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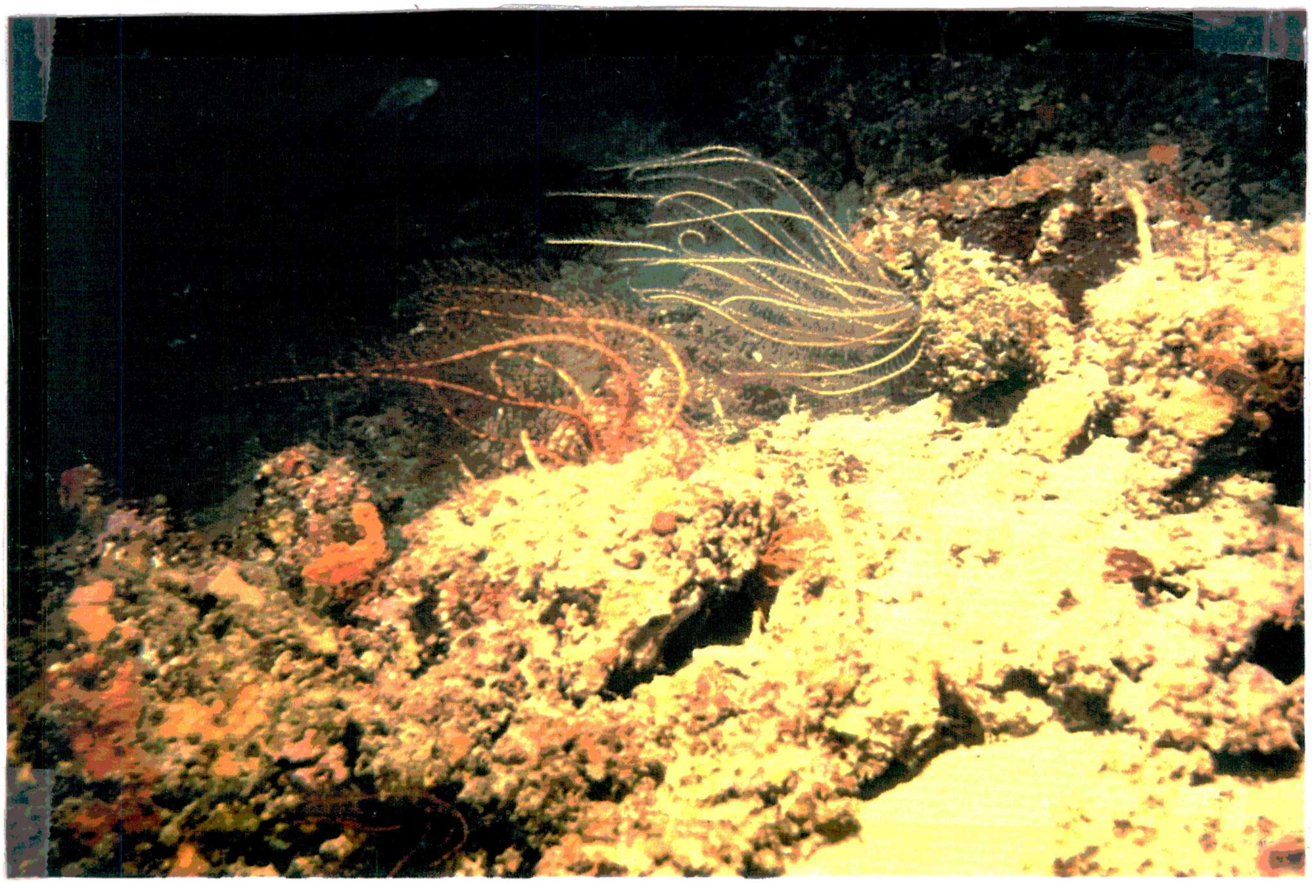
The Flower Gardens: A Compendium of Information



U.S. Department of the Interior
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THE FLOWER GARDENS: A COMPENDIUM OF INFORMATION

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Two associates, Robert Alderdice and David McGrail, were not available to participate in the final review of this document due to untimely deaths. Bob would have contributed much unique data on the history of activities at the Flower Gardens, and Dave would have been able to further his work on the physical oceanography of the banks. Neither of these tasks are complete, but such is not unusual in the research of an important environmental area such as the Flower Garden Banks. This document is dedicated to the memory of these two timeless researchers, Robert Alderdice and David McGrail, who added so much expertise in the knowledge of these sensitive and important features of the Gulf of Mexico.

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SECTION I

HISTORY OF ACTIVITIES AT THE FLOWER GARDEN BANKS

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INTRODUCTION

This document is a product of the Minerals Management Service (MMS). The component of the Service which prepared this document is the former New Orleans Outer Continental Shelf (OCS) Office of the Bureau of Land Management (BLM). On May 10, 1982, a departmental realignment occurred, resulting in the transfer of the New Orleans OCS Office from BLM to MMS.

This document will make reference to both agencies as is appropriate. Generally, reference will be to MMS; reference to studies and/or data generated by contract prior to May 10, 1982, will be to BLM. With this in mind, the reader will better understand the multi-agency references contained herein.

The East and West Flower Garden Banks, some 110 miles south of Galveston, are a unique biological and ecological resource on the OCS of the United States. Rising out of water depths of 100 meters (328 feet) to crest at about 17 meters (55 feet), these two banks harbor the northernmost extension of typically Caribbean coral reefs and their associated plant and animal communities on the Atlantic continental shelf. A good deal of local and national interest is focused on the Flower Gardens. The area is under consideration for designation as a National Marine Sanctuary by the National Oceanographic and Atmospheric Administration (NOAA) of the Department of Commerce. The Gulf of Mexico Fishery Management Council has designated the area a Habitat Area of Particular Concern for the coral reef resources. The Environmental Protection Agency (EPA) requires certain more stringent than usual discharge restrictions on permits granted (exclusively, so far, to the oil and gas industry) under the National Pollution Discharge Elimination System (NPDES) program. Commercial fishermen have fished these and other "snapper banks" for quite some time. Sport SCUBA divers have more recently discovered the bright and beautiful world on the crests of the banks. The environmental community is interested in preserving these unique, relatively pristine areas. Oceanographers, particularly those at Texas A&M University, are interested in studying a coral reefal community at what is the northern extreme of its range in the Gulf of Mexico, and in deeper water than those well-known reefs of the Florida Keys, the Yucatan Peninsula of Mexico, and the reefs of the Caribbean Sea. And, ominously to some, the oil and gas industry has discovered petroleum resources on the flanks of the salt domes which form the geologic base of the banks.

The oil and gas industry began planning for operations in the deep water of the Gulf of Mexico in the early '70s. About that same time, under the provisions of the National Environmental Policy Act of 1969 (NEPA), the Department of the Interior (DOI), responsible for leasing the federal lands of the OCS for oil and gas exploration and development, began writing Environmental Impact Statements (EIS) for such activities and created a studies program to provide data for analyses in the EIS. These studies documented, among other things, a series of banks or topographic features at the edge of the continental shelf (the shelf break). Here, in clear, clean water, reefal communities thrive at water depths appropriate for them. Two of these banks are the East and West Flower Garden Banks.

Concurrently with the initiation of the studies program, measures to protect the reefal communities of the banks were developed and implemented. The implementation device chosen was a stipulation specifying the protective measures. The stipulation became a part of the lease document and thus was binding on the lessee. As more was learned about the banks through the studies program, the stipulation was modified to reflect the best available information, and the provisions of the latest stipulation are applied to appropriate blocks regardless of the actual stipulation (or lack of a stipulation) in the lease.

A. DISCOVERY AND EARLY RESEARCH

Fishermen have longlined at the East and West Flower Garden Banks and other prominences along the shelf break off Texas and Louisiana since the late 1800's. Indeed, snapper fishermen of the turn of the century gave the Flower Gardens their names based on the colors they could see from the surface as well as the colorful plants and animals they often hooked and brought to the surface. However, the first recorded discovery of these banks occurred in 1936 when the U.S. Coast and Geodetic Survey (C&GS), now called the National Ocean Service (NOS) (under NOAA), conducted a hydrographic survey of a large portion of the Gulf of Mexico, mapping the pinnacles with extra survey lines on 1:80,000 scale "smooth sheets". These sheets and the survey records are still held by NOS; this most interesting historical document can be obtained as a routine purchase from NOS in Rockville, Maryland. These data stood as the most detailed survey data on these banks until a chart by Parker and Curray was prepared in 1956 using extra sounding lines from the *Neva J.* during a research survey. Francis Shepard, in 1936, noted 26 banks of interest along the shelf break in the Gulf of Mexico from C&GS data of 1936 and presumed that these pinnacles or banks originated from rising salt plugs. In 1950, Carsey published the first contour map of the East and West Flower Garden Banks and agreed with Shepard on his salt dome hypothesis for origins of the banks.

Stetson, in 1953, first proved the presence of coral at the Flower Gardens. He presumed these banks were bioherms built on top of salt domes showing terraces at 10, 30, and 62 fathom levels representing growth changes during the last major changes of sea level.

In 1956-1957, Parker and Curray presented a generalized map of the Flower Garden Banks, and in 1957 the geophysicist Nettleton conducted bottom gravity surveys of the West Flower Garden Bank. He offered substantial data that the banks were indeed bioherms formed over a salt plug, probably of shallow depth with an overhanging top. Later, work by oil and gas geophysical operations in the 1970's have confirmed Nettleton's work and added considerable detail.

In 1961, Dr. Thomas E. Pulley, Director Emeritus of the Houston Museum of Natural Science, first substantiated that the Flower Gardens were viable, growing coral communities. Appreciation of their great beauty has grown with the use of modern diving and photographic techniques since these banks are the northernmost thriving coral reefs in the Gulf of Mexico. In 1971, Dr. G.S. Edwards published a new map on the "Geology of the West Flower Garden Bank." Robert Alderdice and James Covington had established the Flower Garden Ocean Research Center (FGORC/University of Texas) by then and commenced multi-agency and multi-disciplined research in this area. Through NASA Grant NGT 44-005-114, they developed the concept of a manned platform at the Flower Gardens as the most practical approach to a research station and as a protective surveillance station for these banks. While the FGORC plan was never brought to fruition, the first platform in the area was installed near the East Flower Garden Bank in Block A-389 by Mobil Oil Company on October 5, 1981 (Map No. 1). This platform is somewhat different from that envisioned by Alderdice and Covington. However, its utility as a station for both research and protective surveillance has been realized in cooperation with Mobil.

B. RECENT RESEARCH AND PROTECTIVE ACTIVITIES

The four sections and nine maps included with this report summarize the research activities at the Flower Garden Banks. The authors have joined together recent diverse data and information about the Flower Gardens. Important historical meetings and decisions on protection of the Flower Gardens are recorded here.

The first "multiple use" meeting held by DOI concerning the Flower Garden Banks was convened on November 7, 1973, at the U.S. Geological Survey (USGS) office in Metairie, Louisiana. This meeting was the forerunner to a number of gatherings to design research and lease stipulations to protect the Flower Garden Banks from possible damage due to oil and gas exploration and development activities. At these meetings, the following concepts were agreed to for the Flower Garden Banks: (1) establish protected "no drilling" or "no activity zones"; (2) establish modern positioning and mapping requirements; (3) establish protective buffer zones with shunting and monitoring requirements ("shunting" is placing of all drilling effluents–"muds and cuttings"–to within about 10 meters of the bottom through a large pipe from the drilling rig); and (4) schedule meetings tied to lease sale activities so that new information and concepts of protection could be reviewed for this area in a timely fashion.

In 1974, Drs. Thomas Bright and Linda Pequegnat of Texas A&M University published their book "Biota of the West Flower Garden Bank," the most extensive report on research of any sensitive area in the Gulf of Mexico. This publication contained underwater photographs displaying the great beauty of the coral features. It was prepared in cooperation with the FGORC group and displayed much of the work and findings FGORC had sponsored.

On January 21, 1974, a cooperating group organized by BLM commenced a modern positioning project; FGORC group leader Robert Alderdice and four marine divers, the Coast Guard Vessel *Gentian*, and John Chance and Associates participated. This project established for the first time an accurate position of the Flower Garden Banks, consistent with modern platform positioning in the Gulf of Mexico.

Also in 1974, BLM established stipulation boundary descriptions by the aliquot parts method, based on the 1971 Edwards map for West Flower Garden and the 1956-1957 Parker and Curray map, supplemented by modern geophysical data (at a line spacing of two-by-two miles) from the USGS. These boundaries described the most probable sensitive area of these banks where no drilling activity would be permitted. These first protective stipulation maps were printed in the Final Environmental Impact Statement (FEIS) for OCS Sale 34, in March 1974.

In 1975, DOI again collected additional geophysical data and slightly revised the aliquot part boundaries of the Flower Garden "No Activity Zones." Center points "P" were established for the banks, as well as a 3-mile radius zone beyond the known coral area. These zones are shown on pages 404 and 405 of the FEIS for OCS Sale 41. High resolution lines on a ½-mile survey grid were the basic data used for these boundaries. These boundaries remained unchanged for several years.

In 1975, BLM began a studies contract with Texas A&M University that eventually was extended to investigate and map 38 banks in the Gulf of Mexico including extensive surveys of the Flower Gardens and the Florida Middle Ground. These studies are now known as the "BLM's Topographic Features Studies" and have been administered, for the most part, by Dr. Robert Rogers of MMS. It was public concern over the protection of sensitive areas which resulted in the commencement of the BLM studies program, but the great utility of such studies as the BLM Topographic Features Study allowed the continuation of the program until the careful mapping of these sensitive topographic features was successfully completed and the features were described both biologically and geologically to the extent necessary for DOI to make informed management decisions regarding nearby oil and gas activities.

Significant new data were in hand from the Topographic Features Study by 1977 to be utilized in a DOI meeting on January 27, 1977, whereby new criteria to categorize sensitive biologic areas in the Central and Western Gulf of Mexico utilizing protective lease stipulations were developed. Generally, the 85-meter isobath (in deep water) or a shallower closing isobath (for shallower water) was chosen to define the zone of biologic significance. The following year a Notice to Lessees was published banning the use of halogenated phenol bactericides in drilling muds as a further protective measure in the Gulf of Mexico.

The current status of the stipulation boundaries at the Flower Gardens is depicted on Map No. 1. The stipulation at the Flower Gardens is a modified version of that applied at other sensitive topographic features in the Central and Western Gulf of Mexico; these stipulations may be summarized as follows:

> The general stipulation that has been applied to a number of biologically sensitive banks in the Western and Central Gulf of Mexico has, in all of its versions, consisted of three basic parts:
>
> 1. A "No Activity Zone" on the bank itself in which no oil and gas activities may take place. This provision protects the biota of the bank from mechanical damage due to drilling, platform and pipeline emplacement, and anchors. The studies program has indicated that a water depth of about 85 meters (279 feet) represents, in general, the boundary between reefal communities and the ubiquitous normal Gulf seabottom communities. Thus, the No Activity Zone is generally based on the 85-meter isobath.
>
> 2. A "1-Mile Zone" around the No Activity Zone in which all effluents ("muds and cuttings") from the drilling process must be shunted to near the bottom. It has been shown that shunting these materials will prevent them from getting up on the bank and impinging on the biota of interest, thus saving the biota from smothering by the material as well as from any toxic effects the discarded drilling materials may convey.
>
> 3. A "3-Mile Zone" surrounding the 1-Mile Zone in which either shunting or a monitoring program to assess the effects of not shunting on the biota is required. The premises are that shunting works to protect the biota; that non-shunted material may (or may not) travel over one mile to impact a

> bank; and that if the oil and gas operator does not wish to shunt in that zone, he must monitor the effects of his operations on the sensitive biological communities. It should be noted that the outer boundary of this 3-Mile Zone is at least three miles from the No Activity Zone.

At the Flower Gardens, the stipulation has developed to be more restrictive than that described above since the Flower Gardens are more sensitive and more in the public eye than the other banks. At the Flower Gardens:

1. The No Activity Zone is based on the 100-meter isobath instead of the 85-meter isobath.
2. In the 1-Mile Zone, monitoring of the effects of the operations on the biota of the bank must be performed in addition to shunting.
3. The 3-Mile Zone has been expanded to a "4-Mile Zone" in which shunting must be carried out, but monitoring is not required. The premise, again, is that shunting is known to work.

Since the first efforts by BLM (commenced in the early 1970's), a number of important activities have been accomplished that have aided establishment of protected areas of biologic significance. Accurate positioning of biologic areas or banks was established and accurate boundaries surrounding these areas are now shown on MMS maps. Modern bathymetric maps of 38 banks have been produced. The predictability of biotic zonation from bank to bank in the Central and Western Gulf of Mexico was established along with comparisons of the character, nature, types, and in some cases, health of biologic communities.

The oil and gas industry has contributed a number of stipulation-required monitoring studies of the effects of oil and gas activities on nearby biologically sensitive banks. These studies have documented the effectiveness of shunting near these high relief features. A monitoring study of a non-shunted well near the East Flower Gardens was unable to detect any drilling effluents at a distance of more than about one-half mile from the well site.

The monitoring efforts by industry have supplemented the MMS studies program with important on-site information. Additional information is provided in BLM Open File Report 82-03 (July 1982) on the biologic communities found at petroleum platforms in the northwestern Gulf. These communities are similar in many respects to communities found at some of the natural banks (such as the Flower Gardens). Also, regional geology of the area surrounding the Flower Gardens is provided in MMS Open File Report 82-02, which shows in six maps and additional profiles the regional location of diapirs, faults, stream channels, and other important geologic features that have played a part in the formation of these shelf edge banks.

Additional information regarding the biology of the Gulf in general is given in the Final Regional EIS (FREIS) for the Gulf of Mexico published in January 1983 by MMS. Environmental impact statements updating the information of the FREIS are published by MMS each year for Gulf lease sales.

C. MARINE SANCTUARY STATUS

The Flower Gardens have generated a good deal of interest and concern among a number of other agencies and groups. The area was nominated by several groups for designation as a National Marine Sanctuary. The Marine (and Estuarine) Sanctuary Program is administered by the Sanctuaries Programs Division, in the Office of Ocean and Coastal Resource Management, in NOS, in NOAA, all a part of the U.S. Department of Commerce.

On April 13, 1979, NOAA published proposed regulations (44 FR 22081) and a Draft EIS (DEIS) on the proposed designation of the East and West Flower Garden Banks as a national marine sanctuary. To bring the sanctuary proposal into line with the then revised program regulations, NOAA placed the Flower Garden Banks on the List of Active Candidates on October 31, 1979 (44 FR 62552).

Due to public comments on the DEIS and input from Cooperating Agencies (DOI, EPA, and the Department of Energy), in accordance with the Council on Environmental Quality regulations (40 CFR 1501.6), NOAA revised the original proposed regulations and reproposed them on June 30, 1980 (45 FR 33530). Previous restrictions on hydrocarbon operations were revised to conform with MMS lease stipulations. As a result of public comments on the reproposed regulations, further action on the site was suspended in late 1980. A Final EIS was not prepared.

On April 26, 1982 (47 FR 17845), NOAA announced its decision to remove the site from the List of Active Candidates and to withdraw the DEIS. One of the major reasons for this action was that a Coral Fishery Management Plan (FMP) for the Gulf of Mexico was about to be implemented. It was expected that the FMP would regulate vessel anchoring on the Banks, the one remaining unresolved issue identified in the DEIS and through public comment. The final FMP was approved, but it did not include the "no anchoring" provision for vessels on the Banks. Within the East and West Flower Garden Banks Habitat Area of Particular Concern (the area of each Bank shallower than the 50-fathom [300-foot] isobath), the proposed regulations provided only the following restrictions: (1) fishing for coral would be prohibited except as authorized by permit; and (2) bottom longlines traps, pots, and bottom trawls could not be fished.

Because anchoring was not specifically prohibited at the Flower Gardens in the FMP, the need for the special protection of a sanctuary was once again recognized, and the Banks wer placed on the Site Evaluation List (SEL) under NOAA's revised procedures on August 4, 1983 (48 FR 35568).

The notice initiating preliminary consultation on Flower Garden Banks as an Active Candidate for possible National Marine Sanctuary designation was published in the *Federal Register* on May 4, 1984 (49 FR 19094). A press release was also sent out to all relevant media contacts. Comments were solicited until June 4, 1984.

Forty-one comments were received. All commentors except one supported listing the Flower Garden Banks as an Active Candidate. On August 2, 1984, the Banks were named an Active Candidate for designation as a National Marine Sanctuary (49 FR 30988-30991).

This procedure takes place under the auspices of Title III of the Marine Protection, Research and Sanctuaries Act of 1972, 16 U.S.C. 1431-1434, which authorized the Secretary of Commerce to designate ocean waters as national marine sanctuaries to protect their distinctive conservation, recreational, ecological, or esthetic values. The revised final regulations for the National Marine Sanctuary Program (48 FR 24296 [1983], 15 CFR 922) establish two procedural evaluation status prior to a site being designated as a national marine sanctuary: the Site Evaluation List and the List of Active Candidates. The SEL represents NOAA's preliminary working list, serving as a pool from which sites are drawn for consideration as a national marine sanctuary. Each site on the SEL has been identified as a highly qualified marine area by a regional resource evaluation team.

The Gulf of Mexico Regional Resource Evaluation Team consisted of: Dr. Thomas Bright, Department of Oceanography, Texas A&M University, College Station, Texas; Dr. William McIntire, Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana; Dr. David Gettleson, Continental Shelf Associates, Tequesta, Florida; and Dr. James Ray, Shell Oil Company, Houston, Texas.

Selection of the Flower Gardens as an Active Candidate formally triggers the NEPA environment impact analysis process and NOAA begins preparation of a draft management plan and DEIS. Subsequent steps include a public hearing, preparation of a FEIS, and a recommendation of approval to the Secretary of Commerce and the President. Opportunities for comment exist throughout this process and will be announced in the *Federal Register,* the local media, and other appropriate channels.

In evaluating the Flower Garden Banks for Active Candidate consideration, the following five factors will be considered:

1. A primary reason for considering a site for marine sanctuary designation is the area's high natural resource and human use values. When selecting an active candidate, NOAA considers the site's relative contribution to the program's mission and goals;
2. A consideration of the immediacy of need for sanctuary designation based on the present or potential threats to resources, and the vulnerability of the resources. Consideration will also be given to the cumulative effect of various human activities that individually may be insignificant;

3. An evaluation of the benefits to be derived from sanctuary designation, including an assessment of the site's natural resource and human use values, the adequacy of existing management or regulatory regimes for protecting these resources, and the effectiveness of NOAA's proposed management program;
4. A consideration of the present feasibility of sanctuary designation in light of the sanctuary's size, requirements for managing the site, program staffing, and fiscal constraints; and
5. An initial consideration of the economic impacts and benefits of sanctuary designation, including a consideration of the range of public and private uses which may be consistent with sanctuary designation.

This process is a lengthy one, but it may come to pass that a Flower Gardens National Marine Sanctuary will be designated in the 1980's.

In the interim an important protective action was announced by Jack Brawner, Regional Director, Southeast Region, National Marine Fisheries Service (NMFS); on August 22, 1984, the aforementioned Coral FMP became effective and the NMFS regulations pursuant to the FMP prohibited the taking of coral in the U.S. Fisheries Conservation Zone without a NMFS permit; violators could be subject to up to $25,000 in penalties for each offense. These regulations also establish Habitat Areas of Particular Concern (HAPC) for corals that are currently or potentially threatened. These areas include the West and East Flower Garden Banks off Texas; the Florida Middle Ground off Florida's west coast; and the Oculina Coral Bank off Florida's east coast. Fishing with longlines, fish traps or pots, and bottom trawls in these HAPC's is prohibited. The implementation of these regulations apparently had an immediate protective effect in that a treasure hunter who reportedly was blasting coral at Bright Bank in search of an alleged 300-year old Spanish galleon moved out of the area about that time and apparently ceased such destructive operations.

Another protective action has been proposed recently by MMS to NMFS on behalf of the Gulf of Mexico OCS Regional Technical Working Group. In an October 2, 1984, letter to NMFS, Southeast Region, MMS proposed that NMFS "Investigate the possibility of having coral areas indicated on the appropraite nautical charts with a "Note" or an "Advisory" or even a "Warning" to mariners not to anchor or otherwise damage coral in these areas. We have already suggested this to Mr. Don Moore of your Galveston office for the Flower Gardens. Perhaps with the authority of the Coral FMP in place the National Ocean Service could be persuaded to make such notations. We will be pleased to help identify and define such areas." This proposed note on nautical charts would make mariners aware that these are sensitive areas, that corals in the Gulf of Mexico are under Federal protection, and that these areas could be seriously damaged by anchors. The expectation is that few ship captains would use these areas for anchoring except in cases of emergency and that all mariners would be interested in assisting in the protection of these coral banks.

MMS studies, together with those funded by industry, as well as those conducted by other Federal agencies, will continue to allow inspection and protection of these biologically sensitive areas. Results of such studies have allowed DOI to proceed with leasing and the permitting of wells, platforms, and pipelines in one of the world's largest offshore oil and gas fields. This program established workable investigative methods that can be useful in other areas of expanding offshore oil and gas operations. The ability to characterize sensitive environments, design protective measures, monitor operations near these areas, and continue to observe environmental changes at sensitive areas gives an extra measure of assurance that mitigation of impacts from oil and gas activities can be accomplished with success at the Flower Garden Banks.

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SECTION II

GEOLOGIC STRUCTURE OF THE EAST AND WEST FLOWER GARDEN BANKS AREA

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INTRODUCTION

The East and West Flower Garden Banks (EFG and WFG) are located at coordinates 27°54'N, 93°35'W and 27°53'N, 93°49'W near the outer edge of the continental shelf off the Texas-Louisiana coast (Figure II-1). The Flower Gardens are the two largest of more than 130 calcareous banks in the northwest Gulf of Mexico that form topographic elevations on the otherwise generally smooth continental shelf (Parker and Curray, 1956, p. 2428).

Geophysical data from four sources were used in the study, of which approximately 570 km of high resolution seismic profiles were collected during two surveys conducted for the U.S. Geological Survey (USGS) Office of Marine Geology, Corpus Christi, Texas (Figure II-2). An additional 271 km of similar data were provided by the Conservation Division of USGS, Metairie, Louisiana (now Minerals Management Service (MMS)). The Conservation Division data cover six lease blocks on WFG, four on EFG, and one block in an area of extensive drowned patch reefs (Figure II-2), with a track line spacing of about 0.8 km by 2.4 km. These three surveys included both sparker and 3.5 kHz seismic systems operated simultaneously. Texas A&M University, Department of Oceanography, provided nearly 469 km of both uniboom and 3.5 kHz records over WFG and 205 km of uniboom records over EFG, spaced approximately at 300 m intervals. In summary, 2,825 km of high resolution seismic profiles were used in preparing information for Map Nos. 2, 4, and 5 discussed in this section. Integration of data from the four overlapping surveys was complicated by inconsistencies in location of some data points and the uneven quality of some seismic records.

A. BATHYMETRY AND FAULTS INTERSECTING THE SEAFLOOR

Water depths range from less than 20 m at the crest of EFG to over 270 m southwest of WFG. The bathymetric contours, drawn at ten-meter intervals, are based on seismic data and on large-scale (1:12,000) topographic maps of East and West Flower Garden Banks provided by Texas A&M University. Faults shown on the bathymetry map (Map No. 5) are those that intersect the seafloor; faults covered by younger sediments are shown on the map for geologic structures (Map No. 4).

The topography of both Flower Gardens is essentially fault-controlled. EFG rises 80 m above a wide, flat plain lying at a depth of 100 m. The dimensions of EFG are 6.5 km east to west and 9.7 km north to south. The bank is asymmetrical, with greatest relief along the southeastern flank, where water depth increases from 50-130 m over a distance of 1 km.

WFG, approximately 10 nmi to the west, is larger (about 8 km east to west and 13 km northeast to southwest), rising from slightly deeper water (100-110 m) to the summit at 24 m. The steeply dipping surface just south of WFG marks the beginning of the continental slope at approximately the 150 m contour.

