NORTHERN GULF OF MEXICO TOPOGRAPHIC FEATURES STUDY

EXECUTIVE SUMMARY

Submitted to the
U.S. Department of the Interior
Bureau of Land Management
Outer Continental Shelf Office
New Orleans, Louisiana

Contract No. AA551-CT8-35

Department of Oceanography
Texas A&M University
College Station, Texas

Technical Report No. 81-2-T

Research Conducted Through
the Texas A&M Research Foundation

1981

TEXAS A&M UNIVERSITY COLLEGE OF GEOSCIENCES

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PREFACE

This report is a summary of the five-volume Final Report on work accomplished under Contract AA551-CT8-35 with the U.S. Department of the Interior, Bureau of Land Management. Institutions involved in the study were Texas A&M University, the University of Texas Marine Science Institute, the University of Alabama at Birmingham (Dauphin Island Sea Laboratory), and the University of South Florida. The fourteen principal investigators from these four institutions are listed on the Contributors page of this report.

Volume One of the Final Report includes 1) program management, 2) salt diapirism, 3) biological categorization of banks, 4) water and sediment dynamics, and 5) recommendations. **Volume Two** includes 1) methods, 2) long-term fossil dispersion, and 3) chemical analyses. **Volume Three** provides discussions of the characterization efforts at the Flower Garden Banks. **Volume Four** provides similar characterization for the ten other banks described in this summary. **Volume Five** presents the results of work conducted at the Florida Middle Ground.

The five-volume Final Report is available through the National Technical Information Service or through the Texas A&M Department of Oceanography (Technical Report No. 81-2-T).

ERRATA SHEET

Volumes One Through Five
Northern Gulf of Mexico Topographic Features Study
Contract No. AA551-CT8-35
Technical Report No. 81-2-T

Volume	Page Number	Corrected Readings
1	65	Table IV-3, Column head 3 (Bank Priority Rating), indices for East and West Flower Garden Banks: Reads: 36 (both lines) **Should read: 31.2 (both lines)**
2	5	Table VII-2, Regular Survey Line Spacing, 2nd Mapping Cruise, for the West Flower Garden: Reads: 900 m **Should read: 300 m.**
3	50	Species Dominance Formula: Reads: $\frac{\text{Total of Intercept Lengths for Species "A"}}{\text{Total Transect Length}}$ **Should read:** $\frac{\textbf{Total of Intercept Lengths for Species "A"}}{\textbf{Total Transect Length}} \times 100$
3	51	Relative Density Formula: Reads: $\frac{\text{Total Number of Colonies of Species "A"}}{\text{Total Number of Colonies of All Species}}$ **Should read:** $\frac{\textbf{Total Number of Colonies of Species "A"}}{\textbf{Total Number of Colonies of All Species}} \times 100$
3	51	Frequency Formula: Reads: $\frac{\text{Transect in Which Species "A" Occurs}}{\text{Total Number of Transects}}$ **Should read:** $\frac{\textbf{Number of Transects in Which Species "A" Occurs}}{\textbf{Total Number of Transects}} \times 100$
3	65	Table X-C-II, heading, column 2: Reads: X **Should read: X**
4	117	Figure XVIII-1, caption, line 3: Reads: XVIII-4, 5, 6 and 7 are indicated. Sample stations: 1-4. **Should read: XVIII-5, 6, 7, and 8 are indicated. Sample stations: 1-4.**
5	135	Paragraph 4, lines 3-4. Reads: Middle Ground is a sizeable nutrient source, with peak output in all months. **Should read: Middle Ground is a sizeable nutrient source, with peak output in the fall months.**

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CHAPTER I

INTRODUCTION

This report and the five-volume Final Report were prepared to satisfy the tasks specified in the U.S. Department of the Interior, Bureau of Land Management (BLM) Contract #AA551-CT8-35. The contract was awarded in August 1978 to Texas A&M University (TAMU) through the Texas A&M Research Foundation (TAMRF). Subcontracts were subsequently awarded to the University of Alabama at Birmingham, Dauphin Island Marine Laboratory; the University of Texas at Austin, Marine Science Institute; the University of South Florida at Tampa; and several private service organizations including LGL, Inc. and Sealfleet Operations, Inc.

The main purpose of the study was to gather data in order to characterize selected topographic features in the Gulf of Mexico. Geological, chemical, physical, geophysical, and biological oceanographic data were collected from the Florida Middle Ground, off the west Florida coast, and from twelve topographic features off the Louisiana-Texas coast: Alderdice, Applebaum, Coffee Lump, Diaphus, Elvers, East Flower Garden, Fishnet, Geyer, Jakkula, Rezak-Sidner, West Flower Garden, and 32 Fathom Banks.

This report presents the findings of the work performed during the period August 1978 to November 1980. It extends the efforts begun by researchers from TAMU in 1961 on a cruise to the West Flower Garden Bank conducted by R. Rezak on the R/V HIDALGO.

In previous BLM-funded studies, beginning in 1974, TAMU oceanographers characterized the geology and biology of 28 banks in the northwestern Gulf of Mexico. The present study adds eight banks to this list and provides additional information on four banks previously studied: Applebaum (previously called Little Sister), 32 Fathom, and the East and West Flower Garden Banks.

Descriptive reconnaissance studies were completed in 1978-79 for the Florida Middle Ground and Alderdice, Coffee Lump, Diaphus, Elvers, East Flower Garden, Fishnet, Geyer, Jakkula, Rezak-Sidner, and West Flower Garden Banks. These studies assessed the geology and biology of the banks as observed from the submersible DRV DIAPHUS.

In addition, a variety of special studies were conducted at selected banks. Chemical analysis of sediments for trace metals, high molecular weight hydrocarbons, Delta C-13, and total organic carbon was conducted for Coffee Lump and the East and West Flower Garden Banks. At the East and West Flower Garden Banks, other chemical analyses include: analysis of *Spondylus* and certain fish species for trace metals and high molecular weight hydrocarbons; and analysis of water samples for nutrients and dissolved oxygen. Study of the size distribution and mineralogy of the surrounding sediments was done at

Alderdice, Applebaum, Coffee Lump, Diaphus, East Flower Garden, Fishnet, Jakkula, and 32 Fathom Banks. The study of the distribution of reworked fossil coccoliths on the South Texas Outer Continental Shelf, initiated in 1976 under BLM Contract #AA550-CT6-18, was continued.

The East Flower Garden Monitoring Study was continued with investigations of: coral and coralline algae population estimates; growth and mortality of hermatypic corals; recruitment and early growth of corals; coelenterate larvae and other zooplankton; leafy algae populations; and the brine seep.

Studies at the West Flower Garden Bank included mapping, hydrocarbon analysis, and monitoring. The new maps (generated through more sophisticated techniques than were previously available) and the results of hydrocarbon analysis are reported herein. The monitoring study, identical to that at the East Flower Garden Bank, was initiated under the present contract, but reports on these studies were earmarked for BLM Contract #AA851-CT0-25.

CHAPTER II

GEOLOGY

R. Rezak

INTRODUCTION

This chapter summarizes the geological observations and data that have been acquired on TAMU/BLM contracts since 1974. During this period, 37 banks have been mapped at a scale of 1: 12000 and a two-metre contour interval, except for those banks that have high relief and very steep slopes (Table II-1 and Figure II-1). Twenty-two of these banks have been sampled for sediment analyses. Only two of the banks (the East and West Flower Garden Banks) have been sampled in sufficient detail to permit the construction of sediment distribution maps.

Twenty-six of the banks have been observed directly by use of submersibles. Observations on these banks have been documented by video tapes and 35 mm still, color photos. All video tapes (both biological and geological) have been reviewed for geological content.

Side-scan sonar data have been acquired for all mapped banks having topographic expression (three banks had no topographic expression). Sub-bottom seismic profiles have also been made for 18 of the mapped banks. These data have been interpreted for only the eight banks mapped under this contract. The data on nine other banks are being interpreted on contract #AA851-CT0-25.

SALT DIAPIRISM

Salt diapirism has been a recognized feature of the northwestern Gulf of Mexico (Figure II-1) since the early days of petroleum exploration. These structures are not unique to the Gulf of Mexico. They are also known to occur in West Germany and the Middle East, where there are thick deposits of bedded salt beneath younger sedimentary sequences. With the development of seismic reflection techniques, much has been learned regarding the gross structural features created by the diapirs, and a rather voluminous literature has appeared in the published record. This literature has been mainly descriptive and deals with the occurrences of hydrocarbons associated with these structures.

The present study is based upon the published record, shallow seismic reflection profiles, side-scan sonar records made in the course of mapping the banks described in this report, and direct observations of diapiric structures on the seafloor from the submersible DRV DIAPHUS. All of the banks mapped during the present study are situated on the diapiric structures. In general, these diapirs have much in common. However, there is great variability in the details of the

TABLE II-1
SUMMARY OF BANKS STUDIED (1974-80)

BANK	CONTRACT YEAR(s) STUDIED	MAPPING CRUISE	SAMPLING FOR SEDIMENT ANALYSIS	OBSERVATION FROM SUBMERSIBLE	SIDE-SCAN SONAR	SUB-BOTTOM SEISMIC PROFILES
Alderdice (ALD)	1978	Sep 78	X	X	X	X**
Applebaum (APL) (Little Sister)	1975 & 78	May 75	X		X	
Aransas (ARA)	1975 & 76	Nov 74			X	
Baker (BAK)	1975	Oct 74	X	X	X	
Big Adam Rock (BAD)	1975	Nov 74	X	X	X	
Blackfish (BLA)	1975 & 76	Nov 74		X	X	
Bouma (BOU)	1977	May 77		X	X	X
Bright (BRI)	1977	May 77	X		X	X
Claypile (CLA)	1976 & 77	Jun 77			X	X
Coffee Lump (COF)	1978	Sep 78	X	X	X**	X**
Diaphus (DIA)	1978	Sep 78	X	X	X**	X**
Dream (DRE	1975	Nov 74 Jun 75	X	X	X	
East (EAS)	1975	Nov 74		(no topographic expression)		
East Flower Garden (EFG)	1975-78	Jun 75 Jul 76	X*	X	X	X
Elvers (ELV)	1978	Sep 78		X	X**	X**
Ewing (EWI)	1977	May 77		X	X**	X
Fishnet (FIS)	1978	Sep 78	X	X	X**	X**
Four Rocks (4RO)	1975	May 75		(no topographic expression)		
Geyer (GEY)	1978	Sep 78		X	X**	X**
Hospital Rock (HOS)	1975 & 76	†	X	X	X	

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† Chart prepared in 1969 by Southwest Research Institute - revised by TAMU 1974.
* = Sediment distribution map constructed
** = interpreted

TABLE II-1 (Continued)

BANK	CONTRACT YEAR(s) STUDIED	MAPPING CRUISE	SAMPLING FOR SEDIMENT ANALYSIS	OBSERVATION FROM SUBMERSIBLE	SIDE-SCAN SONAR	SUB-BOTTOM SEISMIC PROFILES
Jakkula (JAK)	1978	Sep 78	X	X	X**	X**
Little Adam Rock (LAD)	1975	Nov 74	(no topographic expression)			
Mysterious (MYS)	1975	Nov 74			X	
N Hospital (NHO)	1975	Nov 74		X	X	
Parker (PAR)	1977	May 77	X	X	X	X**
Rezak-Sidner (RSI)	1978	Sep 78	X	X	X**	X**
Sackett (SAC)	1977	May 77	X	X	X	X
Small Adam Rock (SAD)	1975	Nov 74			X	
Sonnier (SON) (Three Hickey Rock)	1977	May 77	X	X	X	X
South Baker (SBA)	1975 & 76	Oct 74	X	X	X	
Southern (SOU)	1975 & 76	May 75	X	X	X	
Stetson (STE)	1975 & 76	Jul 76	X	X	X	
West Flower Garden (WFG)	1978	Jul 79	X*	X	X**	X
18 Fathom (18F)	1977	May 77		X	X	
28 Fathom (28F)	1975 & 76	Oct 74			X	
28 Fathom, SW Peak	1976	Jul 76	X	X	X	X
29 Fathom (29F)	1975	Oct 74			X	
32 Fathom (32F)	1975	May 75	X		X	

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* = Sediment distribution map constructed

** = interpreted

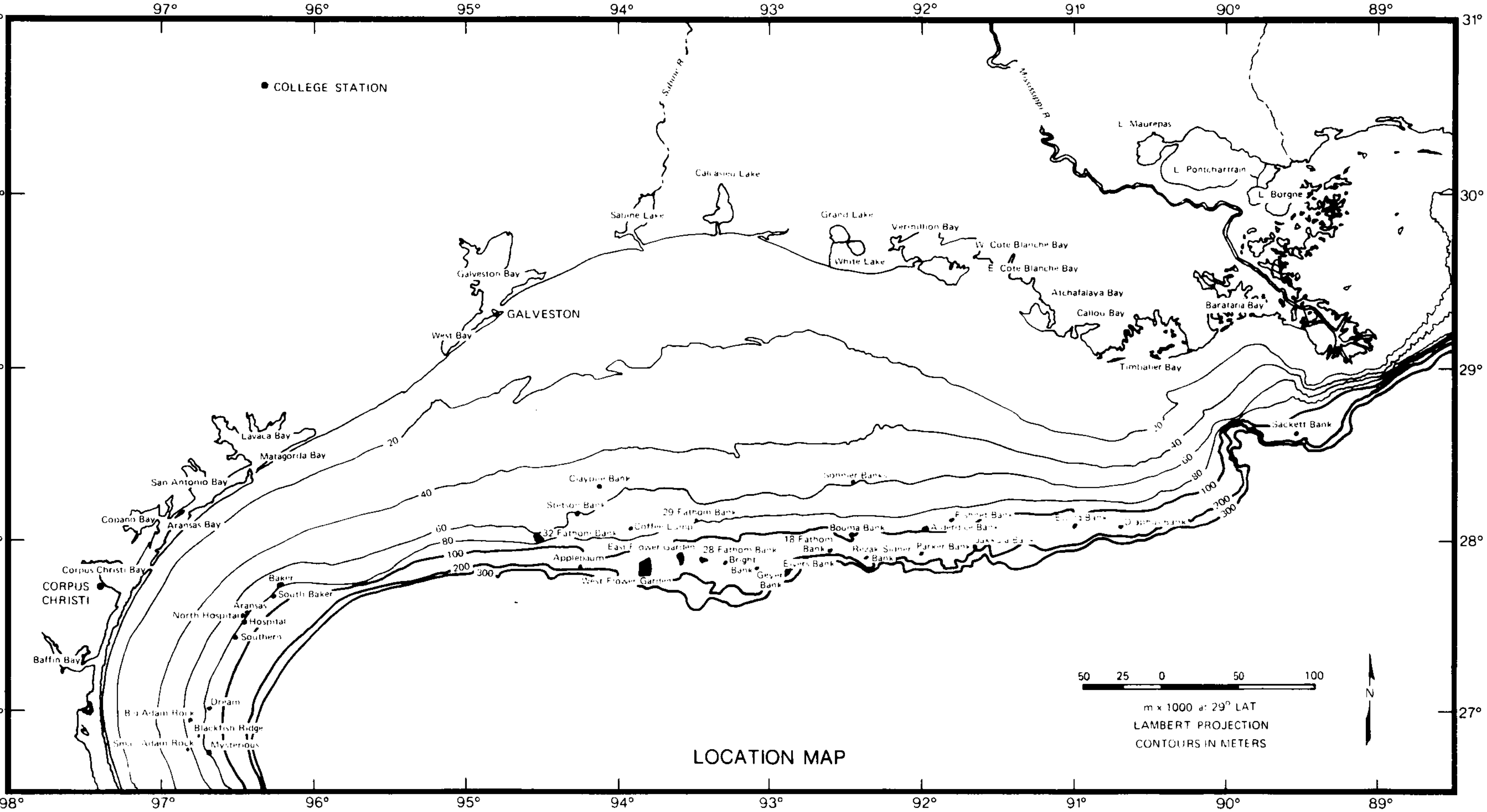

Figure II-1. Location map of topographic features mapped since 1974 in the northwestern Gulf of Mexico.

physiographic and structural expression of the diapirs, apparently due to their varying geologic histories.

Mechanics of Diapirism

During Jurassic time, the ancestral Gulf of Mexico was a slowly subsiding shallow evaporite basin in which over 3,000 m of rock salt (Louann Salt) accumulated (Humphris, 1978). By middle-Late Jurassic time, salt deposition had ended and deposition of shallow-water, normal marine sediments began. Continued deposition of marine sediments during Cretaceous and Tertiary time built a broad continental shelf out into the Gulf of Mexico (Martin, 1978) burying the Louann Salt under nearly 15 km of sediments in the vicinity of High Island, Texas. Near the shelf edge, the salt is approximately 10 km deep. The salt domes of the coastal plain and continental shelf originated as diapirs in the abyssal plain and continental rise. They developed their present form as the prograding wedge of post-Cretaceous sediments altered the bathymetry at their location from lower slope, to upper slope, to shelf depositional environments (Amery, 1978). As early as 1934, Nettleton demonstrated that salt diapirs act in accordance with the laws of fluid mechanics and that they grow as sediments are deposited on and around them. Humphris (1978) attributes the formation of salt diapirs on the continental slope to lateral salt flowage resulting from the sediment loading on the shelf. Martin (1978) suggests that the salt diapirs are youngest at the Sigsbee escarpment and most mature on the interior coastal plain.

The foregoing conclusions were based upon seismic surveys using widely spaced seismic lines. Clearly, the major forces acting upon the salt diapirs are due to density differences between the salt and the surrounding sediments. The result is an upthrusting of the diapir and deformation of the surrounding and overlying sediments. The surveys conducted during the present investigation have closely spaced grids (approx. 275 m track spacing and 152 m between navigation fixes on track), thus permitting a more detailed assessment of the structural features associated with the salt diapirs.

Faulting

Crestal

Faulting is the most common feature associated with salt tectonics. Radial faults at the crests of diapirs are due to domal uplift of the overlying rocks and the production of tensional stresses during the doming. Movement along these faults is probably minimal during the upthrusting of the salt. Some authors have attributed the central graben to the tensional stresses. However, the central graben is a collapse feature formed by annular faults intersecting the radial faults, and the graben occurs later in the development of the salt dome. Nettleton (1934) attributes circular faults to the cutting off of the supply of salt into the dome by the drop of the peripheral sink. Beyond this stage, he states that further growth of the dome is at the expense of the material already within the peripheral sink, and the cross-sectional area of the salt decreases. This decrease causes normal faulting around the salt to fill in the space relieved of salt. Nettleton's model, however, does not fit the observed fault patterns associated with central grabens at the crests of domes. Instead, these patterns indicate a collapse of the dome over the apex of the salt diapir.

Amery (1978) illustrates a crestal graben on a diapir located on the lower continental slope. Apparently, the development of the crestal graben is related to the relative rates of sedimentation and upward movement of the salt. As the crest of the salt plug approaches a depth of about 300 m below the sediment-water interface, dissolution of salt by marine phreatic water begins.

Regional

Also associated with the shelf edge diapirs are regional faults that generally parallel the shelf break. These faults are gravity type structures, probably due to a combination of 1) crustal loading and basement tectonics, 2) slumping along the shelf edge as a result of rapid sediment accumulation, 3) salt and shale flow into local structures and systems of regional extent, and 4) differential compaction (Martin, 1978). The faults occur as interdomal fractures, frequently displacing the seaward portions of salt domes.

Examination of the bathymetry on NOS charts NG 15-2 (Garden Banks), NG 15-3 (Green Canyon), NG 15-11 (Bouma Bank), and NG 15-12 (Ewing Bank) shows NW-SE and NE-SW lineations near the shelf break, accentuated by intrusions of salt. These may be the result of active basement fault systems that create avenues for salt intrusion into the overlying slope sediments. One such fault is seen on the east side of Rezak-Sidner Bank.

Origin of Cap Rock

Salt in the diapirs is a mixture of halide minerals having varying solubility. The two most abundant minerals are halite (NaCl) and anhydrite ($CaSO_4$). As the crest of the salt diapir approaches the sediment surface (about -300 m), marine phreatic water begins to dissolve the more soluble halite and to concentrate the less soluble anhydrite. The anhydrite cap rock can attain thicknesses of several hundred feet. The presence of brines and unconsolidated anhydrite sands along the salt table of domes, the high concentration of halite in cap-rock waters, and the numerous periods of brecciation evidenced by cap rock are all evidence that cap rock has been forming over an extended period of time and is still forming (Feely and Kulp, 1957).

Brecciation of the cap rock may occur due to the upward movement of the salt or collapse of the cap rock into cavities left by the removal of halite. During periods of active upward movement, the salt brecciates the cap rock and probably leaves fragments of it behind on the flanks of the diapir as the salt bypasses it (Feely and Kulp, 1957).

On the basis of geologic evidence, limestone cap rock must be derived from the chemical reduction of the anhydrite cap rock. The products of the biochemical reduction of anhydrite include calcite ($CaCO_3$), hydrogen sulfide (H_2S), native sulfur (S), pyrite (FeS_2), gypsum ($CaSO_4 \cdot 2H_2O$), carbon dioxide (CO_2), and methane (CH_4). Feely and Kulp (1957) conducted a series of experiments using sulfate-reducing bacteria (Desulfovibrio) and natural crude petroleum to determine the rates of sulfur production due to reduction of anhydrite by each agent. Their results proved that sulfate is not reduced by petroleum at salt dome temperatures at a sufficiently rapid rate to produce sulfur deposits such as those of the Gulf Coast in less than 150 million years. Sulfate-reducing bacteria, on the other hand, will reduce sulfate at a rate that is sufficiently rapid to produce the Gulf Coast sulfur deposits in less than a million years.

EVIDENCE FOR CRESTAL COLLAPSE

General

There is accumulating evidence that normal faulting and graben formation at the crests and on the flanks of salt domes may be catastrophic in nature. Much of the evidence is indirect, but taken together it indicates very strongly the probability of catastrophic movements on crestal faults. The evidence for catastrophic collapse includes 1) the East Flower Garden brine lake, 2) the nature of rock outcrops at the crests of domes, 3) earthquakes, and 4) changes in coral growth rates at the East Flower Garden.

East Flower Garden Brine Lake

A detailed description of the East Flower Garden brine system is presented in Volume Three, Chapter X of the Final Report, and summarized below, Chapter V. Examination of the bathymetric chart of the East Flower Garden Bank (Figure V-1, below, Chapter V) shows clearly that there is no central collapse feature. The West Flower Garden Bank, however, has developed a central graben, and the bathymetry and sub-bottom profiles of several of the banks show large-scale normal faulting on their crests.

The area of active brine seeps occurs on the southeastern flank of the East Flower Garden Bank, 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 phreatic water that permeates the porous reef rock. The dense brines (about 200 °/oo total salinity) then flow by gravity to the shores of the brine lake, where they emerge from the porous rock. The outflow of the lake has been calculated to be about 864 m^3/day, or 315,360 m^3/year. 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 24,200 m^3. Other seeps are known to occur at the East Flower Garden, 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. It seems unlikely that this rate is equal to or greater than the rate of removal of salt by dissolution. Therefore we may expect a collapse of the crest of the bank in the not too distant future.

Reef and Non-Reef Outcrops

One of the early pieces of evidence for Recent movement along crestal faults is the outcrop of basalt on Alderdice Bank. The extremely thin encrustation by reef-building organisms is an indication of rather recent exposure of this rock on the seafloor. Bare-rock outcrops occur on Sonnier and Claypile Banks, as well as Geyer Bank, which has both well developed reefs and bare-rock outcrops within 300 m of each other. If these rock substrates had been exposed since Late Pleistocene time, they would all have heavy encrustations of reef-building organisms by this time.

Earthquakes

Several jack-up rigs and platforms have foundered in the vicinity of salt domes. A petroleum company structural engineer reported that a platform in the vicinity of the East Flower Garden had experienced an earthquake (personal communication). The epicenter of the quake is not known, but it could have been at the site of a nearby salt dome.

At Alderdice Bank there is evidence that the loci of upthrusting can be displaced. On the east side of Alderdice Bank, the central graben shows evidence of uplift. Seismic records clearly show a reversal in the direction of movement on the faults on either side of the graben, as evidenced by the fault-bounded uplift of the seafloor over the graben. As this profile is some distance from the crest of the dome, it is clear that seafloor instability due to upthrusting or collapse is not restricted to the crest of the dome. Off-bank areas in the vicinity of salt domes are also susceptible to these instabilities.

Coral Growth Rates

Growth rates of Montastrea annularis at the East Flower Garden Bank have declined since they were first measured. From 1907 through 1956, Hudson and Robbin (1980) report an average growth rate of 8.9 mm/year; from 1957 until the present, the rate has been 7.2 mm/year. Hudson and Robbin examined possible causes of decline in growth rate, such as: 1) commercial shrimping, 2) dumping of chemical wastes (about 75 km west of the East Flower Garden, 3) temperature changes, and 4) air pollution that might reduce light levels. They concluded that no single cause for growth rate reduction can be demonstrated. Moreover, the effects of these possible causes would have been gradual, not abrupt. Shinn (personal communication) feels that a sudden, 10 m depth increase would be enough to reduce the rate of growth by about 2 mm/year.

CLASSIFICATION OF SALT DOMES

Problems of Classification

Classifying salt domes depends heavily on sub-bottom data. Classification is complicated because on many of the banks studied, the core of the dome is seismically non-reflective. The physiography of these banks, which is controlled by the sub-bottom structure, also varies widely (see bathymetric maps and computer-generated perspective diagrams, Chapters V-VI, below). To determine the nature of the core, both sub-bottom profiles and side-scan sonar records must be used together with submersible observations. From these data, conclusions about classification of these domes may be drawn.

Any one or more of several factors may cause the lack of sub-bottom reflectors in bank cores. Sedimentary units in the core may be nearly vertical, as is seen at both Fishnet and Alderdice Banks. Both banks have seismically non-reflective cores, but side-scan sonar records show outcrop patterns of nearly vertical beds. At Geyer Bank, side-scan sonar records show very little in the way of nearly vertical outcrops, but submersible observations on the northern part of the bank show local areas of vertically dipping sedimentary strata.

The East Flower Garden Bank illustrates two other factors that account for lack of sub-bottom reflectors in bank cores: 1) carbonate reefal growths may reflect most of the outgoing signal and thus "wipe out" any reflectors beneath the reef; and 2) salt and/or cap rock may be very close to the surface and no sub-bottom reflectors may be present. At the East Flower Garden Bank, no evidence of bedded outcrops in the core of the bank is displayed on either the sub-bottom profiles or on the side-scan sonar records. Submersible observations, however, have revealed brine seeps that indicate that salt in the core must be shallower than 71 m below sea level. Consequently, the seismic non-reflectivity of the bank core is probably due to a combination of proximity of the salt to the surface and the extensive reef growth at the bank.

Suggested Classification

Because of the complex history of salt diapirs, it is difficult to classify the structures in terms of age. All of these structures began growing when there was probably no more than 1000 m of sediment overlying the source bed of the salt in the diapirs. Since that time there have been repeated periods of sediment deposition alternating with periods of upthrusting of salt, dissolution of salt, collapse of the overlying beds, and exposure to subaerial erosion.

Terms such as "youth" and "maturity" are rather meaningless unless used with reference to specific features on the salt dome. A thick sedimentary sequence showing minor relief on the seafloor with minor faulting over the crest might be referred to as a youthful dome. None of the banks studied under this contract fall into this category. However, one example is provided by Tatum (1979, Figure 10).

Youthful domes may have either high or low bathymetric relief. Domes of this type may be due to renewed upthrusting of salt following a quiescent period during which several hundred metres of sediment were deposited over the crest. If the dome is subaerially exposed at this stage, it could be truncated and result in a bank such as Coffee Lump. Coffee Lump was exposed during the Late Pleistocene and truncated by a stream that flowed into the Gulf just to the west of the West Flower Garden Bank (Henry Berryhill, personal communication).

A mature dome is one that has been uplifted, had the salt at its crest removed due to dissolution by marine phreatic waters, and block faulted at its crest to form a central graben. Examples of this type of dome are Diaphus, Jakkula, Fishnet, Elvers, and West Flower Garden. Previously surveyed banks belonging to this category are: Claypile, Sonnier, Parker, Bright, 18 Fathom, Bouma, and Ewing (see Table II-2).

Rejuvenated domes are those that have been block faulted and/or truncated and subjected to renewed upthrusting by the salt diapir. Most of these domes have a very thin cover of rock over the salt in the crest of the diapir. Examples of this type of dome are the East Flower Garden, Geyer, and Alderdice (see Table II-2). Alderdice is the only bank where direct evidence of rejuvenation is displayed on the sub-bottom profiles. Moreover, on Alderdice there is evidence for a change of the locus of upthrusting from the crest of the bank to the eastern margin.

TABLE II-2

CLASSIFICATION OF SALT DOMES

Young	Mature	Rejuvenated
Coffee Lump	Bouma	Alderdice
Rezak-Sidner	Bright	East Flower Garden
32 Fathom	Claypile	Geyer
	Diaphus	
	Elvers	
	Ewing	
	Fishnet	
	Jakkula	
	Parker	
	Sonnier	
	West Flower Garden	
	18 Fathom	

SEDIMENTOLOGY

General

The normal sediments on the OCS off the Texas and Louisiana coasts are primarily land-derived mud, sandy 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. Hundreds of banks are scattered over the OCS. These banks are located on shallow sub-sea salt domes that have dragged up with them Tertiary age sandstones, siltstones, and shales. The rocks have served as a solid substrate upon which prolific calcium carbonate-producing communities of organisms have 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.

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 (1974). In his classification scheme, Folk used the grade scale devised by Wentworth (1922). According to this grade scale, the diameters of the sediment particles are as follows:

Gravel	> 2.0 mm	
Sand	0.0625 - 2.0 mm	
Silt	0.0020 - 0.0625 mm	— Mud
Clay	< 0.0020 mm	

Folk emphasizes 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. For example, suppose 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 or 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, for example, some sediment appears to be moving downslope due to the force of gravity.

Bank Sediments

The sediment facies that have been delineated at the West Flower Garden (Edwards, 1971) and the East Flower Garden (this study; see below, Figure V-5) are typical of the banks studied during the present investigation. Because of the bathymetric control over the distribution of biotic communities that are the sources of sediments on the banks, there is a consequent bathymetric control over the distribution of the carbonate sediment facies. Minor exceptions to this generalization may be caused by 1) excessively steep slopes, 2) the frequent presence of a nepheloid layer, and 3) vertical movement of the seafloor due to salt tectonics. Excessively steep slopes, such as those present on the southeast side of the East Flower Garden, are the cause of nondeposition of the Amphistegina Sand Facies, which normally occurs at those depths. The presence of a nepheloid layer on low relief banks, such as Coffee Lump, Stetson, Fishnet, and others, limits the growth of the coral reef biota and consequently limits the supply of carbonate sediment. Alderdice Bank is the only bank where carbonate and terrigenous sediment distribution was observed to depart from the normal depth zonation of sediment facies. The two anomalous stations at Alderdice can only be due to relatively recent displacement of the seafloor due to salt tectonics.

The facies that are present at any given bank are dependent upon the relief of the bank and the depth at the crest of the bank. Those banks with the greatest relief and shallowest peaks will have the full sequence of sediment facies, as displayed at the East and West Flower Garden Banks. The deeper the crest of the bank and the lower the relief of the bank, the fewer the facies present on the bank.

Off-Bank Sediments

Bank carbonate sediments merge with the terrigenous off-bank sediments through a transition zone that varies in width with the degree of slope of the outer bank. At the East and West Flower Garden Banks this transition takes place in the Quartz-Planktonic Foraminifers Facies and the Molluscan Hash Facies. The lower boundaries of these facies are artificial boundaries that are due to the necessary change from carbonate sediment classification (generic) to the terrigenous sediment classification (textural).

The dominant skeletal components of the off-bank sediments are: planktonic and benthic foraminifers, echinoderm fragments, mollusc fragments, and bryozoans. The mineralogy of the off-bank sediments is quite uniform except where the samples are taken close to banks. In those places, detritus from the banks affects the mineralogy of both the coarse fraction and the fine fraction of the sediment, depending upon the nature of the bedrock on the bank.

TABLE III-1
CATEGORIES AND ZONES OF HARD-BANKS IN THE GULF OF MEXICO

BANK	CATEGORY*	ZONE	DEPTH (m)
Adam (Big)	D	VII**	?
Adam (Small)	D	VII**	?
Alderdice	A	IV	55-67
	C	Trans. ††	67-79
Applebaum	C	VI	?
Aransas	C	VI	57-70
Baker	C	VI	56-70
Baker (South)	C	VI	59-70
Blackfish	D	VII**	?
Bouma	A	IV	60-75
	C	Trans. ††	75-84
Bright	A	III	37
	A	IV	52-74
	C	Trans. ††	74-?
Claypile (2)***	B	V	40-45
Coffee Lump	C	VI	62-68
Diaphus †	C	VI	73-106
Dream	C	VI	62-70
Elvers	A	IV	60-97
	C	Trans. ††	97-123
Ewing	A	IV	56-72
	C	VI	72-88
Fishnet	C	Trans. ††	66-80
Flower Garden (East)	A	I	20-35
	A	II	28-46
	A	III	35-52
	A	IV	46-82
	C	Trans. ††	82-86
Flower Garden (West)	A	I	20-35
	A	III	35-50
	A	IV	46-88
	C	Trans. ††	88-89
Geyer	A	IV	60-98
	B	V	37-52
	C	Trans. ††	98-123
Hospital (North)	C	VI	58-70
Hospital Rock	C	VI	59-70
Jakkula	A	IV	59-90
	C	Trans. ††	90-94
Mysterious	D	VII**	?
Parker	A	IV	60-82
	C	Trans. ††	82-?
Rezak-Sidner	A	IV	55-93
	C	Trans. ††	93-99
Sackett	C	VI	65-75
Sonnier	B	V	18-52
Southern	C	VI	58-70
Stetson	B	V	20-52
18 Fathom	A	III	45-47
	A	IV	45-82
	C	Trans. ††	82-?
28 Fathom	A	IV	66-92
	C	Trans. ††	92-108
32 Fathom	C	VI	?

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* A: Maximum protection recommended; B: Protection strongly recommended; C: Protection recommended; D: protection not recommended.

** Nepheloid zone probably envelops these banks entirely.

*** Reef-building is poorly developed or arrested.

† Not adequately explored; shallowest portion of bank may harbor yet undetected reef-building populations.

†† Transition zone between Algal-Sponge Zone and deeper, turbid-water, lower bank zones. Comparable to an Antipatharian Zone.

CHAPTER III

CATEGORIZATION AND ENVIRONMENTAL RANKING OF HARD-BOTTOM BIOTIC ZONES AND BANKS

T.J. Bright

INTRODUCTION

The categorization and ranking system presented here is an attempt to produce a more "tangible" means of assessing biotic zones and banks for use in the decision-making process. The system is in response to frequent inquiries concerning the "value" of one bank in comparison to others. It has often been difficult to convey clear and simple opinions. The following should ease the confusion concerning the "environmental priority" and the contemporary biotic zones of the banks.

