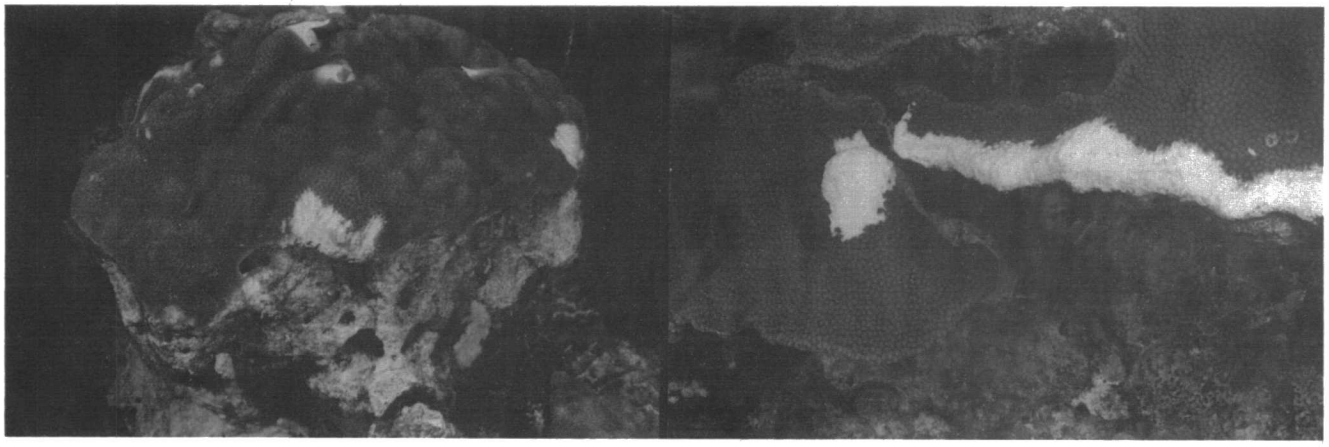


Figure VII-12. CSA Reef Monitoring Site B, May, 1978. Small Porites sp. head exhibiting tooth marks left by a coral eating Stoplight parrotfish (Sparisoma viride).

Figure VII-13. CSA Reef Monitoring Site B, December, 1978. Montastrea annularis severely damaged on margin and knob by presumed coralivores.

Flower Garden Banks. Our September research cruise to the East Flower Garden occurred 2 weeks after these storms. We observed apparent signs of the impact of the heavy surge produced by the storms on the reef. Small coral heads were torn loose and overturned. Many of the photographic station marker floats were wrapped down and under the coral heads. Our long term camera units were all moved from their original positions. The tripod legs of one such unit which was placed in the study sand flat were buried approximately 25 cm in the sand due to heavy sediment transport.

On the two previous cruises to the study area, we had visited a Madracis-soft algae field approximately 200 meters from the sand flat area at a depth of 30 m. Lush growths of soft algae and patches of healthy Madracis finger corals were present (Fig. VII-17). Our post-hurricane visit to this area revealed a drastic reduction in the soft algae population. Some of the Madracis had been broken also. One area which was covered with old Madracis rubble showed ripple marks 15-20 cm high which were not present during the previous cruises. Such ripple marks are indicative of strong water movement.

Perhaps the most striking change we noticed on the reef after the hurricane was the increase in the number of coral heads which had lost all or part of their zooxanthellae populations. These blanched heads were quite obvious to divers swimming over the study area.

Figure VII-18 shows a M. annularis head (BLM Station 22) which lost part of its zooxanthellae. This head subsequently recovered its zooxanthellae, and appeared normal by March, 1978.

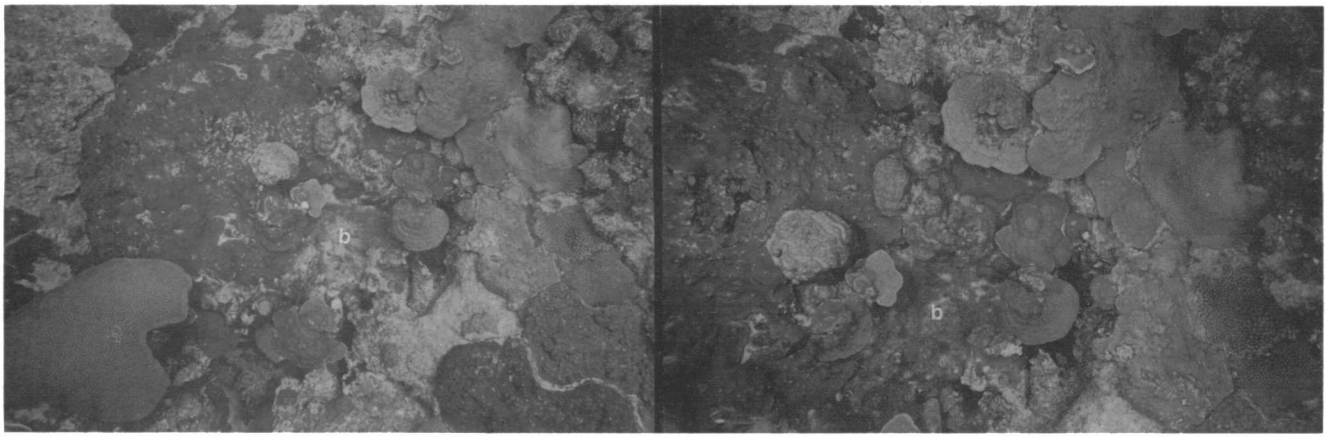


Figure VII-14. September, 1977. Overview of reef area near CSA Monitoring Site B. Note moderate growth of filamentous green algae at (b).

Figure VII-15. November, 1977. Substantial growth of filamentous green algae has occurred at (b) since September, 1977.

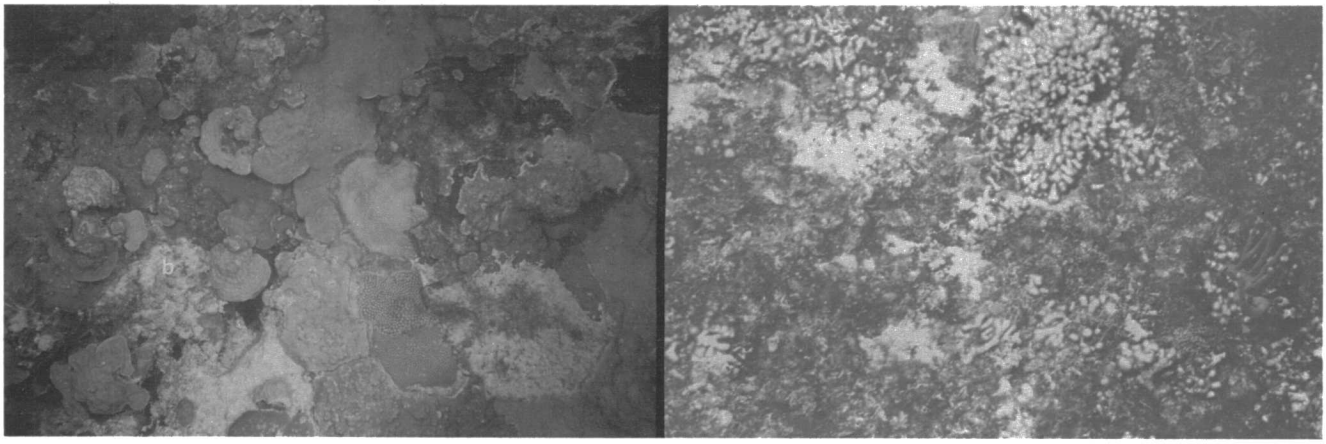


Figure VII-16. December, 1977. Very little algae remains in area around (b). Presumably, these algae have been removed by grazing herbivorous fish and invertebrates.

Figure VII-17. Lush growths of soft algae and Madracis sp. coral growing at 30 m near BLM Monitoring Site.

A 9 month sequence of zooxanthellae loss, partial recovery, then partial mortality on a head of M. cavernosa is illustrated in Figures VII-19 through 21. It is interesting to note that the area of mortality (9th month) occurs where zooxanthellae recovery appeared to be taking place through the fourth month.

Expulsions of zooxanthellae by corals can be caused by stress conditions such as prolonged low salinities, high temperatures and starvation. We do not know the nature of stress which caused the zooxanthellae expulsion at the East Flower Garden.

Recently overturned coral heads were seen following the hurricanes (Figs. VII-22, 23). Most of these were small and were probably only weakly attached to the substratum. One large head of brain coral was seen in the Fall of the year lying on its side with recently living parts of the corallum buried in the sand. Such an occurrence could have been due to the storms, or an anchoring.

MECHANICAL DAMAGE

Man's influence on the East Flower Garden Bank is thus far demonstrable only as mechanical damage. Anchoring on the reef top often results in broken or scarred coral heads (Bright et al., 1978, Continental Shelf Associates, 1978). Abrasion by careless SCUBA divers also causes injury to the corals. Rates and degree of recovery of these damaged corals are difficult to predict. Bak et al. (1977) suggests that recovery depends upon factors such as species of coral, colony size, type of damage (i.e. whether it is to the tissue and skeleton or tissue only), location of damage on the head, and nature of the organisms colonizing the affected area.

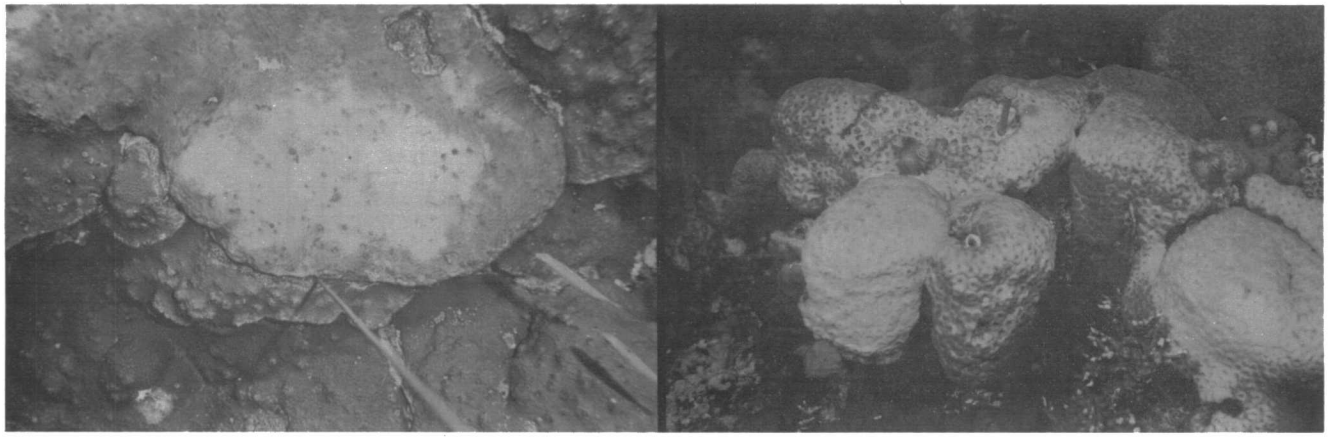


Figure VII-18. September, 1977. BLM Station 22. Montastrea annularis head which has undergone partial zooxanthellae expulsion, presumably due to conditions produced by hurricanes, Anita and Babe. The areas of zooxanthellae loss are white.

Figure VII-19. September, 1977. CSA Station A6. Montastrea cavernosa head exhibiting extensive loss of zooxanthellae. Under stress, reef-building corals frequently expell zooxanthellae. It is believed that the instance of expulsion pictured here may have been triggered by low water temperatures during the passage of two hurricanes in August and September, 1977.

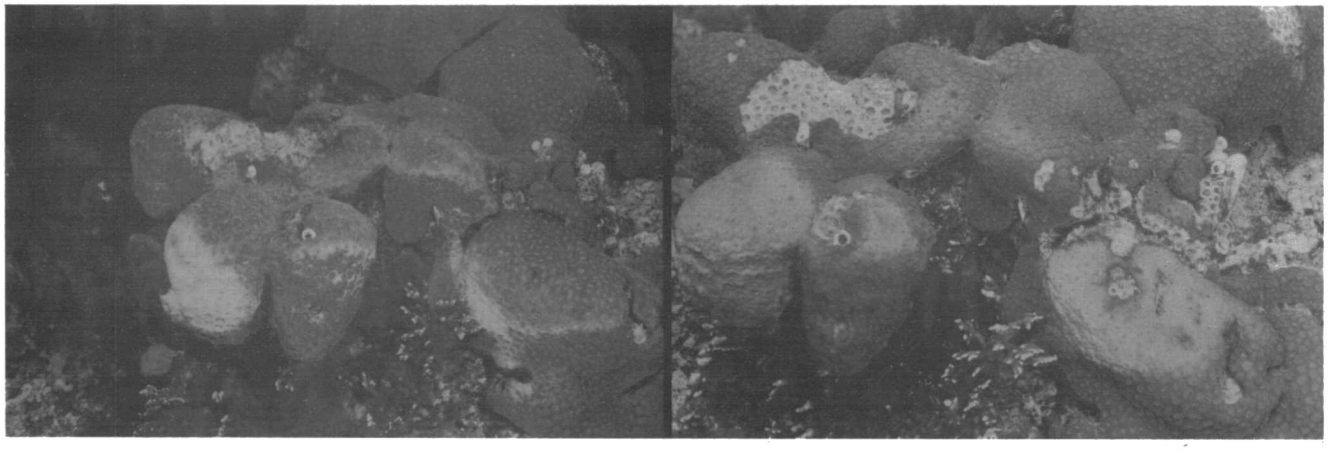


Figure VII-20. December, 1977. CSA Station A6. Substantial recovery of zooxanthellae by Montastrea cavernosa has occurred, resulting in a general "browning" of the tops of the heads which were previously white. Zooxanthellae repopulation is proceeding slower on the sides of the coral head but progressive darkening can be seen in places there as well as on top.

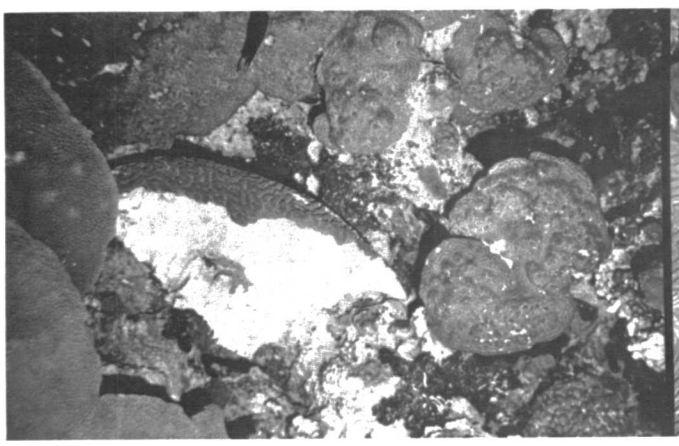
Figure VII-21. May, 1978. CSA Station A6. Zooxanthellae recovery has proceeded until now there are no completely blanched polyps. Mortality has occurred (upper left) since December, 1977, when signs of recovery of this area were apparent.

In an attempt to determine the consequences of abrasion to coral, we artificially damaged a small area of an otherwise healthy head of Montastrea cavernosa. Figure VII-24 shows the area 24 hours after the damage was inflicted by lightly tapping the coral with a hammer. The tissue is completely gone, leaving the white corallum exposed. Figure VII-25 shows the area 8 months later. Filamentous algae and epifauna cover the corallum. Approximately 3 mm of lateral tissue growth (recovery) has occurred during this 8 month period. At this rate, approximately 4-5 years would be required for this area to totally recover.

Mechanical damage to corals at the East Flower Garden is easily detected. However, causes of such damage are often difficult or impossible to determine. Knowledge of coral recovery and/or regression following instances of damage is essential for a proper assessment of the net effects of mechanical damage on coral populations.

COMPETITION FOR SPACE

Competition for living space is quite intense on coral reefs. Different coral species, or occasionally different colonies of the same species, can often be seen in direct competition for available substratum. A distinct band, or zone of competition, of uniform width can usually be seen between the two or more competing colonies (Fig. VII-26). Close examination of this band shows that is usually between 1 and 4 cm wide, and is generally encrusted with filamentous and/or coralline algae. In many cases, the bared coral sclerosepta can be seen, revealing which species is regressing. Lang (1971, 1973) gives a hierarchical list of West Indian coral species in order of



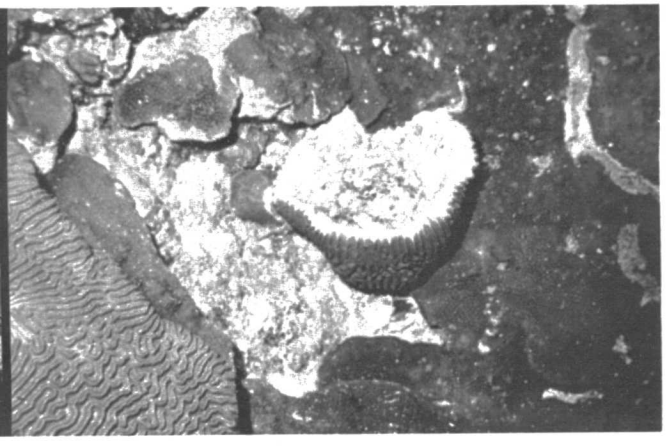


Figure VII-22. September, 1977. BLM Monitoring Site. Small Diploria sp. head presumably broken off by surge during hurricanes Anita and Babe a few weeks earlier.

Figure VII-23. September, 1977. BLM Monitoring Site. Another small Diploria sp. head presumably broken off by surge during hurricane several weeks earlier.

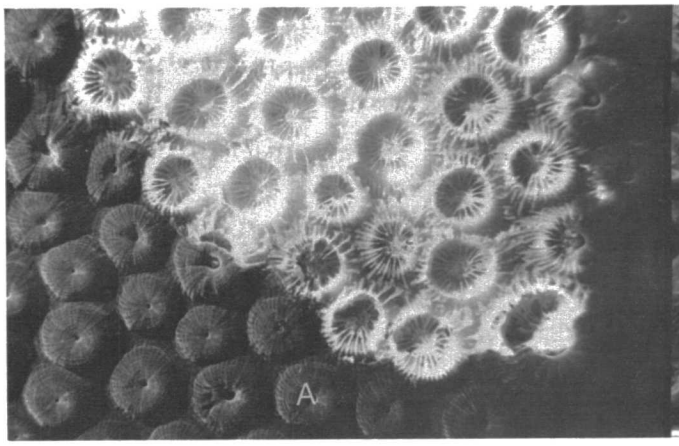


Figure VII-24. August, 1977. BLM Monitoring Site. An artifically damaged area on a Montastrea cavernosa head.

Figure VII-25. March, 1978. Same as Fig. VII-24. Approximately 3 mm of new tissue growth has occurred since August. This is easily seen by comparing position of tissue border relative to polyp (A) for August and March. Note the small polyps along the entire tissue border which are products of extra-tentacular budding.

their competitive dominance over one another. She demonstrates the ability of certain slower growing species such as Mussa angulosa to compete with faster growing coral species by actively attacking them. They do this by extruding mesenterial filaments out over the neighboring corals and digesting their tissues.

Such processes may be involved in the initial stages of the establishment of "competition zones." However, we feel that digestion by mesenterial filaments may not be the only process involved. Our observations show that "competition zones" 4 cm wide exist where Montastrea annularis is the aggressor. The mesenterial filaments of M. annularis appear to extend a maximum of perhaps 1 cm. Therefore, it is concluded that other processes are occurring in the competitive struggle. The nature of the phenomenon suggests that possible chemical inhibitors are produced by the aggressive species which invoke the retreat of the other corals. Research into the biochemistry of the corals is necessary before valid conclusions can be made.

Hildemann et al. (1975) discuss inter- and intraspecific incompatability reactions among corals competing for space. Reactions between species tested range from no reaction to acute interspecific aggression characterized by unidirectional contact killing by the aggressor. Hildemann et al. (1977) propose that competition zones may be the result of cytotoxic macromolecules produced by the aggressor which are capable of degrading neighboring coral tissues. Both modes of aggression are possibly involved in the competitive interactions. Additional behavioral and physiological data are required to elucidate the process by which these competition zones are

established.

Zones of competition are quite commonly seen at the East Flower Garden. However, until the establishment of our selected photographic stations on the reef, we could not determine the rate at which these zones were moving. Observations on the competition zones within our photo stations have shown that the rates at which they migrate over the substratum appear to be quite variable. In cases where a 4 cm wide band covered with coralline algae exists between competing heads (BLM Stations 17 and 20), the progression of the zone appears to have been imperceptible over the past year. Other, generally narrower zones exist (CSA Station A4 and BLM Station 2) where active migration of the band is occurring due to apparent aggression-recession processes underway.

It is probable that the more active the site of competition, the narrower is the zone separating the competing organisms. The advancement of the aggressor may occasionally progress slower than the regression of the retreating species. The activities of browsing and grazing invertebrates and fishes may increase the width of the zones. The width at the band could increase until the distance between the corals is great enough to prevent one from influencing the other. Filamentous and coralline algae colonizing the exposed corallum could further inhibit the advancement of the aggressive species. Such speculation is preliminary. Many more observations are needed to clarify competitive relationships between coral species and between corals and other epibenthic organisms.

Our data show that, at the East Flower Garden, the stony coral *Montastrea annularis* and hydrozoan coral *Millepora* sp. are the two

most "aggressive" species in terms of their advancement over available substratum at the expense of retreating species. M. annularis is the most abundant species on the reef in terms of live coverage. We often observe this species encrusting exposed coralla of other species which are in a retreating phase. Millepora sp. appears to be a more "opportunistic" competitor, occupying coralla exposed by corals retreating due to some other factor (Fig. VII-8). An advance by Millepora sp. of 8-10 cm over an exposed area occurred at BLM Station 1 in a period of 9 months. This is the highest advancement rate observed by us for any encrusting organism during the past year.

CONSTRUCTIVE PROCESSES AFFECTING CORAL POPULATIONS

Coral recruitment and growth obviously offset the destructive processes thus far discussed. Knowledge of the balance between constructive and destructive processes currently acting at the East Flower Garden is of critical importance from a management standpoint.

Encrusting growth is the most commonly observed constructive process on the reef. This occurs when living coral or coralline algae tissue advances in a thin layer over pre-existing substratum, as opposed to massive "upward" growth. Table VII-3 gives data on rates of lateral growth of living coral and coralline algae. Figures VII-27 through 29 show the encrusting advancement of Montastrea annularis over an old exposed Agaricia sp. corallum (CSA Station B11). No active competition appears to be occurring at this station.

Figures VII-30 and VII-31 show encrusting growth of Diploria sp. repairing small dead areas on the colony surface. This appears to be the final stage of repair in a situation similar to the afore-

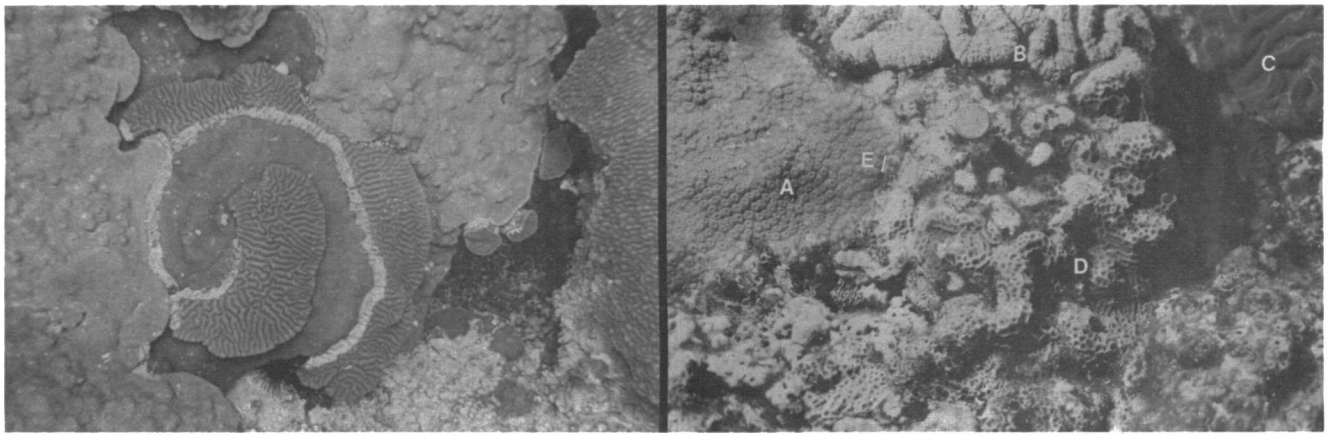


Figure VII-26. BLM Monitoring Site. "Competition zone" approximately 4 cm wide where Montastrea annularis is apparently competing successfully with the brain coral for available substratum. The brain coral tissue regresses along the border of advancing M. cavernosa tissue.

Figure VII-27. September, 1977. CSA Station B11. Montastrea annularis (A), Mussa angulosa (B), Colpophyllia sp. (C) and Agaricia sp. (D) growing in close proximity to one another. The short diagonal line to the right of (E) occupies the same position relative to the coral polyps in all of the photographs shown in Figures VII- 27, 28 and 29.

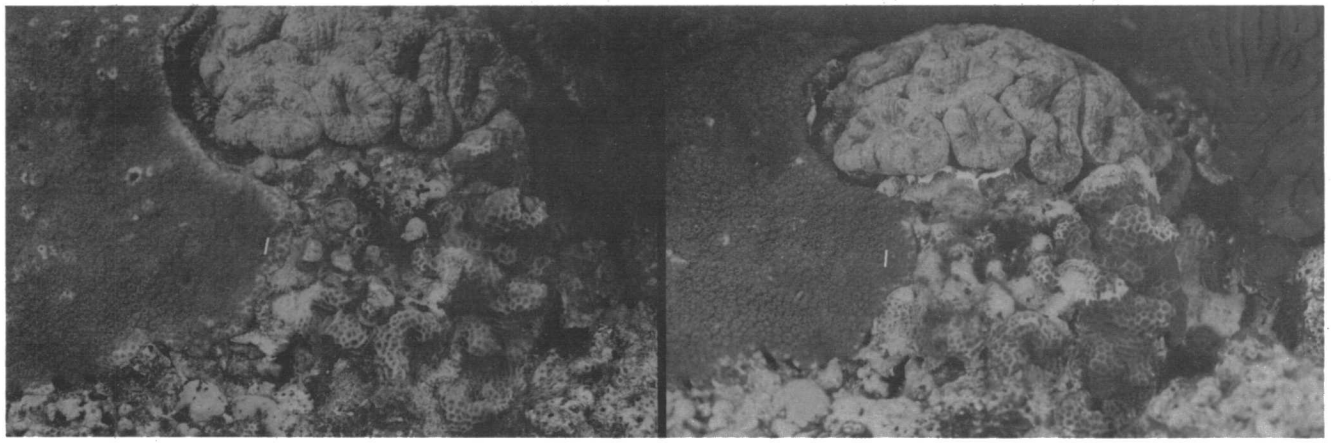


Figure VII-28. December, 1977. CSA Station B11. Since September, some new lateral growth of Montastrea annularis has occurred along its advancing right border (refer back to Fig. VII-27).

Figure VII-29. May, 1978. CSA Station B11. Approximately 2 mm new growth has occurred since December, 1977.

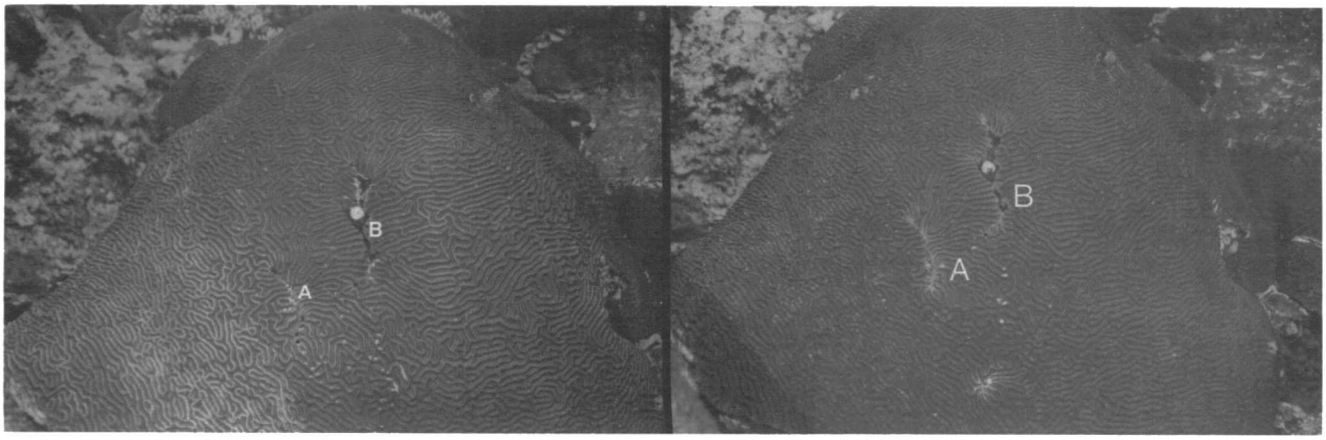


Figure VII-30. September, 1977. CSA Station A7. Healthy Diploria sp. head with nail in area of past mortality. Note holes near (A) and (B), compare with Figure VII-31.

Figure VII-31. May, 1978. CSA Station A7. Six of the small holes at (A) have been completely grown over by healthy coral tissue. No apparent change has occurred at (B).

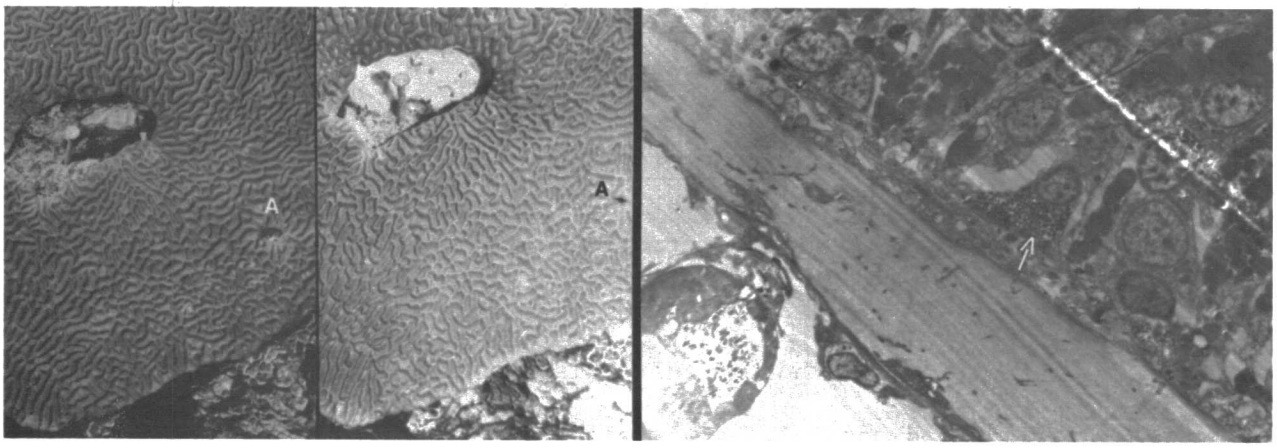


Figure VII-32. September, 1977 - May, 1978. CSA Station B7. Healthy Diploria sp. with nail in area of past mortality. Left photograph (Sept.) shows coralline alga beginning to colonize exposed corallum. Right photograph (May) shows 3-5 cm growth of coralline algae since September. Notice the decrease in size of the small hole at (A).

Figure VII-33. Transmission electron micrograph showing ectodermal, mesogleal and endodermal layers of Montastrea cavernosa tissue. Small ovoid bodies (<1.0μm) present in the ectoderm (at arrow) are possibly pigment granules responsible for the white ectodermal coloration.

mentioned artificially damaged Montastrea cavernosa head (Figures VII-24 and 25), which is in the initial stages of recovery. Bak et al. (1977) state that recovery is more likely when a damaged area is totally surrounded by living tissue, as is the case in the above instances.

Coralline algae (Lithothamnium, Lithophyllum and Lithoporella) are very important encrusting organisms on the reef, adding carbonate substratum and functioning to cement, bind and consolidate loose fragments of skeletal material. Figure VII-32 shows an exposed area on a Diploria sp. head which has been colonized by coralline algae. A 5 cm growth of coralline algae occurred there in 8 months. The coralline algae appear destined to totally cover the exposed area. Studies into the essential growth processes of dominant corals and coralline algae will be pursued within the framework of our long-term monitoring program at the East Flower Garden.

ECTODERMAL PIGMENTS

White ectodermal pigments (formerly called "White Gop") give certain corals a "milky" coloration over all or part of their surfaces. Initially it was thought that this "unnatural"coloration of certain corals could possibly be a manifestation of a pathological condition.

An effort to identify and describe this phenomenon is reported by Bright et al. (1978). Electron (scanning and transmission) and conventional light microscopy, x-ray spectrophotometry and certain chemical tests were employed to describe and identify the white material. Microbial assays were made in an attempt to determine whether

or not bacteria and/or fungi were involved. Time lapse photographs monitoring the behavior of affected heads were taken in the field. Incubation experiments placing affected heads and normal heads adjacent to one another were carried on to test the contagiousness of the agent. Preliminary conclusions were that: (1) the white coloration was due to small (approximately 10 μm diameter) spheres aggregating in botryoidal masses within the mucus or ectoderm of the coral, these spheres contain smaller "granules" of approximately 0.5 μm diameter; (2) the white spheres are organic, not calcuim carbonate; (3) they are neither bacterial, fungal nor algal; (4) the agent is not infectious and (5) the presence of the white material does not alter the behavior of the coral and is probably not pathogenic.

Subsequent investigations have further substantiated these conclusions. Analysis of affected coral heads in certain selected photographic study sites (BLM Stations 9, 14, 16, 17, 20; CSA Station A5) demonstrates that the material had neither spread nor affected the various corals in any way over the 11 month study period.

Kawaguti (1969) reports on pigment cells in the Pacific corals Oulastrea crispata and Lobophyllia robusta. The transmission electron micrographs of these corals reveal small (< 1.0 μm) ovoid bodies which he describes as pigment granules. Figure VII-33 shows what appear to be the same ovoid bodies taken from the ectoderm of an affected M. cavernosa colony from the East Flower Garden.

We now feel that the white material is actually an ectodermal pigment of unknown origin. Communication with various

coral biologists has supported this conclusion. Dr. Phillip Dustan believes that the "White Gop" is an ectodermal pigment which the coral produces as a waste product or protective pigment. Dr. Howard Lasker refers to the "White Gop" on M. cavernosa as a white ectodermal pigment, the intensity of which varies enormously on the same colony or even on single polyps. Dr. Judith Lang also feels that the material in question is a white ectodermal pigment.

Insofar as the supposed white ectodermal pigment is apparently not related to any pathological condition of corals, we prefer to suspend, for now, further observations concerning it.

DISCUSSION

The monitoring study initiated at the East Flower Garden coral reef during 1977-78 is directed toward obtaining a base of quantitative and qualitative information concerning the extent and health of coral populations at the reef. Carefully controlled repetitive determinations generating the same type of information from season to season and year to year will result in an orderly mass of data from which reasonable assessments of the effects of natural and man induced environmental processes can be drawn.

During the first year, we have concluded that approximately 60-65% of the hard-bottom in the vicinity of our BLM reef monitoring site is covered by living hermatypic coral. This figure cannot be considered representative of the entire reef insofar as the BLM monitoring site is near the edge of the reef. It is suspected that live coral cover may be considerably less on the central part of the

reef, where quantitative measurements are yet to be made. At the nearby West Flower Garden reef (Fig. VII-1), similar measurements indicated 34-40% live coral cover on the reef top in 1972. The East Flower Garden is very similar to the West Flower Garden in terms of depth, physiography, hydrography and coral species composition.

Obvious destructive processes affecting live corals at the East Flower Garden include necrosis of coral tissue; mechanical damage by coralivores, browsers, and grazers; massive loss of zooxanthellae and mechanical damage due to hurricanes; anchor and diver caused damage; and competition for space between encrusting organisms.

Necrosis of coral tissue refers to what is usually perceived as a gradual disintegration and regression of the living tissue at the borders of coral colonies. The cause, or causes, of necrosis are not apparent. In many cases there appear to be spatial correlations between the occurrence of necrosis and filamentous or endolithic algae. It is hypothesized that certain algae may secrete chemical substances which induce necrosis in coral tissue, but we have no reliable evidence that this is so. No cases of coral death due to the known coral pathogen Oscillatoria submembranacea (a blue-green alga) (Antonius, 1977) have been encountered at the East Flower Garden.

Whatever the cause, coral necrosis is one of the most important processes resulting in reduction of live coral cover at the East Flower Garden. Measured rates of linear retreat of live coral borders due to necrosis varied from 0.05 cm/mo to 5 cm/mo, with an average of approximately 1 cm/mo. The maximum rate of retreat measured by us at the East Flower Garden (5 cm/mo) is about half the

maximum rate of regression measured by Dustan (1977) for what he calls "plague" at Carysfort Reef off Key Largo, Florida. Dustan's "plague" seems to resemble our necrosis in appearance. Fortunately, most living coral borders at the East Flower Garden are not necrotic . We do not yet have an estimate of the percentage of coral borders which are necrotic.

At the East Flower Garden, mechanical destruction of live coral tissue is attributed to 1. hurricanes which dislodge small coral heads; 2. coral eating fishes (and possibly invertebrates); 3. incidental damage inflicted by browsers and grazers searching for food directly adjacent to live coral tissue borders; and 4. damage by anchors and diver activity.

Mechanical damage by man and storms occurs swiftly and it is unlikely that the act of destruction will be detected during the course of a monitoring study. For this reason, it is nearly impossible to identify the exact cause of supposed manifestations of this type of damage, viz, overturned coral heads and obvious large scars on coral tissue. At present, it can be said that such damage occurs at the East Flower Garden. We cannot, however, define the extent of it on the reef, nor can we speculate on the relative amount of damage caused by storm vs. man. Certainly, the impact of man in this respect has been much less at the East Flower Garden than is the case for shallower, more accessible reefs in the Florida keys (Dustan, 1977).

The destructive impact of coralivores such as the Stoplight parrotfish, Sparisoma viride, may be considerably greater than that currently attributable to man or storms. Such destruction is

more easily observed in progress because of its pervasive and continuous occurrence on the reef. Some of the coralivores appear to work "territories," for a period of weeks or longer. Although our observations of coralivore activities are limited, it is suspected that they are of major importance in the balance between destructive and constructive processes affecting coral populations at the East Flower Garden.

Recovery rates of damaged coral are apparently slow, possibly in the order of several years for a damaged patch of coral 10 cm or so in diameter. It is believed that lateral encrusting growth of a damaged colony is the most important recovery mechanism at the East Flower Garden, although recruitment and establishment of new colonies may play a role.

Lateral coral growth, massive growth and recruitment are logically the constructive processes which compensate for and balance the destructive processes discussed above. We have no information on massive growth and recruitment at the East Flower Garden. Measurements of lateral encrusting growth rates of the major anthozoan corals range from 0.037 to 0.25 cm/mo, with an average of approximately 0.15 cm/mo.

It is felt that the numerical balance between the rate of anthozoan coral tissue regression on the reef due to destructive processes and tissue growth due to constructive processes is the critical measure of reef "health An index of "health" would therefore be G/R=H where G is the rate of lateral tissue growth, R is the rate of lateral tissue regression and H is a value representing "health" of the dominant hermatypic coral population,

and presumably the reef. Where H is greater than one it can be assumed that the percent cover of live hermatypic coral is increasing (healthy). A value of H less than one would indicate a decrease in live coral cover (unhealthy). The complexity of this seemingly simple ratio is apparent when one considers the various elements comprising G and R. G is a function of all of the growth rates of all of the important species of anthozoan corals on the reef, with due consideration for their relative abundances. R is a function of the rates of regression for all of the corals, with due consideration for their relative abundances. These rates will vary with location on the reef, hydrography, season and the nature and rates of processes controlling regression, growth and recruitment of new coral colonies.

One of the objectives of our future efforts at the East Flower Garden will be to devise a feasible methodology for the determination of a numerical index of the "health" of coral populations which will be useful as a management tool. Until such is accomplished, judgements concerning the condition of the reef continue to be somewhat subjective. Nevertheless, on the basis of information gathered during 1977-1978, we have found no evidence that drilling activities in the vicinity of the East Flower Garden have had deleterious effects on the reef communities through the Spring of 1978.

ACKNOWLEDGMENTS

We wish to thank Continental Shelf Associates of Tequesta, Florida and Mobil Oil Company for their cooperation.

TABLE VII-1

Percent Length of Transects Occupied by Indicated Organism or Substratum Type

	Montastrea annularis	*Montastrea cavernosa*	*Diploria* sp.	*Colopophyllia* sp.	*Porites* sp.	*Siderastrea* sp.	*Musa angulosa*	*Madracis* sp.	*Agaricia* sp.	*Millepora* sp.	*Sponge*	*Sand*	*Competition zone*	*Exposed reefrock*	*Exposed reefrock & algae*	*Total live coral cover*	
Transect 1 June, 1977	44.2	2.0	4.2	20.7	3.0	—	1.8	—	2.0	1.0	—	—	—	13.4	7.6	78.9	1. Transect length, 1005 cm. 2. 33 cm Colpophyllia sp. in competition with algae. 3. 10 cm Colpophyllia sp. display mottled area.
Transect 2 June, 1977	26.6	5.5	6.9	2.9	10.6	—	0.75	—	1.0	6.0	—	—	0.75	35.0	4.0	60.2	1. Transect length, 1016 cm. 2. 59.7 cm M. annularis show zooxanthellae expulsion, algal mats on part of head
Transect 3 Sept., 1977	37.6	—	4.3	2.1	3.2	—	3.1	—	—	—	0.2	—	0.8	48.3	0.4	50.3	1. Transect length, 1000 cm. 2. 20 cm Diploria sp. showed white epidermal pigment ("white gop").
Transect 4 Sept., 1977	25.4	4.5	—	2.1	9.0	—	3.2	2.8	0.4	8.6	—	0.6	0.1	41.7	1.6	56.0	1. Transect length, 1000 cm. 2. 25 cm Millepora sp. and 50 cm M. annularis show zooxanthellae expulsion.
Transect 5 March, 1978	39.2	—	12.2	—	4.0	0.6	—	—							4.5	64.4	1. Transect length, 1391 cm.
Transect 6 March, 1978	27.5	1.3	19.9	—	2.0	—	—	2.0	—	4.7	—	10.7	—	32.0	—	57.4	1. Transect length, 1500 cm.
Transect 7 March, 1978	69.0	5.5	3.7	—	0.5	—	—	—	1.3	6.0	—	—	—	11.8	2.1	86.0	1. Transect length, 1495 cm.
Transect 8 May, 1978	27.5	—	10.5	6.7	0.4	1.0	1.0	—	—	—	—	—	—	18.7	34.1	47.1	1. Transect length, 1380 cm.
Transect 9 May, 1978	45.6	—	8.6	2.7	3.5	—	1.1	—	0.3	1.0	—	—	—	26.4	12.6	62.8	1. Transect length, 1500 cm.
Average Coverage	38.0	2.1	7.8	4.1	4.0	0.2	1.2	0.5	0.9	3.6	.02	1.6	0.2	28.7	7.4	62.5	

TABLE VII-2

Linear Tissue Retreat on Selected Coral Heads

Station	Organism	Month (1977-1978)												Total Maximum Linear Tissue Regression	Maximum Rate of tissue Regression (cm/mo)
		JN	JL	A	S	O	N	D	J	F	M	A	M		
BLM-1	Porites sp.				— Total morality of two small heads — 25 cm linear retreat of tissue									25 cm	3.1
BLM-2	Colpophyllia sp.	— 1.0 cm —						2.0 cm						3.0 cm	0.5
BLM-2	Colpophyllia sp.							1.0 cm						1.0 cm	0.125
BLM-5	Diploria sp.	— 0.5 cm —												0.5 cm	0.25
BLM-5	Coralline algae						2 cm							2.0 cm	0.33
BLM-6	Diploria sp.											— 0.5 cm —		0.5 cm	0.25
BLM-8	Montastrea annularis						8 cm							8 cm	1.33
BLM-8	Diploria sp.						3 cm							3 cm	0.5
BLM-8	Porites sp.				— Total mortality of small head 6 cm linear retreat of tissue									6 cm	1.0
BLM-10	Diploria sp.			0.5				0.5 cm						1.0 cm	0.5
BLM-15	M. annularis							1 cm						1.0 cm	0.125
CSA-A4	Diploria sp.						0.5							0.5 cm	0.5
CSA-A6	M. cavernosa							— 3.0 cm —						3.0 cm	0.6
CSA-A8	Diploria sp.						5.0			7.0 cm				12.0 cm	5.0
CSA-A10	Madracis dedactis					0.5 — 0.5 cm —								1.0 cm	0.5
CSA-A11	Diploria sp.					— 1.0 cm —								1.0 cm	0.5
CSA-B10	Diploria sp.					— 1.0 cm —								1.0 cm	0.5
CSA-B15	M. annularis					0.2					0.5 cm			0.7 cm	0.2
CSA-A16	M. cavernosa										1.0			1.0 cm	0.2

TABLE VII-3

Linear Advancement of Tissue on Selected Coral Heads

Station	Organism	Month (1977-1978) JN	JL	A	S	O	N	D	J	F	M	A	M	Total Maximum Tissue Advance	Maximum Rate of tissue Advance (cm/mo)
BLM-1	Millepora sp.								10 cm					10 cm	1.25
BLM-12	Diploria sp.						0.3 cm							0.3 cm	0.05
BLM-16	Montastrea cavernosa			0.2 cm						1.5 cm				1.7 cm	0.2
BLM-17	M. cavernosa										0.3 cm			0.3 cm	0.15
BLM-19	Millepora sp.	0.2 cm			0.2 cm				1 cm					1.4 cm	0.2
CSA-A7	Diploria sp.									0.5 cm				0.5 cm	0.1
CSA-A8	Millepora sp.				0.5		2.0			2 cm				4.5 cm	2.0
CSA-A11	M. annularis						0.2							0.2 cm	0.2
CSA-B2	M. annularis									0.2 cm				0.2 cm	0.04
CSA-B4	Millepora sp.									1.5 cm				1.5 cm	0.3
CSA-B7	Coralline algae									5 cm				5 cm	1.0
CSA-B11	M. annularis				0.4 cm					0.2 cm				0.6 cm	0.2
Artifical mechanical damage	M. cavernosa							0.3 cm						0.3 cm	0.05

or regression of living tissue is evident.

March, 1978: No data.

May, 1978: Millepora has advanced 8-10 cm toward the crest of the knoll. The Millepora has also regained a normal population of zooxanthellae. The two blanched Porites heads appear to be devoid of living tissue. The Millepora has advanced to the edge at the lower Porites head. The small holes on the two dead Porites heads have been attached by boring sponges. The third Porites head still appears quite normal.

Station 2

June, 1977: Two heads of Colpophyllia sp. have grown together. A small Montastrea annularis head is present at the upper margin of the border between the two Colpophyllia heads. A third head of Colpophyllia sp. is also present. At the lower margin of this Colpophyllia head there is a small area occupied by M. annularis. One Colpophyllia head shows evidence of slight blanching of its tissues. Part of this head is dead and the base corallum has been colonized by filamentous algae and epifauna. Calcareous sand has settled on the living tissue of the large Colpophyllia head.

August, 1977: Colpophyllia tissue has regressed approximately 1 cm. Both of these regressing margins are at borders where M. annularis comes in close proximity to the Colpophyllia tissue. The more "aggressive" M. annularis may be killing the Colpophyllia tissue. No other changes are apparent.

September 1977: The Colpophyllia appears to have regressed very little since the August cruise. No other changes are apparent.

March, 1978: No data.

May, 1978: Colpophyllia tissue has regressed approximately 2 cm since the August cruise. However, no advance of the M. annularis colonies onto the exposed Colpophyllia corallum can be detected. The left Colpophyllia head appears to have regressed approximately 1 cm. This is difficult to ascertain because of a slightly different camera angle used in this photograph, which can mislead the observer. The slightly blanched tissue on the Colpophyllia head on the right has not changed significantly since the June cruise.

Station 3

June, 1977: Diploria sp. head has undergone extensive past mortality. Portions of the exposed corallum is colonized filamentous algae. A small Porites colony appears to have been grazed on by predatory fishes or crustaceans, leaving blanched areas on the head.

August, 1977: Diploria head has undergone no apparent change. Knobs of coralline algae are present on exposed corallum. The Porites head appears to have recovered completely.

September, 1977: No apparent change.

March, 1978: No apparent change.

May, 1978: The Diploria head has not regressed since the June cruise, indicating that this colony has stabilized. The

sparseness of cover present on the dead corallum presumably indicates an extensive amount of grazing goes on in this area keeping algae and epifauna levels low.

Station 4

June, 1977: A circular area (∿10 cm diameter) of exposed corallum at the crest of an otherwise healthy knoll of Montastrea cavernosa. This exposed skeletal rock is partially covered by filamentous algae.

August, 1977: No change in extent of dead area. The filamentous algae has apparently been grazed down and some skeletal erosion is apparent.

September, 1977: No apparent change.

March, 1978: No data.

May, 1978: No apparent change. Again, the mortality process appears to be arrested and the living tissue and dead area are at equilibrium.

Station 5

June, 1977: Diploria sp. which has undergone extensive past mortality. Filamentous algae and epifauna cover a large portion of the exposed corallum. A large healthy Diploria sp. head borders the affected colony from above. A small knob of Porites is present. Calcareous algae covers the bare corallum under the "lip" formed where the healthy Diploria colony overhangs the affected one. A worm tube (Spirobranchus gigantous) is visible on the exposed corallum. Holes formed by boring sponges inundate

the exposed corallum.

August, 1977: Slight regression of Diploria sp. tissue (<.5 cm) is evident. There are blanched streaks on the ridges of the coral calices in areas of living tissue. The cause of these streaks is unknown.

September, 1977: No apparent change in the extent of living tissue. Notice that the white streaks present in August are now completely healed. Also, the algae is now almost completely gone. This could be due to grazers or to the passage of hurricanes Anita and Babe through the area just prior to this cruise. Strong water turbulence caused by the storms was possibly involved in the removal of some of this attached algae. Scouring by heavy suspended sediment during the storm periods might also have contributed to this algal removal.

March, 1978: A small area (∿2 cm wide) of what appears to be coralline algae is beginning to cover the exposed corallum.

May, 1978: No apparent change in extent of living tissue. The living portion of the affected Diploria head now has acquired a mottled coloration in several areas. The significance of this coloration is unknown.

Station 6

June, 1977: No data.

August, 1977: Diploria sp. head which has undergone past mortality. Exposed corallum colonized by coralline and filamentous green algae. There appears to be a band of unhealthy tissue approximately 7 cm wide between this bare skeletal area

and normal tissue. Blanched spots and small areas of exposed corallum with attached algae inundate the living tissue in this unhealthy zone.

September, 1977: No perceptible change in the extent of living tissue. The filamentous algae and epifauna appear to be less abundant than in August. Holes in the exposed corallum caused by boring sponges are now quite noticeable. Sediment particles are present on the M. annularis head.

March, 1978: No data.

May, 1978: The variation in camera angle complicates interpretation; however, it appears that some regression (<.5 cm) of Diploria tissue has occurred. Certainly there is a marked increase in the number of blanched areas in the unhealthy zone.

Station 7

June, 1977: Three heads of M. annularis and isolated colonies of Millepora sp. in competition for available substratum.

August, 1977: No apparent change.

September, 1977: No apparent change.

March, 1978: No apparent change.

May, 1978: No apparent change. The corals in this association appear to have been living in equilibrium for this 11 month period.

Station 8

June, 1977: An assemblege of four species of coral, (1) Montastrea cavernosa, (2) M. annularis, (3) Porites sp. and

(4) Diploria sp., all in competition for available living space. No species are in contact with one another. In the case of the M. annularis and M. cavernosa, a band of dead reefrock separates the two. The Porites and Diploria heads are elevated and therefore escape direct contact with other species.

August, 1977: A small Porites knob is starting to lose zooxanthellae in part of the colony. No other changes are apparent.

September, 1977: Several more polyps on the Porites knob have become blanched.

March, 1978: The small Porites knob appears to be dead. Filamentous algae are covering the corallum. The large Porites head shows a band of blanched polyps approximately 1 cm side at the border of its colony. The M. annularis colony shows a regression of living tissue of approximately 8 cm. The exposed skeletal material has been colonized by filamentous algae and epifauna. The border of the Diploria head adjacent to the dying M. annularis also shows a regression of living tissue of approximately 3 cm. This exposed corallum has also been colonized by filamentous algae. The nature of this pattern of mortality suggests an infectious agent or localized mechanical damage. It appears that neither of the two species involved are dying as a result of the others' "aggressiveness."

May, 1978: No apparent change in the extent of living tissue.

Station 9

June, 1977: Montastrea cavernosa head with the white epidermal pigment ("white gop"). An area of past mortality present on the top of the head very similar to Station 4. Filamentous algae and epifauna cover the exposed corallum.

August, 1977: No change in the extent of living tissue, epifauna and filamentous algae are less abundant than during the June cruise.

September, 1977: No apparent change.

March, 1978: No apparent change. This area of past mortality appears to be stabilized.

May, 1978: No data.

Station 10

June, 1977: Large Diploria sp. head with an area of past mortality. Epifauna and algae cover the exposed corallum.

August, 1977: No apparent change.

September, 1977: Slight (<.5 cm) regression of living tissue. Blanched ridges are present on the living tissue of the Diploria colony.

March, 1978: No apparent change in extent of mortality. The blanched ridges however, appear to have recovered.

May, 1978: Approximately 0.5 cm of regression of Diploria tissue has occurred since the March cruise. Blanched ridges on the living tissue have now reappeared.

Station 11

June, 1977: Two colonies of Montastrea cavernosa growing together to form a single head. In this case it appears that the corals are in the process of overgrowing the two exposed areas present on the head. There is an elevated, healthy appearance of the coral tissue along the perimeter of the bare areas. A small pod of healthy polyps is present in the center of an exposed area. The dark polyps are caused by the presence of boring barnacles.

August, 1977: No apparent change.

September, 1977: No apparent change.

March, 1978: No data.

May, 1978: No apparent change.

Station 12

June, 1977: Diploria sp., Mussa angulosa and Montastrea annularis heads growing in competition for space. The M. annularis colony appears to be advancing on both the Mussa angulosa and Diploria colonies. A band of calcareous algae isolates the Mussa angulosa from the Diploria.

August, 1977: One lobe of Diploria appears to be starting to lose zooxanthellae. No other changes are apparent.

September, 1977: The entire large head of Diploria now has a mottled appearance, indicating a reduction in zooxanthellae population. The blanched lobe described on August cruise is now not conspicuous. No other apparent changes have occurred.

March, 1978: The large Diploria head has regained its normal color, indicating the reestablishment of normal zooxanthellae populations. Small Diploria head has advanced 2-3 millimeters onto the exposed skeletal rock. The M. annularis colony appears to be advancing very slowly onto the exposed Mussa angulosa corallum.

May, 1978: No changes apparent.

Station 13

June, 1977: Two colonies of Diploria sp. and one of Colpophyllia sp. growing together. There are two areas of mortality present on the Diploria colonies. One area appears to have existed for some time compared to a freshly killed area. This type of damage appears to be due to coral predators rasping at the tissue and underlying skeletal septa. Another small area of recently damaged tissue is also present.

August, 1977: No change in extent of living tissue. The recently damaged areas described above are now colonized by filamentous green algae.

September, 1977: No apparent change in extent of living tissue. A branch of Millepora sp. has broken off and fallen onto the Diploria tissue.

March, 1978: Damaged Diploria tissue has now recovered. Calcareous algae and a red encrusting sponge have colonized the exposed corallum.

May, 1978: Diploria tissue has died to form a small "island" of living tissue. Diploria tissue appears to have stabilized.

The edge of the more recently damaged head is now smooth and rounded compared to its ragged appearance just after the damage was inflicted.

Station 14

June, 1977: Montastrea cavernosa head with white epidermal pigment ("white gop") growing adjacent to a colony of M. annularis. A large area of algal covered corallum surrounds the marker nail on the M. cavernosa head. Smaller patches of algae surround what appear to be boring barnacles. A blanched edge of one lobe of the M. annularis head is present.

August, 1977: No data.

September, 1977: No apparent change.

March, 1978: No data.

May, 1978: Tissue surrounding boring barnacles appears to have partially recovered. Due to variation in camera angle and lighting, this cannot be definitely determined. Blanched polyps at the edge of M. annularis lobe have recovered their normal coloration. However, just below this area a patch of M. annularis head has lost its color. Again, due to distance from camera, it cannot be ascertained whether this white area is exposed corallum or blanched tissue.

Station 15

June, 1977: Montastrea annularis head with an area of exposed corallum on its surface. Surrounding this patch of bare skeletal rock is a band of polyps 6 to 12 cm wide which are a

milk color compared to the normal brown coloration of the rest of the colony. The bare corallum is covered with filamentous algae and epifauna.

August, 1977: No apparent change.

September, 1977: Polyps along the perimeter of the dead area are blanched.

March, 1978: No data.

May, 1978: Approximately 1 cm of tissue regression has occurred at the perimeter of the dead area, thereby increasing the area of bare corallum.

Station 16

June, 1977: Montastrea cavernosa with white epidermal pigment growing over a knoll of old reefrock, species unknown. Note the rounded, raised edges of the M. cavernosa colony. These are characteristic of an advancing colony border. The exposed reefrock is covered by epifauna and filamentous algae.

August, 1977: No apparent changes.

September, 1977: One to two millimeter advancement of living tissue appears to have taken place.

March, 1978: No data.

May, 1978: Approximately 1 - 1.5 cm growth has occurred.

Station 17

June, 1977: Montastrea cavernosa colony, heavily inundated with the white epidermal pigment ("white gop"), in competition for space with M. annularis, Porites sp. and another M.cavernosa

head. Several areas on the white M. cavernosa head are dark. These are polyps, or parts of polyps,which have a normal, dark coloration. One M. annularis colony has many "unhealthy" patches on its surface. These are all covered with epifauna and filamentous algae. An encrusting red sponge covers two of these patches. Coralline algae covers the bands of exposed corallum between live coral heads. These algae commonly colonize these "competition zones."

August, 1977: No apparent change.

September, 1977: Streaks of blanched polyps appear on a M. annularis head. The origin of these streaks is unknown, but they appear very much like tracks of damaged polyps caused by a grazing coralivore.

March, 1978: No data.

May, 1978: Streaks of blanched polyps on M. annularis colony have recovered their color. M. cavernosa head shows 2-3 mm advancement in area of marker nail. The encrusting red sponge has increased its surface area by several millimeters in all directions, by outcompeting the coral polyps for the available substratum.

Station 18

June, 1977: Area where three Colpophyllia sp. colonies are growing adjacent to one another. One head appears to have white epidermal pigment only in the valleys of the polyps, while another is entirely white. The third colony has a normal dark coloration.

August, 1977: No apparent change.

September 1977: No data. Marker buoy was lost, possibly due to turbulence caused by two hurricanes, Anita and Babe; and the site was never relocated.

Station 19

June, 1977: Montastrea cavernosa in competition with Millepora sp. for available substratum. Area of dead M. cavernosa around marker nail covered by filamentous algae on exposed corallum is quite abundant.

August, 1977: Millepora has advanced 1-2 mm. Filamentous green algae on exposed corallum is quite abundant.

September, 1977: Millepora has advanced 1-2 mm.