The 110-130 m contours on the western side of WFG and the eastern side of EFG reveal well-developed moats, or peripheral seafloor depressions, that are common features around submarine banks on the continental shelf (Figure II-3). The moats are shallow topographic features apparently unrelated to peripheral sinks or rim synclines usually found in proximity to diapirs in the Gulf region (Halbouty, 1967, p. 39). Comparison of the bathymetry map (Map No. 5) and the geologic structures map (Map No. 4) shows that the moats do not coincide with synclinal axes adjacent to the Flower Gardens. These moat-like features appear to be the result of bottom currents scouring the sediments as they are deflected around the steep sides of the banks. On the south Texas outer continental shelf, carbonate banks and reefs that are not associated with diapiric uplifts have similar well-defined moats. The moats surrounding the reefs off south Texas were cored and found to contain lag deposits of mica and coarse reef rubble apparently winnowed by the movement of bottom currents (Berryhill, 1977, pp. 167-229).

B. GEOLOGIC STRUCTURES

Both diapirism and faulting are active processes in the Flower Gardens area. A comparison of faults intersecting the seafloor with those that terminate below it shows that most faults continue to be active; post-Wiscon-

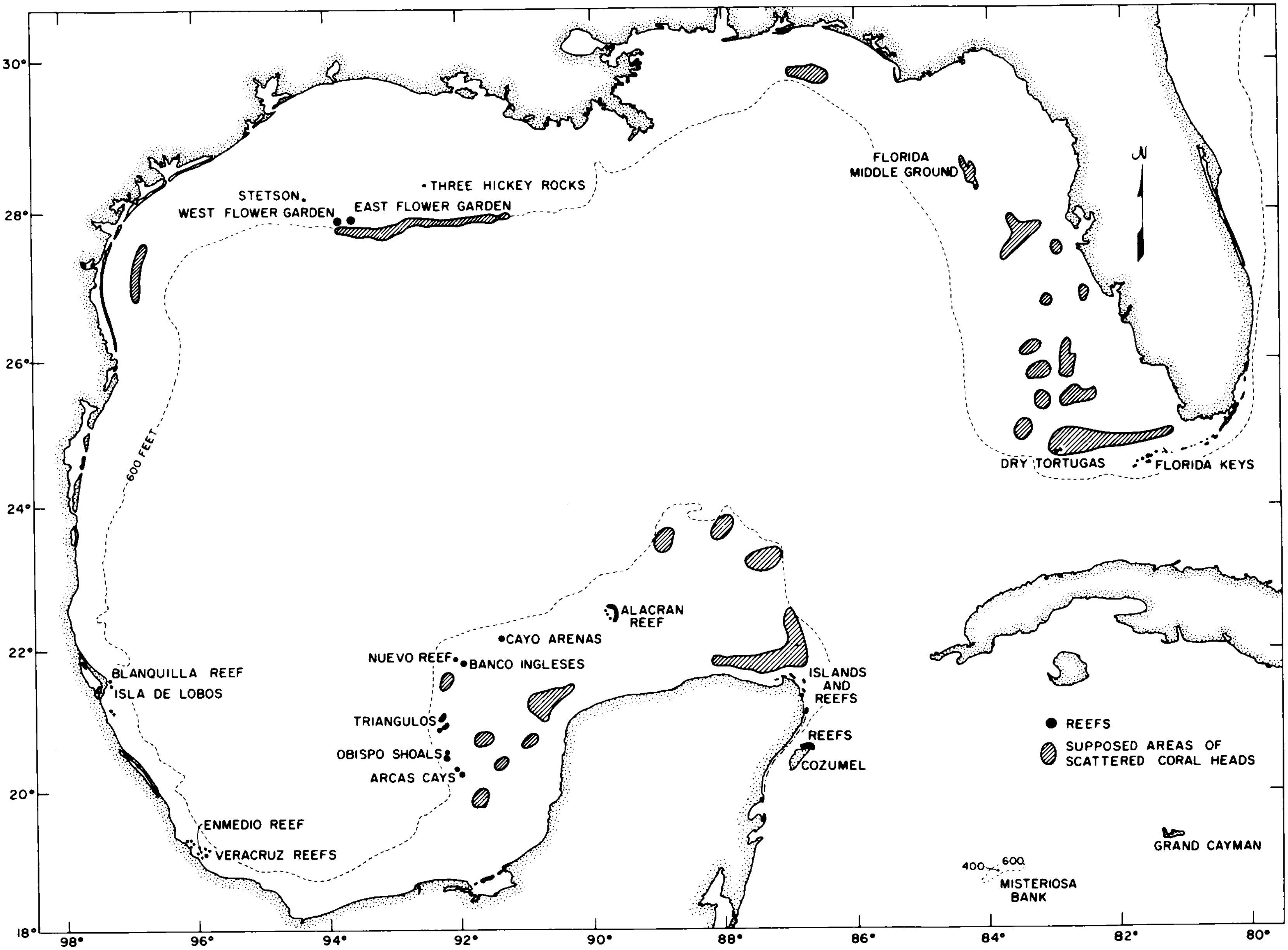

Figure II-1. Location of known coral reefs and zones of limited coral growth within the Gulf of Mexico. (After Jordan, 1952; Logan, 1969; Smith, 1976; and others).

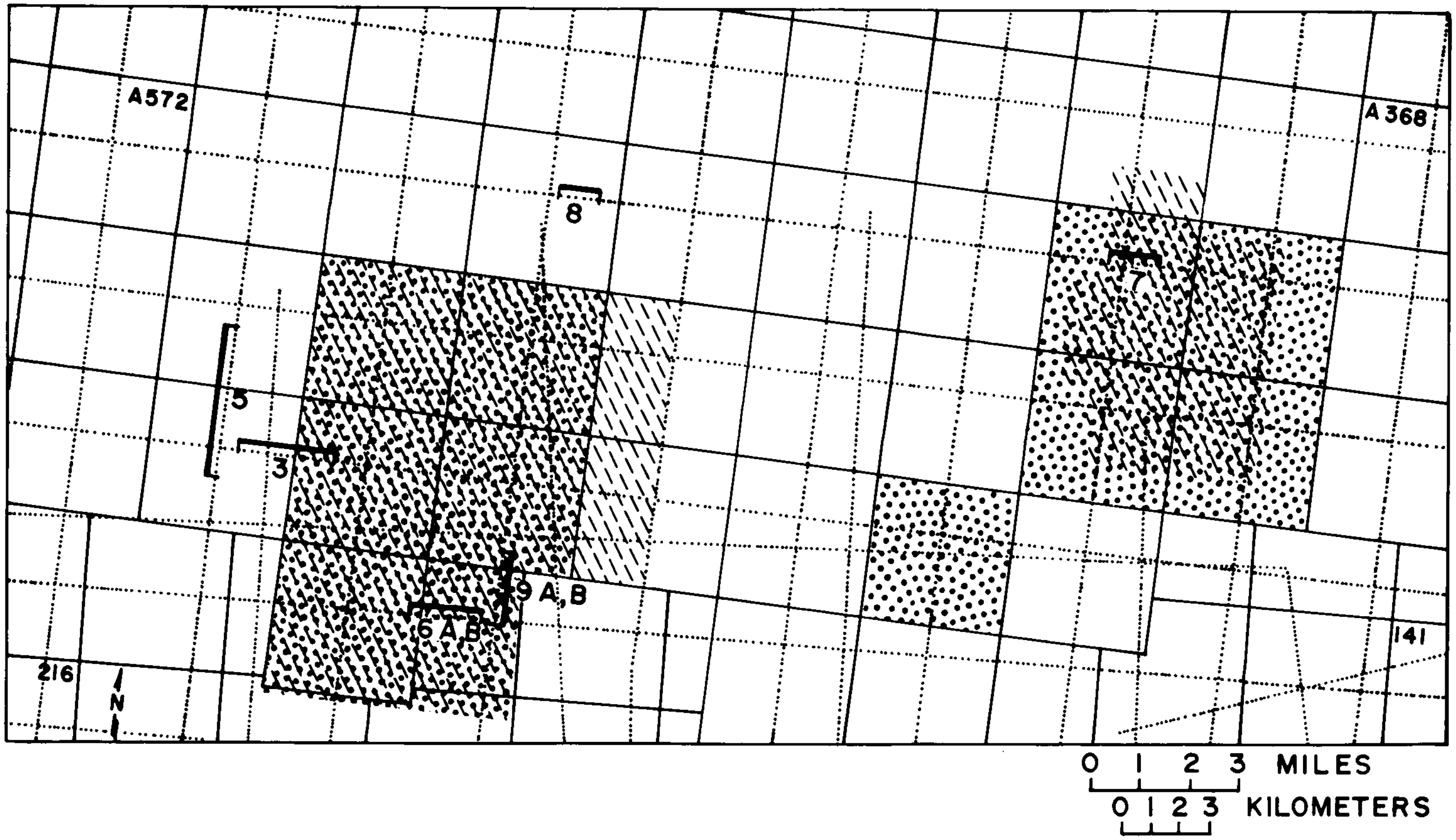

Figure II-2. Locations of seismic profiles. Dotted lines indicate lease block grid. Heavy lines are U.S. Geological Survey records. Slanted lines indicate area of Conservation Division coverage. Stipple pattern represents area of Texas A&M University, Department of Oceanography profiles.

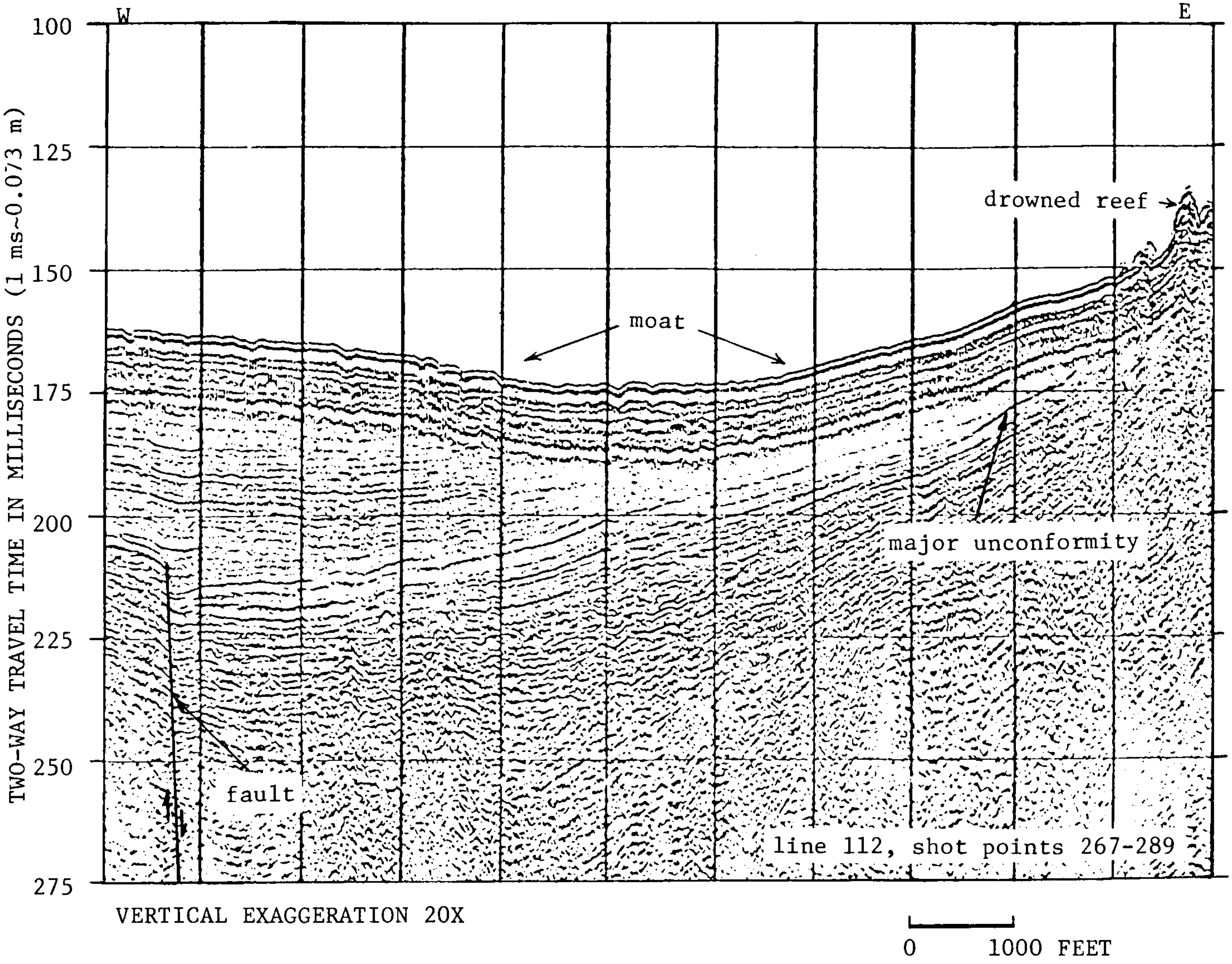

Figure II-3. Minisparker record showing moat west of West Flower Garden Bank. Location shown by Figure II-2.

sin sediments within the area are offset by faulting (Figure II-4). Diapiric uplift seems to be characterized by periods of gradual salt movement alternating with periods of quiescence (Halbouty, 1967, pp. 32-33); therefore, lack of present observable activity is not a reliable indicator of future inactivity. Evidence of regional diapiric movement and active faulting indicates the Flower Garden diapirs are tectonically active.

Faulting around the Flower Gardens appears to be the result of a combination of diapirism and sediment loading. Diapiric uplift of the seafloor controlled the drainage pattern across the exposed land surface during low stands of sea level, channeling sediment-laden streams into interdiapiric basins, which in turn subsided further at least partly in response to the weight of sediment overburden.

Faulting on EFG is concentric to the diapiric core, for the most part, although several large tangential faults trending northwest-southeast are present northeast and southwest of the bank. Some radial faults lie along the east side and on the southwestern edge of WFG; however, most faults on this bank trend northeast-southwest, paralleling the axis of the diapiric core. Faults that may have been caused by sediment loading are shown on the sediment thickness map (Map No. 2).

Surficial slumping of sediments has occurred west of WFG in an area where sediments were deposited by a large river system that crossed the shelf during a low stand of sea level. Diapirs deflected the streams to the west just north of WFG, and the east-west trending extension of the diapiric core acted as a dam. Sediments thickened against it; local slumping has given the seafloor a rumpled, hummocky appearance (Figure II-5). Other less extensive areas of surficial slumping are where sediments are sliding down the sides of diapirs southwest of WFG (Block 173) and in the south-central part of the map (Block A-402).

The dashed contour lines on the map represent the surface of chaotic sediments deformed by salt movement (Figure II-5). The salt source for the diapirs is estimated to be at least 10-12 km below the seafloor (Martin, 1978), but the depth of penetration of the high resolution seismic records is only about 300 m below the seafloor. Diapiric salt has reached the near surface in the profiles shown on Figures II-6 and II-7. The pinnacle of rock bounded by faults has been pushed upward by rising salt.

EFG is underlain by an asymmetrical diapiric core that has caused steepening of the southern and eastern flanks accompanied by concentric faulting. Salt is close to the seafloor surface near the southeastern edge, where a brine seep was observed from the Texas A&M submersible Diaphus (Bright and Rezak, 1976).

WFG is topped by three crests separated by grabens (Map No. 5). Graben fault systems are common on the crests of salt domes and usually aligned parallel to the long axis of the structure, as on WFG (Halbouty, 1967, pp. 66-68).

The synclinal depressions associated with East and West Flower Garden Banks probably were formed by the withdrawal of salt at depth to feed the central core, a process augmented by sediment loading in the interdiapiric basins. Similar rim synclines caused by salt withdrawal have been noted by Halbouty (1967, pp. 27-40). The anticlinal axes between diapirs probably indicate salt ridges buried beyond the penetration range of the high resolution seismic system.

Gas seeping into the water column and mud vents or mud volcanoes caused by gas escaping from the seafloor were mapped where identified on seismic records (Figures II-6 and II-8). Published locations also were plotted (Bright and Rezak, 1976, Figures 46-A, B, and C). Gas seeps on the Flower Gardens are intermittent according to Bright and Rezak (1976, pp. 334-335); consequently, a seismic profile may not record all active gas seeps.

C. THICKNESS OF SEDIMENTS ABOVE YOUNGEST MAJOR UNCONFORMITY AND DISTRIBUTION OF REEFS

The youngest unconformity in the Flower Garden area probably represents the base of sediments deposited since the last low stand of sea level (Berryhill et al., 1982). The post-Wisconsin sediments are limited in areal extent and vary in thickness up to 20 m (Figures II-3 and II-9). The unconformity is actually a disconformity in many places because the base represents a change in the magnitude of deposition and direction of transport rather than erosion.

A second, deeper unconformity pinches out around the flanks of both Flower Gardens (zero contour line). The strong reflective character of this surface, the angularity of bedding planes beneath it, and the conformable, largely parallel bedding of the sediments above it are indicators of an ancient land surface that has been weathered, eroded, and subsequently covered by younger sediments (Figures II-10 and II-11). The distinctive angularity of bedding planes beneath this unconformity implies tectonic activity (probably salt diapirism) that caused a marked change in topography at that time.

Prograded foreset bedding is apparent in the sediments above the unconformity north and west of WFG, indicating deltaic sediments deposited by an extensive river system when most of the area was near sea level (Figure II-5). Sediments eroded from the diapirs contributed to deposition, and the unconformity was ultimately buried by as much as 110 m of sediment in the interdiapiric basins.

Living reefs usually exist to a depth of 46 m on EFG, however, healthy, living reefs have been encountered as deep as 55 m (Bright and Rezak, 1976). The 46 and 55 m bathymetric contours have been shown on both banks to indicate the extent of probable living coral reefs (Map No. 5). Although deep reefs are numerous on other parts of East and West Flower Garden Banks, they are drowned remnants of reefs that grew during a period of lower sea level. Extensive areas of drowned reefs up to 22 m thick have been documented on both banks (Bright and Rezak, 1976; Rezak and Bryant, 1973). Many of the drowned reefs grew initially on the ancient surface now represented by the prominent unconformity (Figures II-6, II-7, II-10, and II-11). In the area southwest of EFG, several small diapiric fingers apparently raised the seafloor sufficiently to enable most ancient reefs to survive some localized deposition; however, they could not grow fast enough to escape drowning by rising sea level.

A large number of reefs buried under younger sediments are located on the lower flanks of the Flower Gardens and in the area in between (Figures II-10 and II-11). Most of the buried reefs grew on the ancient erosional surface at a time when it was covered by warm, shallow water.

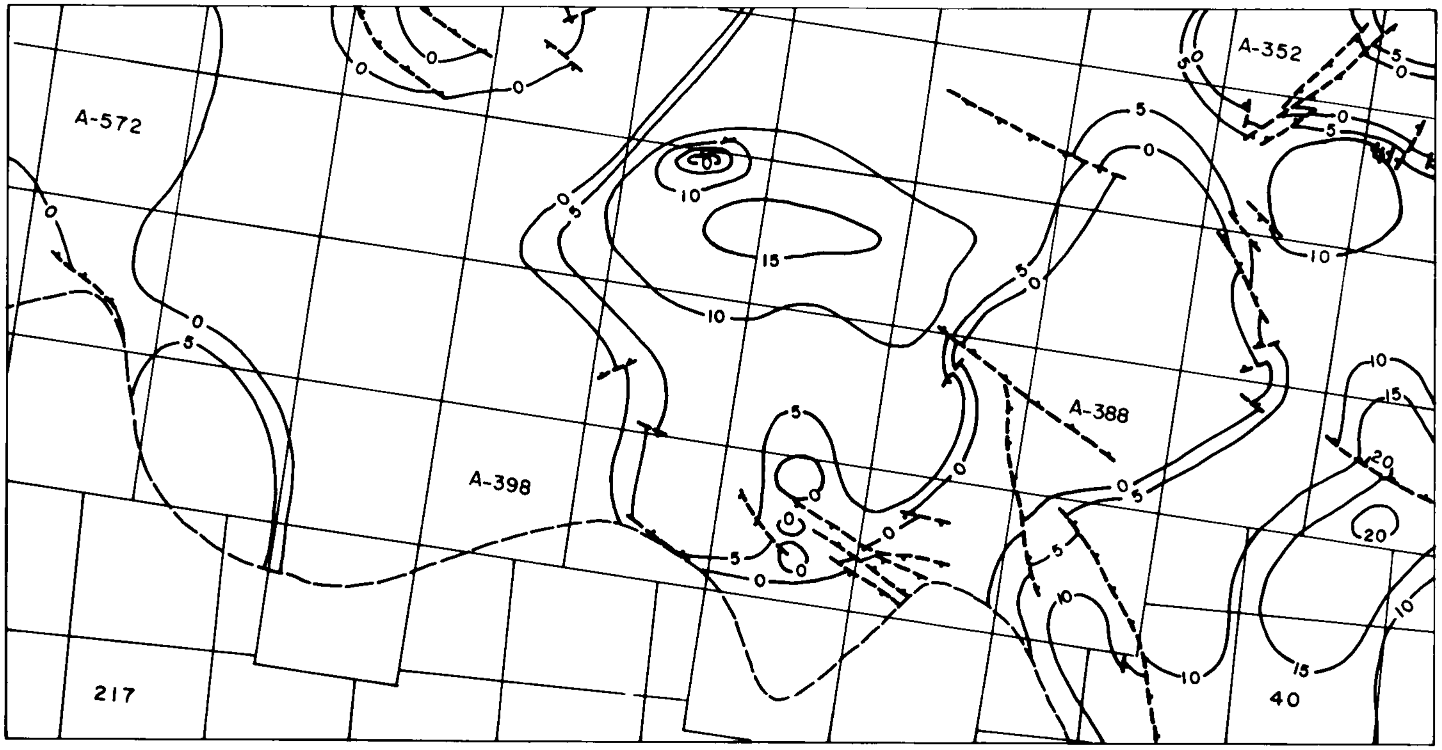

Figure II-4. Thickness of post-Wisconsinan sediments (in meters). Only those faults are shown that seem to have influenced the depositional pattern. Dashed line indicates limit of interpretation. Block A-398 is at West Flower Garden Bank and Block A-388 is a East Flower Garden Bank in High Island Area, East Addition, South Extension. Scale 1:250,000. (After Berryhill et al., 1982).

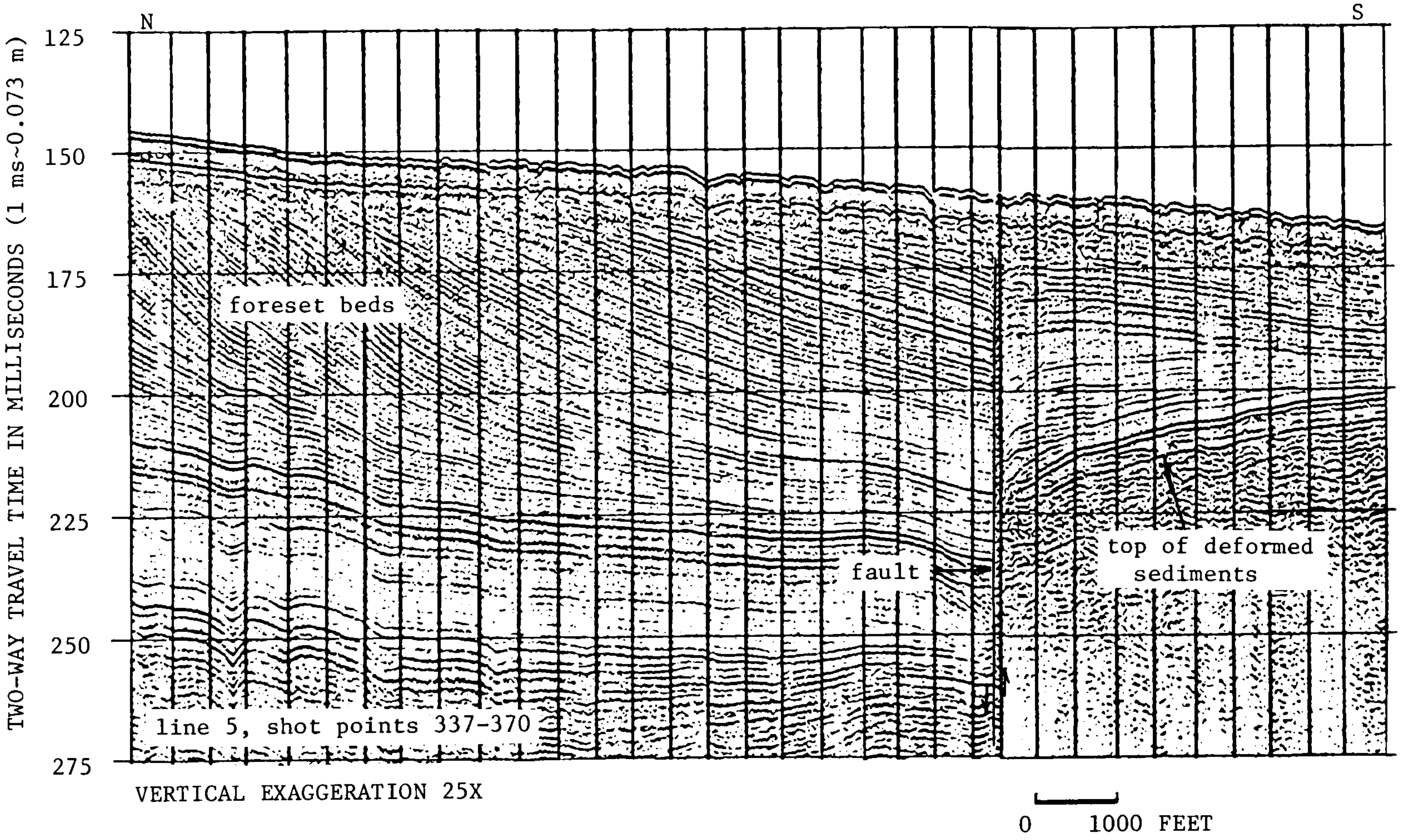

Figure II-5. Minisparker record showing foreset bedding on the left, indicating deposition by streams draining across the shelf. Hummocky appearance of the seafloor is caused by sediments that thicken against the toe of the West Flower Garden Bank diapir. Location shown by Figure II-2.