BANK CATEGORIES

The system of bank categorization presented in past reports (Bright and Rezak, 1978a,b) is now obsolete and should be replaced. The revised categorization does not, however, represent a final word on benthic zonation on hard-banks in the northwestern Gulf of Mexico. The supposed "Antipatharian Zone" and "Nepheloid Zone" are particularly problematic and may not be valid designations in the biological sense. Each surely represents several biotic assemblages of superficial similarity which could all ultimately be given separate zonal designations. However, such "hair splitting" is not feasible at present and would probably serve little purpose in terms of "environmental prioritization."

The most appropriate means of categorizing the banks biologically involves the recognition of a number of distinct benthic biotic zones characteristic of hard-banks in the northwestern Gulf of Mexico, with an indication of the banks on which each zone occurs, and the depth range of each zone on each bank. This system of categorizastion seems more functional than the previous one insofar as certain banks are more complex biologically than was heretofore realized and cannot be easily accommodated by the old system.

Seven characteristic benthic biotic zones have been identified. These are classified within four general categories describing degree of reef-building activity. These four categories and the benthic biotic zones within them are tabulated in Table III-1 and described below.

Category A consists of zones of major reef-building activity; maximum environmental protection is recommended. Category B consists of a zone of minor reef-building activity; environmental protection is strongly recommended. Category C consists of zones of negligible reef-building activity yet containing populations of crustose coralline algae; **environmental protection is recommended.** Category D consists of a zone of no reef-building activity and insignificant populations of coralline algae; **protection is not recommended.**

The Category A zones are:

I. Diploria-Montastrea-Porites Zone: A zone consisting of living, high-diversity coral reefs.

II. Madracis Zone: A zone dominated by the small branching coral Madracis mirabilis, which is producing large amounts of carbonate sediment.

III. Stephanocoenia Zone: A zone consisting of living, low diversity coral reefs.

IV. Algal-Sponge Zone: A zone dominated by crustose coralline algae actively producing large quantitites of carbonate substratum (considered here to extend downward, past the depth at which algal nodules diminish in abundance, to the greatest depths at which coralline algal crusts are known to cover a substantial percentage of the hard substratum). This may be the largest of the reef-building zones in terms of area of sea bottom.

The Category B zone is:

V. Millepora-Sponge Zone: A zone where crusts of the hydrozoan coral Millepora share the tops of siltstone and claystone outcrops with sponges and other epifauna.

The Category C zone is:

VI. Antipatharian Zone: A zone where limited crusts of coralline algae and several species of corals exist within a zone marked by sizeable populations of antipatharians. Banks supporting Algal-Sponge Zones (A, IV above) generally possess a zone comparable to an Antipatharian Zone as a transition between the Algal-Sponge Zone and deeper, turbid-water, lower bank zones. Such "transition" zones are indicated in Table III-1.

The Category D zone is:

VII. Nepheloid Zone: A zone, located at the base of all banks, wherein high turbidity, sedimentation, resuspension of sediments, and resedimentation dominate. Rocks and drowned reefs here are generally covered with veneers of fine sediment. Epifauna are depauperate and variable; deep-water octocorals and solitary stony corals are often conspicuous. This zone occurs in some form on lower flanks of all banks below the depths indicated for Zone VI (Table III-1).

TABLE III-2
PRIORITY RANKING OF BIOTIC ZONES ON HARD-BANKS IN THE GULF OF MEXICO

1 = lowest priority
8 = highest priority

BIOTIC ZONE	RANKS					ZONE PRIORITY INDEX (Avg. Rank)
	Degree of Reef Building	Biological Diversity	Aesthetics	Rarity	Areal Extent	
I. *D-M-P*	8	8	8	7	6	7.4
II. *Madracis*	7	6	6	8	8	7.0
III. *Stephanocoenia*	6	5	5	6	7	5.8
IV. Algal-Sponge	5	7	4	5	4	5.0
V. *Millepora*	4	4	7	4	5	4.8
VI. Antipatharian	3	3	3	3	3	3.0
VII. Nepheloid	2	1	2	2	2	1.8
Surrounding Mud Bottom	1	2	1	1	1	1.2

KEY:

Degree of Reef Building: ranking of relative amount of carbonate substratum produced per unit area (8 = greatest).

Biological Diversity: ranking of apparent relative biological diversity of zones (8 = highest diversity).

Aesthetics: ranking of relative value of zone to sport divers, fishermen, and scientists with concern for "visual appeal" and "quality" of the benthic communities (8 = most valuable).

Rarity: ranking of apparent rarity of occurrence of zones at comparable latitudes in the Western North Atlantic Ocean (8 = rarest).

Areal Extent: inverse ranking of zones in terms of area of sea bottom occupied in northwestern Gulf of Mexico (8 = least area).

Zone Priority Index: average of all ranks for each zone.

ENVIRONMENTAL PRIORITY RATINGS

Any assignment of "environmental priority" to the aforementioned biotic zones is subjective. It is presumed that the considerations in assigning levels of concern for these zones are the degree of active reef-building in progress, biological diversity, aesthetics, rarity, and areal extent. Table III-2 (above) depicts subjective rankings given by the author to the various zones for each of these considerations. The scale of 1 to 8 indicates lowest to highest ranks, respectively. The average of all ranks for each zone is taken as a "priority index," with the highest number representing the highest priority. A priority rating for any individual bank may be obtained by summation of all appropriate priority indices for the zones occurring at the bank (Table III-3).

It should be noted that the depth ranges for the Algal-Sponge Zone (A, IV), Antipatharian Zone (C, VI), and the Nepheloid Zone (D, VII) vary from bank to bank depending on relief, surrounding depth, and water quality. Decisions concerning establishment of boundaries for no-drilling areas and regulations concerning shunting of drill effluents to the bottom near any particular bank should take into consideration the specific depths of distribution of biotic zones to be protected on that bank. For example, whereas the lower limit of the Algal-Sponge Zone at the East Flower Garden Bank is 82 m, at Geyer Bank it is 91 m. If specific measures were taken to protect the Algal-Sponge Zones at these two banks, this depth differential would have to be considered. We also point out that these depth estimates are based on limited reconnaissance studies. More detailed observations on other banks may increase the known depth ranges somewhat.

TABLE III-3
PRIORITY RATINGS FOR EACH BANK
(Listed in descending order of environmental priority)

BANKS	ZONES AND ZONE PRIORITY INDICES								BANK PRIORITY RATING (Sum of Priority Indices)
	D-M-P I	MAD. II	STEPH. III	AL.SP. IV	MILLEP. V	ANTIP. VI	NEPH. VII	Surrounding Mud Bottom	
	7.4	7	5.8	5.0	4.8	3.0	1.8	1.2	
East Flower Garden	x	x	x	x		x	x	x	31.2
West Flower Garden	x	x	x	x		x	x	x	31.2
18 Fathom			x	x		x	x	x	16.8
Bright			x	x		x	x	x	16.8
Geyer				x	x	x	x	x	15.8
Elvers				x		x	x	x	11
28 Fathom				x		x	x	x	11
Alderdice				x		x	x	x	11
Jakkula				x		x	x	x	11
Ewing				x		x	x	x	11
Parker				x		x	x	x	11
Rezak-Sidner				x		x	x	x	11
Bouma				x		x	x	x	11
Sonnier					x		x	x	7.8
Stetson					x		x	x	7.8
Claypile					x		x	x	7.8
Fishnet						x	x	x	6
Diaphus						x	x	x	6
Sackett						x	x	x	6
32 Fathom						x	x	x	6
Applebaum						x	x	x	6
Coffee Lump						x	x	x	6
Southern						x	x	x	6
North Hospital						x	x	x	6
Hospital Rock						x	x	x	6
Baker						x	x	x	6
South Baker						x	x	x	6
Aransas						x	x	x	6
Dream						x	x	x	6
Blackfish							x	x	3
Mysterious							x	x	3
Big Adam							x	x	3
Small Adam							x	x	3

CHAPTER IV

WATER AND SEDIMENT DYNAMICS

D. McGrail

INTRODUCTION

In terms of management requirements, the most critical issue addressed by our hydrodynamic research concerns the East Flower Garden Bank, in particular whether water from the base of the bank can flow up to the living reef. This question is significant in that if water from the base of the bank can reach the reef, so could material introduced into the bottom boundary layer during petroleum drilling operations. However, on the basis of many lines of empirical evidence and the results of dynamical analysis, the possibility of such an occurrence is so remote as to be negligible. Not only are the chances remote, but the circumstances under which water could flow up and over the bank from the sea bed would be so catastrophic that no drill mud could come to rest on the reef, and mechanical damage to the reef builders would be devastating.

The following discourse presents the evidence leading to these conclusions.

PERSPECTIVES FROM GEOPHYSICAL FLUID DYNAMICS

At first inspection, it may seem that the East Flower Garden Bank is a rather insignificant bump on the seafloor. It extends only about 11 km from north to south and is 7 km across. However, most of the bank rises 50 m or more above the continental shelf. Expressed in terms of dynamics, an analogue in the atmosphere would be a solitary mountain rising to half the thickness of the earth's atmosphere with a peak at 80% of the height of the atmosphere.

It should not be surprising that oceanic flow about such an obstacle is exceedingly complex. Each scale of time and length presents the possibility of some new mode of motion. These range from the mean circulation of the shelf waters to infinitesimally small random turbulence. It would be a formidable task indeed to attempt simultaneous analysis of all the superposed motions. Fortunately, that is not necessary. Rather, it is the practice of physical oceanographers to determine which of the many possible modes are actually present, then analyze each mode separately.

In this case, the records from the moored current meters and the many profiles of salinity, temperature, current velocity, and transmissivity were used to determine which frequency bands in the range from 10 cycles per hour (cph) to approximately 4×10^{-4} cph contained significant amounts of energy. These data also yielded information regarding the form of the important modes of motion and their dynamics.

Chapter V of Rezak and Bright (1981) sets forth the mathematical proof that under the worst conceivable conditions the flow at the East Flower Garden Bank could not rise from the seafloor to the height of the living reef. A reasonable expectation would be that 1) the flow would rise 15 to 20 m along the upstream face of the bank; 2) flow over the top of the reef would be sharply accelerated to accommodate the excess volume; and 3) a pressure gradient would be created on the upstream side of the bank that would split the flow and cause it to move horizontally around the bank. In the lee of the bank one might expect some downward flow from the bank crest and either closure of the flow along the bathymetric contours or separation of the flow with the development of eddies.

Some have argued that mixing from surface gravity waves during the passage of storms could raise sediment from the bottom to the height of the living reef. If one considers a wave with a 10 m height and a 20-second period--a monster wave for the Gulf--and employs Airy wave theory, it is found that the maximum orbital diameter at 90 m depth would be only about 60 cm.

THE EVIDENCE

Several lines of evidence clearly show that sediment from the base of the bank does not rise above the 75 to 80 m isobath. Rezak (above, Chapter II) has shown that fine sediment (silt and clay) are nearly absent from the bank substrate above approximately 80 m on the East Flower Garden Bank. Bright (above, Chapter III) has demonstrated significant biotic zonation at about 80 m, above which clear water fauna exist and below which they are missing.

In all of the transmissivity profiles taken at the East Flower Garden Bank since the inception of the monitoring studies, no significant suspended sediment has been found above about 75 m in the water column. In all of the temperature profiles taken at the East Flower Garden Bank, no water with a temperature equivalent to that at the base of the bank has been found above about 80 m depth. The maximum displacement on an isothermal surface during any one survey at the bank did not exceed about 20 m.

The analysis of variance for current meter records described by Freeland, Rhines, and Rossby (1975) was performed on the records from the meters moored on Arrays I and II (Figure IV-1). This analysis determines the major and minor axes of variance relative to true north. The results were that the records from all of the meters at Array II showed strong polarization along the local isobaths. Even the meter at 60 m depth showed very little cross-isobath flow. The meters at 94 m and 96 m showed even stronger topographic steering and an acceleration commensurate with that required to accommodate the excess volume of

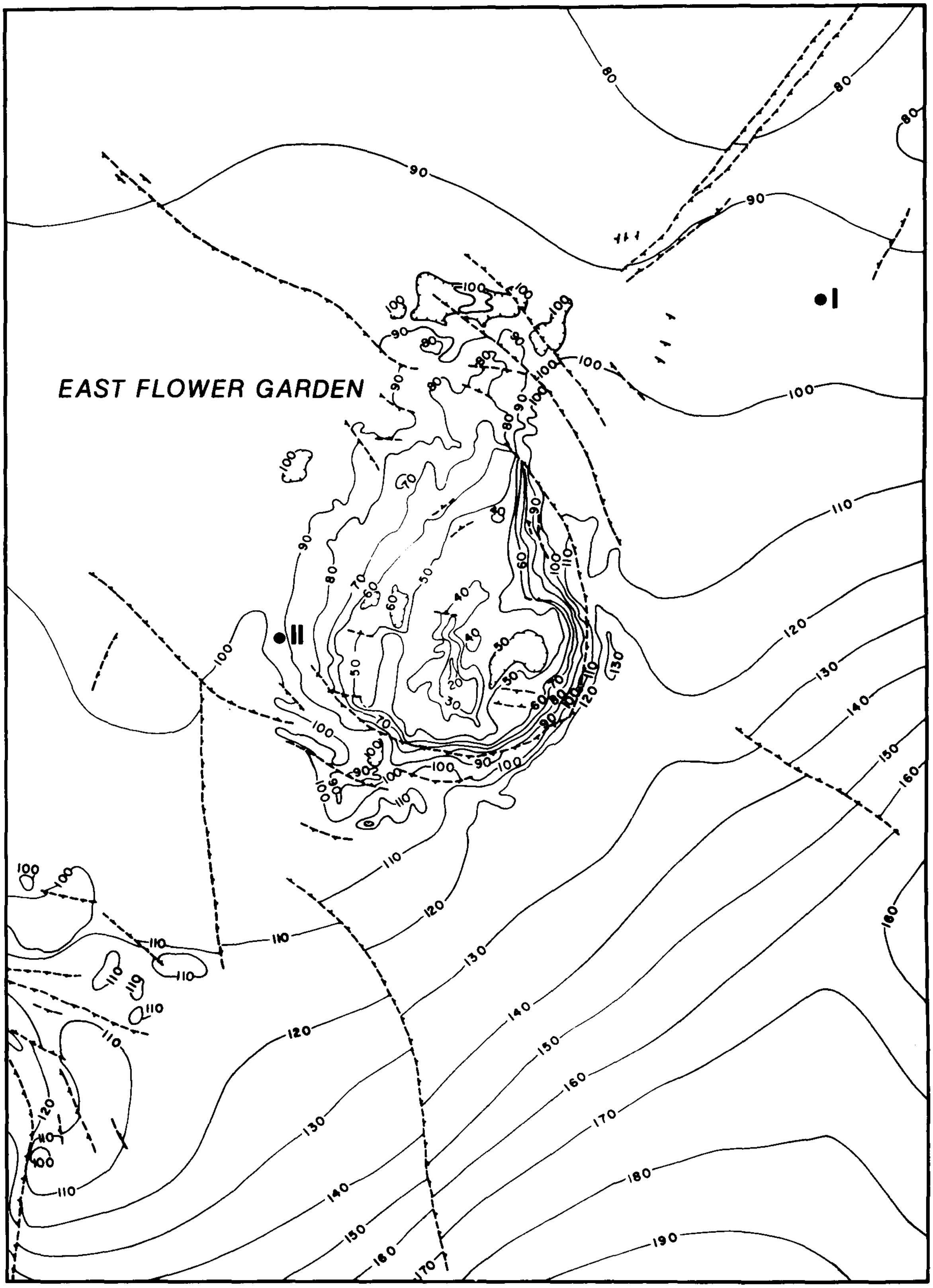

Figure IV-1. Location of current meter arrays, East Flower Garden Bank.

flow blocked by the bank. That is, instead of flowing across the isobaths, the flow accelerated laterally.

The velocity profiles obtained in July 1979 clearly demonstrate the expected topographic steering. The flow split near the middle of the bank, with northerly flow along the isobaths north of the split and southerly flow south of the split. The maximum displacement on the isotherms at station 26, where water in the upper portion of the water column was flowing across the isobaths, was only 15 m. No elevated suspended sediment concentrations were observed in any transmissivity profiles above 80 m on the bank, even with strong flow from the west during the July 1979 sampling cruise.

The evidence from the field observations, therefore, strongly supports the conclusions reached from theoretical considerations. **Water from the base of the East Flower Garden Bank cannot flow up to the level of the living reef. Therefore, material introduced into the bottom boundary layer in the vicinity of the East Flower Garden Bank could not reach the reef-building organisms.**

CHAPTER V

THE FLOWER GARDEN BANKS

R. Rezak, T. Bright, D. McGrail

GEOLOGY AND STRUCTURE

General Description

The East Flower Garden Bank is located at 27°54'32"N latitude and 93°36'W longitude in Blocks A-366, 367, 374, 375, 388, and 389 of the High Island Area (Figure II-1). The bank is pear-shaped and covers an area of about 67 km^2 (Figure V-1). Steep slopes occur on the east and south sides of the bank, with gentle slopes on the west and north sides. The shallowest depth on the bank is about 20 m in the northeastern part of Block 388. The surrounding water depths are about 100 m to the west and north and about 120 m on the east and south sides. An elongate depression in the north-central part of Block 389 has a depth of 136 m.

The West Flower Garden Bank is located at 93°48'47"W longitude and 27°52'27"N latitude in Blocks A-383-85, 397-99, and 401 of the High Island Area, and Block 134 of the Garden Banks Area (Figure V-3). This bank will be described in the Final Report for Contract #AA851-CT0-25.

Computer drawn perspective diagrams of the two banks are included (Figures V-2 and V-4) to aid in visualizing the 3-dimensional aspects of the banks.

Physiography and Structure

The West Flower Garden Bank was mapped at a scale of 1:12,000 and at a contour interval of two metres (Figure V-3). Also, a side-scan sonar mosaic of the EG&G-SMS-960 data has been prepared. Interpretation of the side-scan and seismic data is presently being conducted and will be reported under contract AA851-CT0-25.

For the East Flower Garden Bank, there has been no requirement in the contracts to work up the data from the side-scan and seismic profiles since 1976, when the bank was surveyed. A general discussion of the structure of the bank is given in the Final Report (Volume One, Chapter III, under the heading "Salt Diapirism").

Sedimentology

Introduction

At the West Flower Garden, two bottom sediment samples were taken at each of three stations for hydrocarbon analyses. These results are reported below. Sediment texture parameters and mineralogy will be reported under Contract #AA851-CT0-25.

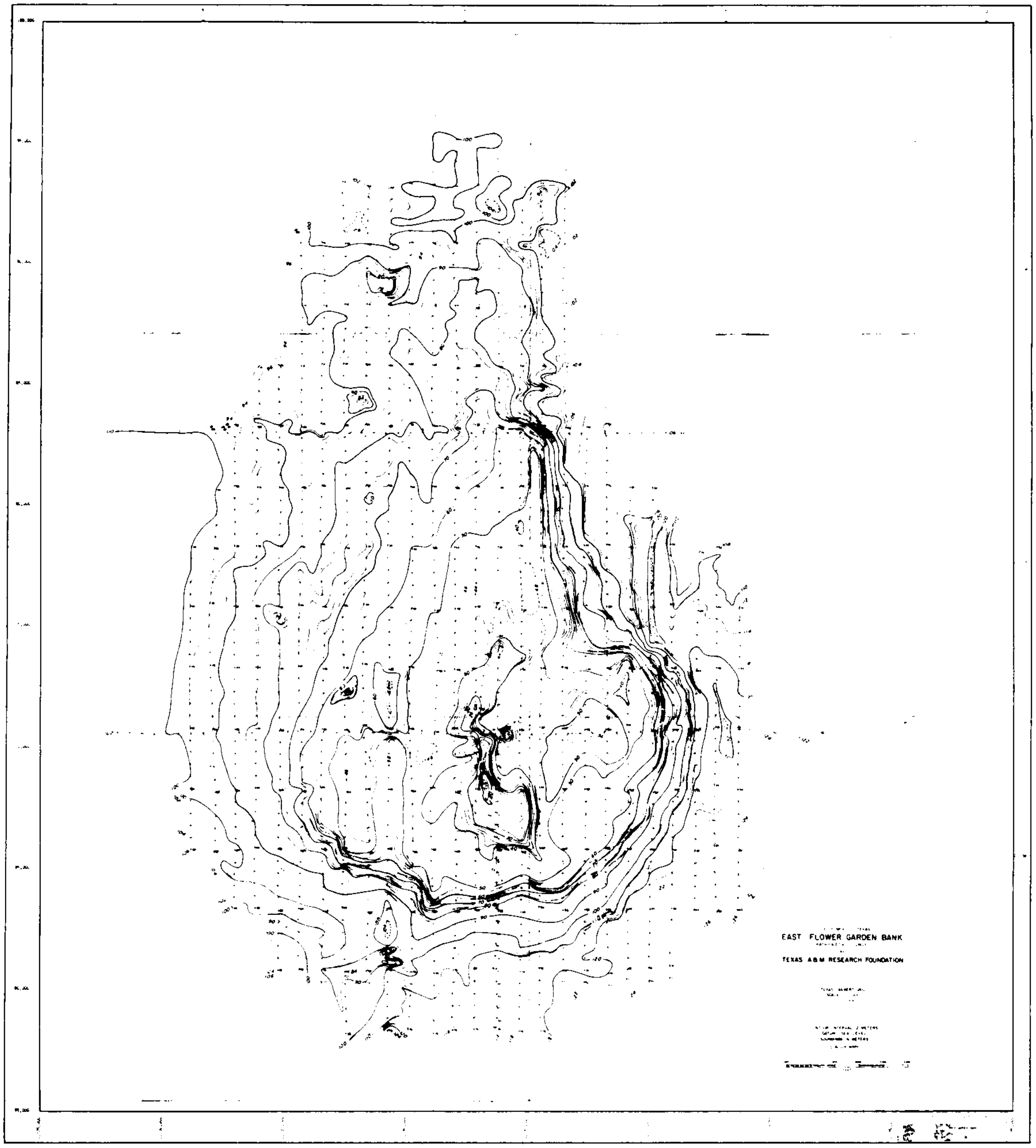

Figure V-1. East Flower Garden Bank bathymetry.

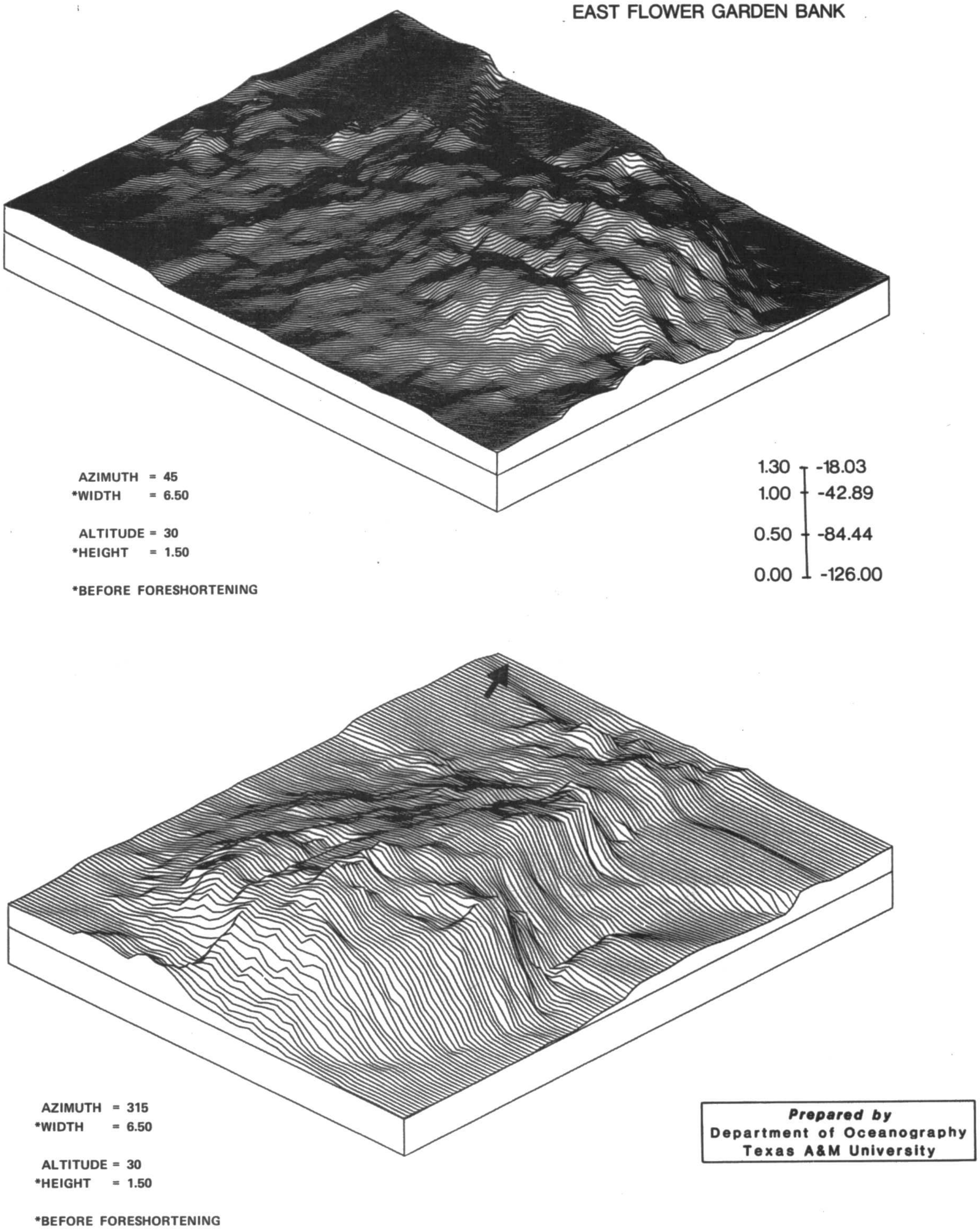

Figure V-2. Three-dimensional perspective views, East Flower Garden Bank.

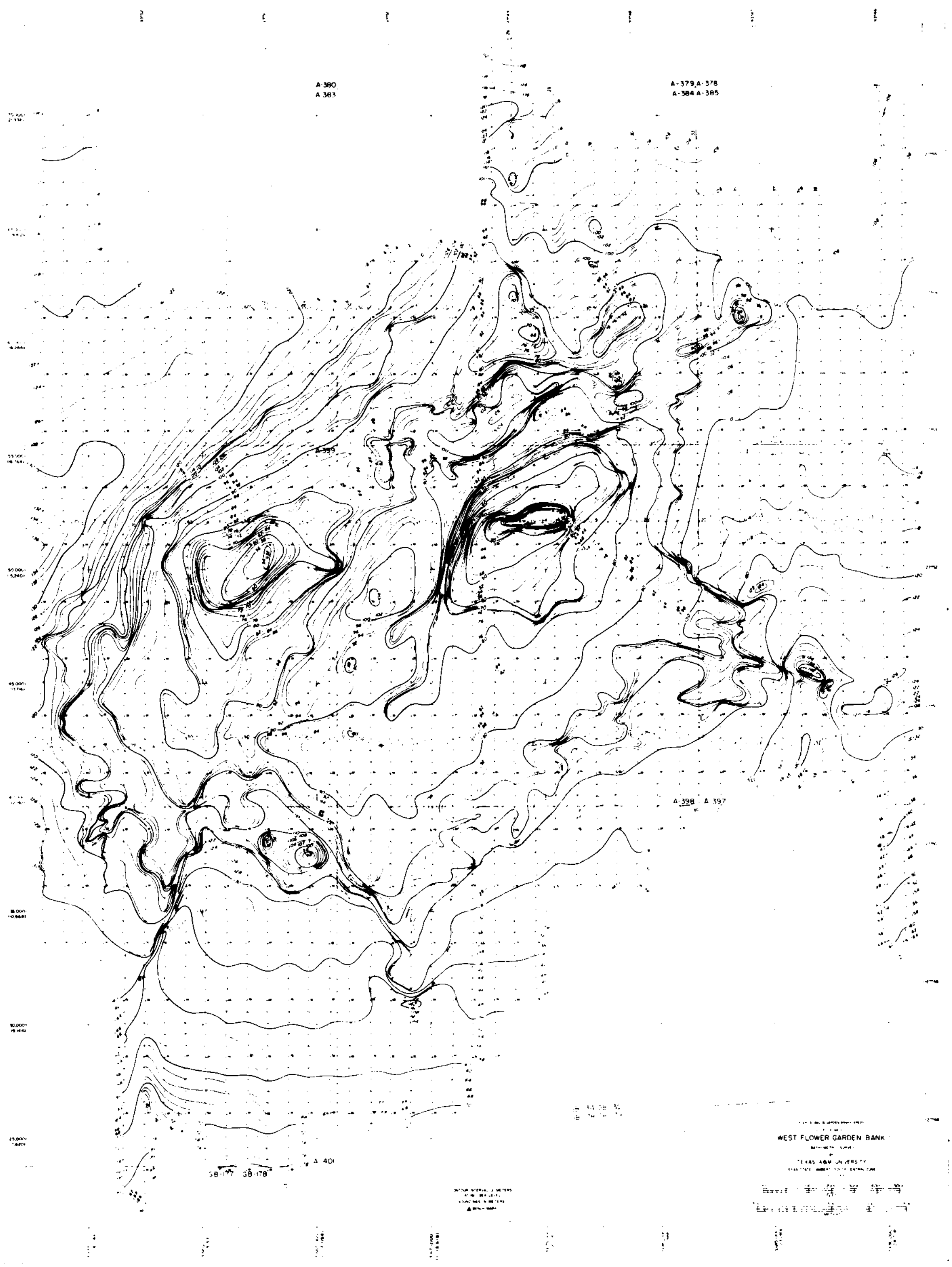

Figure V-3. West Flower Garden Bank bathymetry.

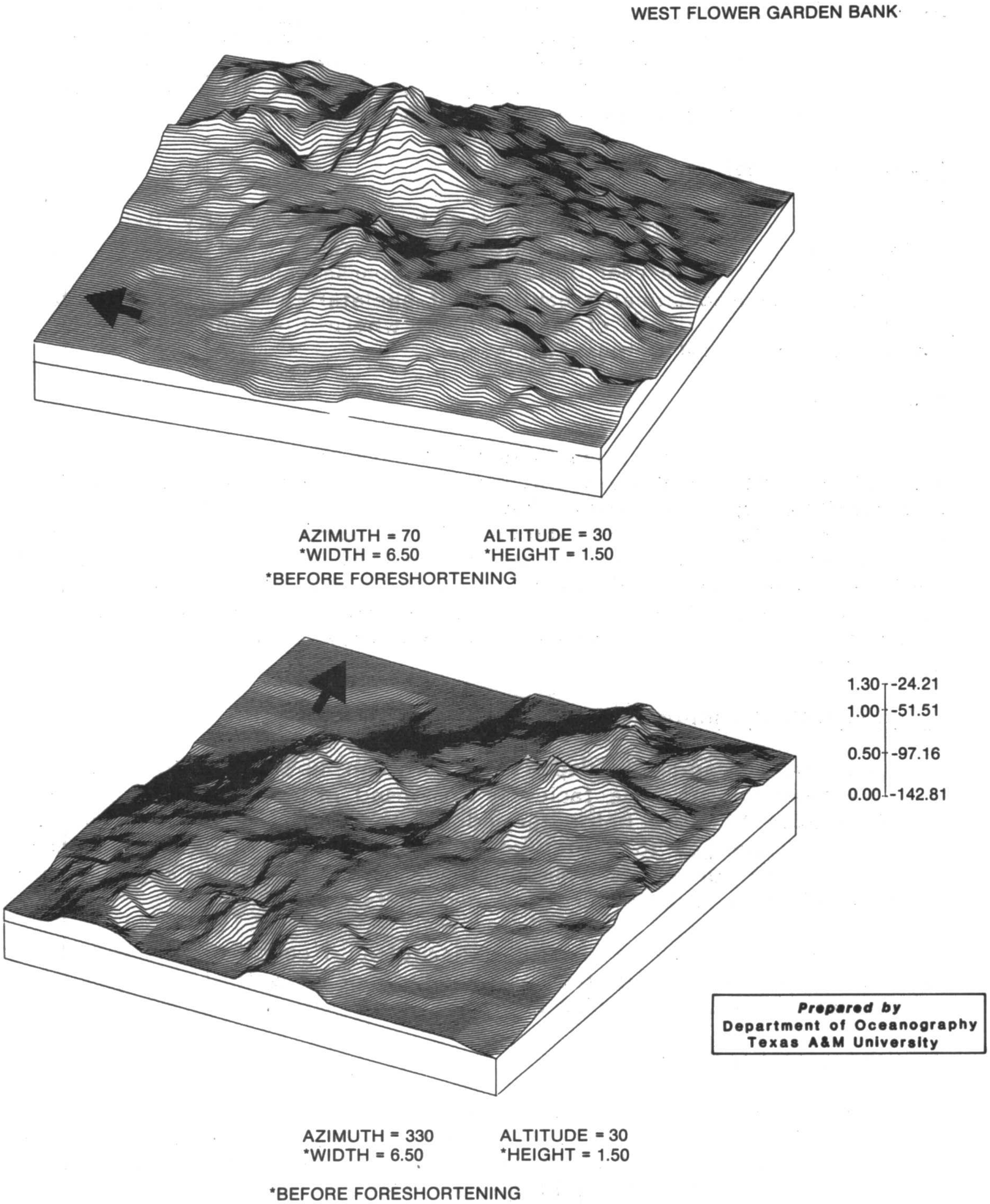

Figure V-4. Three-dimensional perspective views, West Flower Garden Bank.

Data for the East Flower Garden sediment distribution map include samples from 33 stations scattered about the area of the bank and 12 stations around each of two drill sites near the southeast margin of the bank. The shallower portions of the bank, those underlain by the hard bottoms of the living coral reef and the Gypsina-Lithothamnium Zone, were impossible to sample properly with the Smith-McIntyre grab. Facies boundaries in these areas were delineated on the basis of submersible observations and side-scan sonar. Sediment distribution on and around the bank is shown in Figure V-5.

Living Coral Reef

The biota of the living reef has been described by Bright and Rezak (1978a). Sedimentologically, the zone consists of the hard substrates created by the reef biota and the coarse sands and gravels derived from the mechanical breakdown of skeletal carbonate. This zone extends down to a depth of about 50 m, where the sands and gravels merge with the Coral Debris Facies.

Coral Debris Facies

The Coral Debris Facies is derived from the living reef and consists of a coarse coral sand and gravel with minor amounts of mollusc and coralline algae fragments. The facies ranges in depth from approximately 46 to 50 m. Large patches of this sand occur in basins and valleys between coral heads on the living reef. The sands are moved 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 band around the base of the reef.

Gypsina-Lithothamnium Facies

This facies ranges in depth from between 40-50 m to 60-75 m. At the shallower depths, the facies is composed of nodules of encrusting coralline algae that are being formed *in situ*. At greater depths, the growth form changes to a platy or free crust that blankets the loose sediment. The surface is a smooth pavement of coralline algae at any depth within this facies where drowned reefs occur.

The nodules vary in size from granules to cobbles. As would be expected, sorting in this facies is very poor. Both the upper and lower boundaries of the facies are transitional rather than sharp.