March, 1978: Growth of Millepora over the exposed M. cavernosa corallum is quite evident. At least 1 cm growth has occurred since September. The Millepora has grown up adjacent to marker nail. Also, the color of the Millepora appears to be a darker brown now.

May, 1978: No data.

Station 20

June, 1977: Montastrea cavernosa colony exhibiting the white epidermal pigmentation only in the valleys between polyps. Several areas on the colony show exposed corallum. Again, the raised rounded edges of the polyps surrounding this exposed area indicate that recovery by the coral tissue is in progress. A colony of M. annularis borders the M. cavernosa head from

below. There is a band of exposed M. annularis corallum covered with coralline algae between the two species. Observations on the reef commonly reveal a thin veneer of coralline algae growing on "competition zones," 3-5 cm wide, which often exist between living corals vying for available living space. Note the broken branches of Millepora sp. resting on the coralline algae.

August, 1977: No apparent change.

September, 1977: No apparent change.

March, 1978: No data.

May, 1978: No apparent change.

Station 21

June, 1977: No data.

August, 1977: No data.

September, 1977: This site was added during the September cruise. Diploria sp. head recently overturned exposing fresh skeletal material. Heavy water turbulence, probably during the passage of hurricanes Anita or Babe, or boat anchorage are probable causes of the damage. This author feels that storm activity is the more likely cause because no other evidence of anchor scars was seen in the immediate area of the site. Two species of sponges, one possibly Agelas sp., and the other unknown are present. This unknown sponge is the only epifaunal organism growing on the freshly exposed skeletal material. This indicates that this sponge must have grown over the exposed surface quite rapidly.

March, 1978: No data.

May, 1978: The exposed skeletal rock is now totally covered by algae and epifauna. The unknown sponge has grown 1-2 cm since September. The Agelas sp. has apparently deteriorated.

Station 22

June, 1977: No data.

August, 1977: No data.

September, 1977, (Fig. VII-18): This site was added during the September cruise. A large area on a Montastrea annularis head had experienced a massive zooxanthellae expulsion, leaving the polyps totally blanched. Observations on the reef during the September cruise revealed a large number of instances of zooxanthellae expulsion similar to this head. These mass zooxanthellae expulsions presumably are due to the conditions caused by the passage of the two hurricanes through the area.

March, 1978: Complete recovery of zooxanthellae populations within the coral appear to have taken place.

May, 1978: No apparent change. Area of previous zooxanthellae loss now apparently healthy.

Station 23

June, 1977: No data.

August, 1977: No data.

September, 1977: Colpophyllia sp. exhibiting loss of zooxanthellae over much of its surface.

March, 1978: No data. Marker buoy was lost after September cruise. However, this site was located approximately 2 m from Station 22. This author revisited this area on the March cruise and observed total recovery of zooxanthellae by the Colpophyllia colony. Unfortunately, he had no camera with him on this dive.

CSA MONITORING SITE A

Station A-3

September, 1977: The nail marks a *Montastrea cavernosa* head which has suffered partial mortality some time in the past. At the time of marking, all remaining living portions of the coral colony were healthy. The rounded nature of the colony edges indicates that lateral expansion and regrowth are underway.

October, 1977: No discernible change in *Montastrea cavernosa*.

November, 1977: No discernible change in *Montastrea cavernosa*.

December, 1977: No discernible change in *Montastrea cavernosa*.

May, 1978: No discernible change in extent of living *Montastrea cavernosa*. Some apparent recent erosion of exposed corallum.

Station A-4

September, 1977: *Diploria* sp. head exhibiting past mortality. Healthy patches of *Diploria* sp. remain on the top and sides. These patches are expanding laterally in all directions except where they come in contact with an encroaching colony of *Montastrea annularis* to the right of the marker nail. Along this line of contact, the lateral growth of *Diploria* sp. has been arrested and *Diploria* sp. is being killed by the more "aggressive" *Montastrea annularis*. This is a typical occurrence reflecting

natural competition for growing space among the species of coral. A third variety, Porites sp., may be involved in this competitive process.

October, 1977: No data.

November, 1977: Significant changes not apparent.

December, 1977: Close-up photographs indicate that between November and December, mortality of Diploria sp. along the line of competition previously mentioned progressed a maximum of 5 mm. The exposed coral skeleton has become covered with short growths of filamentous algae. No other changes relating to health or mortality of the corals are apparent.

May, 1978: Very slight encroachment of Montastrea annularis onto recently exposed Diploria sp. corallum.

Station A-5

September, 1977: Montastrea cavernosa head with three small areas wherein four to twelve polyps have died (nail is in the largest of these). The head is otherwise healthy. Its "milky" appearance is due to the accumulation of a white organic pigment in the upper epithelial layer of the living tissue. The white pigment is sparse in a spot a few centimeters to the left of the nail. The presence or absence of such pigment does not seem to affect the health or behavior of coral colonies. A small amount of carbonate sediment rests on the top of the coral head.

October, 1977: The carbonate sediment has been removed. No other changes are apparent.

November, 1977: No apparent change.

December, 1977: No apparent change.

May, 1978: Three of the affected areas show signs of recovery presumably due to re-establishment of normal zooxanthellae populations in the polyps. A new area of 4-5 polyps has lost zooxanthellae.

Station A-6 (Figs. VII-19, 20, 21)

September, 1977: *Montastrea cavernosa* head exhibiting extensive loss of zooxanthellae. The areas of zooxanthellae loss are white. Under stress, reef-building corals frequently expel zooxanthellae. It is believed that the instance of expulsion pictured here may have been triggered by low water temperatures during the passage of two hurricanes in August and September 1977.

October, 1977: No discernible change in condition of *Montastrea cavernosa*.

November, 1977: Slight recovery of zooxanthellae by *Montastrea cavernosa* is indicated by the appearance of tan-colored areas where previously the polyps were white.

December, 1977: Substantial recovery of zooxanthellae by *Montastrea cavernosa* has occurred, resulting in a general "browning" of the tops of the heads which were previously white. Zooxanthellae repopulation is proceeding slower on the sides of the coral head but progressive darkening can be seen in places there as well as on top.

May, 1978: Zooxanthellae recovery has proceeded until now there are no completely blanched polyps. The extensively blanched areas present from September to December have recovered only to

the extent of attaining a tan color; though somewhat lighter than the normal brown hue. Several areas of mortality have appeared since December. One area of 8-9 polyps has died, where there were signs of total recovery during the last cruise. Up to 3 cm linear retreat of coral tissue is discernible at one locality.

Station A-7 (Figs. VII 30, 31)

September, 1977: Generally healthy *Diploria* sp. head. Healthy healing of two small patches of dead coral is evident at (A) and (B).

October, 1977: No data.

November, 1977: No apparent change in *Diploria* sp.

December, 1977: No apparent change in *Diploria* sp.

May, 1978: Six of the small holes in (A), each approximately 0.5 cm in diameter, have been completely grown over by the healthy coral.

Station A-8 (Figs. VII 2, 3, 4, 5, 6, 7, 8)

September, 1977: Diseased and dying *Diploria* sp. head. Healthy coral tissue remains on the lower half of the head (A). The zone of tissue necrosis is progressing downward in an irregular band (B) several centimeters wide. Death of living tissue spreads initially along the tops of the ridges of the brain-like convolutions on the surface of the coral. From the ridges the "disease" spreads laterally into valleys, eventually resulting in total mortality and loss of coral tissue in the affected area.

Recently dead areas may soon be occupied by growths of filamentous algae, followed by encrusting coralline algae (C). In this case, the dead Diploria sp. surface with its crusts of coralline algae and other attached organisms is rapidly being covered from the upper left by the encrusting fire coral Millepora sp. (D).

October, 1977: The progress of coral mortality is obvious. There is a substantial increase in the linear amount of diseased ridges which have acquired white coloration due to loss of tissue (approximately 45 cm of ridges experienced mortality between September and October). The Millepora sp. crust has advanced slightly in places (possibly 0.5 cm at one point).

November, 1977: Further Diploria sp. mortality is indicated by the whitest ridges in the advancing band of disease. It is estimated that 40 or so centimeters of ridges experienced mortality between October and November. Filamentous algae have begun to occupy most of the dead ridges but living coral tissue persists in the valleys between ridges over most of the diseased area.

December, 1977: Diploria sp. ridge mortality progressed approximately 45 cm between November and December. Mortality of coral tissue in the area around (E) has spread from the ridges to the valleys. A regression of approximately 5 cm has occurred here since November. The area is now essentially dead and has become covered with a substantial growth of green filamentous

algae. In the region around (D) the healthy Millepora sp. crust has advanced downward nearly two centimeters since November.

May, 1978: Mortality has progressed linearly approximately 7 cm at B since December 1977. Ridge mortality now occupies less than 5 cm. This may be indicative of a retardation of the mortality process. Millepora has expanded laterally 1-2 cm.

Station A-10

September, 1977: An array of at least four species of hermatypic corals; Montastrea cavernosa, Madracis decactis, Porites sp., and Agaricia sp. A crust of Millepora sp. is encroaching on the Montastrea cavernosa head from the upper left. Substantial crusts of purple coralline algae cover many of the dead branches of Madracis decactis. A purple sponge, possibly a species of Ircinia, occupies a depression. The corals, algae and sponges are all living in an intense competition for local growing space. Only Madracis decactis shows signs of recent and rapidly progressing mortality. Past mortality in Madracis decactis is represented. Progressing tissue death can be seen at the tops of twenty of so of the knob-like branches of Madracis decactis (those with white or grayish tops).

October, 1977: Mortality of one Madracis decactis knob has progressed from a circle approximately 0.5 cm in diameter to one nearly 1.0 cm in diameter. Similar advances of mortality can be seen in many of the other necrotic knobs. No apparent change in the health or condition of the other species of coral.

November, 1977: Slight progression of mortality on the same knob and others in the Madracis decactis colony. No apparent changes in other corals.

December, 1977: Area of mortality on the same Madracis decactis knob has increased in diameter to approximately 1.5 cm. Other "diseased" knobs exhibit similar deterioration. No apparent changes in other corals.

May, 1978: No apparent change.

Station A-11

September, 1977: Montastrea annularis and Diploria sp. growing in direct competition for space. Montastrea annularis, the more "aggressive" species, is killing Diploria sp., and is advancing over the dead Diploria sp. corallum (the dead band between the two species is Diploria).

October, 1977: No data.

November, 1977: Substantial fresh killing of Diploria sp. along the band of competition above was observed. The width of freshly killed coral at that point has increased at least one centimeter between September and November.

December, 1977: The area reported as freshly killed in November has acquired a cover of filamentous algae. A freshly killed band of Diploria sp. has appeared (very white coloration). Directly across from this freshly killed area the leading edge of Montastrea annularis appears to have grown slightly and to have added one or two millimeters of skeletal material and living tissue laterally since September.

May, 1978: No apparent change in living coral. Dead perimeter of Diploria sp. which was previously covered with filamentous algae has since been scraped by grazing organisms. The area is now pure white.

Station A-15

September, 1977: Siderastrea sp. head growing in direct competition with Montastrea cavernosa encroaching from above. In this case, Montastrea cavernosa is the more "aggressive" and is overgrowing Siderastrea sp. On the lower right of the Siderastrea sp. head is a lobe which lacks the reddish-brown coloration typical of the rest of the colony. This lobe is subject to periodic burial beneath the shifting coarse carbonate sand at the base of the head.

October, 1977: No apparent changes.

November, 1977: The lower lobe of the Siderastrea sp. head was covered with coarse carbonate sand at the time the picture was taken. This is due undoubtedly to the movement back and forth of sand at the base of the coral heads. No other changes are apparent.

December, 1977: The lower lobe of the Siderastrea sp. head is uncovered. Close examination of this lobe indicated that the lobe was occupied by living coral tissue in the centers of the individual coral calices. No other changes are apparent.

May, 1978: The lobe is now buried again. No other changes are apparent.

APPENDIX

CHAPTER VII

DESCRIPTIONS OF PHOTOGRAPHS, SPECIFIC SUBJECT STATIONS

BLM MONITORING SITE

Station 1

June, 1977: A knoll of dead Montastrea annularis approximately 1 meter across. Millepora sp. is encroaching toward the crest of the knoll from below. Three small mounds of Porites sp. are growing on top of the M. annularis knoll. The exposed corallum is eroded and partially covered with a thin veneer of coralline algae. Leafy and filamentous algae are lacking. A small red encrusting sponge is present on the dead area. Small holes caused by boring sponges (probably Cliona sp.) are present on exposed corallum.

August, 1977: The Millepora has lost a portion of its endosymbiotic zooxanthellae and therefore appears lighter in coloration. Two of the Porites sp. heads also have lost zooxanthellae. The red encrusting sponge is no longer present. No apparent expansion or regression of living tissue has occurred.

September, 1977: Millepora has shown no signs of zooxanthellae recovery. The two blanched Porites heads show small brown areas on the corallum indicating the beginning of zooxanthellae recovery. The right-most Porites head has shown no signs of change since the June cruise. No apparent expansion

Station A-16

September, 1977: No data.

October, 1977: Portion of *Montastrea cavernosa* head exhibiting loss of zooxanthellae in a fashion nearly identical to that described for Station A-6.

November, 1977: Condition similar to that seen in October.

December, 1977: Substantial recovery of zooxanthellae is indicated by the "browning" of a portion of the white area shown in the photograph taken in November.

May, 1978: Blanched polyps have all partially recovered their zooxanthellae, attaining a tan color, similar to those in site A-6. As great as 1 cm tissue regression has occurred.

CSA MONITORING SITE B

Station B-2

September, 1977: *Montastrea annularis* (center) growing in direct competition with *Colpophyllia* sp. At the bottom of the picture, *Colpophyllia* sp. is overgrowing *Montastrea annularis*. Where this occurs, however, the leading edge of *Colpophyllia* sp. is elevated several centimeters above the level at which *Montastrea annularis* is growing. *Montastrea annularis* is the more "aggressive" competitor and will kill *Colpophyllia* sp. where the two species come into contact. This is the case in the upper half of the photograph where the coral colonies are growing in closer proximity to one another.

October, 1977: No data.

November, 1977: A considerable amount of competitive "killing" of *Colpophyllia* sp. by *Montastrea annularis* is apparent along the margin of contact between the two species in the left half of the picture.

December, 1977: The exposed skeletal septa of the recently "killed" band of *Colpophyllia* sp. described for November have been more or less destroyed leaving a surface occupied by carbonate granules and encroaching algae and epifauna.

May, 1978: No apparent increase in mortality. *Montastrea annularis* shows 1-2 mm encroachment upon the eroded *Colpophyllia* sp. head.

Station B-3

September, 1977: Colpophyllia sp. with a dead and eroding area.

October, 1977: No data.

November, 1977: Significant changes are not apparent.

December, 1977: Slight deterioration of living tissue and erosion of septa is apparent. The purple object at the coral border to the right of the nail is a small gastropod shell coated with coralline algae. Frequently these shells contain hermit crabs (Paguridae). In a setting such as this the feeding activities of the snail, or crab, may contribute in some way to the destruction of living coral tissue and to the mechanical disintegration of newly exposed skeletal reefrock. Activities of these organisms may in part account for the rapid crumbling of coral septa after the living tissue dies or is removed.

May, 1978: No apparent increase in mortality. The Colpophyllia sp. borders appear to have stabilized. Note that the borders are rounded and smooth compared to the ragged edges displayed by a regressing tissue border. The red crust has increased in surface area.

Station B-4

September, 1977: Millepora sp. growing on the dead top of a Montastrea annularis head. The Millepora sp. has been attacked by either a crustacean or a fish whose claw or teeth marks can be seen on the upper parts of protuberences in the Millepora sp. colony (most clearly seen in the right half of the photograph

taken in November).

October, 1977: No data.

November, 1977: Significant changes are not apparent. There does not seem to have been further destruction of the Millepora sp. colony by supposed coral-eating organisms.

December, 1977: The previously damaged areas of Millepora sp. have become occupied largely by low growths of filamentous green algae. In places, the algae have spread to an area which in November was occupied by living Millepora sp. tissue.

May, 1978: Millepora sp. has advanced approximately 1-1.5 cm in areas along its border. Very little filamentous algae left on exposed corallum.

Station B-5

September, 1977: Montastrea annularis (below) growing in direct competition with Colpophyllia sp. This zone of dead Colpophyllia sp. between the two living coral colonies is largely covered with filamentous algae and epifauna.

October, 1977: Grazing crustaceans, mollusks or fishes have removed some of the algae and epifauna from the band of dead coral. In the band, red coloration indicates the establishment of an encrusting organism, probably a sponge.

November, 1977: The algae and epifaunal population has recovered slightly in the areas which, in October, were apparently denuded by grazing. The red encrusting organism has spread somewhat.

December, 1977: A rather substantial amount of algae and epifauna have been removed in the dead band of coral to the right of the nail. Again, this is probably due to the activities of mobile grazing invertebrates or fishes. It appears that a certain amount of mechanical damage has been done by the grazers, resulting in the removal of living Colpophyllia sp. tissue and destruction of exposed skeletal septa. This has caused a widening of the so-called zone of competition between the two coral species at the expense of Colpophyllia sp. The apparent spread of the red encrusting organism may be misleading insofar as the removal of overlying algae, epifauna and skeletal rock may have revealed components of the organism occupying subsurface interstices in the coral skeleton.

May, 1978: Colpophyllia sp. borders appear to have stabilized.

Station B-6

September, 1977: Montastrea annularis head exhibiting a considerable amount of past mortality with 20 or more "islands" of surviving living tissue. Numerous individual coral polyps and small groups of polyps have the white coloration which would indicate loss of zooxanthellae.

October, 1977: The numbers of individual polyps with the apparently unhealthy, white coloration has increased since September. Only one additional white polyp in the upper right is clearly detectable. Tufts of filamentous green algae are

present at the centers of some of the white polyps.

December, 1977: No additional white polyps appeared. The intense darkening of the centers of existing white polyps may or may not indicate an advanced stage of ill health. Further observations would be necessary to determine the significance of the blanching of these polyps.

May, 1978: Recovery of the blanched polyps from 18 to 20 and 22 to 24. New areas of blanched polyps have appeared.

Station B-7 (Figure VII-32)

September, 1977: Healthy *Diploria* sp. head with nail in area of past mortality.

October, 1977: No data.

November, 1977: No apparent change.

December, 1977: No apparent change. The decrease in size of the small hole at (A) cannot be clearly interpreted as resulting from growth of the coral. The three photographs were taken from progressively lower angles. Comparison of dimensions between such photographs can be deceptive.

May, 1978: Total surface area of calcareous algae in dead area has increased approximately 675% since December, 1977. This represents a linear expansion of 3-5 cm. Small hole at (A) appears to have decreased in size since December.

Station B-8

September, 1977: *Montastrea annularis* (right) growing in

direct competition with Diploria sp. Montastrea annularis is encroaching on Diploria sp. from below. The band of dead skeletal rock is Diploria sp.

October, 1977: No data.

November, 1977: The band of dead Diploria sp. skeletal rock has increased in width since September. Where maximal deterioration of Diploria sp. tissue occurred, the band of dead skeletal rock increased in width by up to 1 cm.

December, 1977: Further increases in the width of the band of dead Diploria sp. skeletal rock are apparent; up to 1.5 cm since November.

May, 1978: No apparent change in extent of living coral tissue. Algae and epifauna growing on competition zone have been grazed down since December, 1977.

Station B-9

September, 1977: Two colonies of Diploria sp. have grown together. A band of dead skeletal material now exists between them, composed of remains of parts of both colonies. Recent deterioration is indicated at the border of living tissue of the colony on the right. A red encrusting sponge is growing along the line of contact between the two heads.

October, 1977: No data.

November, 1977: Deterioration of living tissue along the border appears to have stopped. Instead, there is evidence of healing of coral tissue and even some incipient regrowth laterally. Such is indicated by the "sharpness" of the border

and the presence of translucent flaps of living tissue bridging gaps over valleys and depressions.

December, 1977: The incipient regrowth along border appears slightly more substantial; the flaps of new tissue are less translucent and there are "hints" of new calcium carbonate deposition beneath the new tissue.

May, 1978: Little or no lateral expansion of border, but defin e signs of stabilization (i.e., borders smooth and rounded) have occurred. The tissue border is elevated, possibly indicating further deposition of carbonate. Encrusting organism (probably Millepora sp., sponge or coralline algae) has established on left Diploria sp.

Station B-10

September, 1977: Small remnant of a Diploria head being overgrown by three colonies of Montastrea annularis. New mortality in Diploria sp. is indicated by the whiter marginal bands at the edge of the colony to the left and right of the nail and on its upper right over-hanging lip. When the nail marker was driven the thin Diploria sp. head was split. The fracture can be seen as a white line crossing the colony from its edge near the nail to its lip in the lower right.

October, 1977: No data.

November, 1977: The areas of Diploria sp. described as "new mortality" in September, 1977 have been overgrown with filamentous algae and epifauna. The upper right lip of the colony has suffered substantial further mortality,

the dead marginal band has increased in width by approximately 1 cm. The crack in the Diploria sp. head has partly healed. Close visual observation indicated that places along the fissure had been bridged by new coral tissue.

December, 1977: Further bridging of the crack in the Diploria sp. head by living tissue was observed.

May, 1978: Signs of zooxanthellae expulsion (blanching) evident at site of fissure and along approximately 1.5 cm of a polyp valley. No other apparent change in coral tissue.

Station B-11 (Fig. VII-23, 24, 25)

September, 1977: Montastrea annularis (A), Mussa angulosa (B), Colpophyllia sp. (C) and Agaricia sp. (D) growing in close proximity to one another.

October, 1977: No data.

November, 1977: The Montastrea annularis colony has grown laterally toward the nail approximately 4 mm distant, adding a new line of polyps to the colony near (E). The short diagonal line to the right of (E) occupies the same position relative to the coral polyps in all of the photographs shown from the survey.

December, 1977: Additional lateral growth of Montastrea annularis has occurred along its advancing right border. The mouths of several very small new polyps can be seen as small brown dots on the white background of the growing border. The white appearance of the new growth reflects the absence

of zooxanthellae in the tissue between the centers of the polyps. The newly deposited white calcium carbonate skeletal material shows a whitish appearance. As the new tissue acquires its population of zooxanthellae its color will change to that of the rest of the colony.

May, 1978: Approximately 2 mm new Montastrea annularis growth. White polyps described on last cruise have acquired more zooxanthellae, gaining a darker coloration.

Station B-15

September, 1977: Montastrea annularis head which is dying from the top downward. A broad brown band bordering the dying edge of the colony contrasts sharply to the "milky" appearance of the rest of the colony. We don't know the physiological significance of the brown band. However, it represents the absence of a white epithelial pigment which gives certain corals the "milky" appearance mentioned above.

October, 1977: The condition of Montastrea annularis is basically the same as described for September, 1977. Because of the difference in framing of the photographs taken during September and October nothing can be said concerning the progress of coral mortality.

November, 1977: Further slight deterioration and death of coral tissue is evident generally all along the dying edge of the Montastrea annularis colony. It is estimated that, on the average, the border of living tissue has retreated 1 to 2 millimeters, if that much.

December, 1977: Slight deterioration in *Montastrea annularis* can be seen along the border of the living tissue.

May, 1978: Less than 5 mm regression of coral tissue has occurred at the bottom and to the right of marker nail.

CHAPTER VIII

HYDROCARBONS AND TRACE METALS IN MACRONEKTON AND *SPONDYLUS*

PART ONE

HEAVY MOLECULAR WEIGHT HYDROCARBONS IN MACRONEKTON AND *SPONDYLUS* SAMPLES

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INTRODUCTION

This project was undertaken to determine the concentration and distribution of heavy molecular weight hydrocarbons in macronekton and Spondylus samples from selected topographic features of the South Texas OCS. As there is relatively little information available on the hydrocarbon content of these marine organisms, the data obtained forms a unique data base for evaluating the effects of petroleum exploration and production on macronekton and Spondylus from the study area.

Samples for these studies consisted of macronekton (red and vermilion snappers) from the East Flower Garden Bank, Ewing Bank and Sonnier Banks and of Spondylus from the East Flower Garden Bank and 18 Fathom Lump. The analytical methods used in our laboratories were based on the hydrocarbons methodology as outlined by BLM; our methods are detailed in the following section. Interpretation of data was based on our previous experience (Giam et al., 1976; Farrington et al., 1972; Farrington et al., 1976) and on the report of Clark (1974).

MATERIALS AND METHODS

MATERIALS[1]

Solvents were Mallinckrodt Nanograde[R] and were used as received or redistilled when required. Silica gel (Woelm, 70-230 mesh) and

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[1] Trade names of reagents, solvents and equipment, and the suppliers are included to facilitate recognition by interested readers of what we use; there is no implication that these are solely recommended.

Aluminum Oxide Woelm Neutral (Activity Grade 1) were activated at 200°C for at least 24 h before use. Hydrocarbon standards were obtained from Analabs and Polyscience Co.

INSTRUMENTATION

A Hewlett-Packard 5830A gas chromatograph (GC) and a Varian 3700 equipped with dual flame ionization detectors and programmable integrators were used. They were equipped with 30 to 50 m OV-101 or SE-30 WCOT glass capillary columns. The injector was at 270°C and the detector at 280°C. The column oven was temperature-programmed from 70 to 270°C at 3°C/min.

PROCEDURE

Background Reduction.

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

gas chromatography. If any impurities were present, rinsing was repeated as needed to obtain an acceptable blank. Glassware checks accompanied each sample run and procedure blanks were performed at frequent intervals. Procedure blanks constituted approximately 10% of the total analyses.

Extraction and Saponification of Tissues.

Approximately 100 g of tissue were used for all analyses. When possible, a minimum of five organisms or portions thereof was used per analysis to minimize the natural variability of hydrocarbon content in conspecifics. Each sample was macerated and the wet weight determined. An aliquot of the sample was then placed in a tared beaker and dried at 60°C until a constant weight was obtained. In this manner, the wet and dry weights of the sample were obtained. The remainder of the sample was saponified.

Saponification was conducted by refluxing the sample with 0.05 g KOH/g tissue in approximately 50 ml methanol/100 g tissue. Saponification was continued until the tissues were digested. After the completion of digestion, an equal volume of purified water was added to the mixture. The mixture was then refluxed overnight. Upon completion of hydrolysis, the mixture was diluted with an equal volume of a saturated NaCl solution. The mixture was then extracted three times with n-pentane. The volume of n-pentane used for each extraction was equivalent to the volume of methanol initially used in the saponification. The n-pentane fractions were then combined and washed with an equal volume of water. The solvent was removed

from the pentane extract (for weight determination) prior to column chromatographic separation.

Column Chromatography.

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

Gas Chromatographic Separations.

Each eluted fraction obtained from the column chromatographic separation was quantitatively dissolved in a small volume of iso-octane for injection into the GC. A WCOT glass capillary column (30-50 m) of OV-101 or SE-30 was used for the analyses. The column resolved n-C_{17} from pristane and n-C_{18} from phytane with a resolution (R) of approximately unity, where

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

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

d is the distance between apices.

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

Gas Chromatography-Mass Spectrometry (GC-MS).

Aliquots of extracts from 10 percent of the GC samples were analyzed by GC-MS. The runs were made by L. Burchfield of the Center for Trace Characterization. Since the concentrations of components were very low (often near the limit of detection of GC-MS), only major components found in gas chromatograms were identified.

The analyses were performed with a Hewlett-Packard 5982A dodecapole mass spectrometer interfaced to a 5710A gas chromatograph. This GC-MS system was supported with a 5933A Data System, a Tektronix 4012 CRT terminal, a Tektronix 4631 Hard Copy Unit, and a 15,000 spectra reference library stored on a single disc (Aldermaston).

Capillary columns coated with SP-2100 (25 m) were used in the GC. Helium was used as the carrier gas. All samples were run in the splitless mode with injector flush occurring 50 s after injection;

the injector temperature was 300°C. The temperature program was held at 80°C for 4 min after injection and then raised at 4°C/min to 270°C. The column effluent was taken through a transfer line at 300°C into the ion source producing a pressure of 6×10^{-6} torr. The source temperature for all runs was 185°C ± 10°C. The mode of ionization was electron impact using a beam of 70 eV electrons at a current of approximately 200 μa. Mass range was scanned from 50 to 500 atomic mass units (amu) at a rate of 162 amu/sec.

The total ion chromatogram for each sample was permanently stored on auxillary discs. The spectra were background-subtracted where necessary. Major sample components which appeared in both GC and GC-MS were identified. Some minor sample components were not identified due to poor signal-to-background spectra. The electron-impact spectra of individual components were permanently stored on disc for comparison with library spectra or for other uses. Individual spectra from data files were compared: (1) by computer with spectra included in the Aldermaston Library on disc using the "search" routine; (2) with reference spectra run on our instrument; and (3) with the "Eight Peak Index of Mass Spectra" (Mass Spectrometry Data Center).

RESULTS

ANALYTICAL PROCEDURES

The analytical methods used for this study were essentially those outlined by the BLM. Excellent procedure blanks (≤0.01 ppm) were routinely obtained. (See Giam and Wong, 1972 and Giam *et al.*, 1975 for a detailed discussion of decontamination procedures.) Recovery

studies were performed with the BLM reference mixture (Table VIII-1) and with our own standards; the results are presented in Table VIII-2. The limit of detection for our procedure was $\leq$0.001 ppm. The capillary columns used in these studies yielded excellent resolutions, as shown in Figure VIII-1. The GC-MS data yielded confirmation of the major aliphatic hydrocarbons. No aromatic hydrocarbons were detected by GC or GC-MS.

ANALYSIS OF MACRONEKTON

The results of the analyses of muscle, liver and gonad tissue from the six macronekton samples received are detailed in Tables VIII-3 to VIII-5 as total concentration of alkanes, percent distribution of *n*-paraffins, the levels of pristane and phytane, the ratios of pristane/phytane, pristane/C_{17}, phytane/C_{18} and the CPI ratios. Total *n*-paraffin concentrations varied from <0.001 to 1.27 ppm in muscle, from 1.84 to 19.27 ppm in liver and 0.67 to 27.89 ppm in gonads. As in previous studies, the C_{15} and C_{17} *n*-alkanes were the dominant *n*-paraffins. Pristane was present in all samples, with a range of 0.01 to 12.96 ppm. Phytane was present in all but one sample at 0.01 to 2.50 ppm. The pristane/phytane ratio varied from 2.0 to 55.0. The pristane/C_{17} ratio ranged from 1.5 to 7.5 while phytane/C_{18} was from 0.3 to 2.3. The CPI_{14-20} varied from 1.6 to 18.9 and the CPI_{20-32} was 1.1 to 1.6. No aromatic compounds were detected.

ANALYSIS OF *SPONDYLUS*

The results of the analyses of the five *Spondylus* samples received are detailed in Tables VIII-6 to VIII-8. Only 3 of the samples

TABLE VIII-1

COMPOUNDS AND PEAK REFERENCE NUMBERS OF BLM REFERENCE MIXTURE

1. Naphthalene
2. 1-Methylnaphthalene
3. Biphenyl
4. 1,3-Dimethylnaphthalene
5. Acenaphthene
6. C_{15}
7. Fluorene
8. C_{16}
9. 9,10-Dihydrophenanthrene
10. C_{17}
11. Pristane
12. Phenanthrene
13. $C_{18:1}$
14. C_{18}
15. Phytane
16. C_{19}
17. 3,6-Dimethylphenanthrene
18. 5α-Androstane
19. $C_{20:1}$
20. C_{20}
21. Pyrene
22. C_{21}
23. C_{22}
24. Nonadecylbenzene
25. C_{26}
26. C_{28}
27. 5α-cholestane
28. C_{30}
29. C_{29}

TABLE VIII-2

PROCEDURAL RECOVERY[1] OF ALIPHATICS AND AROMATICS

COMPOUND	MEAN RECOVERY (%)
n-Pentadecane (C_{15})	78 ± 17
n-Hexadecane (C_{16})	84 ± 12
n-Heptadecane (C_{17})	79 ± 11
Pristane (Pr)	80 ± 11
1-Octadecene ($C_{18:1}$)	69 ± 16
n-Octadecane (C_{18})	79 ± 10
Phytane (Py)	80 ± 12
n-Nonadecane (C_{19})	78 ± 11
1-Eicosene ($C_{20:1}$)	72 ± 13
n-Eicosane (C_{20})	82 ± 11
n-Uncosane (C_{21})	80 ± 11
n-Docosane (C_{22})	81 ± 10
n-Hexacosane (C_{26})	79 ± 20
n-Octacosane (C_{28})	80 ± 13
n-Triacontane (C_{30})	80 ± 17
n-Dotriacontane (C_{32})	92 ± 7
5α-Androstane	82 ± 13
5α-Cholestane	79 ± 14
Naphthalene	51 ± 39
1-Methylnaphthalene	64 ± 33
1,3-Dimethylnaphthalene	80 ± 27
Biphenyl	78 ± 21
Acenaphthene	85 ± 18
Fluorene	81 ± 22
9,10-Dihydrophenanthrene	91 ± 12
Phenanthrene	84 ± 18
3,6-Dimethylphenanthrene	70 ± 13
Pyrene	47 ± 24
Nonadecylbenzene	79 ± 17

[1]Recovery of hydrocarbons subjected to all steps in the analytical procedure in the absence of biota; 20 analyses were performed.

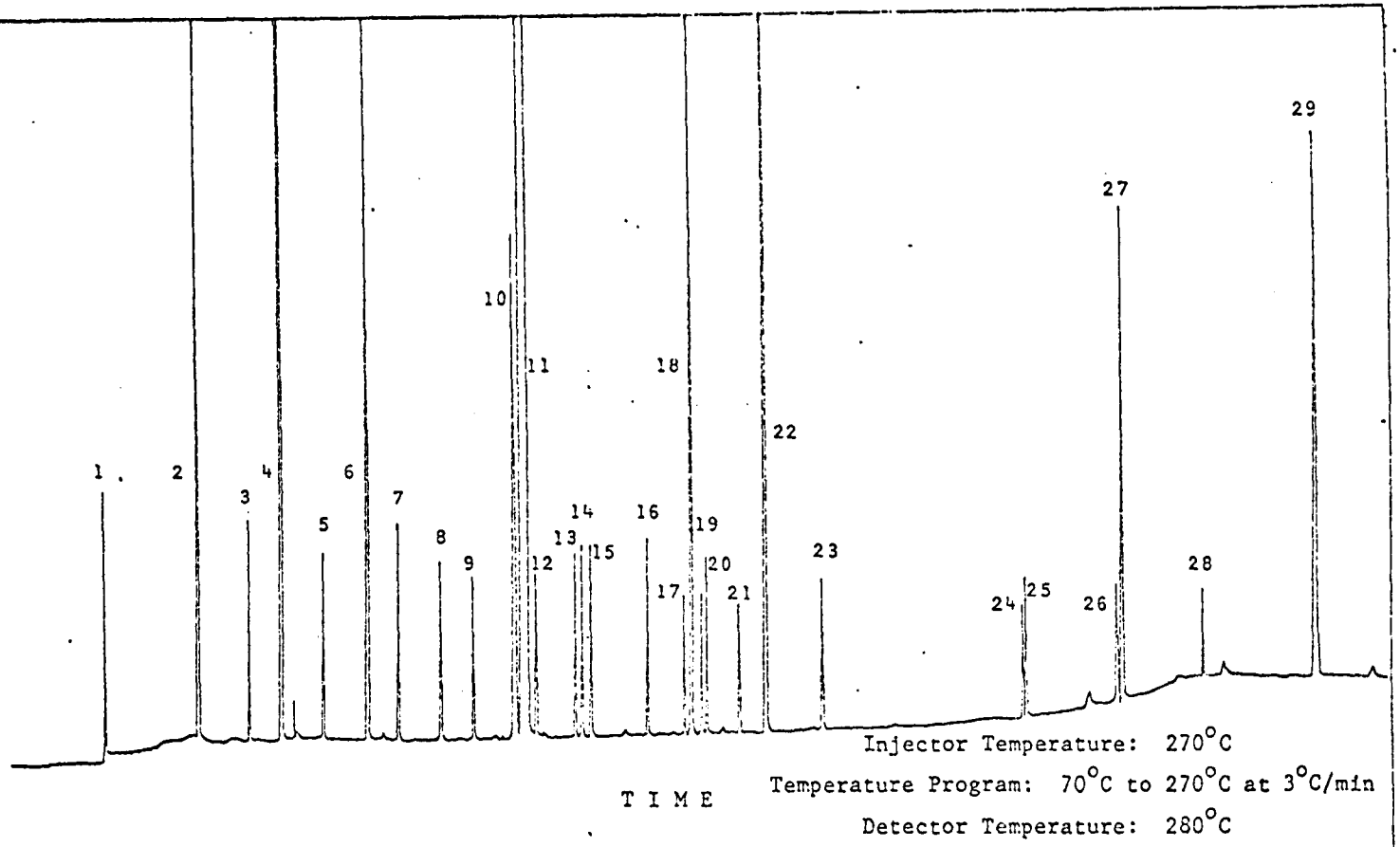

Figure VIII-1. Our Gas Chromatogram of BLM Reference Mixture on a 30-m OV-101 WCOT Column. (See Table VIII-2 for compound identification.)

TABLE VIII-3

Organs and Individuals Analyzed in Macronekton from the South Texas Topographic Features Study (1977)

Banks	Code	Species	Organ Used [a]	# of Individual Fish
East Flower Garden	AMGA→E-M[a]	Red snapper *Lutjanus campechanus*	M	5
	AMGA→E-L		L	5
	AMGA→E-Gd		Gd	5
	AMGF→G-M	Vermilion snapper *Rhomboplites aurorubens*	M	2
	AMGF→G-L		L	2
	AMGF→G-Gd		Gd	2
Ewing	AMGH→L-M	Red snapper *Lutjanus campechanus*	M	5
	AMGH→L-L		L	5
	AMGH→L-Gd		Gd	5
	AMGM→Q-M	Vermilion snapper *Rhomboplites aurorubens*	M	5
	AMGM→Q-L		L	5
	AMGM→Q-Gd		Gd	5
Sonnier	AMGS→W-M	Red snapper *Lutjanus campechanus*	M	5
	AMGS→W-L		L	5
	AMGS→W-Gd		Gd	5

TABLE VIII-3 CONT'D

Banks	Code	Species	Organ Used [a]	# of Individual Fish
	AMGX→ANGA-M[a]	Vermilion snapper *Rhomboplites aurorubens*	M	4
	AMGX→ANGA-L		L	4
	AMGX→ANGA-Gd		Gd	4

[a] M = muscle; L = liver; Gd = gonad.

TABLE VIII-4

Concentration of Alkanes[1] in Macronekton from the South Texas Topographic Features Study (1977)

Banks	Code	Species	Sample Wt. (g)	Conc. in ppm (μg/g dry wt.)
East Flower Garden	AMGA→E-M[a]	Red snapper *Lutjanus campechanus*	99.0	0.01
	AMGA→E-L		26.1	5.51
	AMGA→E-Gd		26.1	18.38
	AMGF→G-M	Vermilion snapper *Rhomboplites aurorubens*	119.3	0.03
	AMGF→G-L		2.0	9.89
	AMGF→G-Gd		3.2	1.42
Ewing	AMGH→L-M	Red snapper *Lutjanus campechanus*	109.0	0.20
	AMGH→L-L		56.1	2.77
	AMGH→L-Gd		51.3	8.40
	AMGM→Q-M	Vermilion snapper *Rhomboplites aurorubens*	99.6	0.41
	AMGM→Q-L		12.3	5.94
	AMGM→Q-Gd		23.1	5.68
Sonnier	AMGS→W-M	Red snapper *Lutjanus campechanus*	110.5	0.15
	AMGS→W-L		14.7	10.36
	AMGS→W-Gd		4.1	40.34

TABLE VIII-4 CONT'D

Banks	Code	Species	Sample Wt. (g)	Conc. in ppm (μg/g dry wt.)
	AMGX→ANGA-M[a]	Vermilion snapper *Rhomboplites aurorubens*	101.2	2.12
	AMGX→ANGA-L		10.3	28.60
	AMGX→ANGA-Gd		8.9	42.71

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

[a] M = muscle; L = liver; Gd = gonad.

TABLE VIII-5

Percent Distribution of n-Paraffins in Macronekton from the South Texas Topographic Features Study (1977)

STATION	East Flower Garden Bank	East Flower Garden Bank	East Flower Garden Bank	East Flower Garden Bank	East Flower Garden Bank	East Flower Garden Bank
SAMPLE CODE	AMGA→E-M	AMGA→E-L	AMGA→E-Gd	AMGF→G-M	AMGF→G-L	AMGF→G-Gd
CARBON NO.						
14	-	2.5	1.2	-	1.2	-
15	-	66.1	47.2	-	15.0	11.5
16	-	3.4	3.8	-	13.1	10.7
17	-	11.3	32.2	-	16.5	25.0
18	-	1.2	2.8	-	7.2	14.1
19	-	1.0	4.7	-	4.4	8.8
20	-	0.4	2.1	-	2.3	4.9
21	-	0.5	1.7	-	2.4	4.0
22	-	0.5	1.0	-	3.0	4.3
23	-	3.7	-	-	5.6	4.6
24	-	1.0	0.8	-	5.0	4.5
25	-	2.0	0.9	-	8.0	4.8
26	-	-	-	-	5.9	2.8
27	-	1.5	0.4	-	5.2	-
28	-	1.7	0.4	-	3.5	-
29	-	-	0.6	-	1.7	-
30	-	2.3	0.2	-	-	-
31	-	-	-	-	-	-
32	-	0.9	-	-	-	-
Total paraffin	-	4.40	10.81	-	6.15	0.67
Pristane	0.01	1.07	7.42	0.02	3.63	0.72
Phytane	-	0.04	0.15	0.01	0.11	0.03
Pr/Py	-	26.8	49.5	2.0	33.0	24.0
Pr/C_{17}	-	2.1	2.1	-	3.6	4.2
Py/C_{18}	-	0.8	0.5	-	0.3	0.3
CPI_{14-20}	-	13.4	10.2	-	1.6	1.7
CPI_{20-32}	-	1.3	1.2	-	1.2	1.0
Total Alkanes	0.01	5.51	18.38	0.03	9.89	1.42

TABLE VIII-5 CONT'D

STATION	Ewing Bank	Ewing Bank	Ewing Bank	Ewing Bank	Ewing Bank	Ewing Bank
SAMPLE CODE	AMGH→L-M	AMGH→L-L	AMGH→L-Gd	AMGM→Q-M	AMGM→Q-L	AMGM→Q-Gd
CARBON NO.						
14	4.0	1.9	3.1	10.2	7.3	11.0
15	70.1	62.1	78.7	56.8	33.7	62.2
16	5.8	4.3	2.5	10.6	7.4	4.2
17	15.6	16.6	11.4	16.9	12.9	11.5
18	4.5	1.2	0.9	5.5	4.8	2.2
19	-	0.9	0.7	-	3.6	1.5
20	-	0.4	0.4	-	0.5	0.6
21	-	0.4	0.3	-	-	0.9
22	-	0.3	0.2	-	0.6	0.6
23	-	1.4	0.4	-	1.5	1.0
24	-	0.6	0.2	-	1.0	1.1
25	-	1.0	0.3	-	3.8	1.2
26	-	-	0.2	-	2.3	0.8
27	-	1.3	0.3	-	4.6	0.8
28	-	1.9	0.2	-	6.2	0.4
29	-	3.3	0.2	-	5.4	-
30	-	1.7	-	-	2.7	-
31	-	-	-	-	-	-
32	-	0.7	-	-	1.7	-
Total paraffin	0.15	1.84	7.10	0.24	3.56	3.44
Pristane	0.04	0.91	1.25	0.15	1.99	2.20
Phytane	0.01	0.02	0.05	0.02	0.39	0.04
Pr/Py	4.0	45.5	25.0	7.5	5.1	55.0
Pr/C_{17}	2.0	2.9	1.5	3.8	4.3	5.5
Py/C_{18}	1.0	1.0	0.8	2.0	2.3	0.5
CPI_{14-20}	7.2	12.1	18.9	3.7	3.3	7.5
CPI_{20-32}	-	1.5	1.6	-	1.1	1.2
Total Alkanes	0.20	2.77	8.40	0.41	5.94	5.68

TABLE VIII-5 CONT'D

STATION	Sonnier Bank	Sonnier Bank	Sonnier Bank	Sonnier Bank	Sonnier Bank	Sonnier Bank
SAMPLE CODE	AMGS→W-M	AMGS→W-L	AMGS→W-Gd	AMGX→ANGA-M	AMGX→ANGA-L	AMGX→ANGA-Gd
CARBON NO.						
14	-	4.4	4.0	5.3	9.8	6.0
15	45.7	58.4	65.3	75.4	58.0	43.0
16	6.2	2.6	4.5	3.7	4.7	5.6
17	27.2	6.3	16.7	8.3	9.9	10.2
18	9.9	1.0	2.3	1.0	3.9	4.8
19	11.0	1.4	2.4	1.4	5.8	4.4
20	-	0.5	0.9	0.8	0.4	4.0
21	-	0.5	0.7	0.6	0.3	3.1
22	-	0.3	0.5	0.5	0.3	2.3
23	-	0.8	0.6	0.8	0.5	3.3
24	-	0.9	0.5	0.6	0.5	2.6
25	-	1.6	0.6	0.6	0.8	2.3
26	-	2.0	0.4	0.5	0.8	2.2
27	-	3.2	0.4	0.5	1.1	2.9
28	-	3.2	-	-	0.8	1.4
29	-	7.0	0.2	-	1.2	1.2
30	-	5.1	-	-	0.8	0.6
31	-	-	-	-	-	-
32	-	0.8	-	-	0.4	0.1
Total paraffin	0.08	8.42	27.89	1.27	19.27	27.25
Pristane	0.06	1.83	12.12	0.83	8.03	12.96
Phytane	0.01	0.11	0.33	0.02	1.30	2.50
Pr/Py	6.0	16.6	36.7	41.5	6.2	5.2
Pr/C_{17}	3.0	3.5	2.6	7.5	4.2	4.7
Py/C_{18}	1.0	1.4	0.5	2.0	1.7	1.9
CPI_{14-20}	5.2	12.2	9.4	12.0	6.1	3.8
CPI_{20-32}	-	1.1	1.4	1.3	1.1	1.2
Total Alkanes	0.15	10.36	40.34	2.12	28.60	42.71

TABLE VIII-6

Organs and Individuals Analyzed in Spondylus from the South Texas Topographic Features Study (1977)

Banks	Code	Species	Organ Used [a]	# of Individual Fish
East Flower Garden	AMGR	*Spondylus americanus*	W-S	1
18th Fathom	ANGB	*Spondylus americanus*	W-S	1
	ANGC	*Spondylus americanus*	W-S	1
	ANGD	*Spondylus americanus*	W-S	1
	ANGE	*Spondylus americanus*	W-S	1
	ANGF [b]	*Spondylus americanus*	--	-

[a] W-S = whole less shell.

[b] No sample in the shell.

TABLE VIII-7

Concentration of Alkanes[1] in Spondylus from the South Texas Topographic Features Study (1977)

Banks	Code	Species	Sample Wt. (g)	Conc. in ppm (μg/g dry wt.)
East Flower Garden	AMGR	*Spondylus americanus*	51.9	0.30
18th Fathom	ANGB	*Spondylus americanus*	127.7	-[b]
	ANGC	*Spondylus americanus*	93.1	0.03
	ANGD	*Spondylus americanus*	108.5	0.01
	ANGE	*Spondylus americanus*	139.7	-
	ANGF[a]	*Spondylus americanus*	--	-

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

[a] No sample in the shell.

[b] Below detection limit of 0.001 μg/g.

TABLE VIII-8

Percent Distribution of n-Paraffins in Spondylus from the South Texas Topographic Features Study (1977)

STATION	East Flower Garden Bank	18th Fathom	18th Fathom	18th Fathom	18th Fathom	18th Fathom
SAMPLE CODE	AMGR	ANGB	ANGC	ANGD	ANGE	ANGF[a]
CARBON NO.						
14	3.3	-	-	-	-	
15	10.9	-	20.0	-	-	
16	10.5	-	-	-	-	
17	47.6	-	80.0	100.0	-	
18	4.7	-	-	-	-	
19	2.6	-	-	-	-	
20	-	-	-	-	-	
21	3.3	-	-	-	-	
22	2.2	-	-	-	-	
23	3.6	-	-	-	-	
24	4.0	-	-	-	-	
25	5.1	-	-	-	-	
26	-	-	-	-	-	
27	2.2	-	-	-	-	
28	-	-	-	-	-	
29	-	-	-	-	-	
30	-	-	-	-	-	
31	-	-	-	-	-	
32	-	-	-	-	-	
Total paraffin	0.28	-	0.03	0.01	-	
Pristane	0.02	-	-	-	-	
Phytane	-	-	-	-	-	
Pr/Py	-	-	-	-	-	
Pr/C_{17}	0.2	-	-	-	-	
Py/C_{18}	-	-	-	-	-	
CPI_{14-20}	3.7	-	-	-	-	
CPI_{20-32}	2.3	-	-	-	-	
Total Alkanes	0.30	-	0.03	0.01	-	

[a] No sample in shell.

had detectable hydrocarbons; one of these had only the n-C_{17} alkane and another had only C_{15} and C_{17} alkanes. The one sample with other hydrocarbons had an n-paraffin concentration of 0.28 ppm and a pristane level of 0.02 ppm. Its pristane/C_{17} ratio was 0.2; the CPI_{14-20} was 3.7 and the CPI_{20-32} was 2.3.

DISCUSSION

PROCEDURES

As in previous years of this study, the analytical methods were adequate for the detection and quantitation of the low levels of heavy molecular weight hydrocarbons in macronekton and Spondylus. The Carbon Preference Indices (CPI_{14-20} and CPI_{20-32}) were used for the determination of odd/even preference (Clark, 1974). They are calculated as follows:

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

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

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

ANALYSIS OF MACRONEKTON

Only six of the contracted ten macronekton samples were received due to sampling problems and thus only 18 (3 organs per sample) rather than 30 analyses were performed. The samples consisted of one sample each of red and vermilion snappers from each of the banks sampled.

As in the previous year of this study, the C_{15} and C_{17} n-alkanes and pristane were the dominant hydrocarbons. This is probably due to the diet of the organisms as the C_{15} and C_{17} n-alkanes are the dominant hydrocarbons in algae (Clark, 1967) and pristane is the major hydrocarbon in zooplankton (Blumer, 1964). Phytane was found in all but one of the samples in contrast to its presence in only 25% of the samples in the previous year. As phytane is generally considered to be of petroleum rather than biological origins, the presence of phytane suggests the possibility of some petroleum contamination of the study area. However, the concentration range was similar to that in the earlier group of samples with the exception of the vermilion snapper liver and gonad samples from the Sonnier Bank. The fish from this bank were poorly wrapped and may have been contaminated. There was also some evidence of decomposition (odor) making it difficult to assess the results of their analyses. These samples also had the highest level of n-alkanes in the macronekton studied.

The CPI_{14-20} values were from 1.6 to 18.9. Only two values below two were found. These values, 1.6 and 1.7, were for liver and gonad from vermilion snappers from the East Flower Garden Bank. This

sample consisted of only two relatively small females rather than the normal sample of five larger males and females. Thus, the low CPI values are probably due to the nature of the samples rather than to petroleum contamination.

The other indices calculated for this study, such as the pristane/phytane, pristane/C_{17} and phytane/C_{18} ratios were not suggestive of petroleum pollution in the study area. The absence of aromatic hydrocarbons further supports the absence of significant petroleum sources.

ANALYSIS OF SPONDYLUS

Five Spondylus samples were analyzed, as required. Four of these samples were from the 18 Fathom Lump. These samples had no detectable hydrocarbons or only C_{15} and C_{17} n-alkanes. The fifth sample was from the East Flower Garden Bank. This sample had a wide range of hydrocarbons, but its CPI_{14-20} of 3.7 and lack of phytane and aromatic hydrocarbons suggest a non-petroleum source of the hydrocarbons.

CONCLUSIONS

The distribution patterns of n-alkanes and the absence of aromatic hydrocarbons in the macronekton and Spondylus samples from the Topographic High study area imply that very low levels or no heavy hydrocarbons of anthropogenic origins are present in organisms from the study area.

PART TWO

TRACE METALS IN MACRONEKTON

AND

SPONDYLUS

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INTRODUCTION

As part of the Topographic Features Study (TFS), the concentrations of selected trace metals have been determined in organisms collected from several topographic highs (i.e. fishing banks) on the Texas-Louisiana Outer Continental Shelf. These baseline trace metal data provide a basis for detecting and evaluating future changes in organismal trace metal levels which could result from increased petroleum exploration and development in this region.

This report presents data from the second year (1977) of the TFS trace metals project. This 1977 study was generally very similar to the first year (1976) effort. The same three species of organisms were analyzed both years. This group included two macronekton species (fish: *Lutjanus campechanus*, red snapper; *Rhomboplites aurorubens*, vermilion snapper) and one epifaunal species (spiny oyster, *Spondylus americanus*). During 1977 samples were collected primarily during September and October (second season) from six banks. The banks sampled were Bouma (BOB), Bright (BRB), Ewing (EB), East Flower Garden (EFG), 18 Fathom (EFB) and Sonnier (SNB). Macronekton samples were taken at EB, EFG and SNB. *Spondylus* were collected at BOB, BRB, EFG and EFB. Only EFG had also been sampled during the 1976 study. All of the banks sampled during 1977 (except BOB and EFG) were further east than those visited during the first year.

A total of 65 analyses, each for ten trace metals (Al, Ca, Cd, Cr, Cu, Fe, Ni, Pb, V, Zn), were conducted on material from 7 macronekton and 9 spiny oyster samples. In addition Ba levels in *Spondylus* were determined. Table VIII-9 summarizes these analyses by species and tissues

TABLE VIII - 9

ANALYSES BY SAMPLE TYPE, SPECIES AND COLLECTION DATA

Sample Type and Species	Species Collection Data: Number of Seasons Sampled	Species Collection Data: Number of Bank Stations Sampled	Number of Samples Analyzed
Macronekton (MNK)			
A. Muscle (tissue pooled from 4-6 individuals)			
1. *Lutjanus campechanus*	1	3	3
2. *Rhomboplites aurorubens*	2	3	4
B. Gill (tissue pooled from 4-6 individuals)			
1. *Lutjanus campechanus*	1	3	3
2. *Rhomboplites aurorubens*	2	3	4
C. Livers (tissue pooled from 4-6 individuals)			
1. *Lutjanus campechanus*	1	3	3
2. *Rhomboplites aurorubens*	2	3	4
D. Livers (tissue from individual fish)			
1. *Lutjanus campechanus*	1	3	16
2. *Rhomboplites aurorubens*	2	3	19
Oysters (homogenized whole organism)			
1. *Spondylus americanus*	1	4	9
		Total analyses	65

analyzed. Except for the analyses of liver tissue from individual fish, this analysis regime was the same as that used during 1976. By analyzing liver tissue from individual fish collected at the same time and place, an estimate of the intra-bank variability in trace metal levels was obtained. Such variance estimates permit us to make more quantitative statistical comparisons among macronekton samples according to species, bank sampled, etc. Liver tissue was selected for additional analysis because it contained measureable levels of all the trace metals analyzed in this study. The analysis of pooled tissue samples was continued in 1977 to permit direct comparisons with identical data obtained during the 1976 study.

Although often difficult to collect, Spondylus was a good organism to choose for a baseline study such as this one. Spondylus contains relatively high levels of all the metals of interest and being a sessile organism it should be a fairly sensitive indicator for the levels of biologically available trace metals in the local environment. Lutjanus and Rhomboplites were selected for this study because they are common inhabitants of topographic highs in the northern Gulf of Mexico. This fact permits a consistency in sampling which is essential for a project where the number of samples analyzed is relatively small. Also there are important commercial and sport fisheries for both species in the northern Gulf. Because of their mobility,trace metal levels in macronekton are probably insensitive to small scale (microenvironmental) changes in ambient trace metal concentrations. However, macronekton probably reflect or integrate trace metal levels existant over a larger geographic area than do sessile organisms. As a result these levels are probably better indicators of large scale fluctuations in ambient trace metal concentrations

than those of sedentary biota.

Of the metals chosen for monitoring in this study, some are associated with potential petroleum related contamination while others represent some of the more toxic trace metals often associated with the increased activities of man. Nickel (Ni) and vanadium (V), for example, have been shown to be present in large concentrations in some oils and tars. Barium (Ba) is a major constituent of the muds used in oil well drilling. Cadmium (Cd) and lead (Pb), two very toxic metals, are frequently observed to be above natural levels near industrial and population centers.

The 1977 baseline trace metals data set is characterized in two ways. First the annual mean concentrations of metals in each species/sample type are compared. Second, although the data are limited, an attempt is made to identify trends in metal levels according to the banks sampled. Data from the 1976 TFS are included to permit comparisons between the two years of the study. Also the same macronekton species were sampled at Hospital Rock (HR) and Southern Bank (SB) during 1976 and 1977 as part of the Bureau of Land Management's (BLM) South Texas Outer Continental Shelf (STOCS) Benchmark Study. Data concerning trace metal levels in these STOCS samples are included both for comparison purposes and to consolidate the trace metals baseline data set for these two snapper species which comprises 37 samples (144 analyses) from 8 different banks over a two year period.

METHODS

All macronekton samples were caught by hook and line. Spondylus samples were collected using the submersible DR/V DIAPHUS. Every reasonable precaution was taken to avoid contamination during sampling. All samples were placed in polyethylene bags. When potentially contaminating sediment or other foreign material was adhering to the exterior surfaces of the organisms collected, they were rinsed prior to being put into the polyethylene bags. Each individual Spondylus was strapped shut with plastic straps before being placed in the sample bag. This was done to minimize the potential contamination of samples resulting from the exchange of materials between the inside and outside of the mantle cavity during sample storage. To avoid any release of metals from organisms caused by microbial activity, all samples were immediately frozen on board ship and remained frozen during transportation and storage until prepared for analysis.

The number and types of samples analyzed for trace metal content during this study are detailed in Table VIII - 9. Due to difficulties in sample collection experienced this year, 3 of the 10 macronekton samples could not be taken. The 3 missing samples were to have been collected at the East Flower Garden. No Lutjanus campechanus were caught during the first seasonal sampling of this bank (June 1977) and neither macronekton species could be caught during the third seasonal cruise (February-March 1978). As a result only one seasonal comparison of macronekton trace metal levels at the East Flower Garden is possible. Complete samples of both macronekton species were collected at all 3 banks sampled during the summer cruise (September-October 1977).

Optimally three oysters (S. americanus) were to be collected at each of five submarine banks during the second seasonal cruise (Sept.-Oct. 1978). However, finding "loose" Spondylus that could be conveniently sampled with the DR/V DIAPHUS was difficult. Consequently, 6 of the 9 samples collected came from Eighteen Fathom Bank. Only a single Spondylus was taken at each of three other banks (i.e. Bouma, Bright and East Flower Garden). At these banks no estimate of intra-bank variability in Spondylus trace metal levels is possible. As a result quantitative statistical comparisons of Spondylus trace metal concentrations among the banks sampled is not possible.