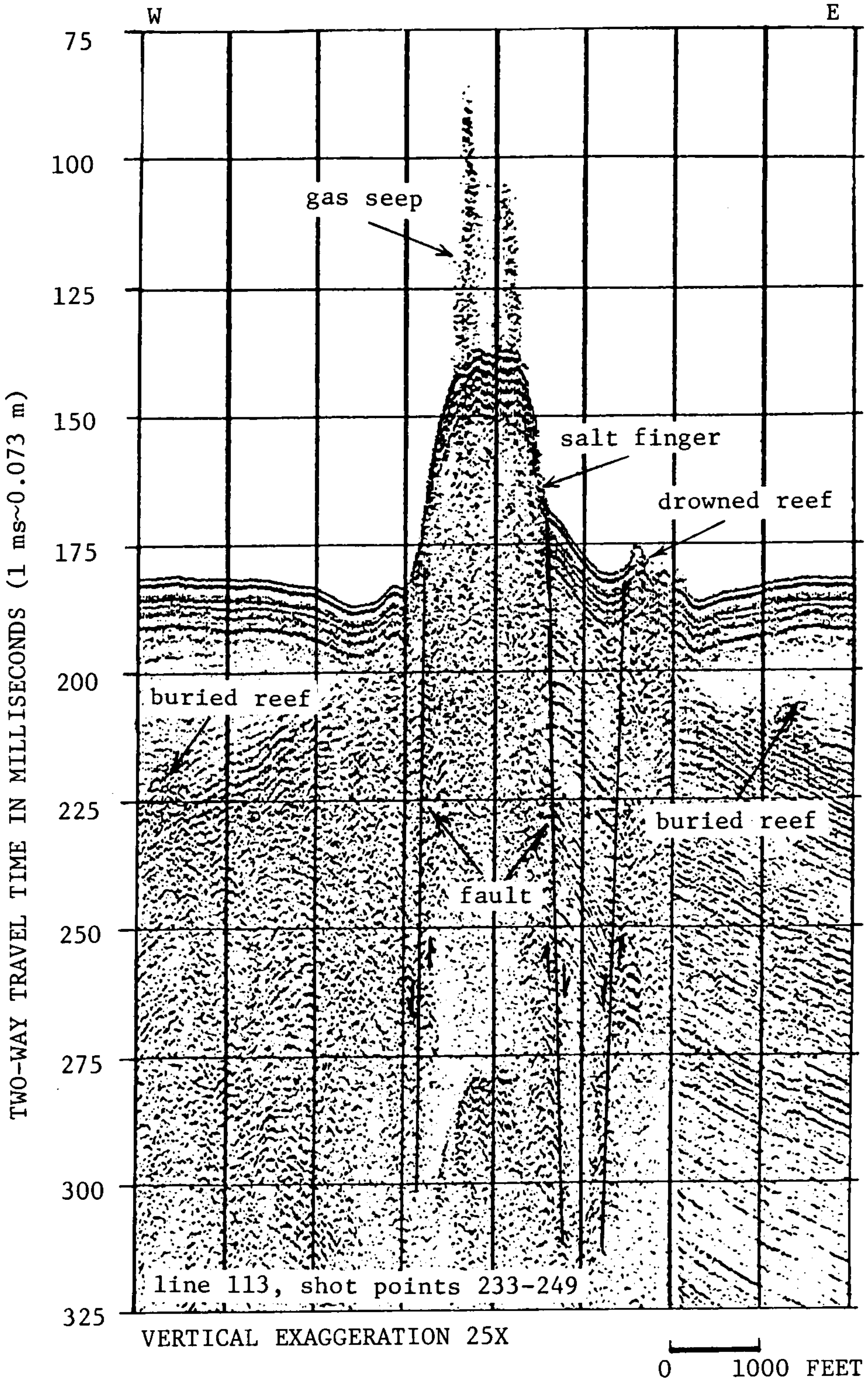

Figure II-6. Minisparker record showing pinnacle of rock on crest of diapiric uplift pushed upward by rising salt below. Gas is escaping into the water column above the pinnacle. Several buried reefs are visible on an unconformable surface. Location shown by Figure II-2.

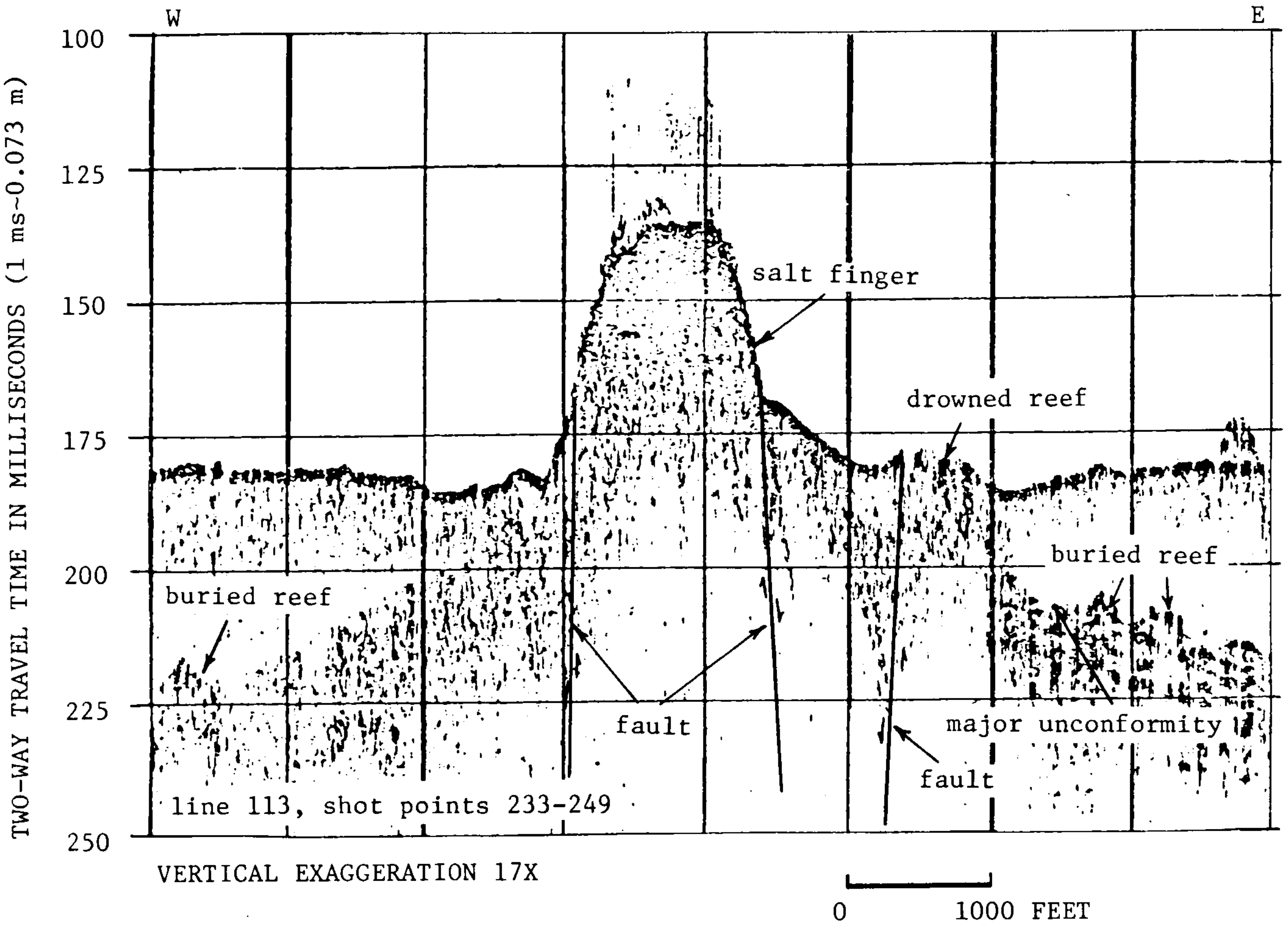

Figure II-7. Section of 3.5 kHz record covering the same area as Figure II-6. Buried reefs are seen in greater detail than on the minisparker record. Location shown by Figure II-2.

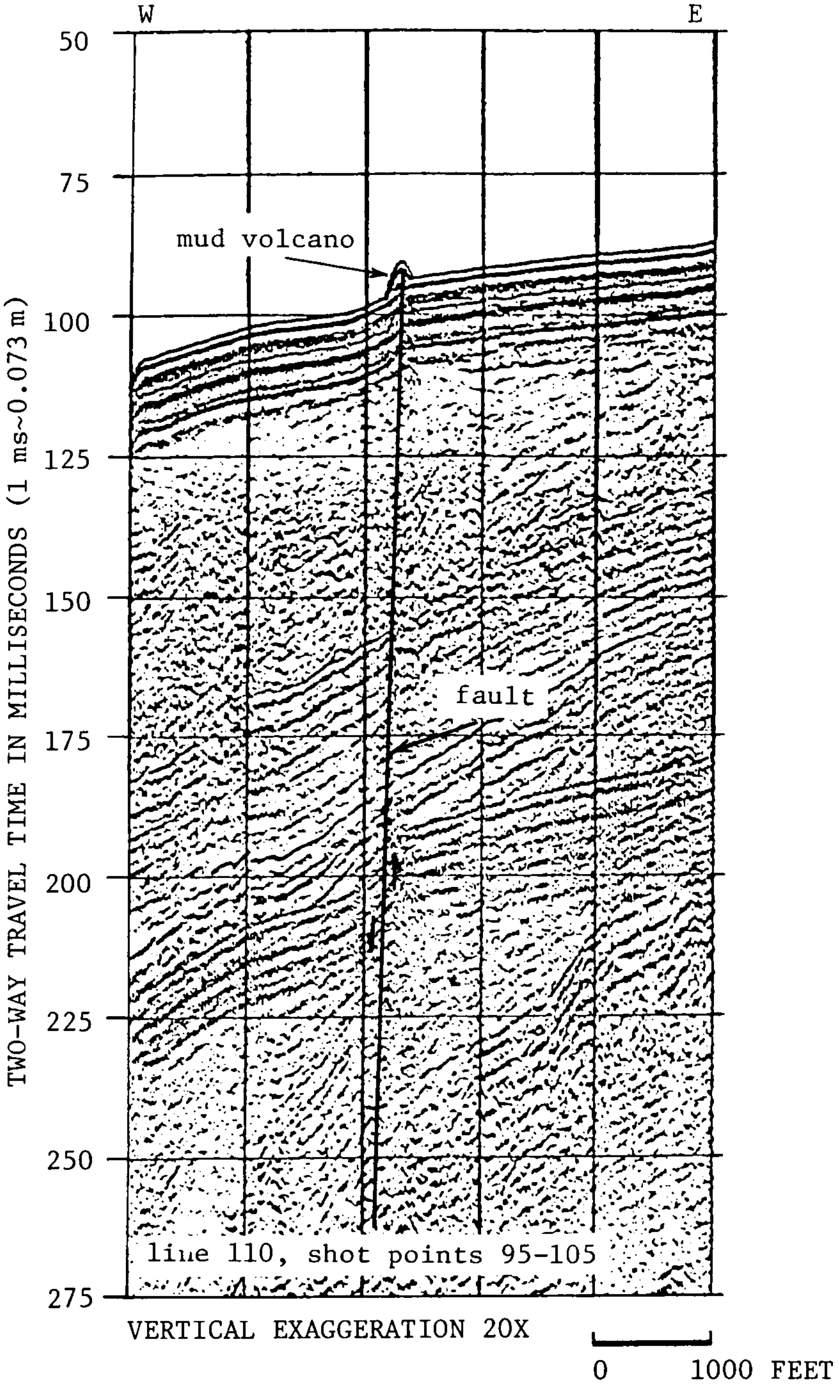

Figure II-8. Minisparker record showing mud vent or mud volcano caused by gas escaping from the seafloor. Location shown by Figure II-2.

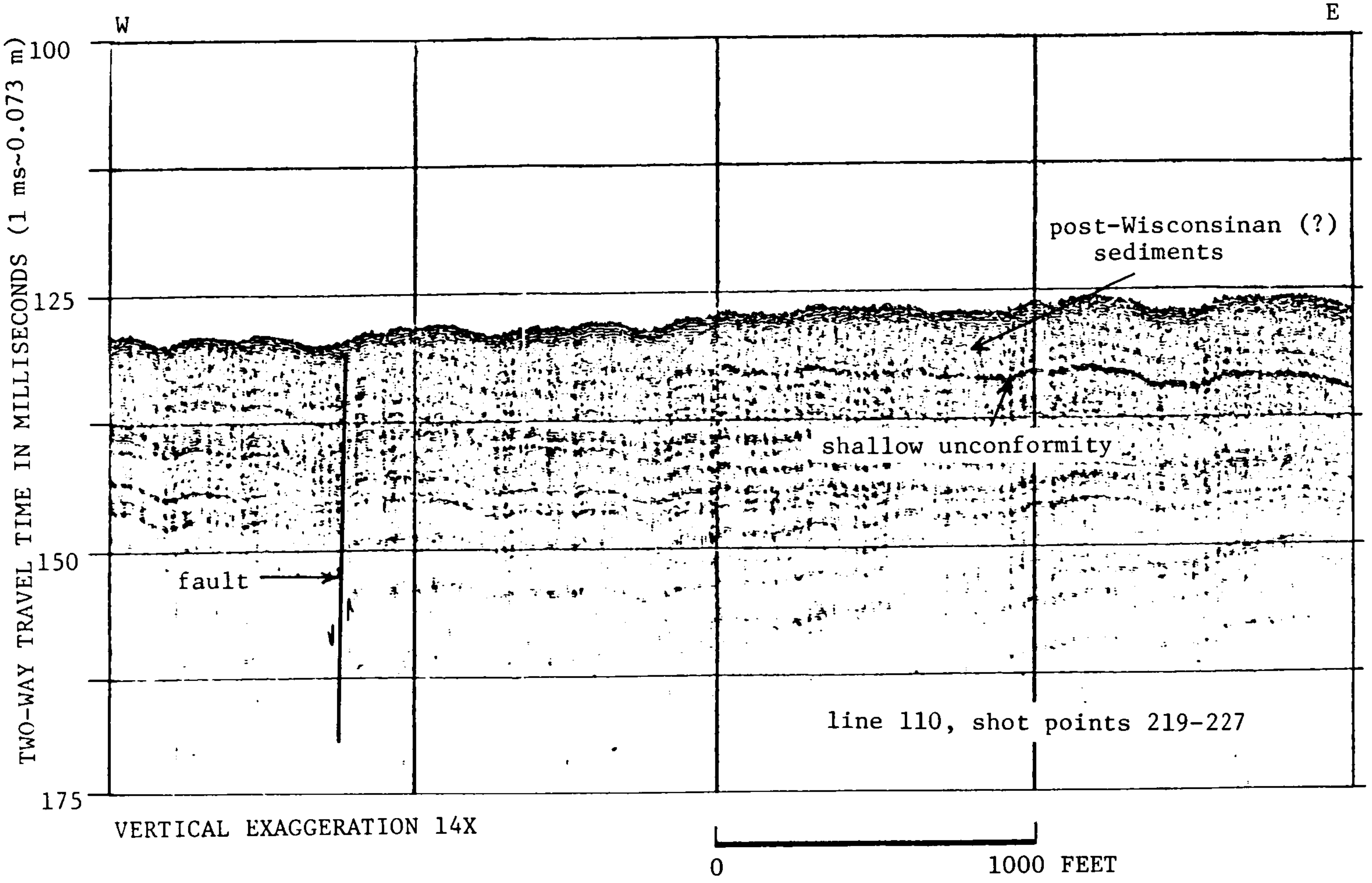

Figure II-9. Section of 3.5 kHz record showing the youngest regional unconformity present in the Flower Garden area; probably marks the base of post-Wisconsinan sediments. Hummocky appearance of the seafloor surface is mainly due to sea state. Location shown by Figure II-2.

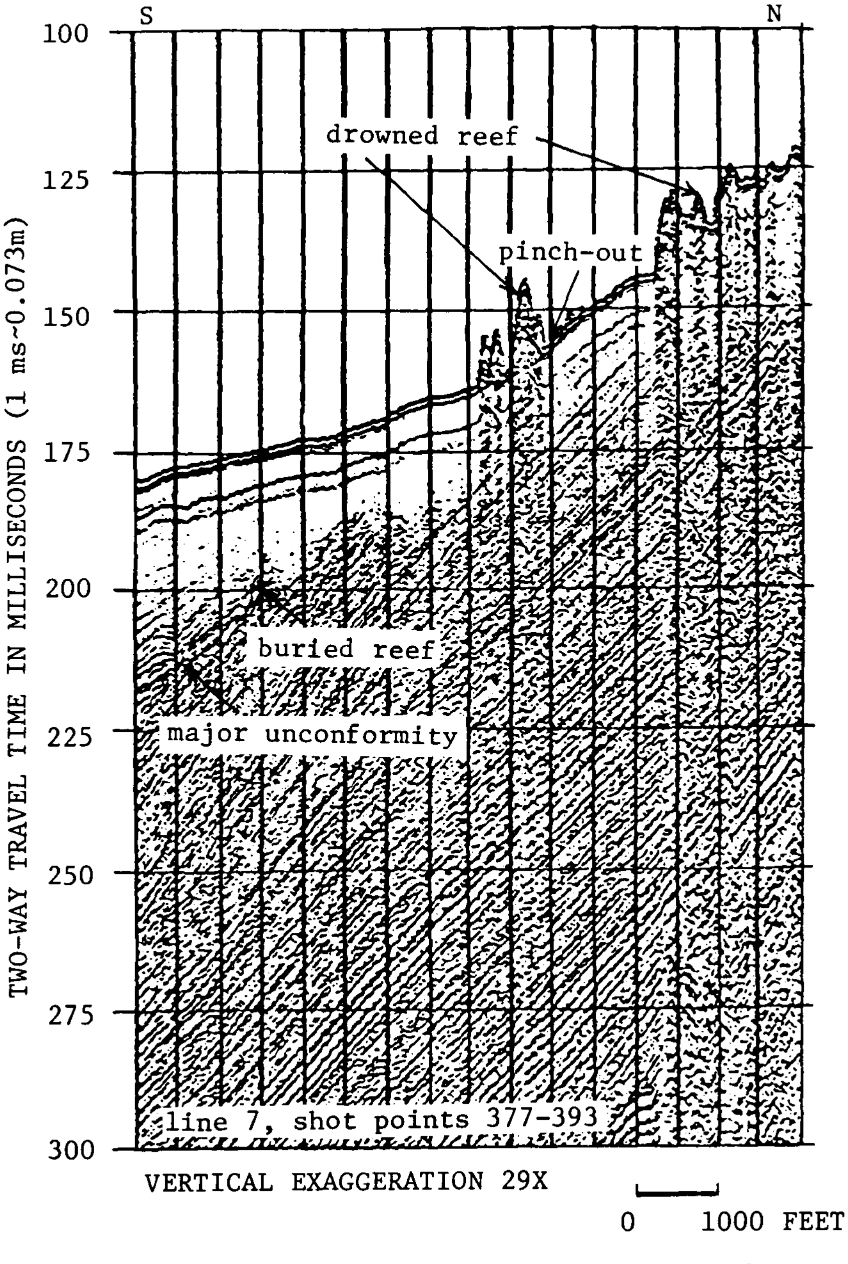

Figure II-10. Minisparker record showing pinch-out of major unconformity against flank of West Flower Garden Bank. Location shown by Figure II-2.

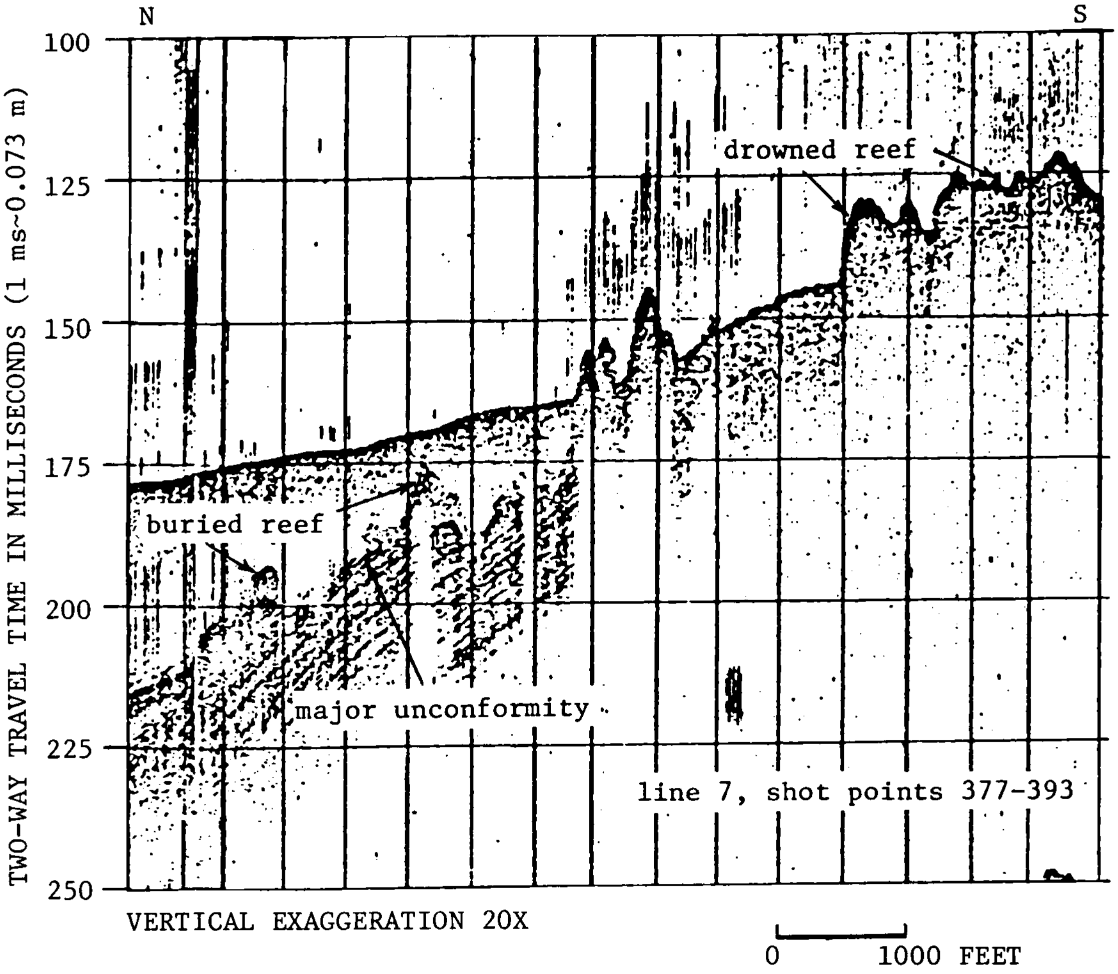

Figure II-11. Section of 3.5 kHz record covering the same area as Figure II-10. Note detail of buried reefs on the angular unconformity. Location shown by Figure II-2.

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SECTION III

GEOLOGY OF THE FLOWER GARDEN BANKS AREA

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INTRODUCTION

This report concentrates on the information shown on Map Nos. 3 and 7. The data used in the preparation of Map No. 3 has been accumulated over the years since 1961. Bathymetric profiles and surface sediment samples were obtained during cruises of: (1) R/V HIDALGO, 1961; (2) R/V ALAMINOS, 1968, 1969, 1970, 1971, and 1973; (3) R/V GYRE, 1974, 1975, 1977, 1978, and (1979; and (4) several lease vessels during 1972, 1975, 1977, 1978, and 1979. In addition, direct observations of the bottom during submersible transects (DRV NEKTON GAMMA, 1972; DRV DIAPHUS, 1974, 1975, 1976, 1977, 1978, and 1979) have been used to augment the surface sampling data.

The surface sediment distribution map (Map No. 3) is based upon a total of 140 samples taken from various sources. Forty-four samples were used by Edwards (1971) to delineate the facies distribution at the West Flower Garden (WFG) Bank. Thirty-five samples were taken at the East Flower Garden (EFG) during 1979 in order to determine the sediment distribution on that bank. Fifty-one Tenneco samples were selected for the area away from the banks and 10 additional samples were taken in December 1979 in order to fill in the gaps in the off-bank areas.

The data for Map No. 7 was obtained in August 1979 by the Survey Vessel PROTON using a 3.5 kHz high resolution subbottom profiler, a Uniboom seismic system, and an EG&G SMS 960 Seafloor Mapping System. The survey lines were spaced at 900' and navigation fixes were taken at 500' intervals on each line. The LORAC system in the hyperbolic mode was used for navigation.

The mosaic covers an area of approximately 40 nmi^2. The original 10-inch records were photographically reduced to 3" strips on mylar film. Overlapping portions were cut off and the strips put together to form a mosaic 6' x 6'. This mosaic was photographed through a half tone screen and printed to a scale of 1:12,000 making it the same size as the original bathymetric map of WFG. Both the mosaic and the bathymetric map were then rephotographed and reduced to their present size on a single print.

No mosaic of EFG has been produced because of the lateral distortion inherent in the records caused by the varying slant range of the sonar beam. EFG was surveyed in 1976 prior to the advent of the SMS-960. However, the side-scan records of the EFG and WFG were used as a supplement to submersible observations in delineating live and dead reefs on both banks.

A. SEDIMENT DISTRIBUTION

The normal sediments in this portion of the OCS off Texas and Louisiana are primarily land-derived mud or muddy sands with minor admixtures of skeletal calcium carbonate derived from organisms that live in the water column, on the bottom, and within the bottom sediment. The Flower Garden Banks are located on shallow, subsea salt domes that have dragged up with them Tertiary age sandstones, siltstones, and shales. These rocks have served as a solid substrate upon which a prolific calcium carbonate producing community of organisms has existed since Late Pleistocene time, and possibly before. The results of this growth are the living reefs and the reef bank sediments that consist almost entirely of skeletal calcium carbonate. These sediments surround the living reefs in the form of aprons that slope gently away from the reefs and merge at their lower extremities with the normal terrigenous sediments of the OCS.

B. CLASSIFICATION OF SEDIMENTS

Sediments may be classified according to texture, mineralogy, or genesis. A textural classification is used to describe terrigenous sediments because they are subject to transport by moving fluids. Determination of the particle size distribution in such sediments allows for the interpretation of the process of transportation and the velocities required to transport the sediment. A greater flow velocity is required to transport a sand than the velocity needed to transport a silt.

The classification of terrigenous sediments in general use by sedimentologists today is that of Folk (1980). Folk used the grade scale devised by Wentworth (1922) in his classification scheme which is shown on Map No. 3. According to this grade scale, the diameters of the sediment particles are as follows:

Gravel	>2 mm	
Sand	0.0625 - 2 mm	
Silt	0.0020 - 0.0625 mm	Mud
Clay	<0.0020 mm	

Folk places major emphasis on the presence of even minute quantities of gravel because he feels that the proportion of gravel is a function of the highest current velocity at the time of deposition. Consequently, even a trace of gravel (0.01%) is enough to term the sediment "slightly gravelly." This emphasis on the importance of gravel creates a problem when dealing with sediments that are mixtures of land-derived sediment and locally produced skeletal matter. Suppose that an echinoid living on the bottom dies and its skeleton is buried by mud. Sampling at that site would yield a sediment consisting of mud and the dissociated plates of the echinoid skeleton. In the analysis, these plates could conceivably amount to 5%-6% of the sediment requiring that the sediment be classified a gravelly mud. Yet the presence of 6% gravel is in no way related to the current velocities at the time the sediment was deposited. Present studies indicate that the amount of gravel in the sediment on the OCS is not a function of the highest current velocities at that site but rather proximity to a reef either living or drowned. This concept has not been understood by those who cite the presence of large amounts of gravel at depths of 60-100 m as an indication of strong bottom currents. The ramifications of this erroneous reasoning have great bearing upon the theorized fate of pollutants introduced into the bottom boundary layer by shunting of cuttings and mud from drilling platforms.

In carbonate sediments, which are produced and accumulate more or less *in situ,* textural analysis is of little value in the interpretation of the origin of the sediment. In this case, a knowledge of the nature of the constituent particles is basic to the understanding of the origin of the sediment. The sediment is intimately related to the fauna and flora from which it was derived. The name of the carbonate sediment facies is derived from the dominant skeletal component in that facies. Because of this, one might expect that sediment facies would coincide with faunal and floral facies; however, this is not always the case. At the Flower Garden Banks, some sediment appears to be moving downslope due to the force of gravity.

C. OFF BANK SEDIMENTS

Examination of Map No. 3 reveals that the dominant sediment away from the banks consists of muddy sands, sandy mud, and mud. In the northwestern portion of the map a tongue of muddy sand extends southeastward towards WFG. This sand is most probably relict Wisconsin sediment associated with the deltaic complex illustrated in Figure II-5. It is interesting to note that on the map showing the thickness of post-Wisconsin sediments (Figure II-4), much of the muddy sand area coincides with the zero sediment thickness based upon seismic records.

D. BANK SEDIMENTS

The sediment types on both the EFG and WFG are identical; however, the distribution of the sediments varies depending upon the individual topographic configuration of each bank. The living reef and its associated coral debris facies occupy the shallowest portions of each bank. Because of its gentler slopes, the sediment distribution pattern is more symmetrical at WFG. However, at EFG steep slopes occur on the east and south flanks between 60 and 90-120 m causing a narrowing of the *Amphistegina* sand belt and its absence on the southeast flank of the bank where the *Quartz-Planktonic Foraminifers* facies is in direct contact with the *Gypsina-Lithothaminum* facies.