Amphistegina Sand Facies

This facies ranges in depth from 60-75 m to 90-100 m. It consists mainly of the dead skeletons of the foraminifer *Amphistegina*. These foraminifers grow attached to the surfaces of the coralline algal nodules in the *Gypsina-Lithothamnium* Facies. Upon dying, their sand size skeletons move downslope to form the *Amphistegina* sand. Sand

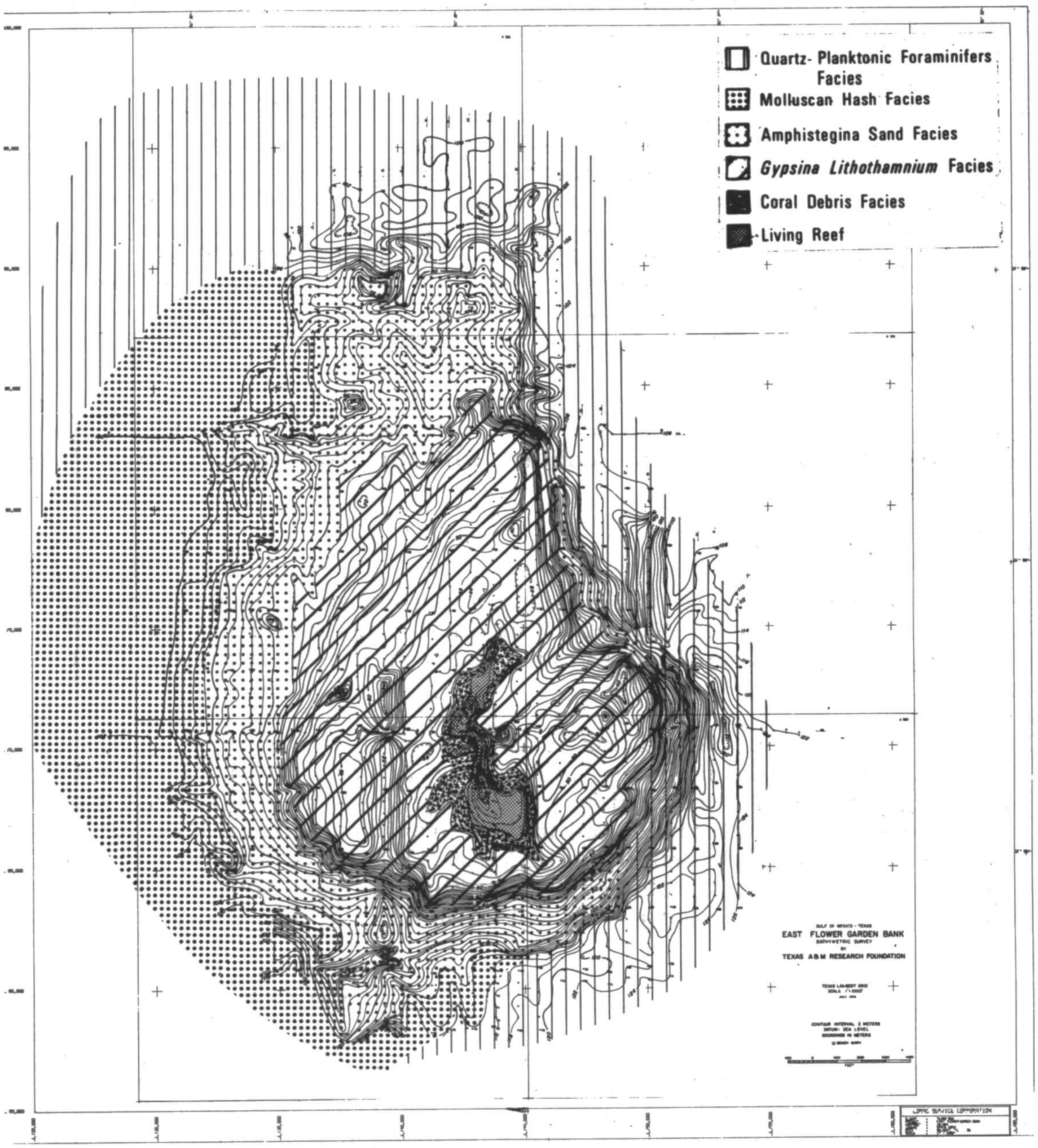

Figure V-5. Recent sediment facies, East Flower Garden Bank.

size fragments of coralline algae, coral, and molluscs also occur in this facies. Much of this material is derived from the bioerosion of drowned reefs (described below) that are common at these depths.

Tests of Amphistegina form up to 57% of the sediment, with the tests varying in appearance from whole tests to stained and rounded tests. The stained and rounded tests are reworked from older deposits that are exposed on the seafloor.

Quartz-Planktonia Foraminifers Facies

This facies occurs on the northern and eastern sides of the bank below depths of approximately 85-100 m. As originally defined by Edwards (1971), the facies ranges from 10% silt and fine sand size quartz grains, and 10% planktonic foraminifers, to a terrigenous silty sand with few carbonate particles. At the East Flower Garden, the facies contains from 2.5-76% quartz grains and from 9.2-79.6% planktonic foraminifers. The silt-plus-clay fraction varies from 24-100%, with an average of 82%.

On the southeast margin of the bank, where the steepest slopes occur, this facies is in direct contact with the Gypsina-Lithothamnium Facies.

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 the West Flower Garden Bank.

As here defined, 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%.

EAST FLOWER GARDEN BIOLOGICAL MONITORING STUDY

Biological monitoring at the East Flower Garden Bank has been directed toward identifying and gaining an understanding of the biological populations and ecological processes of primary importance to the continued "health" of the reef and hard-bank communities. Corals and coralline algae are undoubtedly the dominant organisms at the bank, building substratum and providing essential habitat for the other species comprising the hard-bottom communities. Monitoring efforts were directed toward a consideration of population dynamics and ecology of the overwhelmingly important corals and coralline algae. Non-destructive field methodologies which maximize the amount of data gathered per day at sea have been developed. The two East Flower Garden monitoring sites are shown in Figure V-6.

The study has evolved into a long-term quantitative assessment of population parameters, reproduction, recruitment, growth, and mortality of corals and coralline algae on the coral reef. From the submersible DRV DIAPHUS, yearly qualitative examinations of deep bank communities were performed to detect mass mortalities or apparent changes in benthic populations. A short-term study of leafy algae populations near the top of the bank has also been completed. Certain efforts, namely coral behavior studies and observations of fish and invertebrate activity cycles, have been abandoned because logistical limitations preclude gathering enough data to permit meaningful quantitative interpretation for purposes of long-term biological monitoring. Such techniques are better suited to short-term, intense monitoring efforts during drilling.

It is certain that, using the growing base of quantitative information already gathered, reliable dectection of any future changes in community structure, coral and coralline algae population parameters, rates of recruitment, and growth and mortality of corals and coralline algae can be accomplished.

Population Levels of Corals and Coralline Algae

Results of analysis of 34 plotless line transects taken for purposes of estimating coral and coralline algae population levels at the East Flower Garden are summarized in Table V-1. Several tentative conclusions can be drawn from the data, as follows:

1. *Montastrea annularis* constituted the highest percent cover and relative density of all coral species and algae at both stations of the East Flower Garden. *M. annularis* was present in all transects from both stations. Percent cover (dominance) values for all other corals and coralline algae were substantially lower than those found in *M. annularis*.

2. Dominance (percent cover) of *Montastrea annularis*, *Stephanocoenia intersepta*, and *Mussa angulosa* was found to be statistically higher on the reef edge station (BLM) than on the top reef station (CSA-A), whereas dominance of *Siderastrea siderea*, *Diploria strigosa*, and coralline algae was higher on the top reef area than on the reef edge. Dominance values for each of the other coral species were statistically similar at both stations.

3. Average live coral cover was 61.60% on the reef edge station (BLM) and 52.22% on the top reef station (CSA-A).

4. Species diversity, evenness, and richness values for the reef edge (BLM) and top reef (CSA-A) areas revealed no statistically significant differences.

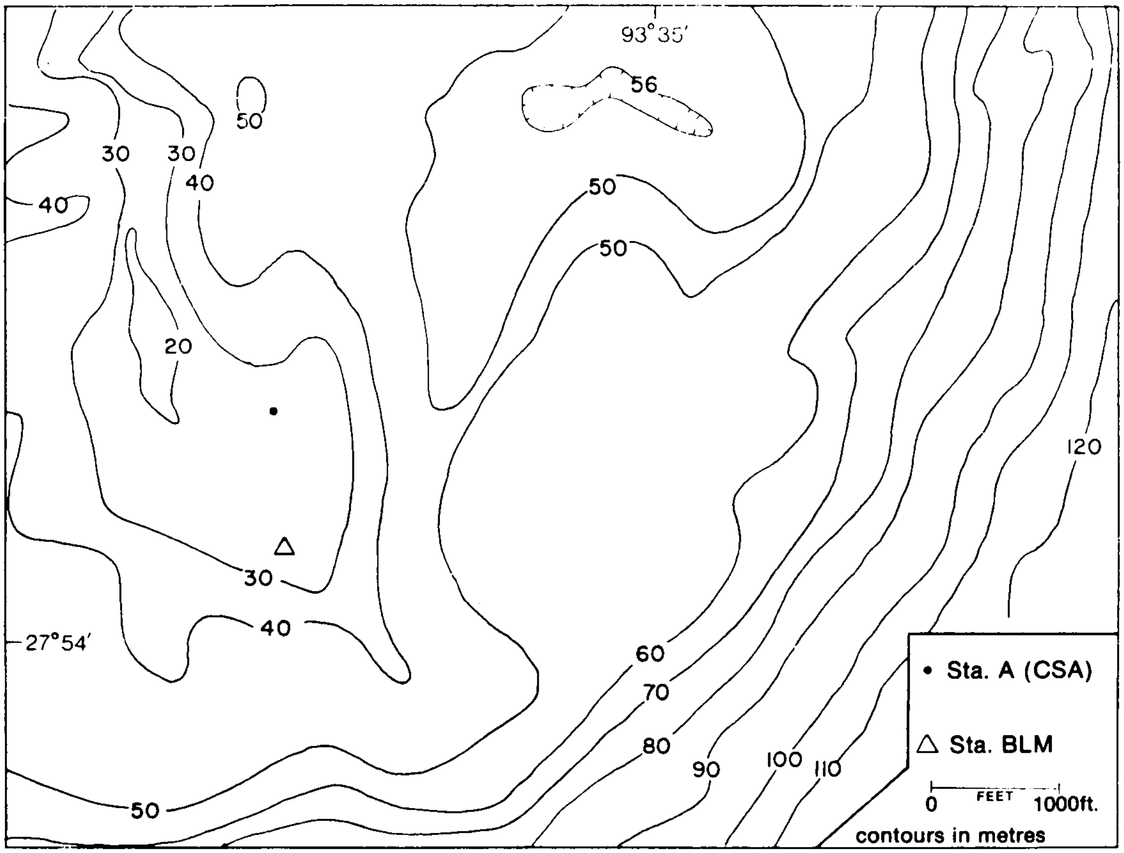

Figure V-6. Locations of the two East Flower Garden reef monitoring sites.

TABLE V-1

POPULATION LEVELS OF CORALS AT EAST FLOWER GARDEN MONITORING STATIONS*

CORAL SPECIES	DOMINANCE (PERCENT COVER)			
	CSA-A (top reef)		BLM (reef edge)	
	Range	Mean	Range	Mean
Montastrea annularis	14.89-31.09	(22.99)	31.19-42.33	(36.76)
Colpophyllia spp.	3.87-11.37	(7.62)	3.45-12.46	(7.95)
Diploria strigosa	3.76-12.62	(8.19)	0.97- 5.20	(3.09)
Coralline algae	3.84- 9.84	(6.84)	2.40- 5.00	(3.70)
Montastrea cavernosa	0.74- 6.24	(3.49)	1.15- 7.59	(4.35)
Millepora sp.	1.01- 6.60	(3.81)	1.89- 4.47	(3.18)
Porites astreoids	1.20- 3.09	(2.16)	1.02- 3.18	(2.10)
Madracis decactis	0.12- 1.62	(0.87)	0.00- 6.59	(3.26)
Siderastrea sp.	0.00- 4.45	(1.66)	0.00- 0.00	(0.00)
Agaricia spp.	0.37- 1.11	(0.74)	0.19- 1.11	(0.65)
Scolymia sp.	0.00- 0.12	(0.04)	0.00- 0.09	(0.03)
Mussa angulosa	0.00- 0.00	(0.00)	0.00- 1.17	(0.65)
Stephanocoenia intersepta	0.00- 0.00	(0.00)	0.01- 0.43	(0.22)

Indices of Diversity	CSA-A	BLM
Shannon-Weaver Diversity Index	1.34- 1.60 (1.47)	1.38- 1.66 (1.52)
Evenness	0.52- 0.62 (0.57)	0.54- 0.65 (0.59)
Richness	3.87- 4.25 (4.07)	3.71- 3.97 (3.84)

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*Expression of population levels is in terms of percent of hard bottom covered, which is also used as an indication of dominance. Means are enclosed in parentheses; the range is the 95% confidence interval of the mean. Dimensionless indices of diversity, evenness, and richness are shown for both stations in a similar fashion.

Growth and Mortality of Hermatypic Corals

Accretionary growth rates for the coral *Montastrea annularis* were determined by sclerochronological analysis of 12 cores from massive heads at 20 m depth on the East Flower Garden reef (Hudson and Robbin, 1980). Hudson and Robbin's results indicate stable growth conditions for *M. annularis* at the East Flower Garden from 1907 to 1957, with growth rates averaging 8.9 mm/yr. From 1957 to 1979 the growth of *M. annularis* averaged only 7.2 mm/yr. These rates are comparable to growth rates for the same species in the Florida reef tract.

Sclerochronological Analysis

Sclerochronological analysis of a specimen of *Stephanocoenia michelini* (synonymous with *S. intersepta*) collected from 38.5 m at the East Flower Garden in 1974 indicated a mean growth rate of 5.8 mm/yr over a 44-year period, with a 95% confidence interval of 5.5 to 6.2 mm/yr. These rates and those of Hudson and Robbin for *M. annularis* imply that environmental conditions at the East Flower Garden have favored growth of hermatypic corals for many decades, and that some of the live coral heads existing at the East Flower Garden are well over 80 years old.

Encrusting Growth and Mortality

Sclerochronological determinations of accretionary growth are appropriate measures of the long-term or historical circumstances of reef development. Contemporary health and condition of coral populations are, however, better reflected over the short term in measurements of percent cover of living corals, rates of lateral encrusting growth (occupation of bare reef rock by advancing live tissue), and mortality rates (loss of living coral cover due to death of tissue).

Encrusting growth and mortality were measured at the two East Flower Garden monitoring sites (Figure V-6) using seasonally repetitive close-up photographic techniques of 19 specific coral heads. Photographs taken of each head during the various seasonal cruises were compared planimetrically to determine gains or losses of live coral cover. Growth or mortality data are expressed as average linear advance or retreat of coral tissue over a selected segment of live coral colony border.

The data were normalized to a 30.42-day month, and for each species the mean growth or mortality rates, ranges of measured rates, standard deviations, and 95% confidence limits of the means were calculated (all expressed as mm/month growth or mortality; see Table V-2). Statistical interpretation of the data with so few observations and such high variability in growth and mortality rates is not feasible. It does appear, however, that where mortality occurs it proceeds at a substantially greater rate than does encrusting growth. Our preliminary results indicate that random observations in greater numbers are required per species studied. The future strategy will be to study only *M. annularis* as a representative massive hermatypic coral

TABLE V-2
COMBINED RESULTS OF ALL GROWTH MEASUREMENTS, POOLED ON A PER-SPECIES BASIS

GROWTH (mm/month)

Species	$\overline{X}$	Range	S	95% confidence limits of mean	n
D. strigosa	0.096	0 to .73	0.240	(-0.057 to 0.248)	12
M. annularis	0.456	0 to 2.81	0.919	(-0.252 to 1.163)	9
M. cavernosa	.3085	0 to 1.87	0.522	(.007 to .624)	13
P. astreoides	0.000	-	0.000	Not valid	2
Millepora	1.210	0 to 3.63	2.096	(-0.223 to 2.643)	3

MORTALITY (mm/month)

Species	$\overline{X}$	Range	S	95% confidence limits of mean	n
D. *strigosa*	4.448	.05 to 15.52	5.751	(-0.878 to 9.773)	6
M. annularis	0.787	.16 to 1.77	0.862	(-1.354 to 2.927	3
M. cavernosa	0.270	.18 to .36	0.127	(-0.874 to 1.414)	2
P. astreoides	3.320	-	-	-	2
Millepora	-	-	-	-	-

and maximize the number of observations on the species in order to obtain a statistically useful sample size.

Coral Recruitment

Arrays of settling plates constructed of cement were placed on the East Flower Garden coral reef in May 1979 to study the process of coral recruitment. Initial recovery and replacement of plates occurred in July 1979, with further recoveries and replacement during each subsequent monitoring cruise.

All newly settled corals collected between 31 May and 16 July 1979 (6.5 weeks) on unprotected plates #1, #3, and #5, were found attached to the plate undersides. Plate topsides were uniformly covered with a mat of filamentous green algae and a few bryozoans; this algal mat did not extend under the plates. A protected plate (enclosed in a large plastic cage) collected four coral polyps on its upper surface during this first sampling period. Slight algae fouling occurred on the upper surface of the protected plate but not on the underside. Heavy fouling by algae and bryozoans was noted on the top and side surfaces of the cage.

Both unprotected and protected plates from the 16 July 1979 collection appeared to be acceptable to coral larvae as suitable substrate. The two configurations collected larvae differently in that a relatively larger average number of polyps attached to unprotected plates than to the single protected plate.

The second collection, on 30 August 1979, included samples spanning the 13-week period since 31 May 1979, and the 6.5-week period from 6 July to 30 August 1979. Four unprotected plates which had been exposed for the entire 13 weeks had also collected twice the number of newly settled coral polyps. An average of nearly 22 polyps per unprotected plate was collected in 13 weeks, and settling polyps preferred plate undersides. During the 13 weeks, a protected plate from within the large plastic cage had also collected twice as many polyps as the protected plate retrieved from the same cage in July 1979, which had sampled only the first 6.5-week period. All polyps on both protected plates from the large cage had settled on the topside, which in both instances was slightly fouled with algae and bryozoans, while the undersides were unfouled.

Unprotected plates, which were placed on a single rod between individually caged protected plates, collected few polyps as compared to other unprotected plates. Three protected samplers from individual cages collected polyps on plate topsides, as previously seen in the aforementioned protected samplers, but yielded low average polyp counts per plate as compared to unprotected samplers. Algal and bryozoan fouling was observed on the small, individual cages, as previously observed on the large cage.

Newly settled coral polyps were either classified as "Type I," which were believed to be members of the family Faviidae, or as

"Type II," believed to be Poritidae. Typical specimens of each type were photographed at low and high magnifications using the Scanning Electron Microscope (SEM), and later taxonomic identification is planned.

Only Type I corals were separated into size-classes, as it was noted that the number of septa generally increased with increasing basal-disc diameter. Type II corals were lumped into one group and comprised about 14% of all corals observed on the nine unprotected plates observed between 31 May and 24 September 1979.

Relative abundance of coral polyps varied with time according to size-class. The 12-septa size-class of Type I corals was similar in abundance during each of the three different sampling periods, while the 24-septa size-class substantially increased in abundance during the same time-span. Polyps with 48 septa were not seen until the 16 5-week samples were collected. Type II polyps showed no such obvious patterns during 16.5 weeks, other than a general increase in numbers of individuals.

Planulae Larvae of Coelenterates

Planulae, assumed to be coelenterate larvae, were collected in metered plankton nets throughout the year. The morphology was similar to that of zooanthids (Hyman, 1940), but the planulae at present are not identified. The maximum abundance of planulae was observed during the spring monitoring cruise. The edwardsia stage (a presettlement stage) was observed sporadically throughout the study. Abundances were quite low (maximum of 11.5/100 m^3), averaging about 1.1/100 m^3 during the year. The maximum for the planula stage was 326/100 m^3, and the average was 21/100 m^3 during the study.

The morphology and duration of the planula stage is not known for most species. The time of development of coral planulae normally ranges from one to several days (Atoda, 1951a; Lewis, 1974). Ostarello (1976) reported that the planula of the hydrocoral Allopora californica was short-lived and that settlement occurred near the parent polyp. Longer times have been reported. Atoda (1951b) found free-swimming planulae after two months. He also reported two morphological types: a small, barrel-shaped swimming form and a larger, cylindrical crawling form. The swimming form was long-lived, while the crawling form was short-lived and did not leave the substrate. The shape of the crawling form is similar to that found in this study. The trends observed in this study reflect a positive phototaxis and/or negative geotaxis as commented on by Connell (1973). Depending on duration of development and direction and velocity of the currents, these planulae could be transported to and from banks in the region having suitable substrate for them to settle.

Whereas planulae were present throughout the year, the largest number of planulae apparently occurred during the spring. The actual source of planulae was not identified, but it probably would be an area of anthozoans of a high density. This area could be the Flower Garden Banks. Secondly, there was a large density of larvae in general.

Levels of several larval types were orders of magnitude higher than have been indicated in similar studies in the northwestern Gulf. The sources could be areas of higher densities of benthic invertebrates and fishes, namely the Flower Gardens and other nearby banks.

Leafy Algae Populations

The leafy algae populations were characterized through analysis of seasonal samples taken on a knoll within the Leafy Algae Zone, a short distance from the BLM monitoring site. The most consistent dominant forms were Dictyota spp. (D. dichotoma and D. bartayresii), Peyssonnelia rubra, and Lobophora variegata. Ranking of these species in terms of relative abundance differs in the several seasonal samples and in transect and quadrat samples within seasons. These differences may be indicative of substantial lateral variation and seasonal variation in distribution and abundance of leafy algae species on the knoll sampled.

Statistical comparison of means and analysis of variance using the F-test for uneven sample size indicated significant differences between the means of spring total biomass samples and all other seasons (spring samples were higher in total biomass). Fall sample means did not differ significantly from winter or spring means, but summer total biomass was significantly higher than winter. These data are preliminary, but there is a strong indication that the leafy algae population was substantially greater in the spring of 1979 than during other sampling periods.

In summary, over 16 species of leafy algae were identified from samples taken at 27 m depth from the knoll near the BLM monitoring site. Three or four species dominated throughout the year, with apparent seasonal changes in relative abundance and substantial lateral variation in distribution and abundance on the knoll. The largest populations seem to have occurred during the spring season.

ANCHORING

In the course of research activities on the reefs at the East and West Flower Garden Banks, evidence of mechanical damage to living coral has repeatedly been observed. Such damage can be caused by the activities of certain marine organisms, by water movement during storms, and by man, primarily as a result of anchoring on the reef. If maximal protection of reefal communities is desired, destruction of living coral cover by anchoring should be eliminated where possible.

Two instances of anchoring at the East Flower Garden by oil tankers were observed during the spring and summer of 1979. It is felt that in both cases substantial damage to living coral on the reef must have resulted from the anchoring. This contention is based on the fact that the locations of these vessels placed them directly over the coral reef, the anchor chains descending vertically into the water. Both anchor chains undoubtedly lay across the reef for some distance contacting live coral; in one case the anchor was dropped unmistakably on the reef.

In October 1978, a freighter was seen anchored 3/8 n.m. southwest of monitoring site CSA-A at the East Flower Garden. On February 19, 1980, a tanker passed within 1/2 n.m. of the TAMU research vessel at the West Flower Garden, and circled intending to anchor. The tanker left the site willingly after being asked not to anchor on the reef.

Anchoring by such large vessels using massive anchors and chains is of particular concern due to the potential for large-scale mechanical damage to corals.

OBSERVATION OF THE SOUTHEAST TRANSECT

The purpose of traversing the southeast transect once a year is to determine, through visual observation from a submersible, whether or not there have been mass mortalities of components of the benthic community or apparent changes in community structure. The southeast transect has been amply described by Bright and Rezak (1976, 1978a, 1978b). Direct observation and video and photographic documentation detected no apparent changes in the benthic assemblages on the southeast transect between September 1977 and September 1978.

Analysis of samples collected during the 1979 submersible dives has resulted in a number of new species records for the Flower Garden Banks. Particularly noteworthy was the discovery of large populations of echinoids (*Pseudoboletia maculata* and *Arbacia punctulata*) and asteroids (*Linckia nodosa*) on the bank west of the main coral reef between 46 and 76 m. It is speculated that the dense assemblages of *P. maculata* and *L. nodosa* were breeding aggregations.

It has also become apparent that elasmobranch populations are seasonally high at the East Flower Garden, with large numbers of sharks often encountered in the winter and early spring. Though it is difficult to identify most sharks to species in the water, Tiger sharks (*Galeocerdo cuvier*), Hammerhead sharks (*Sphyrna* sp.), and Sawfish (*Pristis* sp.) have been sighted on the coral reef. A large Angel shark (*Squatina* sp.), partly buried in the fine sediment at 87 m, was seen from the submersible, on the northeastern edge of the bank.

BRINE SEEP

The presence of a brine pool at the East Flower Garden Bank was first discovered in 1976 (Bright and Rezak, 1978a), and studies have continued since that time. The brine system consists of interrelated components: 1) numerous seeps feeding 2) a brine lake that has 3) an outflow into a canyon that contains 4) a mixing stream that dilutes the brine to a hypersaline condition.

Description of the Brine System

Anoxic, sulfide-rich brine (approximately 200 °/oo) of nearly ambient temperature percolates from the seafloor, forming a small, shallow lake of dense water in a depression at the eastern margin of the bank. Residence time for the brine in the lake is less than one day (probably 2-7 hours). Significant mixing of the brine with overlying seawater apparently does not occur across the interface, although organic gases, sulfate, and other dissolved components of the brine diffuse across the interface into the overlying seawater. Brine overflows the lake and is substantially mixed with seawater in the axis of a 60 m long canyon extending from the lake to the bank edge, where dilutions of greater than 50:1 occur.

Origin of the Brine

An intrusion of Jurassic salt, from depths of 6000 m or more, penetrates to within 150 m of the seafloor (possibly 30 m) directly beneath the bank. The chemical composition of the brine indicates that it is a product of dissolution of this salt by seawater percolating through cracks, faults, or permeable reef rock.

Chemistry of the Brine

Sulfide-oxidizing bacteria are abundant at the brine-seawater interface and on the canyon floor, where mixing brine and entrained seawater flow in a recognizable stream along the bottom. In both areas, hydrogen sulfide and oxygen are present in quantities necessary to support such bacterial activity, resulting in the production of substantial amounts of elemental sulfur and organic matter.

Toxicity of the Brine

Although the anoxic, sulfide-rich brine and oxygenated brine-sea water mixtures are obviously toxic to normal bank biota, deleterious effects on surrounding epibenthic communities are minimal and restricted to a zone measuring from several centimetres to two metres wide surrounding the lake and mixing stream. 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 to 3 m away from the lake interface 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 to 40 °/oo salinity, limited sulfide). Under these conditions, whitecolored, filamentous Cladophorales 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.

Biota of the Brine System

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

In light of the interest over the past 10-20 years in the effects of brine discharges on the communities of the receiving basin, the impact of the East Flower Garden Bank brine discharge on a relatively fragile ecosystem such as the deep-water reef is particularly important. Unquestionably, the biota of the brine system itself is markedly changed. The typical aerobic community has been replaced by an anaerobic one. On the other hand, the remainder of the reef community appears not to be visibly affected by the brine except in a narrow (1-2 m wide) band around the seep. This is certainly not unexpected given the well-known stability of strong pycnoclines and the fortuitous presence of an overflow channel which regulates the level of the brine lake.

Gravity flow down the overflow channel fairly effectively mixes the brine with normal seawater. Although the effects of moderately increased salinity on the adjacent soft-bottom community are not known, the invertebrate population is clearly sizeable and surprisingly diverse. In fact, the effect of the hypersaline water on this community may not be wholly negative. The brine system may provide a significant food source. Continual gravity flow down the outflow channel serves to advect this production to the user community below. This increased food supply may at least ameliorate the effects of the salinity increase. After a detailed study of the brine seep area is completed, the possibility remains that the most important effect of the seep's presence will be shown to be the increased food supply it provides rather than the salinity stress it imposes on the immediately adjacent area.

Significance of the Study of this System

Petroleum production and desalination operations require the discharge of brines into seawater. Construction of certain regional petroleum reserve storage facilities involves dissolution by seawater of the cores of salt domes (similar to the one beneath the East Flower Garden) and the discharge of resulting brines into the ocean. Observations concerning environmental impacts of natural brine discharges such as the one at the East Flower Garden may, therefore, contribute to the formulation of guidelines for brine disposal on the Continental Shelf.

WATER AND SEDIMENT DYNAMICS

Introduction

Studies of water and sediment dynamics were carried out during three seasonal cruises to the East Flower Garden Bank (January, April, and July 1979). Data gathering for information on stratification, transmissivity, and velocity was attempted on all three cruises, but only two sampling cruises (April 1979 and July 1979) yielded usable data. Time series current meter measurements were also undertaken during three sampling periods in 1979: January-April, April-July, and July-September.

Time Series Current Measurements

The program for long-term current measurements at the East Flower Garden Bank commenced in January 1979 with the deployment of two moored arrays and one rigidly mounted instrument. Array I was established just to the northeast of the East Flower Garden Bank (Figure IV-1, above, p. 25) for the purpose of measuring currents that should be only slightly deformed by the presence of the bank. Array II was set in 100 m of water on the southwestern periphery of the bank for the express purpose of measuring the current's response to the bank. On the initial deployment each array was comprised of three Savonius rotor and vane type current meters. The upper meters were placed at 40 m depth to monitor the flow at the level of the broad platform on the East Flower Garden Bank at the base of the main reef. The lower meters were set at 4 m and 6 m off the bottom at each location to record the behavior of the flow in the bottom boundary layer. Each instrument was also equipped with a very sensitive thermistor for measuring temperature.

The sampling rate on the instruments was set so that one record was taken every six minutes. This rate was chosen so that the current behavior due to high frequency internal waves could be recorded, should internal waves be present.

An electromagnetic current meter (ECM) was rigidly mounted on a stand at the reef monitoring site near the summit of the bank. It was necessary to employ this type of current meter on the crest of the bank because the influence of surface gravity waves is expected to penetrate to that depth (30 m) fairly often. ECM's provide more accurate velocity data than do Savonius rotor type sensors when surface gravity waves cause high frequency changes in velocity.

Significance of Findings

The most important result of the study is the observation from Array II that cross-isobath flow rarely occurs and is minimal when it does happen. It is quite clear that the current is constrained to flow around the bank rather than over it throughout the range of velocities encountered from January through September 1979. It should be remembered that the meters were first deployed during extreme storm conditions, with seas of nearly 7 m arising just after the meters were set.

From the records of the near-bottom meters, it appears that one should expect frequent resuspension of silt- and clay-size sediment, particularly at the various tidal frequencies. In light of this observation, neither the presence of the nepheloid layer nor its spatial and temporal changes is surprising.

With continued data acquisition it should be possible to derive more information about the outer shelf dynamics. This information will ultimately enable us to produce at least stochastic models of the flow. These in turn will suggest the probable lines of transport of material which may be shunted to the bottom during drilling operations in this area.

CHEMICAL ANALYSES

Analyses for trace metals, high molecular weight hydrocarbons, total organic carbon, and Delta C-13 were performed on a set of sediment samples from the East Flower Garden (30 samples) and West Flower Garden (3 samples). The results indicate that in most samples the level of contamination by hydrocarbons was at or below background levels. A slight increase in the level of contamination was detected in the immediate vicinity of the Mobil Oil Corp., drill site no. 2. Trace metals analyses of Spondylus samples also showed an increase in the concentration of lead, cadmium, and barium in the immediate vicinity of the drillsites.

CHAPTER VI

OTHER BANKS

R. Rezak

INTRODUCTION

In addition to studies at the Flower Garden Banks, geological and biological characterization was carried out at ten other banks in the northwestern Gulf of Mexico. For eight of these banks, studies included mapping, sub-bottom profiling, and submersible observations. At two banks, 32 Fathom and Applebaum, characterization was based on dredge samples. At selected banks, studies also included sedimentological and chemical analyses, and hydrographic sampling. Significant results for each bank are summarized in this chapter.

COFFEE LUMP BANK

General Description

Coffee Lump is located at 28°04'33"N latitude and 93°55'01"W longitude (Figure II-1, above). Most of the bank lies in the High Island Area, East Addition, South Extension in Blocks A-340, 341, 358, 359, 360, and 361. The western margin of the bank lies in the High Island Area, South Addition, Blocks 521 and 546 (Figure VI-1).

The bank is a low, broad swell on the seafloor elongated in a north-northwest south-southeast direction and covering an area of about 75 km^2. Off-bank depths to the south are 76 m and to the north about 68 m. The maximum topographic relief is approximately 14 m; however, local relief is rarely greater than 3 m (Figure VI-1). The shallowest depths on the bank are located on two peaks in Block A-359 and one peak in Block A-340, both peaks rising to depths of 62 m (Figure VI-1). An elongate, shallow depression with a relief of less than two metres lies in the center of the bank.

Geology

Coffee Lump is a truncated anticline that was eroded during Late Pleistocene or Early Holocene time. The bank is located in the valley of a major stream that flowed into the Gulf just to the west of the West Flower Garden Bank when sea level stood at that point. The only activity on the bank during Recent time has been a minor amount of settling in the central graben, creating the shallow, elongate depression in the middle of the bank (Figures VI-1 and 2). Figure VI-3 shows the steeply dipping truncated beds intersecting the sea bottom.

The sediments of the bank range from muddy sands to sands. The sands are primarily quartz and are probably relict stream deposited sands. Hydrocarbon analyses of four sediment samples taken at Coffee Lump show no obvious contamination by petroleum.