SAMPLE PREPARATION

Non-contaminating procedures used to prepare each of the major sample types (fish flesh, liver, gills, and oysters) are detailed below. Experiments conducted during the 1976 study (Presley and Boothe, 1977) showed that these procedures made no detectable contribution to the levels of the eight metals of interest observed in the resulting samples. Macronekton and Spondylus samples were thawed just prior to being prepared for freeze drying. They were rinsed with deionized water as necessary to remove any mud or other foreign material adhering to the exterior surfaces of the organisms. The deionized water used for all work in this study was prepared by passing distilled water through an ultrapure, mixed-bed demineralizer column (BARNSTEAD D0809). All dissections were done in a clean room on acrylic plastic cutting boards using stainless steel scalpels, scissors and nylon or teflon tweezers as required. At no point during the dissection were the preparer's fingers allowed to touch the tissue to be analyzed. All dissecting equipment was thoroughly rinsed with 1 N HNO_3 and deionized water between each sample. At the

end of each preparation session, all equipment was thoroughly cleaned in a Na_2CO_3 solution and rinsed with 1 N HNO_3 and deionized water. The equipment was stored in polyethylene bags until the next use. The acrylic boards were soaked in 0.5 N HNO_3 between each use.

Muscle, liver and gill tissues from each individual fish were prepared for analysis. A maximum amount of the appropriate tissue from each individual was prepared for freeze drying as described below. This action was taken to insure that extra freeze-dried material would be available for repeat analyses when necessary and to avoid having material from the same sample stored in two different ways for long periods. An equivalent wet weight tissue aliquot was taken from up to six individuals in the sample (if available) and pooled in a tared plastic, snap-cap vial to give a total wet weight of 6-12 g. After dehydration this pooled sample yielded a dry weight of 1-3 g, all of which was analyzed for trace metals. Pooled samples were prepared in this manner to insure that the trace metal concentrations in the pooled sample represented a true average of the concentrations existing in each of the individual organisms included in the sample, and also to avoid having to homogenize a large, pooled sample with a ball mill or mortar and pestle and risk contamination. If sufficient muscle or gill tissue remained, reserve pooled samples identical to the first were prepared in separate vials. If there was insufficient tissue remaining to prepare a second replicate pooled sample, or if there was still tissue left over after the preparation of the additional replicates, the remaining tissue from each individual was placed in separate vials for possible future use. The remaining liver tissue from each fish was analyzed separately to determine trace metal levels in the livers of individual fish from each sample.

The standard length and sex (whenever possible) of each individual fish was determined. In dissecting out the lateral trunk musculature, an effort was made to avoid contamination of the muscle sample which would occur if the sample came into contact with the exterior surface of the skin. On each side of the fish, a dorso-ventral incision was made along the anterior margin of the lateral trunk musculature. This incision was continued posteriorly just lateral to the mid-dorsal and mid-ventral planes. The skin was flayed off and discarded. The muscle was cut away from the axial skeleton. When sufficient tissue was available, the margins, where possible contact with the exterior skin could occur, were trimmed off and discarded. If there was insufficient tissue available, these margins were rinsed sparingly with deionized water and retained. Gill and liver tissues were also sampled. The gills (including gill rakers) were removed by cutting the dorsal and ventral attachments and were rinsed sparingly with deionized water to remove any foreign material. As the last step, the body cavity was opened and the liver excised. All tissues once removed were handled as described below.

The shell length and width of each spiny oyster were measured. The whole organism was then removed and placed in an acid-cleaned 140 mm plastic petri dish. Mucus, particulates and other foreign material were washed off with filtered seawater. Portions of the gut containing ingested material were also removed. The whole oyster was then placed in a tared, snap-cap vial and handled as described below.

At the end of each sample dissection, the tissue was placed immediately in a tared snap-cap vial and weighed immediately to determine wet weight. The samples were covered with parafilm and placed in a freezer. When a sufficient number of samples had accumulated, all samples were

freeze-dried for 24 to 96 h to a constant weight. After removal from the freeze dryer, the samples were reweighed to determine dry weight and the percentage of moisture lost by each sample was calculated. Samples were then stored in a desiccator until analyzed. The following experiment was conducted to confirm the assumption that trace metals were not being lost from the samples during freeze-drying. Three pairs of duplicate fish muscle samples were prepared. One sample of each pair was prepared for analysis in the normal way (cf. next section). The second sample was handled in the same manner except it was digested wet without first being freeze-dried. No significant differences in trace metal levels were observed between any of the three pairs of samples. Any error involved in converting wet weight to dry weight concentrations for comparisons was negligible.

DIGESTION (WET OXIDATION) OF SAMPLES

Freeze-dried samples were prepared for atomic absorption spectrophotometric (AAS) analysis using a nitric (HNO_3): perchloric ($HClO_4$) acid digestion procedure described in Method 3 of Attachment B to the 1977 BLM STOCS Contract (BLM, 1977). This procedure as used in our laboratory yielded very acceptable procedural blanks (Tables VIII-10 and 11. In this procedure the volume of acids used was minimized by employing an essentially closed refluxing system during the digestion process. A 1-3 g dry weight sample was placed in a spoutless, electrolytic style Pyrex beaker and 4-5 ml of 70% HNO_3 per gram of sample and 1 ml total of 70% $HClO_4$ were added. The beaker was covered with a 75 mm, non-ribbed Pyrex watchglass and allowed to sit overnight at room temperature. The mixture was then refluxed at low heat on a

TABLE VIII - 10

SUMMARY OF OPERATING CONDITIONS FOR FLAMELESS ATOMIC ABSORPTION ANALYSIS

Element	Wavelength (nm)	Source[1]	Temperature (°C) Time (seconds) dry	char	atomize	Minimum Detectable Concentration[2] (ppb)	Sensitivity[3] (pg)	Average Total Procedural Blank[4] (ng)
Cd	228.8	EDL (5)	85°	300°	1800°	0.025	9	< 2
		HCL (8)	60 s	60 s	8 s			
Cr	357.9	HCL (10)	85°	800°	2600°	1	25	20
			60 s	30 s	8 s			
Ni	232.0	HCL (20)	85°	1200°	2500°	4	100	<90
			60 s	30 s	8 s			
Pb	283.3	EDL (9)	85°	500°	2000°	0.5	25	18
			60 s	60 s	8 s			

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

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

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

[4] Total nanograms of element added to sample by reagents and labware used in sample preparation.

TABLE VIII - 11

SUMMARY OF OPERATING CONDITIONS FOR FLAME ATOMIZATION ATOMIC ABSORPTION ANALYSIS

Element	Analytical Wavelength (nm)	Non-resonance Wavelength (nm)	Sensitivity[1] (ppm)	Average Total Procedural Blank[2] (ng)
Cu	324.7	322.9	0.05	< 75
Fe	248.3	247.3	0.07	<100
Zn	213.9	220.2	0.02	< 75

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

[2] Total nanograms of element added to sample by reagents and labware used in sample preparation.

hotplate for 6-24 h. A bent glass rod was placed between the beaker lip and the watchglass and the heat increased to permit HNO_3 evaporation. At the first sign of white $HClO_4$ fumes (i.e., when most of the HNO_3 was gone), the glass rod was removed allowing the watchglass to again rest flush on top of the beaker. The sample was allowed to reflux until the solution cleared completely. If the sample did not clear, an additional 1 ml HNO_3 and 0.5 ml $HClO_4$ were added and the refluxing continued until clearing occurred. This step was repeated once if necessary. Finally, the watchglass was removed and the mixture was allowed to evaporate to near dryness. Spike recovery experiments conducted frequently during the 1976 study showed that there was no significant loss of any of the metals studied during this digestion procedure (Presley and Boothe, 1977).

Each digested sample was transferred to a tared 30 ml Oak Ridge type, screw-top polypropylene centrifuge tube by washing the beaker several times with 0.1 N HNO_3 (BAKER ULTREX grade) and pouring the resultant solutions into the centrifuge tube. This transfer procedure was apparently quite complete. Randomly selected beakers were occasionally rinsed with stronger acid (1 N HNO_3) after the sample had been removed to determine the amount of metals remaining. This acid solution was then analyzed using our routine AAS procedures. Even for livers which contain relatively high levels of the trace metals studied, the residual amounts of metals in the digestion beakers were minimal (i.e. $<<1\%$). Each sample was brought to approximately 25 ml, thereby diluting the original dry weight sample 10-20 times. The volume of each sample was determined by reweighing the filled sample tube and making a small correction (e.g. 1.01-1.04, pH $\sim$ 0.5-1) for the specific gravity

of the sample solution which was determined for each digestion. Insoluble residue which occurred in significant amounts in several gill samples was allowed to settle in the tubes. Further dilutions from the original solution were made on a weight/weight basis in 5 dram snap-cap vials using 0.1 N HNO_3.

All digestion glassware were soaked immediately after use in a solution of "Micro" detergent and distilled water in covered polyethylene pans for up to several days. The glassware were then rinsed thoroughly with deionized water and soaked in 3 N reagent grade HNO_3 in covered polyethylene or polypropylene pans until the next use. The centrifuge tubes were prepared for use by cleaning in a "Micro" solution. They were then filled with 5 N reagent grade HNO_3, heated for several days at 50°C and stored at room temperature until used. Prior to use, the tubes were emptied, rinsed thoroughly with deionized water and tared. The 5 dram snap-cap vials used for further dilutions were filled with 1 N reagent grade HNO_3 and allowed to sit at room temperature for several days. Prior to use they were emptied, rinsed with deionized water and tared.

About fifty samples and blanks were digested at any one time using the above procedure. Three to five procedural blanks were included with each group of samples digested to determine the amount of each metal contributed to the samples by the digestion glassware and reagents. These blanks received the same reagents and treatment as the tissue samples. An aliquot of the 0.1 N HNO_3 used to transfer and dilute the samples was placed in a centrifuge tube and analyzed with each digestion as a diluent/tube blank. Reagent blanks were analyzed for all bottles

of acid prior to their use in sample digestion. These blanks were prepared by taking $\geq$ 10 ml of acid, evaporating it to near dryness in digestion glassware and transferring the residue to a centrifuge tube in the same manner described above. For each series of dilutions made using 5 dram vials, one or more vial blanks were prepared and analyzed.

ATOMIC ABSORPTION SPECTROSCOPY (AAS) PROCEDURES

The concentrations of seven elements (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) in the macronekton and oyster samples from the 1977 Topographical Features Study were determined by atomic absorption spectroscopy (AAS). Flameless AAS was used to measure Cd, Cr, Ni and Pb, which occurred at low levels. These analyses were made using a PERKIN-ELMER Model 306 atomic absorption spectrophotometer equipped with an HGA-2100 graphite furnace atomizer. A summary of the instrumental operating conditions and the average procedural blanks for all eight digestions are given in Table VIII-10. External and internal furnace purge gas flow rates were verified at specified levels of 0.9 and 0.3, l/min respectively at 2.75 bar delivery pressure. The injection volume was 25 µl. The furnace temperature gauge was calibrated using a clamp-on (inductive) ammeter and an optical pyrometer. Dry, char and atomization temperatures and times were optimized for each metal using selected representative samples according to the manufacturer's recommendations (Anon., 1974). Nonresonance lines used for this optimization to estimate the magnitude of broad band molecular absorption for various sample types were 226.5 (Cd), 231.6 (Ni), 282.0 (Pb) and 352.0 (Cr) nm. Corrections for non-specific or broad band molecular absorption were made by a deuterium arc background corrector. For Cd and Pb, sample

dilutions $\geq$ 1/50 were used for quantitation, and for Cr and Ni, dilutions of $\leq$ 1/50. Chemical interference was evaluated and corrected as necessary by frequent use of the standard additions technique and check dilutions. Mixed standard metal solutions were prepared in dilute HNO_3 (BAKER ULTREX grade) by diluting concentrated commercial atomic absorption standards. Samples were quantitated by peak height comparison with bracketing standards injected before and after the sample. Consideration was given to temporal variations in instrumental sensitivity, nonlinearity between bracketing standards and gross differences in peak shape.

Copper, Fe and Zn were analyzed by flame AAS using a JARRELL-ASH Model 810 atomic absorption spectrophotometer. Analyses were carried out following the manufacturer's recommended procedure (Anon., 1971; 1972). A summary of the operating parameters for these analyses is given in Table VIII-11. Non-specific absorption was monitored by measuring simultaneously the absorbance of a nonresonance line and the analytical line of the element of interest. A fairly lean air-acetylene flame with flow rates of circa 7 and 2.5 l/min, respectively, were used for all three elements. Aspiration rate was generally 5 to 6 ml/min. Chemical interference was checked by use of the standard additions technique. Mixed standards used were prepared as described above.

The accuracy and precision of AAS analysis was evaluated by analyzing a National Bureau of Standards (NBS) standard biological reference material (i.e. #1577 bovine liver) with each digestion. The results of these analyses compared to NBS certified values are given in Table VIII-12. Why our average Fe concentration is consistently below the NBS value is not known. Several different batches of Fe standards were used to de-

TABLE VIII - 12

ACCURACY AND PRECISION OF ATOMIC ABSORPTION ANALYSIS

Standard Reference Material	Concentration (ppm dry weight ± 1 standard deviation)						
	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Bovine liver (NBS No. 1577)							
This study (n=7)	0.26 ± 0.02	0.09 ± 0.02	183 ± 3	232 ± 10	<0.08 ± 0.02	0.37 ± 0.05	130 ± 7
NBS values	0.27 ± 0.04	<0.2[1]	193 ± 10	270 ± 20	<0.2[1]	0.34 ± 0.08	130 ± 10
Precision[2]							
This study	6	26	2	4	23	14	5
NBS values	15	NA	5	7	NA	24	8
Fish muscle (House Standard)							
This study (n=8)	<0.01 ± 0	0.9 ± 0.4	1.2 ± 0.6	12 ± 5	0.29 ± 0.04	0.12 ± 0.06	19 ± 1
Precision[2]							
This study	0	39	45	44	15	49	6

[1] Not certified values.

[2] Precision expressed as percent coefficient of variation i.e. (std. dev./mean) x 100.

termine these various concentrations during the course of this study. A locally prepared fish muscle house standard was also analyzed with each digestion to estimate the precision of AAS procedures at the very low metal levels observed in many of the sample types analyzed routinely (e.g. fish and shrimp muscle). These results are also summarized in Table VIII-12. Not unexpectedly, precision decreases for several of the metals at these low concentrations. Cadmium was undetected in all eight of the replicate samples analyzed. Taken together these data indicate the AAS techniques used were acceptable.

ANALYSIS OF VANADIUM AND BARIUM IN ORGANISMS

As outlined in the 1977 proposal, an effort was made this year to develop a chelating/co-precipitation procedure using ammonium pyrrolidine dithiocarbamate (APDC) which would improve the sensitivity of Vanadium (V) analysis in organisms by neutron activation analysis (NAA). Several separate recovery studies were conducted using a fish muscle sample matrix spiked with varying concentrations of stable $^{51}V^{+5}$ AA standard or $^{48}V^{+3}$ radiotracer. The sample pH and other parameters of the APDC procedure were varied in an effort to achieve an acceptably high and consistent yield. These experiments were not successful. Yields were generally <60% and very inconsistent. A possible explanation for this situation is that V can exist in a variety of different ionic species in solution. V^{+5} is probably the dominant oxidation state present in the highly oxidized organism digests. Cotton and Wilkinson (1972) list eleven pH dependent ionic species for V^{+5} in aqueous solution. At least three of these occur at the V concentrations and pH (i.e. 3-4) existant in the coprecipitation solutions. These three species can interconvert among themselves over this pH range. Differences in the distribution

of V among these species in various samples plus any differences in the affinity of APDC for these species could be responsible for the variable and apparently very pH dependent yields observed.

Because of the above results, V concentrations in organisms are being determined using the NAA method described in Attachment B to the 1977 BLM STOCS contract (BLM, 1977). In this procedure, sulfuric acid (H_2SO_4) and hydrated antimony pentoxide (HAP) are used as pre-irradiaton chemical treatments to remove interfering chlorine (Cl) and sodium (Na), respectively, from acid digests of organism samples.

To remove Na, an aliquot of each organism digestate is diluted with an equal volume of 16 N HNO_3. The resulting solution is passed through a column of HAP according to the procedure of Girardi and Sabbioni (1968) as modified by Science Applications Inc. (Reed, 1977). Vanadium is not quantitatively eluted from this column. Corrections for incomplete recovery from the column will be made on the basis of spiked replicate samples run with every group of samples. The antimony (Sb) carryover experienced by SAI is a continuing problem. However, careful manipulation of the times for irradiation, pre-counting delay and counting have yielded detection limits of 10-20 ng V which is adequate for most of the STOCS samples. Cl in the elutriate is removed by adding 0.2 ml of concentrated H_2SO_4 and evaporating the solution in a teflon beaker to near dryness or until SO_3 fumes are observed. The teflon beaker contents are poured into a 1.5 ml irradiation polyethylene vial used by the Texas A&M University Nuclear Science Center. The vial is heat-sealed and placed in a secondary polyethylene container and heat-sealed again to prevent sample loss during analysis and handling.

Each sample is irradiated separately for 1 min by a 1 MW TRIGA

REACTOR. This process is facilitated by a pneumatic transport system which can rapidly transfer samples in and out of the reactor core. Standards prepared from commercial AAS standards or pure metals are used.

After return of the sample and an appropriate delay period (usually 2 min so that the dead time was < 30 %), the irradiated sample was placed on an ORTEC Ge(Li) detector and counted using a separate GEOS Quanta 4096 channel pulse height analyzer. After a 2 min counting period, the spectrum is stored on magnetic tape.

Spondylus samples for Ba determination were prepared by placing 1 ml aliquots of each organism digestate in acid-cleaned polyethylene vials and evaporating them to dryness. The vials are then heat-sealed to prevent any loss of sample material during analysis. The samples are then placed in a rotisserie which is moved into the reactor core and irradiated for 14 h. After irradiation samples are allowed to cool for two weeks. The 12 d ^{131}Ba activity is counted on a Ge(Li) gamma ray spectrophotometer system similar to that described above for V determinations. After a two hour counting period the spectrum is stored on a magnetic tape and data reduction is performed as described below.

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

One characteristic of NAA is its capability for analyzing several elements from a single irradiation. Concurrent with V analysis, the concentrations of Al, Ca and Cu are determined. However, the analytical conditions can not be optimized for all four elements during a single irradiation. The sensitivity for Al is good and the Al concentration

data satisfactory. However, the sensitivity for Ca is marginal and many of the samples were below the detection limit, which is quite variable and often very high. The sensitivity for Cu is very poor and almost all the samples are below the elevated detection limit.

RESULTS AND DISCUSSION

Table VIII-13 compares the annual mean concentrations of ten elements in the four major sample types for both years of this study. Barium levels were determined only in *Spondylus americanus* samples and these data are not included here (see Table VIII-17 instead). A comprehensive tabulation of raw trace metals data for all 1977 Topographic Features Study (TFS) samples is included in the data appendix of this report (Appendix A, Table VIII-1). The summary tables in this section were produced using this comprehensive tabulation and comparable metals data from the 1976 Final Report. The mean concentrations given in these tables were calculated using all "less-than" values at the calculated limits of detection to avoid excluding too much data from consideration. Since the detection limits for most metals involved (i.e. Cd, Cr, Ni, Pb) are quite low ($\leq$ 0.01-0.1 ppm dry weight), the overestimation of these means should not be excessive and should not affect the relationships in these general comparisons. Any values more than three standard deviations away from the group mean of the remaining data were not included in the computations.

The large variability and generally small sample sizes (e.g. Table VIII-13) precludes the use of common (parametric) statistical procedures to evaluate trends within the TFS trace metals data set. As in 1976 a rank order approach will be used to characterize the data. The mean concentrations of trace metals in the four major sample types were compared

TABLE VIII - 13

MEAN CONCENTRATIONS OF TRACE METALS IN FISH AND OYSTERS COLLECTED FROM SELECTED TOPOGRAPHICAL HIGHS IN THE TEXAS-LOUISIANA OUTER CONTINENTAL SHELF

Sample Type	Species	Year Sampled	No. of Samples	Concentration (ppm dry weight ± one standard deviation)						
				Cd	Cr	Cu	Fe	Ni	Pb	Zn
Fish Muscle	L. campechanus	1977	3	0.01 ± -	0.04 ± -	0.50 ± 0.10	2.5 ± 0.60	0.05 ± 0.03	0.15 ± 0.25	9.5 ± 0.60
	L. campechanus	1976	17	0.01 ± -	0.03 ± 0.01	0.80 ± 0.30	5.5 ± 3.0	0.06 ± 0.01	0.03 ± 0.01	12 ± 9.5
	R. aurorubens	1977	4	<0.01 ± 0.01	0.18 ± 0.06	0.75 ± 0.15	4.0 ± -	0.05 ± 0.04	0.04 ± 0.02	9.0 ± 1.4
	R. aurorubens	1976	14	0.01 ± 0.01	0.03 ± 0.03	1.0 ± 0.20	7.0 ± 2.5	0.05 ± 0.02	0.03 ± 0.02	11 ± 6.5
Fish Gill	L. campechanus	1977	3	0.50 ± 0.45	0.20 ± 0.04	2.6 ± 0.30	250 ± 65	0.50 ± 0.15	3.5 ± 4.5	75 ± 12
	L. campechanus	1976	16	0.30 ± 0.30	0.11 ± 0.07	2.4 ± 2.2	100 ± 35	0.50 ± 0.15	0.90 ± 1.1	70 ± 25
	R. aurorubens	1977	4	0.55 ± 0.40	0.12 ± 0.04	2.8 ± 1.0	300 ± 25	0.70 ± 0.10	1.2 ± 0.55	90 ± 9.5
	R. aurorubens	1976	14	1.5 ± 1.5	0.13 ± 0.08	3.4 ± 2.8	180 ± 75	0.50 ± 0.10	1.9 ± 0.0	95 ± 65
Fish Liver	L. campechanus	1977	19	4.5 ± 2.8	0.08 ± 0.03	30 ± 20	100 ± 55	0.11 ± 0.09	0.20 ± 0.25	130 ± 21
	L. campechanus	1976	16	1.9 ± 0.8	0.05 ± 0.02	20 ± 15	550 ± 300	0.13 ± 0.07	0.20 ± 0.10	120 ± 40
	R. aurorubens	1977	23	22 ± 15	0.20 ± 0.25	30 ± 19	1200 ± 700	0.45 ± 0.85	0.30 ± 0.30	450 ± 400
	R. aurorubens	1976	12	14 ± 9.5	0.10 ± 0.06	30 ± 30	1300 ± 750	0.35 ± 0.30	0.60 ± 0.45	550 ± 450
Whole Oyster Organism	S. americanus	1977	9	18 ± 7.0	3.0 ± 1.5	11 ± 17	55 ± 40	35 ± 15	0.45 ± 0.25	150 ± 40
	S. americanus	1976	15	30 ± 18	2.5 ± 1.5	25 ± 35	140 ± 90	40 ± 15	3.5 ± 3.0	170 ± 100

in two ways. First the types were ranked from 1 (highest) to 4 using the composite mean for each type (i.e. mean of Lutjanus and Rhomboplites not shown) for each of the seven metals given in Table VIII-13. The average ranking for each type was then calculated (i.e. sum of ranks for each type/7). Spondylus has generally the highest trace metal levels. The order of the remaining types is liver, gill and muscle. This order was the same as that observed in 1976.

The second approach was to order the four types according to the sum total of the seven metals in each one. Again the composite means for each type (not shown) were used in this ranking. Liver tissue has the highest average total metal content (0.98 mg/g) with gill tissue second (0.36 mg). Spondylus tissue has a total of 0.27 mg with muscle tissue having <0.1 mg. As in 1976 liver tissue was highest because of the elevated concentrations of Fe and Zn in this metabolically active tissue. The ranking in 1976 was the same except that the rankings of Spondylus and gill tissue were reversed. Iron levels were higher in 1977 gill samples. However, the major reason for this difference was a decrease in the levels of Cd, Cu, Fe and Pb in 1977 Spondylus samples. The reason for this decrease is not clear. Since all of the oyster samples in 1977 except one (EFG) came from banks not samples in 1976, it is difficult to make direct comparisons between years. The change does suggest a possible difference in metal levels among the 1976 and 1977 groups of banks. However, the one Spondylus collected at EFG in 1977 showed a similar decrease in Cd, Cu and Pb compared with specimens sampled there in 1976. Fish muscle tissue had generally lower levels of most metals with expected higher levels of metabolically active ones such as Cu, Fe and Zn.

Variability in the 1977 trace metals baseline data set is high. The

amount of variability was generally similar to that observed in 1976. However, the ranking of the major sample types according to variability was different. Variability in trace metals content among the four sample types (Table VIII-13) was quantitatively characterized by calculating the mean percent coefficient of variation for seven metals for each type [i.e. %CV= (std. dev./mean) x 100] and then ranking these values. In 1977 the types in order of decreasing variability were liver, Spondylus, muscle and gill. In 1976 this ranking was Spondylus, gill, liver and muscle. No tissue seems to be consistently less variable than any other over the two years. Thus on the basis of variability alone, no single sample type can be recommended as better for any future monitoring study. The amount of variability observed in these grouped data would permit the detection of only large scale fluctuations in trace metal levels (> 100%) using parametric statistics.

Interspecific and intraspecific comparisons of trace metal concentrations within each major sample type are discussed in separate sections below. As in 1976 these comparisons are often based on only one or a few samples per bank and should generally be considered qualitative.

FISH MUSCLE TISSUE

The levels of trace metals in muscle tissue of Lutjanus and Rhomboplites collected during 1977 are similar with no significant differences. The same is true within each species for specimens collected in 1976 and 1977. The variability in trace metal concentrations is similar for both species and years(Table VIII-13). Table VIII-14 gives the mean concentrations in muscle tissue for each species according to the bank of origin. The higher levels of most metals in the Lutjanus sample from

TABLE VIII - 14

MEAN CONCENTRATIONS OF SELECTED TRACE METALS IN FISH MUSCLE ACCORDING TO BANK SAMPLED DURING 1976 AND 1977

Species	Bank Sampled	Year Sampled	No. of Samples	Concentration (ppm dry weight ± one standard deviation)						
				Cd	Cr	Cu	Fe	Ni	Pb	Zn
Lutjanus campechanus	EFG	1977	1	<0.01 ± -	0.03 ± -	0.60 ± -	2.0 ± -	<0.06 ± -	<0.02 ± -	10 ± -
	EFG	1976	1	0.01 ± -	0.02 ± -	0.90 ± -	3.0 ± -	0.05 ± -	0.30 ± -	10 ± -
	EB	1977	1	0.10 ± -	0.18 ± -	2.5 ± -	200 ± -	0.60 ± -	0.50 ± -	60 ± -
	SNB	1977	1	<0.01 ± -	0.04 ± -	0.40 ± -	3.0 ± -	<0.01 ± -	0.40 ± -	10 ± -
	HR	1977	2	<0.01 ± -	0.02 ± -	0.70 ± 0.15	3.0 ± -	<0.06 ± 0.01	<0.03 ± -	10 ± -
	HR	1976	6	0.01 ± -	0.02 ± 0.02	0.70 ± 0.30	5.0 ± 0.90	0.06 ± 0.02	0.03 ± 0.01	10 ± 2.1
	SB	1977	2	<0.01 ± -	<0.02 ± 0.01	0.65 ± 0.07	3.5 ± 0.70	<0.06 ± -	<0.04 ± 0.02	10 ± 1.4
	SB	1976	6	0.01 ± 0.01	0.03 ± 0.01	0.70 ± 0.30	6.0 ± 4.0	0.06 ± 0.01	0.03 ± 0.02	75 ± 16
	STB	1976	1	0.01 ± -	0.05 ± -	0.60 ± -	5.0 ± -	0.05 ± -	0.03 ± -	10 ± -
	TFB	1976	1	0.01 ± -	0.02 ± -	0.90 ± -	3.0 ± -	0.06 ± -	0.04 ± -	12 ± -
	TFBSWP	1976	1	0.01 ± -	0.03 ± -	1.4 ± -	4.0 ± -	0.06 ± -	0.01 ± -	7 ± -
Rhomboplites aurorubens	EFG	1977	2	<0.01 ± -	0.04 ± -	0.85 ± 0.07	4.0 ± -	0.06 ± 0.05	0.04 ± 0.02	8 ± -
	EFG	1976	1	0.01 ± -	0.06 ± -	0.90 ± -	6.0 ± -	0.03 ± -	0.03 ± -	10 ± -
	EB	1977	1	<0.01 ± -	0.04 ± -	0.70 ± -	4.0 ± -	0.05 ± -	0.01 ± -	9 ± -
	SNB	1977	1	<0.01 ± 0.01	0.04 ± -	0.50 ± -	4.0 ± -	0.02 ± -	<0.05 ± -	11 ± -
	HR	1977	2	<0.01 ± -	<0.02 ± 0.01	0.65 ± 0.20	6.0 ± -	<0.07 ± -	<0.02 ± 0.01	9 ± 1.4
	HR	1976	3	0.02 ± 0.01	0.04 ± 0.04	1.0 ± 0.20	7.5 ± 2.5	0.05 ± 0.02	0.03 ± 0.03	9 ± 4.5
	SB	1977	2	<0.01 ± -	<0.02 ± 0.01	0.60 ± -	5.5 ± 0.70	<0.07 ± -	0.04 ± 0.02	10 ± -
	SB	1976	7	0.01 ± 0.01	0.02 ± 0.02	1.0 ± 0.20	6.5 ± 3.0	0.06 ± 0.01	0.03 ± 0.02	10 ± 4.0
	STB	1976	1	0.02 ± -	0.02 ± -	0.90 ± -	5.0 ± -	0.03 ± -	0.03 ± -	12 ± -
	TFB	1976	1	0.01 ± -	0.03 ± -	1.1 ± -	11 ± -	0.04 ± -	0.04 ± -	30 ± -
	TFBSWP	1976	1	0.01 ± -	0.04 ± -	0.90 ± -	4.0 ± -	0.07 ± -	0.03 ± -	11 ± -

East Bank (EB) are probably due to contamination of the sample and not any real difference in metal levels. As observed in 1976, concentrations of the selected trace metals in fish muscle are generally quite low and uniform with few differences among widely separated fishing banks even when sampled during different years. Samples of both species collected at EFG in 1977 and 1976 were not significantly different. The few differences between banks observed did not follow any definite pattern.

Muscle tissue samples are quite variable in terms of the rank order relationships of elemental means. For example the samples in Table VIII-14 exhibit the pattern Zn> Fe> Cu> Ni in 78% of the cases while the relationship Zn> Fe> Cu> Cd or Cr or Ni or Pb occurs 89% of the time. These patterns are less consistent in muscle tissue than the other sample types. Only the relationship Zn> Fe occurs in all the muscle samples analyzed.

FISH GILL TISSUE

Trace metal levels observed in the gill tissue of Rhomboplites during 1977 were generally (5/7) higher than those in the same tissue from Lutjanus. However, these differences were not significant. In contrast the variability in concentrations was greater for Lutjanus gill tissue. Except for possibly Fe, the levels observed within each species were similar for both 1976 and 1977 (Table VIII-13). Trace metal concentrations in gill tissue according to species and bank sampled during both years of this study are summarized in Table VIII-15. Within each species, the metal levels were similar among the banks studied with few significant differences.

All gill samples analyzed showed the rank order relationship Fe> Zn>

TABLE VIII - 15

MEAN CONCENTRATIONS OF SELECTED TRACE METALS IN FISH GILLS ACCORDING TO BANK SAMPLED DURING 1976 AND 1977

Species	Bank Sampled	Year	No. of Samples	Concentration (ppm dry weight ± standard deviation)						
				Cd	Cr	Cu	Fe	Ni	Pb	Zn
Lutjanus campechanus	EFG	1977	1	0.40 ± -	0.17 ± -	3.0 ± -	350 ± -	0.40 ± -	2.0 ± -	80 ± -
	EFG	1976	1	0.07 ± -	0.09 ± -	2.5 ± -	70 ± -	0.70 ± -	1.3 ± -	55 ± -
	EB	1977	1	0.10 ± -	0.18 ± -	2.5 ± -	200 ± -	0.60 ± -	0.50 ± -	60 ± -
	SNB	1977	1	0.95 ± -	0.25 ± -	3.0 ± -	250 ± -	0.60 ± -	8.5 ± -	80 ± -
	HR	1977	2	0.14 ± 0.08	0.10 ± 0.10	1.8 ± 0.90	200 ± 60	0.60 ± 0.10	0.30 ± 0.10	75 ± 7
	HR	1976	6	0.16 ± 0.14	0.10 ± 0.06	1.8 ± 0.80	100 ± 45	0.50 ± 0.20	1.0 ± 1.7	70 ± 25
	SB	1977	2	0.20 ± 0.04	0.10 ± 0.04	1.8 ± 0.10	250 ± 100	0.60 ± 0.30	0.30 ± -	85 ± 7
	SB	1976	6	0.50 ± 0.45	0.10 ± 0.07	1.5 ± 0.60	110 ± 30	0.45 ± 0.20	0.55 ± 0.30	75 ± 30
	STB	1976	1	0.08 ± -	0.12 ± -	1.5 ± -	110 ± -	0.35 ± -	1.2 ± -	65 ± -
	TFB	1976	1	0.07 ± -	0.25 ± -	3.5 ± -	85 ± -	0.50 ± -	0.70 ± -	60 ± -
	TFBSWP	1976	1	0.45 ± -	0.06 ± -	10 ± -	90 ± -	0.45 ± -	2.0 ± -	65 ± -
Rhomboplites aurorubens	EFG	1977	2	0.75 ± 0.50	0.10 ± 0.02	3.0 ± 1.4	300 ± 15	0.80 ± -	0.90 ± 0.40	80 ± -
	EFG	1976	1	1.1 ± -	0.18 ± -	3.5 ± -	190 ± -	0.55 ± -	2.5 ± -	95 ± -
	EB	1977	1	0.40 ± -	0.16 ± -	3.0 ± -	300 ± -	0.60 ± -	1.9 ± -	100 ± -
	SNB	1977	1	0.20 ± -	0.14 ± -	2.0 ± -	250 ± -	0.60 ± -	1.2 ± -	90 ± -
	HR	1977	2	0.60 ± 0.10	0.10 ± 0.01	3.0 ± -	350 ± 70	0.60 ± -	1.7 ± 0.1	85 ± 7
	HR	1976	3	0.60 ± 0.10	0.20 ± 0.10	2.5 ± 1.0	250 ± 110	0.60 ± 0.15	3.5 ± 4.0	160 ± 140
	SB	1977	2	0.40 ± 0.20	0.1 ± 0.01	3.0 ± -	250 ± 80	0.60 ± -	1.3 ± 0.1	95 ± 7
	SB	1976	7	2.1 ± 1.8	0.12 ± 0.07	4.5 ± 4.0	160 ± 75	0.40 ± 0.10	1.6 ± 1.4	75 ± 7.5
	STB	1976	1	0.90 ± -	0.11 ± -	2.0 ± -	160 ± -	0.50 ± -	1.2 ± -	80 ± -
	TFB	1976	1	0.08 ± -	0.04 ± -	2.5 ± -	120 ± -	0.50 ± -	1.4 ± -	70 ± -
	TFBSWP	1976	1	2.6 ± -	0.05 ± -	1.4 ± -	150 ± -	0.50 ± -	1.2 ± -	90 ± -

Cu. The pattern Fe> Zn> Cu> Pb> Cd appears in 14 of 18 cases comprising 67% of the Rhomboplites samplings and 89% of the Lutjanus ones. The relationship Fe> Zn> Cu is so consistent that it may warrant only occasional monitoring. The pattern for the remaining elements appears to be less tightly controlled and more susceptible to environmental variations. These elements merit closer monitoring. Lead was relatively abundant in the gill tissue analyzed and ranked at least fourth in 83% of the means determined.

FISH LIVER TISSUE

Trace metal levels in Rhomboplites liver tissue were consistently greater (6/7) than those in Lutjanus livers. This same relationship was observed in 1976 samples. However, for 1977 samples this difference was significant only for Fe and Cd levels. The variability in liver trace metal concentrations was also greatest among Rhomboplites samples (Tables VIII-13). Table VIII-16 gives trace metals data for liver tissue samples of both species according to bank and year sampled. Metal levels were generally quite similar in liver samples of both species collected at EFG during both years of the study. For 1977 Rhomboplites livers analyzed, Sonnier Banks (SNB) samples exhibited the lowest levels of the three banks sampled for all metals except Pb. Samples from EB had the highest levels of all metals except Cu.

The relationship Fe> Zn> Cu> Cd is consistent among all liver samples analyzed during both years of this study. The pattern Fe> Zn> Cu> Cd> Pb> Ni> Cr holds for 89% of Lutjanus liver samples but only 56% of Rhomboplites samples. Only at EFG in 1977 was the Pb concentration in liver tissue the lowest of all seven metals. This relationship was valid for both species. Lead was fifth most abundant in 1976 at EFG. As

TABLE VIII - 16

MEAN CONCENTRATIONS OF SELECTED TRACE METALS IN FISH LIVERS ACCORDING TO BANK SAMPLED DURING 1976 AND 1977

Species	Bank Sampled	Year	No. of Samples	Concentration (ppm dry weight ± standard deviation)						
				Cd	Cr	Cu	Fe	Ni	Pb	Zn
Lutjanus campechanus	EFG	1977	7	4.0 ± 1.4	0.07 ± 0.04	25 ± 9.0	650 ± 150	0.07 ± 0.04	0.07 ± 0.03	140 ± 30
	EFG	1976	1	0.35 ± -	0.04 ± -	35 ± -	1100 ± -	0.08 ± -	0.19 ± -	120 ± -
	EB	1977	6	6.0 ± 4.0	0.05 ± 0.01	50 ± 30	1700 ± 500	0.08 ± 0.04	0.40 ± 0.30	130 ± 22
	SNB	1977	6	3.0 ± 2.5	0.09 ± 0.03	20 ± 6.0	800 ± 350	0.16 ± 0.13	0.19 ± 0.14	130 ± 17
	HR	1977	12	1.2 ± 0.40	0.04 ± 0.05	14 ± 4.0	550 ± 180	<0.10 ± 0.05	0.20 ± 0.07	110 ± 18
	HR	1976	6	1.5 ± 0.65	0.05 ± 0.01	20 ± 25	700 ± 300	0.14 ± 0.08	0.25 ± 0.08	130 ± 55
	SB	1977	10	2.0 ± 1.0	0.04 ± 0.03	20 ± 10	600 ± 450	<0.20 ± 0.20	0.20 ± 0.10	120 ± 40
	SB	1976	6	1.6 ± 0.50	0.06 ± 0.02	13 ± 6.0	350 ± 150	0.14 ± 0.07	0.20 ± 0.14	110 ± 30
	STB	1976	1	3.0 ± -	0.03 ± -	20 ± -	400 ± -	0.11 ± -	0.19 ± -	130 ± -
	TFB	1976	1	2.0 ± -	0.04 ± -	25 ± -	500 ± -	0.10 ± -	0.13 ± -	120 ± -
	TFBSWP	1976	1	2.6 ± -	0.04 ± -	25 ± -	400 ± -	0.09 ± -	0.10 ± -	140 ± -
Rhomboplites aurorubens	EFG	1977	2	19 ± 18	0.25 ± 0.35	35 ± 20	1000 ± 300	0.80 ± 1.1	0.25 ± 0.14	500 ±300
	EFG	1976	1	25 ± -	0.07 ± -	65 ± -	800 ± -	0.50 ± -	0.65 ± -	1300 ± -
	EB	1977	6	30 ± 13	0.25 ± 0.08	35 ± 20	1900 ±1000	0.20 ± 0.11	0.60 ± 0.45	650 ±600
	SNB	1977	6	18 ± 4.0	0.09 ± 0.02	16 ± 11	800 ± 350	0.08 ± 0.06	0.25 ± 0.04	300 ±300
	HR	1977	11	8.0 ± 2.0	0.03 ± 0.02	25 ± 25	800 ± 300	<0.20 ± 0.10	0.30 ± 0.20	300 ±220
	HR	1976	3	15 ± 3.5	0.13 ± 0.08	14 ± 4.5	1900 ±1100	0.65 ± 0.40	0.75 ± 0.45	500 ±350
	SB	1977	13	14 ± 7.0	0.12 ± 0.09	35 ± 10	1700 ± 650	<0.40 ± 0.20	0.40 ± 0.20	400 ±140
	SB	1976	5	9.0 ± 6.5	0.08 ± 0.03	35 ± 45	1100 ± 650	0.20 ± 0.06	0.35 ± 0.20	350 ±400
	STB	1976	1	13 ± -	0.20 ± -	25 ± -	850 ± -	0.08 ± -	0.45 ± -	1000 ± -
	TFB	1976	1	35 ± -	0.03 ± -	45 ± -	1500 ± -	0.55 ± -	1.7 ± -	800 ± -
	TFBSWP	1976	1	10 ± -	0.05 ± -	20 ± -	1100 ± -	0.25 ± -	0.55 ± -	350 ± -

with gill tissue, there appears to be a group of metals that show a consistent rank order relationship in liver tissue and a second group which exhibits a more variable pattern.

SPINY OYSTER

The mean concentrations of trace metals in all Spondylus analyzed during the TFS are summarized in Table VIII-17 according to year and bank sampled. The variability in trace metal levels among Spondylus samples from both 1977 and 1976 was quite similar. The fact that replicate samples could only be collected at EFB during 1977 makes inter-bank comparisons for that year very difficult. Metal levels (except Fe) in the single specimen collected at EFG in 1977 were lower than comparable levels in oysters collected at the same bank in 1976. EFG Spondylus contained the highest levels of Cd, Cu, Pb and Zn of any individuals collected in 1976. In 1977 the single Spondylus from EFG contained among the lowest levels of these metals observed in any Spondylus. A lack of replicate samples at EFG in 1977 makes it impossible to verify this observation. Lead levels are lower in all 1977 Spondylus compared with 1976 individuals. This relationship is true even for 1977 banks which are relatively close to those sampled in 1976.

All Spondylus collected during 1977 exhibit the pattern Zn> Fe> Ni> Cd. However, this pattern occurs only once among the five banks sampled in 1976. The 1976 bank means show no consistent rank order relationship.

CONCLUSIONS

1. Although 3 of the 4 banks (BOB,BRB,EB) sampled during 1977 had not been visited in 1976, the levels and variability of trace metals observed for both years were generally similar. This observation

TABLE VIII - 17

MEAN CONCENTRATIONS OF SELECTED TRACE METALS IN WHOLE *SPONDYLUS AMERICANUS* ACCORDING TO BANK SAMPLED IN 1976 AND 1977

Bank Sampled	Year Sampled	No. of Samples	Concentration (ppm dry weight ± one standard deviation)						
			Cd	Cr	Cu	Fe	Ni	Pb	Zn
EFG	1977	1	17 ± -	2.5 ± -	4 ± -	50 ± -	30 ± -	0.30± -	150 ± -
EFG	1976	3	50 ± 25	3.0 ± 1.5	85 ± 35	50 ± 10	45 ± 3.0	6.5 ± 4.0	250 ± 85
BOB	1977	1	16 ± -	0.06 ± -	3.5 ± -	150 ± -	55 ± -	0.40± -	200 ± -
BRB	1977	1	11 ± -	2.5 ± -	1.4 ± -	35 ± -	25 ± -	0.20± -	110 ± -
EFB	1977	6	20 ± 8.0	3.5 ± 1.5	7.0 ± 5.0	45 ± 15	30 ± 15	0.50± 0.30	140 ± 45
HR	1976	3	24 ± 8.5	3.5 ± 2.0	9.0 ± 5.0	240 ± 95	30 ± 4.0	1.2 ± 0.10	110 ± 30
SB	1976	3	16 ± 5	3.5 ± 3.0	3.0 ± 1.0	150 ± 35	35 ± 2.5	1.1 ± 0.55	85 ± 70
STB	1976	3	17 ± 4	1.2 ± 0.30	19 ± 6.5	160 ± 120	30 ± 10	2.5 ± 0.70	210 ± 55
TFB	1976	3	35 ± 15	1.9 ± 0.45	12 ± 2.5	75 ± 15	65 ± 25	5.0 ± 2.0	180 ± 150

is significant when one considers that samples of the three species of marine organisms analyzed were collected from banks scattered along a 450 km stretch of the Texas-Louisiana OCS. No indication of substantial trace metal pollution was observed at any of the topographic highs sampled.

2. Significant differences in trace metal levels between bank stations were observed. However, no consistent geographical trend in metal levels was apparent.
3. Spondylus and macronekton liver tissue represent the best sample types for future monitoring because they contain measurable levels of all metals studied during this baseline effort. With sufficient replication of samples ($\geq$ 5-10) at each collection site, intra-station variability in trace metal concentrations could be reduced to permit meaningful quantitative statistical comparisons among different banks.
4. Rank order relationships of elemental means in macronekton gill and liver tissue are sufficiently consistent to suggest that any future departures will be the result of important environmental changes. The pattern is Fe> Zn> Cu> Pb> Cd for gills and Fe> Zn> Cu> Cd> Pb or Cr or Ni for livers.

CHAPTER IX

HIGH MOLECULAR WEIGHT HYDROCARBONS IN SEDIMENTS

HIGH MOLECULAR WEIGHT HYDROCARBONS IN SEDIMENTS

Principal Investigator

Patrick L. Parker

INTRODUCTION

The level of petroleum derived organic compounds in the marine environment relates to two questions which differ only in reference to their respective time-frames. First, it must be established whether present day levels of oil in the sea are having a deleterious effect on plants and animals. Second, it is necessary to establish the long term trends of pollutant levels so that the eventual consequence of the utilization of non-renewable or living resources can be predicted.

The studies reported here provide a partial answer to these two questions. By combining environmental concentration data with data on biological effects from other studies a crude idea of the degree of present day ecological damage can be deduced. The second use of environmental data is to serve as a beginning or baseline against which future levels and patterns of pollutant can be compared. While sophisticated statistical inferences cannot be drawn from the present data base it is the case that "hot spots" would be recognized.

BACKGROUND

Careful chemical analyses have been carried out for a large suite of environmental samples. The approach has been to isolate the hydrocarbon fraction from material from the STOCS area and to identify molecules which are the common components of petroleum. This report deals with hydrocarbons in the molecular weight range of C-15 to C-36, consisting of saturated, unsaturated and aromatic

compounds, isolated from the topographic features sediments. In addition, measurements of $\delta^{13}C$ have been made to evaluate the potential of using this parameter to recognize petroleum derived carbon in sediment.

METHODS AND MATERIALS

The goal of this project was to obtain a significant body of analytical data on environmental hydrocarbon levels which could serve as a baseline against which future levels might be compared. An intense effort was made to identify hydrocarbon molecules which might serve as indicators of petroleum. The experimental elements were: careful collection, preservation and transportation of samples in the field; laboratory analyses using, as nearly as possible, standardized and modern techniques; and central data storage and computer analysis.

SAMPLE COLLECTION

Samples were supplied to this Laboratory by Texas A&M University.

LABORATORY ANALYSIS

Throughout this study, purified solvents, inorganic chemicals and double distilled water were used. Control samples and blanks were used to insure that no gross contamination was present. The laboratory was in a new building and had never been used for any other purposes. At no time was severe contamination encountered.

High Molecular Weight Hydrocarbons (HMWH)

The sediment samples were freeze-dried as the first step of

analysis. This was accomplished by spreading the sample as a thin paste on stainless steel trays. The freeze dryer used was a Virtis Model 25 SRC. The freeze-dried mud was kept frozen until used for analysis.

Extraction. Hydrocarbons were isolated from sediments and purified following the reflux method which was used in the 1976 STOCS study. This procedure is as follows: The freeze-dried sediment sample (300-700 g) was placed in a large round-bottomed flask (1000 m) and covered (approximately 200 ml) with the toluene-methanol azeotrope (3:7) using care that the flask was not more than one-half full so as to avoid severe bumping on the steambath. The flask was placed in reflux on a steam bath for 14 h using a Friedrichs condenser with standard taper joints and a drip tip. The solvent, while warm, was decanted through a prewashed filter (Whatman 541) and set aside for later analysis. Fresh solvent and any sediment on the filter paper were added to the flask and the reflux extraction repeated for 7-10 h. Finally, the sediment was filtered onto a Buchner funnel, washed with warm hexane and all extracts combined. The sediment was dried at 45°C and weighed. This procedure was repeated several times for each sample in order to process 1 kg.

Saponification. The combined extracts were taken to just dryness on a roto-vap and taken up in hot KOH-methanol (0.5 N) for saponification. The lipid extract was saponified by refluxing (6 hours) with the 0.5 N KOH-methanol solution. This reflux solution had been prepurified by extraction with toluene. In cases where GLC indicated that methyl esters were present, the sample was re-saponified. In general, ester formation did not occur if a few milliliters of distilled

water were added to the saponification mixture. When this step was complete, the mixture was transferred while warm to a separatory funnel and enough saturated NaCl colution was added to cause two phases to form when 15 ml of n-hexane was added. The non-saponifiable lipids, which included hydrocarbons, were extracted into three 15 ml portions of n-hexane. The saponifiable fraction was discarded, and the non-saponifiable extracts combined and set aside for purification by column chromatography.

Purification. Column chromatography was carried out to purify the total hydrocarbon extract and to separate it into two chemical fractions, saturated hydrocarbons and the non-saturated hydrocarbons which include both olefins and aromatic molecules. This method is described in the following paragraphs.

A large batch of one part alumina plus two parts silica gel, both Activity I, was prepared using hydrocarbon-free chemicals. Column chromatography was carried out using this material with a sample to packing ratio of 1:300 in a glass column with a teflon stopcock and with a length to inside diameter ratio of about 20:1. As standard procedure, the packed column was washed with two column volumes of hexane prior to sample loading.

The sample from the saponification procedure which had been reduced to a small volume (a few ml) using an all glass flash evaporator was transferred to the top of the column using a transfer pipette. The saturated hydrocarbons eluted with two column volumes of hexane were set aside for gas liquid chromatography (GLC) and gas chromatography-mass spectrometry (GC/MS). Hexane insoluble material not previously added to the column was washed onto the

column with a few ml of benzene. The nonsaturated, or so called "aromatic", fraction was eluted with two column volumes of benzene. The benzene in this fraction was gradually replaced by adding hexane and evaporating under a stream of nitrogen, taking care not to let the sample go dry at any time, yielding a final volume of 1 ml or less. The hexane eluate was reduced in volume in the same way. The weight, when enough material was present to weigh, of each fraction was determined on an aliquot of the eluates. The samples were set aside and later submitted to GLC and, if appropriate, to GC/MS.

Total Organic Carbon and $\delta^{13}C$

The percent total organic carbon was measured using a high temperature combustion technique which has been used for several years in this laboratory. The procedure is as follows. The frozen sample, 1-5 g, was thawed and treated with dilute HCl in a tall beaker to remove carbonate carbon. If magnesium or iron carbonate were suspected of being present the acid was heated to aid decomposition. The mixture was washed with distilled water to remove excess acid. The sediment was collected by filtering onto a glass fiber pad. The damp sediment was removed from the pad, dried at 40°C and ground to pass a 0.42 mm sieve. An aliquot of this powder, 100-200 mg, was weighed into a LECO clay combustion cup, iron powder and CuO were added and the sample burned in a LECO RF furance for two 2-min intervals. The evolved CO_2 was collected by

freezing with liquid nitrogen, the excess O_2 pumped away and the CO_2 measured manometrically. The data are expressed as percent organic carbon on a carbonate free basis.

The samples for $\delta^{13}C$ analysis were treated according to the same procedure. In this case it was necessary to burn a large enough sediment sample to yield 3 ml of CO_2 for mass-spectrometric analysis. The MS analysis was done on a 15.24 cm, 60° sector field mass spectrometer (model 6-60-RMS-26) made by Nuclide Corp. State College, Pa.[1] The data are reported as permil deviations from the PDB standard. The standard deviation for repeated analyses was 0.3 o/oo.

INSTRUMENTATION

Gas Chromatographic Analyses

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

The GC instruments used in this study were Perkin-Elmer Models 900,910,3920B, and a Varian Model 3700. The PE 910 had glass capillary columns. All instruments were equipped with dual column flame ionization detectors. Electronic integration of peaks was

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

done for all instruments by a Hewlett-Packard 3352 Lab Data System. However, due to the complex nature of the GC patterns and the limitations of all the integrators, it was necessary to hand check each result.

The GC instruments, other than the Perkin-Elmer model 910, used 0.32 cm (1/8 in) by 183 cm (6 ft) dual, packed columns to effect the separation. The column packing material was 60-80 mesh Gaschrom Q (acid washed) with a 5% by weight loading of FFAP (a product of Varian Corp.) as the stationary liquid-phase. Generally, the operating conditions were as given in Table IX-1. These columns and conditions were used for virtually all analyses of STOCS samples.

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

Instrument sensitivity and resolution were checked daily by running a standard mixture of components. When the resolution fell below that recommended by BLM the GC columns were replaced. The daily standard check was used to establish the sensitivity of the instrumentation to allow quantification of the GC peak data.

TABLE IX-1

OPERATING CONDITIONS FOR GLC ANALYSIS

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

GC peak data for each sample are presented in Appendix A, Tables IX-1 through -5. The data consist of a listing of the peak retention index and concentrations in the sample for each of the two analyzed fractions: hexane eluate and benzene eluate from liquid column chromatography. The retention index used is normalized to the relative retention times of the n-alkanes. Thus, for example, the hydrocarbon n-hexadecane has a relative retention index equal to 1600, n-heptadecane equal to 1700, etc. Hydrocarbons having intermediate retention times between n-alkanes are assigned interpolated retention indices; for example, pristane (19 carbon atoms) has a retention index of 1670 and phytane (20 carbon atoms) a retention index of 1780 in as much as their peaks are eluted prior to elution of n-heptadecane and n-octadecane, respectively, on the columns in this study. Retention indices depend upon the nature and molecular size of the component being eluted. Thus, on FFAP, branched chain hydrocarbons elute earlier than the straight chain homologs of the same molecular weight. Also unsaturation of carbon to carbon bonds will cause that component to elute later than a saturated compound having the same number of carbon atoms.

RESULTS AND DISCUSSION

The HMWH , $\delta^{13}C$ and TOC data is reported in Tables IX-2 and 3 and Figures IX-1 to 5, along with the derived OEP values.

The TOC values at several stations are higher than the usual 1% for open shelf sediments and represents a higher level of production or lower rate of decomposition. The $\delta^{13}C$ values are similar to open shelf values. No oil is indicated.

TABLE IX-3

$\delta^{13}C$ and TOC for TOPO-HIGH Stations

Code	$\delta^{13}C$	TOC*
EFG1	-20.25	1.30
EFG2	-20.38	1.39
EFG3	-19.52	1.18
EFG4	-20.04	1.39
W561	-20.41	1.50
W562	-20.52	2.38
W563	-18.62	3.47
THB1	-18.19	.90
THB2	-19.89	1.31
THB3	-20.51	.85
THB4	-21.64	1.00
PBO1	-20.07	3.08
PBO2	-20.11	1.74
PBO3	-20.10	1.99
PBO4	-19.95	3.10
EF27	-21.53	1.24
EF37	-20.96	1.15

* TOC is percent total organic carbon on a carbonate free basis.

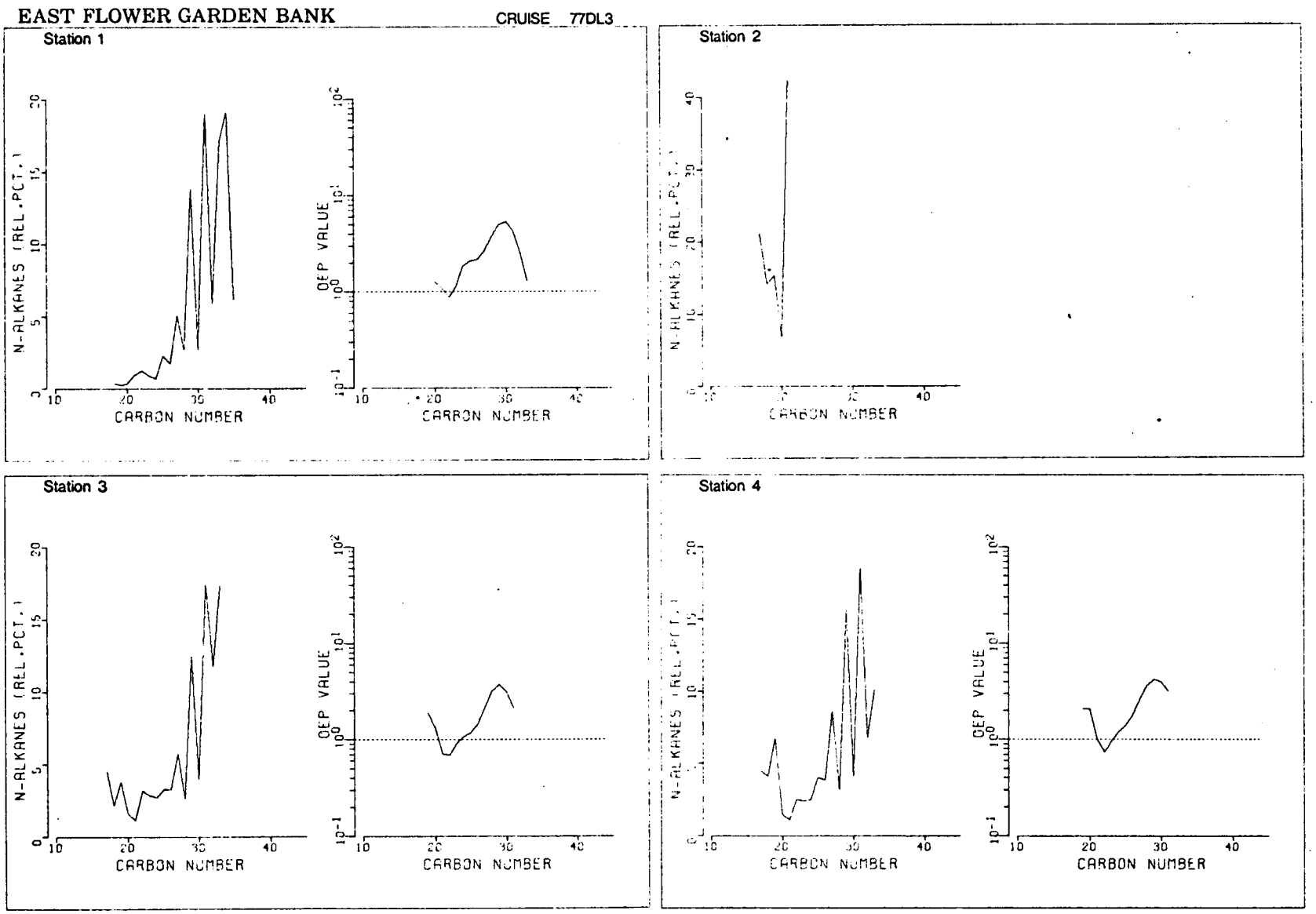

Figure IX-1. High molecular weight hydrocarbons and OEP values in sediments from East Flower Garden Bank, June, 1977.