1. Coral Debris Facies (Figures III-1 and III-2)

The coral debris facies is derived from the living reef and consists of a coarse coral sand and gravel with minor amounts of molluscan and coralline algae debris. The facies ranges in depth from approximately 20-50 m. Large patches of this sand occur in basins and valleys between coral heads on the living reef. The sands are moved

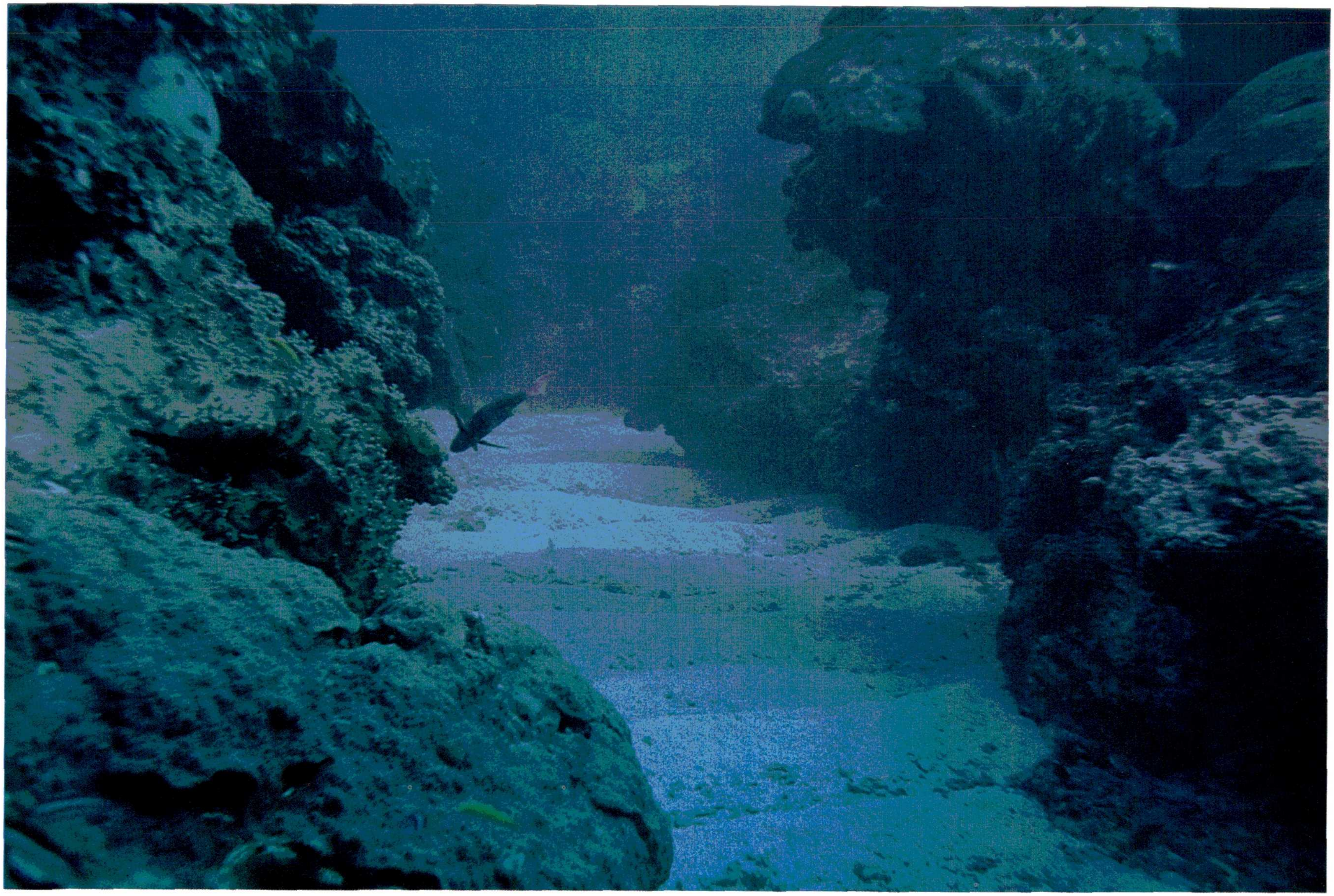

Figure III-1. Coral Debris Facies at crest of East Flower Garden Bank. Depth 27 m. Coarse coral sand and gravel between large massive corals. Note large scale ripple marks.

Figure III-2. Coral Debris Facies at East Flower Garden Bank. Depth 40 m. Coarse gravel of broken *Madracis* branches. Note flattened growth habit of *Montastrea* at this depth.

down the valleys to chutes which carry the sand to the sediment apron surrounding the living reef. Because the sand movement is mainly due to gravity, the facies is restricted to a narrow zone around the base of the reef.

2. *Gypsina-Lithothamnium* Facies (Algal Nodule Zone) (Figure III-3)

The facies extends from depths of from 40-50 m to depths of 60-75 m. It consists predominantly of a gravel of algal nodules that are being formed in situ. The nodules are formed by the growth of concentric crusts of coralline algae and encrusting foraminifers around coral or mollusc shell fragments. In some places in this facies, where the sediment has been stabilized, the coralline algae crusts bridge across the spaces between nodules and form a continuous smooth pavement of living coralline algae on the bottom. The nodules vary in size from 4 mm to over 100 mm in diameter. Because this is not a transported sediment, sorting is very poor. Both the upper and lower boundaries of the facies are transitional rather than sharp.

3. *Amphistegina* Sand Facies (Figure III-4)

This facies ranges in depth from 60-75 m to 90-100 m. It consists mainly of the dead skeletons of the foraminifer *Amphistegina* which grow attached to the surfaces of the coralline algal nodules in the *Gypsina-Lithothaminium* Facies. Upon dying, these sand-sized skeletons move down-slope to form the *Amphistegina* sand. Sand-sized fragments of coralline algae, coral, and molluscs also occur in this sediment. Much of this material is derived from the bioerosion of drowned reefs (described below) that are common at these depths.

4. Quartz-Planktonic Foraminifers Facies

This facies is found below depths of 90-100 m on the Flower Garden Banks. It represents a transition from the bank sediments surrounding the reefs and the normal sediments found on this portion of the continental shelf. The transitional nature of this facies is indicated by the abundance of reef derived skeletal material and detritus derived from the bioerosion of drowned reefs where the facies is in close proximity to the banks. The lower boundary of this facies marks the change from the carbonate sediment classification to the terrigenous sediment classification. The terrigenous sediment classification is used (Map No. 3) for the normal sediments on the OCS.

The facies consists of planktonic foraminifers, pteropods, mollusc and echinoderm fragments, and drowned reef derived skeletons and detritus in various mixtures with silt and fine sand size quartz grains and clay. The foraminifers and pteropods are the remains of free floating and free swimming species that currently inhabit the waters of the Gulf of Mexico. The molluscs (clams and snails) and the echinoderms (sea lilies and sea urchins) are present inhabitants of the sea floor in the area covered by this facies. The quartz sands, silts, and clays are terrigenous sediments that have been carried into the Gulf by streams such as the Mississippi, Sabine, Trinity, and Brazos Rivers.

5. Molluscan Hash Facies

This facies occurs on the western and southwestern margins of the bank below depths of 85-100 m. The facies has not been recognized previously as it apparently does not occur on WFG.

As defined here, the facies is composed of from 15%-54% sand size mollusc fragments and from 0%-34.5% quartz grains. The silt-plus-clay fraction ranges from 5%-62%, with an average of 22%. It is easily distinguished from the Quartz-Planktonic Foraminifers facies by its low content of planktonic foraminifers (0.5%-13.3%) and its low mud content. Also, the percentage of molluscs in the Quartz-Planktonic Foraminifers facies is much less, ranging from 1.0%-14.6%.

This facies is interpreted as a relict Pleistocene beach deposit that has been more or less preserved in the lee shadow of the bank.

6. Drowned Reefs (Figure III-5)

An examination of the faunal distribution charts (Map Nos. 8 and 9) and the side-scan mosaic of WFG (Map No. 7) shows an abundance of drowned patch reefs and barrier reefs below a depth of about 60 m. These drowned features are the dead remains of reefs that were thriving during Late Pleistocene and later low still-stands of sea level. The data documenting the presence of these drowned reefs is derived from side-scan sonar records and direct observations from the DRV DIAPHUS. The deepest direct observation of drowned reefs has been at 153 m on the southeast edge of WFG.

A sample of rock was taken from a drowned reef at a depth of 140 m on WFG. The sample is 12-15 cm thick and consists primarily of encrusting coralline algae, bryozoans, worm tubes, and mollusc borings filled with cemented internal sediment.

The drowned reefs are extensively bioeroded by boring molluscs, echinoids, and sponges. The resulting gravel is incorporated into the sediment surrounding the drowned reef.

E. SURFACE FEATURES AND STRUCTURE OF THE BANKS

The surface features of WFG are shown on Map No. 7. As no side-scan mosaic has been prepared for EFG, references to surface features will be made on Map No. 8. The following discussion is based upon bathymetric, side scan, and subbottom surveys conducted by Texas A&M University at EFG (1979) and WFG (1979). These data are supplemented by direct observations of the bottom along transects made by the Texas A&M University submersible DRV DIAPHUS.

As indicated in Section II, diapirism and faulting are the active tectonic processes at the Flower Garden Banks. Diapirism is the result of the upward movement of salt from the Jurassic salt deposits which lie over 10,000 m below the surface in the Flower Garden area. The upward movement of the salt plugs is due to loading by the sediments deposited on the continental shelf. The salt flows upward piercing the overlying strata as it approaches the surface. Radial and concentric faults are common over the crests of the diapirs. The major movement on these faults, when they intersect the surface of the shelf, does not occur immediately. As the salt reaches a depth of about 300 m below the surface, sea water percolating through the sediment begins to dissolve the salt and concentrate the less soluble gypsum as a cap over the salt diapir. As the crest of the diapir moves closer to the surface, sulfate reducing bacteria begin to work on the gypsum. The resulting products are limestone caprock, native sulfur, hydrogen sulfide, iron sulfides, and methane. Dissolution of the salt beneath the cap-rock continues and creates cavities into which blocks of caprock and overlying sedimentary rocks already fractured by the radial and concentric faults settle to form normal fault blocks and grabens. There is evidence that the normal faulting at the crest of salt domes may be catastrophic. On some banks to the east of the Flower Garden Banks, bare rock with exceedingly thin crusts of sponges and coralline algae are exposed at the crests of the banks. If these rocks had been exposed during the Pleistocene, as they were at the Flower Garden Banks, they should have developed a thick reefal encrustation. Additional evidence for the dissolution of salt at the crests of diapirs is the brine lake at EFG which will be described later.

1. West Flower Garden Bank

The living reef is located in the north central part of Block A-398 (Map No. 7). It is foot-print shaped and is surrounded by large scale ripples on a coarse sand and gravel bottom. The ripples have wave lengths of up to 50 m and are oriented normal to the isobaths. This indicates that the currents are deflected by the peak and move around it rather than over it.

To the north and west of the reef lies the central graben which is elongate in a northeasterly direction. There is no return on the side-scan signal from this area due to the fine sediment in the depressions. Water samples taken in these depressions during 1973 and 1974 had a salinity somewhat higher than normal sea water indicating the possibility of brine seeps in the area.

Faulting is quite apparent on the side-scan mosaic. The greatest displacement at the surface is seen in the central graben. However, a very large radial fault with a displacement of over 30 m is seen in Block

A-401. Another radial fault can be seen in Block A-397 at 27°51.3'. In Blocks A-384 and A-385 in the northeastern part of the bank several radiating lineations are present that may also indicate faulting.

2. East Flower Garden Bank

Faulting appears to be less common over the major portion of the bank than it is at WFG. There is no central graben and the major faults seem to be concentric. The series of drowned reef ridges shown on Map No. 8 at the northern end of EFG is associated with a series of WNW-ESE trending faults that are shown on Map No. 5. The steep southern and eastern sides of the bank are bounded by faults caused by the upward movement of the underlying salt diapir. However, upward movement of salt on the northern and western sides of the bank has been much less, accounting for the more gentle slopes in those areas.

An area of active brine seeps occurs on the southeastern flank of the bank (Figure IV-16) filling a small brine lake. Seismic data indicate that the top of the salt lies within 30 m of the crest of the reef just to the northwest of the brine lake. The brine results from dissolution of the salt by normal marine water that percolates through the porous reef rock. The dense brines (about 200% total salinity) then flow by gravity to the shores of the brine lake where they emerge from the porous rock. Residence time of the brine in the lake is approximately 7 hours. The outflow of the lake amounts to 355 m^3-717 m^3/day. The total amount of salt dissolved from the crest of the salt diapir over the period of a year, as evidenced by this series of seeps, is from 10,765 m^3-21,710 m^3. Other seeps are known to occur at the bank, so this is a minimum figure for the removal of salt. One of the unknown variables is the rate of upward flowage of the salt diapir; however, it seems unlikely that it is equal to or greater than the rate of removal of salt by dissolution. Therefore, a collapse of the bank's crest is expected sometime in the not too distant future.

Numerous gas seeps occur on and around both banks (Figure III-6). Ordinarily, these seeps are intermittent and are associated with faults. The gas is mainly methane and could be derived either from gas reservoirs at depth or from the bacterial activity within the caprock of the diapir during the reduction of Anhydrite to H_2S and $CaCO_3$.

F. GEOLOGIC HAZARDS ASSOCIATED WITH SALT DOMES

1. Faulting - Unstable conditions may develop due to upward movement of salt and possible catastrophic collapse of the crest of the dome due to removal of salt by dissolution. The nature of the instability will be dependent upon the relative rates of uplift and dissolution.

   Faults that intersect the surface could create blowout problems if a gas producing horizon is encountered in a well that is not cased through the faulted interval.

2. Overpressured gassy sediments - High pressure gas in relatively shallow sediments is common in this area. The Pennzoil blowout in Block A-368, which occurred on March 24, 1980, and earlier more disasterous blowouts are good examples of this kind of hazard.

3. Hard bottom structures created by reefs and faulting could be hazardous to pipelines. Active faulting, in particular, could subject pipelines to abnormal stresses and contribute to their failure.

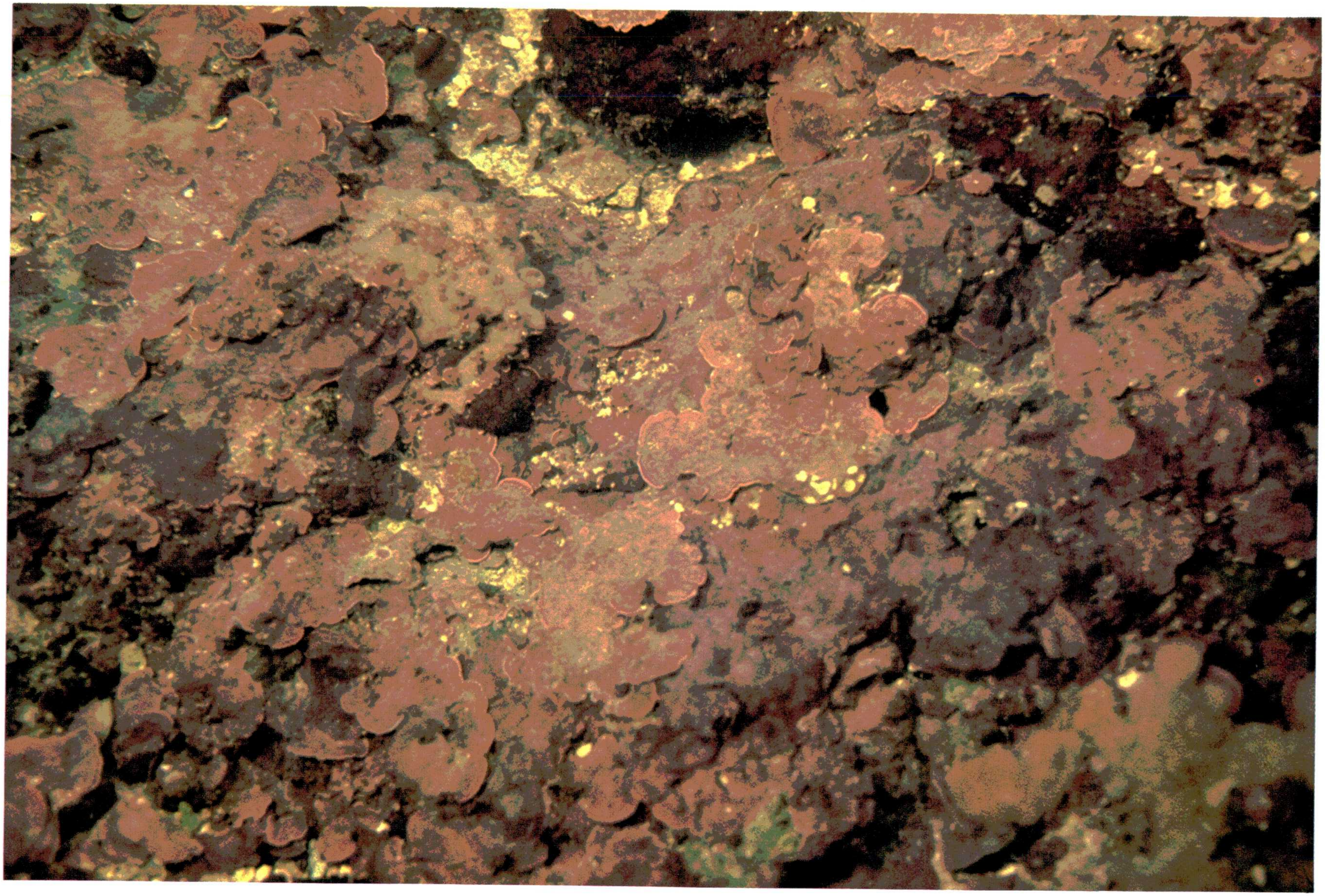

Figure III-3. *Gypsina-Lithothamnium* Facies at East Flower Garden. Depth 60 m. Note continuous pavement formed by living crusts of coralline algae.

Figure III-4. *Amphistegina* Sand Facies at West Flower Garden Bank. Depth 65 m. Sponge and crinoid in burrow crater. Note coralline algae nodules in foreground.

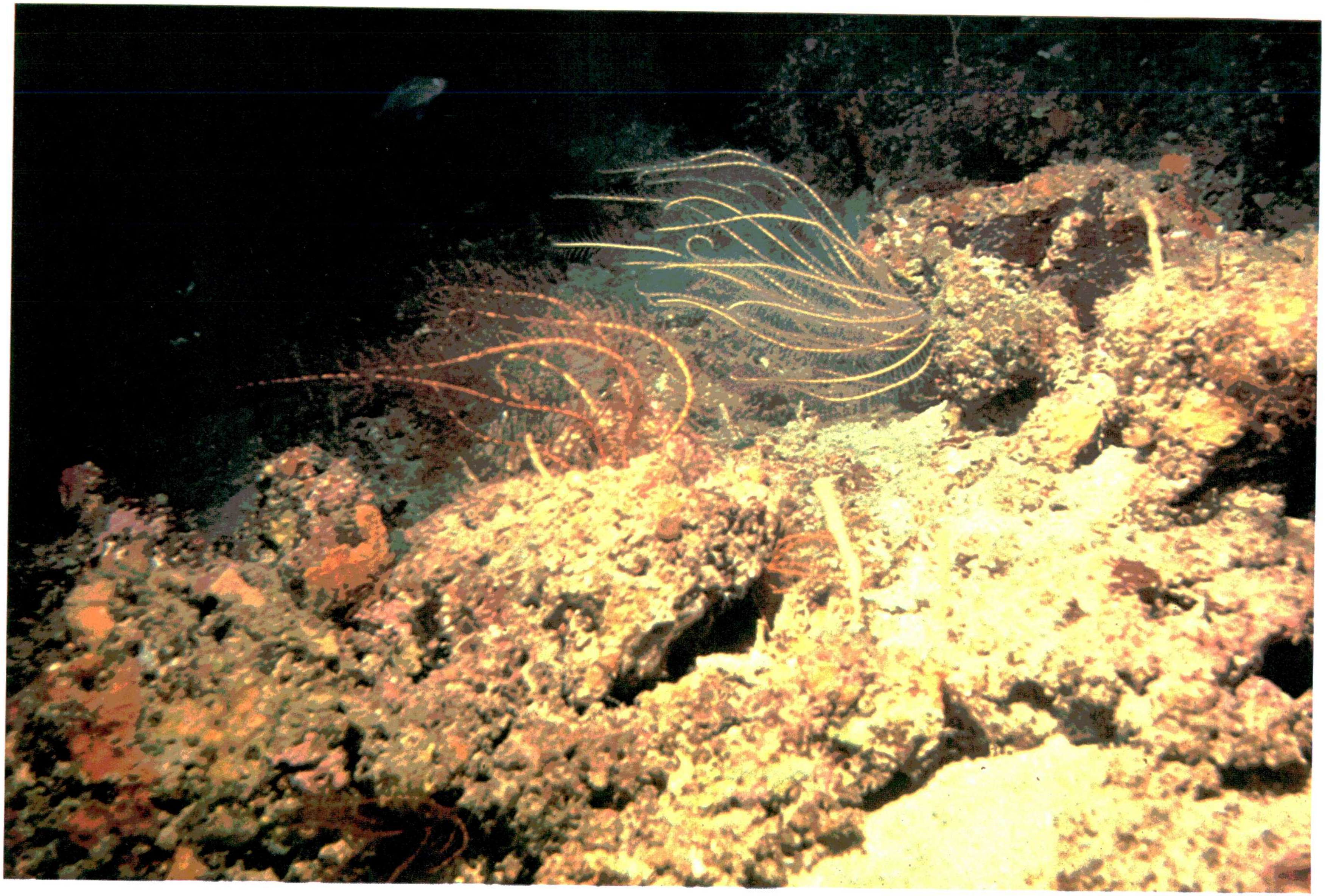

Figure III-5. Drowned Reef at West Flower Garden Bank. Depth 91 m. Note cavernous nature of reef due to bioerosion.

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SECTION IV

BIOTIC ZONATION, EAST AND WEST FLOWER GARDEN BANKS

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NOTE

Figure IV-12 caption: For the scrawled filefish, the correct scientific name is *Aluterus scriptus.*

Figure IV-13: The photograph has been inadvertently printed upside down.

INTRODUCTION

The East and West Flower Garden Banks (EFG and WFG) are located approximately 110 nmi southeast by south of Galveston, Texas, at 27°55'N, 93°36'W and 27°52'N, 93°49'W, respectively (Figure IV-1). Both banks are capped by what are currently considered to be the northernmost thriving tropical shallow water coral reefs on the eastern coast of North America. The northern limit of Bahamian reefs is some 20 miles south of the Flower Gardens' latitude. Reefs of the Bermuda Islands are nearly 300 miles north of the Flower Gardens' latitude but they are situated 570 miles offshore from Cape Hatteras, North Carolina. The ecology of both the Bermudan and Bahamian island systems is influenced greatly by the warm Gulf Stream waters which surround them, and like the Flower Gardens, they harbor elements of the typical Caribbean reef biota.

Within the Gulf of Mexico, the Flower Gardens appear to be elements of a discontinuous arc of reefal structures occurring on the continental shelf. The coral reefs closest to the Flower Gardens are off Cabo Rojo, about 60 miles south of Tampico, Mexico (Villalobos, 1971). Moore (1958) listed 43 species of Caribbean reef invertebrates from there; many of them are also common at the Flower Gardens. However, certain abundant corals, such as *Acropora palmata* (Elkhorn coral) and *A. cervicornis* (Staghorn coral), do not occur at the Flower Gardens. Shallow water octocorals (seafans and seawhips) which are surprisingly absent from the Flower Gardens are present, but scarce, at the Cabo Rojo reefs and reefs several miles south near Isla de Lobos (Chamberlain, 1966; Rigby and McIntire, 1966). Reportedly, octocorals are somewhat more abundant on Alacran reef (Kornicker et al., 1959) and other reefs on the Yucatan continental shelf. Coral reefs off the city of Veracruz were reported by Heilprin (1890). Logan (1969) described the physiography of all reefs and hardbanks on the Yucatan shelf in some detail.

Coral reefs occur in the Tortugas and Florida Keys in the eastern Gulf. Jordan (1952) described aspects of biota from the Florida Middle Ground, approximately 300 square miles of reef formations off Apalachicola Bay, Florida (Figure IV-1). Grimm and Hopkins (1977) indicate octocoral predominance at the Florida Middle Ground above 28 m depth (*Muricea-Dichocoenia-Porites* Zone) with dominance shifting to the hermatypic corals *Dichocoenia* and *Madracis* between 28-30 m. *Millepora* (fire coral) dominates from 30-31 m and becomes co-dominant with *Madracis* from 31-36 m. Zonation at the Florida Middle Ground, therefore, differs considerably from that of the aforementioned coral reefs, even though the dominant organisms are components of the Caribbean biota. Elements of the Caribbean reef biota occupy hardbottoms and "patch reefs" from Tampa Bay to Sanibel Island on the west Florida shelf (Joyce and Williams, 1969; Smith, 1976).

The Gulf, therefore, is ringed by a combination of thriving coral reefs and scattered hardbanks and patches bearing elements of the Caribbean reef biota. To what extent the Caribbean biota are represented at the Flower Gardens with respect to all taxonomic groups is not yet known. Two hundred fifty-three invertebrate species and 103 fishes were reported from WFG by Bright and Pequegnat (1974). Bright and Rezak (1978a) listed over 30 species of benthic algae from EFG. The list of species is expanding through ongoing research sponsored by the Bureau of Land Management (Bright and Rezak, 1976, 1978a, and 1978b).

It is not surprising that thriving reefs occur at the locality of the Flower Gardens. Though not well understood at present, the environmental conditions there seem consistent with the existence of coral reefs (see Stoddard, 1969, for discussion of reef ecology). The oceanic water bathing the reef is clear, with visibility usually over 30 m. Salinity varies very little from 36 parts per thousand (ppt), although we have detected surface salinities as low as 32 ppt and bottom salinities as low as 34 ppt on the coral reefs. The depth is sufficiently shallow at the bases of reefs (40-46 m) to allow penetration of the sunlight necessary for massive coral growth. We have never observed significant suspended sediment in the water on the reefs, and there is no evidence of siltation. Stoddard (1969) indicates that coral reefs grow best at temperatures of 25°-29°C but can thrive in areas with an annual minimum of 18°C and "the resistance of corals to high and low temperatures varies with species and at their latitudinal limits reefs become gradually depauperate rather than suddenly extinguished." This may have some significance with regard to the Flower Gardens but long-term measurements indicate that surface temperatures there, which often extend isothermally to depths below the bases of the reefs, rarely drop below about 18°C and may go as high as 30°C or more during the summer.