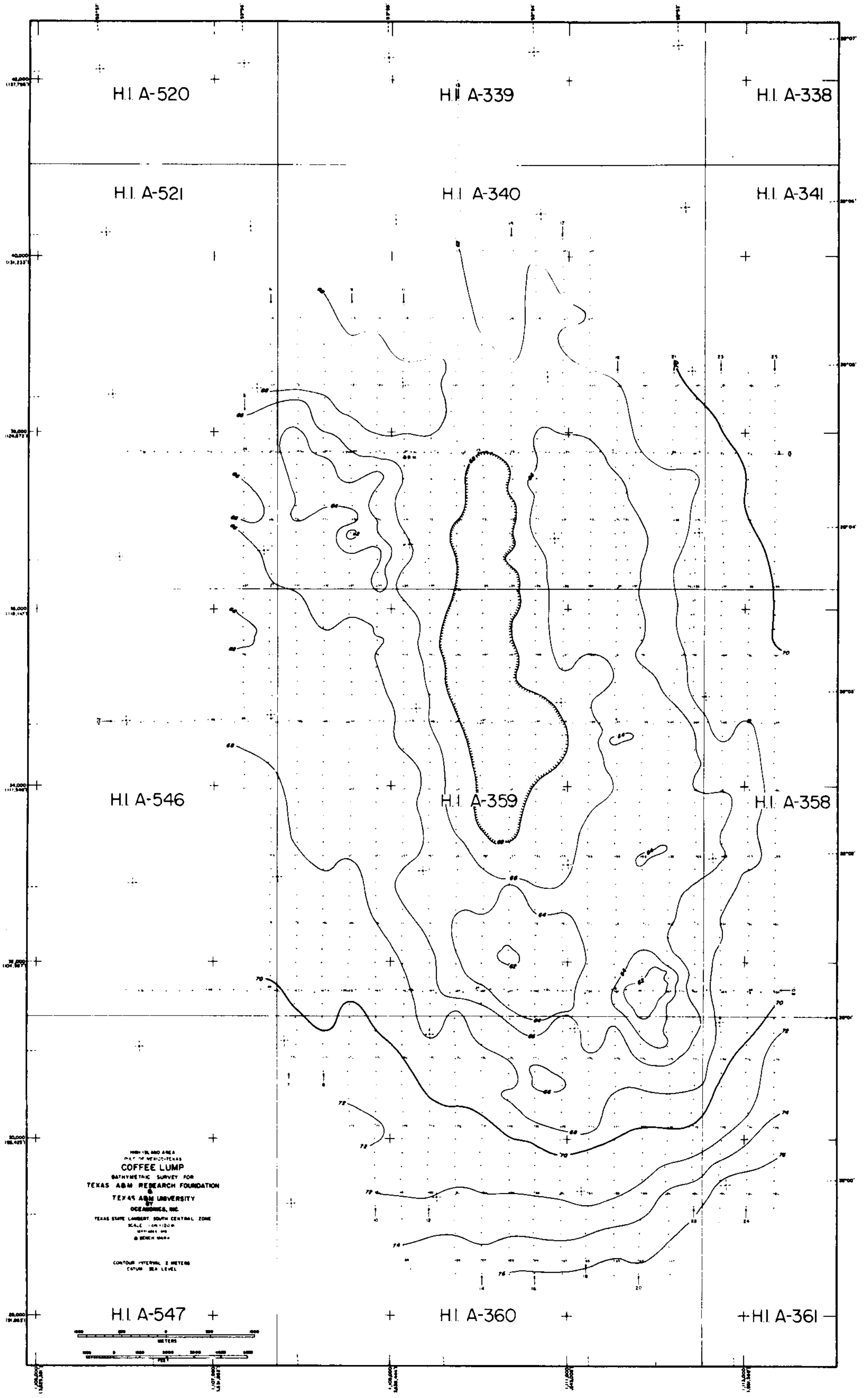


Figure VI-1. Coffee Lump bathymetry.

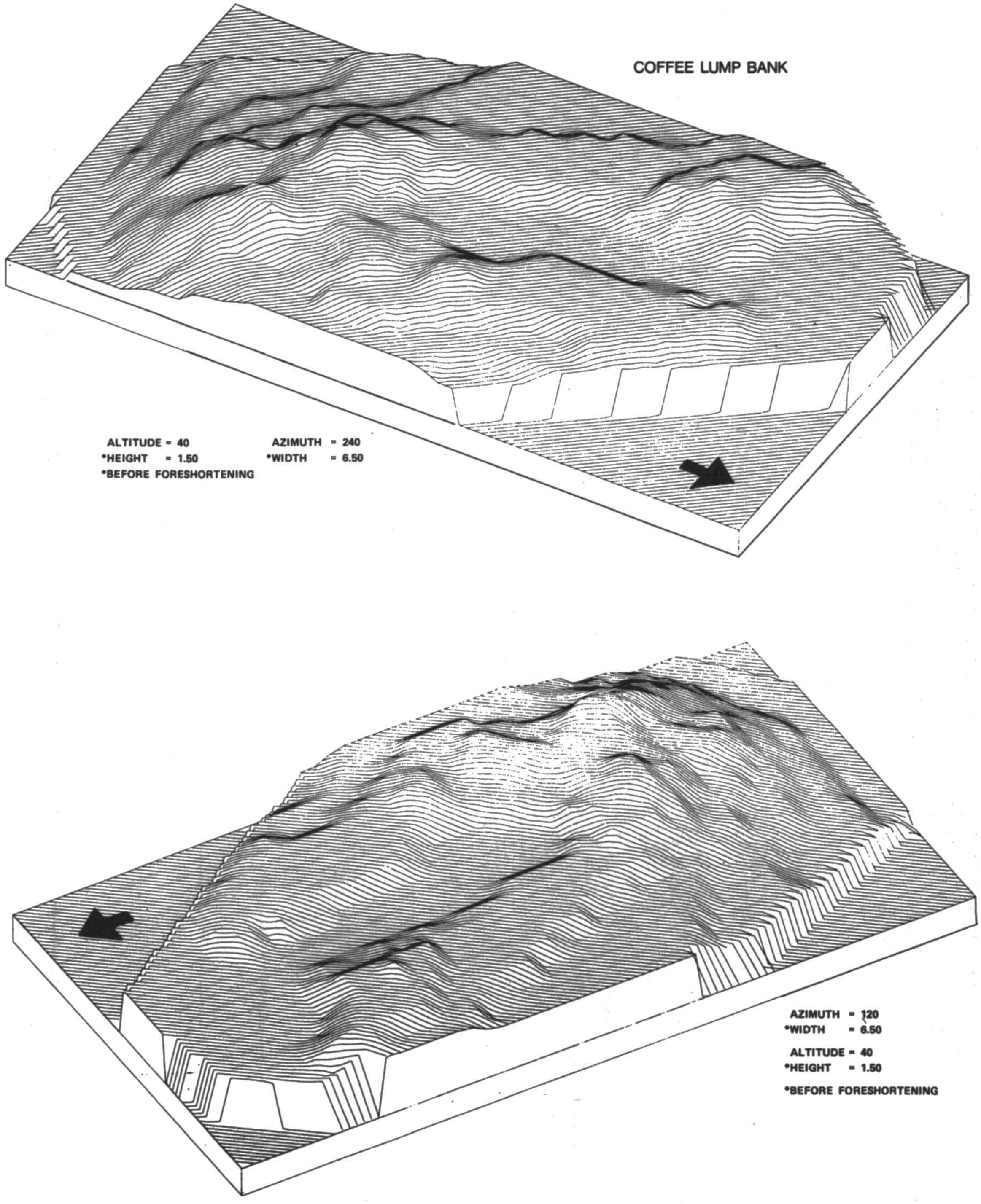


Figure VI-2. Three-dimensional perspective views, Coffee Lump.

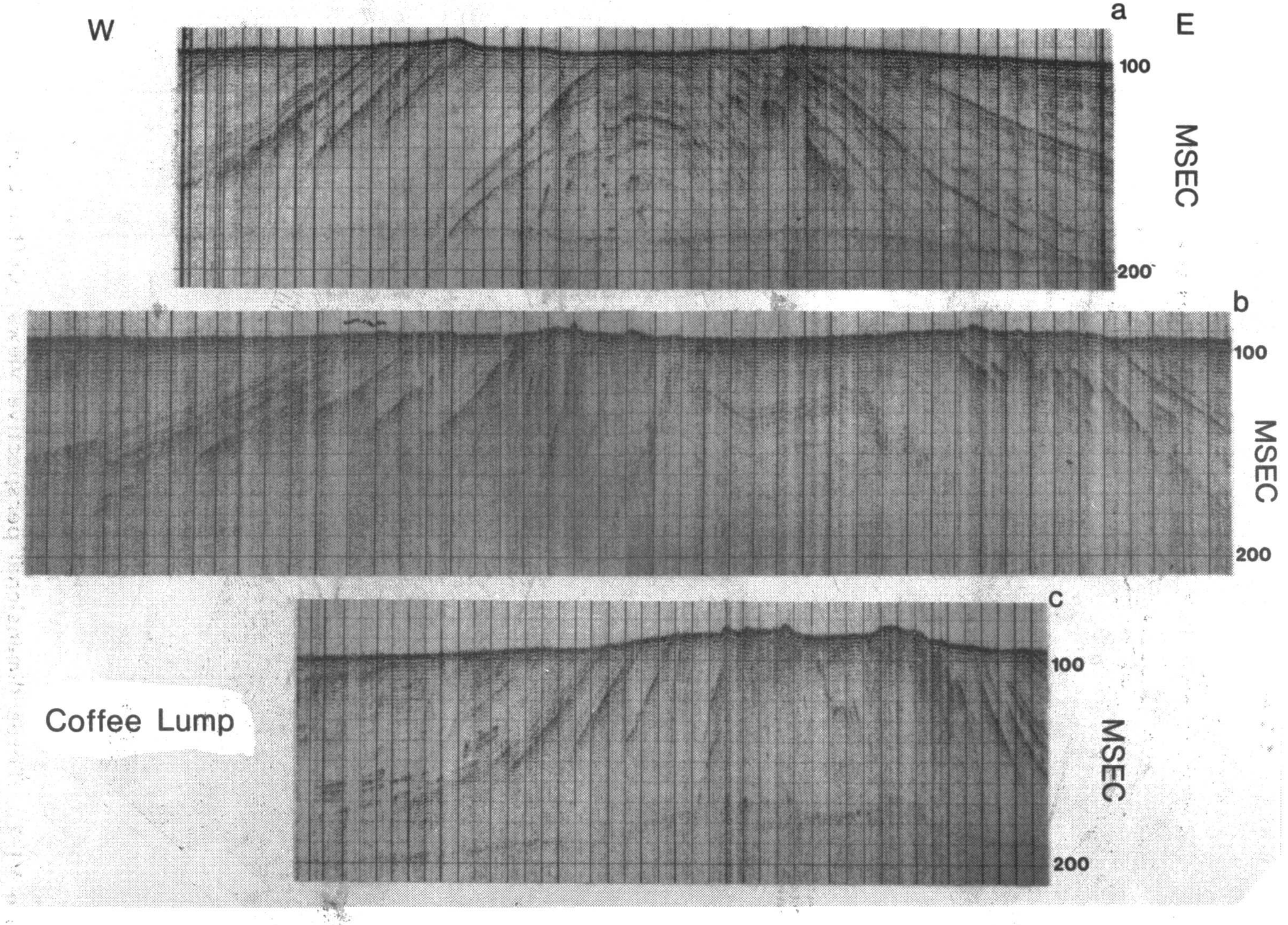


Figure VI-3. E-W boomer seismic reflection profiles across Coffee Lump Bank.

The bank is continually immersed in a nepheloid layer, and the fauna and flora of the bank are similar to those of the South Texas Outer Continental Shelf fishing banks, which are also immersed in a nepheloid layer.

Biology

Preliminary analysis of community structure indicates that above 68 m, at least, Coffee Lump harbors a soft-bottom, macro-epifaunal community which is distinctly bank-related and differs substantially from soft-bottom epifaunal communities found adjacent to banks in the northwestern Gulf of Mexico. The upper Coffee Lump soft-bottom communities appear to be more diverse and to include a greater abundance of organisms than is typical of off-bank, soft-bottom communities.

Biotically, the hard-bottom is an Antipatharian Zone, harboring an assemblage of organisms very similar in composition to those of the South Texas fishing banks. The distribution of such hard-bottom epibenthic communities on Coffee Lump is probably coincident with the bottom irregularities detected on side-scan sonar records.

FISHNET BANK

General Description

Fishnet Bank is located at 28°09'N latitude and 91°48'30"W longitude (Figure II-1, above). The bank lies in the northeastern quarter of Block 356 in the Eugene Island Area. It is the smallest of the eight banks mapped, covering only 1.9 km^2. The bank is nearly circular, with a relatively flat crest that lies at depths of 66-70 m. A raised rim along the southeastern and southern margins of the bank appears to be a reef build-up. Three separate peaks on that reef attain a minimum depth of just greater than 60 m. Surrounding water depths are about 78 m on all sides of the bank. An east-west channel, 78-79 m deep, extends along the base of the north side of the bank (Figures VI-4 and 5).

Geology

Fishnet is a textbook example of a salt dome. It is circular, has steeply dipping beds on its flanks, and has developed a crestal graben. Profiles b and d on Figure VI-6 show Recent movement on the faults of the central graben, reflected by a minor sagging of the sea bottom over the graben. Figure VI-6b is east of the bank, and Figure VI-6d is west of the bank.

The sediments range from gravelly, sandy muds to sandy, muddy gravels. The nepheloid layer frequently envelops this bank, accounting for the large amount of mud in the bottom sediment on the crest of the bank.

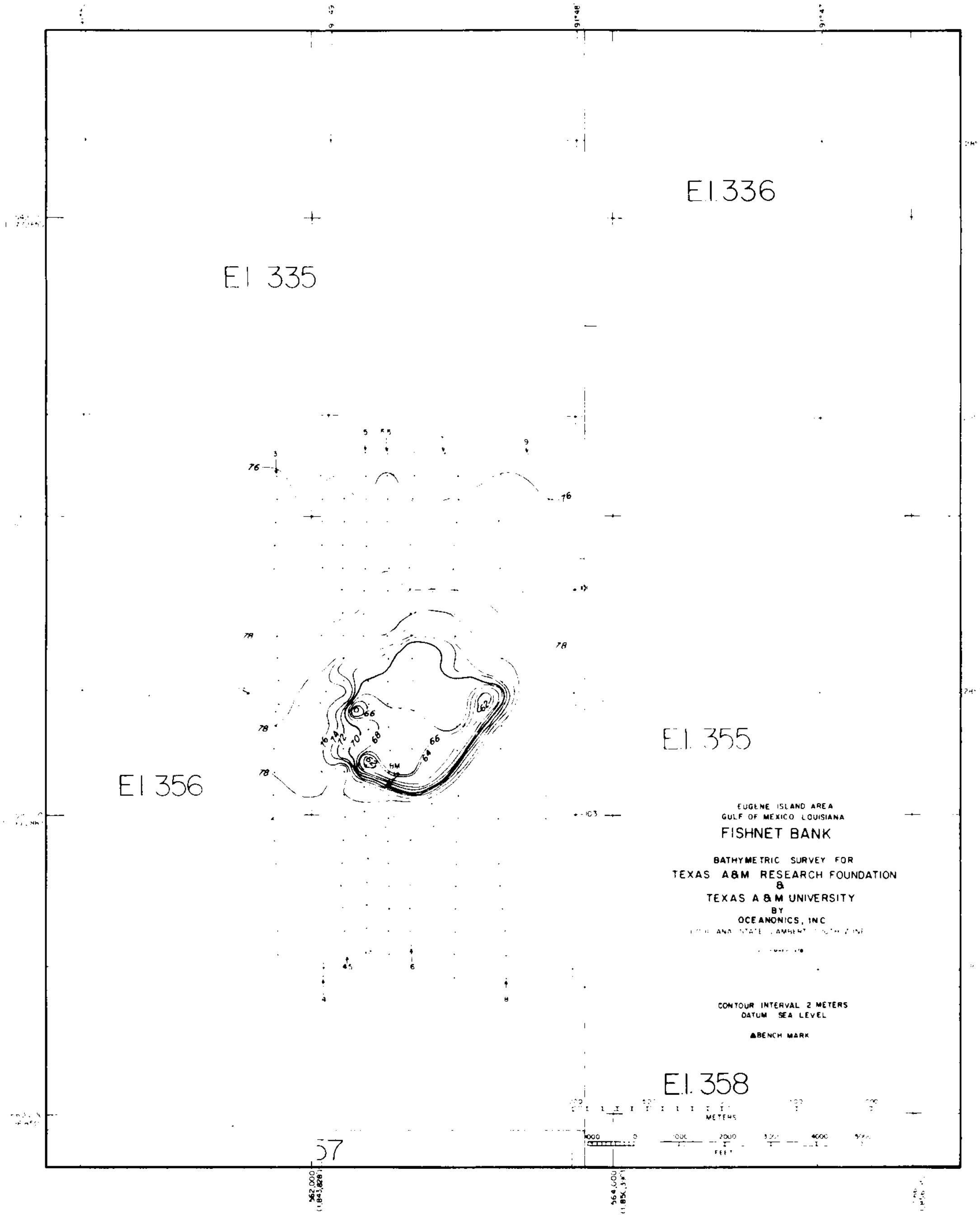


Figure VI-4. Fishnet Bank bathymetry.

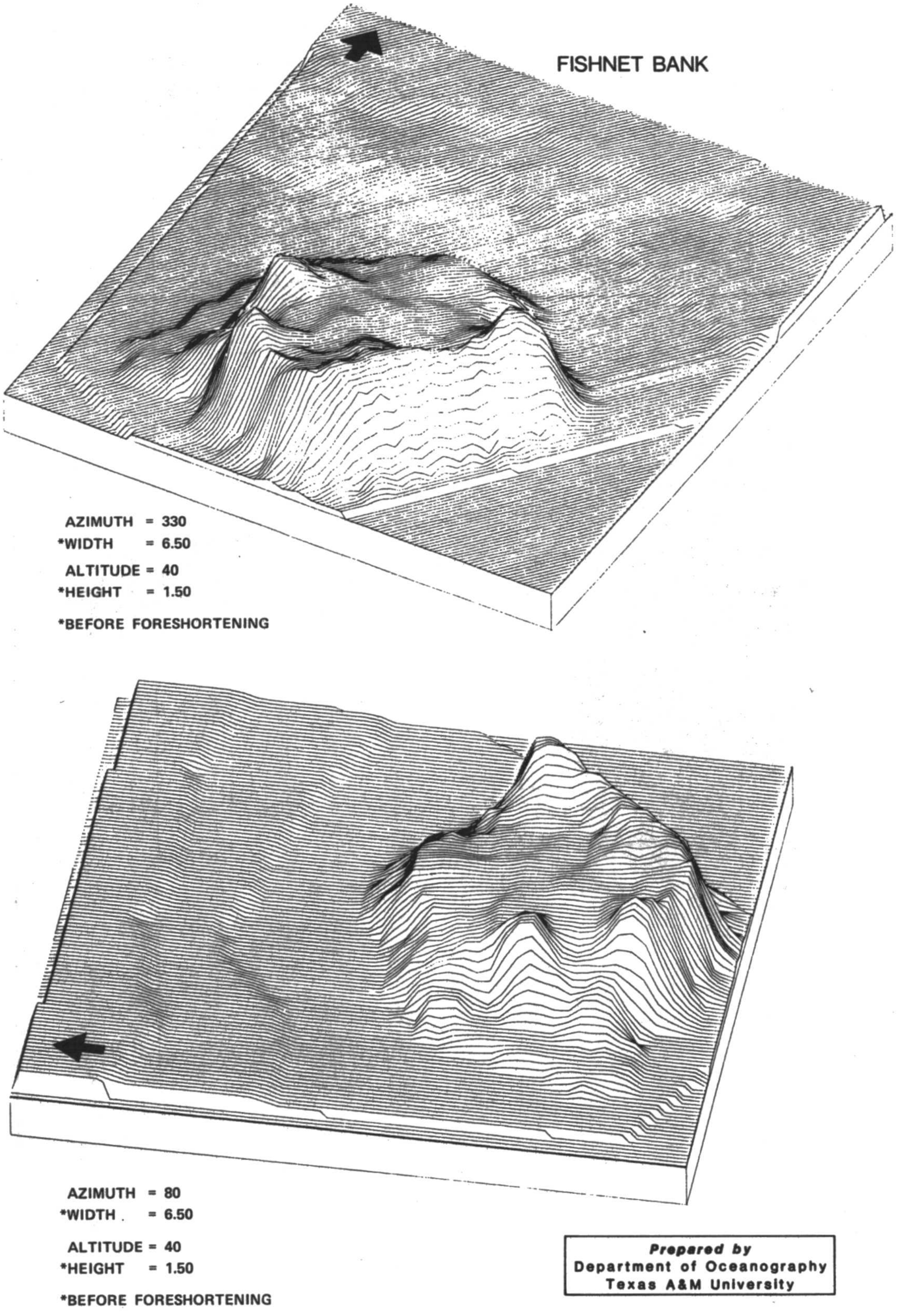


Figure VI-5. Three-dimensional perspective views, Fishnet Bank.

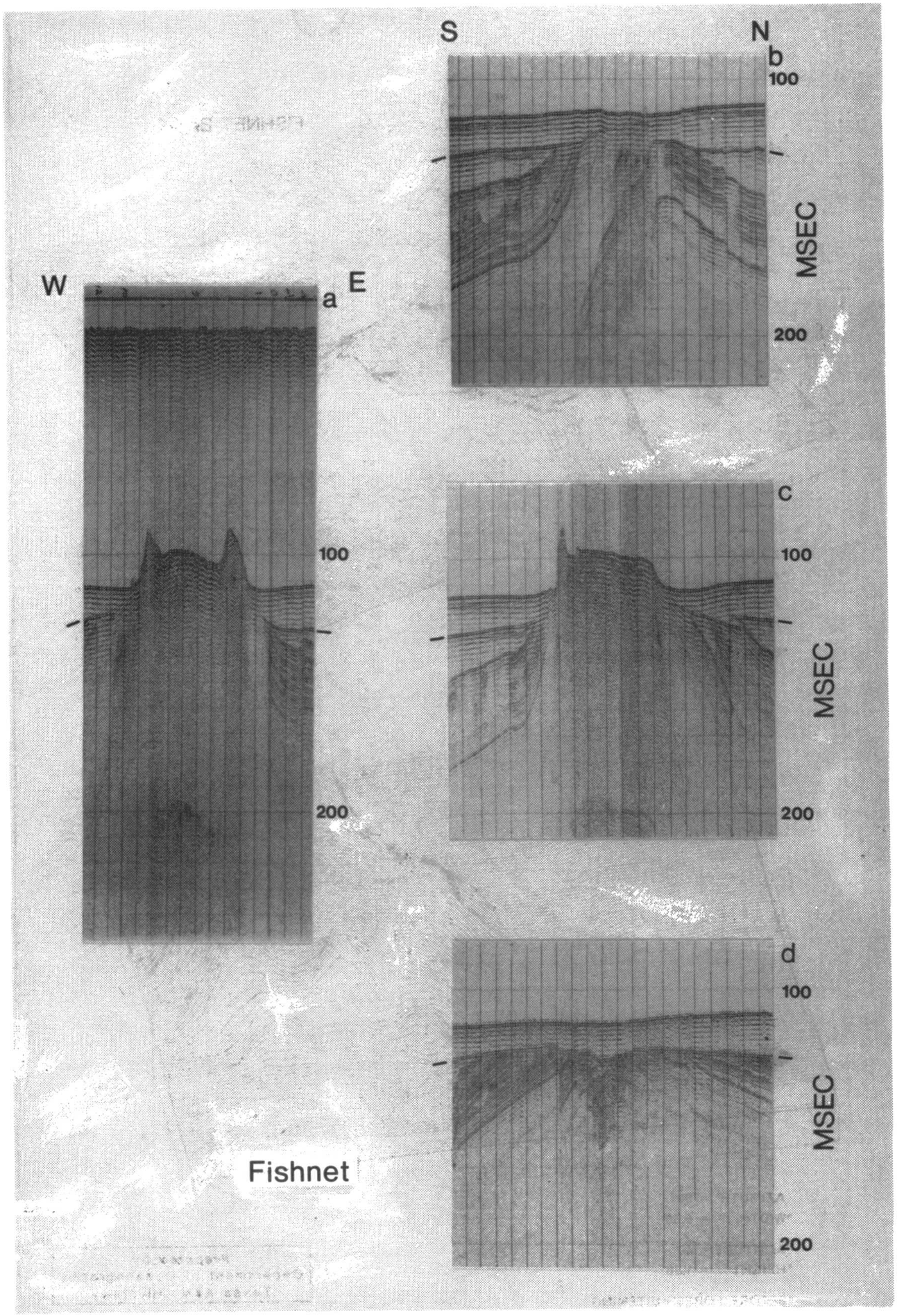


Figure VI-6. Boomer seismic reflection profiles, Fishnet Bank.

Biology

Biotic communities at Fishnet Bank are apparently of low diversity and limited abundance, probably an adjustment to chronic high turbidity and sedimentation. Although some coralline algae were encountered, there is no indication that they comprise a reef-building population. Fishnet Bank communities are somewhat comparable in quality to those occupying certain South Texas Fishing Banks (Baker Bank, for example), but differences in community structure are strongly indicated.

DIAPHUS BANK

General Description

Diaphus Bank is located at 28°05'18"N latitude and 90°42'26"W longitude (Figure II-1, above) in Blocks 314-317 of the South Timbalier Area. It lies close to the shelf edge and is about 50 miles west of the Mississippi Trough. The bank is rectangular and covers an area of about 33 km^2. Superimposed upon this rectangle are two ridges that intersect at nearly right angles to form a rough cross. The surrounding water depths range from 110 m on the north to 130 m on the south, with increasing depths to the south, down the upper continental slope. The bank stands about 40 m above the surrounding shelf, with the shallowest depth at a peak in the center of the bank lying at 73 m (Figures VI-7 and 8).

Geology

Seismic reflection records reveal that Diaphus Bank is a diapiric structure that has been breeched by a major down-to-the-sea fault creating the massive south-facing scarp that is so prominent on the bank. This scarp and associated faults can be seen in Figures VI-7, 8, and 9.

The sediments on Diaphus Bank range from sandy muds to gravelly sands. Submersible observations suggest that the nepheloid layer may, at times, extend up to a depth of 80 m. Over much of the year, background suspended particulates from the Mississippi River may occur in substantially higher concentrations at Diaphus Bank than at the banks to the west.

Biology

That part of Diaphus Bank explored by submersible (82 to 116 m depth) appears to be composed surficially of a grouping of drowned, largely sediment-covered, non-growing reef patches, the largest of which occur near the break in slope at the edge of the bank's upper platform (85 to 95 m) (Figure VI-10). Sediment between the shallower drowned reefs is sand and rubble with little else. Below the break in slope, the ratio of very fine unconsolidated sediment increases, the sediment cover on rocks is thicker, and turbidity of the water is greater.

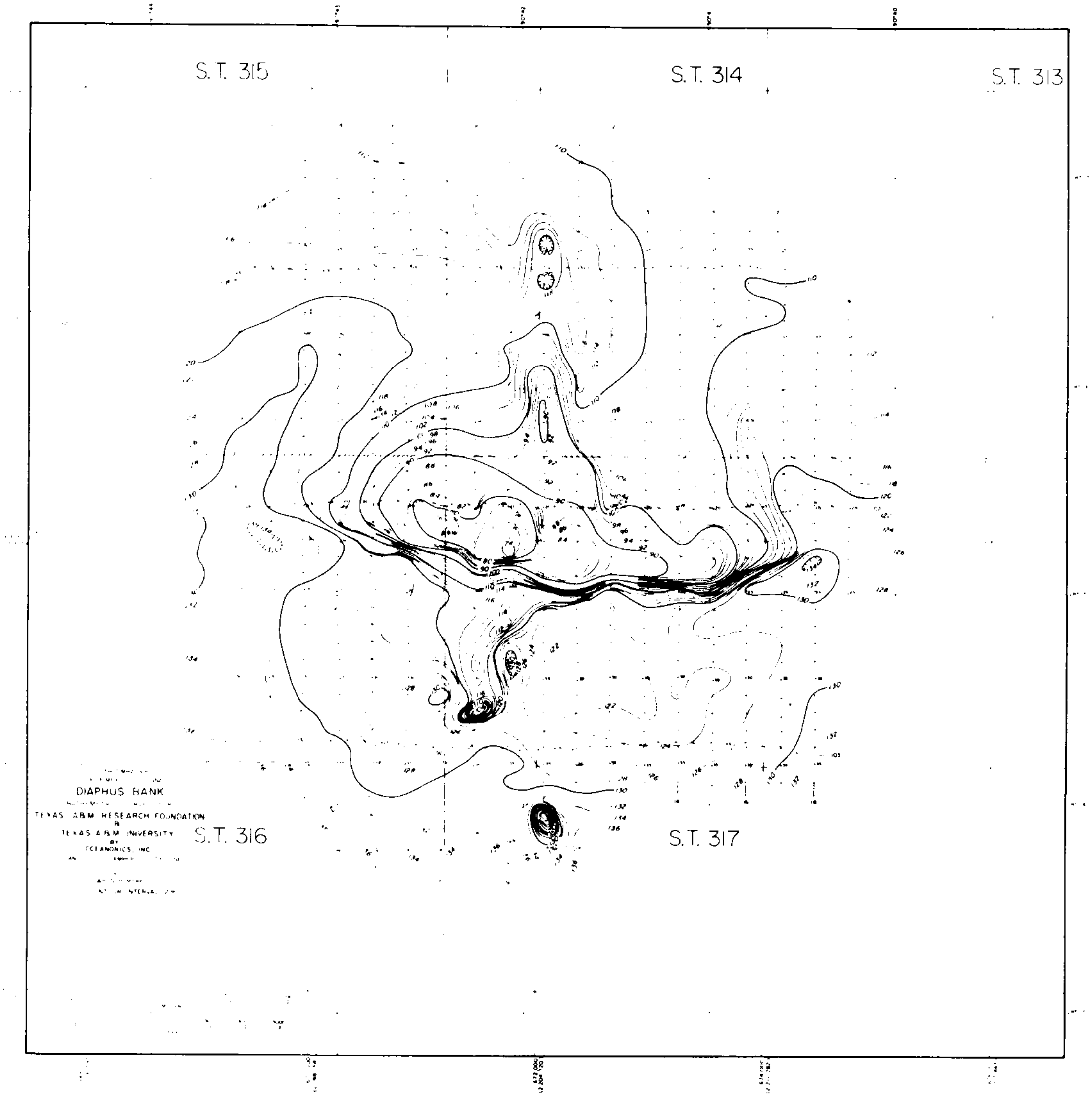
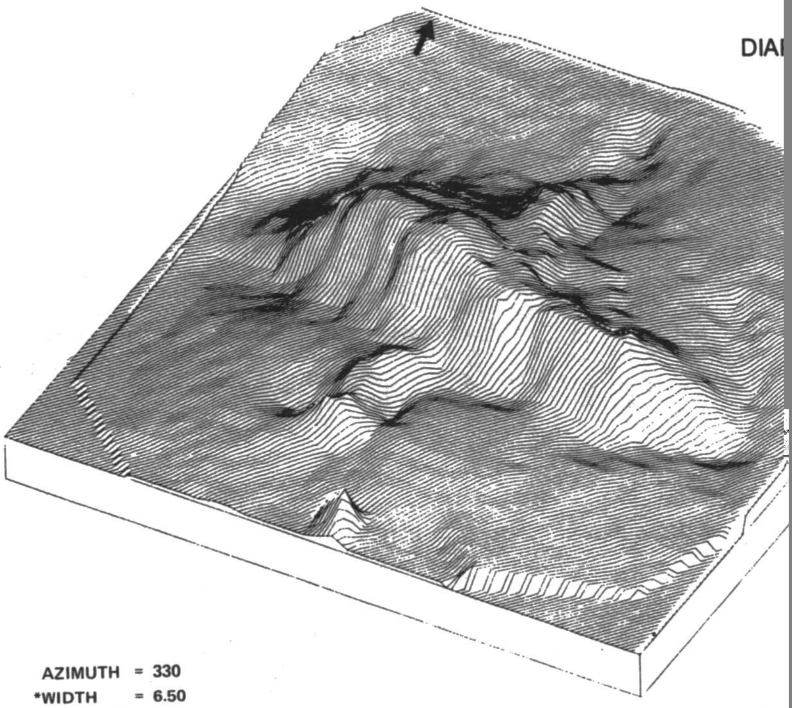


Figure VI-7. Diaphus Bank bathymetry.



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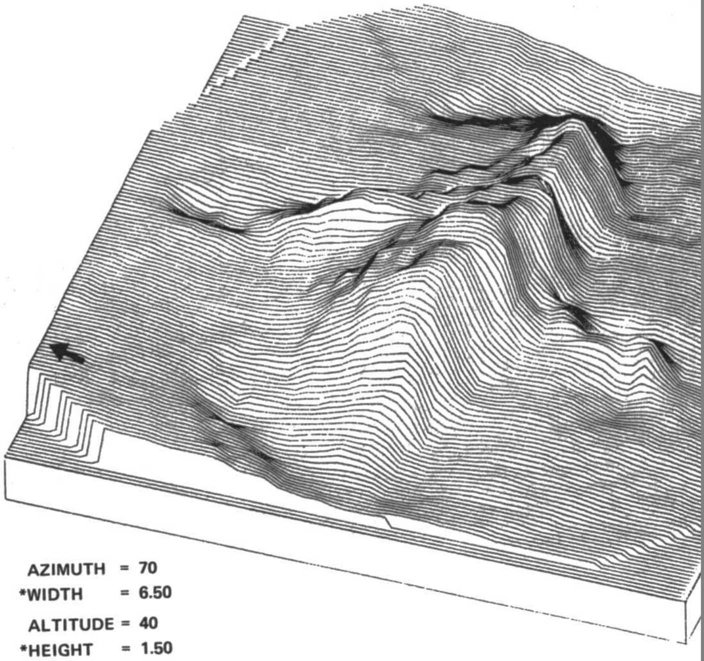

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Figure VI-8. Three-dimensional perspective views, Diap

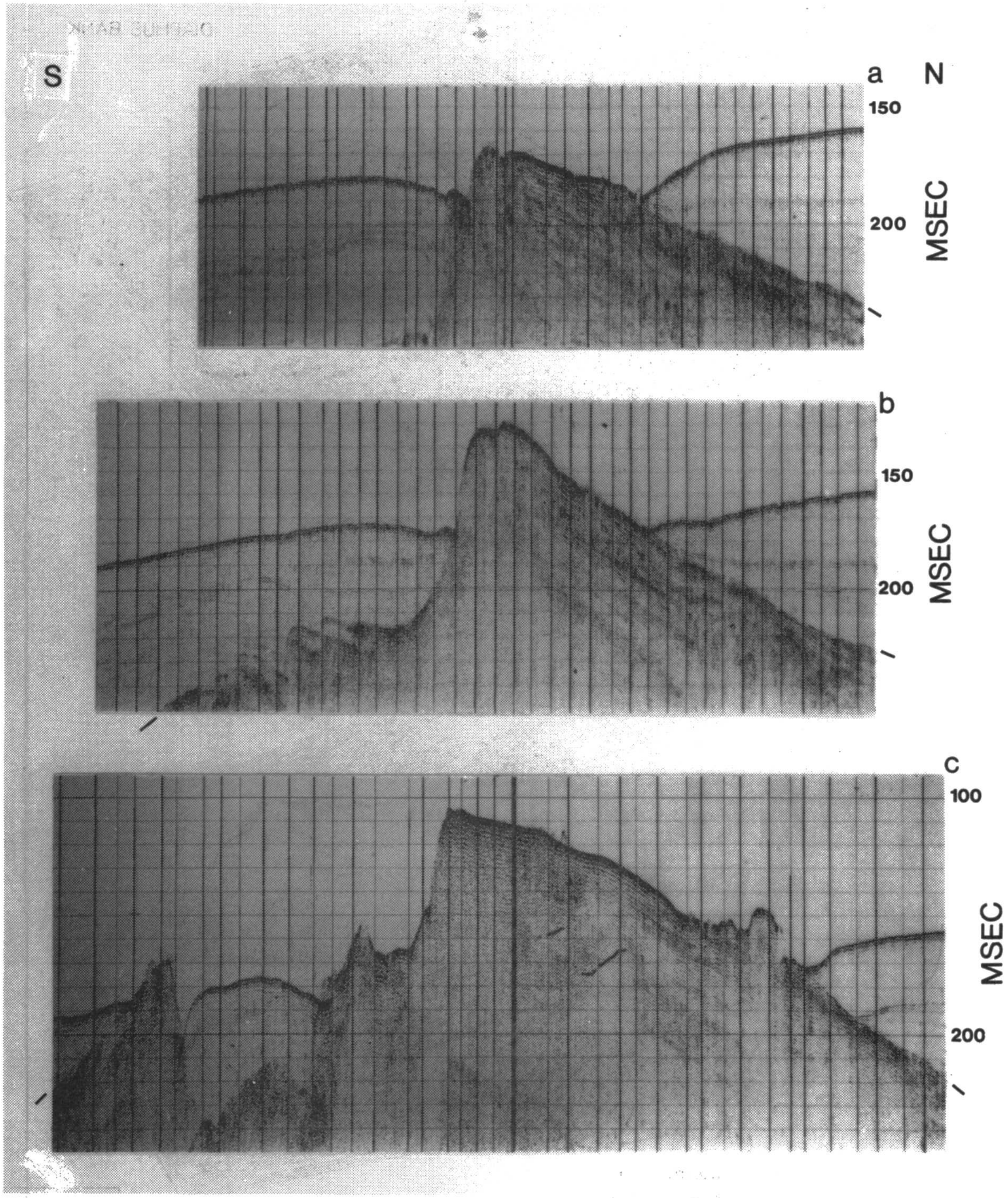

Figure VI-9. N-S boomer profiles, Diaphus Bank.