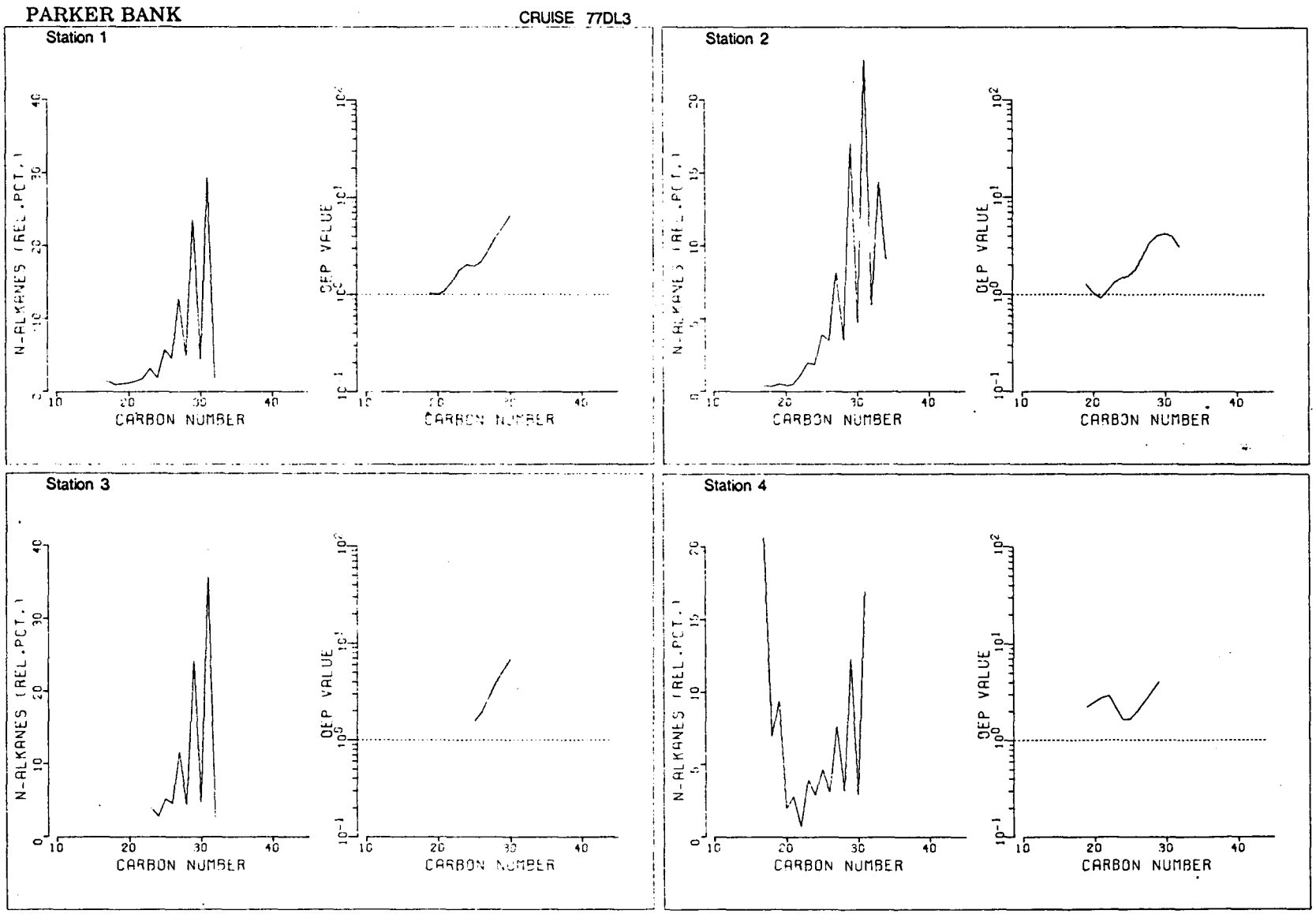

Figure IX-2. High molecular weight hydrocarbons and OEP values in sediments from Parker Bank, June, 1977.

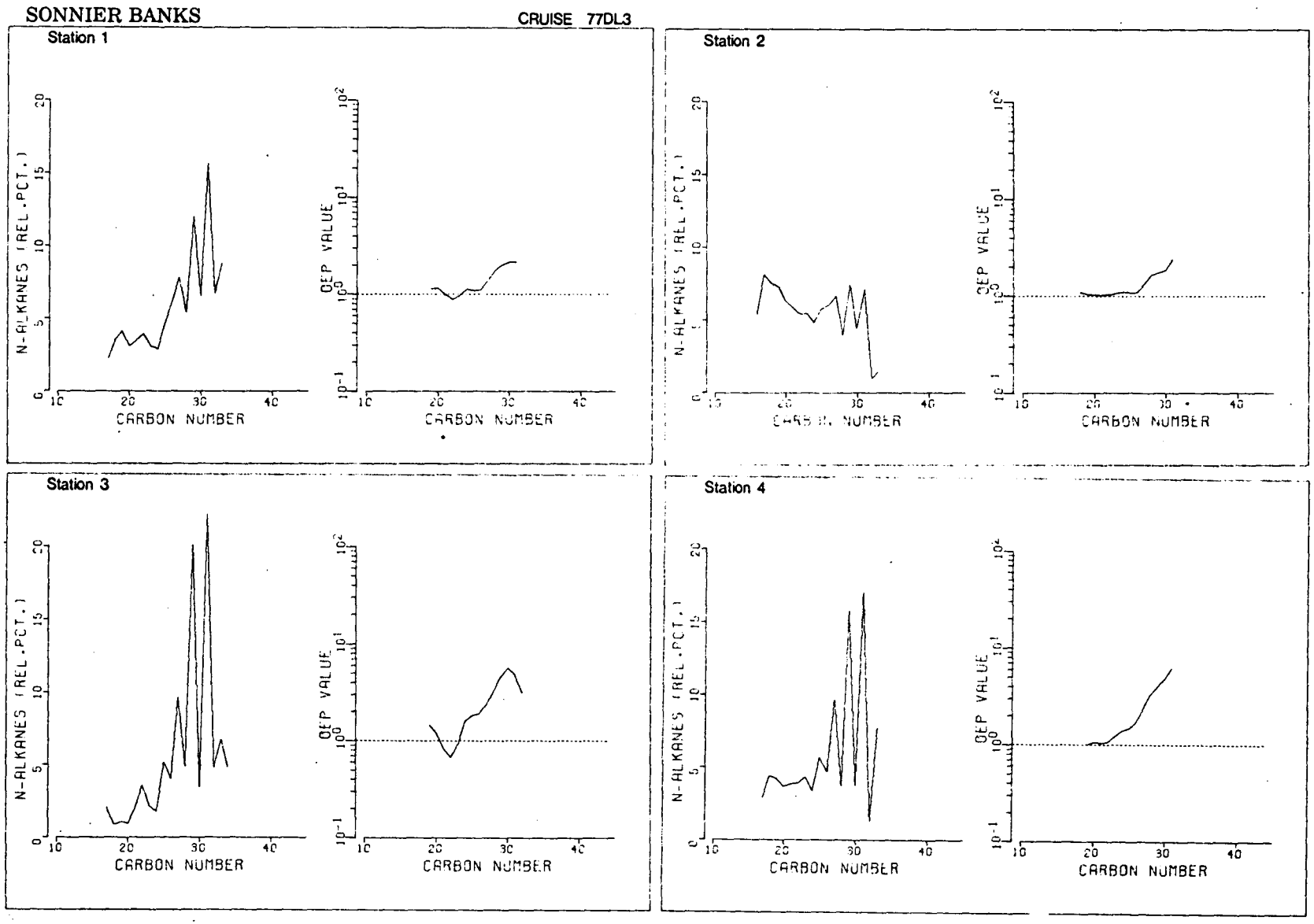

Figure IX-3. High molecular weight hydrocarbons and OEP values in sediments from Sonnier Banks, June, 1977.

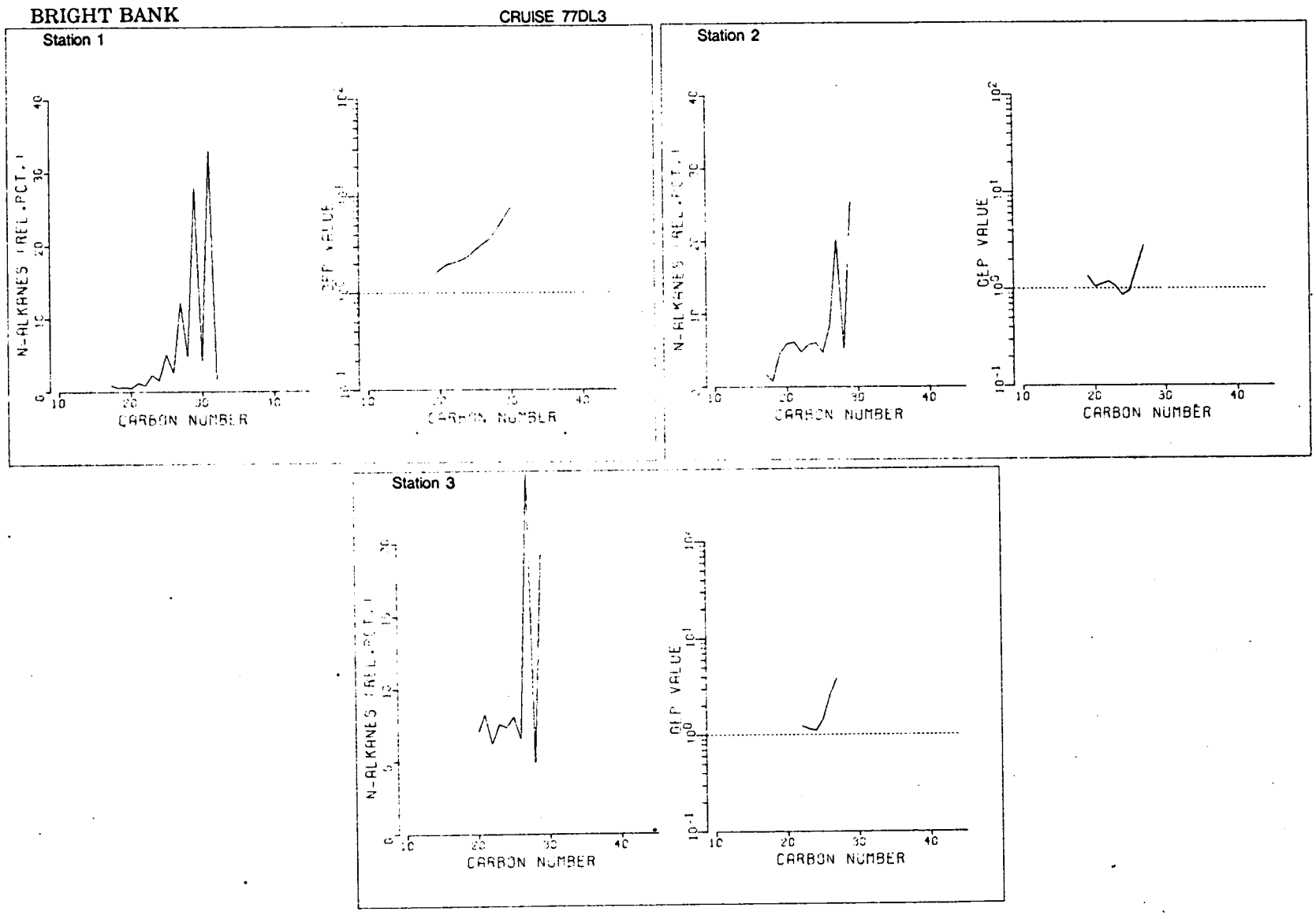

Figure IX-4. High molecular weight hydrocarbons and OEP values in sediments from Bright Bank, June, 1977.

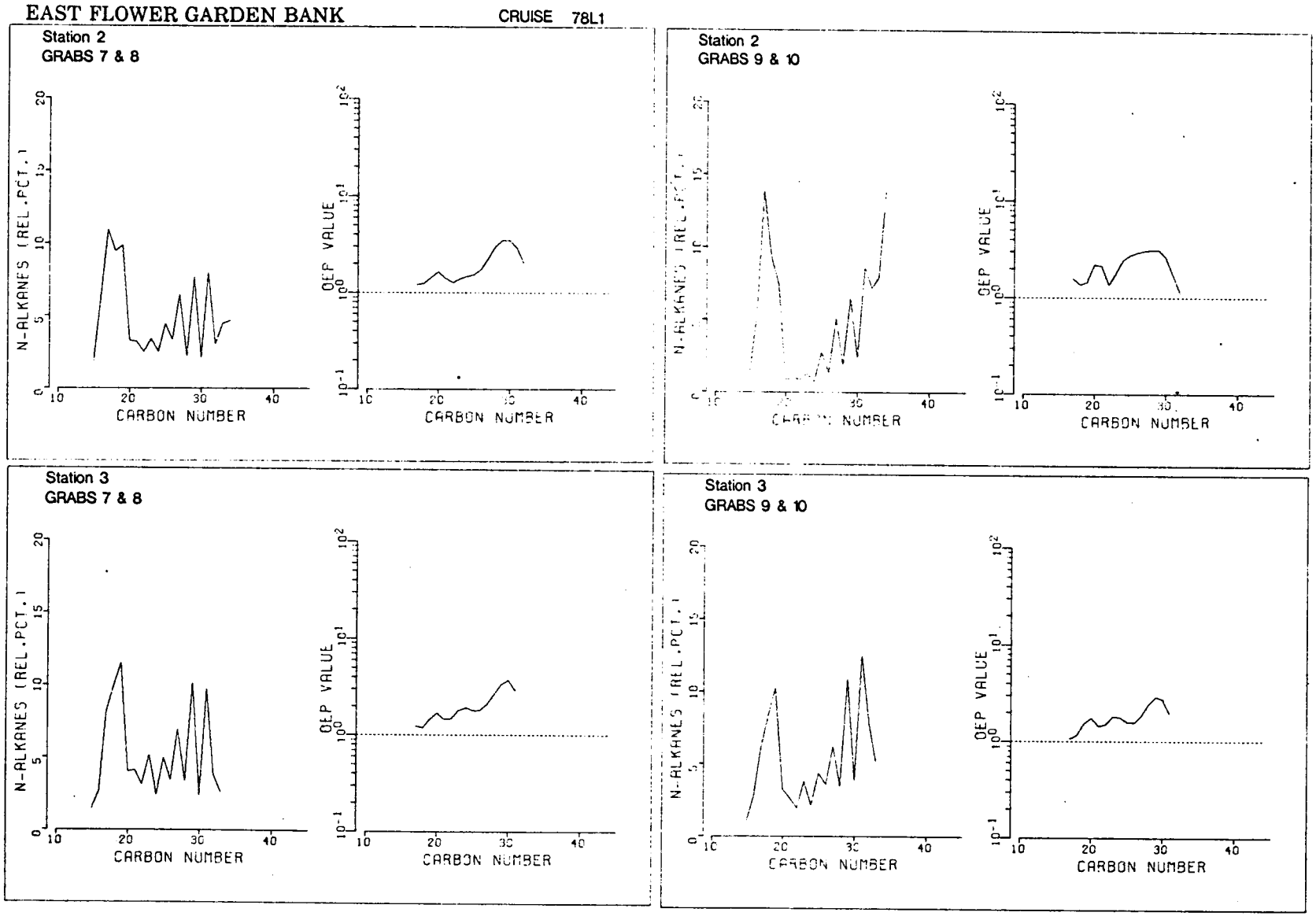

Figure IX-5. High molecular weight hydrocarbons and OEP values in sediments from East Flower Garden Bank, March, 1978.

CHAPTER X

CHEMICAL ASPECTS OF A BRINE POOL AT THE EAST FLOWER GARDEN BANK, NORTHWESTERN GULF OF MEXICO

CHEMICAL ASPECTS OF A BRINE POOL AT THE EAST FLOWER GARDEN BANK, NORTHWESTERN GULF OF MEXICO

by

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INTRODUCTION

In September 1976, a brine pool in a depression on the East Flower Garden (EFG) Bank (27°53'N, 93°38'W) was discovered at a depth of 72 meters using the Texas A&M University research submersible DR/V DIAPHUS and research vessel R/V GYRE (see Bright et al., 1978). The pool is approximately 30 cm deep and 30 m in diameter. The brine flows over a shallow sill (approximately 30 cm), down the axis of a canyon cut into the bank's hard carbonate substratum, and out onto the surrounding level, sandy bottom at 80 m depth. Visual observations indicate that the substained flow of hypersaline water through the 7 to 15 m deep canyon contributes locally to sediment transport and erosional processes resulting in movement of sand-to-cobble sized particle off the hard-bank. Disintegration and dissolution of the old reef, which at this depth is seemingly a coralline algal bioherm, also may be facilitated by the downhill flow.

The brine, no doubt, has its origin in the Triassic-Jurassic evaporite deposits which underlie most of the northwestern Gulf of Mexico. This salt has been displaced by thick overlying accumulations of sediments both laterally and vertically in many areas of the Gulf into ridges and stacks, and ultimately into narrow salt domes. The EFG bank is one of many salt diapirs which dot the northwestern Gulf. Salt tectonics on this shelf and slope may result in many such brine outflows, as witnessed by the recent fortuitous discoveries of the

[1]This work was supported by the Bureau of Land Management Contracts AA550-CT6-15 and AA550-CT7-11, and the National Science Foundation Grant OCE75-13299-A01.

EFG brine (Bright, 1977) and the Orca basin brine (2400 m depth, northwestern Gulf of Mexico, Shokes et al.,1977).

The EFG brine was observed and sampled in September 1976 and August 1977. We wish to thank W. M. Sackett for analysis of deuterium and D. F. Reid for analysis of radium in these brine samples. Dr. R. F. Shokes supervised the major cation analyses of the 1976 samples and Dr. B. J. Presley provided his laboratory facilities for most of the major ion analyses. Dr. Paul LaRock has made preliminary observations on bacteria collected from the brine. Dr. Richard Rezak detected the presence of gypsum on rocks taken from the pool.

METHODOLOGY

Samples from the EFG brine were obtained during 1976 by running a hose from the manipulator arm to a thru-hull valve in the submersible. After flushing the hose, samples were collected via tygon tubing into 500 ml citrate bottles and capped. Analyses of the samples were performed within a few days of collection. Salinity was determined by a refractometer; chloride by the Mohr titration with silver nitrate (Vogel, 1968); sulfate by barium sulfate gravimetry (Vogel, 1968); all the cations by atomic absorption spectrometry using a Jarrell-Ash Model 810 instrument; total carbon dioxide by infrared spectrometry using an Oceanography International, Inc. Total Carbon System; light hydrocarbons by multiple phase equilibrium (McAullife, 1971) using a Hewlett-Packard 5710 Gas Chromatograph; nutrients using a technicon Autoanalyzer (Strickland and Parsons, 1972); dissolved organic carbon (DOC) by wet oxidation (Fredericks and

Sackett, 1970); and stable isotopes using Nuclide and Micromass Isotope Ratio mass spectrometers (Sackett et al., 1970).

In 1977, water samples were obtained in the same general manner. Most samples were again taken in 500 ml citrate bottles, and capped for laboratory analyses, but this time were poisoned with sodium azide. However, dissolved gases were sampled differently and analyzed immediately upon return of the DR/V DIAPHUS to the R/V GYRE. Samples for gaseous hydrocarbons were drawn directly from the thru-hull valve of the submersible into syringes with Luer-Lok stopcocks. The syringes were then analyzed for light hydrocarbons by multiple phase equilibrium. Gas loss was negligible in the 1977 hydrocarbon samples, since any gas lost from solution as a result of the pressure decrease was collected in the syringe. Even without this precaution, there was good agreement in light hydrocarbon concentrations between the two samplings (1976 and 1977). Samples for helium analysis were also collected in syringes. Helium was determined using a modified Dupont Instrument Model 24-120B leak detector whose inlet is connected to a constant pressure reservoir by means of a variable leak valve. Gas extracted from solution was injected into the constant pressure reservoir where a constant into the mass spectrometer gave a current proportional to the ^{4}He content. Oxygen was determined by the Winkler method (Strickland and Parsons, 1972) and radium by the radon emanation method (Broecker, 1965). Following filtration of a 1-ℓ sample through a 0.40 μm Nucleopore filter and preservation in Tris buffer, ATP was determined following the technique of Holm-Hansen and Booth (1966).

RESULTS AND DISCUSSION

Although the salt concentration of the EFG brine is about 25% less than the Orca Basin and Red Sea Brines (Table IX-1), all have similar ionic ratios. The ionic composition of the EFG brine shows a depletion in potassium and magnesium and an enrichment in the other major ions relative to seawater. Tables IX-2 and IX-3 show analyses of the 1976 and 1977 brine samples, respectively. Station C (Table IX-2) and Station A2 (Table IX-3) represent samplings at the center of the brine pool almost one year apart. Although there are some minor differences in ionic composition, these are to be expected considering the dynamic nature of the brine seepage and the small reservoir that the pool represents. These ionic concentrations represent dissolution of a diapiric structure underlying the bank.

Both organic and inorganic carbon in the EFG brine are elevated compared to seawater. The DOC concentration of the brine is a factor of 3 to 5 times higher than overlying shelf waters. There are three possible origins for the elevated DOC levels in the brine. First, the organics could originate from the dissolving salt and be seeping into the pool along with the brine. This possibility is supported by Wilson (1964) who showed that brine pools where seawater was being evaporated during commercial salt recovery operations contained large concentrations of organic carbon. If this is the origin of the carbon in the brine, the organic matter would be expected to be an "old" and more refractory carbon reservoir. Second, the dissolved organic carbon could be derived from bacterial action on particulate organic carbon contributed to the brine pool by the high

productivity of the surrounding benthic and planktonic communities. There is a great deal of organic detritus swept into the pool from the bank itself, as evidenced by the presence of chunks of sponges, algae, mollusc shells, etc. However, the rate of conversion of particulate organics to soluble components by bacteria would have to be rapid considering the brine's short residence time in the pool. Third, organic matter could be produced in the brine by chemosynthetic bacteria themselves. Since the brine pool is well within the photic zone, bacteria could use inorganic hydrogen (e.g., H_2S, H_2, or organic compounds) to convert the energy of radiation directly into energy-rich compounds such as:

$$H_2S + CO_2 \xrightarrow{h\nu} (CH_2O) + 2S^o + H_2O \qquad (1)$$

The adaptability of photosynthetic bacteria to the hypersaline conditions of the brine pool is uncertain. The increased total carbon dioxide in the brine pool over normal seawater could come from dissolution of the salt deposit and/or bacterial sulfate reduction in the brine.

In the marine environment, dissolved oxygen is consumed and nitrate is reduced by organic degradation, phosphate levels increase from regeneration of organic phosphorous during bacterial degradation of organics and silica levels increase from dissolution of diatom frustules or diffusion from the sediments. The biologically sensitive chemical components in the brine indicate that the system has undergone a considerable amount of such biological perturbation. It is uncertain if these processes are continuing in the brine or if the chemical composition of the brine reflects its geochemical history. The variance in measured nutrient concentrations between

the two samplings may be attributed to the fact that samples for nutrient analyses were not filtered. Although samples were allowed to settle before analysis, small particulates from resuspended sediment could drastically affect silica levels. The distinct presence of hydrogen sulfide in the brine indicates that sulfate reduction has occurred.

The above perturbations could be remnants of previous biological processes and are not conclusive evidence for biological activity in the brine pool. The presence of active bacterial processes occurring in the brine or at the interface is, however, suggested visually by white, purple and olive sediment color variations within the pool and along its boundaries, by white particles floating on the brine interface, probably representing elemental sulfur, and by ATP measurements in the brine. ATP levels were about twice that of overlying shelf waters confirming the presence of bacterial activity in the brine. There are several possible chemical reactions mediated by bacteria that could be occurring in the brine including:

$$SO_4^{=} + 2(CH_2O) \rightarrow H_2S + 2HCO_3^- \quad (2)$$

$$SO_4^{=} + CH_4 \rightarrow HS^- + HCO_3^- + H_2O \quad (3)$$

$$H_2S + \tfrac{1}{2}O_2 \rightarrow S^o + H_2O \quad (4)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (5)$$

The presumed presence of elemental sulfur floating on the brine pool implies the presence of heterotrophic sulfide oxidizing bacteria (reaction 4) and/or photosynthetic sulfur bacteria (reaction 1). Heterotrophic sulfide oxidizing bacteria have been isolated and cultured from the brine (P. LaRock, personal communications). Bac-

teria such as Beggiatoa utilize both H_2S and O_2 and therefore can only grow at a diffusion gradient where both these gases simultaneously occur (Jorgensen, 1977). The brine interface apparently provides an excellent site for sulfide oxidation. The presence of autotrophic bacteria within the brine is only speculative at present. If these photosynthetic sulfur bacteria can survive in the hypersaline conditions, there is sufficient light and elevated levels of both H_2S and CO_2 to provide the necessary growth materials. Whether it is the heterotrophic or autotrophic bacteria or both supplying elemental sulfur to the pool, these bacteria must be in near exponential growth to supply the floating white particles that are continually overflowing the brine pool.

The presence of H_2S in the brine suggests the occurrence of reactions (2) or (3), although most of the H_2S probably enters with the brine (sour oil field brines containing H_2S are common in the Gulf of Mexico). Reactions (2), (3), and (5) appear to be occurring in the pool based on differences between two stations sampled in 1977. Sample A2 was taken in the middle of the brine pool and sample B9 from the overflow canyon almost immediately adjacent to the overflow. Salinity measurements of these two samples (Table X-3) indicate that sample B9 has not been diluted with seawater during flow over the sill. Since the residence time of the brine in the pool is probably not greater than two days, any chemical perturbation between these two samples has to result either from active bacterial processes in the brine or some flux across the seawater/brine or sediment/brine interfaces. Between these two stations there is an increase in ΣCO_2 from 25.0 to 48.0 mgC/ℓ. This would suggest that

either reaction (2) or (3) is occurring in the brine pool. Reaction (2), oxidation of organic matter by sulfate reduction, is routinely observed in oxygen deficient environments (Claypool and Kaplan, 1974), and reaction (3) has been inferred to occur in sulfate-reducing environments (Reeburgh, 1976; Barnes and Goldberg, 1976; Martens and Berner, 1977). Since samples for ΣCO_2 were not filtered, suspension of carbonate material could contribute to the elevated levels in the downstream sample, and this evidence for sulfate reduction in the brine is not conclusive. The decrease in sulfate between the two stations was not beyond the analytical precision of the sulfate determination, and cannot therefore be considered significant.

More conclusive evidence for active bacterial processes in the pool is seen in the molecular and isotopic differences in light hydrocarbons between stations A2 and B9. Methane increases from 2.7 ml/ℓ at station A2 to 8.9 ml/ℓ at station B9. This is a very significant increase in methane between these two stations considering that very careful sampling for gaseous hydrocarbons was performed on the 1977 cruise. The factor of three increase in methane concentrations between the two stations is not observed in the other gaseous hydrocarbons, which is further evidence that there is bacterial methane production in the pool and that the sampling does not merely represent intrapool variation. The carbon isotope ratio of the methane decreases from $-40^{o}/oo$ in the pool to $-47^{o}/oo$ along the outflow. This difference is significant considering that the isotopic composition in the brine pool changed only $2.5^{o}/oo$ between the 1976 and 1977 samplings. Bacterially-derived methane is more negative (lighter) than $-60^{o}/oo$ (Bernard _et al._, 1977). The change from -40

to $-47^{o}/oo$ implies a bacterially-derived addition of methane to the water between the two stations. Considering the mass balance, mixing of the methane with a carbon isotope ratio of $-40^{o}/oo$ with biogenic methane of $-60^{o}/oo$ in the proportions indicated above will not result in a mixture with an isotope ratio of $-47^{o}/oo$. This discrepancy may be explained by possible methane oxidation (reaction 2) which would preferentially utilize the lighter methane. It is possible that the brine at station B9 does not represent brine outflow from the main pool, it could have seeped directly out of the substratum forming a separate small pool coincident with the position of the overflow. Additional sampling will be required to resolve questions relating to apparent CO_2 and methane enrichment, and their implications, in the brine pool.

The molecular and isotopic composition of gaseous hydrocarbons in the EFG brine indicate a thermocatalytic origin. Bernard _et al_.(1977) indicate that most thermocatalytic gas mixtures in the Gulf of Mexico have $C_1(C_2+C_3)$ ratios less than 50. The $C_1(C_2+C_3)$ ratio in the brine pool during both samplings was less than 10. This compares to a $C_1/(C_2+C_3)$ ratio of several hundred for the Orca basin brine (Weisenburg _et al._, 1978). The heavy carbon isotopic content of the EFG brine (-40 to $-43^{o}/oo$) compared to the Orca basin ($-74^{o}/oo$) is also indicative of a thermocatalytic origin as compared to a biogenic origin for the Orca basin. This thermocatalytic gas is to be expected since the bank is a site of active petroleum drilling. A gas seep collected on the EFG bank (Bernard _et al._, 1976) also showed thermocatalytic hydrocarbons. The $\delta^{13}C$ of methane from this seep was $-51^{o}/oo$. The EFG brine apparently originates from a diapiric

structure which has accumulated many stratigraphic hydrocarbon traps around its margin.

The δD of the water from the brine is identical to shelf water from this region, within experimental error. The brine could, therefore, represent dissolution of the salt diapir by sea water that has been percolated down through the overlying sediments. Helium is high in the brine since it originates from alpha decay of uranium series nuclides and accumulates in sediments in a manner similar to hydrocarbon gases. The ^{226}Ra level (2.9 dpm/ℓ) is comparable to the Orca brine (R. Key, personal communication) but is almost two orders of magnitude lower than typical oil field brines. In addition, ^{226}Ra levels of brines produced by solution mixing of 4 different salt domes from the Gulf coast region were all below 10 dpm/ℓ (D. Reid, personal communication). These observations suggest that the East Flower Garden brine seep is the product of dynamic dissolution of a salt dome rather than a brine spring. Carbon-14 measurements on the inorganic carbon of the brine seep would further establish the age and origin of the brine water.

CONCLUSIONS

The EFG brine has its origin in the evaporite deposits that underlie the réef bank. Molecular and isotopic comparisons of the EFG and Orca basin brines (Table X-4) indicate that although these brines both originate from Gulf evaporite deposits, they have different histories. The low $C_1/(C_2+C_3)$ ratio resulting from appreciable quantities of ethane and propane and the heavy carbon isotope ratio of methane ($-40^{o}/oo$) in the EFG brine are indicative of thermocata-

lytic hydrocarbons common in oil field produced brines in this region. The Orca basin shows typical biologically produced hydrocarbon compositions with $C_1/(C_2+C_3)$ ratios in the hundreds and $\delta^{13}C$ ratios around $-74^{o}/oo$.

The other major difference between the Orca and EFG brine is in bacterial activity. The extent of bacterial activity in the Orca Basin brine is unknown, although recent measurements indicate that only very low levels exist. The low level of hydrogen sulfide in the Orca Basin is further evidence for its low bacterial activity. It is uncertain at present why there is such a large difference in bacterial activity in these brines, as their carbon reservoirs and nutrient levels are similar. There may be a threshold salinity above which anoxic, hypersaline bacteria cannot function. The presence of light and H_2S as a hydrogen source may also contribute to higher bacterial levels in the EFG brine. The temperature and pressure difference between 72 and 2400 m may also be a controlling factor.

Further studies are continuing at the EFG brine seep to determine the origin of the brine, the cycling of carbon in the reservoir, and bacterial perturbations of chemical constituents within the pool and overflow canyon. The brine seep is a unique biogeochemical phenomenon and should be recognized as being worthy of environmental protection and preservation for its intrinsic scientific value.

TABLE X-1

CHEMICAL COMPARISON OF NATURAL BRINES

RATIO TO 35 ppt SEA WATER	ORCA BASIN	EAST FLOWER GARDEN*	RED SEA	LOUISIANA PETROLEUM* A	LOUISIANA PETROLEUM* B
SALINITY	7.3	5.3	7.2	7.0	7.7
Cl^-	7.7	6.3	8.0	7.3	8.2
Na^+	8.5	5.6	8.6	8.1	9.5
K^+	1.6	0.9	5.4	1.1	0.13
SO_4^{2-}	1.4	1.7	0.3	5.2	1.5
Mg^{2+}	0.8	0.9	0.6	0.7	0.2
Ca^{2+}	2.7	3.2	11.5	1.9	3.3
ELEMENTAL RATIOS BY WEIGHT					
Na/Cl	.612	.498	.598	.623	.643
K/Cl	.004	.003	.014	.003	.0003
SO_4/Cl	.024	.038	.005	.100	.026
Mg/Cl	.007	.009	.005	.006	.002
Ca/Cl	.007	.011	.030	.006	.008

*Louisiana Petroleum Brine A: Gulf of Mexico; 29°05'N, 90°10.5'W

Louisiana Petroleum Brine B: Gulf of Mexico; 29°04'N, 90°08.0'W
(Data provided courtesy U.S.G.S.)

*Ratios are that of the 1976 sampling.

TABLE X-2

CHEMICAL ANALYSES OF EAST FLOWER GARDEN BRINE - 1976

Parameter	Stations* A	B	C
Salinity+	39.6 g/kg	48.4 g/kg	188 g/kg
Salinosity+	39.7 g/ℓ	48.5 g/ℓ	211 g/ℓ
Potassium	0.421 g/kg	0.426 g/kg	0.375 g/kg
Calcium	0.446 g/kg	0.513 g/kg	1.309 g/kg
Sodium	13.3 g/kg	12.7 g/kg	61.1 g/kg
Magnesium	1.421 g/kg	1.387 g/kg	1.133 g/kg
Chloride	22.2 g/kg	28.2 g/kg	122.8 g/kg
Sulfate	2.82 g/kg	2.81 g/kg	4.70 g/kg
	29.4 mmoles/ℓ	29.4 mmoles/ℓ	54.9 mmoles/ℓ
Salinity (sum of ionic species)	40.6 g/kg	46.0 g/kg	191.4 g/kg
ΣCO_2	20.6 mgC/ℓ	22.3 mgC/ℓ	33.5 mgC/ℓ
Methane	42 µl/ℓ	140 µl/ℓ	2.0 ml/ℓ
Ethane	2.8 µl/ℓ	9.5 µl/ℓ	0.24 ml/ℓ
Propane	<10 nl/ℓ	<10 nl/ℓ	1.21 µl/ℓ
$C_1/(C_2+C_3)$	15	15	8.3
$\delta^{13}C$ $[CH_4]$	-	-	-42.5°/oo
δD_{smow} $[H_2O]$	+4.6±2°/oo	+2.9±2°/oo	+3.2±2°/oo
Phosphate	1.89 µM	3.13 µM	>7.5 µM
Nitrate	8.1 µM	7.9 µM	3.6 µM
Silicate	3.8 µM	5.3 µM	16.3 µM
DOC	1.62 mgC/ℓ	1.37 mgC/ℓ	4.56 mgC/ℓ

*Station C is in the brine lake, Station B is in the overflow canyon and Station A is at the base of the canyon.

+Refractometer

TABLE X-3

CHEMICAL ANALYSES OF EAST FLOWER GARDEN BRINE - 1977

Parameter	Station* A1	A2	B8	B9
Salinity+	36.7 g/kg	195.2 g/kg	36.1 g/kg	198 g/kg
Salinosity+	36.7 g/ℓ	215.6 g/ℓ	36.1 g/ℓ	219 g/ℓ
Potassium	0.407 g/kg	0.363 g/kg	0.391 g/kg	0.353 g/kg
Calcium	0.441 g/kg	1.617 g/kg	0.423 g/kg	1.653 g/kg
Sodium	11.3 g/kg	79.3 g/kg	11.2 g/kg	75.8 g/kg
Magnesium	1.327 g/kg	1.067 g/kg	1.326 g/kg	1.018 g/kg
Chloride	20.1 g/kg	131.0 g/kg	19.7 g/kg	135.9 g/kg
Sulfate	2.77 g/kg	4.42 g/kg	2.75 g/kg	4.37 g/kg
	29.6 mmoles/ℓ	52.1 mmoles/ℓ	29.3 mmoles/ℓ	51.5 mmoles/ℓ
Salinity (sum of ionic species)	36.4 g/kg	217.8 g/kg	35.8 g/kg	219.1 g/kg
ΣCO_2	20.2 mgC/ℓ	25.0 mgC/ℓ	21.0 mgC/ℓ	48.0 mgC/ℓ
Methane	940 μl/ℓ	2.73 ml/ℓ	-	8.90 ml/ℓ
Ethane	54 μl/ℓ	0.414 ml/ℓ	-	0.500 ml/ℓ
Propane	70 μl/ℓ	14.7 μl/ℓ	-	18.6 μl/ℓ
Iso-Butane	-	2.6 μl/ℓ	-	3.4 μl/ℓ
n-Butane	-	0.45 μl/ℓ	-	<0.3 μl/ℓ
$C_1/(C_2+C_3)$	15.4	6.4	-	17.2
$\delta^{13}C$ [CH_4]	-	-40.0	-	-47.1
Phosphate	0.31 μM	2.36 μM	0.47 μM	4.00 μM
Nitrate	1.1 μM	0.8 μM	1.3 μM	0.3 μM
Silicate	27.2 μM	203 μM	30.6 μM	192 μM
ATP	43.5 ng/ℓ	83.3 ng/ℓ	38.5 ng/ℓ	-
Radium-226	-	2.9±0.2 dpm/ℓ	-	-
Helium	-	0.8 μl/ℓ	-	-
Dissolved O_2	3.01	0.0	4.38	0.0

*Station A1 is 20 cm above interface in center of main pool, Station A2 is in main pool, Station B8 is 20 cm above Station B9, and Station B9 is in a small brine pool just below and a few meters downstream of the point at which brine overflows from the main pool.

+ Refractometer

TABLE X-4

COMPARISON OF ORCA BASIN AND EAST FLOWER GARDEN BRINES

Parameter	Orca[1] Basin	East Flower Garden
CH_4 (ml/ℓ)	≥20	2.7
C_2H_6 (ml/ℓ)	≥0.03	0.4
C_3H_8 (μl/ℓ)	0.01	14.7
$C_1/(C_2+C_3)$	670	6.4
$\delta^{13}C$ [CH_4] (°/₀₀)	-73	-40
DOC (mgC/ℓ)	3	4
$\delta^{13}C$ [DOC] (°/₀₀)	-27	-
ΣCO_2	50	30
$\delta^{13}C$ [ΣCO_2] (°/₀₀)	-16	-
δD_{smow} [H_2O] (°/₀₀)	-3±2	+3±2
Radium (dpm/ℓ)	-	2.9±0.2
Helium (μl/ℓ)	-	0.8
ATP (ng/ℓ)	-	80

[1]After Weisenburg *et al.* (1978) and Sackett *et al.* (1978).

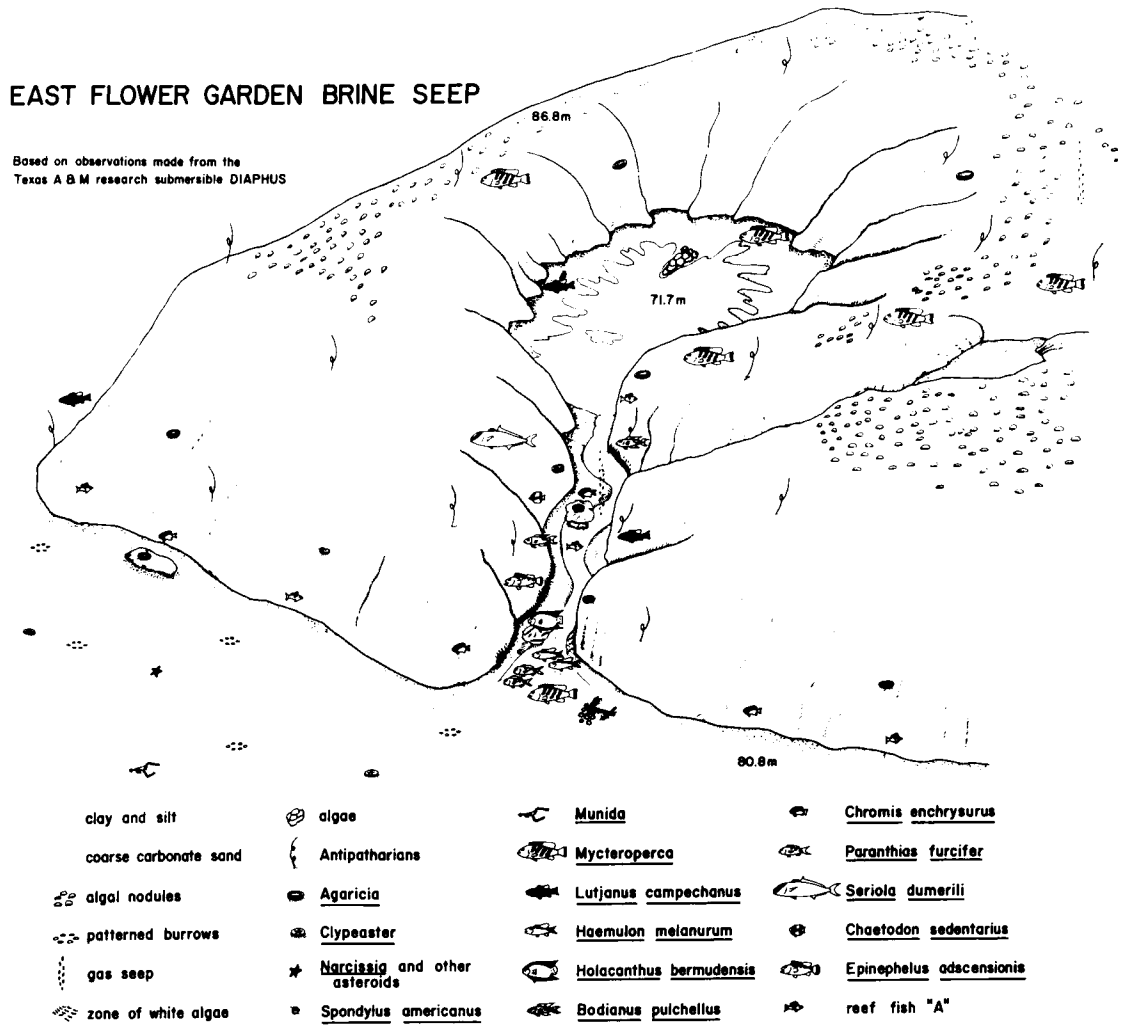

Figure X-1. East Flower Garden Brine Seep.

CHAPTER XI

THE MEIOFAUNA AND MACROINFAUNA FROM SUBMARINE BANKS IN THE GULF OF MEXICO

THE MEIOFAUNA AND MACROINFAUNA FROM SUBMARINE BANKS IN THE GULF OF MEXICO

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INTRODUCTION

OBJECTIVES OF THE STUDY

The principal objective of this study is to provide an understanding of the composition and density of the meiofaunal and macroinfaunal populations living on or around the flanks of the hardbanks called East Flower Garden Bank and Sonnier Banks that are located on the outer continental shelf off the Louisiana/Texas coast. Evidence is mounting that the meiofauna and macroinfauna, through differences or changes in their diversity and/or population densities, permit estimates as to the magnitude of some physical parameters, such as current speed and direction, and provide excellent subjects for judging the impacts of sedimental and other environmental changes that usually accompany the discovery and production of oil and gas.

COMPARISON WITH THE PREVIOUS STUDY

It is important to note that the general biological findings in the present study closely parallel those reported last year. For instance, nothing particularly new was found in regard to numerical dominants among either the meiofauna or the macroinfauna. Also, the same depressing effect of increasing depth upon the meiofaunal populations were observed. Moreover, it was particularly satisfying to find that the same increases in meiofaunal populations occurred on the downcurrent aspects of Sonnier Banks and East Flower Garden Bank, as had been found for the banks studied by us last year. These close similarities of findings have excellent corroborative value and at the same time permit reiterative presentation of data.

BACKGROUND

Definitions

The term meiofauna refers to a taxonomically diverse and numerically abundant assemblage of animals that are further described by their small size. In early studies the meiofauna was separated from the macroinfauna by means of sieves having a mesh opening of 1.0 mm; more recently, however, the upper limit of size is taken as 0.5 mm (McIntyre, 1964; Tietjen, 1969, 1971; Coull, 1970; McIntyre and Murison, 1973; and Gettleson and Pequegnat, 1976). The lower limit has also been variable, but 0.062 mm is now the usual mesh size employed for extraction. Accordingly, the meiofauna in this study is defined by passage through a 0.5 mm and retention on a 62-micron sieve, whereas all other organisms taken by the grab and retained on the 0.5 mm sieve are designated as macroinfauna.

Permanent and Temporary Meiofauna

The meiofauna is composed of both a permanent, and more numerically stable set of organisms as well as a temporary, numerically variable group composed of juvenile macroinfaunal forms (McIntyre, 1961, 1964; Thorson, 1966). The permanent or true meiofauna differs from the macroinfauna not only in size, but also in regard to number, average generation time, and morphological adaptations to their environment. Some protozoans meet the size requirements of the meiofauna but, as Thiel (1975) points out, the Foraminifera have been excluded from most investigations on deep water meiofauna. Up to now, the foraminifers are grouped together with the multicellular meiofauna in only three publications (Wigley and McIntyre, 1964; Tietjen, 1971; and Thiel, 1975). There are several

reasons for this deletion, among them being the difficulty of separating live from dead individuals because material in the tests others than protoplasm may stain red with rose bengal. On the basis of numbers alone, it would appear that they should be included in meiofaunal studies. The present study, as well as the work of others (Wigley and McIntyre, 1964; Tietjen, 1971; and Thiel, 1975), shows that the Foraminifera often are either the most numerous group or the second in abundance behind the nematodes.

Even so, in this report, the metazoan meiofauna are placed in the category of "true" meiofauna (all of which are permanent) and the Foraminifera and temporary meiofauna are lumped into a second category.

The Macroinfauna

The macroinfauna is characterized by two factors, namely size and biotope within the substratum. As indicated above, these organisms are upwards of 0.5 mm in length or diameter. For the most part, infaunal organisms live burrowed or buried in sediments. Some may live only partially buried at the water/sediment interface. By contrast, those animals that live on the surface of either hard or soft bottoms constitute the epifauna. Both the macroinfauna and the meiofauna have some infaunal and epifaunal components.

Previous Work

As Thiel notes, effective work on offshore meiofauna was started as late as 1964 when Wigley and McIntyre (*loc. cit.*) obtained quantitative samples from a transect on the North American Atlantic shelf and down the continental slope to about 600 m. In addition, quantitative samples were taken from slope to abyss by McIntyre from DISCOVERY (Warwick, 1973) and by Thiel from METEOR (Thiel, 1966) both in 1964/1965 in the Arabian Sea.

The meiofauna has received very little attention in the sublittoral of the Gulf of Mexico. Pequegnat and Gettleson (1974) listed the number of individual in major meiofaunal and macroinfaunal taxa from five stations in the vicinity of Stetson Bank. In 1976, they examined meiofaunal-sediment correlations from 24 stations located on the outer continental shelf of south Texas. Gettleson and Pequegnat (1976) reported on an intensive study of the wet weight and abundance of the meiofauna and macroinfauna taken from 10 stations on the outer continental shelf of east Texas. Prior to this report, there have been only a limited number of sublittoral studies in which the wet weight and/or abundance of the meiofauna and macroinfauna have been compared. Krogh and Sparck (1936) described the fauna contained within several cores taken in Copenhagen Harbor; Mare (1942) examined the flora and fauna of a small area in the English Channel; Sanders (1958) examined the macroinfauna and Wieser (1960) the meiofauna of three stations in Buzzards Bay, Massachusetts; McIntyre (1961, 1964) studied two areas off Scotland (Loch Nevis and Fladden Ground, North Sea); Wigley and McIntyre (1964) analyzed ten samples from a transect (40 to 567 m off Massachusetts); Guille and Soyer (1968, 1974) studied the fauna off the French Banyuls-sur-Mer coast (Mediterranean); Stripp (1969) examined samples from the Helgoland Bight (North Sea); Ankar and Jansson (1973), Elmgren (1972), Ankar and Elmgren (1975), and Jansson and Wulff (1977) analyzed samples from the Baltic Sea.

Nematodes usually dominate the meiofauna; however, their systematics and ecology have been neglected to a great extent. Only six known papers have been published on Gulf of Mexico nematology, and all of the material was from the littoral zone (Chitwood, 1951; Chitwood and Timm, 1954; Hopper, 1961a, 1961b, and 1963; King, 1962). Hulings (1967) reviewed

previous papers dealing with the systematics and ecology of podocopid and platycopid ostracods in the Gulf of Mexico. Disregarding the foraminiferans, no other published reports on the components of the permanent meiofauna of the sublittoral Gulf are known. There are, however, a number of papers describing the living, soft-bottom foraminiferans of the Gulf. Phleger's (1951) study dealt with an area similar to that of the present study, but his total number of identified living forms was very low (16) due to the unreliable biuret test used to distinguish living from dead individuals. Phleger (1956) used the more accurate rose bengal method to detect living forms. Walton (1964) in a study of the central Texas coast and continental shelf was able to discriminate among four depth-related assemblages on the shelf. Other foraminiferal studies in the Gulf of Mexico have also resulted in depth-related biofacies. Phleger (1951) recognized six depth facies, Bandy (1954) three within water depths of 8 to 37 m, Parker (1954) six in the northeast Gulf, and Bandy (1956) described five major facies also in the northeast Gulf. Phleger (1960) reviewed much of the Gulf of Mexico foram work. Other studies of living, sublittoral, Gulf of Mexico foraminiferal distributions since 1960 include Walton (1964), Loep (1965), Lankford (1966), Greiner (1970), Poag and Sweet (1972), and Buzas (1967, 1972).

According to Valentine (1963), Pulley (1952) divided the Atlantic and Gulf coasts into eleven provinces based on macroinfaunal pelecypod distributions that were correlated with mean maximum and minimum land temperature differences. Pulley proposed four biotic provinces within the Gulf, and the present study area is included within his "Offshore West Indian Province." Parker (1960) sampled the molluscan macroinfauna of the Texas-Louisiana shelf and utilizing the climatic zones proposed by Hedgpeth (1953) in addition to physical boundaries (e.g., sediment type),

he divided the area into five provinces. The "West Louisiana" province encompassed the longitude of the present region of study, but Parker's provinces generally extended to only twenty meters of depth. Parker (1975) presented a schematic diagram of theGulf of Mexico that included the climate, hydrography, sediment, and measures of benthic community structure such as species diversity. He divided the Gulf into six major areas, but only on the basis of data collected from bays and estuaries.

Hulings (1955) established a transect of 51 stations that extended from the shore near Sabine Pass, Texas to a point approximately 28 kilometers seaward. Water depth along the transect did not exceed twenty meters. Grabs, dredges, and coring gear were utilized for sample collection. Two hundred and twelve species were identified and 72% were mollusks, most of which were dead. The sampling methods allowed only qualitative interpretation of the data, and while assemblages were not specifically determined, the data could have been interpreted in such a manner.

Parker (1956) sampled 280 stations that were located within the east Mississippi Delta region, using an orange-peel bucket grab as well as several dredges and trawls. Three hundred and fourteen species were identified of which greater than 70% were mollusks. He described seven assemblages that ranged from the delta marshes to the inner and outer continental shelf and were based on the predominantly dead mollusks. The outer shelf assemblages were described as "distinct," but of the 122 species identified only 17% were living at the time of collection.

Kennedy (1959) collected samples at 18 stations along a transect that extended across the continental shelf from a point near shore that was midway between Galveston Bay and Sabine Lake. His stations 14 and 15 were within the present area of investigation. He identified 245 species

of mollusks from dredge samples. The species were divided into three major assemblages: a shallow shelf group, a deep shelf biofacies, and a transitional zone at intermediate depths. Of the 170 species occurring on the deep shelf, 62% were restricted to that assemblage. One hundred species were listed as characteristic of the assemblage, but only two were alive when collected. The author stated that the three major assemblages might easily be subdivided into smaller groups. The deepest of the 18 stations was, it seemed to Kennedy, distinct from the remainder of the outer shelf assemblages.

Parker (1960) collected 300 samples on the continental shelf and upper slope off Mobile, Alabama to Port Isabel, Texas. Sampling gear included van Veen and orange-peel grabs, dredges, and trawls. Samples were washed through a 1.0 mm mesh screen. Though no precise positions were given for the stations, it appears that two or three of the stations may have been within the present sampling area. Four soft bottom shelf assemblages were recognized by Parker as follows: inner shelf, intermediate shelf, outer shelf, and pro delta. Parker (1960) showed that the intermediate shelf assemblage was actually composed of two distinct faunal groups, one existing within silt-clay bottoms and the other within sandy bottoms. However, the two groups had enough forms in common to be considered a single assemblage by Parker. The assemblages were composed of mainly dead mollusks as only 37 living individuals were encountered in 13 samples collected from depths of 37 to 73 meters. Because so few living individuals were collected, Parker correctly stated that it would be impossible to locate exact boundaries for the assemblages.

Neumann (1958) in a primarily geological study of Stetson Bank, which lies within the study area, identified mostly dead mollusks that were obtained by washing the contents of a van Veen grab through a 0.635 mm screen.

He proposed an "on-bank" and an "off-bank" assemblage of the mollusk species.

Keith and Hulings (1965) reported major differences in the species composition of the fauna inhabiting sand and mud bottoms. The samples were collected in approximately two meters of water in an area from Sabine Pass to Bolivar Point.

Harper (1970), utilizing a dredge, collected seasonal samples from water depths of three to eleven meters in an area off Galveston Island. The samples were washed through a 1.0 mm mesh sieve and 64 species were identified from the sandy, mixed, and muddy sediments. Harper used numerical dominance and restricted substrate preference to delineate certain species groups that were characteristic of the three bottom types. He found that Parker's (1960) inner shelf assemblage should have been subdivided into three more natural groups that correspond to the sediment types in the Galveston area, viz., Sandy Bottom, Muddy Bottom, and Mixed Bottom.

Based on the analysis of 146 trawl samples collected primarily on the shelf of the northern Gulf of Mexico, Defenbaugh (1976) established twelve faunal assemblages on the shelf and upper slope of the northern Gulf of Mexico. Defenbaugh established inner, intermediate, and outer shelf assemblages, dividing them longitudinally into Louisiana-Texas and West Florida shelf portions. In addition, he established a pro-delta fan and sound assemblages and two submarine bank assemblages, again subdividing them into Louisiana-Texas and West Florida shelf units, as he does the upper slope assemblage.

Holland (1977), by the use of cluster analysis, found, on the south Texas continental shelf, three faunal zones, shallow, mid-depth and deep

station zones, which shifted slightly seasonally. However, he considered the mid-depth station zone to be a depauperate extension of the shallow faunal assemblage because it has no unique species but shared many species unique to the shallow zone as well as ubiquitous species from both shallow and deep zones. Sediment type was also considered; however, the cluster analysis indicated that depth, or the more stable physical environment associated with depth, was more important than substrate in regulating infaunal distribution over wide areas of the shelf.

Conversely, Holland (op. cit.) found at two bank locations two basically different sediment types in near bank area to which he ascribes considerable impact on infauna. One type, a primarily shelly bottom, was found at two stations located on the southwestern side of Hospital Rock and Southern Bank, which had large amounts of gravel-sized rubble and shell material. The other sediment type found at the remaining near bank stations was silt/clay. The communities at the shelly stations were found to be different in species composition, much more diverse and contained far greater numbers of individuals than the silt/clay stations. The silt/clay stations on the other hand were comprised of the more ubiquitous species found in the STOCS area and the general community structure was not significantly different than that expected of normal soft-bottom communities of the Gulf.

METHODS AND MATERIALS

SAMPLING STATIONS

Both the meiofaunal and macroinfaunal samples were collected by means

of a Smith-McIntyre grab that encompasses 0.1024 m^2 of the bottom. Two studies (Smith and Howard, 1972; Dickinson and Carey, 1975) have shown that the Smith-McIntyre grab is a reasonably effective sampler of the macroinfauna living in the upper 5 or so centimeters of the sediments. Because a very high percentage of the meiofauna occur in this stratum, the grab is an even more efficient sampler of this group.

Four sampling stations were established on each of the banks. Attempts were made to establish both upstream and downstream stations. On the basis of the limited data available, it was assumed that the principal flow of bottom water was to the southwest. The stations at East Flower Garden were more nearly around the bank's flanks, whereas those at Sonnier Banks were taken on the bank proper to better accommodate to the needs of a multipurpose cruise.

SAMPLING PERIODS

The four stations on East Flower Garden were sampled in June and September of 1977 and in March of 1978. The four stations on Sonnier Banks were sampled only in June of 1977.

SAMPLE PROCESSING

On deck all meiofauna samples were taken from the grab by means of a plexiglass core tube of 3.42 cm diameter (internal area = 9.187 cm^2) that was pushed into the sediment to a depth of 5 cm. Four such cores were taken and the enclosed sediment was extruded into 8 oz. glass jars. One sample was frozen immediately. The remaining three samples were anesthetized in isotonic $MgCl_2$ for 10 minutes and then placed in 10%

buffered formalin. Only two of the three samples were to be sorted and these received rose bengal in the formalin.

Six grab samples for macroinfauna were taken at each station. The entire contents of each grab was sieved aboard ship. A small amount of sediment was taken immediately from all samples for grain size analysis. The remainder of the sediment was then washed through a series of nested sieves (6.35, 1.0, and 0.5 mm). The material on each sieve was placed immediately in 0.15% propylene phenoxetol for 15 minutes to anesthetize the organisms. They were then transferred to 7% buffered formalin.

In the laboratory the stained meiofauna samples were sieved through 8-inch diameter 500 and 62 micron mesh sieves. The material retained on the smaller sieving was washed into 2 oz. squat jars with 10% buffered formalin, to which 10 ml of rose bengal in formalin (200 mg/l) was added. After the sample had been allowed to stain for between 24 and 48 hours, it was washed in a 3-inch diameter, 62-micron sieve to remove excess stain and then aliquoted into an 80 x 40 mm rectangular sorting dish marked off in a 7 mm square grid. The whole sample was then examined microscopically and the sorted animals placed in vials. When the number of nematodes exceeded 150, the 150 were vialed and the remainder were only counted and archived.

The macroinfauna samples were sugar floated with a saturated water-sugar solution in order to obtain the lighter organisms promptly. The sediment mixture was then stained with rose bengal and again sorted for bivalves and those animals not recovered during flotation. Finally, the remaining material was examined microscopically for extraction of the smallest organisms.

RESULTS

NUMERICAL DOMINANCE AMONG MEIOFAUNA TAXA

Nematodes are the dominant true meiofauna group on the two hard banks studied in 1977-1978, averaging 83% of the total individuals of true meiofauna per station (Appendix A, Tables XI-1 through XI-4) or about 191,470 individuals per m^2 of surface sampled to a depth of 5 cm at the base of the bank. On the bank proper, as on Sonnier Banks, nematodes may account for only 72% of the true meiofauna, and the harpacticoids increase. The harpacticoid copepods are generally a poor second, averaging 10% of the total individuals or 23,029 individuals per m^2 of surface sampled to a depth of 5 cm on the flanks of the reef. On the bank proper they can account for as much as 17% of the total individuals. Excluding the nauplii, the kinorhynchs are third in importance, but they range from a high of 14,150 individuals per m^2 on shallow banks to a low of $540/m^2$. In general, the nematodes form a smaller percentage and the harpacticoids and kinorhynchs a higher percentage of the total meiofauna of banks than they do of the level bottom stations on transects. For instance, Pequegnat (1976) found nematodes to average over 89% of the meiofauna populations on level bottoms off Corpus Christi, Texas, whereas harpacticoids averaged only 2.25%.

The foraminiferans and polychaetes are the numerically dominant groups among the other meiofauna (Appendix A, Tables XI-1 through XI-4).

MEIOFAUNA POPULATIONS

Total Populations of Banks

Considering all taxa of both the true and temporary meiofauna, Sonnier Bank stations yielded the highest number of individuals (Table XI-1). Very likely, depth is a major factor in that Sonnier Banks rises from the shelf at a depth of about 60 m, whereas East Flower Garden stations are located at depths between 99 and 119 m.