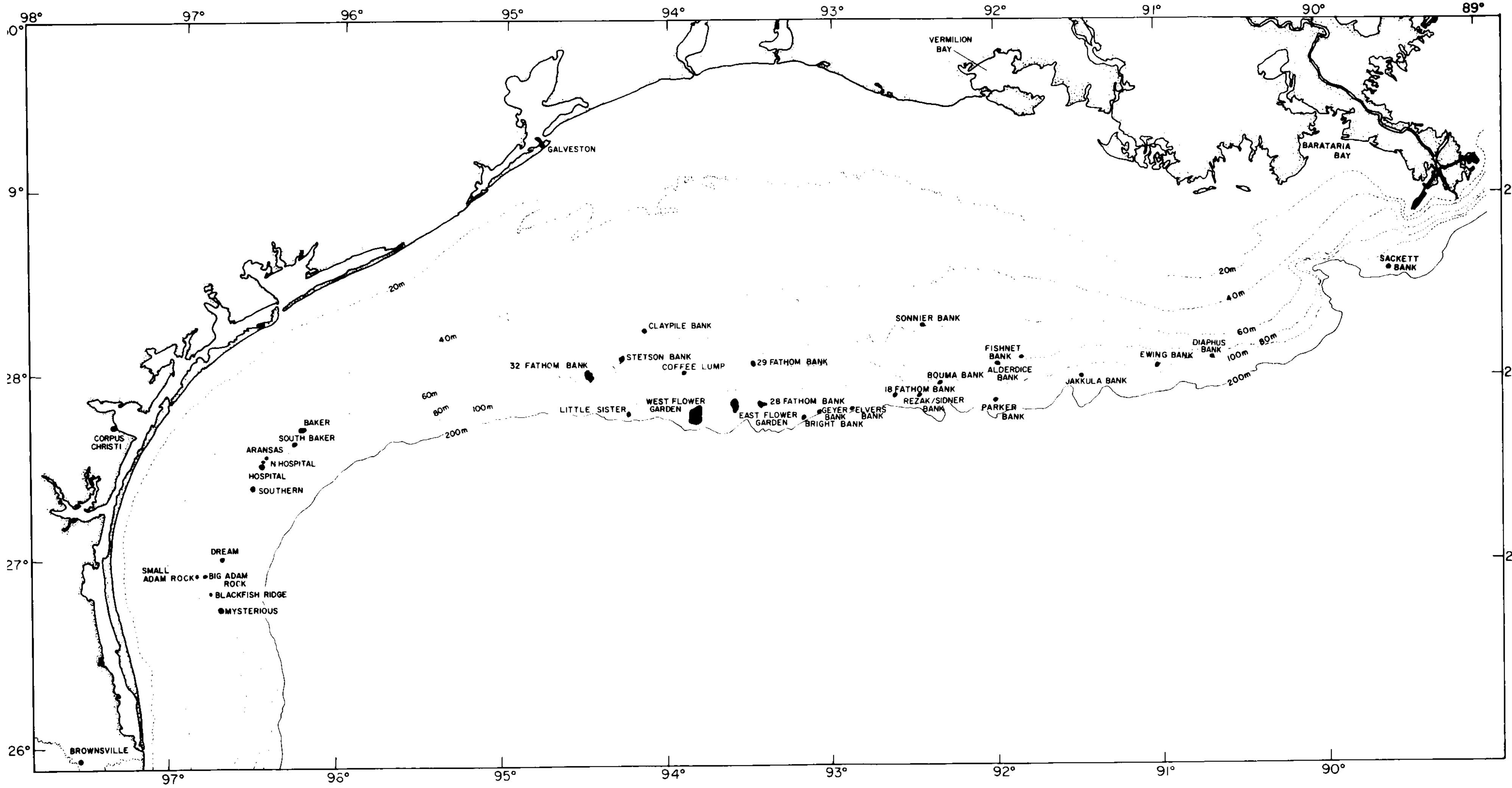

Figure IV-1. Outer continental shelf fishing banks, northwestern Gulf of Mexico.

The most puzzling aspect of Flower Garden benthic community structure is the absence of shallow water octocorals and stony corals of the genus *Acropora*. Both groups are typically very abundant on Caribbean reefs and reefs in other parts of the Gulf of Mexico. One might account for the absence of *Acropora palmata* on the basis of its depth distribution. It is a shallow water form and does not occur in any abundance below 10 m (Logan, 1969), whereas the crests of the EFG and WFG reefs lie at about 16 and 20 m, respectively. However, the author has observed sizeable *Acropora cervicornis* thickets at depths exceeding 30 m in the Bahamas and the Virgin Islands; one might expect this species to occur at the Flower Gardens, it has not been found. Shallow water octocorals occur abundantly elsewhere in the Gulf of Mexico, Caribbean, Bahamas, and Bermuda at Flower Gardens' depths. Their absence from the Flower Gardens is unexplained.

Biotic zonation at the Flower Gardens is distinct. Though most zones overlap or grade into one another to some extent, they are nevertheless very recognizable and their depth ranges correlate consistently with those of known sedimentological facies (Figures IV-2 and IV-3, Map Nos. 5, 8, and 9). The following is a general descriptive account of biotic zonation and biotopes at the East and West Flower Garden Banks.

A. CORAL REEFS

Submerged coral reefs comprise the shallowest and largest reefal structures on the EFG and WFG, occupying the crests of the banks down to 52 m depth in places. (Figures IV-2 and IV-3, Map Nos. 5, 8, and 9). The main reeftops generally vary from 18-28 m, but 15 m depths are common and an 11 m depth has been encountered at EFG. The reefs are made up of closely spaced or crowded coral heads up to 3 m in diameter and height (Figure IV-4). "Patches" of sand or carbonate gravel occur among the coral heads (Figure IV-5). The heads are frequently very cavernous, showing evidences of substantial internal and surficial bioerosion.

Two biotic zones are recognizable on the coral reefs, a high diversity assemblage (18 hermatypic coral species) limited to depths less than 36 m (*Diploria-Montastrea-Porites* Zone) and a comparatively low diversity assemblage (approximately 8 hermatypic coral species) between 36 and 52 m (*Stephanocoenia-Millepora* Zone).

More is known of the *Diploria-Montastrea-Porites* community than of any other at the Flower Gardens because of it is accessible to research divers using SCUBA. Edwards (1971) considered all coral reefs at the WFG to belong to this zone, thereby implying an heirarchy of coral dominance (percent cover) similar to that described by Logan (1969) for submerged reefs on the Yucatan shelf, southwestern Gulf. However, subsequent studies by Bright and Requegnat (1974), Tresslar (1974), and Bright et al. (1984) show conclusively that *Montastrea annularis* is the dominant coral, followed by *Diploria strigosa, Montastrea cavernosa, Colpophyllia* spp., and *Porites astreoides*. Convention should therefore dictate a change in zonal designation for high diversity reefs at the Flower Gardens to *Montastrea-Diploria* Zone to reflect the true order of coral dominance above 36 m. For convenience and to avoid confusion, however, the older designation is retained.

Transect measurements within the zone indicate that approximately 60% of the hard substratum is occupied by living coral (excluding sand and gravel patches). *Montastrea annularis* (Figure IV-6) comprises about half of the living coral population and is, therefore, overwhelmingly dominant. Accretionary growth of this species is estimated at 6-8 mm/yr based on sclerochronological analyses (Hudson and Robbin, 1980). This is comparable to growth rates for the same species in very shallow water (3-5) m, in the Florida Keys.

Over the short term, the balance between lateral encrusting growth of corals vs. mortality may be as important as accretionary growth in maintaining a stable cover of living scleractinian corals on the reefs (Figures IV-6 and IV-7). Encusting growth rates averaging 0.33 mm/mo have been measured for *Montastrea annularis* at EFG.

Crustose coralline algae (Figure IV-6) are abundant on the high diversity reefs and they add substantial amounts of calcium carbonate to the reef substratum. Intuitively, it is felt that the contribution to frame building by the coralline algae on the high diversity reefs is minor compared to that of the hydrozoan and scleractinian hermatypic corals. Standing crops of leafy algae on the high diversity reefs are consistently low, possibly kept so by the grazing activities of mobile invertebrates and fishes.

The 253 species of reef invertebrates and 103 reef fishes reported in Bright and Pequegnat (1974) were almost all taken from the *Diploria-Montastrea-Porites* Zone at the WFG (Figure IV-8). Studies in progress imply a nearly identical community structure and diversity for the *Diploria-Montastrea-Porites* Zone at EFG.

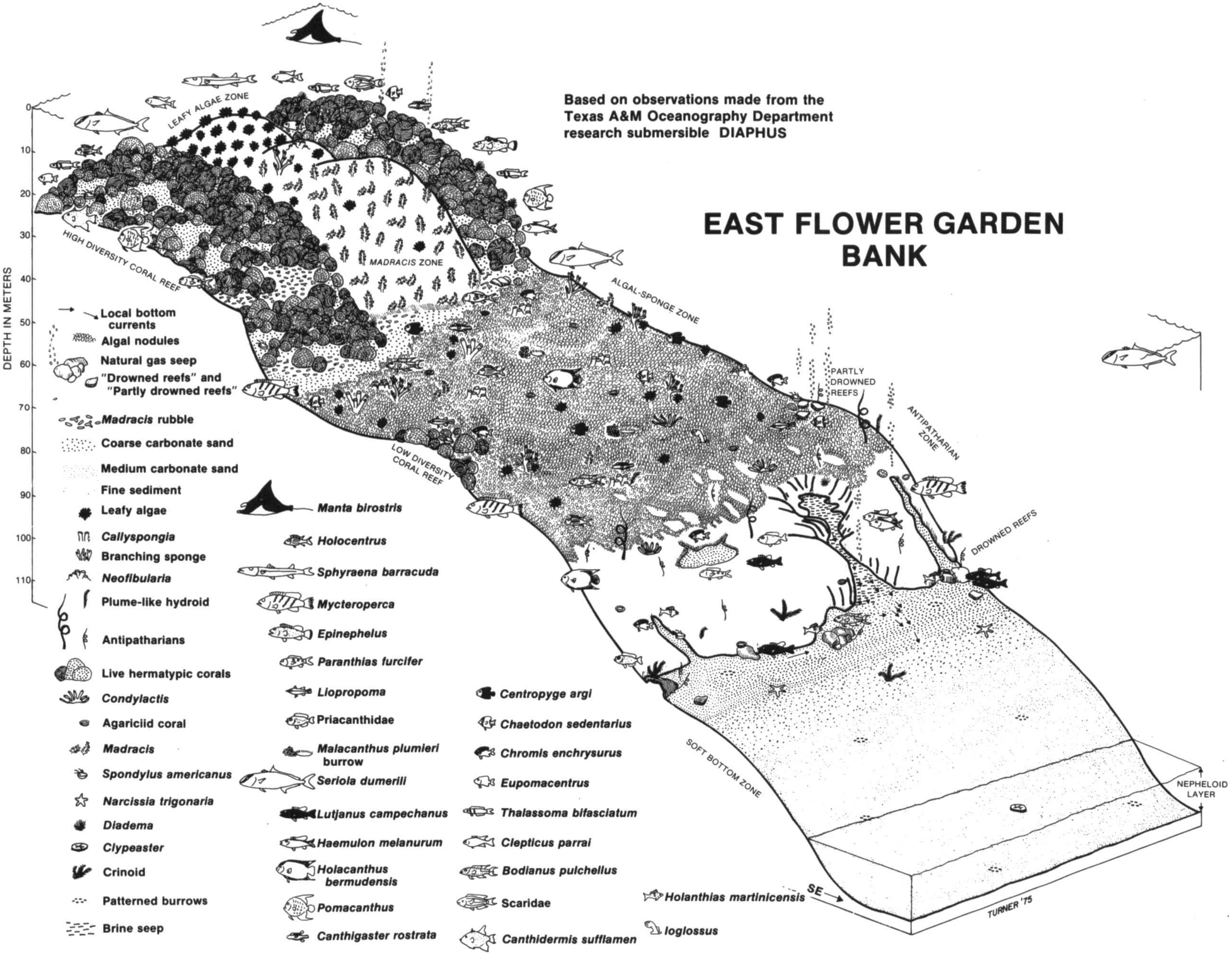

Figure IV-2. Biotic zonation, East Flower Garden Bank, southeast quadrant. The "High Diversity Coral Reef" is equivalent to the *Diplora-Montastrea-Porites* Zone. The "Low Diversity Coral Reef" and lowermost portions of the main reef make up the *Stephanocoenia-Millepora* Zone.

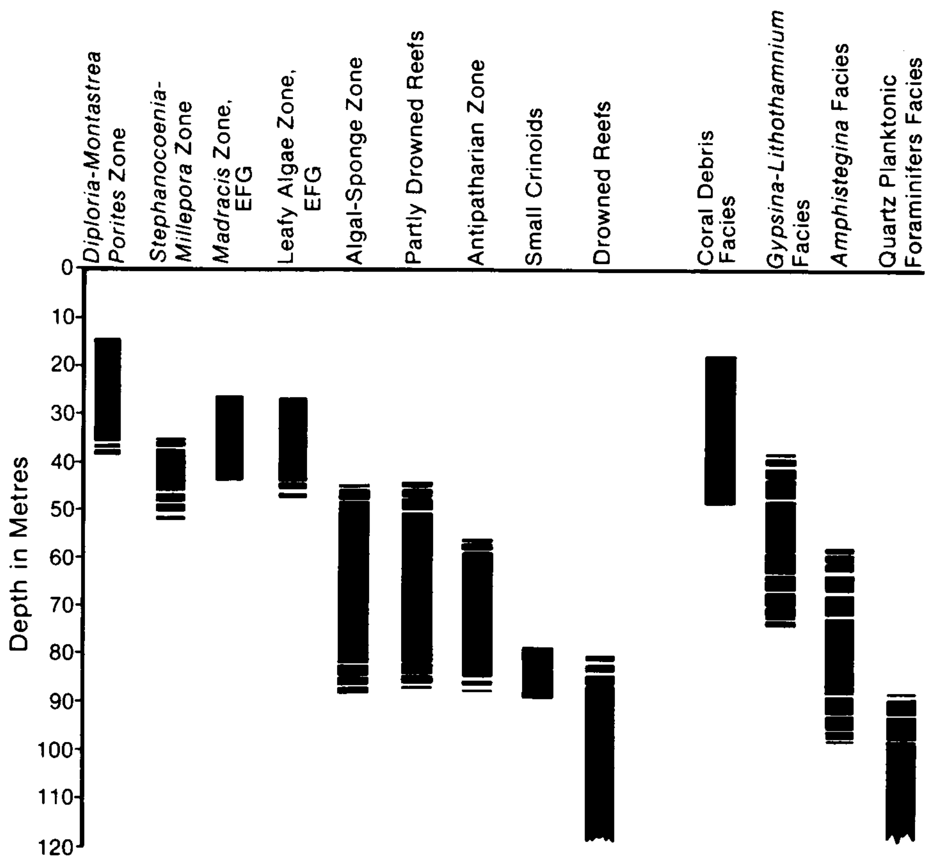

Figure IV-3. Depth ranges of recognizable biotic zones and sedimentary facies. Broken bars indicate varying upper and lower depth extremities for zones depending on location.

Among the typically caught sport and commercial fishes frequenting the high diversity coral reefs are several species of groupers and hinds (*Mycteroperca* spp. and *Epinephelus* spp.), amberjacks (*Seriola* spp.), Great barracuda (*Sphyraena barracuda*), Red snapper (*Lutjanus campechanus*), Vermilion snapper (*Rhomboplites aurorubens*), Cottonwick (*Haemulon melanurum*), Porgys (*Calamus* spp.), and Creolefish (*Paranthias furcifer*).

Spiny lobsters (*Panulirus argus*) are known to occur on the high diversity reefs at both Flower Gardens and have been seen by the author on several other banks (Sonnier Bank, 18 Fathom Bank, and Bright Bank). *Panulirus guttatus* has been seen on the shallow coral reefs (26 m) at EFG and probably occurs also atWFG. The Shovel-nosed lobster (*Scyllarides aequinoctialis*) is reported from the high diversity reef at WFG and probably occurs also at EFG. All these species of lobsters must be widely distributed on OCS banks in the northwestern Gulf, but nothing is known of the magnitude and dynamics of the regional populations or whether they could support a commercial lobster fishery.

Between 36-38 m depth at both banks a transition is apparent from the *Diploria-Montastrea-Porites* assemblage to a reef zone of lower diversity which extends generally down to 46 m, with components to 52 m. Approximately eight species of hermatypic corals are conspicuous in the zone: *Stephanocoenia michelini, Millepora* sp., *Colophyllia* spp, *Diploria* sp., *Mussa angulosa*, and *Scolymia* sp., probably in that relative order of abundance. The designation *Stephanocoenia-Millepora* Zone is, therefore, appropriate (Map Nos. 8 and 9).

Population levels of these corals have not been quantitatively determined but visual observations indicate considerably lower total live coral cover than in the *Diploria-Montastrea-Porites* Zone and a great deal of variation in percent cover and relative abundance from place to place. Crustose coralline algae are substantially more conspicuous in the *Stephanocoenia-Millepora* Zone and are apparently the predominant encrusting forms occupying dead coral reefrock. Sclerochronologic interpretation of a specimen of *Stephanocoenia michelini* from 39 m depth at EFG indicates an accretionary growth rate of approximately 4 mm/yr (assuming the "growth" bands examined are annual).

Little is known of the assemblage of organisms inhabiting the *Stephanocoenia-Millepora* Zone. The reef fish populations appear less diverse than in the *Diploria-Montastrea-Porites* Zone. Population density of the black urchin (*Diadema antillarum*) which is a significant bioeroder of reefrock, may be similar in both zones. Exceptional numbers of the American thorny oyster (*Spondylus americanus*), have been seen in the *Stephanocoenia-Millepora* Zone.

Successional relationships between the shallower, high diversity *Diploria-Montastrea-Porites* reefs and deeper, low diversity, *Stephanocoenia-Millepora* reefs at the Flower Gardens cannot be determined from existing information. The low diversity reefs could represent depauperate remnants of high diversity reefs which have been displaced downward to a habitat too deep to support a majority of the contemporary coral species. In this case, much of the dead reefrock upon which the corals of the low diversity reefs now grow would comprise the remains of coral species now living on the high diversity reefs. Conversely, contemporary high diversity reefs may have developed on the tops of low diversity reefs or other local topographical mounds (possibly accumulations of the coral *Madracis mirabilis*) whose crests achieved a depth above which high coral diversity and rapid coral growth are possible. More information is needed concerning the nature of the reefrock in both zones, rates of deposition of carbonate rock and sediment, and vertical movements of the substratum and sea level relative to one another in the past several thousand years.

B. LEAFY ALGAE AND MADRACIS ZONES

On peripheral parts of the main reefal structure between 28-44 m depth at EFG, large knolls occur which are generally devoid of coral reefs. Certain of these knolls are overwhelmingly dominated by the small branching coral *Madracis mirabilis (Madracis* Zone) (Figure IV-9). Other knolls covered by lush assemblages of leafy algae (Leafy Algae Zone) including species of *Stypopodium*, *Caulerpa, Dictyota, Chaetomorpha, Pocockiella, Rhodymenia, Valonia, Codium*, and others (Figure IV-10). None of these assemblages resemble the adjacent coral reef community in structure although it is likely that most or all of the species found on the knolls also occur on the reefs.

The substratum on these knolls is primarily skeletal remains of *Madracis mirabilis. Madracis* gravel is also the predominant unconsolidated sediment in depressions between coral heads on peripheral parts of the main reef structure below approximately 28 m depth. Similar depressions in the shallower area of the main reef contain

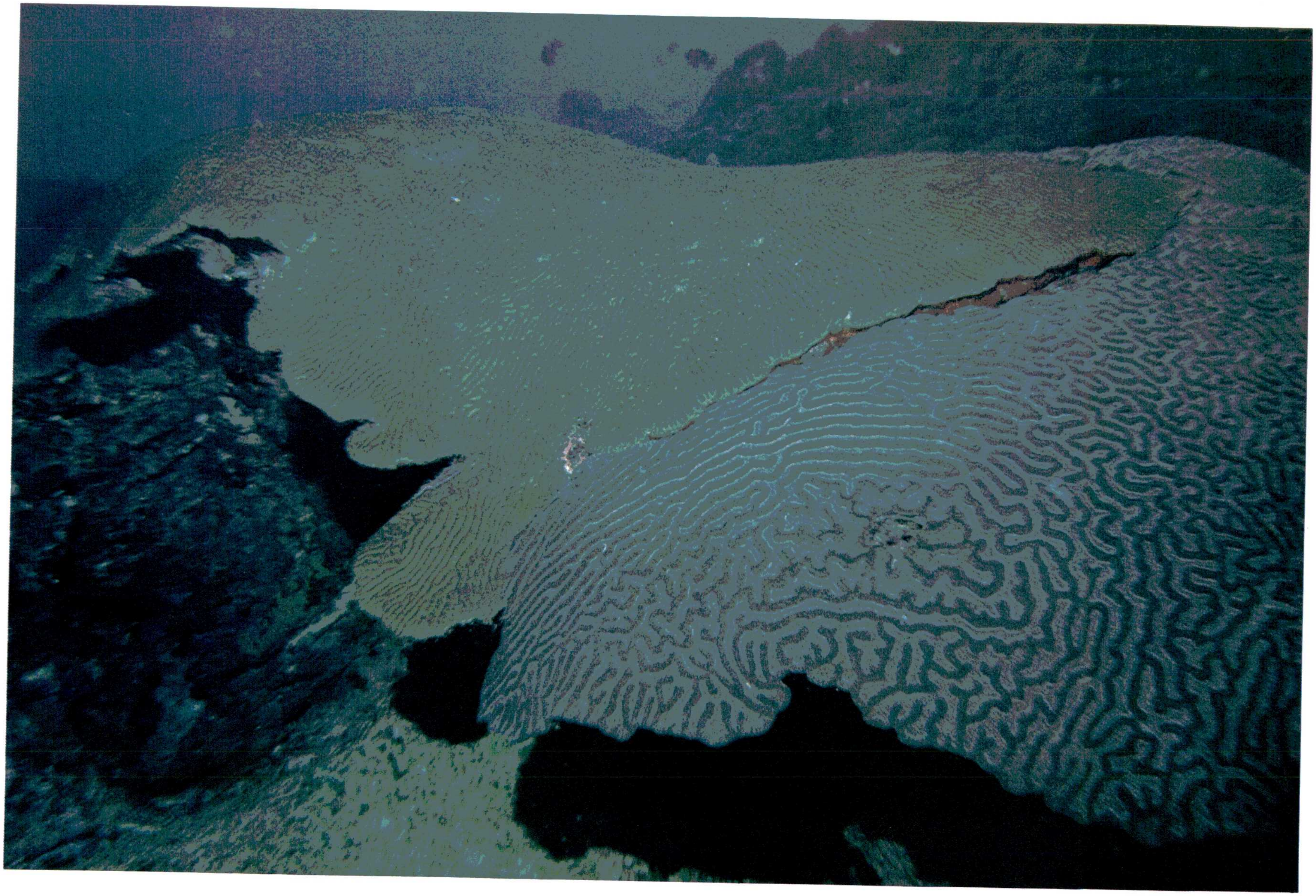

Figure IV-4. Heads of hermatypic scleractinian corals, *Diploria* sp. and *Colpophyllia* sp., growing contiguously in competition for space, 26 m depth, West Flower Garden.

Figure IV-5. Typical sand patch among coral heads at 26 m depth, East Flower Garden.

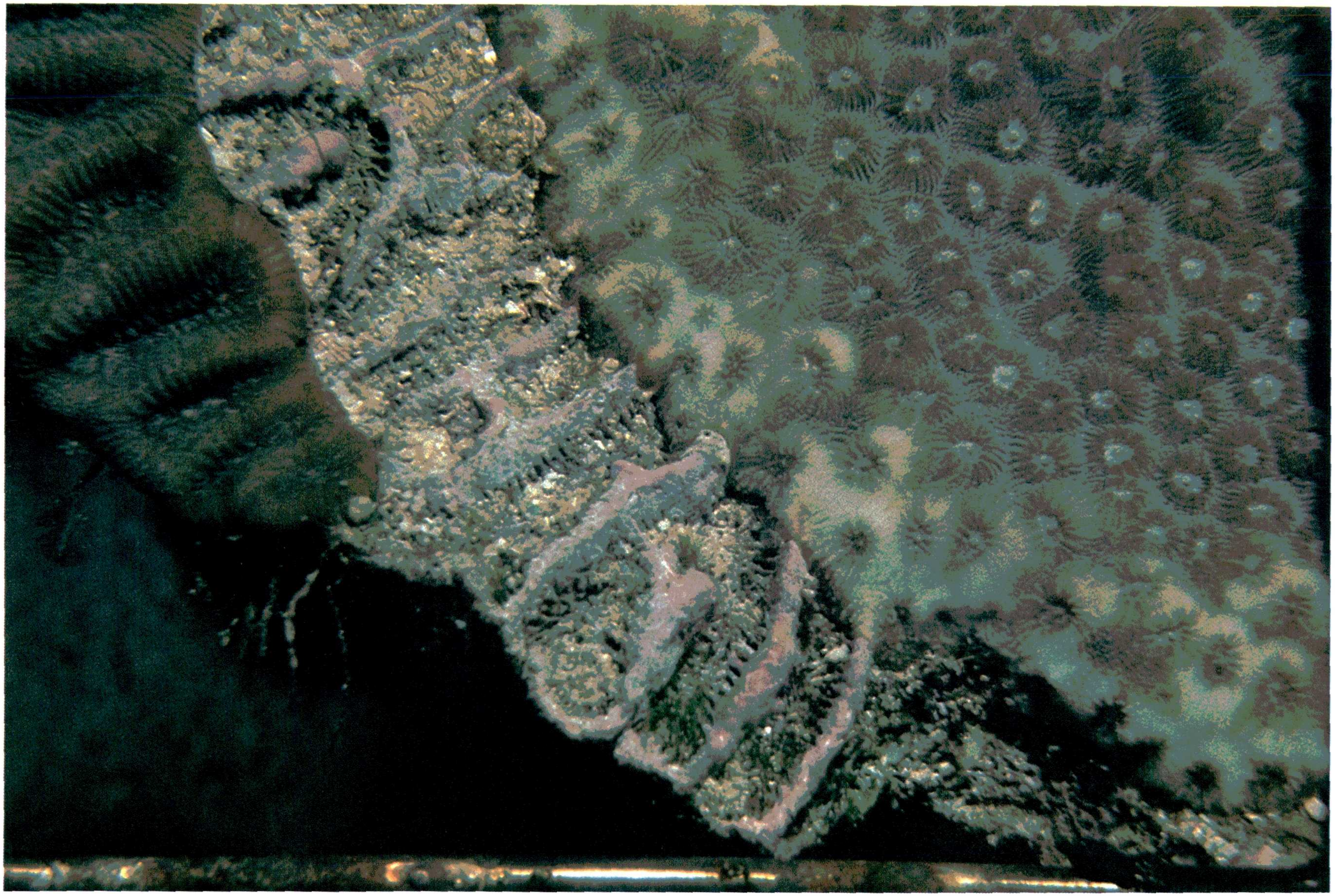

Figure IV-6. *Montastrea annularis* (upper right) encroaching on a receding colony of brain coral, *Diploria* (left). Encrusting growth of stony corals is thought to be an extremely important process by which the coral populations retain dominance as substratum occupiers and builders. Corallum between the two living coral colonies is occupied by coralline algae (purple) on ridges and sand-sized carbonate particles in depressions. 26 m depth, West Flower Garden.