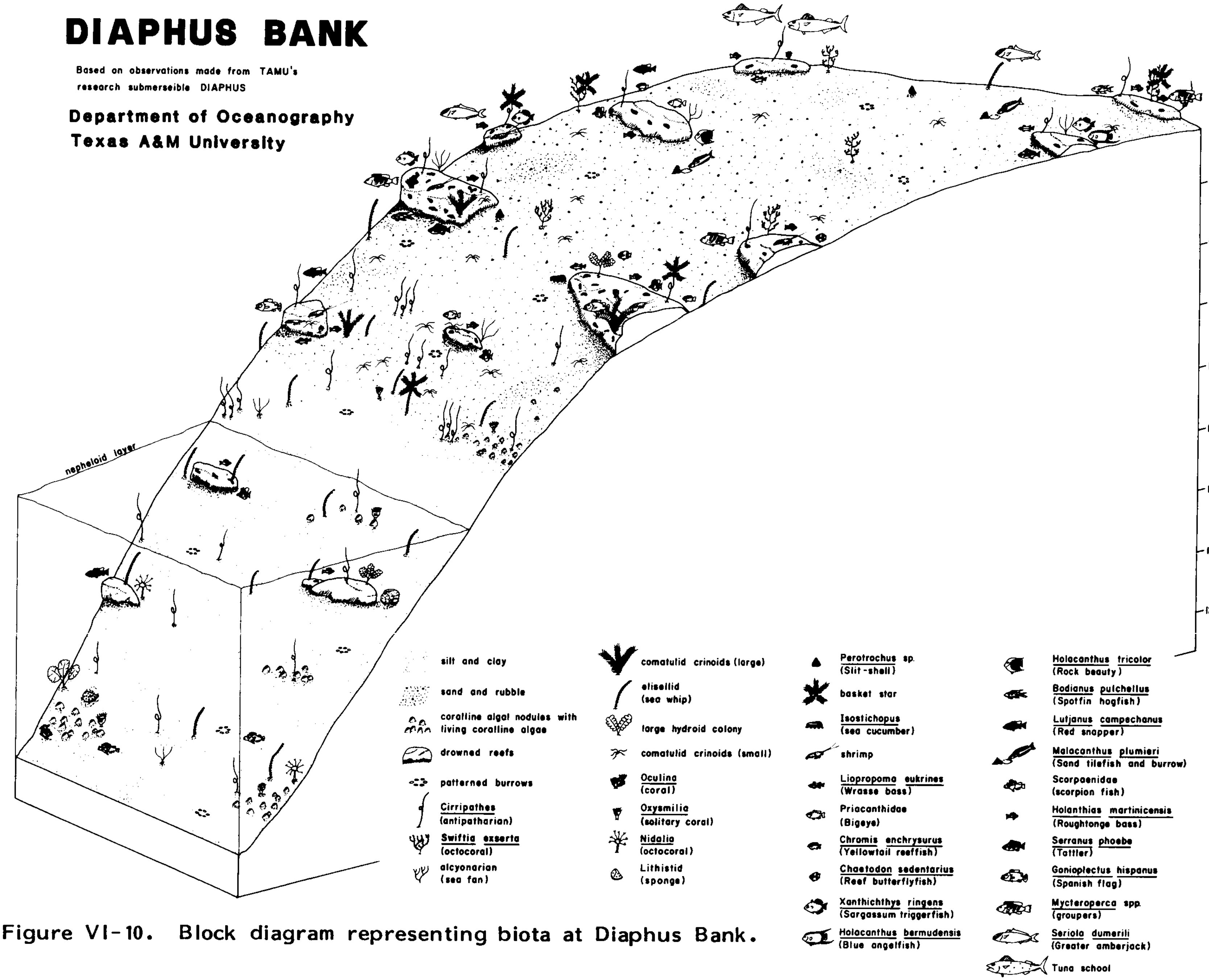

Figure VI-10. Block diagram representing biota at Diaphus Bank.

The apparent lower diversity and abundance of epibenthic biota and fishes below the break in slope are probably related to depth, light penetration, water turbidity, and sedimentation. Overall, the diversity and abundance of benthic biota on Diaphus Bank are low compared to those of many other shelf-edge banks in the northwestern Gulf. This difference may be due to the somewhat deeper crest depth of Diaphus Bank and/or its closer proximity to the Mississippi River outfall.

JAKKULA BANK

General Description

Jakkula Bank is located close to the shelf edge at 27°58'56"N latitude and 91°39'16"W longitude (Figure II-1, above) in Blocks 5 and 6 of the Green Canyon area, Blocks 975 and 976 of the Ewing Bank Area, and Block 390 in the Eugene Island Area (Figure VI-11). The bank is rhomboidal and covers an area of about 8.3 km^2. The main body of the bank is a domal structure. However, the shallowest part is a narrow north-south ridge near the west margin of the bank, with least depths of 59 m (Figures VI-11 and 12). The remainder of the bank crest lies at depths of 63-66 m. Surrounding water depths range from about 140 to 160 m. Slopes on the margins of the bank have gradients ranging from 80 to 200 m per km. The seafloor on the north and west sides displays highly irregular topography due to a combination of structural, erosional, and depositional processes.

Geology

Jakkula Bank is a salt dome that appears to have developed a crestal graben, but renewed uplift of the salt in the crestal portion of the bank has obliterated the evidence for collapse in that area. Evidence for collapse is seen on profiles a and d of Figure VI-13. Profiles b and c are over the crest of the dome. The sawtooth pattern to the north of the peak on section c probably represents the outcrops of steeply dipping bedrock. The sediments on the bank range from mud to algal nodule gravel.

Biology

Jakkula Bank is one of the features with immediate surrounding depths in excess of 120 m and an upper platform well above the lower depth limit of vigorous coralline algal populations. Algal nodules on coarse carbonate sand, therefore, predominate in a typical Algal-Sponge Zone above approximately 78 m depth, becoming smaller and less abundant below 76 m depth. The nodules are generally replaced by carbonate sand and gravel below 90 m.

Large drowned reefs of up to 3 m relief and well covered with healthy crusts of coralline algae characterize the break in slope at the edge of the uppermost platform (70-75 m). Much smaller drowned reefs, less than 1 m high with significant coralline algal crusts, were encountered on sandy bottoms down to 94 m.

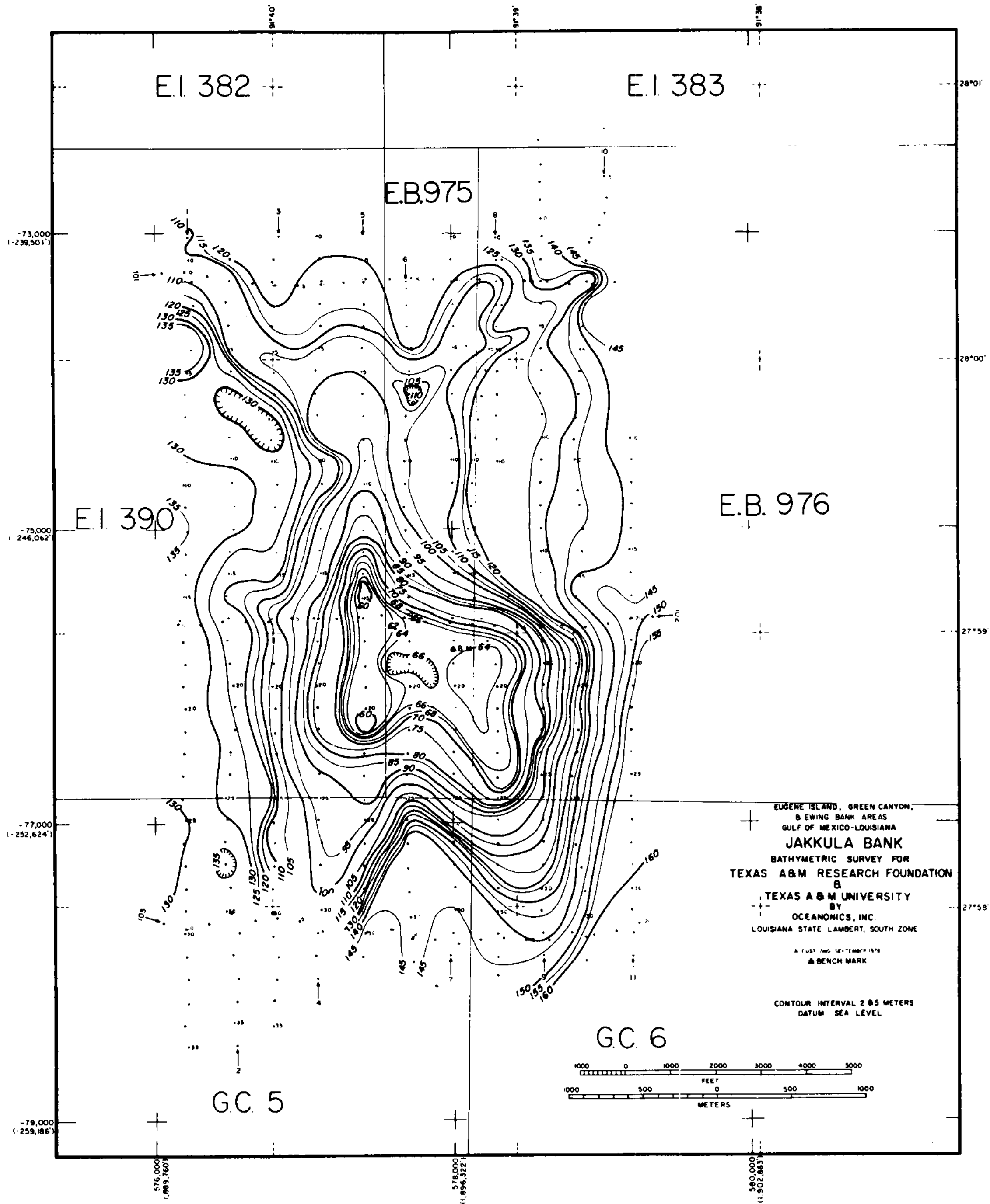

Figure VI-11. Jakkula Bank bathymetry.

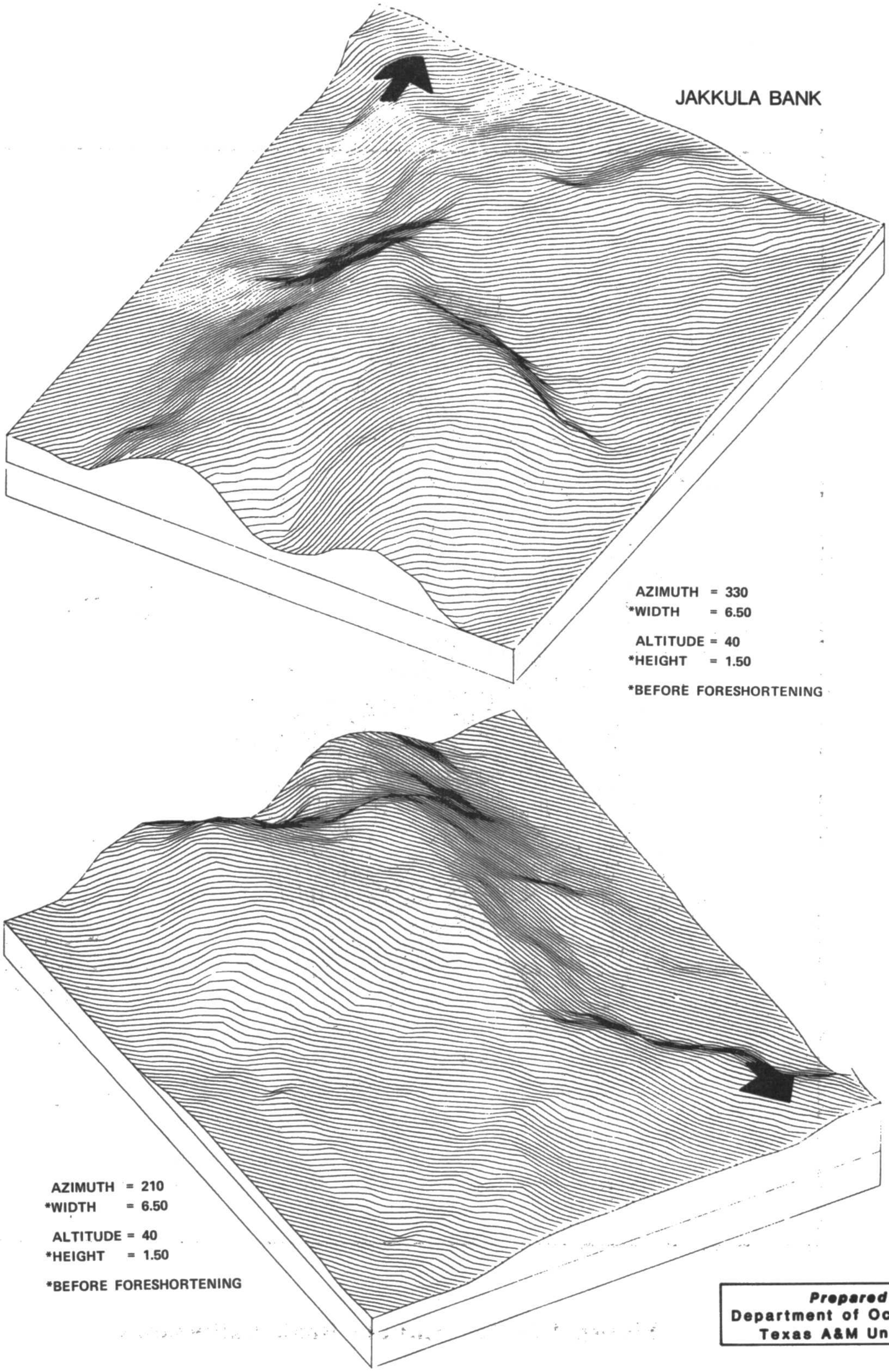

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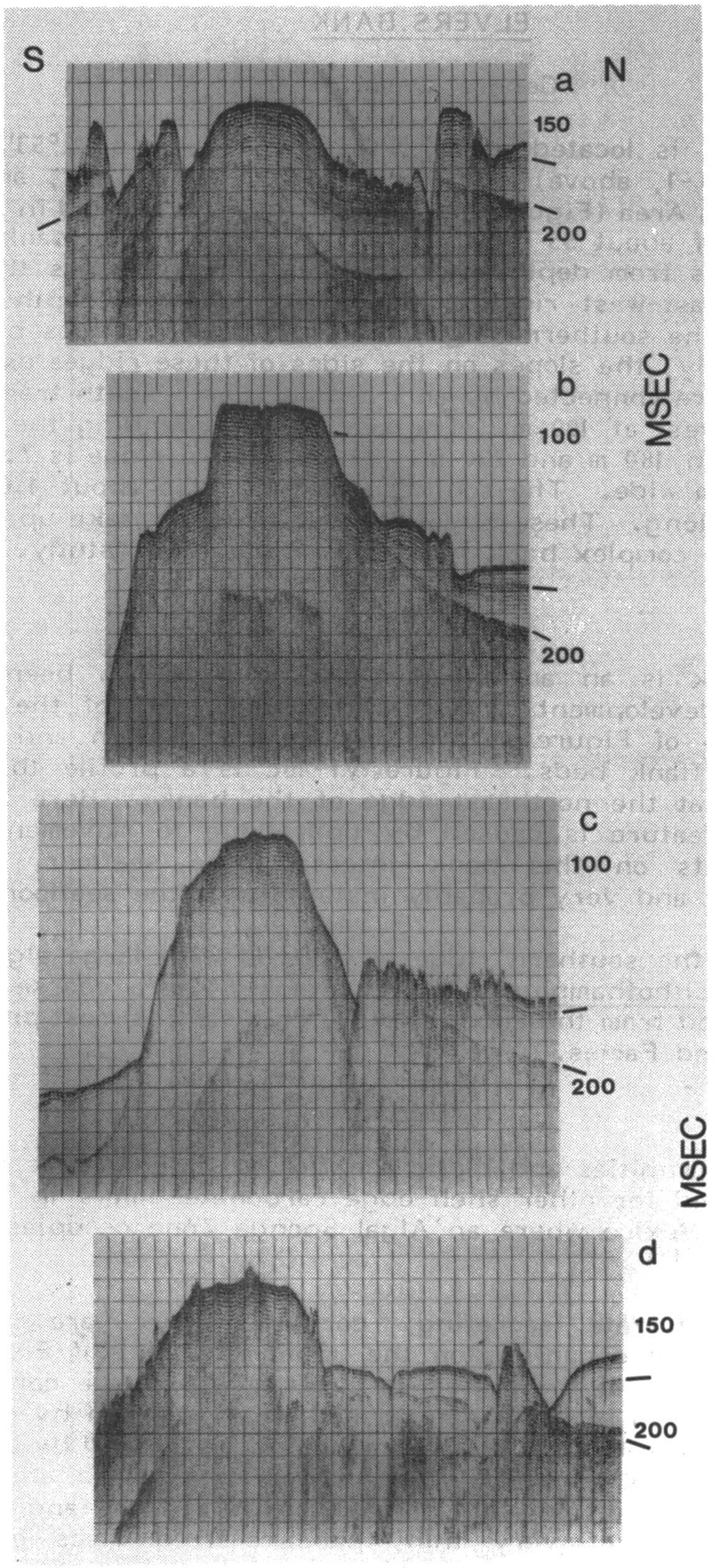
Figure VI-12. Three-dimensional perspective views, Jakkula Bank.



Jakkula

Figure VI-13. N-S boomer seismic reflection profiles, Jakkula Bank.

ELVERS BANK

General Description

Elvers Bank is located at 27°49'15"N latitute and 92°53'36"W longitude (Figure II-1, above) in Blocks 109, 110, 153, 154, and 197 of the Garden Banks Area (Figure VI-14). The bank is sigmoid in shape and covers an area of about 55 km^2. Just northwest of the bank, a large conical peak rises from depths of 160 m to a crest of less than 70 m. The northern, east-west ridge on the bank rises to depths between 100-110 m. On the southern ridge, the crest depth ranges between 60 and 70 m. Locally, the slopes on the sides of these ridges exceed 30°. The two ridges are connected by an irregular north-south trending high that reaches a crest at 100 m. The seafloor surrounding the bank has depths of between 180 m and 220 m. The northern ridge is 7.4 km long and about 1.6 km wide. The southern ridge is also about 1.6 km wide but only 4.2 km long. These physiographic features make up one of the most structurally complex banks surveyed during this study.

Geology

Elvers Bank is an anticlinal structure that has been severely faulted by the development of a graben at the crest of the anticline. Profiles a and b of Figure VI-16 illustrate the graben and show the steeply dipping flank beds. Figure VI-16c is a profile through the east-west ridge at the northeast edge of the bank. Here it appears that the major feature is caused by uplift due to movement of salt. All of the faults on this bank intersect the seafloor, indicating Recent movement and very probably instability of the seafloor.

The top of the southern ridge is covered with large algal nodules of the Gypsina-Lithothamnium Facies. Below 84 m a coarse carbonate sand was observed from the submersible. This sand is most probably the Amphistigena Sand Facies.

Biology

Benthic communities and biotic zonation at Elvers Bank are similar to those described for other shelf-edge carbonate banks in the northwestern Gulf of Mexico where an Algal-Sponge Zone occupies the bank crest (Figure VI-17).

Calcium carbonate secreting, coralline algae are the overwhelmingly dominant organisms on the uppermost part of Elvers Bank. Above 76 m, 75-100% of the bottom is covered with large coralline algal nodules, accompanied by carbonate gravel and underlain by coarse carbonate sand. Below 84 m, the large nodules are replaced by a carbonate sand with substantial amounts of carbonate gravel and shell material bearing live crusts of coralline algae. Between 90 and 97 m, an abundant population of very thin, pancake-sized discs of coralline algae occurs, covering over 20% of the sand and rubble bottom in places. This zone of algal discs terminates rather abruptly at 97 to 98 m depths. Living coralline algae encrust gravel, flakes, and chips

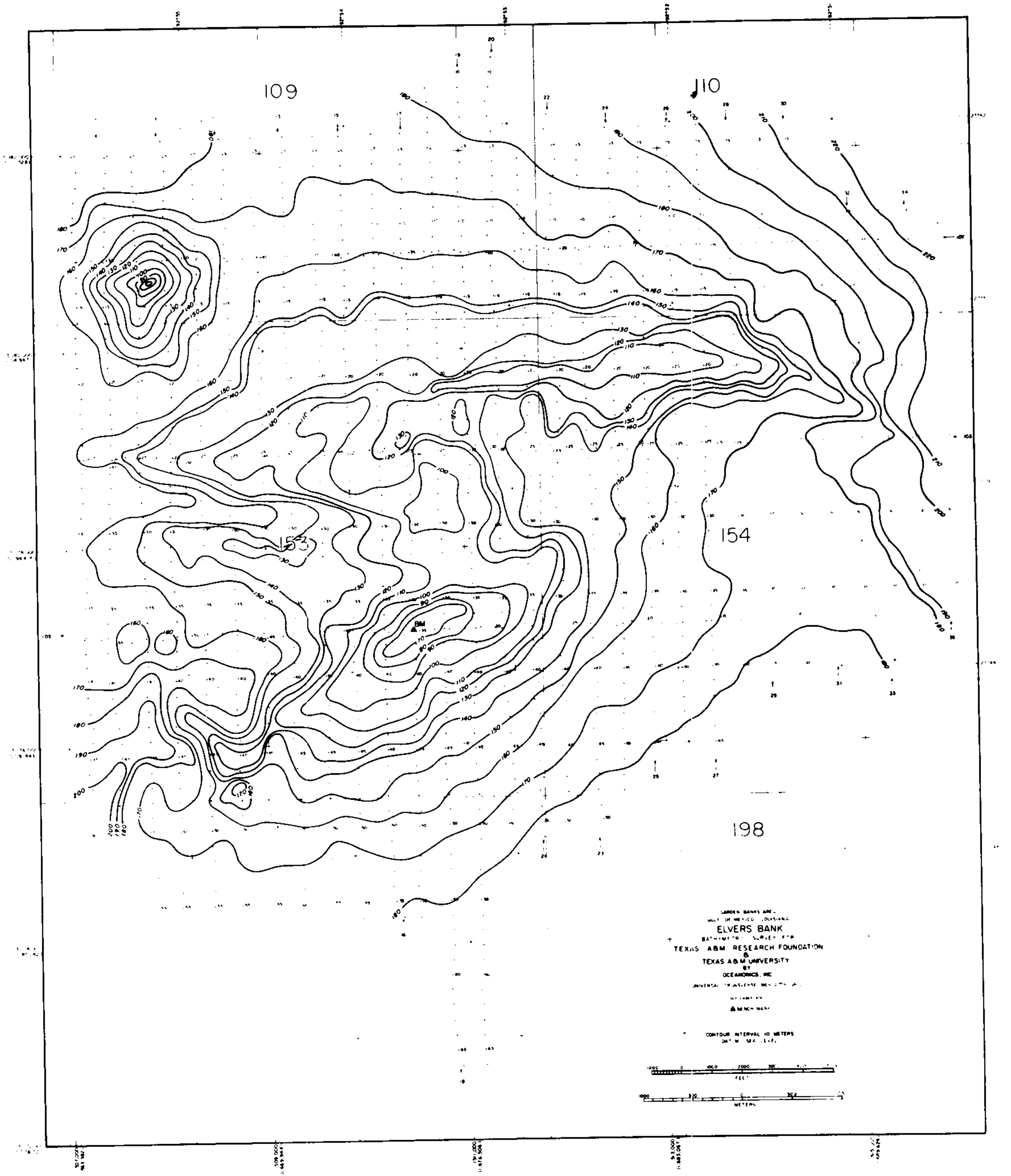


Figure VI-14. Elvers Bank bathymetry.

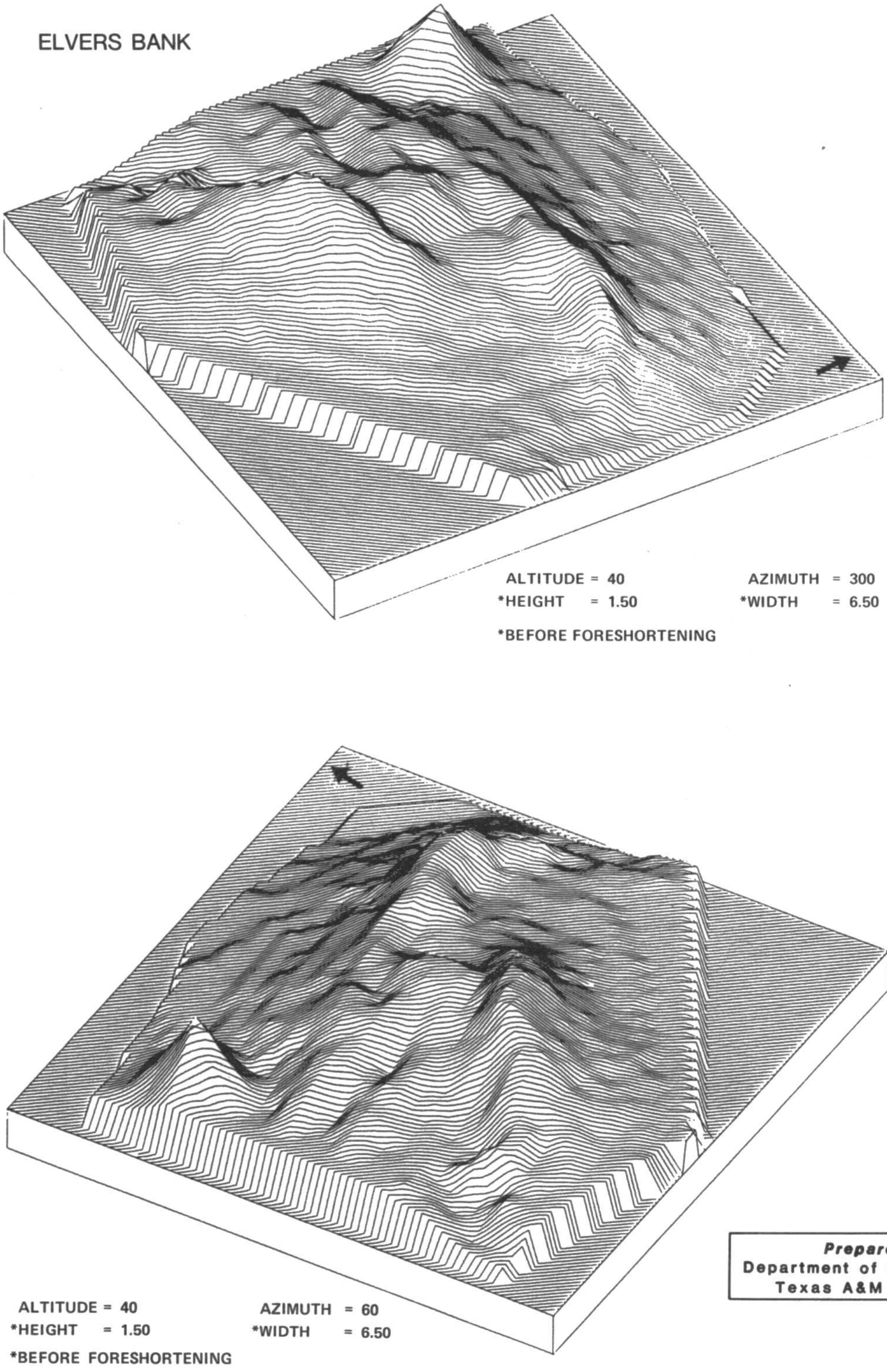


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Figure VI-15. Three-dimensional perspective views, Elvers Bank.

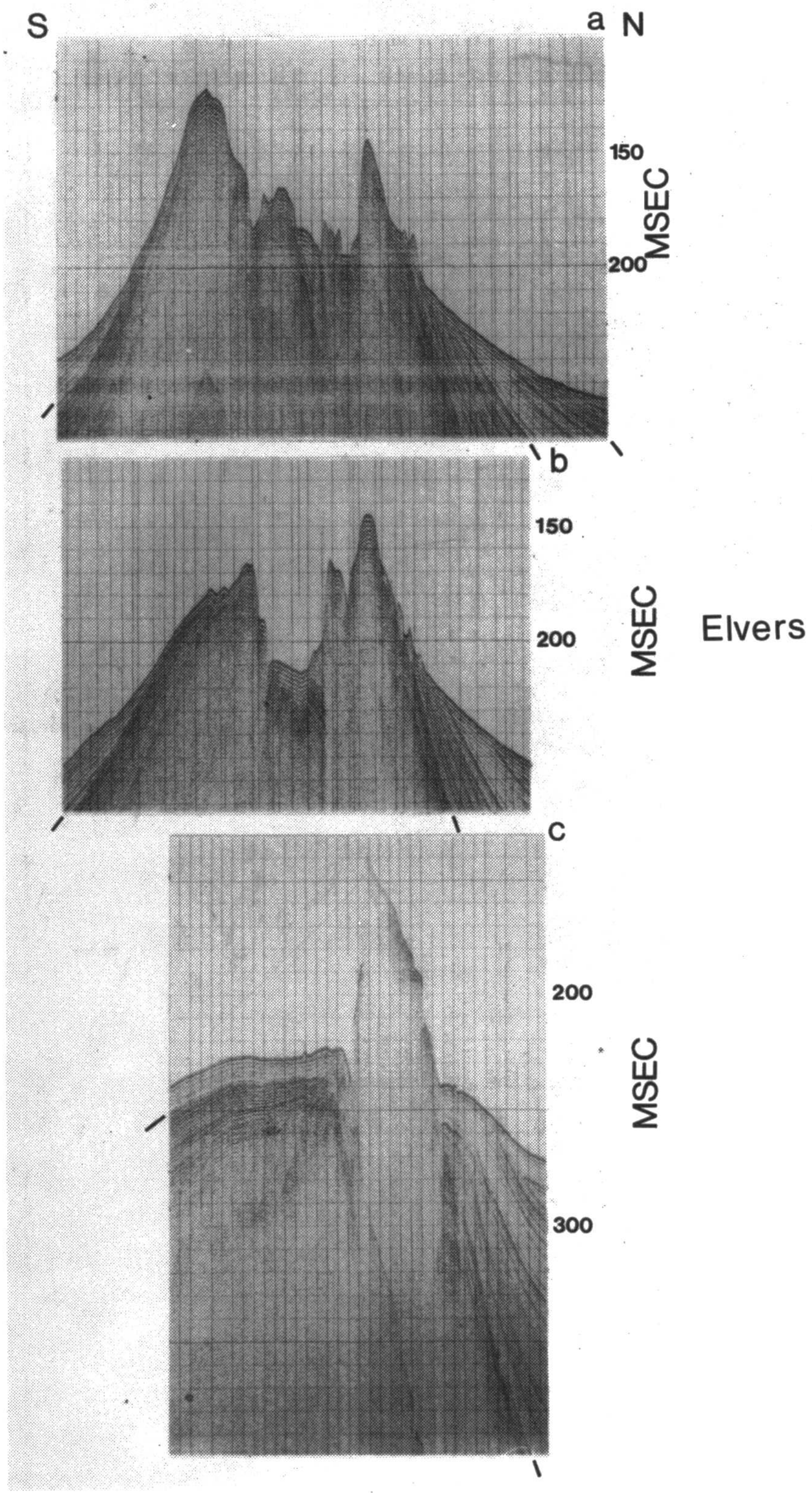
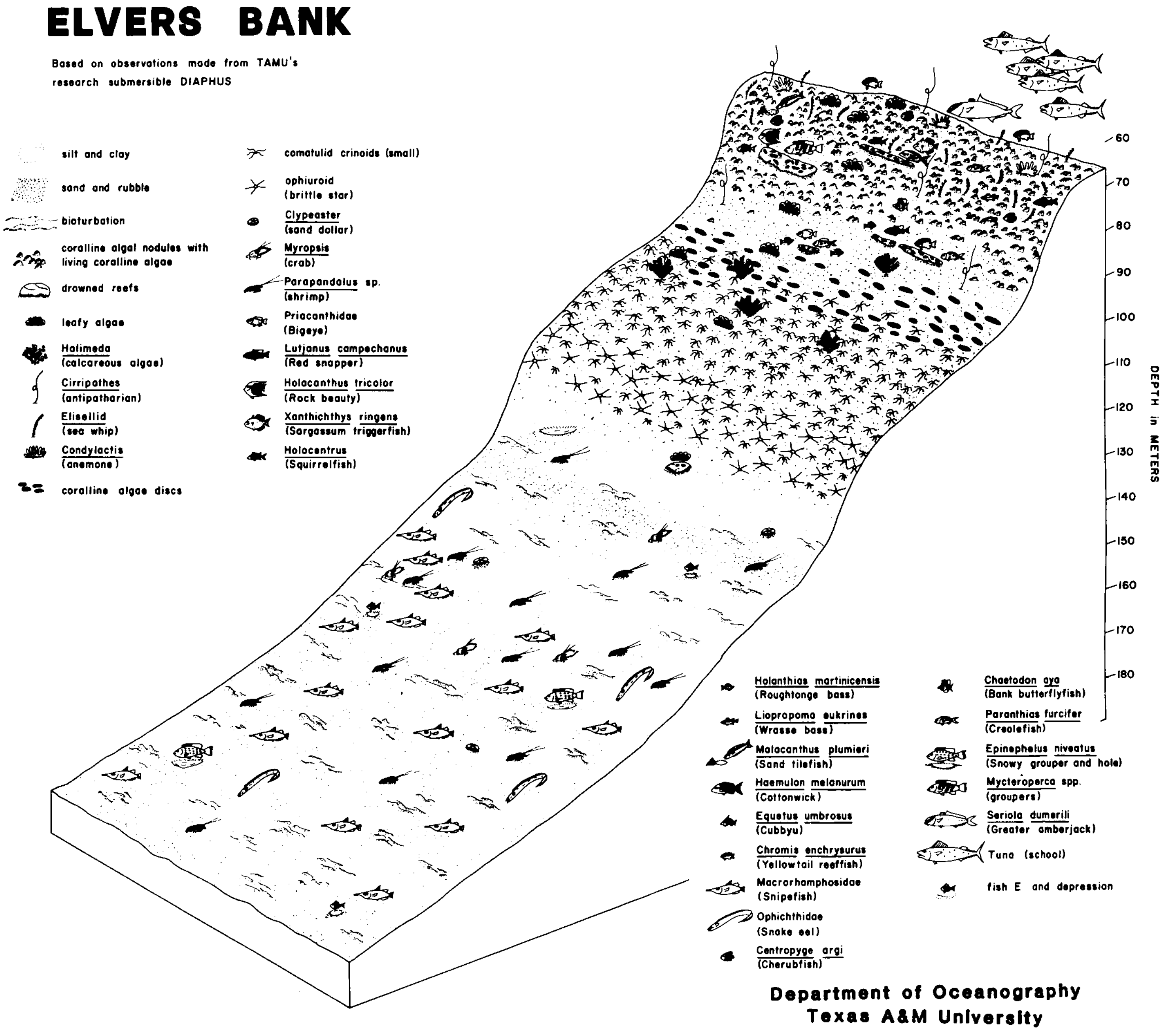


Figure VI-16. N-S boomer seismic reflection profiles, Elvers Bank.