TABLE XI-1

A. THE MEANS OF INDIVIDUALS OF TRUE MEIOFAUNA (ADJUSTED TO 10 CM^2) TAKEN AT THE FOUR BANK STATIONS.

B. SIMILAR DATA FOR FORAMINIFERA AND TEMPORARY MEIOFAUNA.

SAMPLING PERIOD	BANK	
June 1977	East Flower Garden	Sonnier Banks
A. True Meiofauna	240	294
B. Other Meiofauna	46	129
TOTALS	286	423

The Upcurrent-Downcurrent Effect on Populations

Results of our previous population studies (Pequegnat *et al.*, 1978) have led us to believe that the bottom current in this region is flowing primarily to the southwest. Based on this belief, East Flower Garden shows substantially higher meiofaunal populations downstream of the bank than upstream (Table XI-2). Moreover, even on Sonnier Banks where the stations are more nearly on the bank proper, the station on the downstream

side of the bank is much more productive of meiofauna (Table XI-2). Both the physical nature of the sediments and their organic detrital content are believed to account for these population differences. This agrees with our previous assertions that harpacticoid populations are positively correlated with available organic matter in the sediments and that nematodes increase sharply when the coarser components (e.g., sand) predominate. Note in Table XI-2 that harpacticoid populations are significantly higher at downstream stations both on East Flower Garden and Sonnier Banks. The effect is particularly evident on the shallower bank (Sonnier Banks), since harpacticoids tend to avoid deeper waters.

TABLE XI-2

SUMS OF TOTAL MEIOFAUNA (MEANS OF REPLICATE SAMPLES ADJUSTED TO 10 CM^2) AT UPCURRENT AND DOWNCURRENT STATIONS (HARPACTICOID COPEPOD POPULATIONS IN PARENTHESES).

EAST FLOWER GARDEN		SONNIER BANKS (Stations on bank proper)	
UPCURRENT	DOWNCURRENT	UPCURRENT	DOWNCURRENT
58 (2)	412 (19)	209 (8)	139 (23)
99 (2)	546 (82)	222 (6)	1126 (140)
157 (4)	958 (101)	431 (14)	1265 (163)

Comparison of Bank and Level Bottom Meiofauna

In order to make a meaningful comparison between the bank and level bottom meiofaunal populations, two factors must be taken into account.

Pequegnat and Sikora (1977) have demonstrated marked seasonal variations in meiofaunal populations on the shelf. Also, it is now well established by the senior author that depth is a major factor controlling meiofaunal distribution. Accordingly, since the bank samples were taken in June, it is necessary to limit the comparison to level bottom samples taken in the same period and at the same depth. The shelf surrounding Sonnier Banks has a depth of about 60 m; the closest station depth on Transect II (of the South Texas Outer Continental Shelf Baseline Study) is that of Station 2 at a depth of 49 m. The shelf area around East Flower Garden lies at a depth of about 110 m. The closest match on Transect II is Station 6 at a depth of 98 m.

Except for Station 1, the population means for the bank stations are well above the level bottom value (Tables XI-3 and XI-4).

TABLE XI-3

MEAN POPULATION VALUES AT FOUR STATIONS ON SONNIER BANKS COMPARED WITH THE MEAN OF TWO REPLICATES FROM STATION 2 OF TRANSECT II (OFF CORPUS CHRISTI, TEXAS). SAMPLES COLLECTED IN JUNE AND CORRECTED TO 10 CM^2, 5 CM DEEP.

SONNIER BANKS				SHELF TRANSECT II
STATIONS				STATION 2
1	2	3	4	
140	209	1126	222	144

TABLE XI-4

MEAN MEIOFAUNA POPULATION VALUES AT STATIONS ON EAST FLOWER GARDEN COMPARED WITH THE MEAN OF TWO REPLICATES FROM STATION 6 OF TRANSECT II (OFF CORPUS CHRISTI, TEXAS). ALL SAMPLES COLLECTED IN JUNE AND CORRECTED TO 10 CM^2, 5 CM DEEP.

EAST FLOWER GARDEN				SHELF TRANSECT II
STATIONS				STATION 6
1	2	3	4	
81	100	428	546	91

Here again, we see that the bank meiofaunal populations are substantially larger than those of the adjacent level bottom.

Comparison of Bank and Level Bottom Macroinfauna

The macroinfauna on balance shows larger populations on the flanks of the hard banks than on the level bottoms of the adjacent continental shelf. This situation, however, is attributable to the large populations living on the downstream aspects of the banks, as is shown in Table XI-5.

TABLE XI-5

MEAN MACROINFAUNAL POPULATION VALUES AT FOUR STATIONS ON EAST FLOWER GARDEN COMPARED WITH THE MEAN OF SIX REPLICATE GRABS FROM STATION 6 OF TRANSECT II OFF CORPUS CHRISTI, TEXAS. AVERAGE DEPTH OF BANK STATIONS, 110 M; STATION 6 DEPTH IS 98 M. AREA = 0.1024 M^2.

EAST FLOWER GARDEN BANK				SHELF TRANSECT II
STATIONS				STATION 6
1 Upcurrent	2 Upcurrent	3 Downcurrent	4 Downcurrent	
23	25	204	204	42

NUMERICAL DOMINANCE AMONG MACROINFAUNAL TAXA

The numerically dominant macroinfauna groups differ a little between the two banks (Table XI-6).

TABLE XI-6

THE TEN MOST ABUNDANT MACROINFAUNAL TAXA ON EACH BANK

Taxon	Average Number of Individuals per Grab	Average Number of Individuals per m^2
	EAST FLOWER GARDEN BANK	
1. *Polychaeta*	44.62	435
2. *Ostracoda*	19.77	193
3. *Sipunculida*	17.13	167
4. *Bivalvia*	12.10	118
5. *Nematoda*	8.03	78
6. *Foraminifera*	6.52	64
7. *Gammaridea*	4.27	42
8. *Scaphopoda*	2.88	28
9. *Isopoda*	2.05	20
10. *Decapoda*	1.97	19
	SONNIER BANKS	
1. *Polychaeta*	46.42	453
2. *Bivalvia*	39.42	385
3. *Sipunculida*	6.00	58
4. *Gammaridea*	5.38	52
5. *Isopoda*	4.04	39
6. *Gastropoda*	1.84	18
7. *Cumacea*	1.79	17
8. *Decapoda*	1.75	17
9. *Ostracoda*	1.59	15
10. *Nematoda*	1.25	12

The top five taxa on East Flower Garden Bank are the same this sample year as last (1976-1977).

Eight of the 10 most abundant taxa on East Flower Garden Bank are among the top 10 on Sonnier Banks. The *Foraminifera* and *Scaphopoda* on the former list are replaced by the *Gastropoda* and *Cumacea* on Sonnier Banks.

Thus, the numerical rank order of the macroinfaunal organisms of the two banks is:

		average number/m^2
	1. *Polychaeta*	444
	2. *Bivalvia*	252
	3. *Sipunculida*	113
	4. *Ostracoda*	104
	5. *Gammaridea*	47
	6. *Nematoda*	45
E.	7. *Foraminifera*	32
	8. *Isopoda*	30
	9. *Decapoda*	18
E.	10. *Scaphopoda*	14
S.	11. *Gastropoda*	9
S.	12. *Cumacea*	8

E. Taxon found in the top 10 only on East Flower Garden
S. Taxon found in the top 10 only on Sonnier Banks

As established in the previous sampling year between 80 and 90 percent of the individuals of the macroinfauna species on these banks are accounted for by the first four groups. Moreover, the feeding type changes from the top dominant, the *Polychaeta* that are principally

deposit-feeders, to the *Bivalvia* that are primarily suspension-feeders. This is a normal expectation for soft bottom assemblages.

MACROINFAUNAL POPULATIONS

Total Populations of Banks

Considering all taxa, East Flower Garden Bank yielded a slightly smaller number of individuals per 0.1 m^2 than did Sonnier Banks (Table XI-7). This is interesting in light of the fact that in the 1976-1977 sampling series, East Flower Garden had substantially smaller populations than did Stetson Bank, 28 Fathom Bank, and 28 Fathom Bank, southwest peak.

TABLE XI-7

THE MEAN NUMBER OF INDIVIDUALS PER 0.1 M^2 OF MACROINFAUNA TAKEN AT FOUR BANK STATIONS BY MEANS OF THE SMITH-MCINTYRE GRAB DURING JUNE 1977.

STATION	BANK	
	EAST FLOWER GARDEN	SONNIER BANKS
1	49.17	131
2	45.00	109
3	238.67	198
4	204.00	101
TOTAL	536.84	539
$\bar{X}$	134	135

The Upcurrent-Downcurrent Effect on Populations

As was demonstrated by our work during the 1976-1977 sampling period, the macroinfaunal populations are substantially higher downstream of the bank proper than upstream (Table XI-8). This observation is confined to East Flower Garden Bank because the stations on Sonnier Banks were not arranged in a strictly upcurrent-downcurrent pattern.

TABLE XI-8

MEAN MACROINFAUNAL POPULATIONS FROM SIX 0.1 M^2 GRABS PER STATION ARRANGED ACCORDING TO UPCURRENT OR DOWNCURRENT POSITION ON EAST FLOWER GARDEN. SMITH-MCINTYRE GRABS IN JUNE AND SEPTEMBER 1977 AND MARCH 1978.

EAST FLOWER GARDEN BANK

June 1977	Upcurrent	Downcurrent
	49.17	238.67
	45.00	204.00
September 1977	**Upcurrent**	**Downcurrent**
	23.33	203.50
	24.67	------
March 1978	**Upcurrent**	**Downcurrent**
	-----	275.00
	63.33	275.00
TOTALS	205.50	1196.17

This marked difference in numbers may well result from the organic enrichment of downstream sediments by detritus swept from the bank proper.

Taxonomic Considerations

The following organisms are mostly macrofaunal except nematoda, which is so designated.

Cumacea. The cumaceans collected during the 1977-1978 study of two hard banks were assignable to 15 species, 9 genera, and 4 families. This compares with the 1976-1977 study of four banks where the cumaceans were grouped in 21 species, 9 genera, and 4 families.

Species diversity is comparatively high, especially at Sonnier Banks (SNB), where samples were taken on the reef proper (Table XI-9). The fauna is quite similar to that of the other hard banks. Only 3 species (*Sympodomma* sp. A, *Eudorella monodon*, and *Campylaspis* sp. H) were taken at SNB that were not taken at the other banks in 1976. Several new species were added to the East Flower Garden stations, possibly as a result of relocating the stations in an upcurrent/downcurrent manner. At East Flower Garden, the summer sample (June) is dominant in both diversity and abundance to the fall (September) and spring samples (March). Also the downstream stations supported a much richer cumacean fauna than the upstream. Two individuals representing 2 species were taken at the upstream stations as compared with 25 individuals grouped in 10 species taken at the downstream stations.

Many of the species are apparently new to science, and several of the genera have not been recorded from the Gulf of Mexico before. Principals amongs these are *Sympodomma*, *Procampylaspis*, *Heteroleucon*, and probably *Leptostylis*. The cumaceans of the family Leuconidae (*Eudorella* and *Heteroleucon*) seem to be characteristic of the hard bank environment.

TABLE XI-9

THE DISTRIBUTION OF TAXA OF CUMACEA AT THE BANKS.

	EAST FLOWER GARDEN				SONNIER BANKS			
SPECIES STATIONS*	1	2	3	4	1	2	3	4
Eudorella monodon					4	1	-	-
Eudorella sp. A	1				9	2	5	5
Leucon sp. A			1		3	-	1	-
Sympodomma sp. A			1		2	1	2	-
Campylaspis sp. C					2	-	1	-
Marsupial cumacean					0	1	3	-
Procampylaspis sp. A	1		2	1				
Heteroleucon			1					
Bodotriidae			2					
Campylaspis sp. F			2	8				
Cumella sp. I			1					
Leptostylis sp. A			3					
Vaunthompsonia sp. C			1					
Campylaspis sp. I				1				
Damaged juvenile				1				
TOTALS	2	0	14	11	20	5	12	5

*East Flower Garden stations 1 and 2 are upstream and 3 and 4 are downstream of the bank proper.

Isopoda. Eleven taxa of isopods were collected from the hard banks. On East Flower Garden both diversity and abundance were greater at the downstream stations than at the upstream. Seven taxa were found in East Flower Garden of which four were not found on Sonnier Banks (Table XI-10). A different set of seven was found on SNB of which four were

not found on East Flower Garden. One new genus and three new species were found among the isopod samples.

TABLE XI-10

ISOPOD CRUSTACEANS COLLECTED AT THE BANK STATIONS.

SPECIES	*EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
Gnathia cf. *crenulatifrons*		5	1	1	5	2	11	2
Gnathia (larval) *pranzia*		10			2			
Apanthura magnifica		2	1	14	24	3	1	1
Ptilanthura tricarina			6	2			2	
Accalathura crenulata				1				
Horoloanthura irpex				28				
Astacilla sp.				1				
Paranthurid (n. gen., n. sp.)				1				
Pananthura formosa					1			
Xenanthura brevitelson							2	3
?Kupellonura sp.							6	
Cirolana polita								1
TOTAL TAXA	0	3	3	7	4	2	5	4
TOTAL INDIVIDUALS	0	17	8	48	32	5	22	7

*In the 1976 samples from East Flower Garden *Eurydice littoralis* and *Xenanthura brevitelson* were found.

Amphipoda. Twenty taxa of amphipoda were collected from the two banks (Table XI-11). Nineteen of the 20 were found on East Flower Garden and only 9 were found on Sonnier Banks. It is interesting to note that only 5 amphipod taxa were collected from East Flower Garden in 1976-1977. It is clear from data in Table XI-11 that amphipods are far more

abundant and diverse on the downstream stations 3 and 4 of East Flower Garden than at the upstream stations. In fact, only 5 taxa were found at the upstream stations. At East Flower Garden, the summer sample is dominant in both diversity and abundance to the fall and spring samples. Moreover, on EFG some 172 individuals grouped in 17 species were taken at the downstream stations, whereas only 9 individuals in five taxa were collected at the upstream stations.

TABLE XI-11

AMPHIPOD CRUSTACEANS COLLECTED AT THE BANK STATIONS
JUNE AND SEPTEMBER 1977 - MARCH 1978.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
MARCH 1978								
Heterophoxus (nr.) *oculatus*			5	3				
Listriella sp.				5				
Unciola sp.				2				
Stenothoe sp.				2				
Corophium juv.			1	1				
Synopiidae				1				
Ampelisca cristata			13					
Unciola irrorata			2					
Elasmopus juv.			1					
Idunella, n. sp.			2					
Maera sp.			1					
Hippomedon (nr.) *serratus*			3					
JUNE 1977								
Synchelidium americana					1			
Corophiidae juv.							1	
Ampelisca juv.							6	
Harpinia sp.				1				

TABLE XI-11 CONCLUDED

AMPHIPOD CRUSTACEANS COLLECTED AT THE BANK STATIONS
JUNE AND SEPTEMBER 1977 - MARCH 1978.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
JUNE 1977 CONTINUED								
Unciola irrorata			14	17				
Ampelisca agassizi		1	27	13				8
Listriella n. sp.			3	5	10		1	
Ampelisca cristata			7	2				
Hippomedon (nr.) *serratus*			12	2			1	
Corophium acherusicum				1				
Corophiidae juv.				7				
Monoculodes sp.			1					
Heterophoxus (nr.) *oculatus*	1		1		37	6	5	3
Leptocheirus n. sp.		3						3
Maera sp.	2							
Unciola sp.					22	5		
Ampelisca verrilli							1	1
SEPTEMBER 1977								
Ampelisca cristata			2					
Listriella n. sp.			3					
Ampelisca verrilli			4					
Hippomedon (nr.) *serratus*			2					
Unciola sp.		2	2					
Heterophoxus (nr.) *oculatus*			3					
Monoculodes sp.			1					

Decapoda. Twenty-two taxa of decapod crustaceans were obtained from the two hard banks during the 1977-1978 sampling periods (Table XI-12). The numerically dominant among these is the macrurous *Callianassa marginata* followed by the alpheid *Automate evermanni*. It is assumed that *Callianassa*

is a detritus feeder and that *Automate* is a carnivore.

The highest diversity was found in June, but the dominant species were somewhat more abundant in March. Again, the downstream stations on East Flower Garden supported the highest diversity and population densities.

TABLE XI-12

DECAPOD CRUSTACEANS COLLECTED AT THE BANK STATIONS.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
JUNE 1977								
Munida flinti	1							
Eucratodes agassizi	1							
Leptocheles bermudensis		2	1	4				
Callianassa marginata		1	15	16	1		3	
Callianassa (nr.) *latispina*		1					1	2
Parapenaeus sp.			1					
Automate evermanni				6	3	5	8	6
Upogebia sp.				1		1		
Pinnotheridae				2				
Goneplax cf. *sigsbei*				1				
Xanthid or goneplacid				2			2	
Callianassa cf. *batei*					1			
Alpheus floridanus						1		1
Munida simplex						1		
Chasmocarcinus cylindricus							5	1
Callianassa sp.								1
Axiidae								2
SEPTEMBER 1977								
Automate evermanni	1							
Alpheus (nr.) *amblyonyx*		1						

TABLE XI-12 CONCLUDED

DECAPOD CRUSTACEANS COLLECTED AT THE BANK STATIONS.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
SEPTEMBER 1977 CONTINUED								
Callianassa cf. *latispina*		2						
Munida flinti		1						
Callianassa marginata			29					
Munida sp.			1					
MARCH 1978								
Processa sp.		1						
Automate evermanni		1	2	5				
Chasmocarcinus cylindricus		2						
Callianassa marginata			15	26				
Leptochela bermudensis			1					
Dorippidae				4				

Sipunculida. Eight taxa of sipunculids were found on the two hard banks (Table XI-13). The numerical dominants are *Aspidosiphon longirhynchus*, *Golfingia trichocephala*, *Aspidosiphon albus*, and *Golfingia misakiana*.

As can be seen easily in Table XI-13, both species diversity and population densities are higher at the downstream than upstream stations on East Flower Garden Bank.

TABLE XI-13

SIPUNCULIDA COLLECTED AT THE BANK STATIONS
AUGUST 1976, JUNE AND SEPTEMBER 1977, AND MARCH 1978.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
AUGUST 1976								
Aspidosiphon albus	12			20				

TABLE XI-13 CONCLUDED

SIPUNCULIDA COLLECTED AT THE BANK STATIONS
AUGUST 1976, JUNE AND SEPTEMBER 1977, AND MARCH 1978.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS			
STATIONS	1	2	3	4	1	2	3	4
AUGUST 1976 CONTINUED								
Golfingia trichocephala		12	5	10				
Aspidosiphon longirhynchus			5					
Golfingia misakiana				23				
Aspidosiphon sp. A				2				
Aspidosiphon sp. B				4				
JUNE 1977								
Golfingia trichocephala	4	8	3	53	3		14	12
Aspidosiphon longirhynchus	2	5	4	158		2	7	
Aspidosiphon albus			3	8	5			
Phascolion sp.			4		9	12	5	2
Golfingia misakiana				41	8	2	25	
Aspidosiphon sp. B				4				
SEPTEMBER 1977								
Golfingia tricocephala	6	11	1	-				
Aspidosiphon longirhynchus	5	2	1	-				
Golfingia misakiana			22	-				
Aspidosiphon albus			4	-				
Aspidosiphon sp. B			2	-				
Phascolion sp.			3	-				
MARCH 1978								
Golfingia misakiana	-	3	2	72				
Golfingia trichocephala	-	7	2	74				
Phascolosoma juv.	-	2		15				
Aspidosiphon longirhynchus	-		4	69				
Aspidosiphon sp. B	-		4					
Phascolion sp.	-		3					
Aspidosiphon albus	-			114				
Golfingia (Nephasoma)	-			3				

Ostracoda. Seven taxa of macrofaunal podocopid ostracodes were found on East Flower Garden Bank in the 1977-1978 sampling period (Table XI-14). The numerical dominants appaer to be *Pterygocythereis americana, Actinocythereis vandenboldi,* and *Echinocythereis spinireticulata.* The first of these is a common middle and outer shelf species in the Gulf of Mexico and the Atlantic coast as far north as the Gulf of Maine. On the other hand, *Actinocythereis vandenboldi* has been reported only from the Louisiana shelf; *Echinocythereis spinireticulata* is known to occur only on the Louisiana shelf and Mississippi mudlumps. Aside from *Echinocythereis margaretifera,* which is widely distributed in the Gulf of Mexico, Atlantic shelf and Georges Bank, the remaining species are known only from the Mississippi, Louisiana, and Texas shelves.

TABLE XI-14

MACROFAUNAL OSTRACODA COLLECTED ONLY AT STATION 3 OF EAST FLOWER GARDEN BANK.

SPECIES	COLLECTION DATES		
	17 June 1977	15 September 1977	15 March 1978
Pterygocythereis americana	8	9	2
Actinocythereis vandenboldi	11	7	0
Echinocythereis spinireticulata	9	4	0
Echinocythereis margaretifera	7	3	0
Pterygocythereis miocenica	3	5	0
Protocytheretta karlana	0	1	0
Machaerina cf. *tenuissima*	0	0	1
Myodocopid	1	0	0

Fifteen taxa of podocopid ostracodes were collected on the two banks (Table XI-15). Several of the species are new. Again, the majority

of these showed a preference for downstream stations (3 and 4) on East Flower Garden Bank.

TABLE XI-15

PODOCOPID OSTRACODES FROM SONNIER BANKS AND EAST FLOWER GARDEN BANKS June 1977, SEPTEMBER 1977, AND MARCH 1978.

SPECIES	EAST FLOWER GARDEN				SONNIER BANKS (June only)			
STATIONS	1	2	3	4	1	2	3	4
Cypridinidae								
Vargula sp. 1				+			1	
Skogsbergia sp. 1		3						
Skogsbergia sp. 2							+	
Philomedidae								
Philomedes sp. 1			+	+				
Harbansus paucichelatus			+	+		+		2
Pseudophilomedes ferulanus			+		2	1	+	2
Pseudophilomedes sp. 1			+	+			+	
Rutidermatidae								
Rutidermata sp. 1				+	2			
Alternochelata sp. 1	2	+					+	
Sarsiellidae								
Sarsiella sp. 1			+	+	3	+	+	1
Sarsiella sp. 2			+		1	1	1	
Sarsiella sp. 3				+		+		
Sarsiella sp. 4						+		
Cylindroleberididae								
Species 1	+	+		+	2			
Species 2		+						

Nematoda. One hundred nineteen taxa of meiofaunal and thirteen taxa of macrofaunal nematodes were found on East Flower Garden Bank. Interestingly, both the diversity and population densities of these nematodes increased on the downstream side of the bank, as is noted below:

Upstream

Station 1	Station 2
38 taxa, 71 individuals	28 taxa, 67 individuals

Downstream

Station 3	Station 4
58 taxa, 114 individuals	50 taxa, 109 individuals

As we have pointed out before, nematodes appear to be affected much more by sediment differences than by inputs of organic material. Therefore, the above result is very likely accounted for by the increases of coarser components in these downstream sediments.

The predominant taxa of meiofaunal nematodes on the East Flower Garden and Sonnier Banks are as noted below:

1. *Sabatieria*, by a wide margin
2. *Richtersia*
3. *Theristus*
4. *Microlaimus*
5. *Halalaimus*
6. *Monohystera*
7. *Desmodara*
8. Pomponematids
9. *Desmodorella*
10. *Cervonema*

The principal macroinfaunal nematodes on East Flower Garden are:

1. *Anticoma*
2. Mermithids
3. *Crenopharynx*
4. *Enoplolaimus*
5. *Rhabdodemania*
6. Leptosomatids

The principal macroinfaunal nematodes on Sonnier Banks appear to be:

1. *Enoplolaimus*
2. *Rhabdodemania*
3. *Phanodermopsis*
4. *Mesacanthion*
5. *Filoncholaimus*

6. *Sabatieria*
7. Leptosomatids

DISCUSSION

QUANTITATIVE COMPARISONS TO OTHER INVESTIGATIONS

In addition to sampling and processing differences, the magnitude of seasonal variations in benthic populations should be recognized when comparisons are made between different investigations. In this study the community was examined at only three temporal points (March, June, September); and, therefore, the full extent of time dependent variation is not known. However, these periods could well be nearer a high point than a low point in view of the fact that Pequegnat and Sikora (1977) have demonstrated that March and July-August are peak periods for meiofaunal populations at similar and at deeper depths on the Texas continental shelf. There are no known published results for seasonal studies of the macroinfauna on the middle and outer shelf of the Gulf, although Lie (1968), Lie and Evans (1973), Buchanan and Warwic (1974), and Watling and Maurer (1975) indicated for other places seasonal changes in macroinfauna abundance at depths similar to those of this study.

Meiofauna

Tietjen (1969, 1971), Coull (1970, 1973), and McIntyre (1969, 1971) have published summaries of sublittoral meiofauna abundances in various regions. These and other studies revealed that meiofaunal abundance

ranges from 10^1 to 10^3 individuals per 10 cm^2, that a general decline in meiofaunal abundance occurs with increasing water depth, and that nematodes are always the dominant taxon. Data on meiofaunal abundance generated by the present study show that a similar range of abundance occurs here and that nematodes are the dominant taxon. Although the present study was not designed to deal with the effect of depth on meiofaunal populations, our data show that the meiofauna population on Transect II at a depth of 49 m (Station 2) is about 7 times larger than that at 98 m (Station 6). Moreover, the same types of difference is observed between shallow banks (e.g., Sonnier Banks and Stetson Bank) and the much deeper East Flower Garden. Regarding the dominant taxon, it should be mentioned that Parker (1975) and Marcotte and Coull (1974) found higher numbers of copepods than nematodes in organically enriched waters and that Dinet (1973), found very high numbers of meiofauna at the great depth of 2800 m. As we have stressed throughout this study, the upstream-downstream effects on diversity and population density are equal to that of depth on the continental shelf.

Macroinfauna

Macroinfaunal abundance is usually highest in shallow waters, and lowest in the abyssal zone with continental shelves having intermediate values (Rowe *et al.*, 1974). Lists of the results of the present macroinfaunal study are found in Appendix A, Tables XI-5 through XI-18.

On balance, the enumerated individuals in this study are comparable to those of other Gulf studies. However, it must be noted that only in two cases do Gulf values attain even the low end of the range of Long Island populations.

Data from the present study and from Rowe et al. (1974) seem to indicate that the northern Gulf of Mexico continental shelf is depauperate in macroinfauna density, and Gettleson (1976) notes a low standing crop. However, meiofaunal levels are of a similar order of magnitude relative to comparable depths in other regions. There is no generally acceptable explanation for the lower values for macroinfauna if, indeed, such proves to be the case. However, among contributing factors one might cite that warmer waters appear to elicit faster growth, resulting in smaller size and a greater turnover rate of the macroinfauna (Nicol, 1964; Wade, 1972). Gettleson (1976) notes that the Gulf of Mexico shelf supports a macroinfaunal population composed of individuals about a third smaller than those sampled in Long Island Sound. Turnover and annual production data are inadequate for the macroinfauna; even so, Sanders (1956) has proposed that macroinfaunal annual production is probably 2 to 5 times the standing crop. Edwards (1973) calculated that the annual production in 4 to 16 m of water off Venezuela was 4.1 times the standing crop. These data seem to indicate a higher turnover rate in tropical waters, but the rate for the Gulf of Mexico is unknown.

It seems that the meiofauna would also be affected by the warmer waters but, as Gettleson (1976) points out, the meiofaunal standing crop of the Gulf is similar to that of other known areas. If food is a limiting resource in the present study area, the relatively high level of the meiofauna might indicate that either the meiofauna is utilizing a different food source or that, if the meiofauna is competing with the macroinfauna for food, it is better able to adapt or utilize the food that is present.

There is some justification for believing that the meiofaunal annual production in the Gulf is anywhere from two to five times greater than

that of the macroinfauna. This is based on Gettleson's (1976) finding that the standing crops of meiofauna and macroinfauna are essentially the same, and on Gerlach's (1971) estimates that the turnover rate of the meiofauna is approximately nine times per year compared with two to five times for the macroinfauna.

Ratio of True Meiofauna to Macroinfauna

Pequegnat and Gettleson (1974) reported the meiofauna to macroinfauna ratio of individuals on the flanks of Stetson Bank to be 495:1, based on total individuals of meiofaunal size. In our 1977 study (Pequegnat et al., 1977), the average of the three typical stations on Stetson Bank yields a ratio of 465:1, based only on the total of true meiofauna. If the temporary meiofauna are added to the total, the ratio is raised to 535:1, which is remarkably close to the 1974 study, considering that different sampling gear was used and that sampling was carried out in August instead of June.

As was pointed out by Pequegnat and Gettleson (1974), the ratio between the meiofauna and the macroinfauna is sufficiently stable that if the sediment cover is carefully defined, the ratio can be used as a baseline parameter for judging degrees of environmental impacts. It would be expected also that each bank would have a signature ratio that could differ substantially from that of other banks. We now have additional hard data with which to test this hypothesis. Thus, East Flower Garden Bank has an average ratio of 442:1, 28 Fathom Bank has a ratio of 74:1; and 28 Fathom Bank, southwest peak, has a ratio of 103:1. Obviously, these ratios apply to the flanks of the banks where the sediment cover is sufficiently thick to permit taking a sample at least 5 cm in thickness.

Variability of Banks and Samples Taken at the Banks

In regard to macroinfaunal populations, ANOVA computations revealed that the four stations of each bank were much more variable than were the six grabs at each station. This observation supports findings presented in our 1977 report (op. cit.). One contributing factor here is probably the position of the station vis-à-vis the mass of the reef and the mean current direction, as mentioned earlier. This may also help in explaining the fact that stations at any given bank were more variable than were the banks.

Interestingly enough, ANOVA calculations showed that in the case of the meiofauna, the banks were more variable than stations within the banks. In part, this may be explained by the greater sensitivity of some meiofaunal taxa to depth than is generally true of the macroinfauna. Thus, the major depth difference between Stetson and all the other banks studied by us is important. It was also found that meiofaunal populations were much more variable among stations than between cores from a single grab. This might be a logical expectation, but it does not always hold, and the fact that it does here may be due to the fact that the ship was on occasion permitted to drift between grabs.

Harpacticoid:Nematode Ratio

The ratio of the mean number of harpacticoids to nematodes differs markedly between the banks and the corresponding shelf stations.

Sonnier Banks	Station 2, Transect II
0.20	0.07

East Flower Garden	Station 6, Transect II
0.12	0.03

We note above that the ratio is higher for Sonnier Banks in shallow water than that for East Flower Garden in much deeper water. It is encouraging to note that in our previous report the East Flower Garden ratio was almost identical (0.11) with that reported here.

CONCLUSIONS

The following conclusions are similar to previous studies (Pequegnat *et al.*, 1978) and lend stability to the situation.

1. The meiofauna of the flanks of the hard banks off the Texas coast form a stable community that varies in regard to depth, orientation down-current of the main mass of the bank, sediment grain size and, presumably, in regard to the amount of labile carbon compounds in the sediment.
2. The bank meiofaunal populations are, generally, higher than those on the adjacent level bottoms of the outer continental shelf. This may be a reflection of greater inputs of organic materials into the sediments from bank debris and detritus, but again, this is as yet untested. The latter is suspected, however, because harpacticoid copepods, which respond positively to organic inputs, are significantly more abundant on banks than on level bottoms in this area.
3. It is noted that the harpacticoid:nematode ratio is significantly greater at the banks than at transect stations. Also, the ratio differs predictably among banks, appearing to indicate that banks have a

signature ratio that will identify its condition of health. Whereas environmental impacts can be measured among the macroepifauna, primarily by death or no death, such impacts can be estimated and predicted by ratio changes among these two components of the meiofauna. Further work would be required to note signature ratios.

4. The macroinfauna of the flanks of the hard banks off the Texas coast also form a stable community that varies less than the meiofauna in the depth range of this study. However, as in the case of the meiofauna, it is more abundant downstream of the bank proper, and it is significantly more abundant on the bank flanks than on the level bottoms of the transects.
5. The meiofaunal annual production in the Gulf is believed to be two to five times greater than the macroinfauna.
6. The true meiofauna:macroinfauna ratio is considered to be another important signature marker of individual banks. It appears to be stable from year to year.
7. Both the meiofauna and the macroinfauna respond to changes in the characteristics of the sediment bed. However, it appears that the usual division of sediments into gravel, sand, silt and clay is too gross. Rather, the individual grain sizes should be divided into at least 16 categories and percentages for each derived.

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CHAPTER XII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Biological and geological reconnaissance efforts in September, 1977 resulted in the characterization of seven topographical features in the northwestern Gulf of Mexico. In addition, monitoring studies of the biological health of the reef and physical oceanographic parameters of the water column were conducted at the East Flower Garden Bank. A sediment net transport study using fossil coccoliths as tracers has demonstrated two relatively restricted avenues of basinward sediment transport on the South Texas outer continental shelf.

All of the banks in the present study are associated with shallow subsurface salt structures. The shapes of the banks are dependent upon a number of factors, such as:

1. The age of the salt dome, i.e. was the dome subaerially exposed during the Pleistocene or has it developed since the last rise in sea level?
2. The nature of the rocks that have been penetrated by the salt.
3. The amount of dissolution of salt and collapse of the overlying sedimentary rocks.
4. The degree of faulting associated with the salt structure.
5. The amount of reef growth during Late Pleistocene to Recent time.

Reef growth has modified the surficial characteristics of the banks. Young reefs tend to accentuate the original local relief, while older reefs tend to mask the original local relief.

18 Fathom Bank (27°57'N, 92°35'W) is a shelf edge carbonate bank bearing clear water epibenthic communities. Depauperate coral reefs

(*Stephanocoenia*-*Montastrea*-*Agaricia* Zone) occupy the crest of the bank. An Algal-Sponge Zone extends downward to approximately 82 m depth, with healthy populations of coralline algae forming algal nodules and algal reefs. In terms of the bank classification scheme presented in Bright and Rezak (1977), 18 Fathom Bank is a category #1 bank, with living coral reefs (highest environmental priority).

Bright Bank (27°53'N, 93°18'W), Bouma Bank (28°03'N, 92°28'W), Parker Bank (27°56'N, 92°00'W) and Ewing Bank (28°05'N, 90°59'W) are all carbonate banks with biotic communities and zonation similar to 18 Fathom Bank except that they lack living coral reefs. They are, therefore, category #1 banks without coral reefs.

Sackett Bank (28°38'N, 89°33'W) is only 21 miles from the Mississippi Delta. The crest of the bank is carbonate reef rock that was probably produced during the Late Pleistocene when the outflow of the Mississippi River was to the west of the bank. Limited amounts of live coralline algae are present on the bank as crusts and nodules. Most of the carbonate substrate, however, is covered by a thin veneer of sediment or occupied by sparse epifauna.

Benthic communities in general are not as well developed on Sackett Bank as they are at comparable depths on other shelf edge banks. It is hypothesized that this condition results from unfavorable and variable hydrographic conditions related to the Mississippi River outflow (high turbidity, sedimentation, changeable temperature and salinity, etc.). Biologically and structurally, Sackett Bank could be classified as a very depauperate and regressing category #1 bank. In terms of environmental priority, however, it is closer to category #3.

Sonnier Bank (28°20'N, 92°27'W) is a mid-shelf feature comprised of 8 separate peaks. Each peak consists of steeply dipping sandstones, siltstones and claystones of Tertiary age. The constancy of the strike of the beds in each peak and the arrangement leads to the conclusion that the peaks represent individual fault blocks caused by the collapse of the beds overlying the salt plug along radial and angular faults. The crest of the largest of these peaks is occupied by a nearly total cover of hydrozoan corals and sponges. Biotically, it is similar to Stetson Bank and is appropriately classified as a category #2 bank. We detected no evidence of serious, lasting environmental effects on Sonnier Bank due to the drilling of 9 exploratory wells between 4.6 and 9.2 kilometers distance from the bank in the mid 1960's.

Three biological monitoring sites were established on the coral reef at the East Flower Garden Bank. Substantial mechanical destruction of coral tissue by coral eating reef animals was documented. It is suspected that the dislodging of coral heads, expulsion of zooxanthellae by corals and disruption of leafy algae populations may have resulted from water movements and temperature variations associated with the passage of two hurricanes in August and September 1977. Slow death (necrosis) of anthozoan coral heads due to disease-like factors was followed at 14 specific stations. Where necrosis occurred it appeared to result in the lateral regression of living coral tissue at a rate of approximately 1 cm/month, on the average.

Lateral growth rates of anthozoan corals at 7 specific stations averaged approximately 0.1 cm/month. Growth rates of the hydrozoan coral (Millepora) and encrusting coralline algae are substantially higher.

Information concerning the numerical balance between lateral regression and growth of anthozoan corals in terms of area vacated or newly occupied by living coral tissue is to be pursued in the coming year. It is felt that knowledge of this balance will allow us to create a numerical index of reef "health". We have demonstrated that mechanical damage to coral tissue, necrotic death of corals and lateral coral growth are measureable and can be quantified at the Flower Gardens over periods of time less than a year. We hope to develop our techniques to a level which will result in a numerically valid method of monitoring the health and condition of populations of corals and coralline algae, which are the most appropriate "indicator" organisms on the reef.

Neither the studies related to coral health nor submersible reconnaissance observations made in the southeast quarter of the East Flower Garden have revealed undue changes in rates of coral growth and death or apparent conditions of benthic communities between 1976 and 1978.

Hydrographic cruises were conducted during June and September 1977 and February-March 1978 to obtain profiles of temperature, salinity, transmissivity and current velocity at stations at the East Flower Garden Bank. It is quite clear from the data collected that the nepheloid layer is an integral part of the bottom boundary layer. The amount of suspended sediment and its penetration height above the bottom is a function of the local sediment type and the intensity of the turbulence present. Stratification in the water column precludes the transport of sediment above the top of the mixed layer.

The presence of banks on the outer continental shelf induces internal waves similar to the riffles that form over rocks on the bottom of a fast flowing stream. Where the internal waves impinge on the bottom they stir up the sediment and it becomes entrained in the flow over the bank. Some internal waves appear to have a tidal origin. These waves are caused by break-up of the barotropic tide on the shelf edge. They affect the whole water column and contribute large quantities of turbulence to the bottom boundary layers. This, in turn, leads to intermittent suspension of dense clouds of sediment as the waves pass over the bottom.

Mapping of the distribution of redeposited Cretaceous coccoliths in the surface sediments of the South Texas continental shelf has provided an overview of the dispersal pattern of fine silt and clay size particles that are introduced along the shoreline. In general the proportion of redeposited coccoliths decreases with distance from the shoreline, as would be expected. Important exceptions to this generalization are found in the northeastern part of the study area in the region south and east of Matagorda Bay, where a westward onshore transport is suggested by the very low number of land derived redeposited specimens. Immediately south and west of this area of onshore transport are two well defined tongues of offshore transport extending diagonally across the continental shelf, one nearly due east, the other approximately due south from St. Josephs Island-Matagorda Island. These two tongues of offshore transport of fine silt and coarse clay size sediment appear to be related to seasonal shifts in the wind driven surface currents, although the precise relationship is not yet totally clear.

Further south on the South Texas continental shelf offshore transport of coccolith size (fine silt and coarse clay) does not seem to be confined to specific pathways as in the northern part of the area. Rather dispersal seems to occur broadly across the shelf in a manner more or less analogous to diffusion.

It is useful to bear in mind that the dispersal pattern deduced from surface sediment represents an integrated picture of sediment transport over a period of years and decades, not an instantaneous state of sediment transport. The latter can be best deduced from sediment in suspension, and this problem, too, was addressed in this study, albeit less successfully. Coccoliths - both modern and redeposited species - were found in suspended sediment and most notably in near-bottom suspended sediments, their occurrence was found to be notably sporadic, depending very probably on the amount of turbulence and resuspension that was occurring at the time the samples were taken.

It is reasonable to conclude that if a particulate pollutant with particles in the fine silt and clay size range were introduced to the South Texas continental shelf area, the particles would be distributed in the same fashion as are the redeposited coccoliths. If such particulates were known to have harmful effects, a maximum impact would be produced in the area of greatest concentration, that is, the area where the particles are swept across the continental shelf in narrow bands.

RECOMMENDATIONS

Insofar as drilling for and production of petroleum is increasing in the immediate area, it is recommended that environmental and hydro-

graphic monitoring studies at the East Flower Garden be continued. The studies should be directed, in part, toward refining in situ, nondestructive methods to monitor the health and condition of reef corals and coralline algae as indicator organisms. A numerically valid index of reef "health" should be developed using as its basis the quantitative relationship between rates or coral death and lateral encrusting coral growth.

Natural and man induced ecological processes affecting the growth and death of coral tissue and coralline algae should be investigated further to establish cause and effect relationships.

The nepheloid layer is a transient feature in a state of almost constant change. It does, however, represent sediment trapped near the bottom by stratification of the water column. An artificial turbid layer such as the effluent of drilling mud from a rig could be expected to behave in much the same manner. That is, once shunted to the bottom it would be unlikely to rise again to the level of the living reefal communities on the East Flower Garden or other banks of the same type. Dumped on the surface, this effluent might travel long distances before sinking to safe depths. The variability of directions and speed of the surface currents suggest that it is unwise, therefore, to permit surface dumping near these banks.

It is suggested that BLM monitoring studies at East Flower Garden would be greatly facilitated by the establishment of an on site monitoring station on a production platform directly adjacent to the bank.

Bathymetric mapping during the past year was limited to a predetermined depth contour based upon the probable existence of sensitive biotic elements above these depths. As a result, on some banks the entire geological structure of the bank was not mapped. We

recommend that the limits of mapping for each bank be determined by the geological structure as delineated by the subbottom profiles during the mapping process. This will insure complete coverage of the bank and permit a more realistic assessment of the geological hazards at each bank. In addition, two lines, a north-south line and an east-west line on each bank should be extended a distance of at least 5 nautical miles beyond the bank margin so that the structural details of the bank may be related to the regional structural picture that is being developed by the U.S. Geological Survey.

APPENDIX A

DATA SUMMARY

APPENDIX A: TABLE II-1

Cruise Dates, 1977-78

DATE	SHIP	CRUISE NUMBER
	PHASE I-MAPPING	
May 17-26, 1977	M/V DECCA LOCATOR	77DL3-I
26 May - 3 June, 1977	M/V DECCA LOCATOR	77DL3-II
	PHASE II-SAMPLING	
June 9-22, 1977	M/V DECCA LOCATOR	77DL3-III
September 9-21, 1977	R/V GYRE	77G10-I
February 15-22, 1978	M/V DECCA PROFILER	78DP1
March 14-16, 1978	R/V LONGHORN	78L1
	PHASE III-SUBMERSIBLE	
September 9-21, 1977	R/V GYRE-DR/V DIAPHUS	77G10-I
September 23-October 1, 1977	R/V GYRE-DR/V DIAPHUS	77G10-II
	PHASE IV-MONITORING	
June 27-July, 1977	M/V CHIP IV	
August 15-18, 1977	M/V CHIP IV	
September 9-21, 1977	R/V GYRE	77G10-I
October 14-19, 1977	M/V CHERAMIE BO-TRUC #25	
November 1-7, 1977	M/V CHERAMIE BO-TRUC #25	
December 2-15, 1977	M/V CHERAMIE BO-TRUC #25	
March 10-13, 1978	R/V LONGHORN	
May 15-19, 1978	R/V LONGHORN	

APPENDIX A: TABLE II-2

Macronekton and *Spondylus* collected on Cruise 77-G-10

	LUTJANUS CAMPECHANUS (Red Snapper)	RHOMBOPLITES AURORUBENS (Vermillion Snapper)	SPONDYLUS AMERICANAS (Spiny Oyster)
LEG I			
East Flower Gardens			
Trace Metals	5	2	2
HMW HC	5	2	1
Ewing Bank			
Trace Metals	6	5	
HMW HC	5	5	
LEG II			
East Flower Garden Bank			
Trace Metals	3	3	
HMW HC			
Sonnier Banks			
Trace Metals	3	5	
HMW HC	5	4	
18 Fathom Bank			
Trace Metals			6
HMW HC			5
Bright Bank			
Trace Metals			1
Bouma Bank			
Trace Metals			1

APPENDIX A: TABLE II-3

VIDEO TAPES AND FILM FROM DIAPHUS

Location	Video Tapes*	35mm Handheld Camera (rolls)**	8mm Movie Camera (rolls)***
Leg I			
East Flower Garden	23	2	27
Ewing Bank	6	3	1
Sackett Bank	4	3	0
Leg II			
Bright Bank	6	5	0
Bouma Bank	6	3	0
East Flower Garden	4	1	0
Parker Bank	7	2	0
Sonnier Bank	9	1	0
18 Fathom Lump	6	5	0

* Each tape is approximately 30 minutes duration.

** 1 roll = 36 frames

*** approximately 3600 frames

APPENDIX A: TABLE II-4

Submersible Dives Cruise 77-G-10

Leg I

Dive Type	Dive No.	Pilot	Observer	Date	Start Time	End Time	Max. Depth	Location
B	1	Green	Bright	9-11-77	9:50	10:51	190'	Ewing Bank
B	2	Green	Bright	9-11-77	12:13	14:32	320'	Ewing Bank
G	3	Cooke	McGrail	9-11-77	16:02	18:05	310'	Ewing Bank
B	4	Green	Bright	9-12-77	9:34	14:18	295'	Sackett Bank
B	5	Green	Bright	9-13-77	9:50	13:53	250'	East Flower Garden
H	6	Green	McGrail	9-17-77	12:14	15:45	410'	East Flower Garden
H	7	Green	McGrail	9-19-77	10:50	13:01	285'	East Flower Garden
H	8	Cooke	Huff	9-18-77	13:58	17:32	285'	East Flower Garden
B	9	Green	Boland	9-19-77	8:37	10:15	150'	East Flower Garden
B	10	Green	Putt	9-19-77	10:47	12:08	278'	East Flower Garden
H	11	Green	Bandy	9-19-77	15:41	16:17	280'	East Flower Garden
H	12	Cooke	McGrail	9-20-77	11:52	14:50	285'	East Flower Garden
H	13	Green	Horn	9-20-77	15:16	17:27	283'	East Flower Garden

Leg II

G	1	Green	Rezak	9-24-77	13:02	16:50	285'	East Flower Garden
B	2	Barksdale	Bright	9-25-77	9:54	17:21	305'	Bright Bank
G	3	Green	Rezak	9-26-77	9:44	12:07	200'	Sonnier Banks
G	4	Green	Parker	9-26-77	15:13	16:28	180'	Sonnier Banks
B	5	Barksdale	Bright	9-27-77	9:54	12:01	190'	Sonnier Banks
G	6	Cooke	Watson	9-27-77	13:02	15:39	150'	Sonnier Banks
B	7	Barksdale	Bright	9-28-77	9:43	14:06	320'	18 Fathom Lump
B	8	Barksdale	Curran	9-28-77	15:22	17:24	230'	18 Fathom Lump
B	9	Barksdale	Bright	9-29-77	9:24	12:54	275'	Bouma Bank
B	10	Green	Lowe	9-29-77	16:48	18:15	220'	Bouma Bank
G	11	Green	Rezak	9-30-77	16:48	18:15	220'	Bouma Bank
G	12	Barksdale	Tompkins	9-30-77	15:31	17:46	280'	Parker Bank

G = Geological
B = Biological
H = Hydrographical

TABLE III-1. STD, Transmissivity and current meter data for East Flower Gardens Bank, Cruise 77DL3

STATION 1

Temperature	Depth
27.84	0.8
27.6	10
26.88	17.6
24.36	33.2
2.44	48.8
20.69	62.8
19.92	73.6
19.56	83.6
19.44	99.6
19.44	11.6

Salinity	Depth
36.18	0.8
36.18	10
35.82	17.6
35.55	33.2
35.73	48.8
36	62.8
36	73.6
36	83.6
36.18	99.6
36.09	111.6

Transmissivity	Depth
88.2	0.6
86	1.8
88	2.4
88.2	4.8
87.4	9
87.4	12
87.4	19.8
86.6	25.8
86	31.8
85	38.4
83.8	44.4
83.4	51.6
82	57.6
81	63.6
80.8	69.6
80.4	75
82.2	82.8
60.4	90.6
51.2	100.2
21.6	109.8
2.4	115.8

Current Meter

Speed	Depth
45	10
36	20
19	30
9	40
15	50
12	60
10	70
10	80
12	90
10	100
10	110
11	115

Direction	Depth
55	10
5	20
90	30
145	40
150	50
180	60
180	70
250	80
150	90
155	100
180	110
160	115

TABLE III-1 (continued)

STATION 2

Transmissivity	Depth
86.8	1.8
88.8	3
82.4	6
86	7.8
90	11.4
90.2	14.4
90.4	17.4
90.6	19.8
90.2	24
90	26.4
91	29.4
90.2	33
90	36
89.8	39
89.6	42
89.6	45.6
87.6	48
87.8	51.6
87.8	55.8
89.2	58.2
88.8	61.2
88.6	64.2
89.2	67.2
89.2	70.8
89.2	74.4
88.4	76.8
84.2	80.4
83.8	83.4
82.4	86.4
82.2	90
81	91.2
75.2	91.8
74.8	93
72	96.6
61.8	100.8
48.6	103.8
37.8	106.2
39	109.8
39	112.2

Temperature	Depth
27.48	0.8
27.48	18.4
26.04	24.8
25.08	30.4
23.76	38
22.56	43.6
21.48	51.2
21.12	57.2
20.64	62.4
20.4	68.8
20.04	74.8
20.04	81.2
19.8	86.8
19.56	92.4
19.56	100.4
19.56	113.6

Salinity	Depth
36.09	0.8
36.09	10
36.18	13.6
36	18.4
35.91	24.8
36	30.4
36	43.6
36.18	51.2
36	57.2
36.09	62.4
36	68.8
36.18	74.8
36.09	81.2
36.18	86.8
36.18	113.6

TABLE III-1 (continued)

STATION 2 (continued)
Current Meter

Speed	Depth
32	15
27	20
28	30
23	40
21	50
24	60
23	70
16	80
22	90
14	100
12	110
10	115

Direction	Depth
14	15
40	20
40	30
135	40
130	50
110	60
115	70
175	80
185	90
145	100
160	110
210	115

TABLE III-1 (continued)
STATION 3

Temperature	Depth
27.84	2.8
27.84	6.4
27.72	10.4
27.48	14
27.48	18.4
26.28	25.6
26.04	28.8
25.44	32
25.08	35.6
23.88	42.4
22.08	46
21.48	52
21.12	54.8
20.88	58
20.76	61.2
20.4	64
20.4	66.8
20.28	69.2
20.28	72.4
20.16	74.8
20.04	77.6
19.8	80.8
19.8	83.6
19.8	87.2
19.68	89.6
19.55	92.8
19.55	96
19.44	99.6
19.44	101.2

Salinity	Depth
35.64	2.8
35.73	6.4
35.82	10.4
35.82	14
35.82	18.4
36	25.6
35.91	28.8
35.91	35.6
36.18	40
36	42.4
36	52
35.91	54.8
36	58
35.91	61.2
36	61.2
36	101.2

Current Meter

Speed	Depth
32	10
27	22
34	30
17	40
16	50
19	60
13	70
22	80
16	90
14	100

Direction	Depth
225	10
225	22
225	30
260	40
250	50
245	60
50	70
20	80
45	90
85	100

Depth	Transmissivity	Depth	Transmissivity
6.0	91.2	54.0	85.0
7.8	90.2	56.4	85.2
10.8	90.0	58.2	85.4
13.2	90.0	61.2	63.0
16.2	89.0	64.8	84.0
18.6	90.4	67.2	84.6
21.6	89.0	69.0	84.0
24.0	88.2	71.4	82.8
27.0	89.2	72.6	80.6
30.0	89.4	75.0	80.4
33.0	90.0	77.4	77.4
35.4	89.8	79.2	77.0
38.4	90.2	81.0	76.6
41.4	89.2	84.0	75.0
44.4	86.4	85.8	74.0
46.8	83.8	88.2	72.6
49.2	85.4	90.6	72.4
51.6	85.6	92.4	71.6
		94.8	72.0
		97.2	72.0
		99.0	71.6
		101.4	71.8
		102.6	71.6

TABLE III-1 (continued)

STATION 4

Depth	STD Salinity	Temperature
2.4	35.64	28.08
4.0	35.55	28.08
7.6	35.73	28.08
12.0	35.82	27.96
16.4	35.82	27.60
20.8	35.91	27.60
23.6	35.91	27.24
26.0	35.91	25.92
28.0	35.91	25.44
30.0	35.82	24.72
32.4	35.91	24.36
34.8	35.73	23.16
38.0	35.91	22.20
40.0	35.91	21.36
44.4	36.00	20.76
47.6	36.00	20.52
51.6	36.00	20.40
56.0	36.00	20.40
60.0	35.00	19.92
65.2	36.91	19.80
70.4	36.00	19.68
75.2	36.00	19.44
75.6	36.09	19.44
78.4	36.00	19.32
80.4	36.00	19.32
82.4	36.00	19.32
84.4	36.00	19.32
85.2	36.00	19.32

Current Meter

Speed	Depth
27	10
23	20
23	30
21	40
13	50
13	60
12	70
17	80
19	90

Direction	Depth
50	10
30	20
285	30
90	40
310	50
45	60
120	70
180	80
170	90

Depth	Transmissivity	Depth	Transmissivity
1.2	89.4	54.0	86.0
4.2	88.2	57.0	82.2
6.6	87.8	60.0	80.8
8.4	88.2	63.6	84.0
10.8	88.8	66.6	86.0
13.8	88.6	70.2	85.8
16.2	88.4	75.0	86.2
19.2	88.0	79.2	88.6
22.2	88.6	82.2	84.8
25.2	88.2	86.4	80.4
28.8	87.4	88.8	76.6
31.8	88.0	92.4	73.4
36.0	88.2	94.2	71.8
37.8	88.0	94.8	71.6
42.6	86.6	97.8	70.4
50.4	85.4		

TABLE III-1 (continued)

STATION 5

STD

Depth	Salinity	Temperature
1.6	36.54	28.32
3.6	36.54	28.20
8.0	36.45	27.96
14.4	36.27	27.24
20.8	36.54	25.8
26.8	36.54	25.2
33.2	36.45	24.48
39.6	36.54	23.64
46.0	36.54	23.28
52.4	36.45	22.68
58.4	36.45	21.48
65.2	36.45	20.88
70.8	36.72	20.40
77.2	36.54	20.28
84.0	36.63	20.04
89.6	36.63	19.80
96.4	36.63	19.80
102.8	36.63	19.80

Depth	Transmissivity
.6	87.2
1.2	89.2
7.2	91.2
13.8	90.6
20.4	90.6
25.8	90.2
31.8	89.2
38.4	90.6
43.8	89.00
50.4	88.8
56.4	87.4
63.6	85.0
69.6	52.4
76.2	42.4
81.6	70.8
88.2	53.6
94.2	49.2
100.2	46.6
103.8	46.4

Current Meter

Speed	Depth
21	10
25	20
15	30
16	40
16	50
22	60
26	70
24	80
23	90
19	100

Direction	Depth
240	10
200	20
325	30
265	40
230	50
320	60
300	70
255	80
225	90
260	100

TABLE III-1 (continued)

STATION 6

STD

Depth	Salinity	Temperature
1.6	36.18	27.96
6.0	36.18	27.96
10.8	36.27	27.84
15.6	36.09	27.84
22.8	36.00	27.24
31.2	35.91	25.08
39.6	35.91	23.52
47.6	36.00	22.44
56.0	35.82	21.36
67.6	36.18	20.04
75.6	36.18	19.80
82.4	36.18	19.68

Depth	Transmissivity
0.6	74.8
1.2	90.6
2.4	90.6
6.6	91.6
10.8	91.4
14.4	91.4
18.6	91.6
21.6	91.2
25.2	91.0
29.4	90.4
33.6	89.6
36.6	90.0
40.8	89.8
45.0	88.6
48.6	87.6
51.0	88.0
55.2	87.4
58.2	86.6
60.0	84.6
65.4	82.6
69.6	81.0
74.4	79.6
79.2	75.0
83.4	74.0
88.2	72.0
91.2	0

Current Meter

Speed	Depth
32	10
28	20
20	30
15	40
15	50
23	60
11	70
9	85

Direction	Depth
45	10
50	20
320	30
280	40
320	50
270	60
305	70
315	85

TABLE III-1 (continued)

STATION 7

Depth	STD Salinity	Temperature
1.6	35.82	27.84
2.0	25.82	27.84
4.8	25.82	27.84
7.2	25.73	27.72
9.6	35.82	27.48
12.4	35.91	27.48
16.0	36.00	27.36
18.8	36.00	27.24
22.0	36.09	26.76
26.0	36.00	25.68
30.4	36.27	25.08
33.6	36.09	24.72
38.4	36.00	23.52
43.6	36.18	22.68
48.8	36.18	22.32
52.8	36.18	22.2
56.4	36.18	21.96
60.8	36.00	21.48
65.6	36.09	20.88
69.2	36.18	
74.4	36.00	20.28
79.2	36.18	19.92
82.8	36.18	19.80

Current Meter

Speed	Depth
27	10
23	20
15	30
16	40
17	55
24	60
23	70
8	80

Direction	Depth
135	10
123	20
135	30
225	40
135	55
180	60
200	70
180	80

Depth	Transmissivity	Depth	Transmissivity
1.2	90.6	55.2	87.0
3.0	89.4	59.4	85.4
6.0	90.0	61.8	84.2
8.4	88.6	64.8	84.0
12.0	89.2	67.8	84.0
15.0	89.2	72.0	84.4
18.0	89.8	74.4	83.6
20.4	90.2	77.4	75.0
24.0	90.2	80.4	74.60
27.6	90.0	83.4	53.6
30.6	90.4	83.4	74.4
33.6	89.4		
36.6	89.8		
40.2	89.2		
43.2	89.2		
46.2	88.6		
49.2	88.8		
52.8	87.8		

TABLE III-1 (continued)

STATION 8

Transmissivity	Depth
80.8	0.6
88.8	2.4
88.6	4.8
87.8	6.6
86.8	9.6
87.6	12
88	15
87.8	18
88.2	21
88.2	24
88.6	27
88.4	29.4
88.2	32.4
87.6	34.8
88.2	37.2
88.2	40.8
87.4	49.8
87.6	52.8
87	56.4
85	58.2
85.4	61.2
84.2	64.2
85.2	66.6
85.2	85.2
86	73.2
76.2	85
82.8	86
85.4	86.4
83	89.4
82.2	93
80.2	96
77.6	99
73	100.2

Current Meter

Speed	Depth
32	10
29	20
20	30
13	45
15	50
12	60
18	70
15	80
12	95
18	100

Direction	Depth
320	10
45	20
320	30
90	45
30	50
80	60
125	70
170	80
190	95
185	100

Depth	Salinity	Temperature
1.2	35.64	27.96
2.4	35.82	27.48
5.2	35.82	27.36
9.6	35.73	26.52
15.2	36.00	25.32
19.6	35.91	24.48
25.2	35.91	23.52
30.8	35.91	22.80
37.2	35.91	22.08

Depth	Salinity	Temperature
42.4	36.09	21.00
48.4	36.09	20.64
53.6	36.09	20.52
58.8	36.00	20.52
64.8	36.00	20.04
70.4	36.00	19.92
76.0	36.09	19.8
81.2	36.00	19.68
84.8	36.09	19.44
86.8	36.09	19.44
89.2	36.00	19.32
89.6	36.00	19.44

TABLE III-1 (continued)

STATION 9

Temperature	Depth
27.84	0.8
27.84	1.6
27.6	2
27.48	2.8
27.36	4
27.36	6
27.12	8.4
26.52	10.4
25.92	12.8
25.8	15.2
25.56	18
25.44	21.2
25.44	21.6
25.44	23.2

Salinity	Depth
35.82	0.8
35.82	1.6
35.73	2
35.82	2.8
35.91	4
35.91	10.4
36	12.8
36	18
36.09	21.2
36.09	21.6
36	22.8
36	23.2

Transmissivity	Depth
84	2.4
86.8	3.6
86.6	6
85.4	9
84	12.6
84.2	15.6
85	18.6
84.2	21.6
86	24.6
84.6	28.2
85.2	31.2
75.8	33.6
82.4	34.2

Current Meter

Speed	Depth
14	10
26	20
15	35

Direction	Depth
90	10
50	20
30	35

TABLE III-1 (continued)

STATION 10

Temperature	Depth
27.96	1.2
28.08	5.6
27.96	6
27.96	7.6
27.84	10
27.6	14.4
27.48	20.4
27.48	26
27.36	32.4
27	38.8
26.16	45.2
25.68	52.8
25.2	60.4
24.96	67.6
24.72	76.8
24.36	86
23.16	97.2
23.04	98.8

Salinity	Depth
35.55	1.2
35.55	6
35.64	7.6
35.64	10
35.73	14.4
35.73	20.4
35.82	26
35.82	32.4
35.91	38.8
35.91	45.2
35.82	52.8
35.91	60.4
36	67.6
35.91	76.8
35.91	86
36	97.2
35.91	98.8

Transmissivity	Depth
87.4	1.8
87	3
88	6
88	8.4
88.2	10.8
88	13.2
88	16.2
87.8	19.8
86.8	21.6
86.8	24.6
85.8	27.6
86	31.2
85.6	34.2
84.6	37.2
86	40.2
85.4	43.8
85	46.8
84.8	49.8
85	52.8
85.4	55.8
83.8	59.4
84.2	62.4
85.4	65.4
84.4	68.4
83.4	71.4
81.2	74.4
81.2	78
81.2	80.4
80.8	84
80.8	87.6
81.2	90
6.2	91.8

Current Meter

Speed	Depth
25	10
25	20
38	30
34	40
32	55
33	60
33	70
31	80
29	90

Direction	Depth
230	10
220	20
180	30
165	40
145	55
135	60
120	70
120	80
130	90

TABLE III-1 (continued)

STATION 11

Temperature	Depth
27.96	0.48
27.6	1.56
27.48	3.24
27.36	5.4
26.76	8.64
25.44	13.32
24.84	17.16
23.4	21.36
22.32	27.36
22.32	31.44
21.48	36.96
20.88	42.24
20.64	48.12
20.64	58.8
20.4	60.4
21.04	64.4
20.04	70
19.8	75.2
19.68	80.4
19.68	86.8
19.56	92.4
19.32	97.6
19.08	102.8
18.48	107.6
18.48	113.6

Salinity	Depth
35.64	0.48
35.64	1.56
35.82	3.24
35.82	5.4
35.91	8.46
35.91	13.32
36	17.16
35.82	21.36
35.82	31.44
35.91	36.96
35.82	42.24
36	48.12
36	58.8
35.91	60.4
35.91	80.4
36	86.8
35.91	92.4
36	97.6
35.82	102.8
36	107.6
36	112.4
36.09	113.6

Transmissivity	Depth
87.6	1.8
88.4	4.2
88	7.2
87.8	10.2
87.8	13.2
88.2	16.8
86.8	19.8
86.2	22.8
84.8	25.8
86.8	28.8
87.2	31.8
86.8	35.4
86.2	38.4
84.4	42
84.6	45
85	51.6
83	54
83.6	58.2
84.8	61.2
85.2	64.2
85.4	67.2
84.8	70.2
84.4	73.8
82.8	76.8
80.4	80.4
79	83.4
78	85.8
76.2	90
73.2	92.4
69.6	96
70.6	99
71.6	102.6
71	105.6
70	109.2
72.2	112.2
84.8	115.8
88	118.2
73.6	121.8
67.8	125.4
68	127.8

TABLE III-1 (continued)

Station 11 (continued)

Current Meter

Speed	Depth
21	10
33	20
25	30
18	40
25	50
25	60
32	70
13	80
7	90
9	100
5	110
14	120
14	126

Direction	Depth
270	10
250	20
260	30
305	40
20	50
70	60
110	70
115	80
215	90
205	100
215	110
75	120
65	126

TABLE III-1 (continued)

Station 12

Temperature	Depth
27.84	3.2
27.6	7.6
26.28	12.4
23.4	23.6
21.84	36.4
20.64	44
20.04	49.2
19.8	58.2
19.44	65.6
19.44	87.6
19.32	94.8
18.96	101.2
18.84	110
18.48	118.8
18.24	130.8
18.24	133

Salinity	Depth
35.91	3.2
35.82	7.6
35.37	12.4
35.46	23.6
35.46	36.4
36.09	44
36	49.2
36	58.2
35.91	65.6
36	70.4
36	87.6
35.91	94.8
35.91	118.8
36	130.8
36.09	134.8
36.18	136
36.18	138

Transmissivity	Depth
83.8	0.6
84.4	3.6
84.2	6
83.7	7.8
83.6	9.6
84.8	11.4
84.2	15
84	18
83.8	20.4
84.4	23.4
83.4	26.4
83.6	28.8
82.8	32.4
83.2	35.4
82.8	38.4
81.8	42
80.2	44.4
81.2	47.4
82	50.4
80.8	53.4
82	56.4
79.8	59.4
79	62.4
80.6	66
81.2	69
80.6	72.6
80.8	75
82.6	78.6
79	81.6
72.8	84.6
68.2	88.2
73.8	91.2
77.8	94.2
79.6	97.8
87	100.8
87	104.4
87.2	106.8
88	111
88	114
88.4	117
89.2	120
88.4	123
84.8	130.2
85.2	133.2
85.8	138.6
72.8	142.8
66.2	148.2
0.2	154.2
0	158.4

TABLE III-1 (continued)

Station 12 (continued)

Current Meter

Speed	Depth
19	7
20	20
19	30
8	45
10	50
6	60
14	70
12	80
8	90
9	100
10	110
8	120
7	130
7	140
13	150
9	170

Direction	Depth
225	7
250	20
265	30
315	45
105	50
90	60
135	70
85	80
135	90
205	100
215	110
235	120
45	130
315	140
310	150
15	170

TABLE III-2. STD, Transmissivity and current meter data for East Flower Gardens, Cruise 77G10.