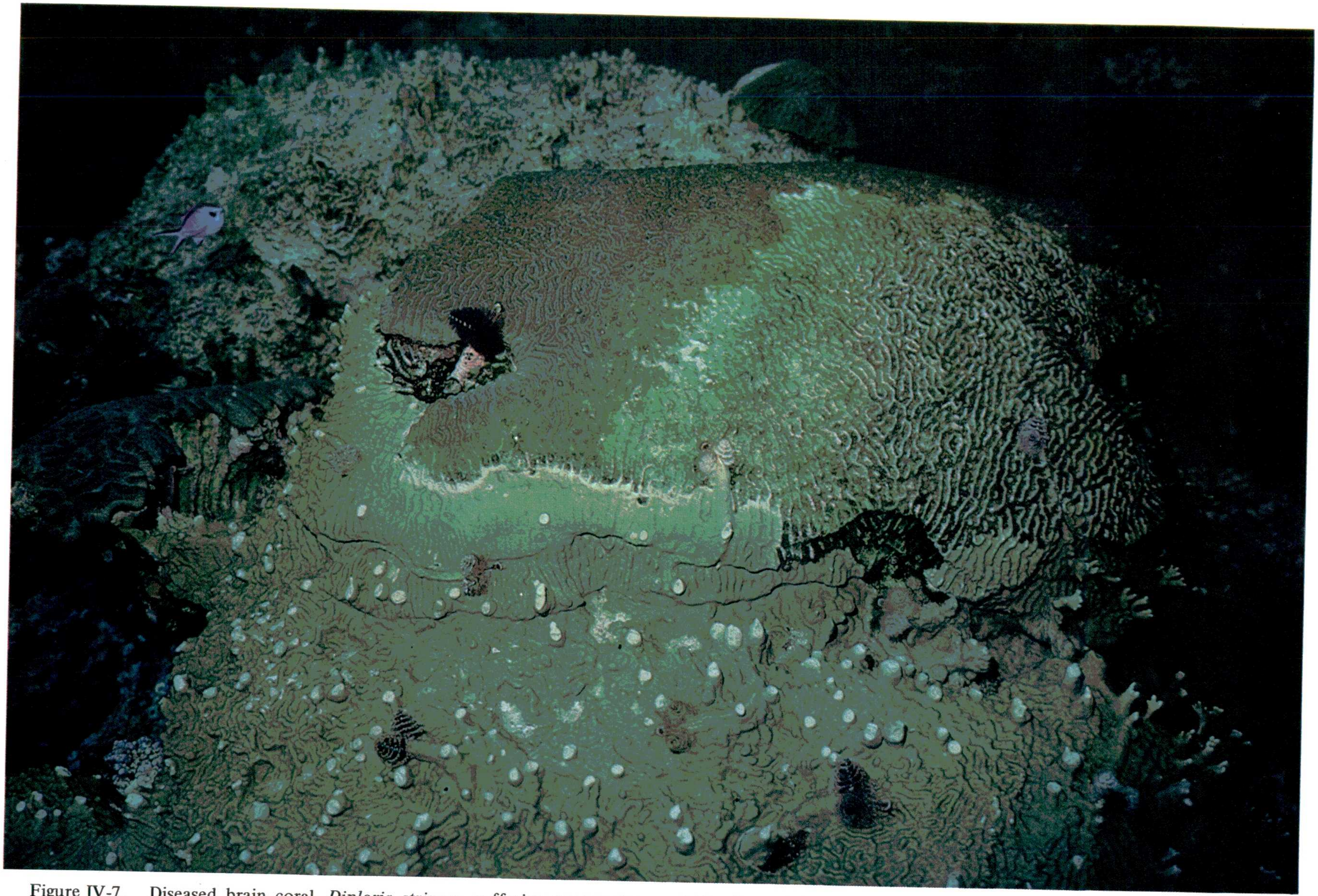

Figure IV-7. Diseased brain coral, *Diploria strigosa*, suffering progressive mortality from right to left while being encroached upon from below by an encrusting colony of the hydrozoan coral *Millepora* sp. Filamentous algae are frequently conspicuous as a green colored band along the receding border of diseased coral. It is not known whether such algae are in any way responsible for death of coral.

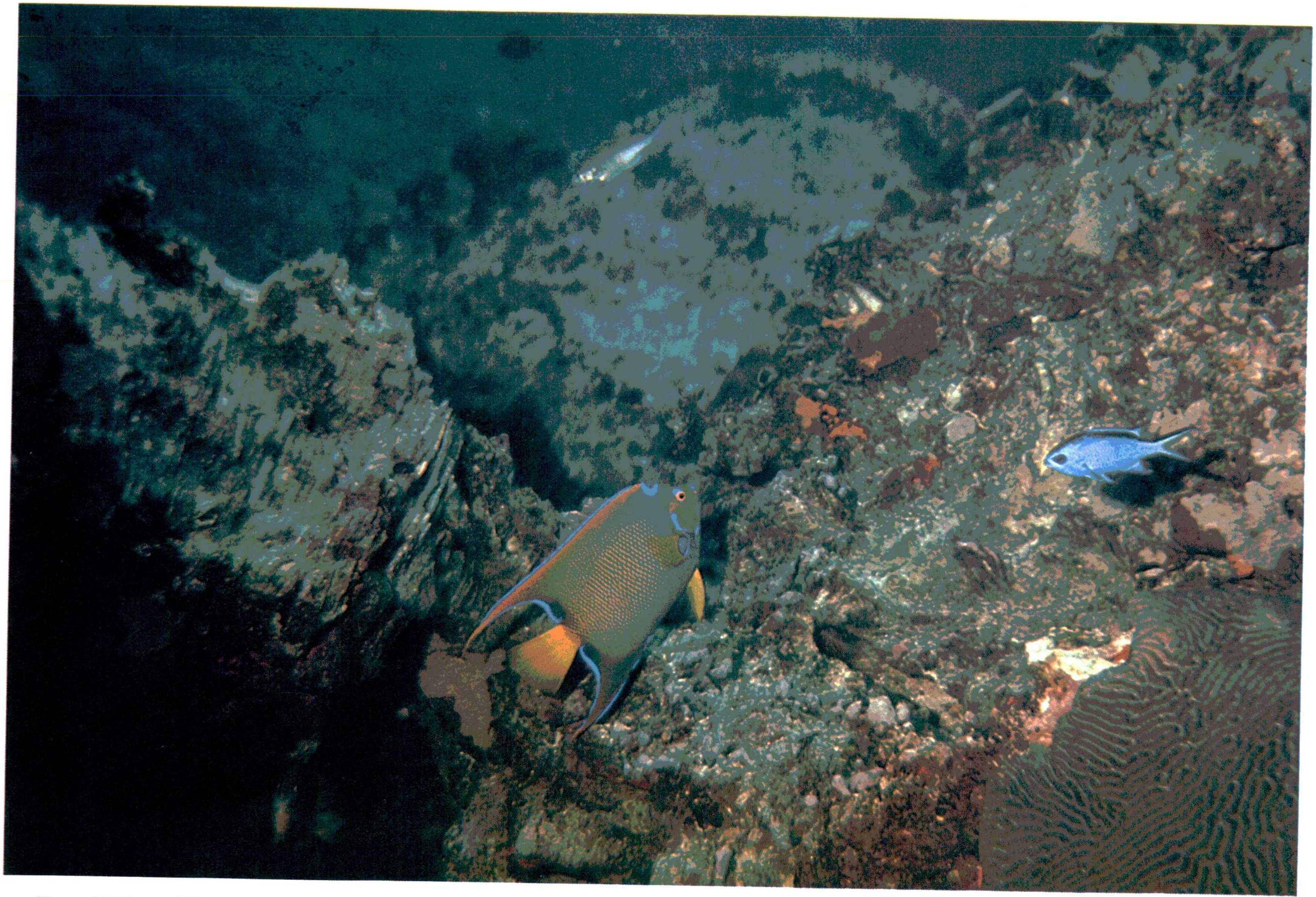

Figure IV-8. Reef fishes, *Holacanthus ciliaris, Chromis cyaneus* and others at 26 m depth, West Flower Garden.

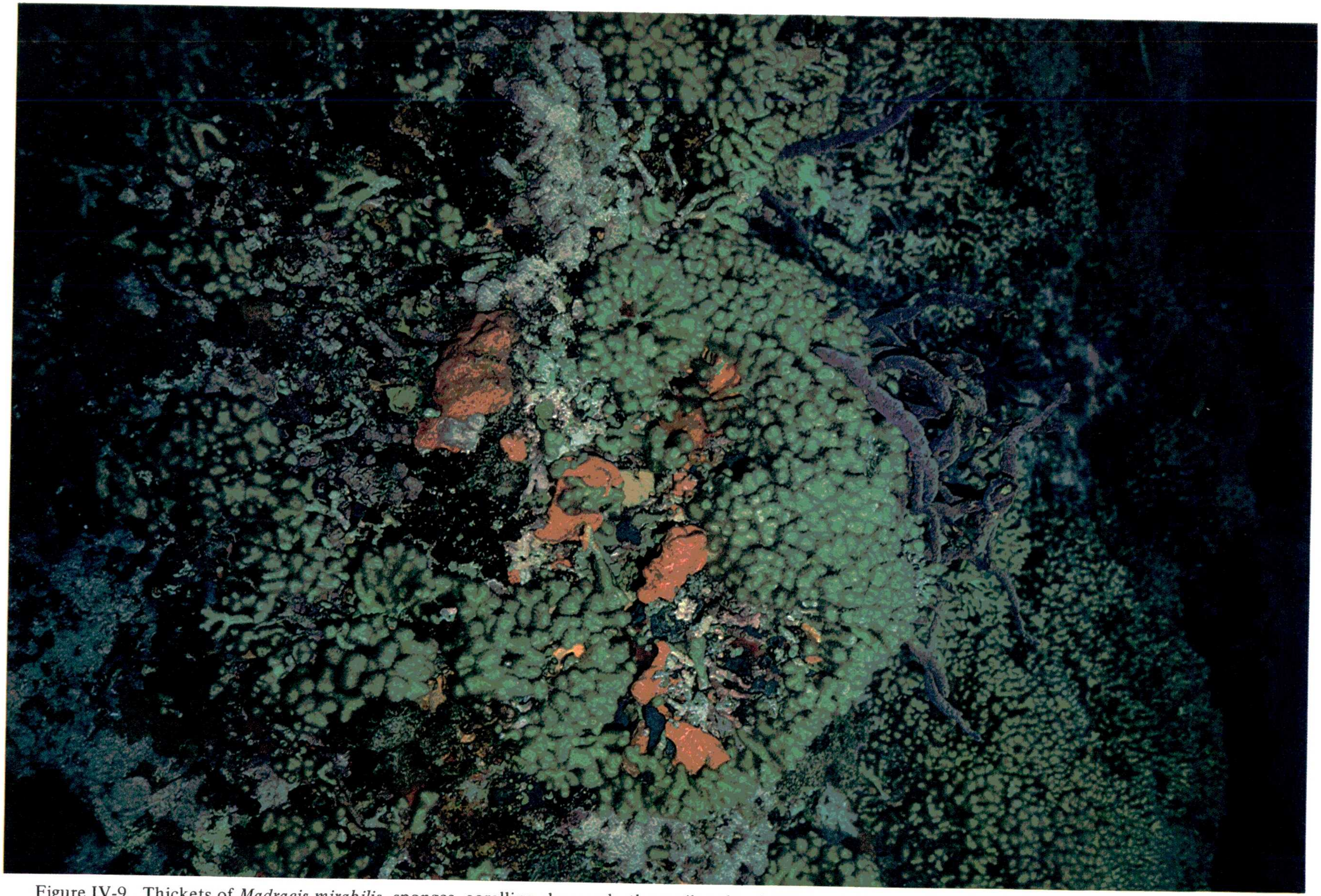

Figure IV-9. Thickets of *Madracis mirabilis*, sponges, coralline algae and other epibenthos in *Madracis* Zone at 28 m depth, East Flower Garden.

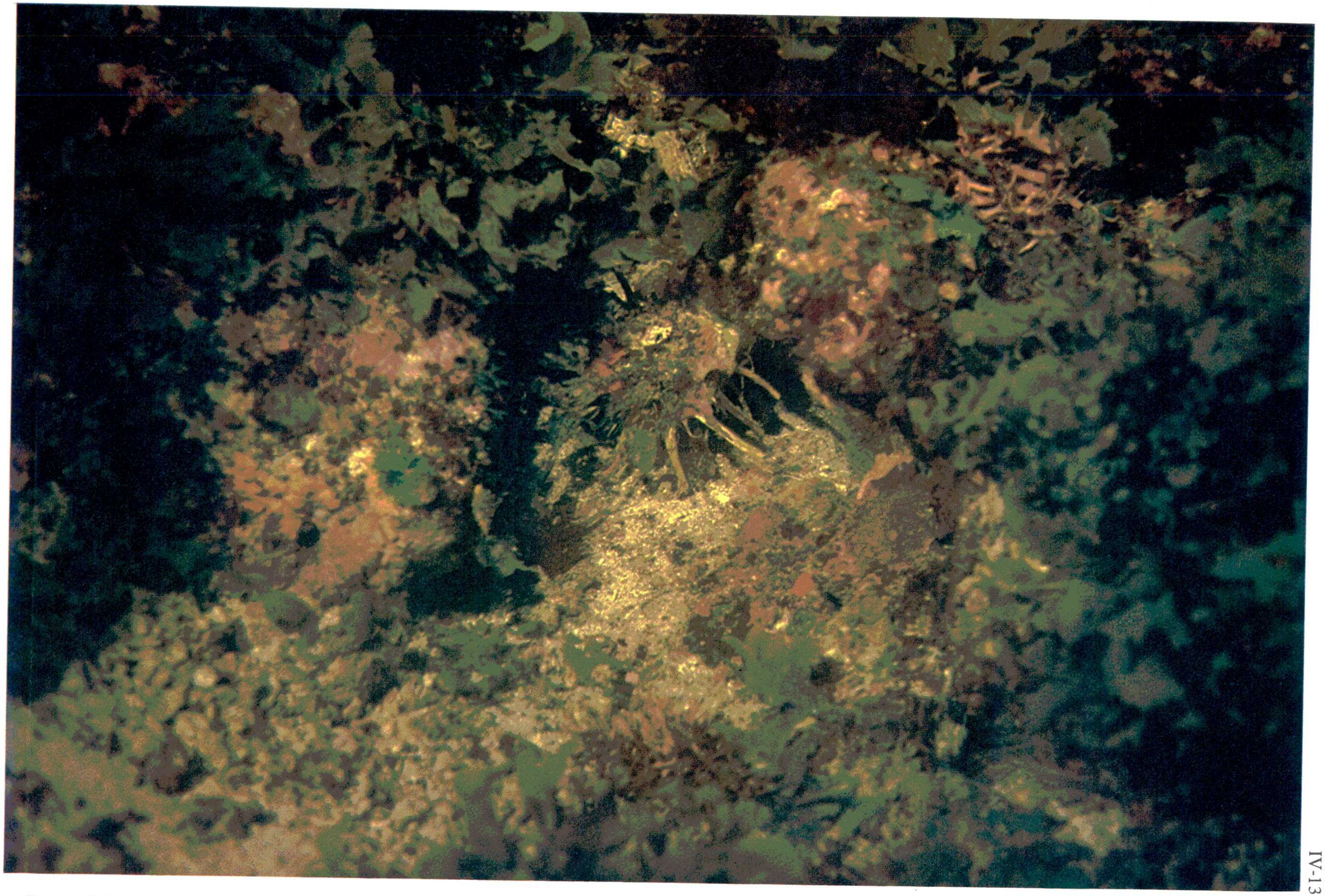

Figure IV-10. Several species of leafy algae surrounding a *Spondylus* Leafy Algae Zone knoll at 40 m depth, East Flower Garden.

coarse carbonate sand. Presence of *Madracis* gravel among coral heads on the deepest parts of the high diversity coral reef, where large populations of living *Madracis mirabilis* do not occur, may imply that the high diversity coral reef is encroaching upon the *Madracis* knolls at the reef edge. Therefore, formation of these knolls may be one of the sequential steps in development of high diversity coral reefs at EFG. Comparable knolls bearing *Madracis* Zones, but not Leafy Algae Zones, have been encountered on the eastern extremity of the main reefal structure at WFG.

C. ALGAL-SPONGE ZONE

The Algal-Sponge Zone includes a number of biotope types occurring between 46-82 m at the EFG and 46-88 m at WFG. Coarse carbonate sand and rubble (gravel-size particles) surrounding the living coral reefs (Coral Debris Facies) mark a geobiological transition between the coral reefs and the surrounding sedimentological platform, which is largely covered with carbonate sand, gravel, nodules and partly drowned reefal structures. In general, the Algal-Sponge biotic zone is spatially conincident with this platform.

Large areas on both banks where nodules predominate compose the *Gypsina-Lithothamnium* sedimentological facies. The most important contemporary producers of carbonate nodules and crusts on rubble and reefal structures are the coralline algae, mostly *Lithothamnium* and *Lithoporella,* and the nodules are typically referred to as algal nodules (Figure IV-11). These corralline algae are also the overwhelmingly dominant living organisms of the Algal-Sponge Zone.

The algal nodules (which range in size from less than 1 to 10 cm or more, and in most places cover 50%-80% of the bottom) create a biotope which harbors an infaunal and epifaunal community which is probably comparable in diversity to the living coral reefs. In addition to coralline algae and the encrusting foraminifer *Gypsina*, the nodules themselves house an abundance of boring species and attached epibenthos (Abbott, 1975). Numerous mobile invertebrates and small fishes find shelter under, between, and within the nodules. Beneath the nodules, coarse carbonate sand contains active soft bottom infaunal populations, as evidenced by the presence of numerous burrows.

Most of the leafy algae occurring at both banks occurs among the algal nodules and on reefal structures within the Algal-Sponge Zone (the aforementioned algae-covered knolls in shallower water at EFG are comparatively small in area). Leafy algae are pervasive among the nodules and on hard surfaces within the Algal-Sponge Zone but are neither uniformly distributed nor uniformly abundant from place to place. At certain locations lush growths of *Stypopodium* sp. and *Peyssonnelia* sp. may obscure all else on the bottom. The highly productive and renewable benthic algae populations must furnish substantial amounts of food to the surrounding communities.

Calcareous green algae, *Halimeda* spp. and *Udotea* sp., contribute to sediment production within the Algal-Sponge Zone (Figure IV-12). Patches in excess of 10 m diameter composed almost exclusively of *Halimeda* sp. have been seen at both banks within the algal nodule zone. These patches are apparently long-lived, semi-permanent features because the platelike remains of dead *Halimeda* sp. extend at least several centimeters deep into the substratum. *Halimeda* spp. occur also as individual plants among the nodules and on reefal structures.

Several species of hermatypic corals are abundant enough among the algal nodules to be considered major sediment producers within the Algal-Sponge Zone. Saucer-like colonies of *Helioseris cucullata* and *Agaricia* sp. are pervasive but unevenly distributed, with populations varying from less than one to over ten colonies per square meter. Several small species of *Madracis* likewise occur with varying abundance among the algal nodules.

Of the various species of sponges which are conspicuous and abundant within the Algal-Sponge Zone, *Neofibularia nolitangere* is most distinctive (Figure IV-13). Subcircular crusts of this sponge a meter or so in diameter occur on nodules, sand, or rock within the zone. Fishes and mobile invertebrates are attracted to the sponge, swimming or crawling among its chimneylike spires.

Populations of echinoderms within the Algal-Sponge Zone must add significantly to the carbonate substratum. Sizeable comatulid crinoids and a number of asteroid species are to be found everywhere on the banks except on the living coral reefs. A particularly large population of the asteroid starfish *Linckia nodosa* (Figure IV-14) and great numbers of the urchins *Pseudoboletia maculata* and *Arbacia punctulata* were see on the algal nodules and reefal structures of the platform west of the main reef at EFG. Interestingly, similar concentrations of these particular asteroids and echioids have not been seen on other parts of either bank. This may imply a small-scale environmental control on their distribution which could be reflected in carbonate sediment composition.

Small gastropods and pelecypods are abundant on and among the nodules, and gastropod shells are known to be nuclei around which some of the nodules are formed. The largest abundant pelecypod in the Algal-Sponge Zone is the American thorny oyster, *Spondylus americanus* (Figure IV-13), which occurs attached to nodules as well as reefs. Its distribution, as with many of the conspicuous organisms in the Zone, appears irregular and locally contagious resulting in a high degree of lateral variation in population levels. Small clumps (approximately one-half meter in diameter) of vermicularian gastropod tubes occur infrequently among the nodules and on sand bottoms within the Algal-Sponge Zone. Their contribution to the carbonate sediment is probably minor. The coiled tubes of this species sometimes occur in masses, embedded in the sponge *Chelotropella* sp.

There are obviously many species of plants and animals associated with Algal nodules within the Algal-Sponge Zone which are involved to varied extents in the frame and sediment building processes. Their successful effort in this respect is probably the dynamic factor on which the stability of benthic community structure within the Zone depends.

Small Yellowtail reeffishes (*Chromis enchrysurus*) are the most abundant of the conspicuous fishes which congregate around irregularities in the Algal-Sponge Zone. Conical burrows one meter across and one-half meter deep produced by the Sand tilefish (*Malacanthus plumieri*) are scattered about the Zone from the base of the main coral reef down to at least 70 m. Other particularly characteristic fishes among the algal nodules are the small Cherubfish (*Centropyge argi*) and Orangeback bass (*Serranus annularis*).

D. PARTLY DROWNED REEFS AND DROWNED REEFS

The nature of both types of living coral reefs has been discussed. As indicated, uncertainty exists concerning the successional relationship, if any, between the high diversity and low diversity coral reefs. The developmental history of the deeper, and presumably older, partly drowned and drowned reefs may be even more complex, possibly involving subaerial exposure of the reefrock (Section III).

The biota now occupying partly drowned and drowned reefs at the Flower Gardens probably do not reflect the history of the reefs as much as they do contemporary environmental limitations on depth distributions of the organisms. Accordingly, partially drowned reefs are defined here as those reefal structures which exist now at depths below which hermatypic corals are capable of building sizeable heads or crustose colonies which would cover substantial portions of the rock, but within a depth range favoring the predominance of crustose coralline algae (46-82 m at EFG and 46-88 m at WFG). Drowned reefs are those reefal structures now existing at depths below which hermatypic corals commonly exist and below which crustose coralline algal populations are significant (below 82 m at EFG and below 88 m at WFG).

Not unexpectedly, partially drowned reefs are generally restricted to the Algal-Sponge Zone, where they are a major biotope component. They bear crusts dominated by coralline algae, accompanied by other sessile organisms which are also typical of the algal nodules (Figure IV-15). In addition, they house large anemones such as *Condylactis gigantea* and *Lebrunia danae*, an abundance of large comatulid crinoids, occasional basket stars, limited crusts of the hydrozoan coral *Millepora* sp., and infrequently, small colonies of the hermatypic corals *Agaricia* spp., *Helioseris cucullata, Montastrea cavernosa*, and *Stephanocoenia michelini*.

The partly drowned reefs attract a number of fish species which occur on the living coral reefs. Most of these "expatriate" reef fishes occur consistently on similar structures at other banks in the northwestern Gulf which do not possess living coral reefs and, therefore, may not necessarily be recruited from the shallower coral reef fish assemblage at the Flower Gardens. The most abundant fish frequenting the partly drowned reefs is the small Yellowtail reeffish, *Chromis enchrysurus*, which is not often seen on the high diversity coral reefs.

Drowned reefs occur below approximately 82 m at EFG and 88 m at WFG where coraline algae do not thrive and hermatypic corals are absent. Comatulid crinoids, small deepwater octocoral whips and fans, antipatharians, encrusting sponges, and solitary ahermatypic corals are the most conspicuous attached organisms.

The assemblage of fishes frequenting drowned reefs include Red snappers (*Lutjanus campechanus*), Spanish flag (*Gonioplectrus hispanus*), Snowy grouper (*Epinephelus niveatus*), Bank butterflyfish (*Chaetodon

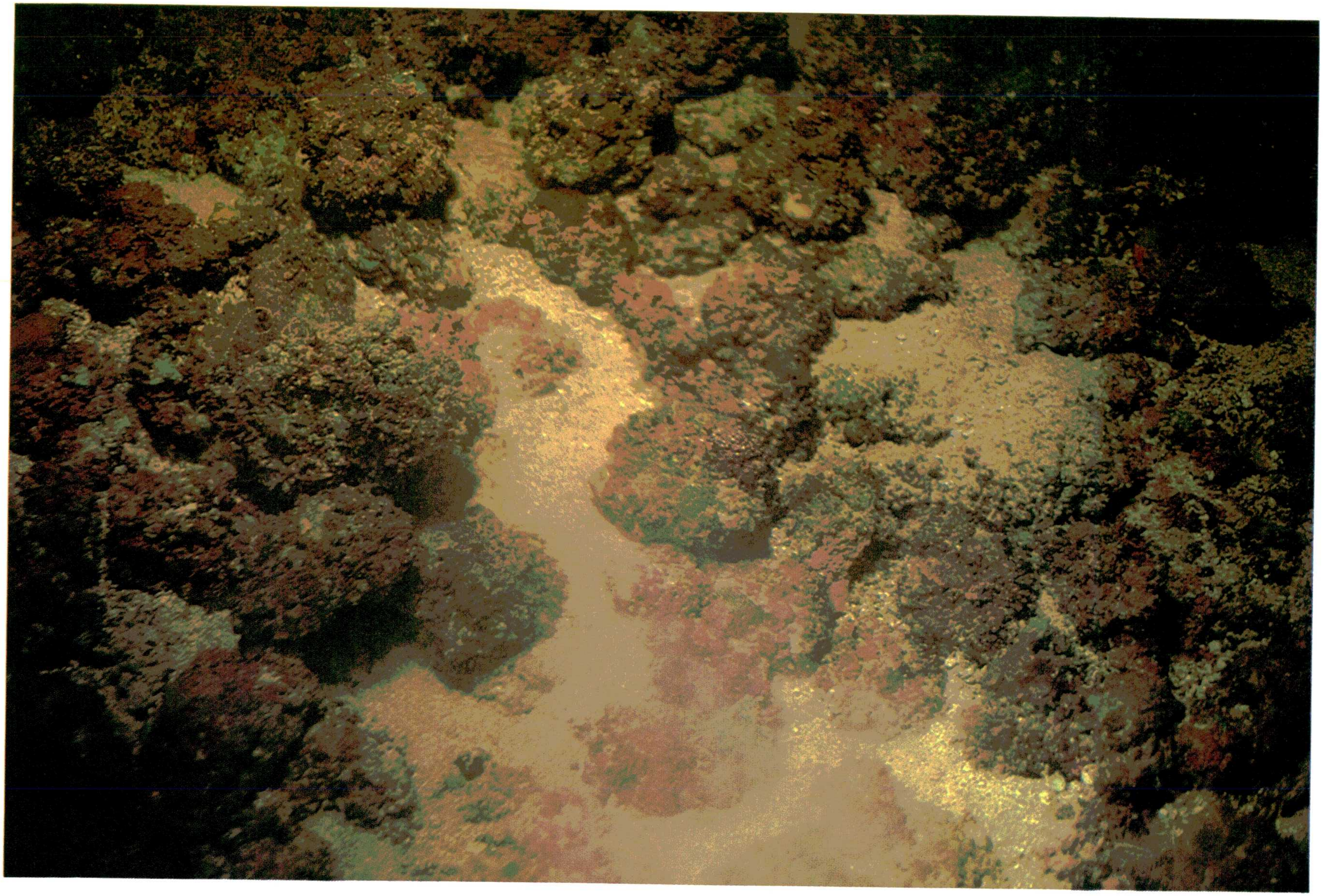

Figure IV-11. Algal nodules on coarse carbonate in Algal-Sponge Zone at 60 m depth, East Flower Garden.

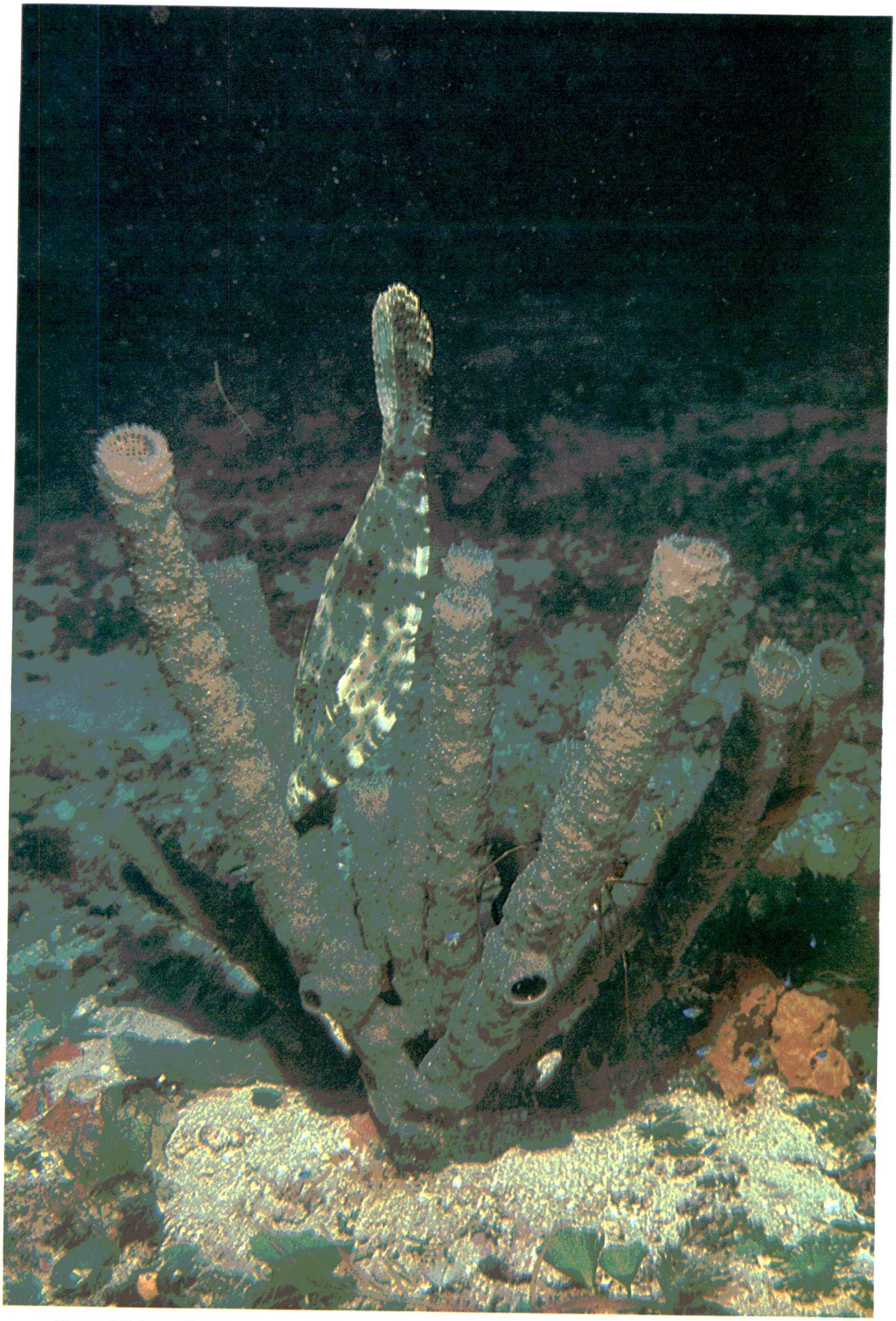

Figure IV-12. Tube sponge, *Callyspongia* sp.; scrawled filefish, *Aluterus scriptusi;* calcareous green algae, *Udotea* sp.; and other benthic organisms on coarse carbonate sand at 52 m depth, West Flower Garden.