Figure VI-17. Block diagram representing biota at Elvers Bank.



lying on the sand to depths of at least 108 m, but populations of coralline algae are substantially reduced on the unconsolidated sediment below 100 m. Carbonate sand with gravel persists as the predominant sediment down to approximately 110 m. Below this, with increasing depth, greater and greater amounts of silt- and clay-size particles are present.

Abundant covers of coralline algae occur on reef rock down to at least 94 m depth. A 10-15% live coralline algae cover was observed on a small (1 m high), boulder-like reefal structure encountered at 123 m in a hole in the sand-and-silt bottom. Significant algal populations on rocks at this great depth have not been seen on other banks studied in the northwestern Gulf, with the exception of Geyer Bank, which has relief and surrounding depths similar to Elvers Bank.

It is suspected that the extreme depths to which living coralline algae extend on Elvers and Geyer Banks are in some way related to the banks' greater relief compared to neighboring shelf edge banks. Possibly, the high relief tends to reduce the frequency of occurrence and magnitude of turbid nepheloid layers at mid-depths on the bank, thereby facilitating deeper and more continuous penetration of light essential to algal growth. Thus, at Elvers and Geyer Banks, environmental circumstances may be such that downward limits of algal distribution are controlled primarily by the extent of light penetration through rather clear water, uncomplicated by the blocking effects of greatly increased turbidity, which reduce the degree of light penetration at similar depths on the other banks.

GEYER BANK

General Description

Geyer Bank is located at 27°51'17"N latitude and 93°04'09"W longitude (Figure II-1, above). The bank lies in the Garden Banks Area, Blocks 105, 106, 149, 150, 193, and 194 (Figure VI-18).

Situated just south of the shelf break on the upper continental slope, the bank rises from depths of 210 m on the north and 190 m on the south. It is a north-south elongate structure covering about 55 km^2. The steepest slopes are found at the northern end of the bank, with gentle slopes on the east and west sides and moderately steep slopes on the southeast and southwest sides (Figures VI-18 and 19). The bank is "hamshaped" with the "shank" end to the north. The top of the bank is broad and relatively flat, with prominences on the north and south ends rising to depths of less than 60 m and separated by a saddle around 90 m depth.

The unusual distribution of depths surrounding the bank is due to the fact that Geyer Bank is the northern part of an arcuate salt diapir complex. The southern boundary of Geyer Bank is on a saddle between the bank and the next diapir to the south.

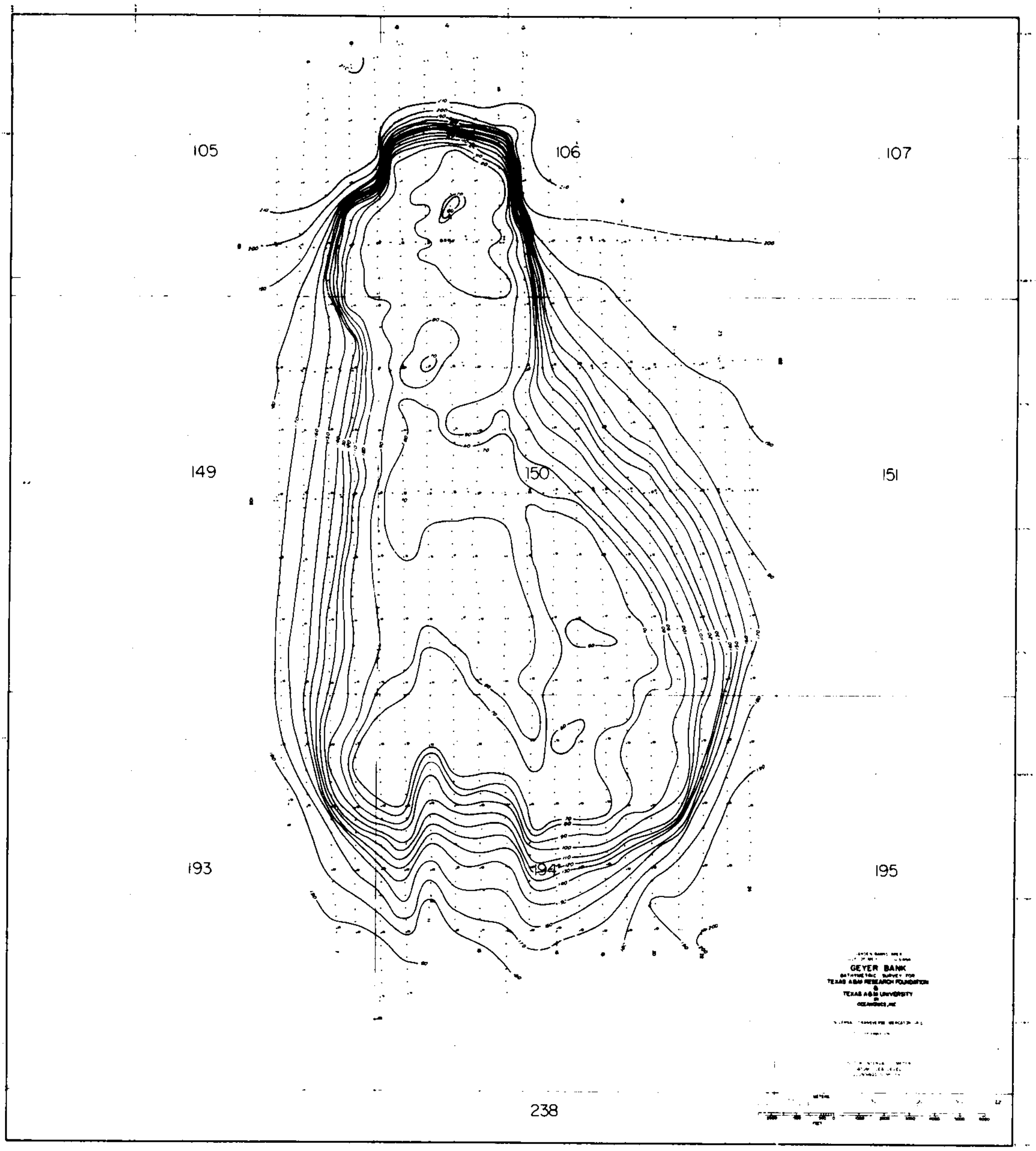


Figure VI-18. Geyer Bank bathymetry.

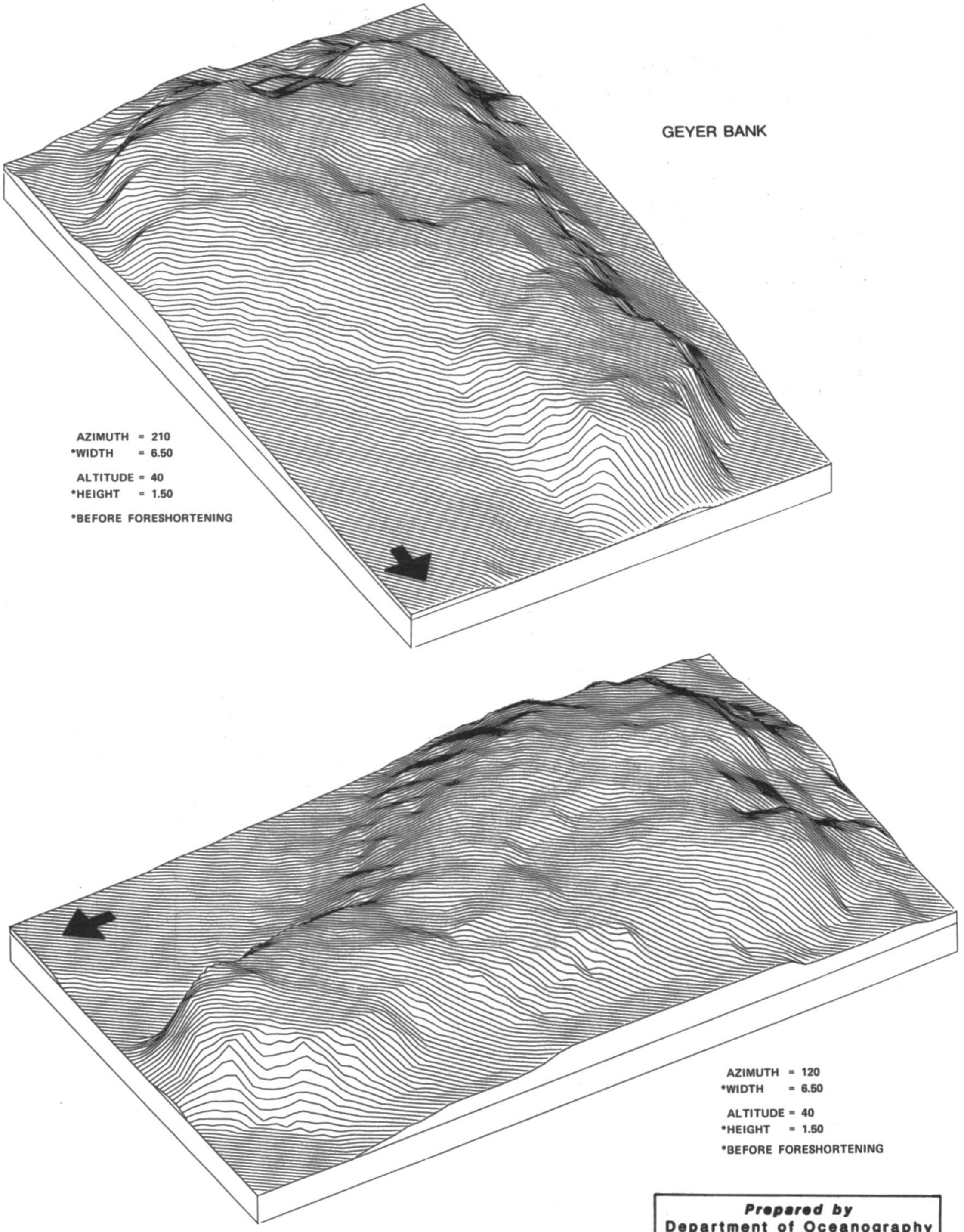


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Figure VI-19. Three-dimensional perspective views, Geyer Bank.

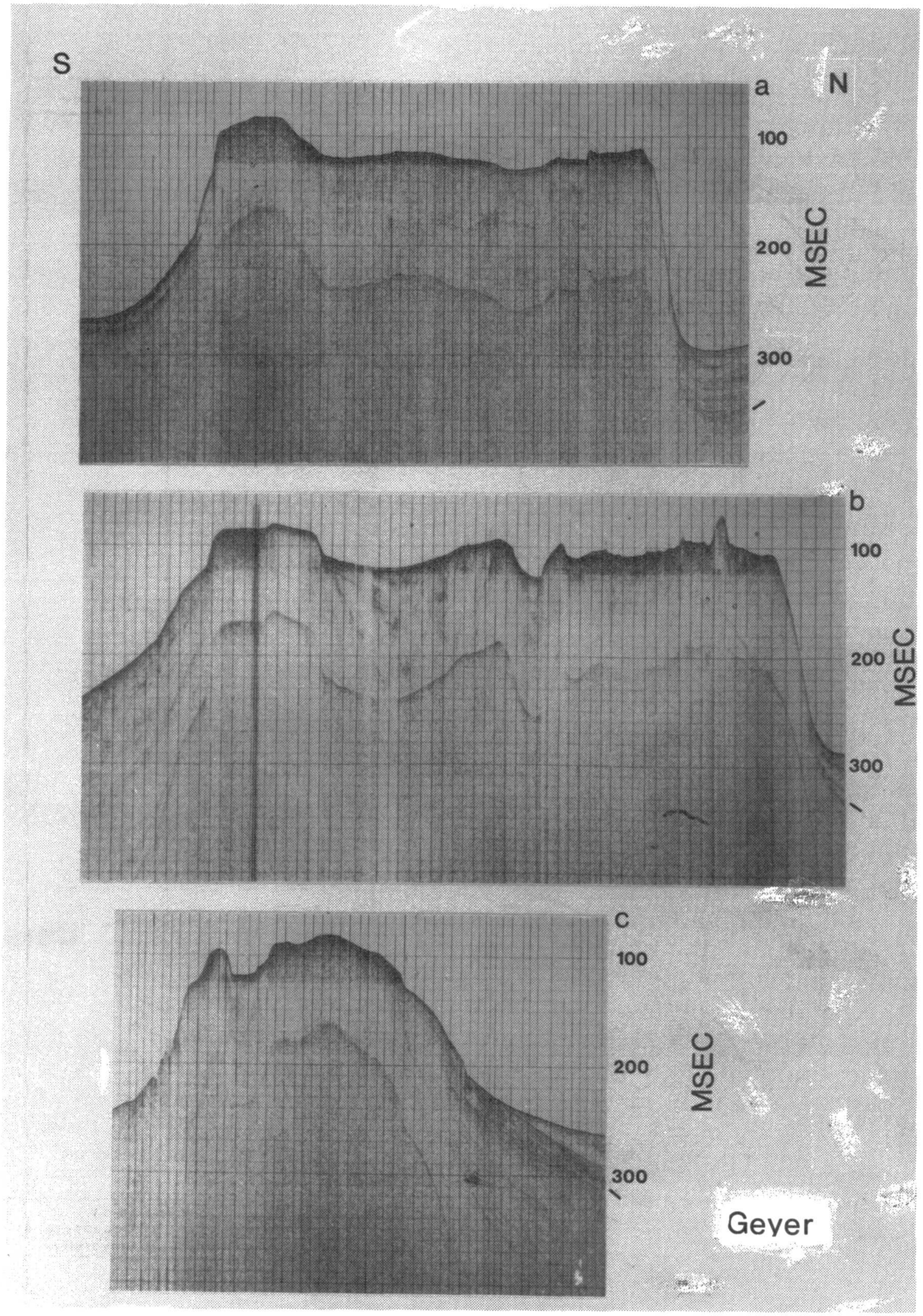
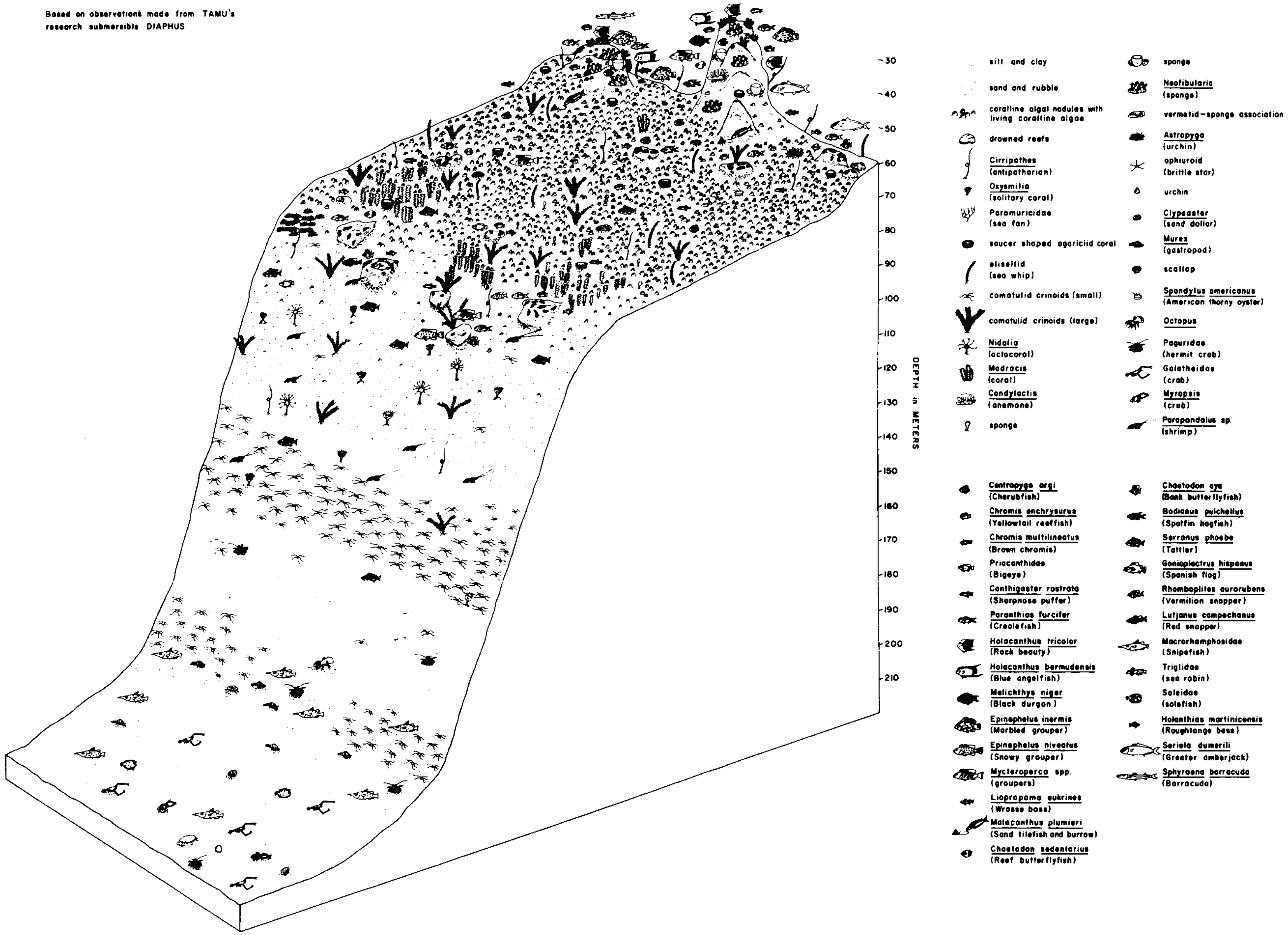


Figure VI-20. Boomer seismic reflection profiles, Geyer Bank.

Figure VI-21. Block diagram representing biota at Geyer Bank.

GEYER BANK

Based on observations made from TAMU's research submersible DIAPHUS



Geology

Structurally, Geyer Bank is somewhat similar to the East Flower Garden Bank in that it has just recently begun the collapse to form the crestal graben. The pinnacle on the north side of Figure VI-20b is a well developed coral reef. About 450 m to the south of this peak is a smaller prominence that has little or no growth of reef-building organisms on the bedrock. This latter prominence must have been exposed at the sea bottom only very recently. Otherwise, it too would be heavily encrusted with organisms.

The sediment facies at Geyer Bank are almost identical to those at the Flower Garden Banks except that the reefs are only small patch reefs.

Biology

Geyer Bank possesses four distinct biotic zones characterized by differences in substratum, depth, and structure of biotic communities: Millepora-Sponge Zone (37-61 m, claystone outcrops); Algal-Sponge Zone (61-87 m; algal nodules, algal reefs extending to 97 m, carbonate sediment); Bank Slope Zone (approximately 87-189 m; carbonate sand, silt, gravel, and nodules at top, grading to mud with carbonate gravel at bottom); and the Mud Zone (189-213+ m)(see Figure VI-21).

The Algal-Sponge Zone harbors by far the most diverse and abundant populations and is overwhelmingly dominated by frame-building coralline algae, with substantial local contribution by small branching hermatypic corals. Probably because of the bank's great relief, coralline algae are significant to depths of 113 m or so and occur as deep as 124 m.

The presence of fresh and abundant tracks, trails, burrows, and holes in the deep Mud Zone is indicative of a healthy and active soft-bottom benthic community.

REZAK-SIDNER BANK

General Description

Rezak and Sidner Banks are described as a single unit in this report because they are parts of a single geological structure. The center of the structure that forms the two banks is located at 27°57'N latitude and 92°23'W longitude (Figure II-1, above) in Blocks 404, 405, 411, and 412 of the Vermillion Area. The Rezak-Sidner structure is rectangular in shape and covers an area of 78 km^2. It is bounded by steep slopes on the north, east, and south sides, with a more gentle slope to the west (Figures VI-22 and 23). Local depressions are abundant at the base of the eastern and southern slopes. The eastern slope has very irregular and complex relief. Although it is a single structural unit, the bank can be divided into northern and southern halves on the basis of bathymetry. The shallowest portion of the northern

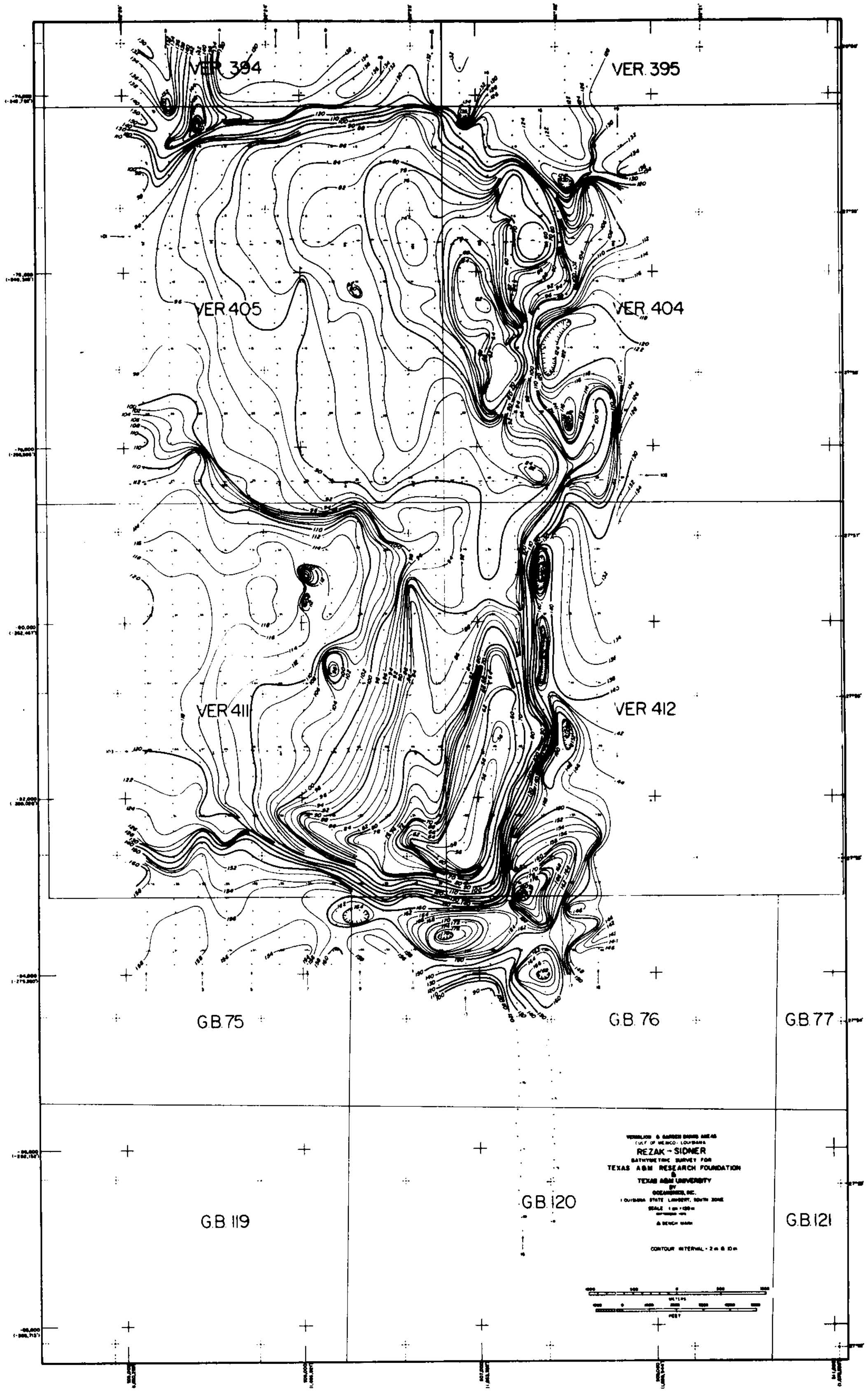


Figure VI-22. Rezak-Sidner Bank bathymetry.

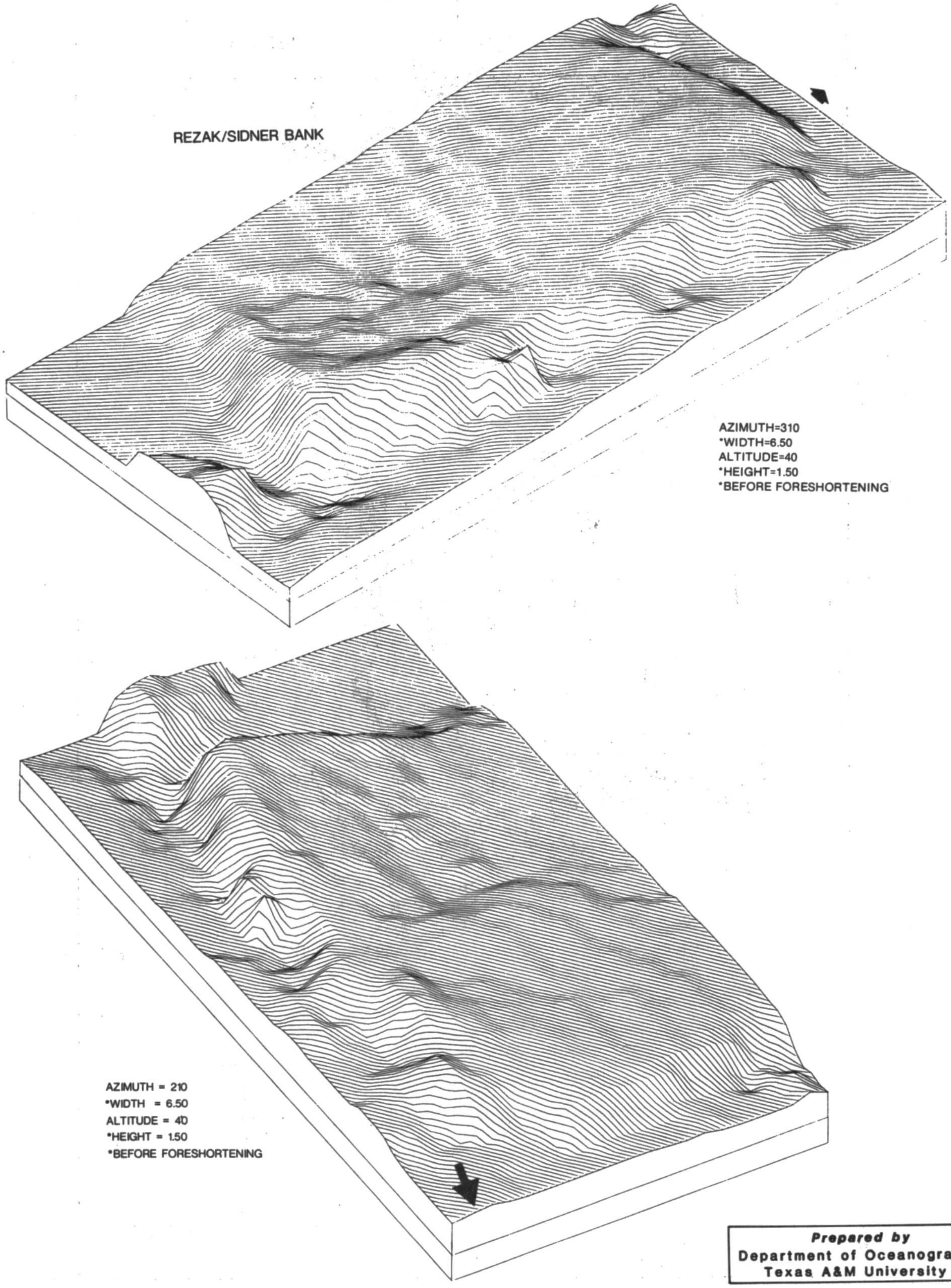


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Figure VI-23. Three-dimensional perspective views, Rezak-Sidner Bank.

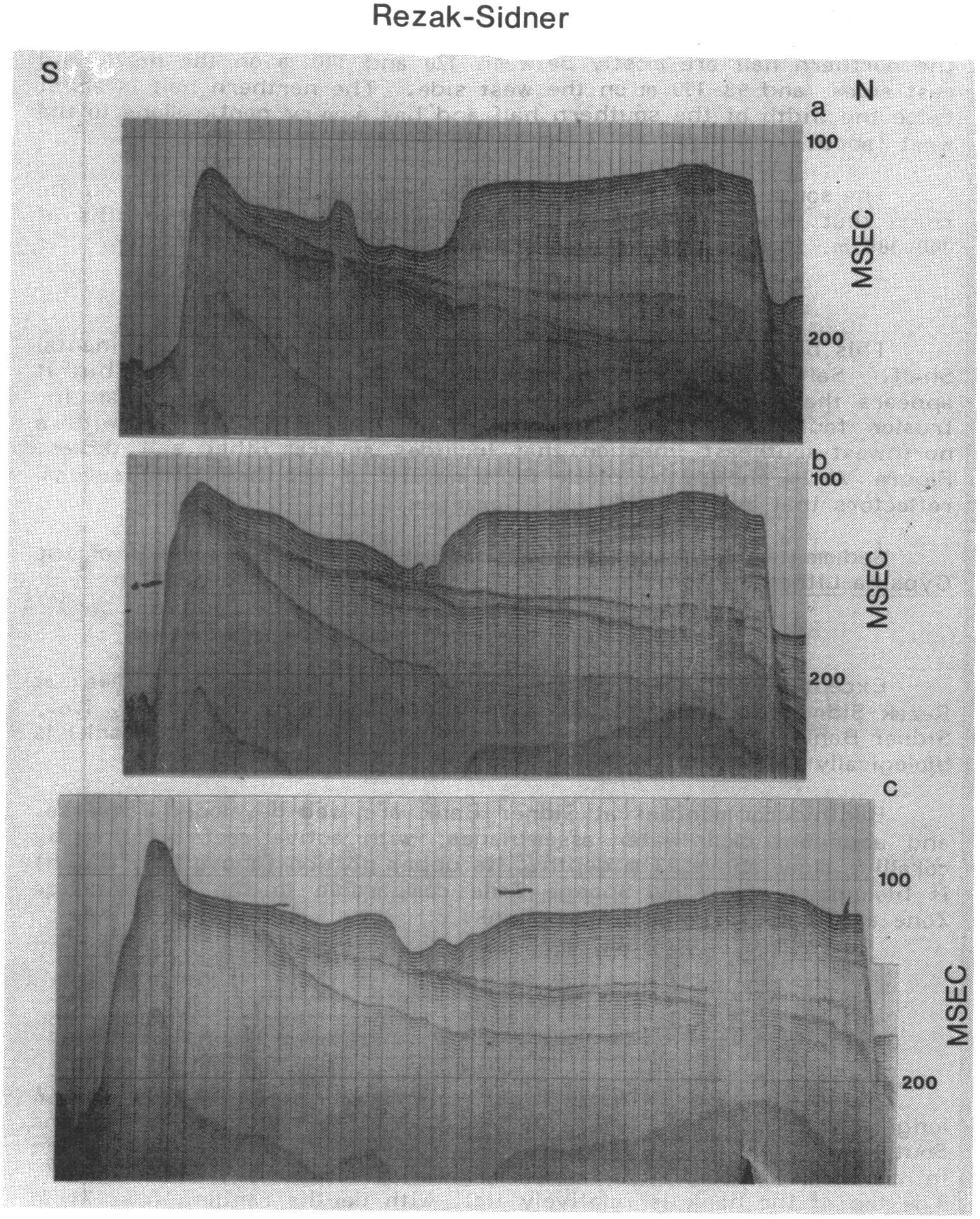

Figure VI-24. N-S boomer profiles through the central portion of Rezak-Sidner Bank.

half (Rezak Bank) has a minimum depth of 60 m on a peak at the northeast corner of the structure. Depths of the adjacent seafloor around the northern half are mostly between 120 and 140 m on the north and east sides, and 98-110 m on the west side. The northern half is about twice the width of the southern half and has a very gentle slope to the west (about 10 m/km).

The southern half (Sidner Bank) has a minimum depth of 55 m on the ridge that forms the eastern margin and has surrounding depths of 140-180 m.

Geology

This bank is atypical of the salt domes on the Outer Continental Shelf. Salt tectonics are probably involved in the structure, but it appears that the shape of the structure is controlled by pre-salt intrusion faulting. The eastern margin of the bank lines up with a northwest-southeast lineation that includes several other salt domes. Figure VI-24 shows the block fault nature of the bank and several reflectors that are probably unconformities.

Sediments on the top of the bank are algal nodule gravels of the Gypsina-Lithothamnium Facies.

Biology

Except for submersible reconnaissance, biological studies at Rezak-Sidner Bank focused on the southern part of the bank, i.e., Sidner Bank. It is presumed that the northern portion (Rezak Bank) is biologically similar to the southern portion.

Benthic communities at Sidner Bank are well-developed, diverse, and abundant clear-water assemblages, with active reef building by coralline algae above 93 m depth. Its upper portion (above 93 m depth) is biologically an Algal-Sponge Zone comparable to the Algal-Sponge Zone at the East Flower Garden Bank.

ALDERDICE BANK

General Description

Alderdice Bank is located at 28°04'40"N latitude and 91°59'36"W longitude (Figure II-1, above) in Blocks 170, 171, 178, and 179 of the South Marsh Island Area (Figure VI-25). The bank is an oval, elongate in an east-west direction, and it covers an area of about 16 km^2. The top of the bank is relatively flat, with depths ranging from 78 to 82 m. Superimposed upon this broad surface is a smaller scale relief formed by ridges and peaks. The shallowest bank depths (59 m) are two of these peaks. Depth of the seafloor surrounding the bank on the south, west, and northwest sides is about 92-94 m, while on the northeast and east sides it is about 84 m. Although the relief is not great along the margins of the bank (generally less than 10 m), the margins are rather steep around the western half of the bank. Although the features on top of the western part of the bank have a rather random distribution, the eastern part of the bank displays a dominant north-south ridge. There is also a gentle north-south oriented swell on the seafloor extending northward from the eastern part of the bank (Figures VI-25 and 26). The gentle depression on the northwest margin of the bank is the head of a north-south oriented valley that curves around the western margin of the bank. This valley was probably eroded during a lower stand of sea level during Late Pleistocene or Early Holocene time.

Geology

Alderdice Bank appears to be a typical salt dome, but with two unique aspects. An outcrop of basalt was found on the southwestern peak (Rezak, 1980). The basalt was dated by K-Ar method at 76.8 million years (Late Cretaceous). It was rafted upwards within the salt diapir from about 10 km below the sea surface. This is the oldest known rock on the continental shelf of Louisiana. It was exposed at the surface due to collapse of the surrounding sediments into the crestal graben. The basalt has been exposed for a very short time, probably no longer than about three years, as evidenced by the millimetre-thick incrustations on its surface.