STATION 1

Temperature	Depth
26	0
26	30
22.5	47.5
21.5	65
20.5	70
20.5	82.5
19.5	85
18	95

Salinity	Depth
35.85	0
35.85	30
36.1	32.5
36.1	35
36	37.5
36.1	47.5
36.3	50
36.4	65
36.1	67.5
36.25	72.5
36.3	75
36.15	79
36.3	82.5
36.2	85
36.4	95

Transmissivity	Depth
82	0
82	6
84	12
84	30
82	36
80.5	42
78	48
78	54
75	60
76	66
76	72
80	78
82	84
80	90
73	96
73	102
67	108
67	116

Current Meter

Speed	Depth
30.7	0
30.7	3
29.9	10
25.3	18
19.4	25
32.1	34
40.23	43
20.9	52
8.5	60
7.8	68
19.5	76
30.45	85

Direction	Depth
94.5	0
94.5	3
98.05	10
104.9	18
106.14	25
114.7	34
94.3	43
85	52
74.95	60
98.76	68
130	76
127.9	85

TABLE III-2 (continued)

Temperature	Depth
28.5	0
28	22.5
28	27.5
24	41
22.5	48
21.5	67.5
19.5	92.5
18	97.5
17	110

Salinity	Depth
35.85	0
35.9	22.5
36.05	25
36.05	29
35.9	30
36.1	35
35.7	37.5
36.2	40
35.55	41
36.2	45
35.85	48
36.2	52.5
36.2	65
36.2	95
35.9	100
36.3	110

Transmissivity	Depth
83	0
83	6
84	12
84	18
82	24
80	30
79	36
80	42
79	48
78	54
79	60
76	66
80	72
80.5	78
81	84
79.5	90
80	96
80	102
78	108
72	112

STATION 2 Current Meter

Speed	Depth
12.5	0
7.3	3
11.9	10
8.95	18
5.54	25
11.9	34
17.9	43
14.3	52
11.2	60
10.7	68
19.1	76
17.6	85

Direction	Depth
213.7	0
211.8	3
210	10
214.3	18
150.1	25
157.9	34
90	43
156.6	52
189.5	60
109.7	68
149.2	76
145.1	85

TABLE III-2 (continued)

STATION 3

Temperature	Depth
28.62	0
28.75	10
28.8	20
28.8	30
26.1	40
23.77	47.5
22.9	55
22.4	60
21.6	70
20.78	83
19.4	92.5
19.4	100

Salinity	Depth
36	0
36.15	10
36.2	20
36.2	30
36.15	37.5
35.6	40
36	42.5
35.55	45
36.1	50
36.2	60
36.2	70
36.2	100

Transmissivity	Depth
85	0
86	6
86	12
85	18
85.5	24
86	30
86	36
84	42
82	48
83	54
81	60
82	66
82	72
85	78
84	84
82	96
84	102
84	108

Current Meter

Speed	Depth
14.45	7
10.7	10
4.3	18
9.15	25
5.5	34
20.2	43
22.5	52
25.3	60
11.9	68
7.4	76
12.4	85
9.06	86

Direction	Depth
88.6	7
67.13	10
161.55	18
171.5	25
210.1	34
263.04	43
311.6	52
290.7	60
273.16	68
238.8	76
177.45	85
195.04	86

TABLE III-2 (continued)

STATION 4

Temperature	Depth	Current Meter Speed	Current Meter Depth
28.96	0	4.3	0
28.84	10	10.5	10
28.79	20	1.96	18
28.82	30	7.12	25
27.9	40	6.85	34
24.5	50	6.32	43
23	60	14.9	52
22.3	70	15	60
20.4	80	17.7	68
20.1	90	1.24	72
19.92	95	31.14	104

Salinity	Depth	Direction	Depth
36.2	0	98.05	0
36.19	10	77.3	10
36.23	20	144.53	18
36.27	30	226.5	25
36.46	40	159.1	34
36.34	50	289.4	43
36.3	60	267.3	52
36.36	70	267.3	60
36.38	80	276.2	68
36.35	90	316.3	72
36.35	95	344.43	104

Transmissivity	Depth
84	0
84	24
83	30
84	36
84	42
82	48
82	54
80	60
81	66
82	72
82	84
84	90
79	96

TABLE III-2 (continued)

STATION 5

Temperature	Depth
28.96	0
28.95	10
28.82	20
28.74	30
28.75	35
28	40
25.15	50
23.8	60
22.36	70
21.3	80
20.7	88

Salinity	Depth
36.05	0
36.15	10
36.21	20
36.2	30
36.2	40
35.75	45
35.8	50
36.16	55
35.98	60
36.15	70
36.2	80
36.3	88

Transmissivity	Depth
86	12
85	18
85	24
84	30
85	36
81	42
79.5	48
78	54
82	60
82	66
83	72
82	78
83	84

Current Meter

Speed	Depth
11.1	0
25.34	10
17.7	18
12.7	25
10.3	34
18.05	43
17.7	52
8.8	60
12.2	68

Direction	Depth
120.96	0
83.88	10
69.5	18
100	25
52.5	32
350.4	43
1.6	52
21.3	60
40.35	68

TABLE III-2 (continued)

STATION 6

Temperature	Depth
28.9	0
28.9	10
28.75	20
28.73	30
26.1	40
24.55	50
22.9	60
21.4	70
20.45	80
19.58	90
19.3	94

Salinity	Depth
36.1	0
36.1	10
36.13	20
36.25	30
35.75	40
35.54	42.5
36.03	50
35.98	60
36.05	70
36.18	80
36.12	90
36.27	94

Transmissivity	Depth
85	0
85	18
86	24
86	30
81	36
81	48
85	54
82	60
82	66
86	72
86	78
88	84
82	90
64	96

Current Meter

Speed	Depth
28.8	3
20.3	7
27.1	18
16.55	25
3.65	34
17.5	43
25.2	52
23.7	60

Direction	Depth
84.4	3
69.7	7
58.4	18
60.6	25
339.5	34
10.6	43
18.3	52
34.7	60

TABLE III-2 (continued)

STATION 7

Temperature	Depth
28.75	0
28.8	5
28.8	26
28.7	32
25.7	42
23.2	50
22.6	60
22.45	65
22.3	72

Salinity	Depth
36.2	0
36.25	30
36.3	34
36.2	35
36.7	39
35.95	41
36.7	42.5
36.25	46
36.5	48
36.3	50
36.3	72

Transmissivity	Depth
87	0
87	9
88	12
88	21
87	24
86	27
87	30
87	39
86	42
85	45
83	48
82	51
80	54
80	57
82	60
82	72
83	75

Current Meter

Speed	Depth
27.6	3
17.1	7
19.1	18
12.6	25
13	34
2.1	43
9.5	52
10.4	60

Direction	Depth
116.8	3
118.8	7
93.1	18
124.5	25
204.1	34
337.95	43
24.32	52
65.92	60

TABLE III-2 (continued)

STATION 9

Temperature	Depth
28.85	0
28.85	20
28.9	23
28.8	30
28.25	31

Salinity	Depth
35.8	0
35.8	10
35.85	20
35.9	30

Transmissivity	Depth
84	0
84	21
85	24
86	27
86	30

Current Meter

Speed	Depth
22.8	0
18.4	7
15.9	10
20	18
13.8	25
36.9	32

Direction	Depth
152.3	0
138.4	7
130.55	10
115.9	18
116	25
183.1	32

TABLE III-2 (continued)

STATION 10

Temperature	Depth
28.58	0
28.6	25
28.55	27.5
27.3	32.5
26.55	45
22	62

Current Meter Speed	Current Meter Depth
18.4	10
16.1	18
12.7	25
10	34
6	43
11.1	52

Salinity	Depth
35.3	0
35.3	25
35.5	30
35.9	37.5
35.6	40
36.35	42.5
35.8	45
35.8	62

Direction	Depth
121.2	10
125.1	18
146.2	25
163.3	34
235.1	43
107	52

Transmissivity	Depth
86	0
86	33
85	36
84	39
83	42
82	45
80.5	48
80.5	51
79	54
78	57
78	63
82	66

TABLE III-2 (continued)

STATION 11

Transmissivity	Depth
85	0
87.5	6
88	12
87.5	18
87.5	36
87	42
86	48
80	54
78	60
78	66
79	72
80	78
79	84
78	90
82	96
72	102
70	108
70.5	114
74	120

Current Meter

Speed	Depth
36.3	0
33.1	10
29.5	18
32.2	25
30.2	34
31.4	43
36	52
32.15	60
34.4	68
30.5	76
33.3	85
27.2	94

Direction	Depth
325.85	0
319.4	10
313.8	18
317.21	25
316.8	34
314.8	43
308.2	52
307.9	60
308.3	68
314.4	76
315.7	85
316	94

TABLE III-2 (continued)

STATION 12

Temperature	Depth
28.81	0
28.78	10
28.7	20
28.78	30
27.75	40
24.65	50
23.45	60
23.01	70
22.45	80
20.26	90
19.45	100
18.5	110
18.05	120
17.75	130
17.32	140
17.05	147

Salinity	Depth
35.98	0
36.08	10
36.1	20
36.17	30
36.15	40
36.05	50
36.2	60
36.25	70
36.25	80
36.3	90
36.3	110
36.33	120
36.31	130
36.29	140
36.27	147

Transmissivity	Depth
82.5	0
84.5	6
85	12
85	18
82.5	24
83	30
82	36
79	42
78	48
75	54
76	60
79	66
78	72
77	78
76	84
78	90
80	96
74	102
72	108
70	114
68	120
80	126
80	132

Current Meter

Speed	Depth
5.45	0
0.95	10
17.5	18
18.35	25
23.3	34
36.03	43
22.45	52
17.75	60
28.8	68
37	76
20.4	85
20.75	94
22.85	104
13.75	105

Direction	Depth
132	0
168	10
159.4	18
135.75	25
159.2	34
73.5	43
159.4	52
171.6	60
215.05	68
232.8	76
215.65	85
170.4	94
190.8	104
173.75	105

TABLE III-3. STD, Transmissivity and current meter data for East Flower Gardens, Cruise 78 DP1.

STATION 1

Transmissivity	Depth
81.4	0
83.2	4.8
83.6	15.6
82.8	21
84.2	30.6
84	40.8
83.2	49.2
82.6	57
83.2	66.6
82	75
81	84
76.8	95.4
48.4	105
36.8	111
16.6	115.2
0.1	115.2

Salinity	Depth
36.32	3.6
36.34	9.6
36.34	18
36.32	22.2
36.34	25.4
36.32	29.2
36.32	45.2
36.32	50.4
36.3	53.2
36.32	57.2
36.32	60
36.32	60.8
36.34	61.6
36.32	64.4
36.32	65.2
36.3	66
36.32	68.8
36.28	72
36.24	74.8
36.32	78
36.26	78.8
36.24	80.4
36.18	81.6
36.22	84.4
36.12	84.8
36.12	90
36.1	98.4
36.22	101.2
36.18	103.2
36.16	108.4
36.14	111.2
36.16	112
36.2	115.6
36.26	116

Temperature	Depth
18.5	3.6
18.44	9.6
18.42	18
18.42	25.2
18.42	22.4
18.4	29.2
18.4	45.2
18.4	50.4
18.4	53.2
18.4	57.2
18.4	60
18.38	60.8
18.38	61.6
18.36	64.4
18.34	65.2
18.34	66
18.34	68.8
18.24	72
18.08	74.8
17.72	78
17.68	78.8
17.66	80.4
17.64	81.6
17.54	84.4
17.36	84.8
17.18	90
17.08	98.4
16.98	101.2
16.96	103.2
16.84	108.4
16.74	111.2
16.64	112
16.62	115.6
16.64	116

TABLE III-3 (continued)

STATION 2

Salinity	Depth
36.26	0.4
36.26	6.8
36.28	12.8
36.28	20
36.28	26.8
36.28	31.6
36.28	35.2
36.28	37.6
36.26	41.2
36.28	44.8
36.28	48
36.28	49.6
36.28	54
36.28	61.6
36.26	65.6
36.28	66
35.8	76.8
36.04	82.4
36.14	89.2
36.12	99.6
36.14	103.6
36.14	108
36.16	111.6
36.14	114
36.16	115.6
36.18	116.4

Transmissivity	Depth
88.2	0
87.6	5.4
87	15
87	26.4
85.4	37.2
86.4	47.4
86.2	53.4
86.8	61.2
87.2	69
85	76.2
82.4	84.6
80.6	92.4
72.8	100.2
57.8	105
52.2	108
55	111.6
43	114.6
0.1	115.8

Temperature	Depth
18.46	0.4
18.46	6.8
18.46	12.8
18.44	20
18.44	26.8
18.44	31.6
18.44	35.2
18.44	37.6
18.44	41.2
18.44	44.8
18.44	48
18.44	49.6
18.44	54
18.44	61.6
18.38	65.6
18.44	66
18.18	76.8
17.24	82.4
17.12	89.2
17.06	99.6
17	108
16.98	115.6
16.92	116.4

TABLE III-3 (continued)

STATION 3

Transmissivity	Depth
86.8	0
87.2	6.6
86.6	12.6
87	18.6
86.8	24.6
87.4	30
87.2	33.6
86.8	39.6
87.6	44.4
87	49.2
86.8	53.4
87.4	57.6
86.4	62.4
86.4	71.4
87.8	81.6
75.4	93
31.2	105
24.6	106.2

Salinity	Depth
36.14	1.6
36.22	4.4
36.22	11.2
36.28	16.8
36.28	26.4
36.3	35.6
36.28	48
36.28	57.6
36.28	68
36.28	74
36.28	80.4
36.26	88
36.26	92
36.26	95.6
36.2	98.4
36.24	102.8
36.34	106.4

Temperature	Depth
18.46	1.6
18.5	4.4
18.52	11.2
18.52	16.8
18.52	26.4
18.52	35.6
18.5	48
18.5	57.6
18.5	68
18.5	74
18.5	80.4
18.5	88
18.48	92
18.48	95.6
18.44	98.4
18.4	102.8
17.16	106.4

TABLE III-3 (continued)

STATION 4

Salinity	Depth
36.28	2.8
36.3	7.2
36.38	11.6
36.36	16.4
36.34	22.4
36.38	30.8
36.34	40.8
36.32	51.2
36.34	55.6
36.36	59.6
36.3	65.6
36.28	72.4
36.34	79.2
36.26	87.2
36.2	94
36.06	98.4
36.38	101.6
36.56	102

Temperature	Depth
18.54	2.8
18.56	7.2
18.54	11.6
18.54	16.4
18.56	22.4
18.56	30.8
18.56	40.8
18.56	51.2
18.56	55.6
18.54	59.6
18.54	65.6
18.56	72.4
18.56	79.2
18.54	87.2
18.42	94
17.9	98.4
17.62	101.6
17.62	102

Transmissivity	Depth
86	0
84.6	7.8
86.6	15.6
87.8	22.2
87.8	28.2
88.6	33
88.2	38.4
88.2	44.4
88	48.6
88.2	53.4
88	57
87.8	58.2
87.6	60.6
87.4	63
87.4	67.2
86.8	70.8
87.2	72.6
87.6	74.4
87.8	76.8
87.8	82.2
87.4	85.2
85.8	87.6
61.4	93
5	96

TABLE III-3 (continued)

STATION 5

Salinity	Depth
36.24	6
36.16	8.8
36.3	12.8
36.32	19.6
36.32	26.4
36.32	33.6
36.3	41.6
36.26	51.6
36.26	60
36.26	66.8
36.24	72.8
36.24	76.8
36.2	79.2
36.1	83.6
36.1	88.4
36.14	92.8
36.22	97.2
36.12	100.8
36.28	104.4
36.22	104.8
36.18	105.2
36.18	106
36.18	106.8

Transmissivity	Depth
85.8	0
86.8	1.2
86.2	3
85.4	5.4
85.4	7.2
86.8	9.6
86.6	13.2
86.6	19.8
86.2	24.6
85.8	31.8
86	38.4
86.4	43.2
85.8	52.8
88.4	66.6
87.4	78
83.6	83.4
84.6	89.4
72.2	93.6
40.8	98.4
33.4	102.6
18.2	103.8
0.1	103.8

Temperature	Depth
18.84	6
18.84	8.8
18.84	12.8.
18.84	19.6
18.84	26.4
18.82	33.6
18.76	41.6
18.66	51.6
18.6	60
18.46	66.8
18.4	72.8
18.34	76.8
18.18	83.6
17.72	88.4
17.52	92.8
17.42	97.2
17.36	100.8
17.26	104.4
17.24	104.8
17.24	105.2
17.24	106
17.24	106.8

TABLE III-3 (continued)

STATION 6

Salinity	Depth
36.42	5.2
36.4	11.2
36.42	18
36.4	23.2
36.42	28.4
36.42	34.4
36.38	41.2
36.38	48.4
36.32	56
36.32	62.4
36.28	68
36.32	71.6
36.48	76.4
36.54	77.2
36.58	77.6

Temperature	Depth
19.86	5.2
19.7	11.2
19.68	18
19.66	23.2
19.66	28.4
19.66	34.4
19.64	41.2
19.64	48.4
19.54	56
19.32	60.4
19.28	68
19.16	71.6
18.78	76.4
18.74	77.2
18.76	77.6

Transmissivity	Depth
82.8	0
84.4	3
84.2	8.4
85.4	13.2
85	20.4
84.8	25.8
84.6	28.8
85.4	29.4
85	34.8
85.8	39
85.4	42.6
85	45
85.2	48
85.2	49.8
85.4	52.2
84.8	54.6
85.4	57
85.6	60
86	62.4
85.8	66.6
86.2	69
85.8	69.6
86	71.4
85	72.6
85.6	74.4
86	76.2
85.6	79.2
79.6	80.4

TABLE III-3 (continued)

STATION 7

Transmissivity	Depth
87.4	0
88.4	4.8
89	7.2
89.2	11.4
88.6	18
87.6	26.4
88.6	34.8
88.2	44.4
87.6	52.8
88	60.6
87.8	68.4
87.6	76.2
87	84.6
1.2	85.2

Salinity	Depth
36.3	3.6
36.12	12
36.22	12.6
36.26	14
36.3	17.2
36.32	20
36.3	23.6
36.32	26.8
36.32	28
36.32	34.4
36.32	38
36.34	41.6
36.32	45.6
36.32	50
36.32	55.6
36.32	59.2
36.3	62
36.3	66
36.3	72.8
36.3	76.4
36.3	79.2
36.24	83.2
36.34	84.4
36.28	84.4

Temperature	Depth
18.76	3.6
18.84	12
18.78	12.6
18.76	17.2
18.76	23.6
18.76	28
18.74	34.4
18.74	41.6
18.74	50
18.74	59.2
18.74	66
18.74	76.4
18.74	79.2
18.62	83.2
18.56	84.4

TABLE III-3 (continued)

STATION 8

Salinity	Depth
36.26	2
36.26	9.2
36.28	15.2
36.26	20.8
36.24	24.4
36.28	27.6
36.3	32
36.32	35.6
36.32	36.8
36.32	41.6
36.32	48
36.32	51.2
36.32	57.6
36.3	62.8
36.3	67.2
36.3	71.6
36.3	76.4
36.3	81.6
36.3	86.8
35.98	90.8
36.18	95.6
36.26	99.2
36.34	103.2
36.38	104.4

Transmissivity	Depth
87.2	0
87.2	3
87.6	8.4
87.2	13.8
86.4	20.4
85.6	27.6
87.2	36.6
87.2	43.8
87.2	51.6
87	58.8
86.6	67.8
86.2	75.6
86.4	85.2
85.6	90.6
82.8	94.2
74.2	99.6
55.4	103.2

Temperature	Depth
18.7	2
18.7	9.2
18.7	18.7
18.68	24.4
18.68	24.4
18.68	27.6
18.68	32
18.68	35.6
18.68	36.8
18.68	41.6
18.68	48
18.68	51.2
18.68	57.6
18.68	62.8
18.68	67.2
18.68	71.6
18.68	76.4
18.68	81.6
18.66	86.8
18.28	90.8
17.36	95.6
17.32	99.2
17.26	103.2
17.26	104.4

TABLE III-3 (continued)

STATION 9

Transmissivity	Depth
86	1.8
87	7.2
86.8	16.2
87.8	22.8
86	27
88	30
88.4	34.8
88.8	40.2
87.6	45
86.4	46.8

Salinity	Depth
36.34	0.4
36.32	9.6
36.34	14
36.34	19.6
36.34	22.4
36.34	24.8
36.34	27.2
36.34	29.6
36.34	33.2
36.34	36.8
36.34	40.4
36.32	44.4
36.32	44.8

Temperature	Depth
18.44	0.4
18.42	9.6
18.42	14
18.4	19.6
18.4	22.4
18.4	24.8
18.4	27.2
18.38	29.6
18.36	33.2
18.38	36.8
18.38	40.4
18.38	44.4
18.36	44.8

TABLE III-3 (continued)
STATION 10

Transmissivity	Depth
86.8	0
87.6	4.2
85.8	9
86.6	16.8
87.4	27
87.2	34.2
87.6	44.4
86.6	54.6
87.4	62.4
87.6	67.2
88	72
87.8	79.8
88	85.2
87.6	92.4
0.1	97.8

Salinity	Depth
36.3	2.8
36.3	9.2
36.32	14.4
36.32	27.2
36.32	38
36.32	40.8
36.32	46.8
36.34	50.8
36.34	60.4
36.34	66.4
36.34	68
36.3	80.4
36.36	84.8
36.32	92.4
36.32	95.6
36.24	98.8

Temperature	Depth
18.46	2.8
18.44	9.2
18.44	14.4
18.42	27.2
18.42	38
18.4	40.8
18.4	46.8
18.4	50.8
18.4	60.4
18.4	66.4
18.4	68
18.4	80.4
18.4	84.8
18.4	92.4
18.38	95.6
18.38	98.8

TABLE III-3 (continued)

STATION 11

Transmissivity	Depth
86.8	0
85.4	4.2
84.2	9
85.2	15
84.8	21.6
85.4	29.4
85.4	37.8
86.2	45
86.2	52.2
86	57.6
86.2	63.6
86.2	72.6
85	84
85.4	96
70.2	105.6
67.6	118.2
68.6	123.6
1	130.2

Salinity	Depth
36.22	2.4
36.22	11.6
36.34	18.8
36.34	28.4
36.34	35.6
36.34	40.8
36.34	46.4
36.34	52
36.32	56.8
36.34	60
36.34	64.4
36.34	65.2
36.34	69.2
36.34	70.8
36.34	74.8
36.36	79.2
36.34	84.4
36.32	89.6
36.34	94.8
36.34	99.2
36.34	103.2
36.18	106.4
35.82	112.8
35.9	116.8
36.08	123.2
36.22	126.8
36.16	128.8
36.2	130.4
36.32	131.6

Temperature	Depth
18.58	2.4
18.46	11.6
18.44	18.8
18.44	28.4
18.42	35.6
18.4	40.8
18.4	46.4
18.4	56.8
18.4	60
18.4	64.4
18.4	65.2
18.4	69.2
18.4	70.8
18.4	74.8
18.4	79.2
18.4	84.4
18.4	89.6
18.36	94.8
18.34	99.2
18.32	103.2
17.9	106.4
17.22	112.8
16.5	116.8
15.92	123.2
15.68	126.8
15.44	128.8
15.32	130.4
15.34	131.6

TABLE III-3 (continued)

STATION 12

Transmissivity	Depth
84.6	0
84.4	6
83.8	17.4
82.6	29.4
83.2	37.2
83.4	47.4
84.4	54
83.6	61.2
85.6	67.8
85.4	73.8
84.8	79.8
83.8	85.8
85.6	92.4
85.2	100.8
85	108.6
73.8	117
67.8	125.4
76	132.6
81.6	139.8
75.2	148.2
0.1	156

Salinity	Depth
36.2	1.2
36.26	9.2
36.3	16.4
36.3	24
36.3	29.6
36.32	33.6
36.32	39.2
36.32	44.8
36.32	49.2
36.32	54.4
36.32	61.6
36.32	69.6
36.32	77.2
36.32	81.2
36.32	86.4
36.32	90
36.32	96.4
36.34	100
36.32	102.8
36.22	105.2
36.28	108.4
36.28	110.8
36.24	113.6
36.26	115.2
36.28	118
36.16	118.4
36.12	121.2
36.1	129.2
36.18	131.2
36.14	132.4

Temperature	Depth
18.6	1.2
18.46	9.2
18.46	16.4
18.44	24
18.44	29.6
18.44	33.6
18.42	39.2
18.42	44.8
18.4	54.4
18.4	61.6
18.38	69.6
18.4	77.2
18.38	81.2
18.38	86.4
18.38	90
18.38	96.4
18.38	100
18.38	102.8
18.08	105.2
17.52	108.4
17.36	110.8
17.26	113.6
17.1	115.2
16.74	118
16.66	118.4
15.8	121.2
15.74	129.2
15.68	131.2
15.6	132.4

TABLE III-4. STD, Transmissivity and current meter data for East Flower Gardens Bank, Cruise 78L1.

STATION 1

Transmissivity	Depth
15.5	0
2.2	0.6
73.4	11.4
75	14.4
74.8	19.2
74	23.4
75.6	30
75.6	33
77	37.2
77	38.4
83.8	43.8
84.6	51.6
83.6	55.8
83.6	62.4
79.6	66.6
83.6	72.6
82.2	78.6
78.8	85.2
78.4	92.4
83.6	93
68.6	105.6
58.2	108.6
53.4	113.4
0	117.6

Salinity	Depth
35.89	4.4
36.05	11.2
36.01	19.6
35.95	29.2
36.05	39.6
36.15	49.6
35.99	60
36.01	71.6
35.85	82
35.91	94
36.09	108.4
36.23	114.8
36.33	116

Temperature	Depth
18.82	4.4
18.58	11.2
18.5	19.6
18.44	29.2
18.14	39.6
17.92	49.6
17.64	60
17.32	71.6
17.06	82
16.62	94
16.5	108.4
16.48	114.8
16.52	116

Current Meter

Speed	Depth
10	10
11	20
8	30
2	40
3	50
3	60
7	70
5	80
4	90
7	100
7	110
4	115
3	117.5

Direction	Depth
90	10
97	20
105	30
60	40
90	50
115	60
260	70
195	80
200	90
210	100
200	110
215	115
225	117.5

TABLE III-4 (continued)

STATION 2

Transmissivity	Depth
68.4	6
68.4	12
67.6	16.8
69	21
73.6	25.2
71.6	30
75	36
78.6	41.4
79	46.2
85.2	57
84.2	61.8
82.6	71.4
80.4	77.4
75.8	86.4
71	92.4
51.4	102
49.8	109.2
0.1	117

Salinity	Depth
35.39	3.6
35.99	8.4
36.09	15.6
36.07	31.2
36.23	40.8
36.21	46.8
36.15	51.6
36.11	57.6
36.13	64.4
36.11	69.6
36.13	76
36.07	82.4
36.15	88.8
35.99	96.4
36.13	103.6
36.17	111.2
36.15	118.4
36.21	119.2

Temperature	Depth
19.38	3.6
18.08	8.4
17.84	15.6
17.56	31.2
17.32	40.8
17.18	46.8
17.1	51.6
16.92	57.6
16.72	64.4
16.56	69.6
16.38	76
16.18	82.4
16.02	88.8
15.98	96.4
15.74	103.6
15.72	111.2
15.74	118.4
15.76	119.2

Current Meter

Speed	Depth
19	10
16	17
10	20
13	25
10	30
9	35
15	40
9	45
8	50
7	55
6	60
6	65
5	70
6	75
2	80
3	85
3	90
2.5	95
3	100
2	105
1	110
8	115

Direction	Depth
50	10
50	17
60	20
60	25
70	30
60	35
30	40
30	45
45	50
60	55
70	60
90	65
70	70
90	75
60	80
90	85
85	90
125	95
45	100
50	105
65	110
135	115

TABLE III-4 (continued)

STATION 3

Salinity	Depth
35.91	4
36.01	11.6
36.11	19.6
36.11	25.2
36.05	30
36.15	34
35.95	38
35.93	42.4
36.13	46.8
36.05	51.6
36.01	56.8
36.11	61.2
36.11	66
36.11	70.4
36.13	75.2
36.13	79.6
36.13	84
36.05	88.8
36.11	94.4
36.13	99.2
36.19	104.4
36.25	105.2
36.29	105.6

Temperature	Depth
17.86	4
17.5	11.6
17.3	19.6
17.16	25.2
17.1	30
17.04	34
17.02	38
17	42.4
16.96	46.8
16.88	51.6
16.68	56.8
16.42	61.2
16.4	66
16.34	70.4
16.32	75.2
16.32	79.6
16.3	84
16.2	88.8
16.04	94.4
15.96	99.2
15.9	104.4
15.9	105.2
15.9	105.6

Transmissivity	Depth
75.8	0.6
73.4	3
73.6	7.2
75.4	9
74.2	14.4
75.8	18
77.8	23.4
82	27.6
83.4	31.8
83.4	36
83.8	41.4
84.8	44.4
84.6	48
85.4	52.2
85	55.8
85.4	60
85.4	65.4
85.2	68.4
83.4	73.2
84.6	78
83	81.6
84	84.6
80	91.2
78.8	96
74.2	101.4
56.6	103.2
0.1	106.2

TABLE III-4 (continued)

STATION 3 (continued)

Current Meter

Speed	Depth
10	10
22	15
8	20
8	25
8	30
7	35
6	40
5	45
10	50
11	55
7	60
6	65
5	70
6	75
6	80
4	85
3	90
4	95
3	100
1	105

Direction	Depth
135	10
135	15
225	20
285	25
315	30
315	35
320	40
310	45
340	50
345	55
345	60
310	65
265	70
280	75
265	80
270	85
275	90
270	95
285	100
270	105

TABLE III-4 (continued)

STATION 4

Salinity	Depth	Temperature	Depth
36.09	0.8	17.98	0.8
36.09	9.6	17.5	9.6
36.09	15.2	17.38	15.2
36.11	20.8	17.18	20.8
36.15	25.2	17.1	25.2
36.19	28	17.06	28
36.19	30.8	17.04	30.8
36.17	33.2	17.02	35.2
36.17	35.2	16.98	37.6
36.17	37.6	16.98	40.4
36.19	40.4	16.94	42.4
36.17	42.4	16.94	44.8
36.17	44.8	16.92	47.2
36.17	47.2	16.9	49.6
36.17	49.6	16.86	52.8
36.15	52.8	16.8	55.6
36.15	55.6	16.66	58.4
36.17	58.4	16.44	60.8
36.15	60.8	16.38	63.6
36.13	63.6	16.28	66
36.15	66	16.26	68.8
36.13	68.8	16.26	71.6
36.13	71.6	16.24	73.6
36.15	73.6	16.1	76.4
36.11	76.4	16.08	78.8
36.15	78.8	16.1	81.6
36.15	81.6	16.08	84.4
36.15	84.4	16.08	86.6
36.15	86.8	16.06	89.2
36.15	89.2	16.06	92.4
36.15	92.4	16.06	94.8
36.15	94.8	16.04	97.2
36.15	97.2	16.06	97.6
36.15	97.6		

TABLE III-4 (continued)

STATION 4 (continued)

Transmissivity	Depth
79.2	1.2
78.6	3.6
80	7.2
78.2	12
78.8	16.2
80.2	18
81.8	21.6
84.2	25.8
84.6	29.4
84.4	33
84.2	36.6
83.8	42
83.4	45.6
84.2	48
84.2	51.6
85.2	56.4
85	59.4
85.8	64.8
86.8	67.8
86.8	70.8
87	73.8
87.2	77.4
86	81.6
82	84
81.4	87.6
82.2	91.2
80.6	94.8
0.1	98.4

Current Meter

Speed	Depth
21	10
9	15
15	20
16	25
13	30
13	35
15	40
16	45
18	50
17	55
15	60
8	65
10	70
8	75
6	80
5	85
5	90
3	95
1	96

Direction	Depth
180	10
210	15
225	20
230	25
240	30
220	35
230	40
230	45
240	50
240	55
220	60
198	65
210	70
205	75
220	80
220	85
285	90
240	95
300	96

TABLE III-5. STD, Transmissivity and current meter data for Sonnier Banks, Cruise 77DL3.

STATION 1

Temperature	Depth
27.824	4
27.632	6
27.176	8.4
26.744	11.2
26.672	11.6
26.624	12
25.64	15.2
24.464	18.8
23.72	21.6
22.568	29.6
21.848	34
21.416	38.4
21.104	41.2
21.176	42

Salinity	Depth
35.404	4
35.545	6
35.95	8.4
35.978	11.2
35.908	11.6
35.754	12
35.782	15.2
35.796	18.8
35.835	21.6
35.95	29.6
35.95	34
36	38.4
36.356	41.2
36.174	42
36.174	42

Transmissivity	Depth
87.8	1
86.6	5.6
84.4	8.5
89.2	11.7
89.6	14.6
85.6	17.6
88.8	21.2
88.6	33.4
88.8	36
89	39.6
89.4	42.3
89.4	45.7
88.8	48.4
85.6	51.7
49.6	55.1

Current Meter

Speed	Depth
28	10
14	20
10	30
17	40
26	50
19	58

Direction	Depth
90	10
90	20
50	30
180	40
45	50
60	58

TABLE III-5 (continued)

STATION 2

Temperature	Depth
28.088	5.2
27.512	7.6
27.272	9.2
27.08	10.8
26.312	13.2
25.352	16.8
23.36	24.8
22.52	32
21.56	36.4
21.2	40.4
21.128	42.4

Salinity	Depth
35.46	5.2
35.88	7.6
35.908	9.2
35.908	10.8
35.74	13.2
35.628	16.8
35.852	24.8
35.894	28
35.838	32
36.006	36.4
36.104	40.4
36.454	42.4

Transmissivity	Depth
84	2.4
83.2	5.4
85	7.8
85	12
85	15
84.4	20
84.8	24
84	27.6
84	33.6
84.8	37.2
84.8	40.2
85.2	42.6
84.6	46.2
73.6	49.6
41.8	52.8
26.2	55.8
22.4	58.8

Current Meter

Speed	Depth
7	10
18	20
19	30
15	40
16	50
8	60

Direction	Depth
95	10
90	20
60	30
50	40
110	50
155	60

TABLE III-5 (continued)

STATION 3

Temperature	Depth
27.584	6.4
27.272	7.6
26.816	11.2
23.768	19.2
22.16	28.4
22.016	30.8
21.224	36.4
21.272	38.4
21.296	39.2
21.272	40.8

Salinity	Depth
36.048	6.4
35.824	7.6
35.824	11.2
35.502	16
35.768	19.2
35.74	23.6
35.964	28.4
35.74	30.8
36.342	36.4
36.594	38.4
35.628	39.2
36.356	40.8

Transmissivity	Depth
85	1.6
86.8	2.7
86.4	5.4
88.4	8.8
88.2	11.3
88	14.9
88.2	17.8
88	21.4
88	24.1
88.4	27.5
87.8	30.4
87.8	33.7
88.8	37.1
87.2	39.9
87.2	43.4
79.4	46.9
79	50.4
70	53.1
41	56.3
27.8	59
1.4	61.4

Temperature	Depth
27.824	2.4
27.632	3.5
27.152	4.6
26.912	6.96
26.48	10.9
24.92	15.36
22.976	21.5
22.64	24.5
21.992	27.96
21.368	32.76
21.248	36.2
21.224	39.12
21.224	39.96

Salinity	Depth
35.516	2.4
35.516	3.5
35.992	4.6
35.712	10.9
35.586	15.36
35.866	21.5
35.81	24.5
35.922	27.96
35.992	32.76
36.118	36.7
36.244	39.12
36.104	39.96

Transmissivity	Depth
76.5	3.4
77.9	6
78.3	9.8
87.6	15.5
88.2	20.2
88	23.2
88.2	26.1
87.2	28.98
88.4	30.02
87.8	37
87.8	41.2
75.6	45.5
53	51
29.4	53
25.2	55
25.2	55.4
22.2	57.9
21.8	59.4

TABLE III-5 (continued)

STATION 3 (continued)

Speed	Depth
27	10
15	20
6	30
8	40
17	50
10	60

Direction	Depth
180	10
135	20
135	30
75	40
150	50
225	60

Speed	Depth
28	10
21	25
23	30
26	40
14	50
9	60

Direction	Depth
220	10
165	25
155	30
120	40
170	50
170	60

TABLE III-6. STD, Transmissivity and current meter data for Bright Bank, Cruise 77DL3.

STATION 1

Temperature	Depth
27.344	4.8
27.296	6.4
26.432	8.8
25.016	12
23.936	15.6
23.288	20.4
22.928	25.6
22.28	31.2
21.44	35.6
20.868	40.8
20.72	45.2
20.168	49.6
19.816	58
19.744	62.4
19.6	68
19.384	72.8
19.264	76.8
19.24	81.2
19.216	86.8
19	92.8
18.976	95.6
18.952	98
18.952	99.2

Salinity	Depth
36.04	4.8
36.02	6.4
35.81	8.8
35.978	12
36.048	15.6
36.062	20.4
36.02	25.6
36.216	31.2
36.118	40.8
36.062	45.2
36.09	49.6
36.188	53.6
36.174	58
36.16	62.4
36.146	68
36.188	72.8
36.202	76.8
36.178	81.2
36.174	86.8
36.202	92.8
36.3	95.6
36.356	98

Transmissivity	Depth
87.4	1.2
86.4	1.8
86	4.2
86	7.2
86.8	10.2
85.4	16.2
86.4	22.8
87	25.8
87	28.8
86.8	31.8
86.8	34.8
86.4	37.8
85.6	41.4
85.6	44.4
85.2	48
84.2	51
83.6	54
83.6	57.6
84	60.6
82.6	63.6
82.8	66.6
84.4	70.2
84.4	73.2
86	76.2
86.4	79.8
86.6	82.8
86.8	85.8
88.2	88.8
87.4	92.4
82.8	95.4
79.2	99
76.4	102
74.6	105
72.8	108
71	111.6
66	114.6
47.8	118.2
0.2	119.4

TABLE III-6 (continued)

STATION 1 (continued) Current Meter

Speed	Depth
26	17
25	20
30	32
25	40
19	50
8	60
20	70
16	80
14	92
16	100
12	110
10	118

Direction	Depth
196	17
205	20
225	32
255	40
275	50
90	60
120	70
105	80
95	92
105	100
135	110
180	118

TABLE III-6 (continued)

STATION 2

Temperature	Depth
27.584	1.2
27.56	6
27.488	7.2
27.488	9.2
27.32	11.6
26.624	14
25.136	18
24.248	21.6
23.6	24.8
22.52	28.4
22.184	33.2
22.016	38.8
20.72	43.2
20.48	46.2
20.216	51.6
19.84	55.6
19.648	60.4
19.504	64.8
19.528	67.2
19.528	68
19.504	70

Salinity	Depth
36.034	1.2
36.048	6
36.034	7.2
36.034	9.2
35.922	11.6
35.964	14
35.88	18
36.048	21.6
35.964	24.8
36.104	28.4
36.146	33.2
36.146	43.2
36	46.2
36.174	51.6
36.146	55.6
36.146	60.4
36.174	64.8
36.328	67.2
36.328	68
36.328	70

Transmissivity	Depth
83.2	1.8
83.4	2.4
77.6	5.4
84.2	6.6
82.6	7.2
85.2	13.8
85.2	17.4
81.4	22.2
81.2	27.6
84.2	33
83.8	37.6
83	44.4
82.2	49.8
80.8	54
80	59.4
81.8	63.6
81.2	65.4
82.8	70.2
82	73.2
83	73.8
81.6	75.6
82.4	81.6
81.6	85.2
61	88.2
74	88.8

Current Meter

Speed	Depth
18	10
13	20
13	30
13	40
16	50
17	60
19	70
16	80
9	84

Direction	Depth
90	10
75	20
60	30
305	40
300	50
45	60
45	70
85	80
70	94

TABLE III-6 (continued)

STATION 3

Temperature	Depth
28.04	4
27.968	6
27.824	7.6
27.512	10
25.736	13.6
24.536	19.2
22.78	24.8
22.184	31.2
21.8	37.2
21.44	42.4
21.272	49.2
21.2	53.6
20.888	58.4
20.24	66

Salinity	Depth
35.978	4
36.02	6
35.922	7.6
35.698	10
35.824	13.6
35.712	19.2
35.922	24.8
35.964	31.2
36.006	37.2
36.048	42.4
36.076	49.2
36.062	53.6
36	58.4
36.3	66

Transmissivity	Depth
86.4	25.2
88.4	28.8
88.4	32.4
88.2	35.4
87.4	39
87.6	42
87.4	46.2
87.6	50.4
87.4	53.4
87	57
84.8	61.2
86.8	64.8
85	69
83.2	72
87	75.6
84	78.6
85.4	82.2
86	84.6

TABLE III-6 (continued)

STATION 4

Temperature	Depth
27.94	4.6
27.656	8
27.44	10.6
24.584	15
23.528	21.1
22.856	26.52
22.016	32
21.224	38
21.032	44.5
21.104	46.4
21.104	47.2

Salinity	Depth
35.922	4.6
35.936	8
35.628	10.6
35.754	15
36.006	21.1
35.964	26.52
35.936	32
36.09	38
36.23	44.5
36.552	46.4
36.678	47.2

Transmissivity	Depth
66.8	16.8
79.6	21
80.2	25
79.4	28.2
81.4	31.8
80.8	34.8
78.8	37.8
81.2	41.4
80.6	45
82.2	48
80.5	51
77.4	54.6
77.6	57.6
77.2	60.6
79	64.2
78.8	66.6

TABLE III-7. STD, Transmissivity and current meter data for Parker Bank, Cruise 77DL3.

STATION 1

Temperature	Depth
27.97	1.6
27.99	4
27.8	6.8
27.2	9.2
26.86	11.6
26.34	14.4
25.83	17.2
24.7	20.8
24.46	24.8
24.06	27.6
23.84	30.4
23.5	33.2
22.74	39.2
22.38	41.6
22.04	44.8
21.51	48.4
21.44	50.4
21.344	54.4
21.29	59.6
21.056	63.2
20.936	67.6
20.936	68.4
20.96	68.8

Salinity	Depth
36.13	1.6
36.13	4
36.12	5.2
36.08	6.8
36.08	9.2
36.13	11.6
36.05	14.4
36.08	17.2
35.96	20.8
35.94	24.8
36.02	27.6
35.94	30.4
36.02	33.2
36.08	36.4
36.104	39.2
36.104	41.6
36	44.8
36.076	48.4
36.09	50.4
36.034	54.4
36.02	59.6
36.048	63.2
36.202	68.4
36.23	68.8

Transmissivity	Depth
87.8	5.2
88.2	8.6
87.8	15.7
87.8	19.26
87.2	22.7
87.4	26.1
87	29.34
87	32.4
86.8	43.8
86	45.4
84.8	68.2
84.8	71.5
84.4	74.81
84.4	84.2
84.6	84.4
85.2	86.6
76.14	98.6

Current Meter

Speed	Depth
36	10
36	25
23	30
8	40
8	50
22	60
23	70
23	80
8	88
8	90

Direction	Depth
75	10
80	25
80	30
90	40
80	50
80	60
75	70
75	80
57	88
45	90

TABLE III-7 (continued)

STATION 2

Temperature	Depth
28.21	0.4
28.16	1.6
28.06	2.8
28.04	4.4
27.92	6.8
26.936	12.4
25.904	18.8
24.56	25.6
23.768	30.8
23	37.2
22.616	42.4
22.304	46.4
21.56	55.6
21.152	63.6
20.696	70
20.624	74.8
20.192	84
20.056	89.2
20.056	90
20.128	90.4

Salinity	Depth
36.216	0.4
36.202	1.6
36.202	4.4
36.132	6.8
36.09	12.4
35.81	18.8
35.95	25.6
35.922	30.8
36.132	37.2
36.09	42.4
35.796	46.4
36.034	55.6
36	63.6
36.062	70
36	74.8
36.034	84
36.314	89.2
36.44	90
36.482	90.4

Transmissivity	Depth
89	8.4
89.2	11.4
89.4	14.4
89	17.4
88.8	20.4
89.6	23.4
88.6	27
89	30
88.6	33
89	36.6
88.8	39
88.6	43.2
87.8	46.2
87.6	49.2
87.4	52.8
87.4	55.8
87.4	63
87.2	66
82.6	69
87.4	72
86.2	76.2
85.6	79.2
85.4	85.8
86.2	90
87	93
86.6	97.2
86.5	100.2
85.8	104.4
84.4	107.4
72.2	111
56.4	114
1.4	116

TABLE III-7 (continued)

STATION 2 (continued)

Current Meter

Speed	Depth
36	10
36	20
27	30
22	40
22	50
17	60
24	70
21	80
16	90
6	100
11	110
9	115

Direction	Depth
55	10
105	20
70	30
90	40
90	50
55	60
60	70
60	80
40	90
255	100
210	110
225	115

TABLE III-7 (continued)

STATION 3

Temperature	Depth
28.352	3.6
28.112	4.8
28.016	5.6
27.584	8
26.768	10.4
25.52	14
24.896	18
24.32	22
24.08	26
23.936	30.8
23.504	34.4
23.336	37.6
22.808	43.2
22.4	49.2
21.608	54
21.296	54.8
20.888	70.4
20.864	76
20.744	79.6
20.36	83.6
20.384	84
20.36	84.4

Salinity	Depth
36.118	3.6
36.146	4.8
36.104	5.6
36.146	8
36.062	10.4
36.09	14
36.006	18
35.992	22
36.034	26
36	30.8
36.118	34.4
35.964	37.6
36.062	43.2
35.88	49.2
36.034	54
35.992	54.8
36.034	64.8
36.062	70.4
36.062	76
36.09	79.6
36.258	83.6
36.258	84
36:314	84.4

Transmissivity	Depth
89	4.8
88.6	7.8
88.4	11.4
88.2	15.6
88.6	17.4
88.8	24.6
87	27
87	30.6
87.2	34.2
86.4	37.8
87.4	42
86.8	44.4
86.2	48
86.8	51.6
86.2	54.6
86.2	57.6
85.4	61.2
86.8	64.8
85.4	67.8
85.4	85.2
86	88.2
86.8	91.2
86	94.8
87	98.4
85	100.8
1.4	104
0.8	105

Current Meter

Speed	Depth
27	10
26	20
29	30
24	40
26	50
30	60
28	70
27	80
25	90
13	100
12	105

Direction	Depth
150	10
115	20
90	30
75	40
105	50
105	60
110	70
90	80
80	90
95	100
90	105

TABLE III-7 (continued)

STATION 4

Temperature	Depth
28.424	3.2
28.232	4
28.136	4.4
28.112	5.6
28.088	6.8
27.896	9.2
27.104	12
26.504	15.2
25.496	18
24.896	19.6
24.632	24
24.638	27.6
24.104	31.2
23.936	34.8
23.528	37.6
23.192	40.8
23.048	43.6
22.28	50.4
22.04	53.6
22.016	56.4
21.56	63.6
21.344	66.8
21.128	71.2
21.152	72
21.2	73

Salinity	Depth
36.174	3.2
36.16	4
36.16	4.4
36.16	5.6
36.146	6.8
36.062	9.2
36.09	12
36.07	15.2
36.02	18
36.062	19.6
36.09	24
36.09	27.6
36.034	31.2
35.992	34.8
36.048	37.6
36.09	40.8
36.062	43.6
36.006	50.4
36.09	53.6
36.076	56.4
36.062	63.6
36.062	66.8
36.16	71.2
36.244	72
36.3	73

Transmissivity	Depth
88.8	1.2
88	4.2
87.8	7.2
88	11.4
86.8	15
87.8	19.2
87.8	23.4
87.2	27.6
87.6	31.8
87.6	34.2
87.6	37.8
87	40.8
87.2	43.8
86.8	47.7
86.8	50.4
86	54
86	57.6
86.4	60.6
85.8	64.8
85	68.4
85.8	71.4
85.4	74.4
86.6	77.4
86.8	81
86.4	84
85.8	87.6
84.6	90.6
70.6	93.6
71.8	94.2
79.4	94.2

Current Meter

Speed	Depth
27	10
26	20
25	30
25	40
24	50
18	60
21	70
20	80
11	87
9	90

Direction	Depth
90	10
90	20
60	30
45	40
50	50
75	60
120	70
120	90

TABLE III-7 (continued)

STATION 5

Transmissivity	Depth
90	4.2
91.4	7.2
91.6	10.2
90.7	12.6
89.2	15.6
90	17.4
90.6	20.4
90.4	22.2
90	25.2
87.2	28.2
87	31.8
87.4	34.2
87.2	37.8
86.6	40.2
87.2	44.4
87	46.8
86.6	49.8
84	53.4
86	56.4
85.8	58.8
86.4	65.4
86.2	68.4
86	71.4
86.2	74.4
85.6	77.4
85.8	81.6
85.6	84
85.8	87
85	90.6
85.4	94.2
84.6	94.8
83.2	98.4
84.6	102

Current Meter

Speed	Depth
25	10
41	20
39	30
26	40
28	50
32	60
23	70
20	80
10	90
11	100
17	105

Direction	Depth
90	10
95	20
105	30
101	40
80	50
85	60
85	70
65	80
130	90
140	100

TABLE III-8. STD, Transmissivity and current meter data for Sackett Bank, Cruise 77G10.

STATION 1

Temperature	Depth
28.6	0
28.1	10
27.85	20
27.75	30
27	40
23.8	47.5
22.35	57.5
21	70
20.4	78

Current Meter Speed	Depth
42	0
24	10
8	18
12	25
14	34
4	48
17	52
15	60
4	68

Salinity	Depth
32.06	0
35.05	10
35.9	20
36	30
36.1	40
36.1	42.5
35.8	43
36.3	47
35.75	48.5
36.28	50
36.46	60
36.41	70
36.4	78

Current Meter Direction	Depth
55	0
70	10
255	18
275	25
270	34
55	48
80	52
55	60
60	68

Transmissivity	Depth
70	0
70	6
80	12
84	18
84	24
84	30
82	36
82	40
78	46
80	52
70	60
64	66
62	72
60	78
52	84

TABLE III-8 (continued)

STATION 2

Temperature	Depth
28.4	0
28	10
27.6	20
27.5	30
26.8	40
24	50
22.3	60
21.2	70
20.1	80
19.8	82

Salinity	Depth
32.5	0
34.3	10
36	20
36	30
36.2	32.5
36.2	37.5
36.8	40
35.8	43
36.7	50
36.6	60
36.55	70
37.4	75
36.4	80
36.4	82

Transmissivity	Depth
70	0
70	6
80	12
82	18
82	24
85	30
85	36
82	42
79	48
82	54
80	60
73	66
68	72
62	78
69	84
40	90
34	96
20	97

Current Meter

Speed	Depth
31.5	0
21.9	10
14.1	18
8.6	25
9	34
10.8	43
6.9	52
13.9	60
13.9	68

Direction	Depth
97.9	0
64.4	10
342.9	18
322.7	25
332.6	34
294.9	43
41.5	52
42.4	60
44.1	68

TABLE III-8 (continued)

STATION 3

Temperature	Depth
28.8	0
28.33	10
28.25	12.5
28.5	16
28.27	20
28	27.5
28	30
26.4	40
24	50
22.5	60
21.47	70
18.3	80
18.2	86

Salinity	Depth
32.46	0
34.2	10
35.9	20
36	30
36.13	40
36.4	50
36.42	60
36.41	70
36.34	80
36.4	86

Transmissivity	Depth
69	0
69	6
68	12
83	18
83	30
82	36
82	42
78	48
80	54
80	60
77	66
70	72
66	78
50	84
53	90
20	96

Current Meter

Speed	Depth
75	0
10	10
17	18
32	25
35	34
28	43
19	52
8	60
15	68

Direction	Depth
85	0
130	10
160	18
145	25
115	34
265	43
295	52
300	60
120	68

TABLE III-8 (continued)

STATION 4

Temperature	Depth
28	0
28	10
27	20
27	33
25.5	42.5
25.4	47
24	50
22.5	60
20.75	70
20.5	75
18	77
17.5	84

Salinity	Depth
32.8	0
33.5	10
35.7	20
36	30
36.2	40
36.35	50
36.35	60
36.3	70
36.4	77
35.15	78
36.3	82
36.4	84

Transmissivity	Depth
84	0
75	6
75	12
72	18
80	24
82	30
86	42
82	48
82	54
84	60
83	66
70	72
82	78
70	84
64	90

TABLE III-9. STD, Transmissivity and current meter data taken during dives of the submersible DR/V DIAPHUS at the East Flower Garden Bank during cruise 77G10.

Dive 6

Transmissivity	Depth
85	0
82	42
82	48
80	54
80	60
79	66
80	72
78	78
78	84
82	90
83	90
80	102
73	108
67	114
62	120

Current Meter

Speed	Depth
11.6	0
36.6	20
31.6	30
25.6	40
27.3	50
21	60
21.6	70
20	80
22.3	90
21.6	100
20	110
20	120

Direction	Depth
148.5	0
154.5	20
148.5	30
158.5	40
148.5	50
148.5	60
128.5	70
128.5	80
143.5	90
163.5	100
163.5	110
173.5	120

TABLE III-9 (cont.)