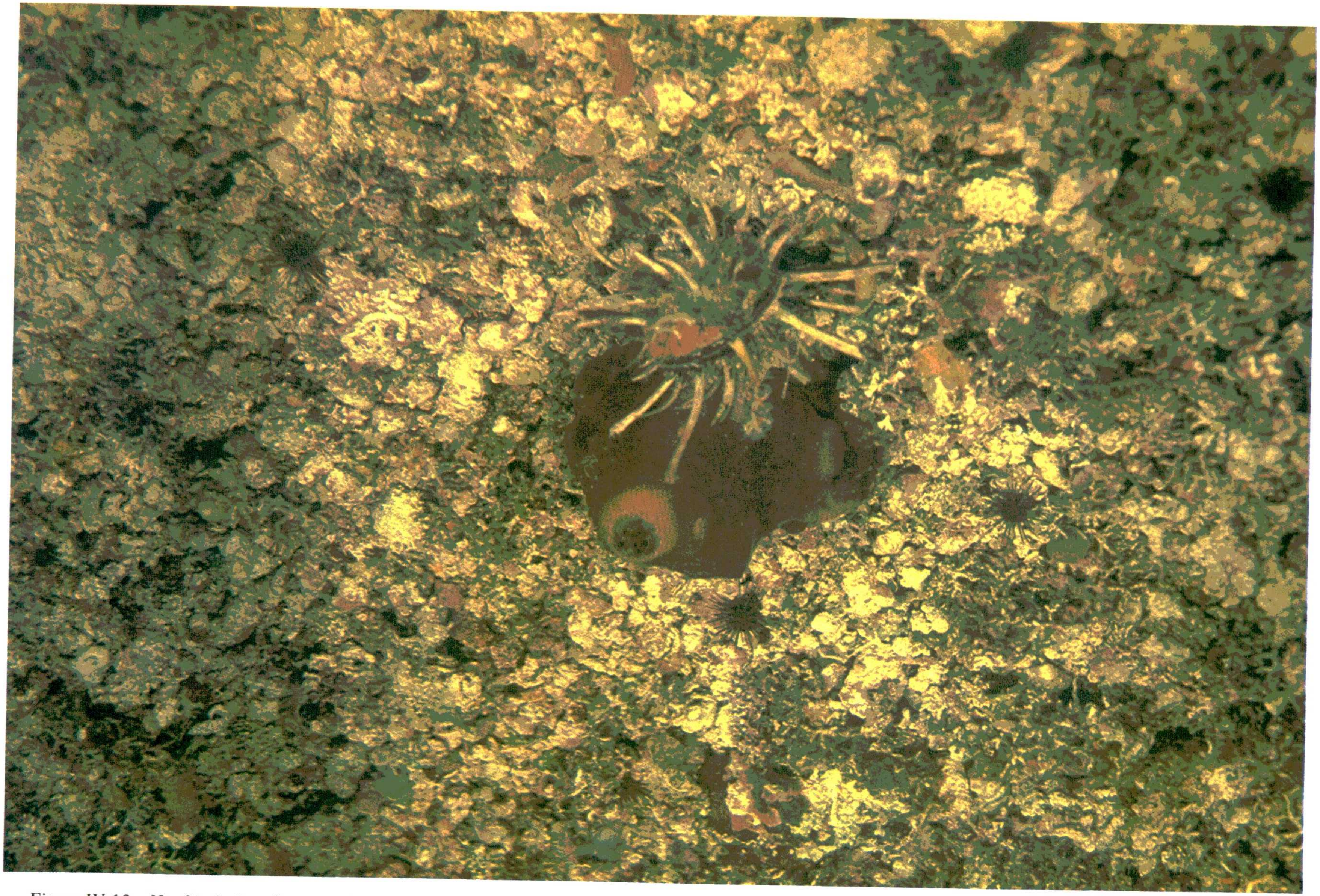

Figure IV-13. *Neofibularia nolitangere* behind an American thorny oyster, *Spondylus americanus*, on algal nodule covered bottom at 55 m depth, East Flower Garden.

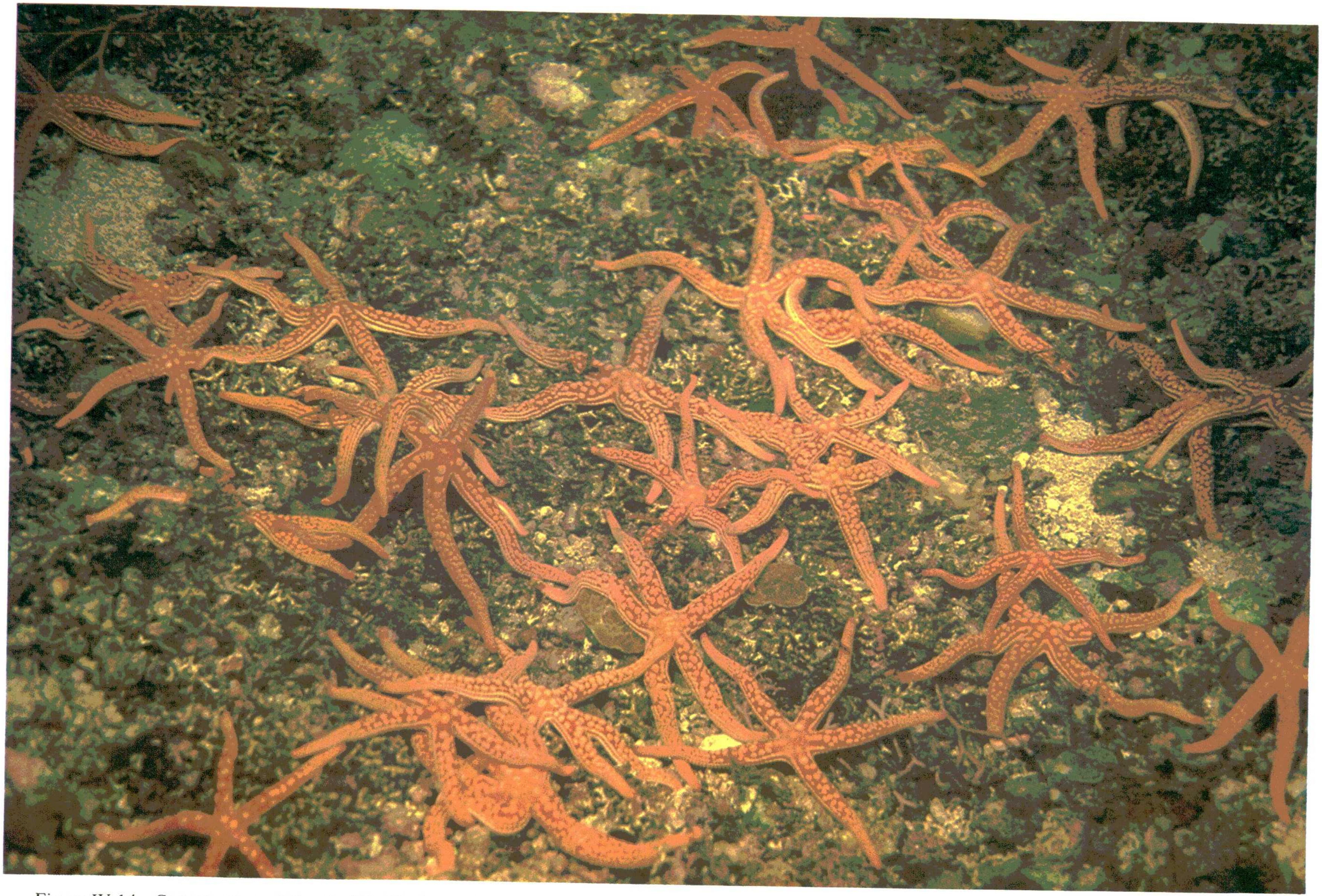

Figure IV-14. Congregation of the starfish *Linckia nodosa* on algal nodule bottom at 55 m depth, East Flower Garden.

Figure IV-15. Surface of partly drowned reef showing crusts of coralline algae, leafy algae, the large anemone *Condylactis gigantea* and other epibenthic organisms at 59 m depth, East Flower Garden.

aya), scorpionfishes (*Scorpaenidae*), and most characteristically, the Roughtongue bass (*Holanthias martinicensis*). The snappers are highly mobile schooling fish which congregate around reefal structures at all depths on the banks but seem to prefer the deeper "drop-offs" and bank-edge features and show little affinity for the high diversity reef tops. The other fishes listed are commonly found only on the drowned reefs and the deepest partly drowned reefs. The drowned reef ichthyofauna is, therefore, substantially different in basic species composition from, and of much lower diversity than, that of the partly drowned reefs or the coral reefs.

Drowned reefs at the Flower Gardens exist in comparatively turbid water and are generally covered with veneers of fine sediment, the veneers being thicker on the deeper reefs. Light penetration, water turbidity, sedimentation, and temperature are probably the most important factors controlling the present distribution of hermatypic corals and coralline algae on the banks. It is suspected that were it not for the chronically turbid bottom water and sedimentation around the peripheries of the banks, the living algal nodules, partly drowned reefs, and other elements of the Algal-Sponge Zones would extend to slightly greater depths, as they do on certain other banks farther offshore where the surrounding soft bottoms are deeper (Texas A&M Research Foundation, 1983).

E. TRANSITION ZONES

White, bedspring-shaped antipatharian whips, *Cirlipathes*, occur from 52 to over 90 m depth and, where they are most abundant (generally around 60-85 m), they mark a transition between biotic assemblages which exhibit distinct shallow water affinities (leafy algae, abundant coralline algae, hermatypic corals, and sizeable shallow water reef fish populations) and those which are deepwater oriented. The upper parts of this supposed "Antipatharian Zone" blend with the Algal-Sponge Zone and it is impossible to find any sharp demarcation between the two. One might just as well speak of a lower Algal-Sponge Zone which has a sizeable antipatharian population.

Deeper parts of the "Antipatharian Zone" (over 80 m) are recognizably less diverse and characterized by antipatharians, comatulid crinoids, few if any leafy algae, thin to sparse populations of coralline algae and a distinctly limited fish fauna including *Holanthias martinicensis, Bodianus pulchellus, Chromis enchrysurus, Chaetodon sedentarius, Holacanthus bermudensis*, and a few others.

Between 73-76 m the nature of the bottom changes, usually rather abruptly, from algal nodules and crusts to a soft, level bottom of mixed, coarse calcareous sand with an abundance of *Amphistegina* tests and fine silt and clay-sized particles which are easily stirred up and remain in suspension for a long while. The foraminifer *Amphistegina* sp. is known to live on the algal nodules at both banks. Nonliving tests of this protozoan account for a large portion of the *Amphistegina* sands occurring on the banks (Figure IV-3). Presumably, remains of spent *Amphistegina* from the algal nodule biotope are transported downslope to become incorporated into the *Amphistegina* sand.

The *Amphistegina* sedimentary facies is characterized by the presence of a conspicuous population of echinoderms, particularly the urchin *Clypeaster ravenelii* and the asteroids *Chaetaster* sp., *Narcissia trigonaria*, and others. Also, patterned burrows (6-12 burrows in circular arrangements of diameters up to approximately one-half meter) are overwhelmingly numerous. In places between 80-90 m a tremendous population of small comatulid crinoids clings to carbonate gravel and other objects on the *Amphistegina* sand. These crinoids do not occur in such numbers elsewhere on the banks and their distribution does not appear to be related to the distribution of larger crinoid species which occupy the lower Algal-Sponge Zone, rocks, and drowned reefs to depths exceeding 120 m. The presence of the small crinoids indicates a final transition from shallower, higher diversity, clear water communities dominated by frame building corals and coralline algae to subdued, deep water communities subjected to turbidity, sedimentation, and chronically low light levels. With increasing depth, the coarser sediments of the *Amphistegina* Facies are replaced by mud in the Quartz-Planktonic Foraminifer sedimentary facies.

The deepwater populations, whether on hard or soft bottom, represent an assemblage of organisms which differs substantially from the clearwater assemblages. Few conspicuous species of fish and invertebrates occur in both the clear, shallow water and the turbid, deep water environments on the banks.

F. THE EAST FLOWER GARDEN BRINE SEEP, A UNIQUE ECOSYSTEM

Hypersaline (~ 200°/oo), sulfide-rich brine issues from coarse carbonate sand in the floor of a small basin at 71 m depth at the eastern edge of EFG (Bright, 1977) (Figure IV-16, Map No. 9). A shallow brine lake occupies part of the basin floor. A canyon into which the lake overflows extends from the east-southeast margin of the basin to the edge of the bank at 80 m depth.

The brine is denser than seawater, anoxic, and contains exceptionally high levels of dissolved hydrocarbon gases (methane, ethane, and propane) and hydrogen sulfide. The density differential inhibits mixing of the lake brine with overlying seawater, although diffusion of dissolved components, particularly hydrocarbon gases, across the brine-seawater interface is implied (Brooks et al., 1979). Because of the lack of mixing, chemical characteristics of water above and below the lake interface differ drastically over a vertical distance of less than 2 cm (e.g., salinity 36.7°/oo vs 200°/oo).

Normally, the lake's interface is perfectly flat with thin, white masses (thought to be bacterially derived sulfur flakes) floating at the interface. Residence time of brine in the basin is 2-7 hours (Bright et al., 1980a).

The overflow rate of brine from the lake into the canyon was visually estimated to be 5-20 liters/sec. Mixing starts immediately as the brine spills out of the lake in turbulent flow down a 0.5 m fall. Salinity in the overflow was 55°/oo, representing an initial entrainment of approximately 7 parts seawater to 1 part brine. Mixing continues as brine flows at a rate of 10-25 cm/sec down a 1-3 m wide channelized depression in the canyon axis. Near mid-canyon (30 m from outflow) the salinity is 48°/oo (dilution factor of 14) and near the canyon mouth (60 m from outflow) it is 38-40°/oo (dilution factor ~ 50). At the canyon mouth the brine stream leaves its channel, spreads laterally, decreases substantially in height, and dissipates as it moves onto the level bottom adjacent to the bank.

The sand and rubble substratum of the canyon has obviously been affected by the flow. Well-sorted, coarse, carbonate sand has been piled in sandbar-like deposits on either side of the stream channel and along the bases of the canyon walls. The stream channel bed is relatively rough, containing rubble, sizeable boulders, mollusk shells, and even a stick of waterlogged wood. Scour and erosional undercutting of carbonate rock is apparent where large boulders occur in the stream or where the stream contacts the canyon wall.

Natural gas seeps (primarily methane with small amounts of ethane and propane) occur along the axis of the canyon in the mixing stream and on the canyon and basin walls. Typically, they emit series of small bubbles in intermittent bursts lasting several seconds (Section III, Figure III-6). Such seeps are common over the entire EFG (Bright, 1977) and on most other banks in the northwestern Gulf (Bernard et al., 1976).

Geothermal warming of the brine is minimal. One temperature measurement in the mixing stream just below the lake overflow was 22.5°C (0.3°C higher than overlying water). Measurements further down the canyon indicated a lesser temperature differential. No direct *in situ* temperature measurements have been made in the lake; however, upon collecting the brine, we noticed no difference in its temperature compared to that of water samples taken above the brine-seawater interface (22.2°C in 1977, 20.3°C in 1976).

EFG and most other banks off northern Texas and Louisiana are topographic manifestations of upward intrusions from deep Triassic-Jurassic salt deposits (salt domes). Seismic records confirm that EFG salt intrusion has penetrated from depths of 6,000 m or more to at least within 150 m of the sea floor. It is likely that the salt comes almost to the sea floor near the brine seep. Comparisons of ^{226}Ra levels in EFG brine, typical oil field brines, and a mixture of brines from four salt domes in the Gulf coast region led Brooks et al. (1979) to suggest that EFG brine is a product of dissolution of salt deposits beneath the bank by seawater which percolates down through overlying sediments. The presence of gypsum deposits on carbonate nodules collected from the brine lake implies dissolution of caprock typically associated with subsurface salt domes.

The seep described above may not be the only one the EFG bank. In 1978 several small (1 m diameter) volcano-shaped structures were observed on the soft bottom at 100 m depth on the northeastern flank of the bank. No samples were taken nor measurements made, but the coloration of the substratum and associated surficial deposits suggested brine seepage, possibly intermittent.

The dominant organisms in the brine lake are apparently bacteria. ATP levels in the brine, mixing zone, and overlying waters were 83.3, 38.5 and 43.5 ng/liter, respectively, in September 1977. All of these values are 10-20 times greater than those expected in Gulf water at comparable depths (2.0-5.0 ng/liter) and are equivalent to bacteria values obtained from surface waters in portions of the Gulf. Sulfur bacteria have been cultured from

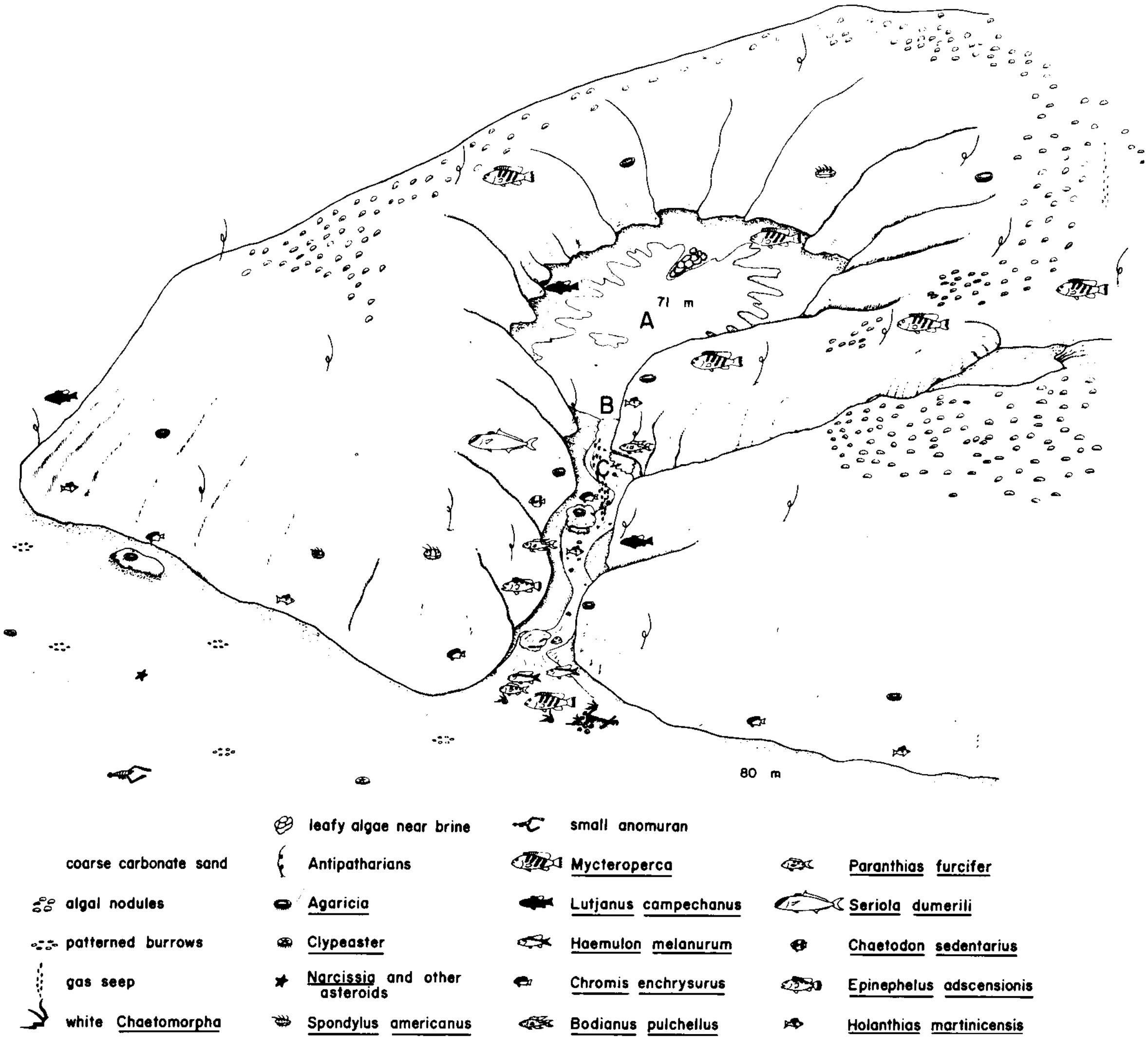

Figure IV-16. East Flower Garden brine seep. A – shallow brine lake of 200^{o}/oo salinity. B – overflow from lake into "mixing stream" in canyon (55^{o}/oo). C – arrow points to small pool of 200^{o}/oo brine below overflow. Salinity of brine near anchor at mouth of canyon is approximately 40^{o}/oo.

brine lake sediments and the substratum within the lake has a distinctive color zonation which suggests the presence of a sulfuretum (habitat in which sulfur bacteria are dominant, producing visible white patches of dense cell masses and elemental sulfur, Jorgensen, 1977) (Bright et al., 1980a).

Although the anoxic, sulfide-rich brine and oxygenated brine-seawater mixtures are obviously toxic to normal bank biota, deleterious effects on surrounding epibenthic communities are minimal and restricted to a zone several centimeters to 2 m wide surrounding the brine and mixing stream (Bright et al., 1980b). No living macroscopic plants or animals occur in the brine or in the mixing stream for most of its length. However, living coralline algae, leafy algae, foraminifers, sponges, bryozoans, anemones, polychaetes, sipunculids, amphipods, and pelecypods occur 1 or 2 cm above the brine seawater interface. Scleractinian corals, antipatharians and a seemingly normal assemblage of epibenthic organisms occupy the hard substratum 1-3 m away from the lake interface and mixing stream.

In the carbonate sand beneath the mixing stream there exists a sulfide tolerant community of meiobenthic animals (thiobios) dominated by members of the little known phylum Gnathostomulida (Powell and Bright, 1981). This is undoubtedly the most unique biotic assemblage yet discovered at the Flower Gardens. It is suspected that these and other organisms derive much of their nutrition from highly productive chemosynthetic and photosynthetic bacteria and blue-green algae populations in the brine pool and mixing stream.

Toxicity of the brine decreases as it is diluted with overlying seawater and certain epibenthos and infauna can exist in the mixing stream where the ratio of seawater to brine approaches 50 :1 (38-40^{o}/oo salinity, limited sulfide). Under these conditions, white-colored, filamentous algae grow on the hard substratum, and coarse carbonate sand harbors polychaetes, podocopid ostracods, nematodes, gammarid and caprellid amphipods, tanaidaceans, isopods, harpacticoid copepods, pelecypods, and gastropods.

Demersal fishes repeatedly pass in and out of the mixing stream where sea water dilution is moderate to high. Several species will briefly enter the full-strength brine in the lake.

Petroleum production, with attendant discharge of formation brines, is expected at EFG in the future. Construction of certain regional petroleum reserve storage facilities involves dissolution by seawater of the cores of salt domes (similar to the one beneath EFG) and the discharge of resulting brines into the ocean. Observations, such as those described herein, are pertinent to an understanding of the possible impacts of these types of discharges on marine communities.

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SECTION V

CURRENTS AND SUSPENDED SEDIMENTS AT THE EAST FLOWER GARDEN BANK

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PREFACE

Due to the illness and the tragic and untimely death of the author, this section could not be updated to incorporate the additional data at the East Flower Garden Bank and the new data at the West Flower Garden Bank depicted on Map No. 6.

INTRODUCTION

This section of the study addresses material shown in Map No. 6. The data used in developing the map has been accrued over a period of three years during all seasons.

There are three types of data which have been used in the development of the map: water column profiles; *in situ* boundary layer observations; and records from moored current meters. At each station where water column profiling was done, several parameters were measured as synchronously as possible. These were current speed and direction, transmissivity, salinity, and temperature. In all, 54 individual stations were occupied. At three of those stations, profiles were taken hourly for 8-12 hours.

During the boundary layer studies, observers in Texas A&M's DR/V DIAPHUS recorded various flow visualization experiments on super 8 mm movie film and video tape. In the last two years of this phase of the investigation, the submersible was also fitted out with a transmissometer and thermistor to aid in quantifying sediment response to boundary layer flow phenomena. In addition, time series profiles from the tending vessel were obtained so that conditions in the upper water column could be correlated with those observed in the boundary layer.

The moored current meters were first deployed in late January 1979. Two tautline arrays with subsurface flotation were set in approximately 100 m of water near East Flower Garden Bank. Array I was placed to the northeast of the bank away from the direct topographic influence of the bank. Array II was placed on the southwestern margin of East Flower Garden Bank for the express purpose of measuring the modification of the flow induced by the presence of the bank. (See Map No. 6 for the location of the arrays.)

Each array was fitted out with three internally recording savonius rotor type instruments designed to measure current speed and direction as well as water temperature. The shallowest meter on each array was placed at 60 m depth, corresponding to the break in slope on the bank marking the transition from reef top to flank. The lower meters were placed at 94 m and 96 m (6 m and 4 m above the bottom, respectively) so that they were well within the bottom boundary layer. All of these instruments were set to record once every 6 minutes and deployed for 90 days at a time.

An electromagnetic current meter was rigidly mounted on the reef in approximately 30 m of water. This type of instrument was used rather than a savonius rotor variety on the bank top because the savonius rotors are omnidirectional and subject to wave pumping. Due to the relatively high power consumption of the electromagnetic current meter, it was set to record only once every 20 minutes.

A. NEPHELOID LAYER

The term nepheloid has its origin in the Greek word for cloud, nephe'le'. A nepheloid layer is nothing more mystical than water rendered turbid or cloudy by sediment. Such a layer will form in the sea whenever a current of sufficient strength flows over a substrate of silt or clay-sized sediment.

Unfortunately, there is no standard concentration of suspended sediment in seawater which is recognized as the threshold limit of a "nepheloid layer." The reason for this is rather straightforward, the degree of turbidity of the water is a function of particle type and size as well as the absolute amount present. Given two equal concentrations of a particular suspended sediment in a volume of water, the one with the smaller particles will appear cloudier because the smaller particles present a greater surface area to reflect or scatter the light.