The second unique characteristic is the change in locus of upthrusting by the salt. The north-south ridge on the east side of the bank is a relatively recent feature. Figure VI-27 illustrates this fact. Profile a is along the crest of the ridge. Profile b is to the east of the crest and on its east side. Both profiles a and b show upthrusting of the ridge, but typically lack reflectors in the axial portion of the ridge. Profile c, on the other hand, shows an axial graben bounded by two major faults. These faults intersect the sea bottom and displace it upwards. The sequence of events is as follows:

1. Dissolution of salt at crest of dome.
2. Collapse of crest to form crestal graben.
3. A change in the direction of motion on the faults, due to the upthrusting of salt.

This feature not only demonstrates a change in the sense of movement on the bounding faults of the crestal graben, but also a change in the locus of upthrusting by the salt to the eastern margin of the bank.

Biology

Alderdice Bank is composed of four major topographic peaks on a flattish platform of about 80 m depth. In addition, a spectacular basalt outcrop juts vertically out of the bottom at 76 m, cresting at 55 m (Figure VI-28).

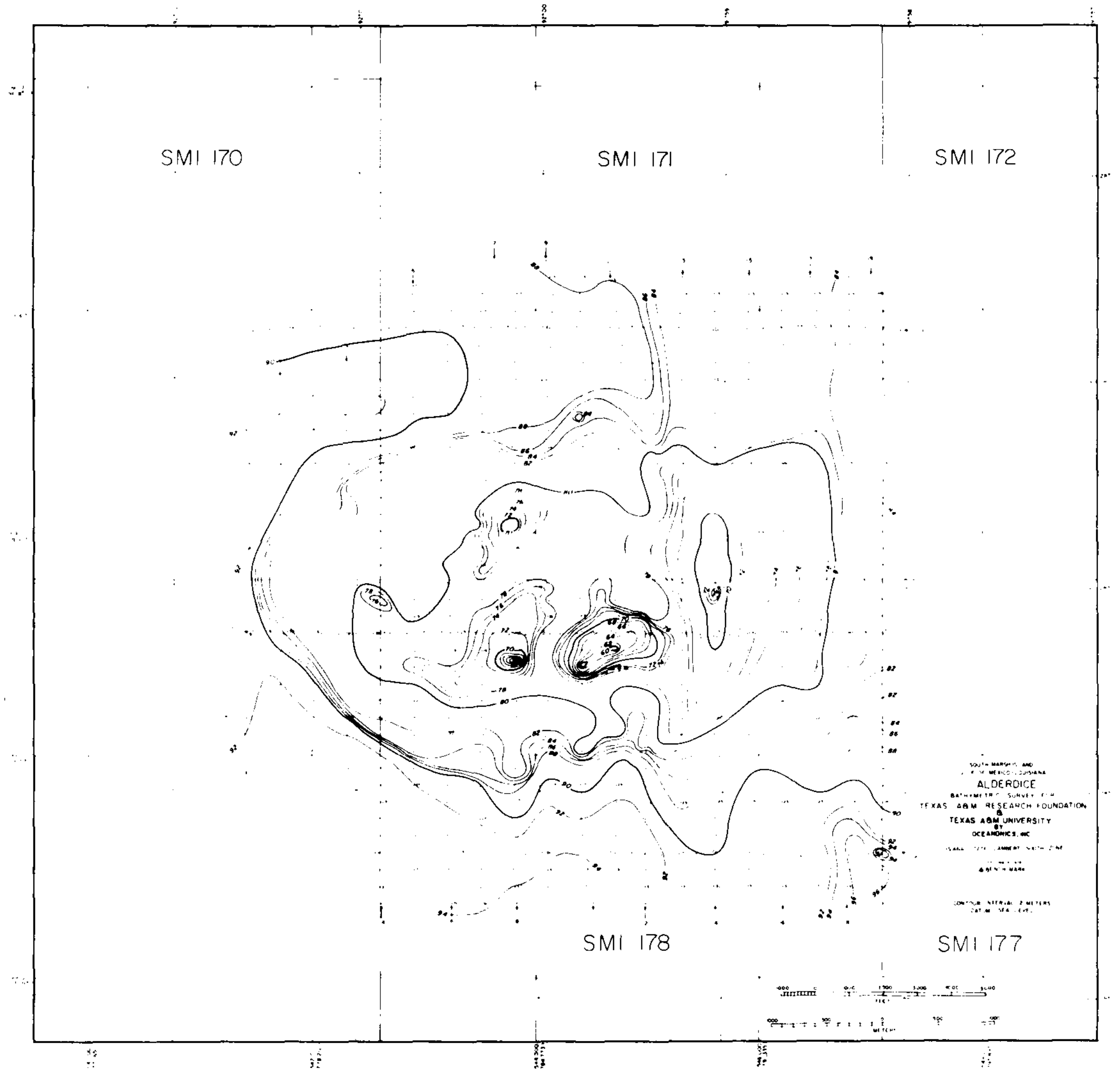

Figure VI-25. Alderdice Bank bathymetry.

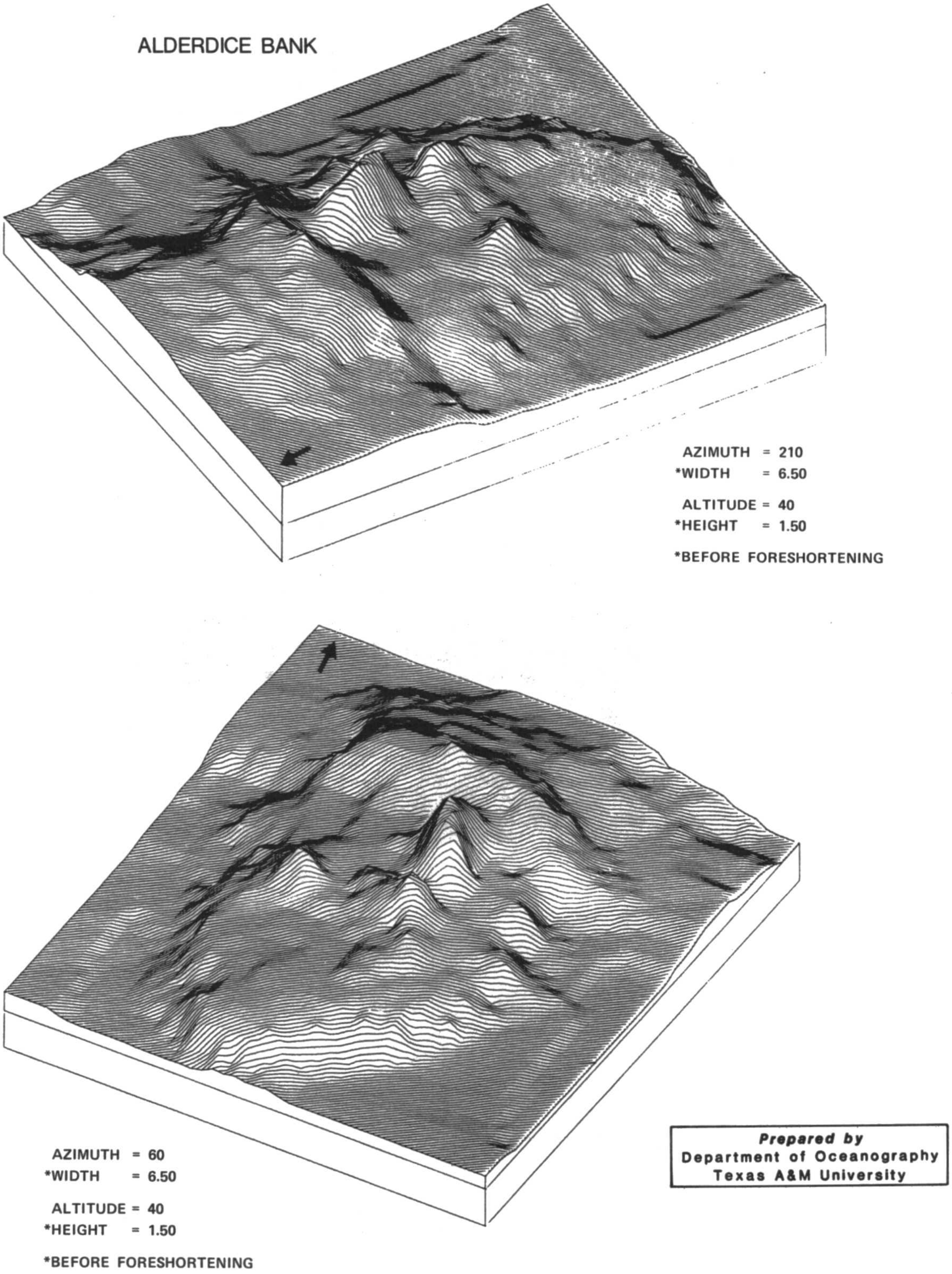

Figure VI-26. Three-dimensional perspective views, Alderdice Bank.

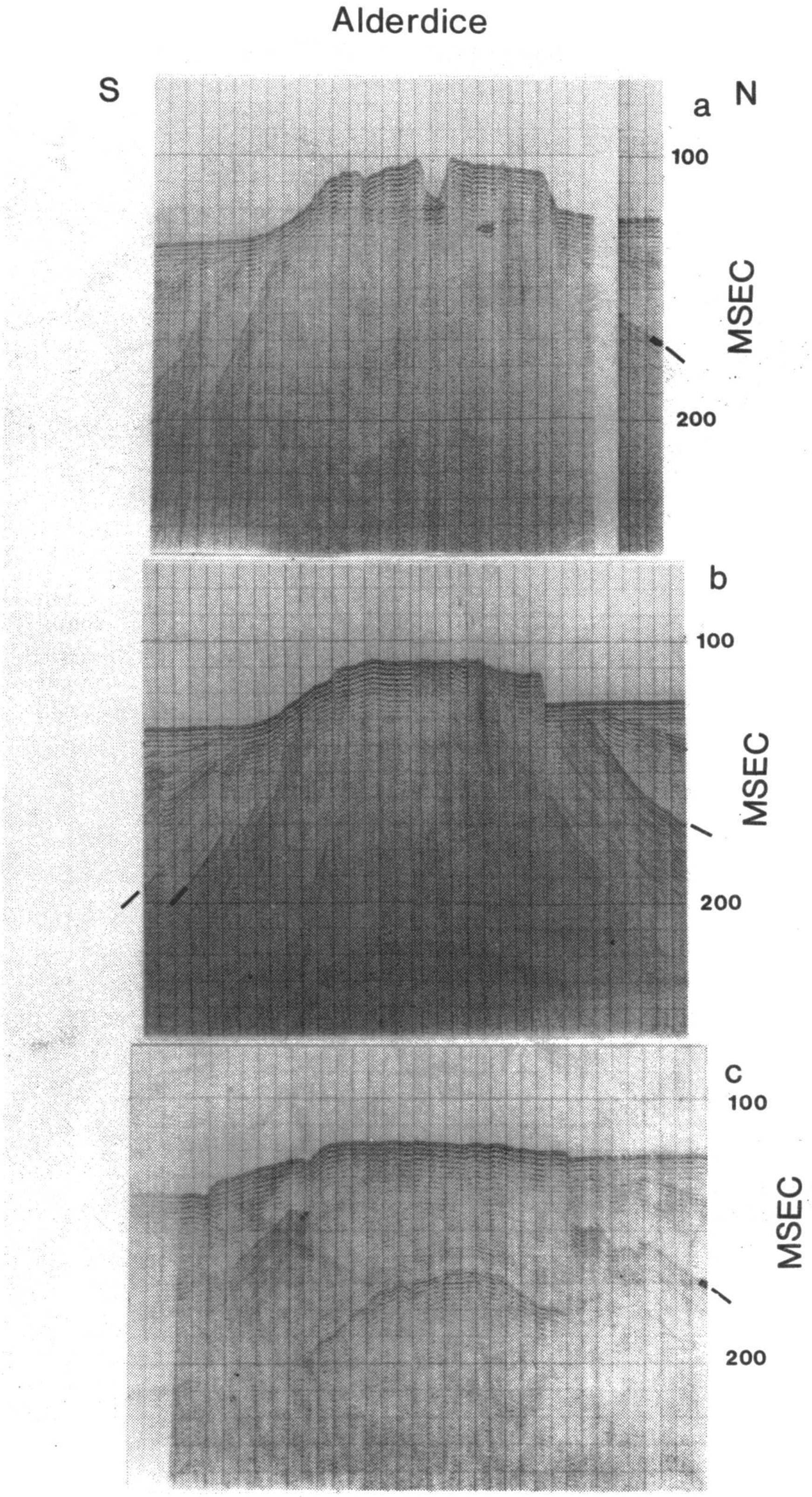

Figure VI-27. N-S boomer seismic reflection profiles across eastern part of Alderdice Bank.

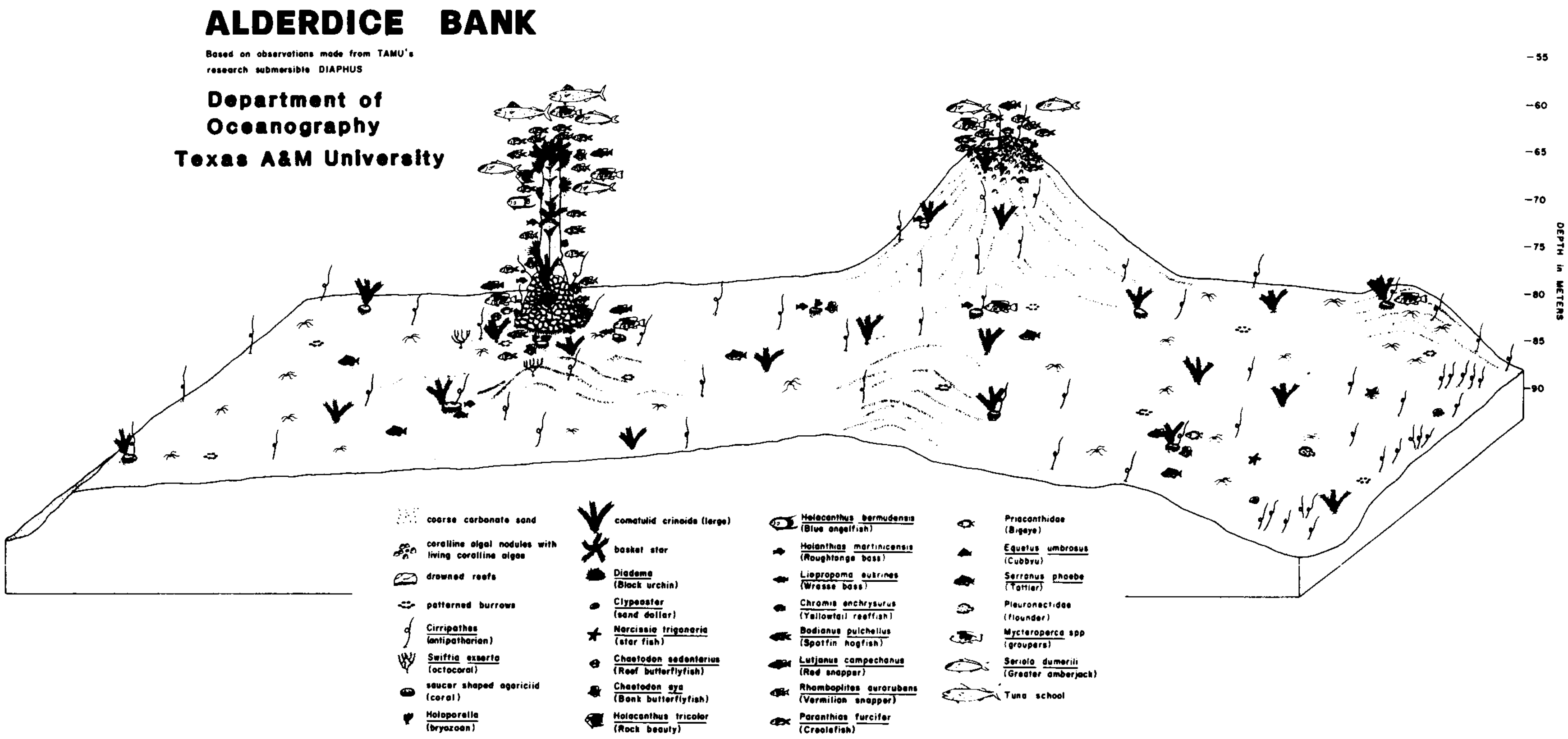

Figure VI-28. Block diagram representing biota at Alderdice Bank.

Healthy, growing, coralline algal nodules underlain by carbonate sand occur in an Algal-Sponge Zone at the crest of the large southeastern peak (58 to 67 m depth). The nodules are accompanied here and there by very small reefal structures and carbonate blocks covered with the dominant coralline algae. The extreme variability in size of nodules, blocks, and firmly affixed reef rock gives the substratum an irregular appearance not typical of other algal nodule zones. Contributing to the irregularity is the "lumpy" nature of the highly bioturbated sand, where it is exposed.

The Algal-Sponge Zone described above is probably restricted to the crests of the several peaks at Alderdice Bank and, therefore, is of limited areal extent. It nevertheless is a zone of active reef-building and carbonate substratum production deserving special consideration from the standpoint of environmental protection.

Reefal structures below the Algal-Sponge Zone are typically laden with veneers of sediment which are entrapped by mats of low epifaunal growth (Figure VI-28). Below 82 m, the drowned reefs are almost totally covered with thin layers of fine sediment. Small amounts of coralline algae, nevertheless, occur on the drowned reefs down to at least 79 m (5% cover at 76 m). No algae were seen below 79 m.

Two species of hermatypic corals were encountered at 76 m: saucer-shaped agariciids and a small head of what appeared to be Stephanocoenia sp. Neither was abundant, and both occurred on drowned reefs.

The most impressive feature on Alderdice Bank is the basalt outcrop. It is an elongate narrow ridge extending vertically upward from the 76 m surrounding depth to 55 m crest depth. The spires examined at the crest were two or so metres across at the top (Figure VI-28), with sheer cliffs extending downward to approximately 67 or 69 m, below which large blocks of bedrock talus were piled around the base of the outcrop.

The hard basalt is covered with thin crusts of coralline algae, sponges, bryozoans, and other epifauna. Near the top of the outcrop, these crusts are nearly total, up to 50% being coralline algae. At 69 m on the large blocks, coralline algal cover is 70-80%, but the cover decreases with increasing depth to small patches at 76 m. Large basket stars, Diadema urchins, and branching colonies of the bryozoan Holoporella are particularly abundant and visible on the outcrop and talus slope. Cirripathes, Antipathes, large comatulid crinoids, and small branching alcyonarians are numerous on the talus slope surrounding the outcrop, and fishes swarm round the crest of the outcrop.

Because of the existence of clear-water reefal communities on at least one, and probably all of the major topographic peaks at Alderdice Bank, and because of the presence of the spectacular basalt outcrop bearing a diverse and abundant assemblage of epibenthic organisms and fishes, **it is recommended that Alderdice Bank be classified as a top priority bank from the standpoint of environmental protection.**

32 FATHOM BANK

Introduction

32 Fathom Bank was mapped in May 1975 when only the acquisition of bathymetric and side-scan sonar data were required. No sub-bottom profiling nor submersible observations and sediment sampling were specified. During the present study, a requirement for dredging was included in order to characterize the biota and sediments on the bank.

General Description

The bank is located at 28°01'47"N latitude and 94°31'29"W longitude (Figure II-1, above) in Blocks A-532-535, 558, and 559 of the High Island Area (Figures VI-29 and 30). It is a nearly circular bank covering an area of about 45 km^2. It has a broad dome shape with a total relief of about 6 m. The shallowest depth is 52 m and the greatest depth is 58 m. Two sub-bottom profiles made during the spring 1975 mapping cruise indicate that 32 Fathom Bank is a deeply eroded diapir similar to Coffee Lump.

Sedimentology

Five rock dredge hauls were made on 32 Fathom Bank (Figure VI-29). Four of these stations yielded sediment samples. Station 3 was a hard substrate that yielded a living hard bottom calcareous biota.

The sediment types at the other four stations were gravelly, muddy sand (Stations 1 and 2) and slightly gravelly sand (Stations 4 and 5).

Particle type identification shows that at all four stations quartz is the dominant component of the sediment, with minor amounts of molluscan hash. The texture and composition of the sediments are similar to those parameters of the sediments at Coffee Lump, indicating a common origin.

Biology

No submersible dives were made at 32 Fathom Bank, and the samples dredged were less satisfactory for interpretation of biotic communities than were those taken at Applebaum Bank. The types of organisms taken in the dredge are reminiscent of the types seen and collected at Coffee Lump. For lack of better information, a tentative suggestion is that 32 Fathom Bank is somewhat similar to Coffee Lump in "quality" of biotic community development.

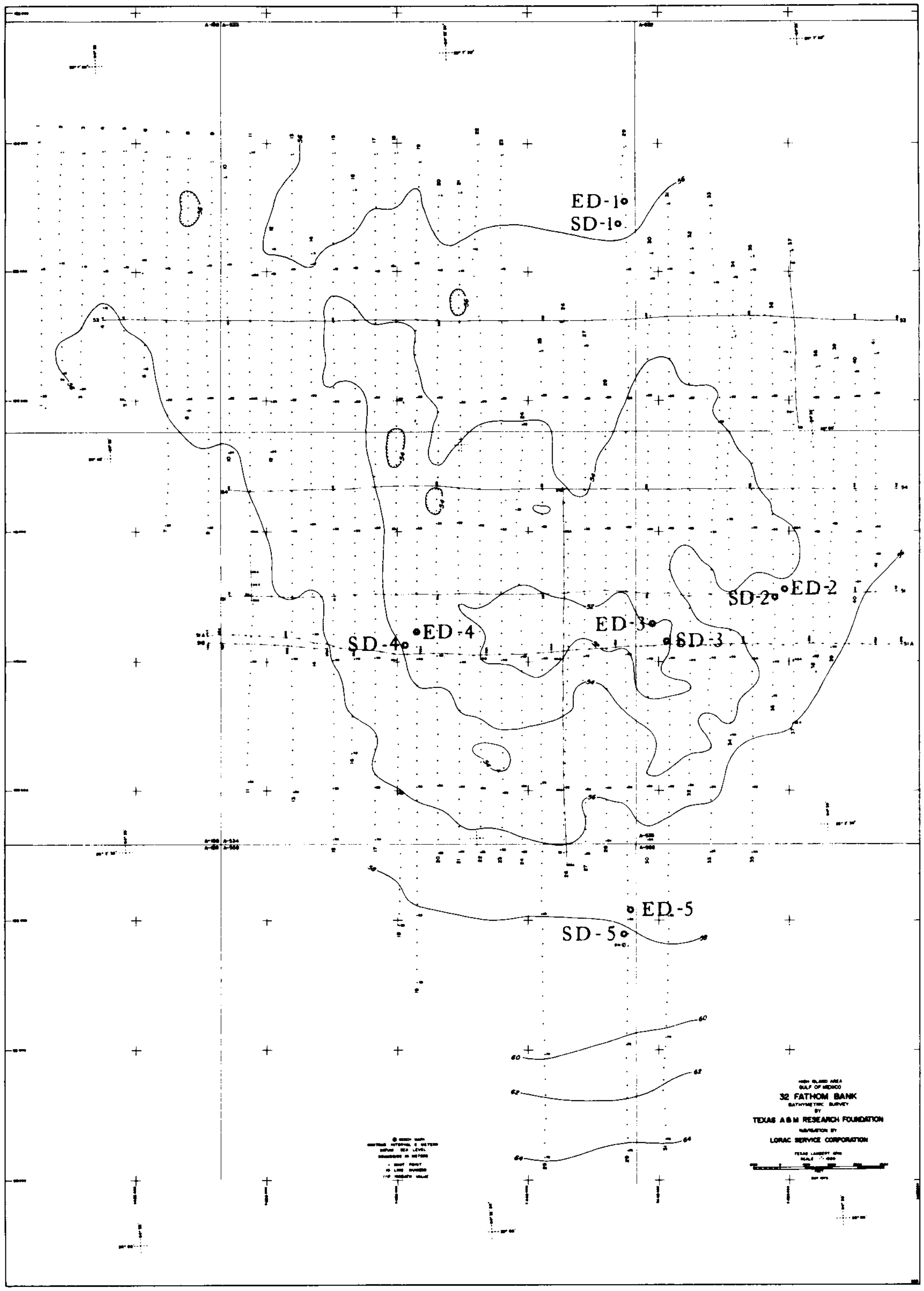

Figure VI-29. Bathymetry on 32 Fathom Bank with dredge sample locations. SD = Start Dredging, ED = End Dredging

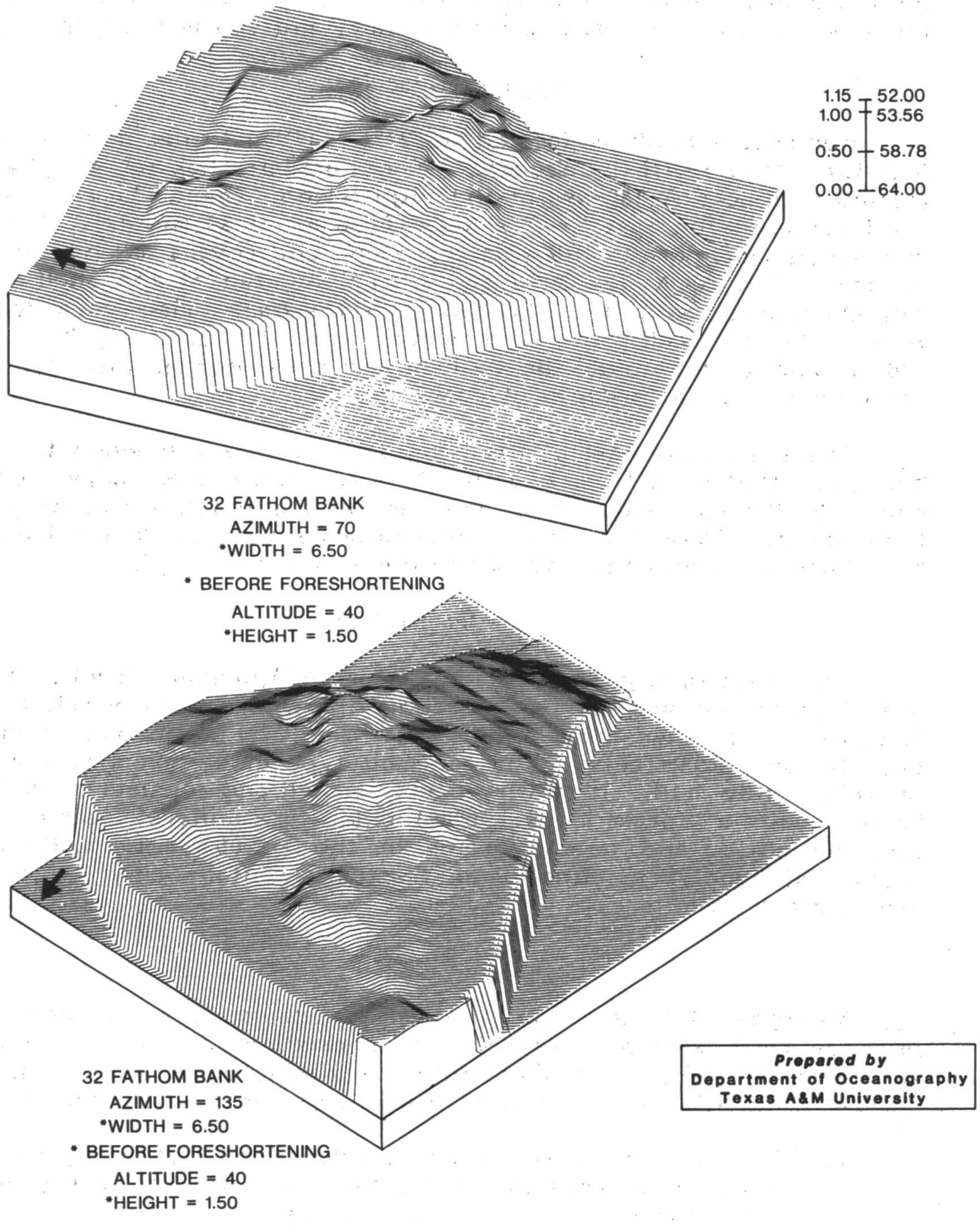

Figure VI-30. Three-dimensional perspective views, 32 Fathom Bank.

APPLEBAUM BANK

Introduction

Applebaum Bank (previously designated incorrectly as Little Sister Bank) was mapped in May 1975 and has the same history of study as 32 Fathom Bank. During the present study, a requirement for dredging was included in order to characterize the biota and sediment on the bank.

General Description

Applebaum Bank is located at 27°51'41"N latitude and 94°15'16"W longitude (Figure II-1, above). The northern half of the bank is located in Blocks A-589-591 of the High Island Area. The remainder of the bank is in the East Breaks Area (Figures VI-31 and 32). It has an oval shape, elongate to the east and west, and covers an area of about 35 km^2. The bank lies on a salt diapir situated at the shelf break. The shallowest peak, near the center of the bank, rises to a depth of 76 m. To the north, the base of the bank lies at a depth of about 120 m, and to the south the base of the bank merges into the upper continental slope at a depth of about 160 m.

The shallowest part of the bank is a north-south elongate, amoeboid peak that rises from a depth of 92 m. Immediately adjacent to the peak, on the east side, is a large depression that bottoms at greater than 100 m. These centrally located prominences and depressions must be related to normal faulting at the crest of a salt diapir.

Sedimentology

Four rock dredge stations were made on Applebaum Bank. At only one of these stations was there enough fine sediment to permit textural analysis. The other three stations are mainly algal nodules, molluscan gravels, and algal reefs. The sediment type at station 1 is a slightly gravelly sandy mud. It is very poorly sorted and consists of molluscan hash, benthic foraminifers, planktonic foraminifers, echinoderms, coralline algae, and quartz grains in the > .062 mm fraction. The coarse silt and very fine sand fractions contain only quartz and planktonic foraminifers.

Biology

No submersible dives were made at Applebaum Bank and dredge samples are an inadequate basis for interpretation of benthic community structure, zonation, and distribution of marine organisms. Little can be said concerning the biology of Applebaum Bank except the following:

1. The rocks retrieved in the dredge were carbonate, produced primarily by coralline algae, but less than 3% of the surface of the rocks bore live coralline algae.

2. Encrusting sponges covered more of the collected rocks (possibly 20%) than did other types of organisms.

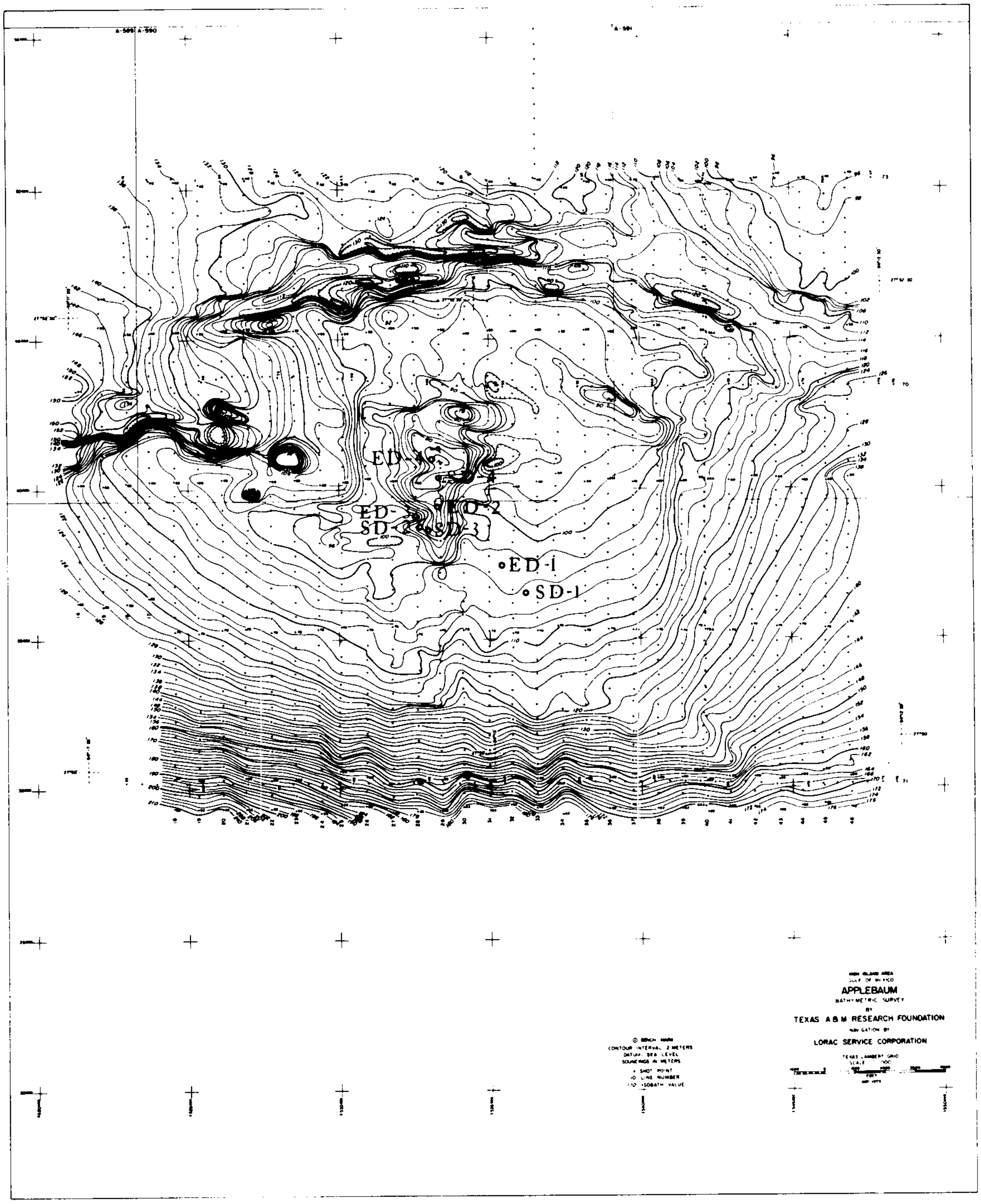

Figure VI-31. Bathymetry on Applebaum Bank showing dredge sample locations. SD = Start Dredging, ED = End Dredging.