Dive 7

Temperature	Depth
29.05	0
28.85	10
28.87	20
28.65	30
26.75	40
23.8	50
23.51	60
22.56	70
21.14	80
20.37	85

Salinity	Depth
36.24	0
36.24	10
36.27	20
36.27	30
36.22	40
36.26	50
36.26	60
36.29	70
36.35	80
36.34	85

Transmissivity	Depth
86	0
86	6
88	12
88	18
87	24
87	30
87	36
87	42
86	48
82	54
80	60
80	66
80	72
80	78
80	84
78	90
80	95
0.1	96

Profile 1

Temperature	Depth
29.05	0
28.85	10
28.9	20
28.75	23
28.75	28
28.65	32
28.2	37.5
24.4	45
23.75	50
23.5	60
22.55	70
22.5	75
21	80
20.4	85

Salinity	Depth
36.2	0
36.25	10
36.3	30
36.35	31
36.3	32
36.25	37.5
35.55	38.5
36.2	40
36.2	42
36	43
36.2	45
36.3	80
36.4	81
36.4	85

TABLE III-9 (cont.)

Current Meter

Speed	Depth
28	0
22	15
24	20
20	30
25	45
8	50
10	60
12	70
16	80
24	85
26	88
30	93
32	95
25	98
14	105

Direction	Depth
83.5	0
248.5	15
258.5	20
228.5	30
218.5	45
238.5	50
218.5	60
193.5	70
183.5	80
163.5	85
148.5	88
143.5	93
133.5	95
113.5	98
113.5	105

TABLE III-9 (cont.)

Dive 8

Profile 1

Temperature	Depth
29.15	0
29.15	5
28.75	7.5
28.85	18
28.8	20
28.85	35
28.5	42.5
23.75	51
23.65	70
20.05	85

Salinity	Depth
35.8	0
35.8	7.5
35.95	8
36.1	20
36.2	30
36.2	42.5
36	43
36.2	45
35.5	47.5
36.1	49
36.1	52.5
35.95	53
36.15	55
36.2	72
36.05	73
36.1	80
36.3	85

Profile 2

Temperature	Depth
28.95	0
28.75	3
28.85	13
28.8	31
23.75	49
23.55	67
20.2	85

Salinity	Depth
35.8	0
36	2
36.4	35
36.6	42.5
36.2	43
36.6	45
36.3	46
36.9	47.5
36.3	50
36.3	67.5
36.5	70
36.5	85

Profile 3

Temperature	Depth
29.15	0
28.74	2
28.78	10
28.87	13
28.79	18
28.81	20
28.84	30
28.35	40
23.6	50
23.35	60
22.3	70
20.83	80
20.8	85

Salinity	Depth
35.75	0
36	4
36.1	10
36.2	20
36.25	30
36.26	40
35.25	48
36.15	50
36.2	53
36.2	60
36.1	68
36.22	70
36.3	80
36.3	85

Profile 4

Temperature	Depth
28.87	0
28.83	10
28.8	20
28.83	30
25.85	40
23.73	50
23.15	60
21.65	70
21.34	75

Salinity	Depth
36.15	0
36.15	10
36.25	20
36.28	30
36.22	40
35.75	42.5
36	45
36.2	50
36.21	60
36.32	70
36.3	75

TABLE III-9 (cont.)

Dive 8 (cont.)

Profile 5

Temperature	Depth
28.9	0
28.81	10
28.8	30
28.6	40
25.3	50
23.7	60
23.1	70
21.7	80

Salinity	Depth
36.05	0
36.05	10
36.1	20
36.18	30
36.25	40
35.81	46
36.1	50
36.18	60
36.21	70
36.3	80

TABLE III-9 (cont.)

Dive 12

Transmissivity	Depth
80	0
82	6
82	12
82	18
83	24
82	30
82.5	36
81	42
80	48
79	54
76	60
74	66
78	72
80	78
82	84
80	90
68	96
0.1	97

TABLE IV-1. EAST FLOWER GARDENS BANK SEDIMENT TEXTURE DATA, 1977-78. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	0.57	4.90	32.33	62.20	7.88	8.31	1.84	-1.65	4.00
1-2	0.45	9.44	40.82	49.28	7.34	7.97	2.24	-0.89	0.49
1-3	0.03	7.33	36.58	56.06	7.74	8.21	1.99	-1.10	0.86
1-4	0.34	9.02	42.55	48.09	7.46	7.93	2.09	-1.07	1.06
1-5	0.20	4.71	46.72	48.37	7.47	7.93	1.99	-0.73	0.24
1-6	0.08	4.20	38.43	57.29	7.90	8.23	1.78	-1.11	1.41
1-7	0.14	3.88	37.21	58.77	7.97	8.27	1.75	-1.35	2.72
1-8	0.0	0.14	31.65	68.21	8.33	8.51	1.33	-0.82	0.51
1-9	0.0	0.0	36.07	63.93	8.24	8.42	1.39	-0.75	0.19
2-1	0.04	5.35	34.89	59.72	7.93	8.33	1.81	-1.11	1.07
2-2	0.0	1.21	44.55	54.24	7.96	8.14	1.51	-0.69	0.43
2-3	0.0	0.0	47.45	52.55	7.96	8.11	1.51	-0.35	-0.68
2-4	0.0	0.0	35.16	64.84	8.27	8.44	1.38	-0.71	0.11
2-5	0.0	0.0	38.99	61.01	8.15	8.40	1.47	-0.56	-0.48
2-6	0.0	0.0	39.58	60.42	8.15	8.29	1.29	-0.52	-0.07
2-7	0.0	0.0	42.90	57.10	8.00	8.27	1.50	-0.52	-0.51
2-8	0.0	0.0	44.20	55.80	8.03	8.20	1.40	-0.45	-0.41
2-9	0.0	0.0	45.29	54.71	8.05	8.18	1.39	-0.35	-0.54
2-10	0.0	0.0	48.16	51.84	7.94	8.08	1.53	-0.36	-0.65

TABLE IV-1. EAST FLOWER GARDENS BANK SEDIMENT TEXTURE DATA, 1977-78. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
3-1	0.0	82.26	9.89	7.85	3.59	3.30	2.04	1.79	2.88
3-2	0.0	88.75	5.34	5.91	3.34	3.01	1.81	2.29	5.13
3-3	0.17	85.25	9.06	5.52	3.25	2.77	1.86	2.23	5.28
3-4	0.12	78.87	13.06	7.95	3.59	3.20	2.06	1.72	2.72
3-5	0.0	79.99	11.59	8.42	3.71	3.17	2.08	1.76	2.30
3-6	0.0	78.88	11.04	10.08	3.66	3.01	2.27	1.70	1.98
3-7	0.04	79.09	10.37	10.50	3.68	2.98	2.27	1.66	1.83
3-8	0.11	84.81	9.25	5.83	3.43	3.22	1.82	2.11	4.83
3-9	0.06	74.19	18.86	6.89	3.77	3.50	1.86	1.81	3.28
3-10	0.06	83.91	6.31	9.73	3.65	3.05	2.19	1.70	1.92
4-1	3.72	77.03	6.61	12.64	3.32	2.51	2.78	0.96	0.22
4-2	3.33	69.00	14.25	13.41	3.31	2.32	3.08	0.80	-0.38
4-3	3.09	69.24	14.47	13.19	3.52	2.70	2.68	0.86	-0.09
4-4	3.63	66.61	13.08	16.69	3.67	2.61	3.12	0.75	-0.54
4-5	7.15	75.68	9.13	8.04	2.71	2.08	2.69	1.05	0.95
4-6	3.62	57.24	17.30	21.83	4.31	3.53	3.28	0.35	-1.10
4-7	10.55	68.61	7.11	13.73	3.00	2.12	3.13	0.85	0.03
4-8	4.80	60.99	15.10	19.11	3.89	3.08	3.30	0.50	-0.91
4-9	3.64	65.05	13.05	18.26	3.83	2.88	3.20	0.63	-0.72
4-10	0.24	52.78	16.82	30.15	5.28	3.90	2.99	0.35	-1.37

TABLE IV-2. SEDIMENT TEXTURE DATA, EAST FLOWER GARDENS BANK, CRUISE 77G10-I

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	0.0	8.20	37.53	54.27	7.17	8.15	2.06	-0.93	0.23
1-2	0.0	0.0	54.19	45.81	7.93	7.90	1.22	-0.21	0.27
1-3	0.0	6.93	38.94	54.12	7.73	8.13	2.03	-1.34	1.95
1-4	0.0	9.19	47.52	43.29	7.29	7.75	2.11	-0.94	0.66
1-5	0.0	5.40	63.34	31.26	6.82	7.15	1.94	-0.41	-0.27
1-6	0.14	7.26	51.00	41.60	7.07	7.55	2.19	-0.45	-0.51
1-7	0.0	7.01	45.17	47.83	7.49	7.93	2.01	-1.07	0.94
2-1	0.0	1.97	48.81	49.22	7.82	7.98	1.53	-0.94	1.57
2-2	0.0	2.26	42.44	55.29	7.97	8.15	1.60	-1.10	1.86
2-5	0.0	0.0	41.53	58.47	8.17	8.29	1.49	-0.49	-0.47
2-6	0.0	0.45	49.41	50.13	7.70	8.00	1.75	-0.63	-0.30
3-1	0.31	85.43	5.63	8.63	2.53	1.78	2.56	1.76	2.42
3-2	32.64	36.95	11.99	18.41	2.16	-0.01	4.16	0.82	-0.96
3-3	0.0	78.99	15.94	5.07	2.98	2.55	2.15	1.37	2.33
3-4	0.0	70.57	21.54	7.89	3.22	2.52	2.40	1.38	1.58
3-5	0.0	82.58	8.54	8.88	2.89	2.14	2.47	1.67	2.10
3-6	0.0	77.24	11.51	11.25	3.35	2.53	2.60	1.40	1.12
3-7	0.0	83.34	7.72	8.94	2.95	2.21	2.46	1.62	2.09

TABLE IV-3. EAST FLOWER GARDENS BANK SEDIMENT DATA, 1978. CRUISE 78L1

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
2-1	0.0	0.0	24.87	75.13	8.61	8.93	1.43	-1.10	0.72
2-2	0.0	7.43	33.87	58.70	7.76	8.20	1.97	-1.36	1.72
2-3	0.0	4.91	38.85	56.24	7.73	8.17	1.96	-1.30	1.83
2-4	0.0	3.34	31.85	64.80	8.14	8.70	1.91	-1.20	1.24
2-5	0.0	0.0	38.47	61.53	8.11	8.51	1.67	-0.66	-0.57
2-6	0.0	3.77	33.71	62.52	8.05	8.67	1.92	-1.08	0.74
2-7	0.0	15.51	31.30	53.19	7.30	8.23	2.58	-0.82	-0.41
2-8	0.0	0.0	51.37	48.63	7.49	7.96	1.79	-0.42	-0.93
2-9	0.0	2.85	33.01	64.15	8.18	8.63	1.79	-1.11	0.95
2-10	0.0	0.0	36.50	63.50	8.14	8.48	1.58	-0.76	-0.18
3-1	0.0	84.11	13.16	2.73	3.00	2.83	1.59	1.95	6.49
3-2	0.0	90.16	6.20	3.64	2.60	2.21	1.81	2.11	6.22
3-3	0.0	73.74	25.64	0.62	3.35	3.49	1.26	0.81	2.26
3-4	0.0	54.32	22.32	23.37	5.02	3.80	2.82	0.64	-0.97
3-5	0.12	95.83	1.83	2.23	2.18	2.03	1.59	2.08	7.99
3-6	0.0	46.23	29.00	24.77	5.30	4.31	2.83	0.52	-1.05
3-7	0.0	87.80	5.58	6.62	3.23	2.86	2.04	1.94	3.98
3-8	0.0	67.26	15.05	17.70	3.96	3.24	2.97	0.85	-0.47
3-9	0.0	92.17	4.99	2.85	2.54	2.23	1.74	1.87	5.78
3-10	0.0	97.49	1.13	1.38	2.23	2.01	1.25	2.68	12.30

TABLE IV-3. EAST FLOWER GARDENS BANK SEDIMENT DATA, 1978. CRUISE 78L1

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
4-1	12.82	82.65	1.76	2.78	1.40	1.35	2.16	1.38	3.56
4-2	6.19	77.10	8.69	8.02	2.36	1.75	2.78	1.22	1.27
4-3	9.98	74.68	3.92	11.41	2.10	1.32	3.14	1.32	0.88
4-4	0.0	95.53	1.87	2.60	1.58	1.30	1.84	2.30	7.17
4-5	0.0	95.79	1.03	3.17	1.81	1.58	1.83	2.40	7.84
4-6	4.52	85.45	6.36	3.67	1.91	1.59	2.15	1.68	4.14
SUSPENDED SEDIMENT DATA									
STATION-DEPTH (M)									
1-117	0.0	0.0	16.49	83.51	8.97	8.93	0.98	-0.83	3.21
2-110	0.0	0.0	21.52	78.48	8.65	8.53	0.84	-0.84	5.62
3-110	0.0	0.0	20.10	79.90	8.75	8.61	0.90	-0.74	4.33
4-100	0.0	0.0	7.70	92.30	9.44	9.71	0.98	-1.64	5.33

TABLE IV-4. SONNIER BANK SEDIMENT TEXTURE DATA, 1977. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	30.23	39.31	14.93	15.52	2.30	0.46	4.03	0.71	-1.07
1-2	12.06	16.12	23.79	48.03	5.96	7.90	4.01	-0.87	-0.83
1-3	12.87	25.45	28.16	33.53	5.05	6.74	4.06	-0.44	-1.38
1-4	32.78	37.15	10.48	19.59	2.12	0.20	4.21	0.81	-1.07
1-5	51.99	29.79	7.05	11.17	0.88	******	3.65	1.44	0.61
1-6	18.60	23.11	24.53	33.76	4.67	6.29	4.34	-0.28	-1.58
1-7	30.11	34.30	12.16	23.43	2.80	0.83	4.29	0.48	-1.45
1-8	33.24	36.56	11.74	18.45	2.21	0.44	4.13	0.76	-1.06
1-9	27.07	37.43	15.04	20.45	2.84	0.95	4.19	0.49	-1.40
1-10	24.57	26.85	20.78	27.81	3.73	3.14	4.47	0.09	-1.72
2-1	26.59	30.23	29.18	14.00	3.30	3.09	3.93	0.12	-1.46
2-2	19.20	25.91	24.08	30.81	4.51	5.55	4.20	-0.24	-1.52
2-3	2.93	23.18	35.50	38.38	6.23	7.51	3.28	-0.84	-0.56
2-4	34.46	27.67	18.29	19.58	2.85	1.38	4.27	0.40	-1.45
2-5	7.91	32.32	29.35	30.42	5.17	6.13	3.64	-0.34	-1.21
2-6	34.18	39.39	14.22	12.22	2.07	1.00	3.77	0.78	-0.75
2-7	53.28	15.41	14.86	16.45	1.88	******	4.33	0.75	-1.10
2-8	32.62	31.44	17.48	18.46	2.85	1.70	4.13	0.39	-1.37
2-9	42.89	36.74	12.67	7.71	1.36	0.30	3.50	1.04	-0.20
2-10	8.86	26.28	28.77	36.08	5.54	7.19	3.74	-0.60	-1.06

TABLE IV-4. SONNIER BANK SEDIMENT TEXTURE DATA, 1977. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
3-1	2.93	22.83	46.46	27.78	5.95	6.81	2.98	-0.73	-0.38
3-2	2.20	19.40	35.96	42.44	6.66	7.71	3.02	-1.04	0.01
3-3	2.27	23.51	34.39	39.83	6.31	7.57	3.16	-0.78	-0.59
3-4	3.20	29.89	32.55	34.36	5.78	7.33	3.40	-0.58	-1.04
3-5	3.55	31.49	40.79	24.16	5.34	6.21	3.18	-0.37	-1.01
3-6	1.91	23.88	42.55	31.66	6.09	7.23	2.99	-0.71	-0.60
3-7	3.33	24.18	38.06	34.43	5.99	6.99	3.15	-0.70	-0.59
3-8	2.28	30.09	38.59	29.05	5.78	7.08	3.17	-0.57	-0.97
3-9	4.92	27.32	39.99	27.77	5.62	6.97	3.31	-0.62	-0.86
3-10	7.81	27.99	37.45	26.75	5.19	6.71	3.60	-0.48	-1.16
4-1	2.04	3.32	45.75	48.89	7.62	7.96	2.13	-1.97	5.63
4-2	1.06	4.48	59.05	35.41	7.29	7.61	1.94	-1.60	4.42
4-3	2.16	3.87	47.70	46.27	7.51	7.90	2.15	-2.03	5.61
4-4	0.79	4.22	49.08	45.91	7.57	7.88	1.92	-1.58	4.21
4-5	2.43	6.27	52.07	39.23	7.13	7.63	2.32	-1.62	3.41
4-6	0.97	3.67	55.82	39.55	7.26	7.66	2.04	-1.27	2.71
4-7	0.87	2.95	50.18	45.99	7.50	7.86	2.00	-1.37	3.15
4-8	0.60	6.18	46.89	46.33	7.52	7.88	2.01	-1.35	2.65
4-9	0.92	2.36	42.92	53.80	7.80	8.12	1.95	-1.68	4.53
4-10	1.00	5.94	58.98	34.08	6.98	7.44	2.10	-1.01	1.62

TABLE IV-5. SEDIMENT TEXTURE DATA, BRIGHT BANK, 1977. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	0.0	5.37	29.14	65.49	8.14	8.50	1.72	-1.34	1.69
1-2	0.0	7.66	33.06	59.29	7.90	8.33	1.91	-1.06	0.50
1-3	0.19	12.04	35.63	52.14	7.53	8.09	2.19	-0.97	0.29
1-4	0.0	10.58	29.78	59.65	7.82	8.34	2.03	-1.14	0.52
2-1	31.77	64.47	1.61	2.15	0.53	0.46	2.08	1.80	5.43
2-2	1.91	94.65	1.38	2.06	1.54	1.35	1.67	2.24	8.85
2-3	11.10	82.63	2.42	3.85	1.17	0.96	2.18	2.08	5.67
2-4	43.40	51.00	3.78	1.81	0.22	-0.10	2.21	1.82	4.36
3-1	64.50	31.34	1.40	2.76	-0.11	******	2.46	1.96	4.27
3-2	9.75	81.49	3.71	5.05	2.17	1.88	2.30	1.34	3.14
3-3	0.22	85.24	9.30	5.23	3.48	3.36	1.73	1.99	5.59
3-4	33.00	56.23	7.27	3.49	1.38	1.51	2.66	0.83	0.89

TABLE IV-6. SEDIMENT TEXTURE DATA, PARKER BANK, 1977. CRUISE 77DL3.

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	39.11	56.23	2.16	2.50	0.35	0.19	2.23	1.91	4.93
1-2	7.65	87.39	2.10	2.86	1.32	1.01	1.95	2.18	6.69
1-3	21.43	75.01	1.29	2.27	0.63	0.60	1.94	2.20	7.73
1-4	10.12	86.62	1.13	2.13	0.98	0.84	1.73	2.50	10.02
2-1	0.36	47.84	17.85	33.96	5.75	4.60	2.91	0.08	-1.49
2-2	0.44	49.73	22.28	27.55	5.36	3.99	2.89	0.22	-1.33
2-3	0.69	40.37	29.94	29.00	5.66	6.22	2.94	-0.15	-1.23
2-4	0.75	39.78	26.90	32.58	5.88	6.44	2.88	-0.14	-1.23
3-1	5.39	70.58	10.29	13.74	3.08	1.92	3.15	0.86	-0.33
3-2	6.49	69.24	9.64	14.62	2.93	1.74	3.23	0.96	-0.26
3-3	3.96	66.14	14.64	15.26	3.50	2.25	3.19	0.69	-0.74
3-4	4.83	76.27	10.41	8.50	2.52	1.71	2.82	1.17	0.53
4-1	10.87	79.17	4.19	5.77	1.52	1.02	2.54	1.77	2.97
4-2	17.79	71.62	4.26	6.32	1.28	0.72	2.73	1.74	2.63
4-3	4.31	76.24	8.95	10.50	2.88	2.00	2.90	0.96	0.15
4-4	1.43	64.26	15.61	18.69	4.15	3.59	3.02	0.55	-0.61

TABLE IV-7. SEDIMENT TEXTURE DATA, SACKETT BANK, CRUISE 77G10-I

STATION-GRAB	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
1-1	12.61	40.82	18.43	28.14	3.78	1.55	4.34	0.20	-1.70
1-2	4.17	21.16	40.91	33.76	5.78	7.11	3.69	-0.79	-0.85
1-3	7.66	46.66	19.59	26.09	3.74	1.45	4.20	0.25	-1.68
1-4	12.01	69.32	7.58	11.09	1.51	-0.03	3.36	1.49	0.69
2-1	9.62	32.79	27.84	29.75	4.63	6.36	4.13	-0.21	-1.62
2-2	0.56	36.03	25.79	37.61	5.36	6.98	3.84	-0.33	-1.54
2-3	0.42	8.80	50.04	40.73	7.12	7.68	2.54	-1.53	2.10
2-4	1.30	10.23	44.28	44.19	7.03	7.77	2.68	-1.32	1.23
3-1	3.14	73.93	8.38	14.56	2.21	0.68	3.43	1.24	-0.05
3-2	5.84	69.63	9.37	15.16	2.83	1.57	3.32	1.00	-0.37
3-3	4.64	73.97	8.35	13.05	2.03	0.65	3.37	1.35	0.28
3-4	3.47	79.57	7.68	9.29	1.99	1.17	2.90	1.62	1.38
4-1	4.27	19.84	37.96	37.93	5.99	7.47	3.61	-0.86	-0.71
4-2	11.14	27.11	20.87	40.87	5.11	7.35	4.36	-0.38	-1.59
4-3	1.34	7.75	48.70	42.21	7.21	7.75	2.53	-1.74	2.94
4-4	3.27	19.34	31.89	45.49	6.37	7.79	3.68	-0.97	-0.55

TABLE IV-8

Total Carbonate Percentage and Particle Identification of the Coarse Fraction (All Values in %)

STA-CRAB	Qtz.	FORAMS Plank.	FORAMS Beath.	SHELLS Echin.	SHELLS Moll.	Coral	Algae	Pellets	Lith.	Misc.	TOTAL CARBONATE Scheibler Method	TOTAL CARBONATE Wt % Method	Comments on Miscellaneia
East Flower Gardens Bank													
1-7	15.0	34.0	28.0	2.5	7.0	-	10.5	1.0	0.5	1.0	22.17	17.50	Pteropod, Radiolaria
2-7	4.5	30.0	46.0	2.5	5.5	-	2.0	0.5	0.5	8.5	19.04	30.0	Worm Tube, Alcyanarian, Sponge, Radiolarian, Diatom
3-7	5.0	17.0	14.0	2.0	18.0	5.5	32.0	-	-	6.5	91.18	64.7	Radiolarian, Bryozoan, Diatom
4-7	6.0	17.5	15.5	6.0	18.0	4.0	30.0	-	-	3.0	75.5	67.8	Pteropods, Radiolaria, Bryozoan
Bright Bank													
1-3	0.5	31.0	23.5	2.5	10.5	2.5	22.0	0.5	-	7.0	31.26	24.5	Ostracod, Radiolaria Spines, Pteropod, Bryozoan
2-2	7.0	4.0	12.0	5.5	11.0	8.5	43.5	1.0	3.5	4.0	100	88.3	Ostracod, Radiolaria Spines, Pteropod, Bryozoan
3-1	6.5	6.5	15.5	6.0	17.5	5.0	35.0	0.5	1.0	6.5	100	86.5	Worm Tube, Sponge, Diatoms, Radiolaria Spines
Parker Bank													
1-4	0.5	9.0	20.0	5.5	15.0	33.5	7.0	-	6.0	3.5	100	91.8	Bryozoans, Worm Tube, Pteropods
2-4	4.0	21.0	19.5	5.5	9.0	3.5	29.5	-	-	8.0	58.23	44.4	-
3-4	-	20.5	27.5	8.5	16.5	6.5	9.5	1.5	1.0	8.5	100	72.8	Spines, Alcyonarian Spicules, Pteropods, Bryozoans
4-4	6.0	13.0	17.5	7.0	9.5	5.0	30.5	1.0	-	10.5	100	91.2	Sponge, Pteropod, Ostracod, Diatom
Sackett Bank													
1-4	8.5	17.0	20.5	6.0	4.5	3.0	27.5	1.0	1.5	10.5		70.7	Sponge, Worm Tube, Radiolaria
2-4	13.0	5.5	8.5	2.5	16.0	3.0	40.0	4.0	4.5	3.0		23.1	
3-3	60.0	4.0	15.5	1.5	1.5	2.0	8.0	4.0	2.0	1.5		37.2	Alcyonarian Spicules, Worm Tube
4-1	5.0	7.0	15.0	2.0	7.0	1.5	54.0	0.5	0.5	7.5		25.8	
Sonnier Banks													
1-7	6.0	7.5	19.5	1.5	26.0	2.5	13.0	-	9.0	17.5	62.5	51.0	All Miscellaneous was Calcite Rhombs
2-8	4.0	2.0	11.5	2.5	22.5	3.0	47.5	1.0	2.0	3.0	70.2	60.0	Radiolaria, Calcite Rhombs
3-8	22.0	8.0	19.0	4.5	27.5	0.5	8.5	3.5	-	4.5	5.93	8.4	Radiolaria
4-8	Not Enough Sample										11.97	9.4	

TABLE IV-9

CORE DESCRIPTIONS

Page 1

Cruise 77-G-10-1 Core No. EFG 2 No. Sections 2 Date 5/23/78

Position East Flower Gardens Station # 2 Total Length 171 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	light brown silty clay	isolated burrows filled with shell hash			
20	shell fragments	silt laminations			
40		shell fragments			larger shells and hash
60	medium to light gray clay	mottled appearance with some laminations			homogeneous except for occasional shell fragments
80					
100		shell fragment concentration			
120		shell fragments			
140	shell fragments shell fragments				
160		some short and thin burrows			
180					

TABLE IV-9

CORE DESCRIPTIONS

Page 2

Cruise 77-G-10-1 Core No. EFG 2' No. Sections 2 Date 5/23/78

Position East Flower Gardens Station #2' Total Length 152 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	greenish gray shelly clay	shell fragments			
20	shell fragments				homogeneous clay with shell fragments
	grennish gray clay				scattered throughout the total core
40		extremely disturbed portion of core			
60					
	silt lamina-tions				silt laminations
80					
	silt lamina-tions occasional shell fragments	shell fragments			silt laminations
100					
120					
140					
160					

TABLE IV-9

CORE DESCRIPTIONS

Page 3

Cruise 77-G-10-1 Core No. SKT 1 No. Sections 1 Date 5/23/78

Position Sackett Station # 1 Total Length 25 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	tan to brown shell hash	coarse carbonate sand with some fine sediment			
10					
	medium gray clay	burrowed filled with coarse fraction carbonate sand			silt laminations
20					isolated burrows filled with shell hash
30					

TABLE IV-9

CORE DESCRIPTIONS

Page 4

Cruise 77-G-10-1 Core No. SKT 2 No. Sections 1 Date 5/23/78

Position Sackett Station # 2 Total Length 20 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	light brown shelly clay	extensive burrows filled with coarse carbonate sand			
	greenish gray clay				silt laminations
10	medium gray clay				isolated burrows filled with shell hash
20					

TABLE IV-9

CORE DESCRIPTIONS

Page 5

Cruise 77-G-10-1 Core No. SKT 3 No. Sections 1 Date 5/23/78

Position Sackett Station # 3 Total Length 53 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	greenish gray shelly clay	mottled shell hash that continues into burrows below			small shell fragments incorporated in a fine matrix
10					
		sharp contact between shell hash and clay			
20	shell fragments				
	medium gray clay				
30		large shell fragments in remnant burrows			
40					
		silty laminations			appears homogeneous
50					
60					

TABLE IV-9

CORE DESCRIPTIONS

Page 6

Cruise 77-G-10-1 Core No. SKT 4 No. Sections 1 Date 5/23/78

Position Sackett Station # 4 Total Length 19 cm Described by R. Tompkins

Depth	Lithology & Color	Radiography	Samples	Smear Slides	Miscellaneous Remarks
	light brown shelly clay	coarse carbonate sand			
10	medium gray clay	burrows filled with coarse and fine sediments			isolated burrows filled with shell hash
20					

Table V-1

Counts of total coccoliths and redeposited coccolith in coretop samples

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
4	0	0	30.1	30.1	0	0	-	-
16	5	212	26.3	4.0	5	1394	279	3
24	64	190	25.9	1.0	64	500	9	1
42	5	27.9	27.9	27.9	5	188	38	2
48	2	208	26.8	26.8	2	208	104	3
51	3	372	27.0	5.0	3	2009	670	3
68	0	0	28.2	28.2	0	0	-	-
73	19	165	28.2	28.2	19	165	9	1
78	4	403	29.3	2.0	4	5904	1476	4
79	4	146	27.1	0.2	4	19783	4946	4
81	9	274	26.5	0.2	9	36305	4034	4
82	4	181	28.9	0.2	4	26155	6539	4
83	9	122	28.5	0.2	9	17385	1932	4
85	6	313	28.3	0.2	6	44290	7382	4

Table V-1 (con't)

Core No.	Counts of Specimen Reworked	Counts of Specimen Total	Counting Distance (mm) Reworked	Counting Distance (mm) Total	Normalized Counts Reworked	Normalized Counts Total	Ratio	Exponential Value
95	1	113	28.7	10.0	1	324	324	3
106	4	197	27.9	1.0	4	5496	1374	4
110	3	198	28.2	0.2	3	27918	9306	4
114	6	348	28.4	0.2	6	49369	8228	4
115	2	298	27.6	0.2	2	41124	20562	5
127	5	7	29.1	29.1	5	7	1	1
131	7	136	28.1	0.5	7	7643	1092	4
134	12	155	27.5	5.0	12	8525	700	3
146	33	205	28.1	5.0	33	1152	35	2
149	7	119	27.9	1.0	7	3320	474	3
156	3	380	28.9	0.2	3	54910	18303	5
157	5	307	27.9	0.2	5	42827	8565	4
161	68	121	28.7	2.0	68	1736	26	2
165	40	264	28.5	10.0	40	752	18	2

Table V-1 (con't)

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
171	27	152	29.5	0.2	27	22420	830	3
172	19	169	28.6	0.2	19	24167	1272	4
185	52	182	27.8	2.0	52	2530	49	2
193	15	319	29.3	0.2	15	46734	3116	4
194	12	366	27.8	0.2	12	50457	4205	4
199	25	261	27.5	5.0	25	1436	57	2
213	12	144	28.6	0.2	12	20592	1716	4
225	76	182	28.9	3.0	76	1753	23	2
235	31	254	28.0	0.2	31	35560	1147	4
241	32	94	29.1	0.2	32	13677	427	3
245	94	90	29.8	1.0	94	2682	29	2
254	21	225	28.9	0.2	21	32513	1548	4
269	51	124	27.2	1.0	51	3373	66	2

Table V-2

Counts of total coccoliths and redeposited coccoliths in suspended sediment samples, November, 1976

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
13B	1	181	24.3	24.3	1	181	181	3
14B	0	930	23.8	23.8	0	930	∞	5
16B	28	604	23.6	23.6	28	604	22	2
17B	10	489	16.7	16.7	10	489	50	2
18B	5	371	24.4	1.0	5	9052	1811	4
19B	0	51	24.1	24.1	0	51	∞	5
20B	6	399	23.3	4.0	6	2324	387	3
21B	9	202	23.9	2.0	9	2414	268	3
22B	32	225	23.3	4.0	32	1311	41	2
23B	78	213	24.0	2.0	78	2556	33	2
23AB	88	350	23.4	4.0	88	2048	23	2
24B	172	381	23.4	23.4	172	381	2	1

Table V-2 (con't)

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
1B	46	62	24.0	24.0	46	62	1	1
1AB	52	139	24.2	24.2	52	139	3	1
2B	53	106	24.0	24.0	53	106	2	1
3B	1	294	24.7	24.7	1	294	294	3
4B	1	345	21.5	1.5	1	4945	4945	4
5B	1	234	24.4	0.5	1	11419	11419	5
6B	0	439	33.5	33.5	0	439	∞	5
7B	0	7	22.4	22.4	0	7	∞	5
8B	1	320	23.3	1.0	1	7456	7456	4
9B	50	249	23.7	23.7	50	249	5	1
9AB	20	207	24.2	24.2	20	207	10	1
10B	4	259	24.0	1.0	4	6216	1554	4
11B	0	292	23.4	23.4	0	292	∞	5
12B	0	534	17.9	17.9	0	534	∞	5

Table V-3

Counts of total coccoliths and redeposited coccoliths in suspended sediment samples, June, 1977.

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
1B	30	30	23.3	23.3	30	30	1	1
1AB	32	34	23.5	23.5	32	34	1	1
2B	73	80	23.2	23.2	73	80	1	1
3B	27	44	8.3	8.3	27	44	2	1
4B	1	2	-	-	1	2	2	1
5B	1	16	18.3	18.3	1	16	16	2
6B	0	22	10.7	10.7	0	22	∞	5
7B	0	0	-	-	0	0	-	-
8B	0	0	-	-	0	0	-	-
9B	19	21	23.8	23.8	19	21	1	1
9AB	34	34	23.6	23.6	34	34	1	1
10B	4	6	11.3	11.3	4	6	2	1
11B	5	31	23.8	23.8	5	31	6	2
12B	0	3	18.5	18.5	0	3	∞	5

Table V-3 (con't)

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
13B	8	86	11.4	11.4	8	86	11	2
14B	3	4	11.7	11.7	3	4	1	1
16B	1	7	11.2	11.2	1	7	7	1
17B	0	0	-	-	0	0	-	-
18B	4	49	11.3	11.3	4	49	12	2
19B	0	2	11.1	11.1	0	2	∞	5
20B	0	0	-	-	0	0	-	-
21B	8	86	11.5	11.5	8	86	11	2
22B	3	12	11.0	11.0	3	12	4	1
23B	33	62	23.1	23.1	33	62	2	1
23AB	17	28	23.5	23.5	17	28	2	1
24B	17	25	24.1	24.1	17	25	2	1

Table V-4

Counts of total coccoliths and redeposited coccolithis in suspended sediment samples, March, 1977

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
1AB	2	3	23.9	23.9	2	3	2	1
1B	15	190	22.4	22.4	15	190	13	2
2B	2	7	24.2	24.2	2	7	4	1
3B'	17	129	25.0	25.0	17	129	8	1
4B	0	0	-	-	0	0	-	-
5B	0	66	24.0	24.0	0	66	∞	5
6B	0	0	-	-	0	0	-	-
7B	0	15	23.4	23.4	0	15	∞	5
8B	0	0	-	-	0	0	-	-
9AB'	49	306	24.2	24.2	49	306	6	1
9B	0	3	23.8	23.8	0	3	∞	5
10B	0	0	-	-	0	0	-	-
11B	0	0	-	-	0	0	-	-
12B	0	0	-	-	0	0	-	-

Table V-4 (con't)

Core No.	Counts of Specimen		Counting Distance (mm)		Normalized Counts		Ratio	Exponential Value
	Reworked	Total	Reworked	Total	Reworked	Total		
13B	0	0	-	-	0	0	-	-
14B	0	0	-	-	0	0	-	-
16B	0	0	-	-	0	0	-	-
17B	0	0	-	-	0	0	-	-
18B	0	0	-	-	0	0	-	-
19B	0	0	-	-	0	0	-	-
20B	0	18	23.4	23.4	0	18	∞	5
21B	0	0	-	-	0	0	-	-
22B	0	0	-	-	0	0	-	-
23AB	1	1	22.8	22.8	1	1	1	1
23B	8	13	22.9	22.9	8	13	2	1
24B	55	61	23.9	23.9	55	61	1	1

TABLE VIII-1
EXPLANATION OF APPENDIX

1. SAMPLE CODE:

A unique alphanumeric code number was assigned locally to each sample analyzed. The initial number refers to the collection season (cf. paragrph 4). The next two letters specify the common name of the organism sampled (cf. paragraph 2). The remaining letters indicate the bank of origin for each sample (cf. paragraph 3). A final number which appears in the individual liver sample codes identifies the indvidual fish from which the sample was taken.

2. GENUS SPECIES:

A. Complete genus and species names, common names and codes for all sample types in the order presented in the raw data tabulation are listed below:

Lutjanus campechanus	Red snapper	RS
Rhomboplites aurorubens	Vermilion snapper	VS
Spondylus americanus	Spiny oyster	SO

B. Suffixes of all samples are defined as follows:

PF Muscle tissue pooled from all individuals (4-6) in a sample.

PG Gill tissue pooled from all individuals (4-6) in a sample.

PL Liver tissue pooled from all individuals (4-6) in a sample.

IL Liver tissue from a single fish.

3. BANK STATION

A. Bank Stations:

BOB	Bouma Bank	28° 19' 49.15"N	94° 08' 29.72"W
BRB	Bright Bank	27° 53' 16.09"N	93° 18' 06.26"W
EB	Ewing Bank	28° 05' 43.87"N	90° 59' 41.37"W
EFG	East Flower Garden	27° 54' 31.9" N	93° 35' 59.8" W
EFB	18 Fathom Bank	27° 57' 48.47"N	92° 35' 45.04"W
HR	Hospital Rock	27° 32.1' N	96° 28.3' W
SB	Southern Bank	27° 26.8' N	96° 31.3' W

4. SEASON:

1 = First	June 1977	
2 = Second	September - October 1977	
3 = Third	February - March 1978	(No Samples Collected)

5. DRY WT:

Sample dry weight in grams.

6. CD, CR, CU, FE, NI, PB, ZN:

Concentration of each metal in mgms/kgm - parts per million (ppm) dry weight.

7. % WATER:

Percentage of wet weight lost during freeze-drying to a constant dry weight. To convert from dry weight to wet weight concentrations, multiply dry weight concentration by [(100-% water)/100].

TABLE VIII-1

RAW DATA TABULATION TOPOGRAPHICAL FEATURES STUDY 1977 TRACE METALS PROJECT

CODE NUMBER	CENUS SPECIES	TISSUE CODE	STATION	SEASON	NO. OF SPECIMENS	DRY WT	Cd	Cr	Cu	Fe	Ni	Pb	Zn	% Water
1VSEFG	R. aurorubens	PF	EFG	1	5	1.003	<0.01	0.05	0.80	4.	< 0.03	0.03	8	77.6
1VSEFG	R. aurorubens	PG	EFG	1	5	0.513	1.1	0.11	4.0	300	0.80	0.60	80	85.1
1VSEFG	R. aurorubens	PL	EFG	1	5	0.546	11	0.06	60	950	0.10	0.20	750	77.4
1VSEFG1	R. aurorubens	IL	EFG	1	1	0.174	4.5	0.18	50	650	< 0.20	0.05	300	78.1
1VSEFG2	R. aurorubens	IL	EFG	1	1	0.22	22	0.13	55	800	0.10	0.35	700	75.5
1VSEFG3	R. aurorubens	IL	EFG	1	1	0.25	14	0.12	60	1300	< 0.10	0.21	1200	77.6
1VSEFG4	R. aurorubens	IL	EFG	1	1	0.26	5.5	0.09	50	1000	0.30	0.05	750	78.4
2RSEFG	L. campechanus	PF	EFG	2	6	1.374	< 0.01	0.03	0.6	2	< 0.06	<0.02	10	77.7
2RSEFG	L. campechanus	PG	EFG	2	6	0.744	0.40	0.17	2.8	350	0.40	2.1	80	85.2
2RSEFG	L. campechanus	PL	EFG	2	6	0.638	5.0	0.06	30	850	0.04	0.10	180	74.2
2RSEFG1	L. campechanus	IL	EFG	2	1	0.269	2.5	0.13	13	500	< .01	0.10	110	72.3
2RSEFG2	L. campechanus	IL	EFG	2	1	0.436	2.4	0.08	25	500	< .08	0.04	130	74.0
2RSEFG3	L. campechanus	IL	EFG	2	1	0.393	4.0	0.09	35	800	< 0.09	0.07	140	77.1
2RSEFG4	L. campechanus	IL	EFG	2	1	0.394	4.5	0.09	20	550	< 0.09	0.05	140	75.0
2RSEFG5	L. campechanus	IL	EFG	2	1	0.604	2.6	0.06	16	650	< 0.06	0.04	95	70.3
2RSEFG6	L. campechanus	IL	EFG	2	1	0.55	6.0	0.06	35	800	0.15	0.10	170	76.6
2RSEB	L. campechanus	PF	EB	2	5	1.087	< 0.01	0.04	0.5	2	< 0.07	<0.01	9	78.0
2RSEB	L. campechanus	PG	EB	2	5	0.689	0.10	0.18	2.3	200	0.60	0.50	60	84.3
2RSEB	L. campechanus	PL	EB	2	5	0.841	0.20	0.04	45	1600	0.14	0.40	130	73.7
2RSEB1	L. campechanus	IL	EB	2	1	0.491	10.0	0.06	30	2500	0.06	1.00	130	71.6
2RSEB2	L. campechanus	IL	EB	2	1	0.618	2.0	0.06	95	1100	0.13	0.50	150	76.3
2RSEB3	L. campechanus	IL	EB	2	1	0.767	9.0	0.05	60	1600	0.05	0.40	140	70.7
2RSEB4	L. campechanus	IL	EB	2	1	0.511	7.5	0.06	40	1300	< 0.07	0.09	130	76.1
2RSEB5	L. campechanus	IL	EB	2	1	0.684	8.0	0.05	14	1800	0.04	0.20	85	72.0
2RSSNB	L. campechanus	PF	SNB	2	3	1.312	< 0.01	0.04	0.4	3	0.01	0.40	10	78.2
2RSSNB	L. campechanus	PG	SNB	2	3	0.67	1.0	0.25	2.8	250	0.6	9.0	80	86.4
2RSSNB	L. campechanus	PL	SNB	2	3	0.613	4.0	0.09	20	850	0.40	0.20	130	74.6
2RSSNB1	L. campechanus	IL	SNB	2	1	0.427	1.0	0.09	25	500	0.09	0.10	140	73.3
2RSSNB2	L. campechanus	IL	SNB	2	1	0.475	1.4	0.05	12	450	0.25	0.05	95	69.0

TABLE VIII-1

RAW DATA TABULATION TOPOGRAPHICAL FEATURES STUDY 1977 TRACE METALS PROJECT
CONT'D

CODE NUMBER	GENUS SPECIES	TISSUE CODE	STATION	SEASON	NO. OF SPECIMENS	DRY WT	Cd	Cr	Cu	Fe	Ni	Pb	Zn	% Water
2RSSNB3	L. campechanus	IL	SNB	2	1	0.357	2.6	0.12	18	700	0.08	0.08	130	76.6
2RSSNB4	L. campechanus	IL	SNB	2	1	0.328	7.0	0.12	30	1100	0.07	0.40	140	78.1
2RSSNB5	L. campechanus	IL	SNB	2	1	0.514	5.5	0.09	25	1300	< 0.09	0.25	140	76.2
2VSEFG	R. aurorubens	PF	EFG	2	5	1.072	0.01	0.04	1.0	4	< 0.10	0.06	8	78.3
2VSEFG	R. aurorubens	PG	EFG	2	5	0.788	0.40	0.08	2.0	350	0.80	1.2	80	84.5
2VSEFG	R. aurorubens	PL	EFG	2	5	0.638	30	0.07	19	1300	0.60	0.20	300	77.3
2VSEFG1	R. aurorubens	IL	EFG	2	1	0.413	65	0.08	25	1200	0.01	0.40	350	74.7
2VSEFG2	R. aurorubens	IL	EFG	2	1	0.042	26	<0.80	35	1200	< 2.5	<0.45	300	81.2
2VSEFG3	R. aurorubens	IL	EFG	2	1	0.155	12	0.17	16	550	< 0.60	0.06	500	78.8
2VSEFG4	R. aurorubens	IL	EFG	2	1	0.133	7.5	0.07	10	900	< 0.80	0.30	140	80.0
2VSEFG5	R. aurorubens	IL	EFG	2	1	0.028	5.0	1.0	17	1400	< 3.5	0.19	250	71.8
2VSEB	R. aurorubens	PF	EB	2	5	1.306	<0.01	0.04	0.70	4	0.05	0.01	9	78.4
2VSEB	R. aurorubens	PG	EB	2	5	0.602	0.40	0.16	3.0	300	0.60	1.9	100	85.8
2VSEB	R. aurorubens	PL	EB	2	5	0.507	35	0.10	50	2000	0.20	0.40	650	79.1
2VSEB1	R. aurorubens	IL	EB	2	1	0.242	45	0.16	35	1200	0.20	0.30	1700	78.2
2VSEB2	R. aurorubens	IL	EB	2	1	0.170	30	0.25	20	1100	< 0.20	1.5	180	77.9
2VSEB3	R. aurorubens	IL	EB	2	1	0.114	15	0.35	13	1900	< 0.40	0.40	190	79.3
2VSEB4	R. aurorubens	IL	EB	2	1	0.243	50	0.20	20	4000	0.10	0.60	190	78.7
2VSEB5	R. aurorubens	IL	EB	2	1	0.187	16	0.25	65	1500	0.10	0.40	1000	81.5
2VSSNB	R. aurorubens	PF	SNB	2	5	1.39	< 0.01	0.04	0.50	4	0.02	<0.05	11	77.1
2VSSNB	R. aurorubens	PG	SNB	2	5	0.598	0.20	0.14	2.0	250	0.60	1.2	90	85.2
2VSSNB	R. aurorubens	PL	SNB	2	5	0.535	18	0.09	16	800	0.04	0.20	250	71.9
2VSSNB1	R. aurorubens	IL	SNB	2	1	0.46	14	0.08	10	500	< 0.06	0.18	120	67.4
2VSSNB2	R. aurorubens	IL	SNB	2	1	0.612	21	0.08	40	600	0.05	0.19	850	75.5
2VSSNB3	R. aurorubens	IL	SNB	2	1	0.489	23	0.09	12	1200	0.06	0.25	160	70.1
2VSSNB4	R. aurorubens	IL	SNB	2	1	0.587	15	0.08	9.0	1200	0.20	0.30	140	70.9
2VSSNB5	R. aurorubens	IL	SNB	2	1	0.398	14	0.12	10	500	0.10	0.25	140	75.7
2SOEFG	S. americanus		EFG	2	1	1.602	17	2.5	4.0	50	30	0.30	150	84.3

TABLE VIII-1

RAW DATA TABULATION TOPOGRAPHICAL FEATURES STUDY 1977 TRACE METALS PROJECT
CONT'D

CODE NUMBER	GENUS SPECIES	TISSUE CODE	STATION	SEASON	NO. OF SPECIMENS	DRY WT	Cd	Cr	Cu	Fe	Ni	Pb	Zn	% Water
2SOEFB	S. americanus		EFB	2	1	1.189	23	2.2	8.0	55.	25.	0.90	170.	84.8
2SOEFB	S. americanus		EFB	2	1	1.41	30	2.3	55.	40.	25.	0.80	180.	83.8
2SOEFB	S. americanus		EFB	2	1	1.604	21	3.5	6.5	60.	60.	0.50	190.	84.8
2SOEFB	S. americanus		EFB	2	1	1.455	14	5.5	3.5	55.	25.	0.30	110.	85.8
2SOEFB	S. americanus		EFB	2	1	1.235	25	5.5	15.	40.	45.	0.60	120.	86.4
2SOEFB	S. americanus		EFB	2	1	1.577	7.5	2.0	2.0	17.	15.	0.10	80.	83.5
2SOBRB	S. americanus		BRB	2	1	1.213	11	2.5	1.4	35.	25.	0.20	110.	86.3
2SOBOB	S. americanus		BOB	2	1	1.114	16	0.06	3.5	150.	60.	0.40	200.	84.2

TABLE IX-1

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 1
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00008	2067	.01020
1668	.00021	2181	.00182
1700	.00042	2221	.00315
1772	.00018	2302	.00075
1800	.00047	2327	.00069
1900	.00030	2539	.00113
1942	.00024	2641	.00104
1972	.00018	2853	.00160
2000	.00049	2958	.00319
2047	.00191	3106	.00091
2100	.00130	3168	.00301
2140	.00246	3236	.00521
2200	.00167	3374	.00583
2300	.00118		
2400	.00087		
2460	.00151		
2500	.00307		
2600	.00231		
2700	.00691		
2800	.00365		
2900	.01880		
3000	.00369		
3100	.02590		
3200	.00798		
3245	.00892		
3300	.02320		
3336	.01520		
3400	.02600		
3500	.00834		
TOTAL	.16744	TOTAL	.03853

TABLE IX-1 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 2
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1668	.00485	1963	.00376
1700	.00402	2063	.00480
1772	.00179	2107	.00071
1800	.00268	2132	.00077
1854	.00285	2173	.00519
1900	.00291	2213	.00278
1949	.00112	2294	.00105
1975	.00066	2319	.00147
2000	.00128	2352	.00218
2043	.01660	2397	.00066
2100	.00804	2426	.00120
2139	.00732	2531	.00478
2300	.00441	2743	.00396
2400	.00284	2845	.00345
2465	.00350	2953	.00470
2500	.00762	3037	.00850
2600	.00710	3167	.00345
2700	.01790	3238	.00440
2800	.00908	3318	.00289
2900	.04130	3377	.00654
3000	.00798		
3100	.07030		
3200	.00653		
3257	.03030		
3317	.06580		
TOTAL	.32878	TOTAL	.06724

TABLE IX-1 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 3
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00166	1879	.00062
1654	.00103	2102	.01310
1668	.00229	2177	.00176
1700	.00529	2291	.00250
1739	.00014	2327	.00085
1772	.00126	2481	.00123
1800	.00247	2539	.00107
1865	.00071	2679	.00122
1900	.00438	2751	.00067
1946	.00143	3030	.00176
2000	.00185	3155	.00370
2055	.00138	3244	.00135
2100	.00131		
2141	.00116		
2200	.00365		
2300	.00328		
2400	.00312		
2500	.00377		
2547	.00057		
2600	.00376		
2700	.00663		
2755	.00007		
2800	.00302		
2900	.01440		
3000	.00458		
3100	.02010		
3200	.01360		
3241	.00194		
3300	.02000		
3391	.01820		
3500	.00105		
TOTAL	.14810	TOTAL	.02983

TABLE IX-1 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 4
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00066	1795	.00264
1653	.00049	1960	.00166
1668	.00389	2001	.00074
1700	.00620	2058	.00470
1739	.00149	2099	.02180
1772	.00381	2172	.00701
1800	.00568	2210	.00156
1866	.00156	2316	.00151
1900	.00932	2362	.00127
1945	.00014	2425	.00214
2000	.00198	2528	.00264
2055	.00192	2628	.00099
2100	.00152	2666	.00073
2141	.00105	2736	.00201
2200	.00346	2838	.00325
2300	.00331	2895	.00075
2400	.00307	2945	.00346
2462	.00125	3022	.00728
2500	.00558	3120	.00474
2545	.00094	3195	.00096
2600	.00529	3254	.00418
2700	.01190	3360	.00643
2800	.00434		
2900	.02170		
3000	.00566		
3100	.02560		
3200	.00933		
3242	.00050		
3300	.01400		
3333	.00389		
3391	.03380		
TOTAL	.19373	TOTAL	.08245

TABLE IX-2

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

PARKER BANK
STATION 1
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1668	.00223	2039	.00136
1700	.00318	2092	.01870
1772	.00079	2527	.00148
1800	.00227	2739	.00392
1900	.00233	2841	.00623
2000	.00268	2947	.00627
2045	.00320	3130	.02490
2100	.00329		
2200	.00400		
2300	.00704		
2400	.00417		
2500	.01280		
2600	.01020		
2700	.02850		
2800	.01100		
2900	.05280		
3000	.00980		
3061	.00185		
3100	.06570		
3200	.00404		
3255	.00828		
3321	.04220		
TOTAL	.28235	TOTAL	.06286

TABLE IX-2 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

PARKER BANK
STATION 2
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00042	1965	.00903
1668	.00062	2006	.00207
1700	.00153	2061	.01450
1772	.00040	2104	.02180
1800	.00140	2175	.00280
1900	.00198	2191	.00124
2000	.00158	2294	.00391
2100	.00201	2421	.00868
2200	.00436	2524	.00415
2300	.00775	2598	.00403
2400	.00741	2730	.00251
2500	.01560	2801	.00612
2600	.01390	2938	.00540
2700	.03270	3006	.01380
2800	.01410	3109	.00242
2900	.06810	3144	.00265
3000	.01880	3211	.00646
3100	.09120	3352	.01220
3200	.02370		
3241	.01190		
3300	.05760		
3400	.03610		
TOTAL	.41316	TOTAL	.12377

TABLE IX-2 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

PARKER BANK
STATION 3
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1668	.00219	1759	.00226
1700	.00417	1946	.00247
1772	.00106	1999	.00339
1800	.01180	2040	.00805
1857	.00229	2092	.02650
1900	.00446	2165	.02740
2000	.00222	2214	.00738
2100	.01130	2252	.00067
2200	.00178	2282	.00100
2300	.00488	2314	.00091
2400	.00346	2353	.00375
2466	.00092	2390	.00084
2500	.00643	2453	.00022
2600	.00561	2525	.00292
2700	.01430	2600	.00157
2800	.00543	2666	.00068
2900	.02970	2740	.00065
3000	.00579	2765	.00053
3100	.04380	2813	.00109
3200	.00317	2845	.00041
3258	.01090	2960	.00489
3321	.01910	3024	.00329
		3152	.01380
		3245	.00255
TOTAL	.19476	TOTAL	.11722

TABLE IX-2 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

PARKER BANK
STATION 4
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1668	.00048	1797	.00046
1700	.00200	1981	.00050
1772	.00023	2075	.00124
1800	.00067	2116	.00342
1852	.00038	2184	.00038
1900	.00091	2207	.00038
2000	.00019	2365	.00017
2044	.00037	2434	.00020
2100	.00027	2567	.00025
2200	.00007	2844	.00027
2300	.00038	2952	.00026
2400	.00028	3040	.00023
2459	.00013	3136	.00068
2500	.00045		
2600	.00030		
2700	.00074		
2800	.00031		
2900	.00119		
3000	.00028		
3100	.00164		
3283	.00089		
3372	.00059		
TOTAL	.01275	TOTAL	.00844

TABLE IX-3

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

SONNIER BANKS
STATION 1
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00032	1713	.00109
1668	.00096	1797	.00118
1700	.00235	1881	.00347
1772	.00067	2038	.00121
1800	.00381	2079	.01510
1864	.00064	2130	.01750
1900	.00444	2207	.00613
2000	.00337	2238	.00667
2100	.00379	2322	.00275
2200	.00428	2357	.00126
2300	.00330	2433	.00094
2400	.00312	2513	.00078
2500	.00507	2568	.00187
2600	.00665	2641	.00170
2700	.00849	2709	.00090
2800	.00587	2776	.00181
2900	.01300	2845	.00053
3000	.00707	2882	.00057
3100	.01700	2987	.00261
3200	.00729	3047	.00254
3300	.00954	3094	.00403
3394	.00712	3167	.01400
3500	.00110	3263	.00131
TOTAL	.11925	TOTAL	.08995

TABLE IX-3 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

SONNIER BANKS
STATION 2
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1500	.00263	1697	.00038
1600	.00480	1785	.00034
1668	.00640	1870	.00089
1700	.00730	1899	.00008
1726	.00056	1916	.00010
1772	.00159	1965	.00027
1800	.00677	1994	.00035
1824	.00077	2026	.00020
1846	.00189	2064	.00063
1900	.00651	2085	.00034
1948	.00384	2118	.00264
2000	.00564	2144	.00047
2032	.00099	2175	.00031
2100	.00524	2196	.00023
2138	.00038	2213	.00003
2200	.00484	2224	.00003
2340	.00490	2290	.00042
2400	.00433	2310	.00017
2500	.00520	2342	.00006
2600	.00543	2367	.00016
2700	.00598	2404	.00069
2800	.00355	2451	.00018
2900	.00669	2495	.00050
3000	.00394	2557	.00032
3100	.00640	2609	.00054
3200	.00087	2638	.00129
3300	.00134	2692	.00102
		2732	.00207
		2762	.00321
		2803	.00216
		2859	.00730
TOTAL	.10878	TOTAL	.02738

TABLE IX-3 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

SONNIER BANKS
STATION 3
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00111	1696	.03290
1653	.00063	1782	.02260
1668	.00218	1867	.03440
1700	.00932	2064	.01180
1772	.00123	2118	.03280
1800	.00399	2194	.00872
1900	.00490	2224	.01340
1947	.00092	2298	.00260
1974	.00153	2341	.00251
2000	.00430	2395	.00663
2048	.00771	2495	.00571
2100	.00895	2551	.00215
2140	.00700	2596	.00583
2200	.01650	2693	.00991
2300	.00977	2793	.01370
2400	.00800	2896	.01300
2470	.00205	2992	.01290
2500	.02380	3094	.01630
2600	.01850	3176	.01980
2700	.04460	3311	.03060
2800	.02230		
2900	.09290		
3000	.01580		
3100	.10300		
3200	.02210		
3246	.01520		
3300	.03100		
3333	.00481		
3400	.02230		
TOTAL	.50640	TOTAL	.29826

TABLE IX-3 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

SONNIER BANKS
STATION 4
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1600	.00028	1664	.00028
1668	.00074	1744	.00041
1700	.00137	1833	.00150
1772	.00157	2032	.00161
1800	.00210	2164	.00034
1853	.00117	2850	.00029
1900	.00201	2896	.00026
1947	.00046		
2000	.00175		
2038	.00100		
2100	.00184		
2140	.00055		
2200	.00188		
2300	.00208		
2400	.00160		
2500	.00272		
2600	.00225		
2700	.00463		
2800	.00177		
2900	.00759		
3000	.00178		
3045	.00023		
3100	.00818		
3200	.00061		
3300	.00372		
TOTAL	.05388	TOTAL	.00469

TABLE IX-4

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

BRIGHT BANK
STATION 1
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1668	.00274	1976	.00566
1700	.00272	2071	.01990
1772	.00067	2114	.03510
1800	.00156	2188	.00176
1900	.00178	2225	.01580
2000	.00134	2334	.00142
2049	.00618	2383	.00131
2100	.00334	2411	.00136
2147	.01450	2441	.00871
2200	.00229	2590	.00063
2300	.00659	2620	.00114
2400	.00434	2762	.00186
2500	.01480	2796	.00309
2600	.00749	2834	.00083
2700	.03570	2867	.00333
2800	.01410	3000	.01160
2900	.08160	3073	.00935
3000	.01240	3155	.05250
3100	.09640	3282	.02200
3200	.00475	3399	.03450
3270	.00305		
3319	.06410		
TOTAL	.38244	TOTAL	.23185

TABLE IX-4 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

BRIGHT BANK
STATION 2
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1421	.00181	2026	.00278
1668	.00177	2075	.00461
1700	.00152	2125	.03060
1772	.00049	2200	.00758
1800	.00065	2236	.00233
1900	.00388	2341	.00160
1961	.00025	2548	.00187
1977	.00049	2758	.00122
2000	.00500	3045	.00334
2044	.00755		
2074	.00321		
2100	.00522		
2118	.00115		
2145	.00216		
2180	.00128		
2200	.00404		
2222	.00282		
2245	.00328		
2300	.00490		
2363	.00505		
2400	.00508		
2437	.00136		
2470	.00181		
2500	.00400		
2522	.00127		
2600	.00700		
2660	.00086		
2700	.01700		
2771	.00070		
2800	.00438		
2846	.00024		
2900	.02140		
2978	.02770		
3033	.01000		
3078	.01240		
3112	.00212		
3205	.02050		
3274	.09590		
TOTAL	.29024	TOTAL	.05593

TABLE IX-4 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

BRIGHT BANK
STATION 3
CRUISE 77DL3

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1402	.00741	1892	.00019
1466	.00335	2054	.00658
1552	.00085	2224	.00055
1668	.00206	2390	.00011
1700	.00036	2491	.00105
1851	.00058	2554	.00047
1900	.00178	2712	.00067
1963	.00044	2863	.00037
2000	.00156	3004	.00026
2042	.00173	3133	.00167
2074	.00068		
2100	.00185		
2142	.00038		
2178	.00031		
2200	.00139		
2223	.00091		
2244	.00126		
2300	.00170		
2366	.00101		
2400	.00165		
2438	.00037		
2472	.00057		
2500	.00182		
2600	.00147		
2659	.00025		
2700	.00559		
2777	.00006		
2800	.00110		
2846	.00005		
2900	.00439		
2983	.00154		
TOTAL	.04847	TOTAL	.01192

TABLE IX-5

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 2 - GRABS 7 AND 8
CRUISE 78L1

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00395	1633	.01160
1446	.00241	1721	.01630
1500	.00709	1738	.02460
1541	.00222	1837	.03830
1558	.00104	1951	.03530
1600	.02340	1997	.05420
1633	.00801	2126	.02460
1658	.00296	2166	.03760
1668	.02060	2234	.03750
1700	.04070	2415	.03040
1738	.00571	2572	.02760
1772	.01590	2598	.03970
1800	.03520	2737	.16800
1839	.00456	2785	.02570
1866	.00993	2900	.02720
1900	.03660	2943	.02780
1942	.00176	3001	.06710
1954	.00351	3054	.02970
1966	.00175	3100	.02040
2000	.01210	3195	.04870
2043	.00258	3231	.09970
2055	.00171	3300	.05800
2100	.01190		
2138	.00338		
2200	.00925		
2244	.00252		
2300	.01260		
2342	.00169		
2400	.00934		
2500	.01640		
2547	.00175		
2600	.01250		
2700	.02410		
2800	.00828		
2900	.02860		
3000	.00790		
3100	.02980		
3200	.01130		
3243	.00492		
3300	.01660		
3338	.00558		

TABLE IX-5 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 2 - GRABS 9 AND 10
CRUISE 78L1

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00117	1602	.00324
1500	.00285	1684	.00610
1600	.00981	1701	.00885
1635	.00509	1785	.00492
1658	.00094	1799	.00878
1668	.00813	1865	.00386
1700	.02610	1898	.01620
1739	.00605	1949	.03060
1772	.00477	2056	.04550
1800	.01770	2095	.02100
1866	.00230	2167	.03130
1900	.01420	2183	.01180
1941	.00196	2208	.01910
1967	.00223	2235	.00868
2000	.00165	2266	.01350
2100	.00189	2292	.01390
2139	.00457	2346	.02000
2200	.00161	2396	.01380
2246	.00160	2422	.02570
2300	.00241	2499	.01050
2400	.00135	2539	.02390
2500	.00523	2602	.01530
2600	.00255	2636	.00393
2700	.00962	2657	.00926
2800	.00355	2700	.01130
2900	.01230	2736	.00342
3000	.00444	2830	.00502
3100	.01630	2901	.01650
3200	.01360	2949	.00785
3237	.01220	3016	.01120
3300	.01500	3099	.02300
3334	.01030	3225	.00776
3400	.02630	3298	.01190
		3362	.00941
		3392	.01070
TOTAL	.24977	TOTAL	.48778

TABLE IX-5 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 3 - GRABS 7 AND 8
CRUISE 78L1

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00041	1702	.00127
1500	.00101	1799	.00287
1549	.00049	1868	.00111
1600	.00182	1961	.00325
1632	.00137	1997	.00142
1662	.00063	2055	.00487
1668	.00267	2103	.00099
1700	.00561	2174	.00198
1739	.00071	2185	.00135
1772	.00289	2212	.00171
1800	.00684	2294	.00085
1863	.00232	2320	.00110
1900	.00792	2363	.00086
1952	.00133	2399	.00111
1966	.00070	2424	.00098
2000	.00277	2450	.00197
2043	.00161	2500	.00111
2100	.00284	2604	.00175
2140	.00085	2642	.00116
2200	.00215	2703	.00192
2300	.00355	2746	.00177
2400	.00167	2814	.00364
2500	.00343	2851	.00315
2600	.00236	2902	.00248
2700	.00478	2959	.00262
2800	.00232	3023	.00446
2900	.00699	3100	.00267
3000	.00164	3128	.00214
3100	.00672	3226	.00265
3200	.00262	3295	.00183
3262	.00060	3376	.00399
3300	.00180		
3356	.00191		
TOTAL	.08733	TOTAL	.06503

TABLE IX-5 (Cont.)