In order to obtain a measure of the relative amount of suspended sediment in the water column, a transmissometer was employed in this study. The transmissometer used in these early studies employed white light source with a filter window in the blue-green range. The instrument measures the intensity of a light beam which has passed through a 1-m path of seawater against the intensity of the source light. Transmissivity is therefore reported as the percentage of light transmitted over the 1-m path. In clear seawater, the transmissivity of the instruments is on the order of 80%-85% per meter. Other transmissometers with different light sources or filters would produce different transmissivity values for a given sediment load.

For the purpose of showing the distribution of suspended sediment around East Flower Garden Bank, it was decided to use 60% transmissivity as the highest value that would be called a "nepheloid layer." This value is the highest at which our observers in the submersible could perceive that the water was turbid, and it is the most common value marking the inflection between clear seawater and the more turbid bottom water in transmissivity profiles at the bank.

The bottom boundary layer is a zone near the bottom dominated by processes involving the turbulent transfer of energy from the flowing water to the bottom. It is a region of strong velocity gradients and mixing. The turbulent mixing produces shearing stresses on the weakly cohesive sediment at the water-bottom interface around the base of East Flower Garden Bank tearing the sediment loose from the bottom and lifting it into suspension. Outside of the boundary layer, vertical mixing is inhibited by both stratification and effects of the earth's rotation so that the suspended sediment is trapped near the bottom. Or, stated alternatively, the locally-produced nepheloid layer, when present, is contained in the bottom boundary layer.

Two cases are shown in Figures V-1, V-2, and V-3. Figure V-1 indicates the location of Station 1. Figure V-2 shows data taken in July 1979 at Station 1. It is rather typical of summer and fall conditions. The water is strongly stratified and the flow is baroclinic (depth dependent). Near bottom flow is approximately 25 cm/sec and there is relatively little suspended sediment in the water column above 100 m. The bottom boundary layer is not well mixed, possibly because of some onshore flow along the bottom.

In April 1979 an extreme condition was observed at Station 1. At that time the flow was barotropic (constant with respect to depth) and very strong ($>$ 90 cm/sec) (Figure V-3). Under this energetic flow, the bottom boundary layer reached a maximum thickness of well over 20 m. These conditions persisted for at least 24 hours, but the boundary layer did not thicken further. Therefore, under the worst case (little stratification and extremely rapid flow) the "nepheloid layer" was still trapped within 20 m of the bottom in 120 m of water.

The contours on Map No. 6 represent the shallowest occurrence of the 60% transmissivity level from all stations. The surface contour, therefore, represents the time-integrated location of the nepheloid layer. Note that in the three years of observation, the transmissivity values at stations on the bank shallower than 80 m never fell as low as 60%. The reason for this is that the sediment on the bank in depths of 80 m or less is made up of coarse biogenic debris too large to be placed in suspension. Also, stratification and rotational effects tend to make the flow around the bank strongly two dimensional (horizontal). Therefore, the nepheloid layer which develops over the silt and clay at the base of the bank cannot be carried up onto the shallower portions by those currents.

B. CURRENTS

The data sets from the July 11 to September 5, 1979, deployment of the current meters were used to prepare the information on Map No. 6. Unfortunately, the top meter on Array II recorded only direction and temperatures but no speed.

Each record was plotted as a time series subjected to spectral analyses, low pass filtered and replotted. Because of the quantity of data in the raw records, it was necessary to break them into segments of about 30 days for the initial spectral analyses. By averaging the spectra from each segment, the degrees of freedom, and hence statistical confidence, were increased for the high frequency power spectra. It was necessary, however, to low pass filter the data in order to produce the low frequency power spectra. A cascading Butterworth filter was used because of its sharp frequency cut off and phase preservation properties (Roberts and Roberts, 1978). All of the programs used for filtering and spectra generation were tested on synthetic data containing various combinations of sinusoidal signals to assure accuracy.

Plots of these low frequency current and temperature records ($<$ 0.04 cycles per hour) appear as Figures V-4 and V-5. Figure V-4 represents the data from Array I. The strong correlation of temperature and current variance as well as the directional difference between the top and bottom meters demonstrates the baroclinicity of the flow during the summer months. This is also borne out by the differences in mean speeds and direction from upper to bottom meters shown in Table V-1. Flow at 60 m during 1979 had a net drift of 7.4 cm/sec to the WSW, whereas bottom flow was to the SE. However, results from all deployments through 1981 show a monthly mean flow of 5 cm/sec to 25 cm/sec toward the east at a nominal depth of 60 m.

The power spectra of the unfiltered data from the top meter at Array I show that the most significant energy peak in temperature, u (east-west) and v (north-south) velocity components occurs at 0.04 cycles per hour (CPH). This is the frequency of both the diurnal tide and local inertia at the latitude of East Flower Garden Bank. An analysis of both the tidal components and original records suggest that most of the 0.04 CPH energy peak is

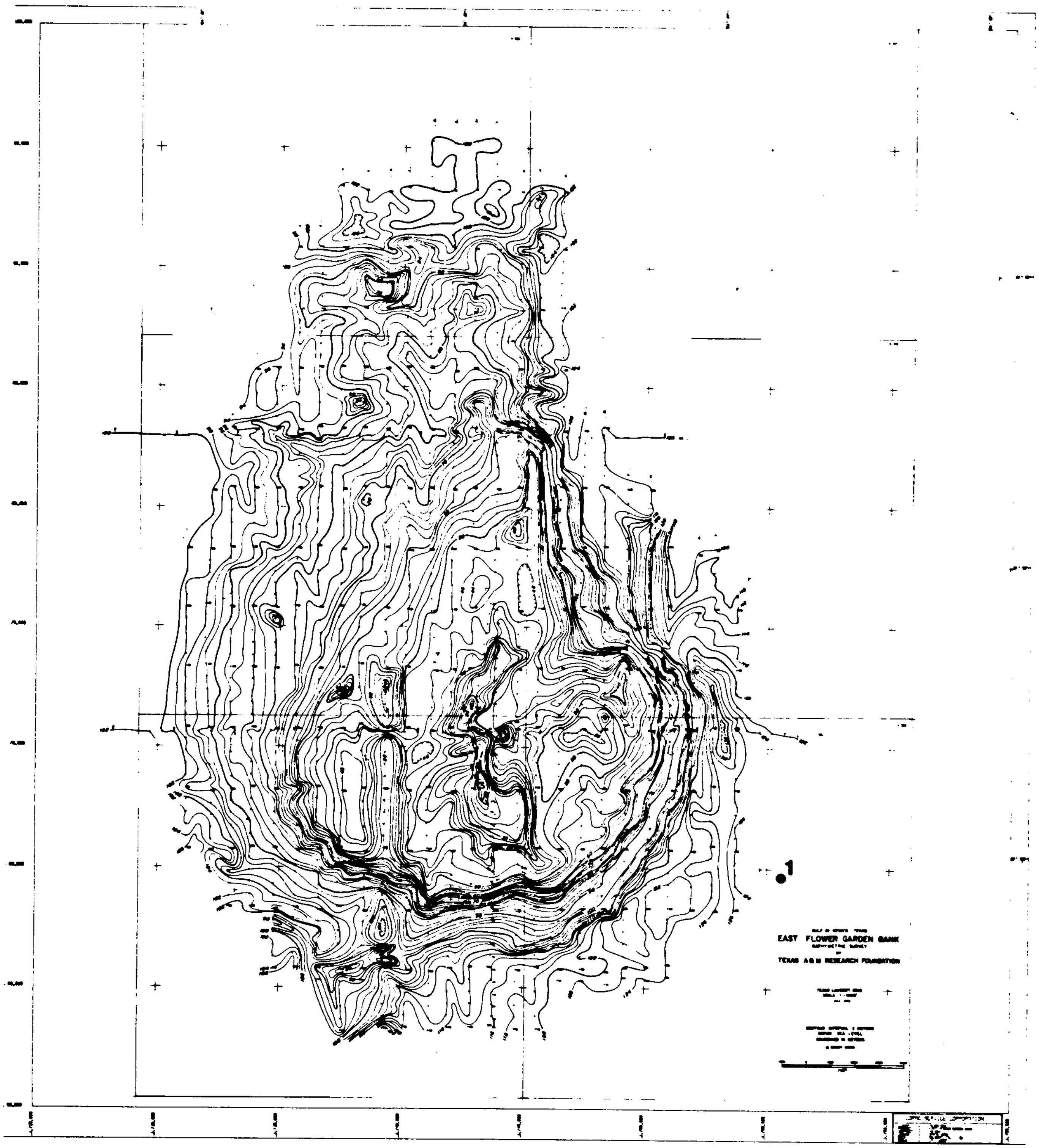

Figure V-1. Bathymetric chart of the East Flower Garden Bank with the location of Station 1 shown in the southeast corner.

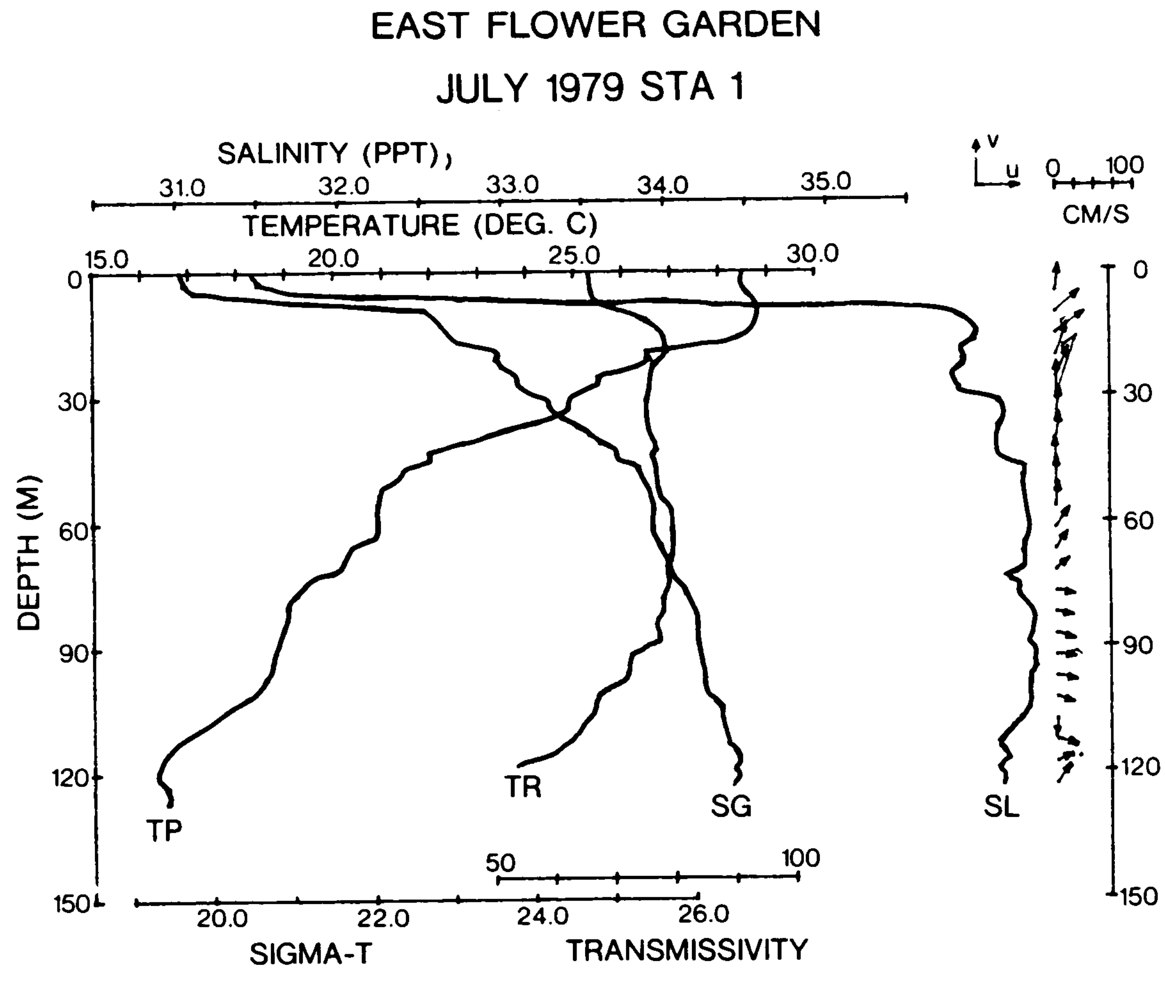

Figure V-2. Profiles of salinity (SL), temperature (TP), transmissivity (TR), Sigma-T (SG), and current velocity taken at the location shown in Figure V-1 in July 1979. The arrows representing the current velocity have their origin at the depth of measurement, point in the direction of flow, and have a length proportional to the speed.

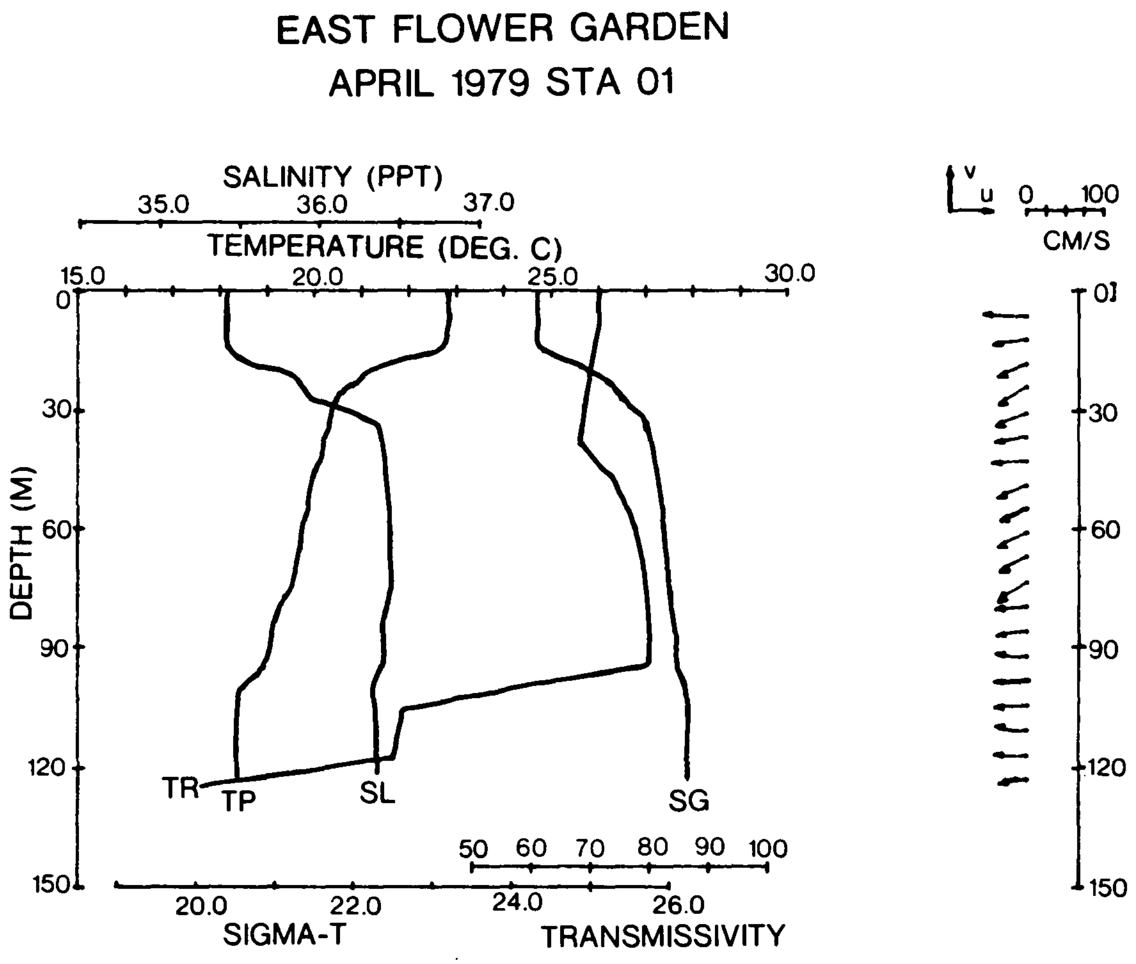

Figure V-3. Profiles of salinity (SL), temperature (TP), transmissivity (TR), Sigma-T (SG), and current velocity taken at the location shown in Figure V-1 in April 1979. The arrows representing the current velocity have their origin at the depth of measurement, point in the direction of flow and have a length proportional to the speed.

ARRAY 1

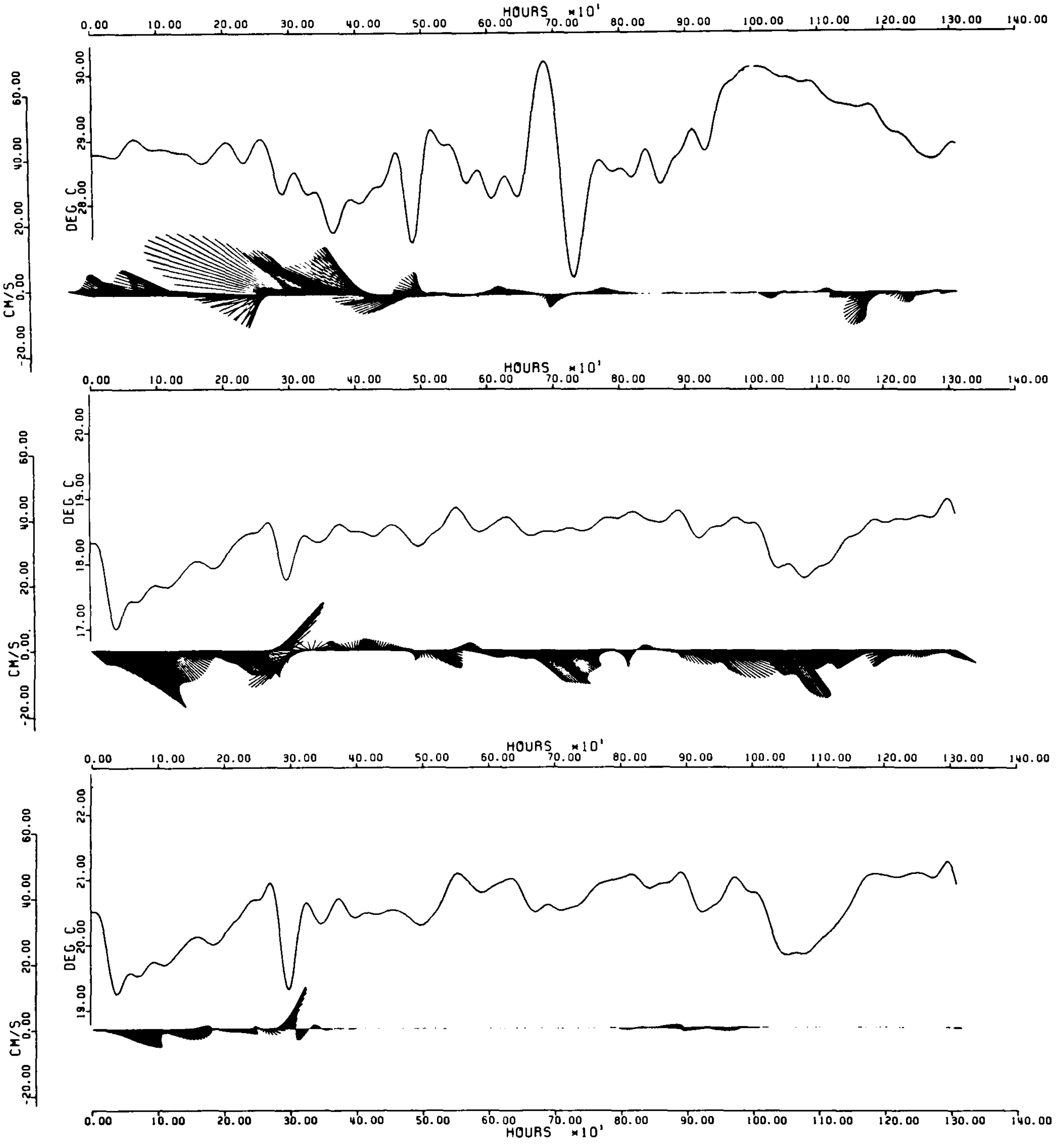

Figure V-4. Low pass filtered time series of current meter records from Array I, June - September 1979. The current vectors point in the direction of flow and have a length proportional to the speed. The temperature is shown above the "stick plot" of the velocity as a continuous line. Note that a post-deployment calibration of the lowest meter revealed an approximate 2°C offset in the temperature. The top frame is from 60 m, the middle is from 94 m, and the bottom is from 96 m depth.

ARRAY 2

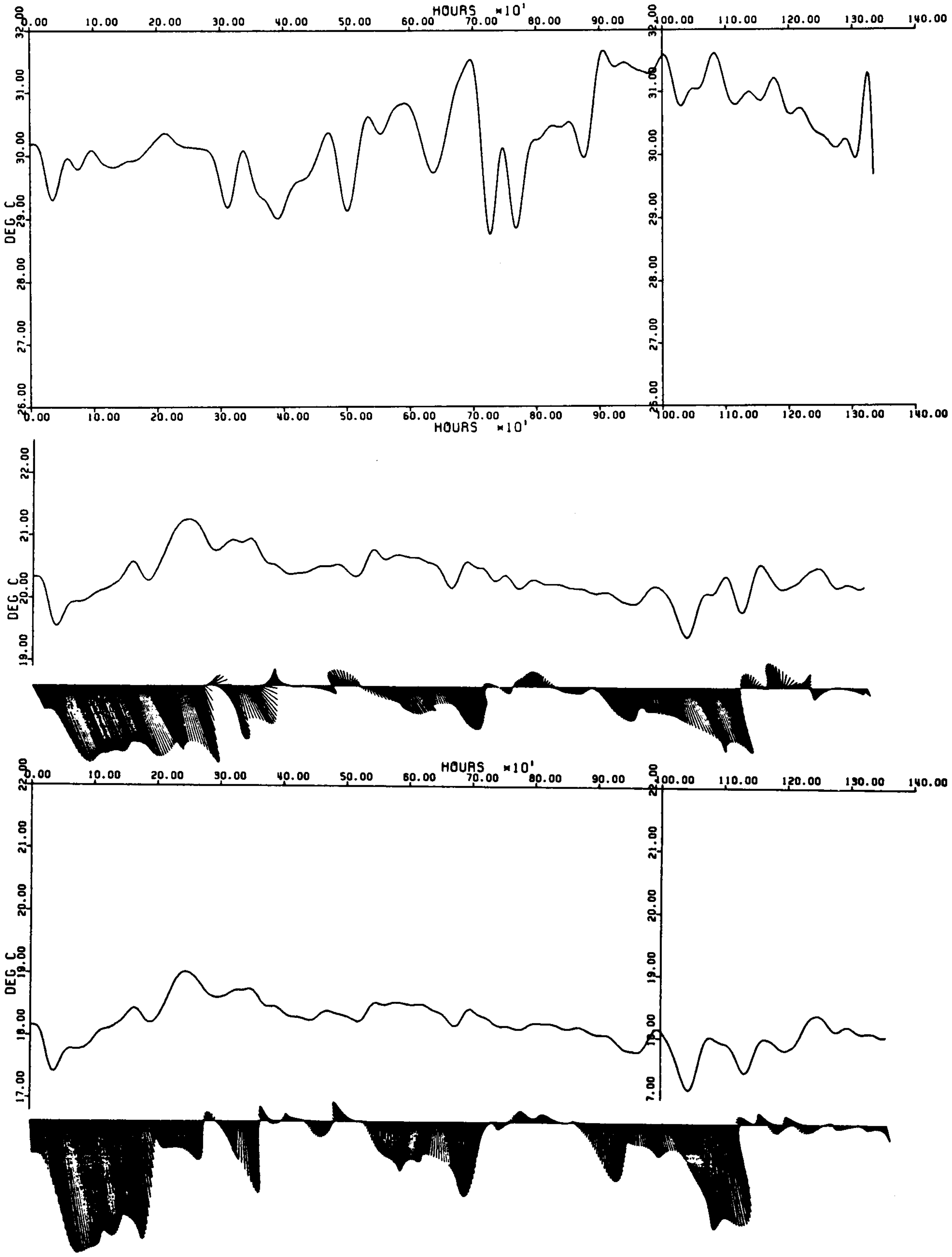

Figure V-5. Low pass filtered time series of current meter records from Array II, June - September 1979. Details are as in Figure V-4. The temperature recorded by the instruments at both 60 m and 94 m are offset upward by approximately 2°C.

due to inertial oscillations. The semidiurnal tide appears only in the v component autospectrum and has substantially less energy than the diurnal tide. Lower frequency oscillations occur at periods of 50 hours, 3 and 6 days. The latter two have significantly more energy in the clockwise rotary spectra (Gonella, 1972) and are probably quasigeostrophic shelf wave type phenomena induced by atmospheric forcing. Since these peaks also appear in the temperature spectra, it is quite likely that they are at least hybrid baroclinic-barotropic phenomena.

The spectra from the lower meters on Array I have a similar pattern execpt that the diurnal and semidiurnal peaks are more equal and there is less disparity between the clockwise and anticlockwise rotary components. The orthogonal lines plotted on Map No. 6 at the location of Array I are the eigenvalues of the variance sensors for each meter. These were computed using the method of Freedland et al. (1975). They represent the orientation of the major and minor axes of variance, with the length of the line proportional to the variance in the record aligned with that axis. The results of the computation appear in Table V-1. At all three depths the major axis of variance trends WNW-ESE are nearly parallel to the trend of the local isobaths. Note also that there is 3-5 times as much energy in the oscillations oriented parallel to the isobaths as those oscillations which cross isobaths.

Table V-1

Current Meters at East Flower Garden Bank

		Mean		Variance Tensor	
				Major Axis	Minor Axis
Array	Meter	Spd	Dir	cm^2/sec^2	cm^2/sec^2
I	T (60 m)	7.4 cm/sec	259°	159	42
I	M (94 m)	6.2 cm/sec	131°	66	14
I	B (96 m)	5.8 cm/sec	117°	28	5
II	M (94 m)	8.4 cm/sec	152°	165	6
II	B (96 m)	10.2 cm/sec	176°	300	8
Electromagnetic	(30 m)	11.5 cm/sec	119°	63	5

The currents at the base of the bank measured by the current meters on Array II were significantly different from those measured at Array I. The current vectors in Figure V-5 indicate very strong offshore flow over most of the period with protracted periods when the flow, only 4 m above the bottom, exceeded 50 cm/sec or 1 knot.

The high frequency energy spectra from the Array II records are also dominated by oscillations at ~ 24-25 hours and ~ 12 hours. As would be expected, there is an order magnitude more energy in the v (north-south) component than in the u (east-west) component. The rotary spectra are identical suggesting that no appreciable rotation of the flow takes place during these oscillations.

Significant peaks in the low frequency energy spectra of the Array II meters appear at $\sim 2 \times 10^{-2}$ CPH (50 hours), $\sim 5 \times 10^{-3}$ CPH (8.3 days), and $\sim 2.3 \times 10^{-3}$ CPH (18 days). The last peak is rather broad and probably includes energy contributed from several modes of motion. As with the high frequency spectra, the v component of the spectra contains an order magnitude more energy than the u component.

The axes of variance from the records of the Array II meters plotted on Map No. 5 possess considerable information. They demonstrate that topographic steering of even the oscillating components of flow is almost total. At 6 m above the bottom less than 4% of the variance of the flow was oriented normal to the major axis, and at 4 m above the bottom less than 3% of the variance was aligned with the minor axis. Also, note that between the two meters the orientation of the major axis of variance rotated by 10° so that the flow nearer the bottom was most closely aligned with the local isobaths. Table V-1 also shows that the mean flow was strongly deformed by the topography of East Flower Garden Bank.

The evidence suggests that the near bottom flow on the shelf around East Flower Garden Bank is strongly deformed by the bank. The higher mean velocity and greater variance at the bottom meter on Array II suggest that much of the adjustment takes place quite near the bottom and that the displaced water is constrained to accelerate along the isobaths rather than up or down slope.

The analysis of variance for the January-April deployment of the upper meter (60 m depth) on Array II (not shown) revealed that the major axis of variance was oriented at 349°, indicating that the topographic steering of the flow extends well up into the water column.

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