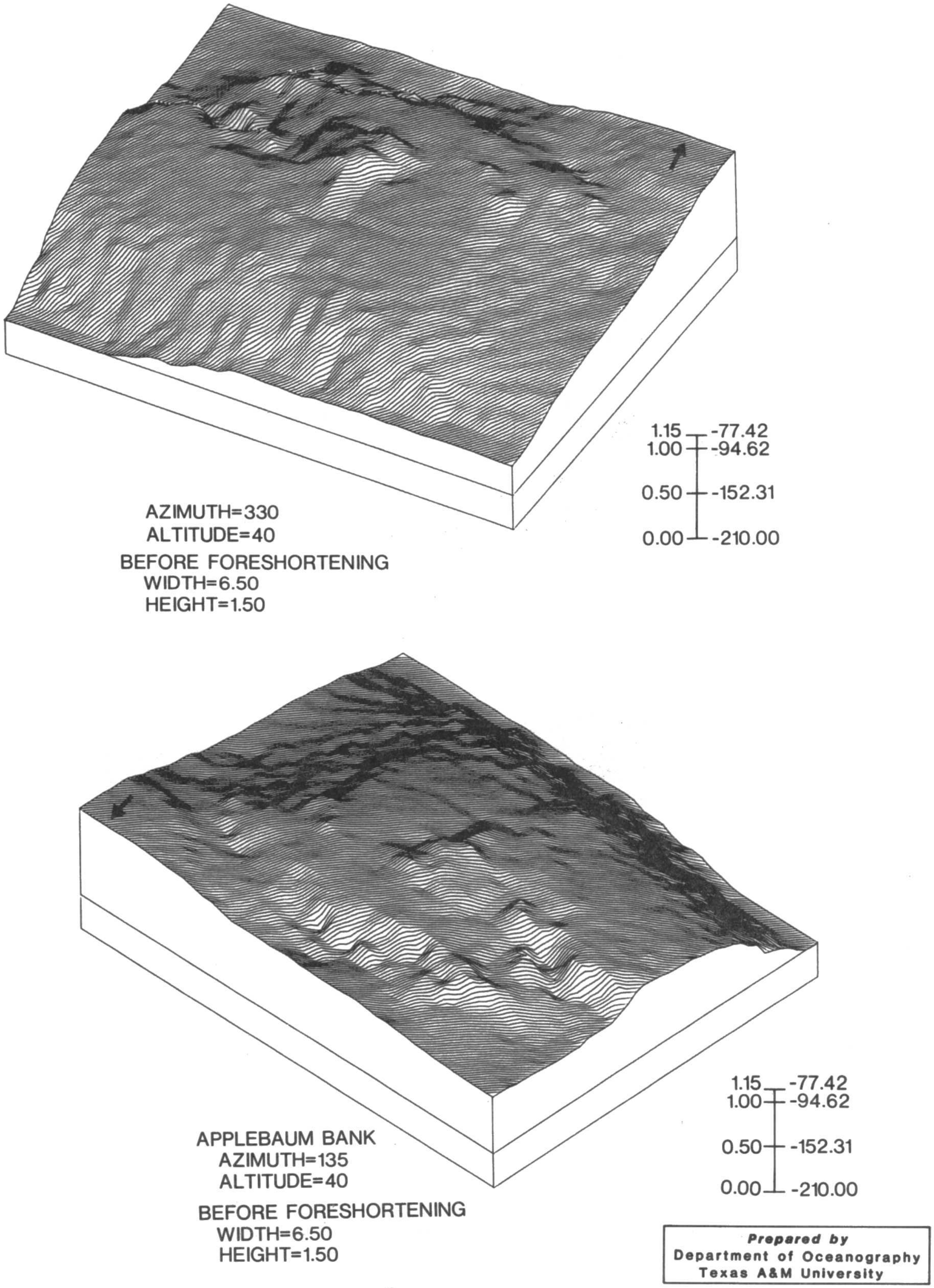

Figure VI-32. Three-dimensional perspective views, Applebaum Bank.

3. The organisms collected are typical of Outer Continental Shelf banks in the northwestern Gulf of Mexico. The antipatharian Cirripathes, various small alcyonarians, gorgonocephalan basket stars, other ophiuroids, and the Rough tongue bass, Holanthias martinicensis, were also collected and are probably conspicuously abundant on the bank. Leafy algae are also present.

4. Based on the nature of the dredge sample, it is speculated that Applebaum Bank bears areas of carbonate hard-bottom with an assemblage of organisms resembling that found on some of the South Texas Fishing Banks (viz. Southern and South Baker Banks).

CHAPTER VII

FLORIDA MIDDLE GROUND

T.S. Hopkins

INTRODUCTION

The overall objective of studies at the Florida Middle Ground was to characterize this topographic high using submarine sampling, geophysical profiling, open circuit SCUBA, shipboard instrumentation, and *in situ* instruments for measuring currents, salinity, and temperature. The characterization was designed to establish ranges of spatial and temporal variation in the chemical, geological, and physical environment of the Florida Middle Ground, and to produce qualitative and quantitative management-oriented biological data describing the lesser known aspects of the fauna and flora of the central portion of the Florida Middle Ground.

The geophysical, physical, and geological data were used to describe the setting for biological data. The collection of biological data itself was designed around management concepts to address two diverse management objectives: 1) to determine whether the Florida Middle Ground (or portions thereof) should be designated as a "Habitat Area of Particular Concern," i.e., in need of protection; and 2) to devise specific monitoring approaches which are feasible and cost effective. Of parallel interest is the question of annual and seasonal variability in weather patterns and how these processes must dictate and sometimes moderate the decision-making process.

DESCRIPTION OF THE STUDY

The study area lies on the Outer Continental Shelf (OCS) of the eastern Gulf of Mexico about 150 km south of the north Florida coast and 160 km northwest of Tampa Bay. The mapping area lies in BLM lease blocks 249-254, 293-298, 337-342, 382-387, 426-431, 471-475, 515-519, and 559-562 on the Florida Middle Ground NOS NH 16-12 (OCS) chart. The reefal portion of the Florida Middle Ground has the distinction of being the northernmost living coral reef habitat in the Gulf of Mexico (Hopkins, 1974). It is located in an area bounded by 28°10'N to 28°43'N and 84°10'W to 084°25'W (see Figure VII-1). The greatest reef development lies within this radius; the relief varies from 23 to 40+ m in depth. The overall complex trends north and south, and exhibits complex and rugged topography in sharp contrast to the relatively smooth bottom characterizing most of the west Florida Outer Continental Shelf.

MAPPING AND SUB-BOTTOM PROFILING

The northern Florida Middle Ground consists of long north-south reef structures built up from a former Pleistocene erosional terrace.

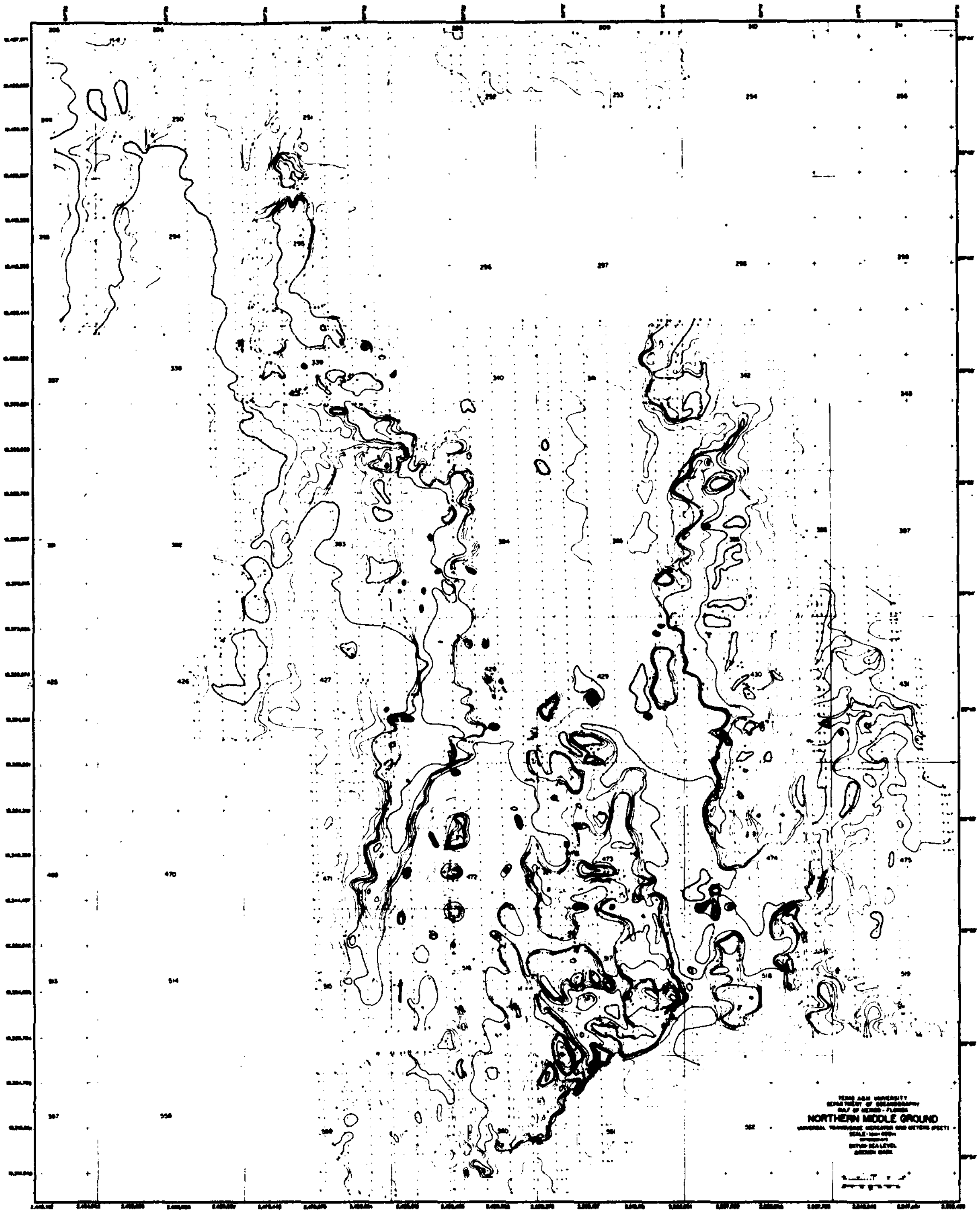

Figure VII-1. Florida Middle Ground bathymetry.

Two periods of Pleistocene subaerial exposure produced extensive erosional terraces. The older surface was cut into consolidated carbonate rock and developed karst topography. Following a rise in sea level and a period of primarily carbonate deposition, a second low stand of sea level resulted in a younger erosional terrace (possibly as young as 10,000 yrs B.P.). This erosional surface cut completely through sediments of the previous depositional period and into the former erosional surface in the eastern part of the survey region. Channels in this surface indicate drainage from the east and north. It is from this younger erosional terrace that the Florida Middle Ground reefs have been constructed.

Recent carbonate sediments, derived in part from the reefs (even though locally high in molluscan shell content), have been deposited over the former erosional surface, between the reefs.

Bottom currents, prevailing northeastward directions of storms, and hurricanes exert major control on the distribution of the recent carbonate sediments, building talus slopes on the east margins of ridges and scour channels on their west margins. Ripple patterns on the ridges and their flanks suggest dominant north-south bottom currents.

Live or very recent reef growth is observed in the seismic reflection records and bathymetry as scattered pinnacles on top of and at the margins of the broader ridge profiles. Beneath these pinnacles, the ridges are believed to be dead reef structures. Presently growing reefs, based on relief, are scattered throughout the region but are more abundant in the southern part of the survey area at depths of about 30 m. This distribution may be related to destructive forces of hurricanes and storms at shallower depths.

GEOLOGY AND SEDIMENTOLOGY

Sediments on the Florida Middle Ground are carbonate sands, characteristically a molluscan shell hash. Sands are better sorted on the ridge tops than in the valleys. Textural distribution of sediments is patchy, with a weak tendency for coarser material to lie on the ridge tops and the finer material in the valleys between. Sediment distribution suggests that even the valleys of the Florida Middle Ground are actively winnowed of fine sediments.

There is no apparent difference in sediment carbonate constituents between the ridge tops and valleys. Carbonate constituents in the sediments are more similar to those of the surrounding shelf than to the remains of organisms living on the Florida Middle Ground at present.

The carbonate constituent assemblage and the corroded nature of the grains show that local production of carbonate sediment is either masked by corroded carbonate shelf sands swept onto the Florida Middle Ground by storms and/or that the Florida Middle Ground is not as flourishing as it may locally appear, but in reality adds little carbonate to the relict assemblage. The latter conclusion is reinforced by television observation that the reef growth is primarily vertical with little horizontal spreading.

The foraminiferal assemblages are dominated by nine species, the predominant of which is Amphistegina gibbosa. Diversity and evenness of populations of foraminifera increased regularly from November 1978 to June 1979.

PHYSICAL AND CHEMICAL OCEANOGRAPHY

Seasonal meteorological observations were consistent with the established maritime conditions for the geographical position of the study site.

The seasonal water column hydrography (temperature, salinity, and dissolved oxygen) observations did not differ significantly from the anticipated regimes for an outer shelf area of the open northeastern Gulf of Mexico. Near-bottom temperatures were lowest from late January through most of April, while highest temperatures were recorded from late July through most of October. The absolute range in temperatures was 15.2 to 29.4°C. The near-bottom salinities ranged from 33 to 36 ppt. This range is consistent with previously reported values. With the exception of silicate, all of the nutrient data values are considerably higher than previously reported. The Florida Middle Ground is a sizeable nutrient source, with peak output in the fall months.

Light penetration measurements indicate rapid attenuation during the winter, particularly after the passage of a cold front (20% relative illuminance at depths of 4 to 5 m). During the summer, less attenuance is observed with depth (50% relative illuminance occurs to depths of 25 m).

Power spectra analysis indicates that most of the energy in the current records occurs at approximately 12.4 hours (semidaily tides) and 23.8 to 26.9 hours (combined daily tide and inertial motions). Rotary spectral analysis shows that there is more inertial energy (clockwise rotation) than daily tide energy (anti-clockwise rotation).

Mean flow calculations show that the near-bottom currents can be highly variable with very low mean speeds (< 2.0 cm/sec). Generally, the direction of the mean flow is either northwest or southeast, which is close to the orientation of the regional isobaths when considered on a scale of 10's to 100's of kilometres.

Hurricanes and tropical storm events generated the highest recorded current velocities. The maximum near-bottom speed measured was approximately 61 cm/sec during tropical storm "Claudette," while the maximum near-surface speed measured was approximately 87 cm/sec during Hurricane "Frederic."

BIOLOGY

Algae

The 79 algal species collected in June-July 1979 contrast with the 74 species collected in June-July 1976. Comparing the two different years' collections, only a 36.6% similarity was found in species composition. The algal population indicates that the Florida Middle Ground suffered a serious trauma between June-July 1976 and October 1978.

Hard and Soft Corals

In situ inspection and color photography indicate that the Florida Middle Ground hard and soft corals experienced a major trauma between June-July 1976 and June-July 1978. The more delicate and/or tropically restricted species (e.g., *Agaricia*) were the best indicators of this trauma. Soft corals were greatly reduced in number, and many were emaciated when present. The calcareous milleporine, *Millepora*, which was formerly a major contributor to reef dimension, also showed effects of trauma. The major trauma was probably a combination of 12-13°C water and a storm surge whose severity in these waters was documented for 1977 and 1978.

Polychaeta

The polychaete family, Syllidae, proved to be an excellent bioindicator of polychaete cryptofaunal diversity occurring in 57 habitat/hosts investigated. Syllids showed significant differences in "number/host" type, but much less difference between "same host" and "different station" and "host/station/season." Epitokes occurred predominantly during the summer and fall, and were virtually absent in the winter.

Crustacea

Amongst the crustacea, isopods and caridean shrimp are the best major taxa for developing target species in cryptofaunal studies.

The cryptofaunal isopod fauna of the Florida Middle Ground was found to be relatively rich (21 species) and generally undescribed (seven forms new to science). The isopod host/species relationship with the sponge *Agelas* was smaller and more consistent than the same relationship in the coral clump of *Madracis*. No easily discernible seasonal or station differences were observed in the isopod fauna; however, three distinct spatial habitats were encountered. These were a) planktonic, b) rubble, and c) specific host (e.g., *Agelas* and *Madracis*).

This study has produced a wealth of new biological/systematic information on Caridea; e.g., two (2) new species and unprecedented descriptions of color patterns in twenty-six (26) other Caridea. The Caridea are a major component of the cryptofaunal community and the

Florida Middle Ground biotope. Fifty-nine (59) species are now known to occur in conjunction with this locality. Forty-eight (48) species was the previous record from a single locality in the Western Atlantic. Twenty five (25) species of carideans were associated with sponges (18 species examined). Of the twenty five (25), six (6) species are obligate commensals of sponges. Eighteen (18) species of carideans were associated with hard corals; however, none appear to be obligate commensal species.

Host relations of *Agelas* and *Madracis* reveal differences in dominance and species make-up. Treating *Agelas* (sponge) and *Madracis* (coral) quantitatively (volume to number of individuals), revealed that 1) *Synalpheus townsendi* dominates the *Madracis* community and 2) *Synalpheus agelas* and *S. townsendi* are the dominants in *Agelas*.

A seasonal decline in cryptofaunal Caridea was observed during the winter season; commensal species with strong tropical affinities were possibly excluded in winter sampling. A seasonal effect was also noted in reproductive activity. Reproductive activity during winter became attenuated or even eliminated. This situation applies to *S. townsendi* and *S. agelas*; the former a Caribbean eurythermic species and the latter a Caribbean restricted species.

Ten species of anomurous and brachyurous crabs account for 85% of the crab fauna. Two (2) species are new to science.

Echinoderms

The increased abundance of the temperate species sea urchin, *Arbacia punctulata*, and the concomittant decrease of the formerly ubiquitous tropical sea urchin, *Diadema antillarum*, is another possible indicator of trauma imposed by cold water. Furthermore, there was a sharp decrease in the general numbers of *Astrophyton muricatum*, a basket star (Ophuiroidea).

Aggregations of *Echinaster* were noted and assumed to be breeding aggregations. Almost nothing is known about the biology of this starfish.

Ichthyofauna

Results of the ichthyofaunal studies tend to confirm speculations by previous workers that the Florida Middle Ground supports a fauna with largely tropical West Indian affinity. A majority of the reef-associated (non-pelagic) species identified have distributions including Caribbean and southern Florida waters. Florida Middle Ground fishes exemplify the northern extension of tropical faunal elements observed on deep hard-bank and sponge bottom substrates in the Gulf and along the Atlantic coast as far north as the Carolinas. An attempt at a detailed comparison of the Florida Middle Ground ichthyofauna with that of the Flower Garden Banks (Bright *et al.*, 1974) and other hard bank areas of the western Gulf of Mexico would be premature. While obvious differences exist in the species occurrences of these eastern and western Gulf deep-reef assemblages, both faunas remain relatively poorly known in contrast with adjacent, shallow, inshore faunas. Most important, more information is needed on the respective abundances of those species which occur in both areas of the Gulf.

Perhaps the most glaring gap in knowledge of the Florida Middle Ground ichthyofauna concerns cryptic fishes. While the present study has shed light upon the overall community structure of the more "visible" component species, much remains to be determined as to the abundances of the "hidden" forms, such as *Lythrypnus* spp., *Ogilbia* sp., and all of the apogonids. The fact that several species (*Ogilbia* sp., *Psilotris celsus*, and *Gobulus myersi*) were taken only in artificial habitat samples leads to the conclusion that additional species have escaped collection. Intensive collecting efforts emphasizing poison stations would be required to obtain abundance information on most of the cryptic species.

CHAPTER VIII

SUMMARY AND RECOMMENDATIONS

INTRODUCTION

In the northwestern Gulf of Mexico, eleven banks (East Flower Garden, Coffee Lump, Fishnet, Diaphus, Jakkula, Elvers, Geyer, Rezak-Sidner, Alderdice, 32 Fathom, and Applebaum) were characterized biologically and geologically using observations and samples taken by surface vessel, research submersible, and/or rock dredge. Six of the banks (East Flower Garden, Coffee Lump, Fishnet, Diaphus, Jakkula, and Alderdice) were also subjected to water and sediment dynamics studies. A strong correlation was found between biotic zonation, nature of the substrate, and depth at the top of the nepheloid layer. Data were also collected at the West Flower Garden Bank for interpretation under a subsequent contract. A brief overview is included below.

Five banks bear reef-building populations of coralline algae within well developed Algal-Sponge Zones on their crests (Elvers, Geyer, Jakkula, Rezak-Sidner, and Alderdice). These banks also display the normal carbonate sediments such as algal reef rock, algal gravels, and carbonate sands associated with biogenic reefs. The crests of all these five banks lie above the normal depth of the nepheloid layer. Diaphus Bank may also have an Algal-Sponge Zone, but its crest is near the lower depth limit of this zone at the Flower Garden Banks. The other four banks (Coffee Lump, Fishnet, 32 Fathom, and Applebaum) bear less diverse benthic assemblages adapted to chronic turbid water conditions. Numerical ranking of biotic zones and banks indicates that there are at least seven levels of "environmental snesitivity" to which the banks studied can be assigned.

At the Florida Middle Ground, mapping, geological sampling, as well as physical and chemical studies established a background for biological studies. The Florida Middle Ground was found to be a unique biotope worthy of designation as a habitat of particular concern. Biota are extremely fragile, requiring prudent management decisions.

EAST FLOWER GARDEN BANK

Geology

No significant normal faulting has occurred at the East Flower Garden Bank. The crestal graben which is typical of most of the banks examined has not yet developed. However, the dissolution and removal of prodigious amounts of salt from the crest of the diapir have been documented, and graben formation at this bank cannot be far in the future. At that time, radial faults that may extend some distance away from the bank can develop. Therefore, it would be unwise to emplace any permanent structures in close proximity to the bank. **It is strongly recommended that sensors be emplaced at several sites on the**

East Flower Garden so that the amount and direction of movement at the crest may be measured.

Biology

In general, there is no indication of a significant change in benthic community structure or condition during 1978 and 1979.

Living coral covers 50 to 62% of the hard-bottom in the *Diploria-Montastrea-Porites* Zone (high diversity coral reef) at the East Flower Garden Bank. *Montastrea annularis* is the most dominant coral, covering 23 to 37% of the hard bottom. No apparent changes were observed in the population levels of corals or in their dominance ranking during the years 1978 and 1979.

Current accretionary growth of *M. annularis* may average 7.2 mm/yr., and that of *Stephanocoenia intersepta*, 5.8 mm/yr. There appear to have been no changes in rate of accretionary growth of these two dominant corals over the past decade. Rates of encrusting coral growth and coral mortality are highly variable, but there is no indication that encrusting growth has been generally impaired nor that mortality has substantially increased during 1978 and 1979.

Settling of larval corals and early growth and development have taken place during 1978 and 1979 at a rate which is believed to be normal.

Leafy algae populations were greater in the spring of 1979 than in fall, winter, or summer. The genera *Dictyota*, *Peyssonnelia*, and *Lobophora* dominated throughout the year, with seasonal changes in relative abundance.

There was no obvious change in "health" of benthic communities southeast of the main coral reef at the East Flower Garden. The condition of corals and coralline algae within the Algal-Sponge Zone appeared similar in 1978 to that of previous years. There were no signs of mass mortalities on any conspicuous component of the community.

The effects of a natural brine seep on benthic biota at the East Flower Garden were found to be restricted to an area within a few metres of the brine and recognizable brine-seawater mixture.

Water and Sediment Dynamics

Water column data taken during 1980 clearly indicate that the water from the base of the East Flower Garden Bank cannot flow up to the level of the living reef. This conclusion is supported by several lines of evidence. Rezak (this report) has shown that silt and clay are nearly absent from the bank above about 80 m and that the movement of sediment on the banks is mainly by gravity. Bright (this study) has demonstrated a significant biological zonation at an approximate depth of 80 m, above which clear water fauna exist and below which they are missing. Sediment from the base of the bank cannot rise above the 75 to 80 m isobath. We recommend that water column monitoring be extended for another year. Data taken during 1979 were anomalous due to the excessive amount of run-off caused by heavy rains in the Mississippi embayment.

WEST FLOWER GARDEN BANK

Geology

A crestal graben has developed at this bank, and continued movement on these faults may be expected. During the surveying of the bank, an active fault that displaced the seafloor was observed about three kilometres southeast of the reef. High resolution sub-bottom surveys should be made prior to emplacing permanent structures on the bottom to insure that they are not in close proximity to an active fault.

Biology

Biological zonation at the West Flower Garden Bank is similar to that at the East Flower Garden. Stipulations required by BLM should be continued in order to protect sensitive environments.

Water and Sediment Dynamics

Observations at the West Flower Garden Bank indicate that currents are steered by topography. Shunting stipulations similar to those for the East Flower Garden Bank should be required for drill effluents. A side-scan sonar mosaic, prepared for Contract No. AA851-CTO-25, indicates that at times surface currents exceed two knots.

COFFEE LUMP BANK

Geology

Coffee Lump is a relatively inactive bank, underlain by a salt diapir that has not moved upward appreciably since Late Pleistocene time. The removal of salt by phreatic marine waters from the crest of the bank has been minimal, as evidenced by the low relief at the crest of the bank.

The bank is continually immersed in a nepheloid layer, and the fauna and flora of the bank are similar to those of the South Texas fishing banks, which are also immersed in a nepheloid layer.

Biology

Preliminary analysis of community structure indicates that above 68 m, at least, Coffee Lump harbors a soft-bottom, macro-epifaunal community which is distinctly bank-related and differs substantially from soft-bottom epifaunal communities found adjacent to banks in the northwestern Gulf of Mexico. The upper Coffee Lump soft-bottom communities appear to be more diverse and to harbor a greater abundance of organisms than is typical of off-bank, soft-bottom communities.

Biotically, the hard-bottom is an Antipatharian Zone, harboring an assemblage of organisms very similar in composition to those of the South Texas fishing banks. The distribution of such hard-bottom epibenthic communities on Coffee Lump is probably coincident with the bottom irregularities detected in side-scan sonar records.

Coffee Lump should be classified as low priority, requiring no restrictions to hydrocarbon exploration and production activities.

Water and Sediment Dynamics

Coffee Lump is completely enveloped in a nepheloid layer most of the time. Topographically accelerated flow will inhibit the accumulation of fine sediment on the uppermost parts of the bank.

FISHNET BANK

Geology

Evidence for Recent activity of faults on and in the immediate vicinity of Fishnet Bank suggests that areas in close proximity to the bank may be subject to seafloor instability. **Care should be taken to avoid emplacement of structures on the bottom in areas of severe normal faulting that does not appear to intersect the seafloor but shows subtle signs of recent movement.**

Biology

Fishnet Bank does not appear to support clear-water, reef-building communities at the present time, probably due in part to chronic turbidity and sedimentation. The benthic community on the bank is presumably adjusted to such conditions, being comparatively low in diversity and numbers. Nevertheless, snappers and certain other potentially commercial and game fishes are numerous. **This bank should be assigned a low priority for protection from drilling activities.**

Water and Sediment Dynamics

Even though an extensive nepheloid layer was not encountered during the extremely limited period of hydrographic sampling, direct observations of the bottom (Rezak, this report) and the texture of the sediment samples, indicate that the nepheloid layer frequently envelops this bank.

DIAPHUS BANK

Geology

Typical of shelf-edge banks, Diaphus Bank may be expected to continue in the development of its normal faults. Continued movement along the major east-west fault should be expected.

Biology

The apparent lower diversity and abundance of epibenthic biota and fishes below the break in slope are probably related to depth, light penetration, water turbidity, and sedimentation. Overall, the diversity and abundance of benthic biota on Diaphus Bank are low compared to those of many other shelf-edge banks in the northwestern Gulf. This may be due to the somewhat deeper crest depth of Diaphus Bank and/or its closer proximity to the Mississippi River outfall.

Water and Sediment Dynamics

A well developed nepheloid layer was encountered at all stations except the shallowest one. The presence of coarse sediment at the crest of the bank and the apparent low diversity of the biota indicate that the bank may be frequently enveloped in a nepheloid layer but that fine sediment does not accumulate at the crest, due to topographically accelerated flow.

JAKKULA BANK

Geology

Active faults, as evidenced by those that intersect the seafloor, and lack of evidence for collapse of the central portion of the bank warrant the designation of Jakkula Bank as one which may have a very unstable crest that should be monitored.

Biology

At the crest of the bank the presence of a large area designated as the Algal-Sponge Zone warrants the protection of this bank by shunting stipulations similar to those required at the Flower Garden Banks.

Water and Sediment Dynamics

The high relief on this bank prevents the bank from being enveloped by the nepheloid layer. Sediment distribution and the biological zonation indicate that the nepheloid layer does not rise above a depth of about 90 m.

ELVERS BANK

Geology

Most of the faults on Elvers Bank displace the seafloor, indicating that it is a tectonically active bank. **Extreme caution should be exercised prior to placing any kind of structure on this bank.**

Biology

The distribution of benthic biota on Elvers Bank, particularly the great depths to which algal populations extend, indicates a somewhat different balance of environmental factors influencing populations at this bank compared to banks bearing similar communities slightly closer to shore (28 Fathom, 18 Fathom, East and West Flower Garden Banks, etc.). The obvious physical difference is Elvers Bank's greater base depth and consequent greater relief. Also to be noted is the failure to detect substantial turbidity in the bottom water at Elvers during the reconnaissance dive, even at 180 m. Simplistically, biological conditions at Elvers and Geyer Banks seems to imply that the greater the relief of the bank, the less likely it is for turbid water layers to occur at mid or shallow depths on the bank.

We can only speculate concerning the ecological significance of interrelationships between light, water clarity, turbulence, circulation, sediment suspension, sedimentation, turbidity, geological structure, and other environmental factors. That balances occur between these natural factors greatly influencing hard-bank benthic populations is, however, certain. Careful observation and study of the aforementioned factors and processes relating to them at several selected banks could do much to clarify critical aspects of natural physical-geological-biological interrelationships on and around the banks.

GEYER BANK

Geology

Geyer Bank lies on an active salt diapir on the upper continental slope. Because of its great relief and evidence for Recent movement on faults at the crest of the bank, one would expect accelerated dissolution of salt and continuing activity of faults on the crest and along the margins of the bank. **Emplacement of large structures on the crest of the bank or in close proximity to its flanks should be discouraged.**

It is strongly recommended that additional work be conducted at Geyer Bank. Only a very small part of the bank has been observed from the submersible (See Volume Four, Figure XVI-1). Additional submersible observations are needed to characterize the biota, to determine the nature of the bedrock outcrops, and to observe the lineations shown on Figure XVI-2 (Volume Four) in order to determine whether or not they represent recently active faults. Geyer Bank would be an excellent site for emplacing sea-bottom sensors to record tectonic activity on the bank. The major tectonic activity observed on the sub-bottom profiles is the upward movement of the salt diapir. The presence of both bare bedrock outcrops and well developed reef growth at the crest of the bank indicates Recent and possibly continuing movement along normal faults that will eventually develop into a central graben.

Biology

The presence of large areas characterized by the Millepora-Sponge Zone and the Algal-Sponge Zone biotic communities warrants the protection of Geyer Bank. These unique communities should be protected by stipulations similar to those in use at the East and West Flower Garden Banks.

REZAK-SIDNER BANK

Geology

Rezak-Sidner Bank appears to be a geologically active structure that has been created by a deep-seated salt diapir. Although there is evidence of repeated exposure of the bank during the Pleistocene epoch, there is no normal faulting within the bank proper that would indicate removal of salt from the crest of a diapir by dissolution. In general, the movement of the bank has been in an upward direction and will probably continue to be so for some time to come.

Biology

Biologically, Rezak-Sidner is similar to Geyer, Elvers, and 28 Fathom Banks. The upper part of the bank (above 100 m) is comparable to the Algal-Sponge Zone at the East and West Flower Garden Banks. **The biota of this zone should be protected.**

ALDERDICE BANK

Geology

Alderdice Bank is another tectonically active bank. Faulting is common both on the crest of the bank and on its flanks. The shift in the locus of upthrusting by the salt diapir creates potentially dangerous conditions on and around the bank. If the locus of the greatest upward movement has actually shifted and dissolution of salt is continuing beneath the present crest, then an increased rate of collapse of the crest may be expected. This situation on Alderdice Bank indicates that instability of the sea bottom due to tectonism is not restricted to the crest of the bank but may occur some distance away from the crest in areas that otherwise may appear stable.

Biology

Because of the existence of clear-water reefal communities on at least one, and probably all, of the major topographic peaks at Alderdice Bank, and because of the presence of a spectacular basalt outcrop bearing a diverse assemblage of epibenthic organisms and fishes, it **is recommended that Alderdice Bank be classified as a top priority bank from the standpoint of environmental protection.**

Water and Sediment Dynamics

The flow observed at Alderdice Bank stations was strongly depth and time dependent and was topographically steered. Because of the low relief of the bank and observations on the vertical extent of the nepheloid layer at other banks, it is reasonable to expect that fine sediment is advected over the broad platform of Alderdice Bank. It seems highly unlikely that fine sediment would reach the crests of the peaks that rise above the platform surface.

32 FATHOM AND APPLEBAUM BANKS

Geology

Bathymetric profiles, side-scan sonar records and the limited number of rock dredge samples on these banks indicate that 32 Fathom Bank is similar to Coffee Lump in its structure and sediments. Without sub-bottom profiles, it is impossible to determine if the bank has been planed by erosion during the Pleistocene or if the bank is a series of conformable sedimentary rocks broadly bowed upward by a deep-seated diapir.

Lineations in the bathymetry on the north and west sides of Applebaum Bank indicate the possibility of faulting in those areas. Dredge hauls on the main peak recovered carbonate rocks that may represent drowned Pleistocene coralgal reefs.

Biology

Dredge samples taken at 32 Fathom Bank were inadequate for interpretation of biotic communities. The limited biota recovered suggests that it is similar to Coffee Lump in biotic community development.

Applebaum Bank bears areas of carbonate hard-bottom with an assemblage of organisms resembling that found on some of the South Texas Banks (e.g., Southern Bank and South Baker Bank).

FLORIDA MIDDLE GROUND

The Florida Middle Ground is a demonstratively unique biotope worthy of designation as a habitat of particular concern. This biotope supports both a Caribbean eurythermal species complex and a Caribbean restricted species complex of algae, invertebrates, and fishes. It can be hypothesized that 1) the northward intrusion of the Gulf Loop current in spring and summer, 2) the usually short period of low water temperatures, and 3) concomittant high organic productivity encourage the survival of tropical recruits and breeding populations of the more hardy Caribbean restricted species. However, periodic extremely cold winters occur, and a combination of storm surge and cold water (12-13°C) remaining for several days may bring about depauperation of the more tropical species. How often such a natural phenomenon occurs should be deduced from historical meteorological records.

The study has successfully explored the possibility of using selected cryptofaunal hosts as quantitative sampling units for biological monitoring, and elucidated which faunal groups will yield the most useful results. It found that 1) syllid polychaetes, (2) bivalve and gastropod molluscs, 3) isopod and caridean crustaceans, and 4) inquiline fishes are demonstrably useful.

The study suggests that the Florida Middle Ground biota is extremely fragile and susceptible to nature's vagaries. Consequently, those charged with stewardship of the Florida Middle Ground must be prudent when granting permission to drill. It would not be prudent to drill exploratory wells for several years after major storm and cold water damage. The Florida Middle Ground will in all likelihood recover from nature's own devastation. However, like any organism already weak from serious injury, its susceptibility to either further depauperation or permanent change to a community of more temperate species is greatly enhanced.

In view of the foregoing, it is recommended that should exploratory drilling on or near the Florida Middle Ground be necessary, it should be programmed during a mild winter season. In this effort management should make use of a) the historical meteorological record and b) the predicted path of the Gulf Loop Current in response to the meteorological conditions forecast.

Results of the mapping effort indicate that future offshore BLM surveys should always include shallow penetration seismic reflection profiling. This work and the bathymetric surveying should be carried out at least a year in advance of other seafloor studies so that the results can be used to guide the other studies.

It should also be noted that requirements for future studies could be simplifed without compromising the objectives of the investigation or the quality of the results.

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The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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