HEAVY HYDROCARBON ANALYSIS - STOCS - 1977

EAST FLOWER GARDENS BANK
STATION 3 - GRABS 9 AND 10
CRUISE 78L1

HEXANE ELUATE		BENZENE ELUATE	
RETENTION INDEX	CONCENTRATION (UG./G.)	RETENTION INDEX	CONCENTRATION (UG./G.)
1400	.00102	1794	.00035
1500	.00077	1870	.00021
1600	.00195	1925	.00018
1661	.00042	1962	.00067
1668	.00223	1998	.00012
1700	.00421	2056	.00158
1740	.00066	2100	.00042
1772	.00293	2172	.00101
1800	.00578	2211	.00030
1838	.00048	2320	.00017
1864	.00244	2364	.00033
1900	.00719	2402	.00011
1942	.00166	2423	.00022
1967	.00081	2449	.00101
2000	.00226	2549	.00023
2043	.00133	2645	.00048
2068	.00042	2678	.00067
2100	.00185	2748	.00052
2137	.00085	2806	.00067
2200	.00137	2851	.00131
2300	.00265	2900	.00015
2400	.00151	2959	.00100
2448	.00066	3015	.00038
2500	.00306	3064	.00017
2600	.00252	3161	.00033
2700	.00436	3222	.00032
2800	.00244	3264	.00038
2900	.00764	3369	.00197
3000	.00271		
3100	.00879		
3200	.00558		
3262	.00130		
3300	.00365		
3331	.00186		
3353	.00296		
3389	.00205		
TOTAL	.09437	TOTAL	.01526

TABLE XI-1

MEIOFAUNA, EAST FLOWER GARDEN BANK, JUNE 17, 1977

STATION NUMBER	1				2				3				4			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TAXA																
Nematoda	69	53	76	22	40	60	26	113	189	294	545	275	372	180	243	358
Harpacticoida	1	0	0	1	0	1	0	3	13	9	17	16	88	65	60	90
Foraminifera	13	7	47	5	1	11	5	100	16	2	57	22	143	27	8	46
Polychaeta	3	0	0	0	0	0	1	3	9	15	20	12	15	20	23	29
Ostracoda	0	0	1	0	0	0	0	0	0	1	1	0	3	4	4	2
Kinorhyncha	0	0	0	0	0	0	0	0	0	0	4	4	5	3	2	1
Bivalves	0	0	1	0	0	0	0	0	0	0	0	0	5	1	2	2
Gastropods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nauplii	0	0	0	0	0	0	0	3	0	0	20	1	45	39	18	71
Tanaidacea	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
Priapulida	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Halacaridae	0	0	0	0	0	0	0	0	0	0	1	1	2	4	1	1
Echiurida	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Sipunculida	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Unknown	0	0	0	0	0	0	0	0	13	0	11	0	5	15	0	2
MEAN	$\bar{X}$ = 74.0				$\bar{X}$ = 91.7				$\bar{X}$ = 393.3				$\bar{X}$ = 501.7			

TABLE XI-2

MEIOFAUNA, SONNIER BANKS, JUNE 17, 1977

STATION NUMBER	1				2				3				4			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TAXA																
Nematoda	108	71	56	7	68	47	92	153	541	291	669	703	94	62	158	146
Harpacticoida	20	40	15	11	9	3	4	12	131	65	159	160	5	1	11	5
Foraminifera	16	71	31	3	35	10	244	47	50	88	181	514	48	11	83	124
Polychaeta	1	11	0	4	2	5	2	14	53	41	69	83	10	2	19	14
Ostracoda	2	4	2	0	1	0	0	0	9	6	3	5	0	0	1	0
Kinorhyncha	0	3	1	0	1	1	1	0	16	11	10	22	0	0	1	0
Bivalves	0	0	1	0	0	0	1	0	1	1	3	2	0	0	0	0
Gastropods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nauplii	0	19	5	2	5	0	2	4	27	66	21	113	2	1	12	0
Priapulida	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0
Halacaridae	1	3	0	0	0	0	1	0	2	3	3	7	0	0	0	0
Turbellaria	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Cyclopoids	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Unknown	0	0	2	0	0	0	0	4	0	5	0	0	1	0	1	0
MEAN	$\bar{X}$ = 128.3				$\bar{X}$ = 192.0				$\bar{X}$ = 1034.5				$\bar{X}$ = 203.5			

TABLE XI-3

MEIOFAUNA, EAST FLOWER GARDEN BANK, SEPTEMBER 15, 1977

STATION NUMBER	1				2				3			
	A	B	C	D	A	B	C	D	A	B	C	D
TAXA												
Nematoda	35	29	21	16	26	21	14	16	398	281	216	61
Harpacticoida	6	2	0	0	0	1	0	2	30	10	21	3
Foraminifera	12	1	0	0	2	8	0	1	14	17	39	2
Polychaeta	2	0	1	2	0	0	1	2	18	7	4	1
Ostracoda	0	0	0	0	0	0	0	1	7	2	0	0
Kinorhyncha	0	0	0	0	0	0	0	0	6	0	4	0
Bivalves	0	0	0	0	0	0	0	0	6	3	0	1
Gastropods	0	0	0	0	0	0	0	0	0	0	0	0
Nauplii	0	1	0	0	0	0	0	0	45	0	6	3
Tanaidacea	0	0	0	0	0	0	0	0	2	0	0	1
Halacaridae	0	0	0	1	0	1	0	0	2	1	0	0
Sipunculida	0	0	0	0	0	0	0	0	0	1	0	0
Cyclopoids	0	0	0	0	0	0	0	0	1	0	0	0
Holothuria	0	0	0	0	0	0	0	0	2	0	0	1
Unknown	0	1	0	0	0	0	0	0	11	1	0	3
MEAN		$\bar{X}$ = 32.5				$\bar{X}$ = 24.0				$\bar{X}$ = 307.3		

TABLE XI-4

MEIOFAUNA, EAST FLOWER GARDEN BANK, MARCH 1978

STATION NUMBER	2				3			
	A	B	C	D	A	B	C	D
TAXA								
Nematoda	172	30	148	157	376	157	307	484
Harpacticoida	0	1	4	3	25	14	26	29
Foraminifera	17	6	3	12	15	5	3	7
Polychaeta	4	1	1	18	36	10	12	35
Ostracoda	0	0	0	0	2	0	3	1
Kinorhyncha	2	1	0	5	8	0	6	6
Bivalves	1	0	1	1	1	1	0	0
Gastropods	0	0	0	0	0	0	0	0
Nauplii	0	2	7	3	22	4	22	45
Tanaidacea	0	0	0	0	0	0	0	0
Priapulida	0	0	0	0	0	0	6	0
Halacaridae	0	0	0	0	0	0	0	0
Echiurida	0	0	0	0	0	0	0	0
Sipunculida	0	0	0	0	0	2	0	0
Unknown	11	2	0	13	6	16	0	23
MEAN	$\bar{X}$ = 156.50				$\bar{X}$ = 434.25			

TABLE XI-5

11 June 1977

EAST FLOWER GARDEN - 1

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	4	3	7	7		7	3		3	5		5	3		3	10	2	12	6.17
Sipunculida	2	1	3	2		2				1		1							1.00
Bivalvia				1		1					1	1	1		1	1		1	0.67
Gastropoda																			
Scaphopoda																			
Foraminifera				2	5	7	14	8	22	7	2	9				2		2	6.67
Nematoda																			
Ostracoda				1		1										1		1	0.33
Copepoda	4		4	8	1	9	2		2	7		7	1		1	5		5	4.67
Cumacea													1		1	1		1	0.33
Tanaidacea	1		1													3		3	0.67
Isopoda	1		1																0.17
Gammaridea	1		1							3		3	2		2	2		2	1.33
Caprellidea																			
Decapoda														1	1				0.17
Brachyura								1	1										0.17
Ophiurordea																			
Asteroidea																			
Holothuroidea																			
Echinoidea																			
Crinoidea																			
Other	48	1	49	19	1	20	5	1	6	32	1	33	22	2	24	16		16	
Unknown	1	1	2	4	1	5				2	2	4	2						
TOTALS	62	6		44	8		24	10		57	6		32	3		41	2		
COMBINED	68			52			34			63			35			43			

RANK ORDER: 1. *Foraminifera*, 2. *Polychaeta*, 3. *Copepoda*, 4. *Gammaridea*, 5. *Sipunculida*, 6. *Bivalvia*, 7. *Tanaidacea*, 8. *Ostracoda*, 9. *Cumacea*, 10. *Isopoda*

TABLE XI-6

14 June 1977

EAST FLOWER GARDEN - 2

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	11	1	12	12	1	13	6	1	7	12	1	13	5	1	6	14	3	17	11.33
Sipunculida	4	1	5	1	1	2		1	1	3		3	2	2	4				2.50
Bivalvia	2		2	3		3				4		4	1		1	2		2	2.00
Gastropoda	1		1							1		1							0.33
Scaphopoda	2		2							2		2	1		1				0.83
Foraminifera	9	2	11	4		4	3	1	4	2		2	11		11	15		15	7.83
Nematoda																			
Ostracoda				1		1				2		2							0.50
Copepoda	10		10	1	1	2	2		2	3		3	2		2	1		1	3.33
Cumacea																			
Tanaidacea	3		3																0.50
Isopoda				1		1				15		15							2.67
Gammaridea				2	1	3							1		1	1		1	0.83
Caprellidea																			
Decapoda	1		1								2	2	1		1				0.67
Brachyura																			
Ophiurordea																			
Asteroidea																			
Holothuroidea																			
Echinoidea																			
Crinoidea																			
Other	18	1	19	7		7				12		12	10		10	9		9	
Unknown	8	1	9	1	1	2										2		2	
TOTALS	69	6		33	5		11	3		56	3		34	3		44	3		
COMBINED	75			38			14			59			37			47			

RANK ORDER: 1. *Polychaeta*, 2. *Foraminifera*, 3. *Copepoda*, 4. *Isopoda*, 5. *Scaphopoda*, 6. *Bivalvia*, 7. *Scaphopoda*, 8. *Gammaridea*, 9. *Decapoda*, 10. *Ostracoda*

TABLE XI-7

17 June 1977

EAST FLOWER GARDEN - 3

	1			2			3			4			5			6			$\bar{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
	25	7	32	19	8	27	31	18	49	24	10	34	46	13	59	26	33	59	43.33
Polychaeta	25	7	32	19	8	27	31	18	49	24	10	34	46	13	59	26	33	59	43.33
Sipunculida	1	2	3	1	1	2	2	2	4	1	3	4		6	6	2	2	4	3.83
Bivalvia	24	17	41	20	7	27	17	11	28	8	15	23	11	9	20	30	24	54	32.17
Gastropoda				3		3	5	1	6	1		1	1		1	2	1	3	2.50
Scaphopoda	6	3	9	12	8	20	12	10	22	4		4	4	2	6	8	1	9	11.67
Foraminifera	9	1	10	48	1	49	21	5	26					1	1		2	2	14.67
Nematoda	3		3	5		5	9	1	10	2		2	4		4	2		2	4.33
Ostracoda	64		64	84		84	106	2	108	43		43	72		72	80	2	82	75.50
Copepoda	4		4										2		2	4		4	1.67
Cumacea										3		3	6		6	2		2	1.83
Tanaidacea				3		3	8		8				2		2				2.17
Isopoda	2	1	3				1	4	5	5		5	7	1	8	3	4	7	4.67
Gammaridea	6	5	11	10	8	18	15	6	21	9	4	13	6	4	10	3	5	8	13.50
Caprellidea	3		3										2		2				0.83
Decapoda		2	2		1	1		1	1		1	1		2	2		1	1	1.33
Brachyura																			
Ophiurordea	1	1	2		2	2										2		2	1.00
Asteroidea																			
Holothuroidea																			
Echinoidea		1	1		1	1		1	1		2	2					1	1	1.00
Crinoidea											1	1				3	2	5	1.00
Other	9	7	16	15	3	18		1	1	2		2	4	1	5	14	16	30	
Unknown	8	3	11	2	3	5	9	2	11	2	2	4	8	5	13	10	5	15	
TOTALS	165	50		222	43		236	65		104	38		175	44		191	99		
COMBINED	215			265			301			142			219			290			

RANK ORDER: 1. *Ostracoda*, 2. *Polychaeta*, 3. *Bivalvia*, 4. *Foraminifera*, 5. *Gammaridea*, 6. *Scaphopoda*, 7. *Isopoda*, 8. *Nematoda*, 9. *Sipunculida*, 10. *Gastropoda*

TABLE XI-8

17 June 1977

EAST FLOWER GARDEN - 4

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	23	17	40	57	22	79	78	17	95	73	21	94	58	22	80	56	30	86	79.00
Sipunculida	14	20	34	28	15	43	31	22	53	24	35	59	30	25	55	16	15	31	45.83
Bivalvia	13	10	23	10	6	16	14	6	20	7	12	19	2	5	7	7	9	16	16.83
Gastropoda											2	2							0.33
Scaphopoda	1		1								1	1							0.17
Foraminifera	14	2	16	1	9	10		1	1	1	5	6		2	2		1	1	6.00
Nematoda	4	1	5	3		3	4		4				2		2	2	1	3	2.83
Ostracoda	4		4	3		3	7		7	6	1	7	1		1	2		2	4.00
Copepoda	4		4	4		4	3		3		1	1	9		9	3		3	4.00
Cumacea										2		2							0.33
Tanaidacea																			
Isopoda	6		6	9	6	15	2		2	8	2	10	4	5	9	4	1	5	7.83
Gammaridea	2	2	4	4		4	5	1	6	4	3	7	1	1	2	2	2	4	4.50
Caprellidea				1		1										2		2	0.50
Decapoda		2	2		5	5		6	6		2	2		3	3	1		1	3.17
Brachyura		1	1								1	1		2	2				0.67
Ophiurordea	1	2	3					1	1		2	2		3	3				1.50
Asteroidea																			0.33
Holothuroidea		1	1		1	1													0.33
Echinoidea				1		1					1	1							1.00
Crinoidea				3		3	2		2							1		1	
Other	4	12	16	11	5	16	5	5	10	2	5	7	10	1	11		2	2	
Unknown	11	7	18	4	11	15	2	6	8	1	9	10	2	8	10		25	25	
TOTALS	101	77		139	80		153	65		128	103		119	77		96	86		
COMBINED	178			219			218			231			196			182			

RATE ORDER: 1. *Polychaeta*, 2. *Sipunculida*, 3. *Bivalvia*, 4. *Isopoda*, 5. *Foraminifera*, 6. *Gammaridea*, 7. *Ostracoda*, 8. *Copepoda*, 9. *Scaphopoda*, 10. *Nematoda*

TABLE XI-9

14 September 1977

EAST FLOWER GARDEN - 1

Mean Number of Animals = 23.33

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	1	1	2	4	2	6	9	2	11	4	2	6	2	1	3	6	1	7	5.83
Sipunculida	2	2	4				1		1	1	2	3				3	1	3	2.00
Bivalvia				1		1	1		1							1		1	0.50
Gastropoda							1		1										0.17
Scaphopoda	1		1													1		1	0.33
Foraminifera	5		5				3		3	7		7				3		3	3.00
Nematoda																			
Ostracoda	4		4	6	3	9	1		1	7		7				1		1	4.00
Copepoda																			
Cumacea																			
Tanaidacea				1		1													0.17
Isopoda																			
Gammaridea																	1	1	0.17
Caprellidea																			
Decapoda		1	1											2	2				0.50
Brachyura																			
Ophiurordea																	1	1	0.17
Asteroidea																			
Holothuroidea																			
Echinoidea																			
Crinoidea																			
Other	5		5	1		1				3		3	4		4	3		3	
Unknown	1		1				2		2				17		17	5		5	
TOTALS	19	4		13	5		18	2		22	4		23	3		23	4		
COMBINED	23			18			20			26			26			27			

RANK ORDER: 1. *Polychaeta*, 2. *Ostracoda*, 3. *Foraminifera*, 4. *Sipunculida*, 5. *Bivalvia*, 6. *Decapoda*, 7. *Scaphopoda*, 8. *Gammaridea*, 9. *Tanaidacea*, 10. *Gastropoda*

TABLE XI-10

14 September 1977

EAST FLOWER GARDEN - 2

Mean Number of Animals = 24.67

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	6		6	6		6	11	3	14	9	5	14	7		7	5	1	6	8.83
Sipunculida		3	3		3	3		1	1		2	2	1		1		2	2	2.00
Bivalvia										1		1							0.17
Gastropoda										1		1		1	1	1		1	0.50
Scaphopoda				3		3				1		1							0.67
Foraminifera	1		1					1	1					8	8				1.67
Nematoda																			
Ostracoda	2		2	1		1				16		16	2		2	5		5	4.33
Copepoda																			
Cumacea																			
Tanaidacea	1		1										1		1				0.33
Isopoda										2	2	4							0.67
Gammaridea	2		2	1		1	1		1	3		3							1.17
Caprellidea																			
Decapoda	1	1	2								2	2							0.67
Brachyura																			
Ophiurordea																			
Asteroidea																			
Holothuroidea																			
Echinoidea																			
Crinoidea																			
Other	2	3	5	4		4					1	1	2	1	3		1	1	
Unknown		1	1	2	1	3	1		1		3	3							
TOTALS	15	8		17	4		13	5		33	15		13	10		10	4		
COMBINED	23			21			18			48			23			15			

RANK ORDER: 1. *Polychaeta*, 2. *Ostracoda*, 3. *Sipunculida*, 4. *Foraminifera*, 5. *Gammaridea*, 6. *Scaphopoda*, 7. *Decapoda*, 8. *Isopoda*, 9. *Gastropoda*, 10. *Tanaidacea*

TABLE XI-11

15 September 1977

EAST FLOWER GARDEN - 3

Mean Number of Animals = 203.50

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	18	19	37	18	28	46	15	20	35	58	20	78	29	12	41	34	24	58	49.17
Sipunculida	5	6	11	7	9	16		1	1	2	3	5	1	1	2	4	1	5	6.67
Bivalvia	16	9	25	9	8	17	19	8	27	37	5	42	33	8	41	19	13	32	30.67
Gastropoda							2		2		1	1				3	1	4	1.17
Scaphopoda	6		6				9		9	10	4	14	7	8	15	7	1	8	8.67
Foraminifera	7		7	11	1	12	16		16	15	3	18	13		13	18	1	19	14.17
Nematoda	7		7				16		16	11		11	7		7	6		6	7.83
Ostracoda	13		13	2		2	56		56	90		90	89		89	40	1	41	48.50
Copepoda																			
Cumacea										3		3	1		1				0.67
Tanaidacea					2	2	7		7	6		6	1		1	1		1	3.00
Isopoda	1		1					1	1	3	1	4				1	1	2	1.83
Gammaridea		3	3	1	3	4	5		5	3	1	4	1	3	4	1	1	2	3.67
Caprellidea																			
Decapoda		6	6		1	1		7	7		10	10		1	1		5	5	5.00
Brachyura																			
Ophiurordea					4	4	1		1	2		2					1	1	
Asteroidea																			
Holothuroidea																			
Echinoidea								2	2		1	1							0.50
Crinoidea																			
Other	3	11	14	1	2	3		2	2	12	12	24	10	4	14	13	6	19	3.17
Unknown	2	11	13	2	2	4	9	13	22	12	14	26	1	7	8	3	6	9	
TOTALS	78	65		51	60		155	54		264	75		193	44		150	62		
COMBINED	143			111			209			339			237			212			

RANK ORDER: 1. *Polychaeta*, 2. *Ostracoda*, 3. *Bivalvia*, 4. *Scaphopoda*, 5. *Nematoda*, 6. *Sipunculida*, 7. *Decapoda*, 8. *Gammaridea*, 9. *Tanaidacea*, 10. *Isopoda*

TABLE XI-12

15 March 1978

EAST FLOWER GARDEN - 2

Mean Number of Animals = 63.33

	1			2			3			4			5			6			$\bar{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	15	4	19	10	4	14	19	7	26	12	8	20	17	8	25	12	8	20	20.67
Sipunculida	1		1	1	1	2	3		3	2		2	1		1	3		3	2.00
Bivalvia				2		2	1		1	3		3	2	2	4	2		2	2.00
Gastropoda				1		1							1		1				0.33
Scaphopoda																			0.33
Foraminifera		1	1		1	1													
Nematoda																			
Ostracoda				51		51	24	3	27	37	2	39	10	1	11	45	1	46	29.00
Copepoda																			
Cumacea																			
Tanaidacea																			
Isopoda											1	1							0.17
Gammaridea														1	1				0.17
Caprellidea																			
Decapoda	1		1	2	1	3										1		1	0.83
Brachyura								2	2										0.33
Ophiurordea					2	2		1	1										0.50
Asteroidea																			
Holothuroidea																			
Echinoidea																			
Crinoidea																			
Other				1	3	4		5	5		7	7		6	6		1	1	3.83
Unknown	8	3	11					1	1		4	4		2	2		1	1	3.17
TOTALS	25	8		68	12		47	19		54	22		31	20		63	11		
COMBINED	33			80			66			76			51			74			

RANK ORDER: 1. *Ostracoda*, 2. *Polychaeta*, 3. *Sipundulida*, 4. *Bivalvia*, 5. *Decapoda*, 6. *Ophiuroidea*, 7. *Scaphopoda*, 8. *Gastropoda*, 9. *Brachyura*, 10. *Gammaridea*

TABLE XI-13

15 March 1978

EAST FLOWER GARDEN - 3

Mean Number of Animals = 275

	1			2			3			4			5			6			$\bar{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	48	3	51	70	21	91	51	14	65	56	28	84	49	20	69	107	30	137	82.83
Sipunculida					6	6	4	2	6	51	1	52	1	3	4	4	3	7	12.50
Bivalvia	19	11	30	29	2	31	5	2	7	8	3	11	27	8	35	15	2	17	21.83
Gastropoda	1		1										2		2	1		1	0.50
Scaphopoda	3	1	4	4	4	8	1		1	1	1	2	12	3	15		2	2	5.33
Foraminifera	3		3	2		2	3		3	5		5	38		38	16		16	11.17
Nematoda	7		7	69		69	40		40	1		1	55		55	128		128	50.33
Ostracoda	95	3	98	12	1	13	5		5	5		5	2		2	12		12	22.50
Copepoda	1		1	2		2	2		2							3		3	1.33
Cumacea				1		1													0.17
Tanaidacea	2		2	9		9	4		4	3		3	6		6	4		4	4.67
Isopoda		1	1		2	2		1	1	1	2	3					1	1	1.33
Gammaridea	2	2	4	2	4	6	1		1	1	3	14	1		1	1	2	3	4.83
Caprellidea											1	1							0.17
Decapoda		4	4				1	2	3		6	6					3	3	2.67
Brachyura																			
Ophiurordea	2		2					1	1	1		1	1	1	2	1	3	4	1.67
Asteroidea																			
Holothuroidea											1	1		1	1				0.33
Echinoidea	1	2	3											2	2				0.83
Crinoidea																			
Other	25		25	10		10	6		6	9		9	6		6	24	2	26	9.33
Unknown	6		6	7		7	3		3	3		3				5		5	
TOTALS	240	27		217	40		126	22		155	46		200	38		321	48		
COMBINED	267			257			148			201			238			369			

RANK ORDER: 1. *Polychaeta*, 2. *Nematoda*, 3. *Ostracoda*, 4. *Bivalvia*, 5. *Sipunculida*, 6. *Foraminifera*, 7. *Scaphopoda*, 8. *Gammaridea*, 9. *Tanaidacea*, 10. *Decapoda*

TABLE XI-14

15 March 1978

EAST FLOWER GARDEN - 4

Mean Number of Animals = 275

	1			2			3			4			5			6			$\bar{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	104	26	130	89	28	117	111	46	155	104	57	161	107	28	135	110	26	136	139
Sipunculida	26	57	83	16	26	42	15	13	28	17	24	41	23	74	97	29	64	93	64
Bivalvia	9	4	13	5	5	10	3	5	8	7	10	17	15	6	21	9	7	16	14.17
Gastropoda																	1	1	0.17
Scaphopoda		1	1							1		1		2	2		1	1	0.83
Foraminifera																			
Nematoda	20		20	27		27	4		4	8		8	13	1	14	17		17	15
Ostracoda	5		5	4		4	4		4	10		10	26		26	5		5	9
Copepoda																			
Cumacea				1		1				2	1	3	1		1				0.83
Tanaidacea																			
Isopoda		1	1					1	1		2	2		3	3				1.17
Gammaridea	19		19	8	1	9	20	1	21	12		12	7	2	9	3	2	5	12.50
Caprellidea	2		2	1		1				1	4	5							1.33
Decapoda		4	4		10	10		1	1		2	2		3	3		8	8	4.67
Brachyura		1	1					1	1										0.33
Ophiurordea		2	2		1	1	1		1	1		1							0.83
Asteroidea																			
Holothuroidea											1	1					1	1	0.33
Echinoidea				1		1	2		2										0.50
Crinoidea																			
Other	2	5	7	5	10	15	1	4	5	2	3	5	1	1	2	2	4	6	6.67
Unknown		5	5		4	4		3	3		3	3		5	5				3.33
TOTALS	187	106		157	85		161	75		165	107		193	125		175	114		
COMBINED	293			242			236			272			318			289			

RANK ORDER: 1. *Polychaeta*, 2. *Sipunculida*, 3. *Nematoda* 4. *Bivalvia*, 5. *Gammaridea*, 6. *Ostracoda*, 7. *Decapoda*, 8. *Isopoda*, 9. *Cumacea*, 10. *Scaphopoda*

TABLE XI-15
20 June 1977
SONNIER BANKS

Mean Number of Animals = 131

	1			2			3			4			5			6			$\bar{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	21	26	48	15	31	46	15	26	41	32	36	68	40	38	78	18	5	23	50.67
Sipunculida	1	2	3	2	3	5	1	5	6	2	6	8	6	7	13	16		16	8.50
Bivalvia	10	8	18	23	7	30	22	12	34	40	8	48	34	1	35		1	1	27.67
Gastropoda										5	3	8				1		1	1.50
Scaphopoda	1		1	1		1													0.33
Foraminifera											1	1							0.17
Nematoda				1		1	3		3	1	1	2	5		5	3	1	4	2.50
Ostracoda	2		2	2		2	4		4	1		1				1		1	1.67
Copepoda										1		1							0.17
Cumacea	1	1	2	4		4	3		3	5		5	2		2	3		3	3.17
Tanaidacea														1	1				0.17
Isopoda		1	1	2	1	3	12		12	3	3	6	8		8	11	2	13	7.17
Gammaridea	11	4	15	9	2	11	14	6	20	8	6	14	10	3	13	11	1	12	14.17
Caprellidea																			
Decapoda								1	1		1	1		3	3				0.83
Brachyura														1	1				0.17
Ophiurordea		1	1											1	1				0.33
Asteroidea																			
Holothuroidea					1	1													0.17
Echinoidea		3	3		3	3													1.00
Crinoidea																			
Other		4	4		11	11		16	16		4	4		4	4		4	4	7.17
Unknown		3	3		4	4		2	2		7	7		5	5				3.50
TOTALS	47	53		59	63		74	68		98	76		105	65		64	14		
COMBINED	100			122			142			174			170			78			

RANK ORDER: 1. *Polychaeta*, 2. *Bivalvia*, 3. *Gammaridea*, 4. *Sipunculida*, 5. *Isopoda*, 6. *Cumacea*, 7. *Nematoda*, 8. *Ostracoda*, 9. *Gastropoda*, 10. *Echinoidea*

TABLE XI-16

20 June 1977
SONNIER BANKS - 2

Mean Number of Animals = 109.40

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	19	23	42	20	6	26	13	2	15	15	11	26	3	1	4	47	16	63	29.33
Sipunculida	1	2	3	3	3	6	3	3	6		3	3				1	3	4	3.67
Bivalvia	19	19	38	36	8	44	19	6	25	19	6	25		1	1	31	11	44	29.50
Gastropoda	6		6	3	3	6	2	1	3	2		2				1		1	3.00
Scaphopoda	3		3	2		2				1		1				1		1	1.17
Foraminifera																			
Nematoda				2		2	2		2	1		1	1		1	5		5	1.83
Ostracoda	4		4	2		2	1		1	1		1				10		10	3.00
Copepoda				1		1	2		2				3		3	1		1	1.17
Cumacea	1		1		1	1										2	1	3	0.83
Tanaidacea																2		2	0.33
Isopoda	1		1	2		2	1		1	1		1				1	1	2	1.17
Gammaridea	1		1	2	1	3	1		1	2	2	4				1	1	2	1.83
Caprellidea	2		2																0.33
Decapoda		3	3		1	1				1	2	3	1		1	2	1	3	1.83
Brachyura		2	2								1	1					3	3	1.00
Ophiurordea	1		1							3	1	4				2		2	1.17
Asteroidea					1	1					1	1							0.33
Holothuroidea																			0.17
Echinoidea											1	1							
Crinoidea																			
Other		18	18	1	10	11	1	4	5	1	17	18		3	3		20	20	
Unknown		7	7		3	3					1	1		3	3		6	6	
TOTALS	58	74		74	37		44	16		47	46		8	5		107	44		
COMBINED	132			111			60			93			13			151			

RANK ORDER: 1. *Bivalvia*, 2. *Polychaeta*, 3. *Sipunculida*, 4. *Ostracoda*, 5. *Gastropoda*, 6. *Gammaridea*, 7. *Decapoda*, 8. *Nematoda*, 9. *Scaphopoda*, 10. *Copepoda*

TABLE XI-17

20 June 1977

SONNIER BANKS - 3

Mean Number of Animals = 197.60

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	50	40	90	21	12	33	34	28	62	7	17	25	46	51	97	28	39	67	62.17
Sipunculida	4		4	3	2	5	10	1	11	4	2	6	4	2	6	20	5	25	9.50
Bivalvia	92	15	107	37	8	45	87	11	98	10	5	15	58	9	67	92	13	105	72.83
Gastropoda							1		1				3		3	3		3	1.17
Scaphopoda	1		1																0.17
Foraminifera	1		1				3		3										0.67
Nematoda				1		1				1		1				2		2	0.67
Ostracoda	8	1	9	4		4	7		7				5		5	12		12	6.17
Copepoda																			
Cumacea	2		2	4		4							6		6	2		2	2.33
Tanaidacea	1		1							1		1							0.33
Isopoda	11	2	13	4		4	2		2	2		2	3		3	5	1	6	5.00
Gammaridea	8	1	9	1		1	4		4		1	1	1	2	3	1		1	3.17
Caprellidea																			
Decapoda		2	2					6	6		2	2		1	1		1	1	2.00
Brachyura														2	2		1	1	0.50
Ophiurordea					1	1							1	1	2				0.50
Asteroidea		1	1																0.17
Holothuroidea														1	1		1	1	0.33
Echinoidea																			
Crinoidea																			
Other				1	3	4							3		3				
Unknown	3		3	3	3	6	10	2	12				6		6	2		2	
TOTALS	181	62		79	29		158	48		25	27		137	69		167	61		
COMBINED	243			108			206			52			203			228			

RANK ORDER: 1. *Bivalvia*, 2. *Polychaeta*, 3. *Sipunculida*, 4. *Ostracoda*, 5. *Isopoda*, 6. *Gammaridea*, 7. *Decapoda*, 8. *Gastropoda*, 9. *Foraminifera*, 10. *Nematoda*

TABLE XI-18

20 June 1977

SONNIER BANKS - 4

Mean Number of Animals = 100.83

	1			2			3			4			5			6			$\overline{X}$
	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	0.5	1.0	TOT	
Polychaeta	17	55	72	27	22	49	16	11	27	23	16	39	19	10	29	27	18	45	43.50
Sipunculida		2	2	2	1	3				1	1	2				3	4	7	2.33
Bivalvia	12	10	22	36	8	44	24		24	11	2	13	22	5	27	33	3	36	27.67
Gastropoda							4		4				1		1	4	1	5	1.67
Scaphopoda																			
Foraminifera	2		2	3		3							1		1				1.00
Nematoda																			
Ostracoda				1		1							2		2	3		3	1.00
Copepoda																			
Cumacea				2	1	3		1	1							1		1	0.83
Tanaidacea				1		1				1		1	2		2				0.67
Isopoda	1	3	4	4		4				2		2	2	1	3	3	1	4	2.83
Gammaridea	3	2	5		2	2		1	1	1	1	2	3	1	4				2.33
Caprellidea																			
Decapoda		1	1		4	4		2	2		3	3	2	1	3		1	1	2.33
Brachyura																			
Ophiurordea		2	2										1		1				0.50
Asteroidea																			
Holothuroidea																			
Echinoidea								1	1										0.17
Crinoidea																			
Other	5		5	3	4	7	5	2	7	9		9	14		14	16		16	
Unknown				7		7	6		6	4		4	2		2	4	3	7	
TOTALS	40	75		86	42		55	18		52	23		71	18		94	31		
COMBINED	115			128			73			75			89			125			

RANK ORDER: 1. *Polychaeta*, 2. *Bivalvia*, 3. *Sipunculida*, 4. *Isopoda*, 5. *Gammaridea*, 6. *Decapoda*, 7. *Gastropoda*, 8. *Foraminifera*, 9. *Ostracoda*, 10. *Cumacea*

TABLE XI-19

EAST FLOWER GARDEN

Polychaeta = 107

8 x 10 = 80
3 x 9 = 27
107

Bivalvia = 70

1 x 9 = 9
3 x 8 = 24
3 x 7 = 21
1 x 6 = 6
2 x 5 = 10
70

Sipunculida = 69

2 x 9 = 18
2 x 8 = 16
2 x 7 = 14
3 x 6 = 18
1 x 5 = 5
1 x 2 = 2
69

Ostracoda = 71

2 x 10 = 20
3 x 9 = 27
1 x 8 = 8
1 x 5 = 5
1 x 4 = 4
2 x 3 = 6
1 x 1 = 1
71

Foraminifera = 52

1 x 10 = 10
1 x 9 = 9
1 x 8 = 8
2 x 7 = 14
1 x 6 = 6
1 x 5 = 5
52

Gammaridea = 51

1 x 8 = 8
1 x 7 = 7
3 x 6 = 18
1 x 5 = 6
4 x 3 = 12
1 x 1 = 1
51

Isopoda = 32

2 x 7 = 14
1 x 6 = 6
1 x 4 = 4
2 x 3 = 6
2 x 1 = 2
32

Copepoda = 19

2 x 8 = 16
1 x 3 = 3
19

Tanaidacea = 11

1 x 4 = 4
3 x 2 = 6
1 x 1 = 1
11

Cumacea = 9

1 x 5 = 5
2 x 2 = 4
9

TABLE XI-20

EAST FLOWER GARDEN

Scaphopoda = 32

1 x 7 = 7
2 x 5 = 10
3 x 4 = 12
1 x 2 = 2
1 x 1 = 1
32

Decapoda = 26

1 x 6 = 6
1 x 5 = 5
3 x 4 = 12
1 x 2 = 2
1 x 1 = 1
26

Nematoda = 31

1 x 9 = 9
1 x 8 = 8
1 x 6 = 6
1 x 4 = 4
1 x 3 = 3
1 x 1 = 1
31

Gastropoda = 9

1 x 3 = 3
2 x 2 = 4
2 x 1 = 2
9

Ophiurordea = 5

Brachyura = 2

Echinoidea = 1

Polychaeta	=	107
Ostracoda	=	71
Bivalvia	=	70
Sipunculida	=	69
Foraminifera	=	52
Gammarida	=	51
Isopoda	=	32
Scaphopoda	=	32
Nematoda	=	31
Decapoda	=	26
Copepoda	=	19
Tanaidacea	=	11
Cumacea	=	9
Gastropoda	=	9
Ophiurordea	=	5
Brachura	=	2
Echinoidea	=	1

APPENDIX B

BANKS AND TRANSECTS

The banks and related transect information are depicted in Figures B-1 through B-8 and as follows:

Figure	Bank	Cruise	Dives
B-1	Bouma	77-G-10-II	9, 10
B-2	18 Fathom	77-G-10-II	7, 8
B-3	Bright	77-G-10-II	2
B-4	Ewing	77-G-10-I	1, 2, 3
B-5	Parker	77-G-10-II	11, 12
B-6	Sackett	77-G-10-I	4
B-7	East Flower Garden	77-G-10-I, II	1, 5, 9, 10
B-8	Sonnier	77-G-10-II	3, 5, 6

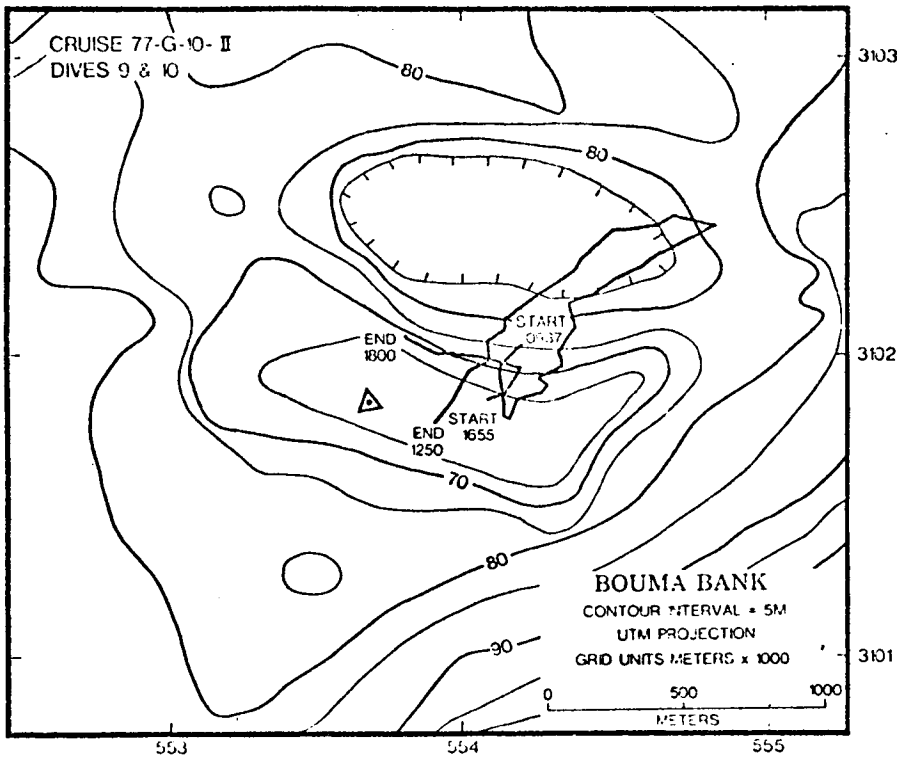

Figure B-1. Bouma Bank with transects.

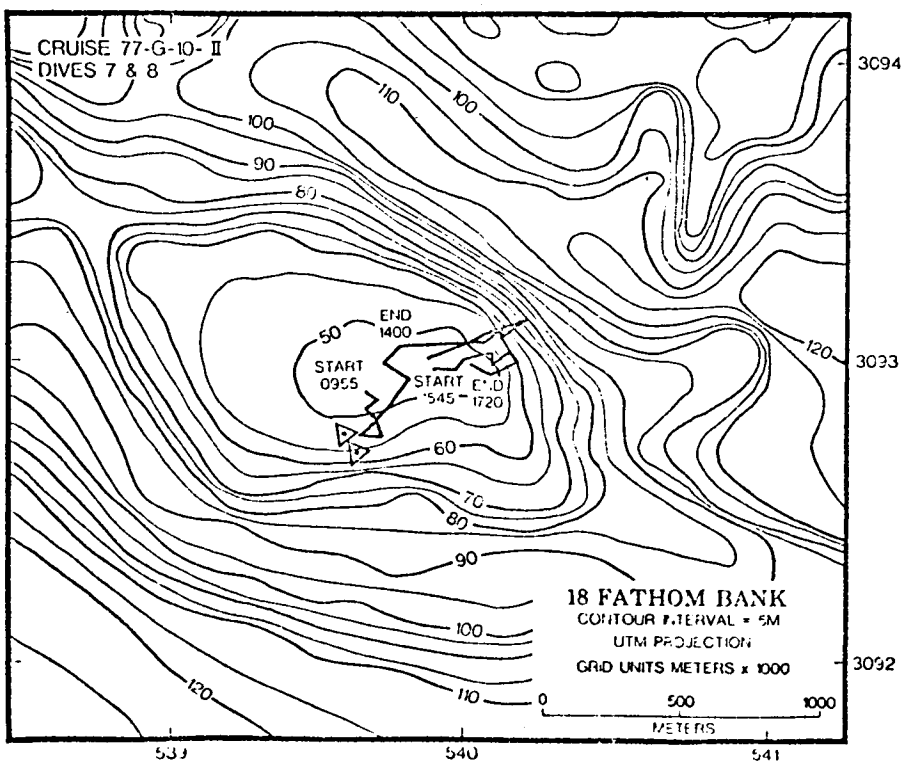

Figure B-2. 18 Fathom Bank with transects.

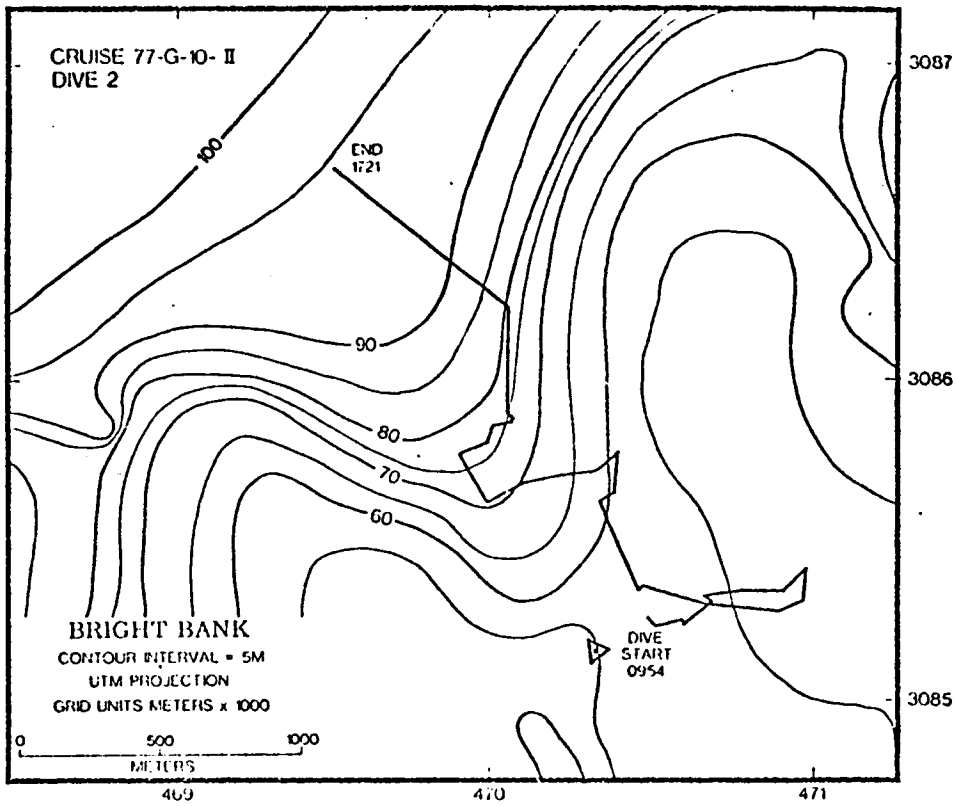

Figure B-3. Bright Bank with transects.

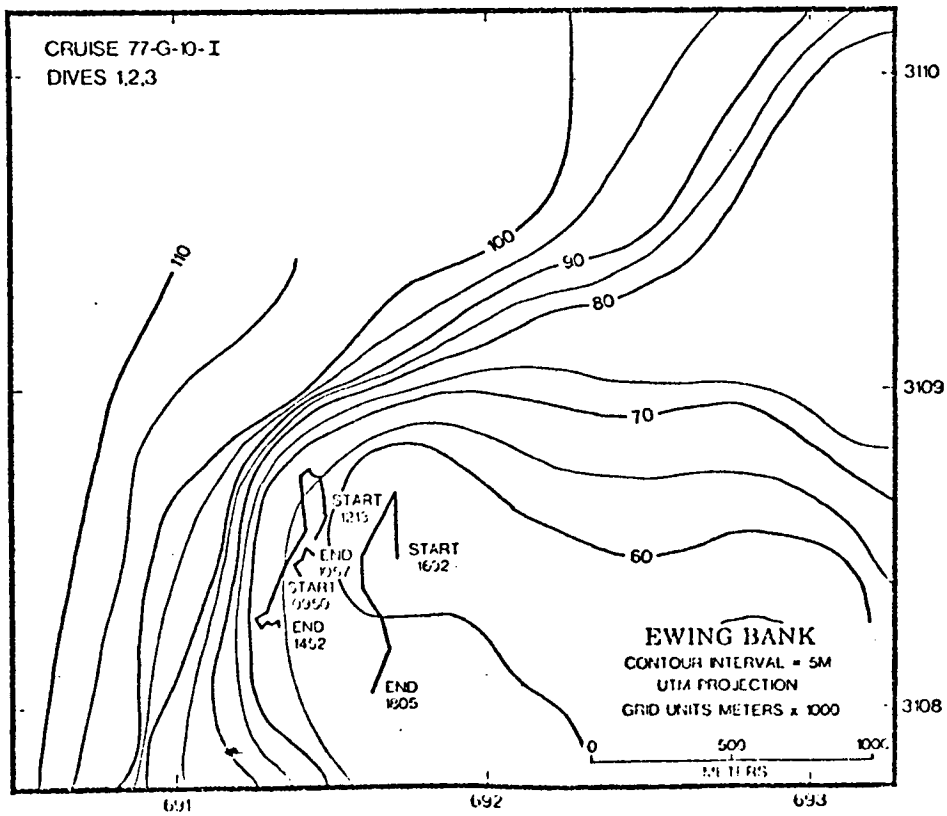

Figure B-4. Ewing Bank with transects.

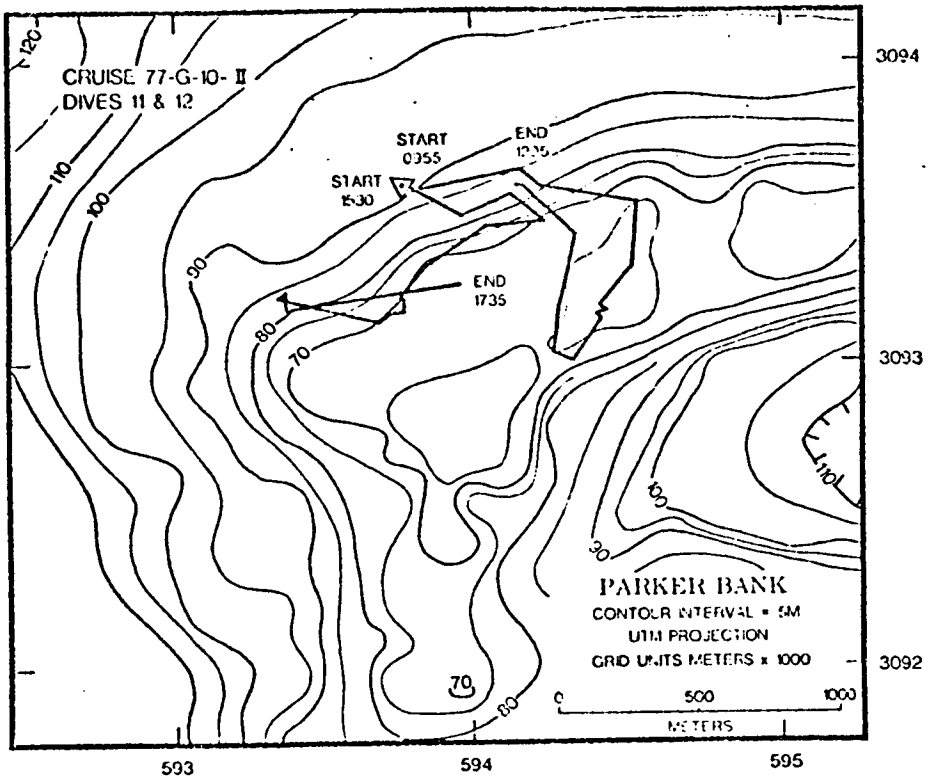

Figure B-5. Parker Bank with transects.

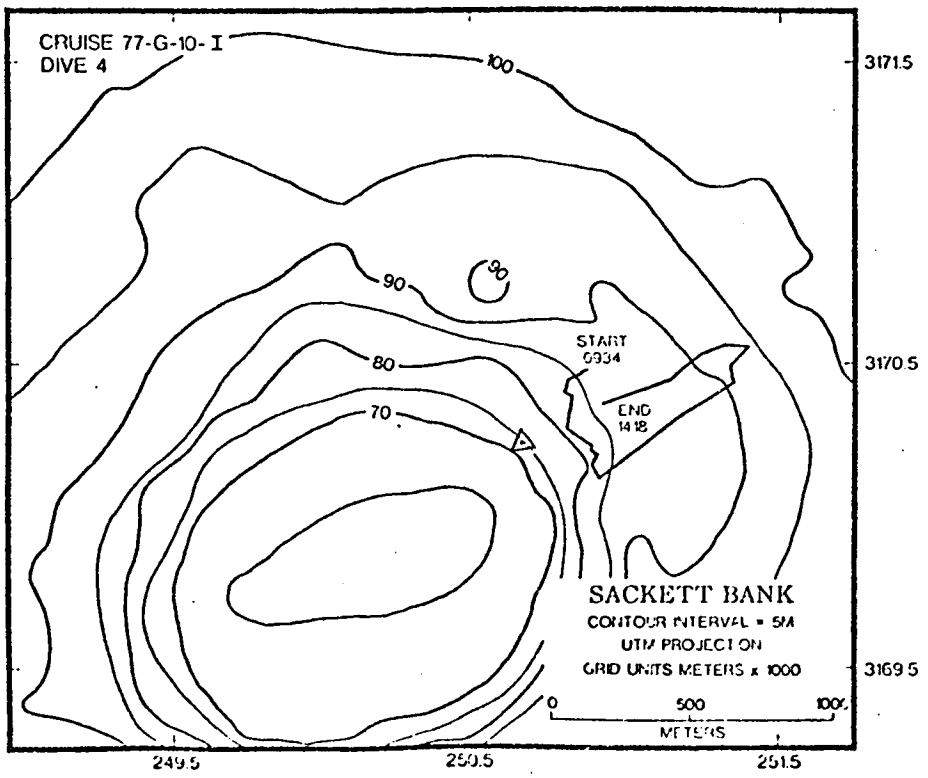

Figure B-6. Sackett Bank with transects.

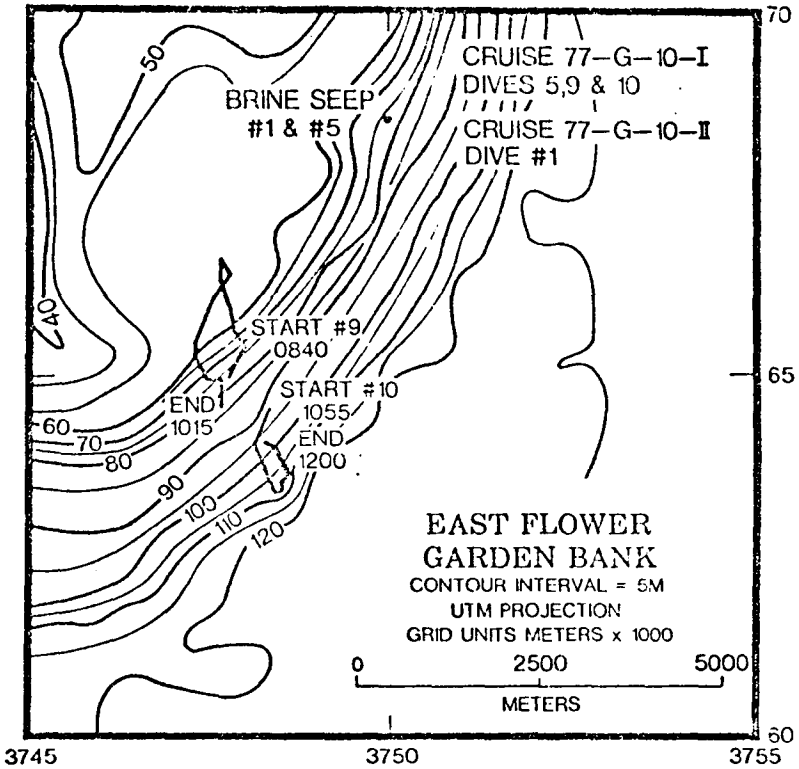

Figure B-7. East Flower Garden Bank with transects.

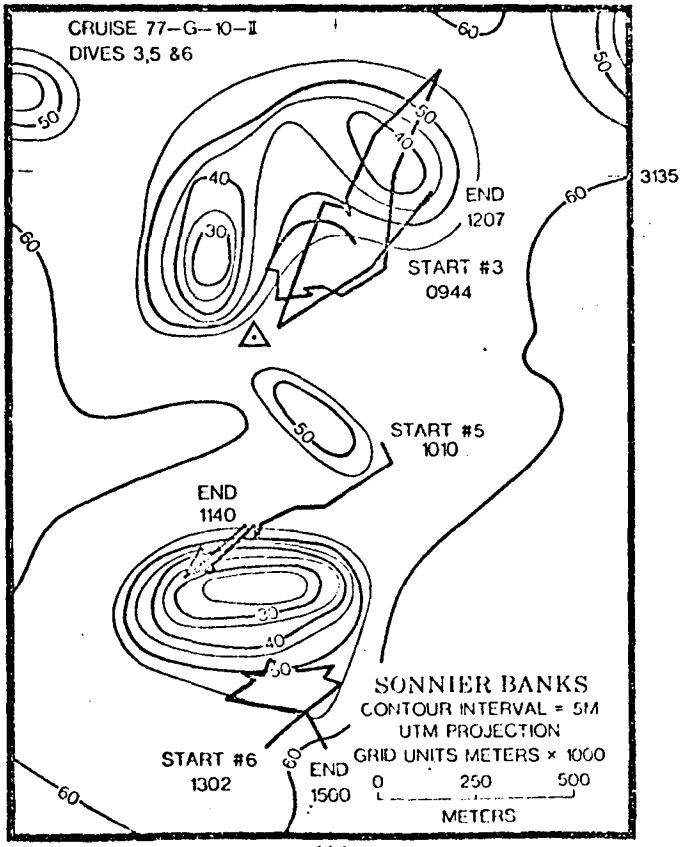

Figure B-8. Sonnier Bank with transects.

APPENDIX C

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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.