29136

NORTHERN GULF OF MEXICO TOPOGRAPHIC FEATURES STUDY

FINAL REPORT

VOLUME ONE

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

MARCH 1981

TEXAS A&M UNIVERSITY COLLEGE OF GEOSCIENCES

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This volume has been reviewed by the Bureau of Land Management and approved for publication. Approval does not signify that. the contents necessarily reflect the views and policies of the Bureau, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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CHAPTER I

INTRODUCTION

J. LeBlanc

STUDIES

This report was prepared to satisfy the tasks specified in the U .S. Department of the Interior (DO I} , Bureau of Land Management (BLM) Contract #A A551-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 (UAB) , Dauphin Island Marine Laboratory; the University of Texas at Austin (UTA) , U.T. Marine Science Institute (UTMSI) ; the University of South Florida (USF) at Tampa; and several private service organizations including LGL, Inc., Oceanonics, Inc., Sealfleet Operations, Inc. , and Lorac Service Corp.

The main purpose of the study was to gather data from selected areas and topographic features in the Gulf of Mexico, and then reduce, map, analyze, synthesize, integrate, and report findings and conclusions. 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 and extends the efforts begun in 1961 by researchers from TAMU on a cruise to the West Flower Garden Bank conducted by R. Rezak on the R/V HIDALGO.

[n previous BLM-funded studies, beginning in 1974, TAMU oceanographers characterized the geology and biology of 28 banks in the north w'estern 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 for the Florida Middle Ground and Alderdice, Applebaum, Coffee Lump, Diaphus, Elvers, East Flower Garden, Fishnet, Geyer, Jakkula, Rezak - Sidner, West Flower Garden, and 32 Fathom 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 Alderdice, Coffee Lump, Diaphus, East and West Flower Garden, Fishnet, and Jakkula 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, chemical analysis of Spondylus and certain fish species for trace metals and high molecular weight hydrocarbons was also undertaken. 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. Chemical analyses of the water column for nutrients, dissolved oxygen, and low molecular weight hydrocarbons were done at the East and West Flower Garden Banks. The study of the distribution of reworked fossil coccoliths on the South Texas Outer Continental Shelf, initiated during 1976 under BLM Contract #A A550-CT6-18, was continued.

The East Flower Garden Monitoring study was continued and resulted in data in the following areas: coral and coral line 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.

This report is organized in six volumes. Volume One includes a chapter on program management, special chapters on geological, biological, and hydrographic studies, and a summary and recommendations chapter. Volume Two contains a general methods chapter and chapters on chemical analyses and the fossil coccolith study. Volume Three is devoted entirely to the East and West Flower Garden Banks, and Volume Four reports the geological and biological characterization of ten other banks in the northern Gulf of Mexico, each one comprising a separate chapter. Volume Five includes all data from the Florida Middle Ground study, including methods, mapping, physical and chemical oceanography, geology, and biology. The last volume is an Executive Summary Report.

BACKGROUND

The U.S. Department of the Interior has been mandated by federal statutes to conduct critical or information gathering studies in waters adjacent to the continent. The information from such studies is used to make policy and management decisions on oil and gas related activities in the open waters. The Office of Management and Budget (OMB) has a priority system to rank all mandated and/or critical studies, and the Government Accounting Office (GAO) oversees the expenditure of funds approved by the United States Congress. The Bureau of Land Management, U.S. Geological Survey (USGS), and others are responsible for the DO I studies.

The Department of Transportation (DOT) has been mandated other sea-related responsibilities handled by the U.S. Coast Guard (USCG) . l-he Environmental Protection Agency (EPA), Department of Commerce

(DOC) , Department of Defense (DOD) , and others have also been mandated responsibilities related to pollution, marine environments, and marine resources. These mandated responsibilities are sometimes overlapping and have affected progress in some marine studies.

The relevant public laws, acts, or orders include:

Clean Air Act of 1963, 42 USC 1857 et seq., PL 88-206 (Agency: EPA); amended: 1966, 42 USC 1857c, 18571, PL 89-675; 1970, 42 USC 1857b et seq. , PL 91-604; 1977, 42 USC 7401 et seq. , PL 95-95.

Clean Water Act of 1977, 33 USC 1251 et seq. , PL 94-217 (Agency: EPA).

Coastal Zone Management Act of 1972, 16 USC 1451 et seq., PL 92-583 (Agency: DOC, National Oceanographic and Atmospheric Agency [NOAA] , and Office of Coastal Zone Management [OCZM]); amended: 1976, 16 USC 1451,1453 et seq., PL 94-370.

Deepwater Port Act of .1974, 33 USC 1501, PL 93-627 (Agency: DOC, NOAA) .

Endangered Species Act of 1973, 16 USC 1531-43, PL 93-205 (Agency: DOI, Fish and Wildlife Service [FWS] ; and DOC, National Marine Fisheries Service [NMFS]).

Environmental Quality improvement Act of 1970, 42 USC 4371 et seq. , PL 91-224 (Agency: EPA).

Federal Water Pollution Control Act of 1960, 33 USC 1251 et seq., PL 92-500 (Agency: EPA); amended: 1961, 33 USC 466 et seq., PL 87-88; 1972, 33 USC 1251 et seq., PL 92-500.

Fishery Conservation and Management Act of 1976, 16 USC 1801-1883, PL 94-265 (Agency: DOC, Regional Fishery Management Councils; DOT, USCG).

Land and Water Conservation Fund Act of 1965, PL88-578, 16 USC 460d, 4601-4 et seq. (Agency: DOI, FWS).

Marine Mammal Protection Act of 1972, 16 USC 1361 et seq. , PL 92-522 (Agency: Marine Mammal Commission; DOI, FWS; DOC, NMFS).

Marine Protection, Research, and Sanctuaries Act of 1972, 33 USC 1401 et seq. , PL 92-532 (Agency: EPA).

Marine Resources and Engineering Development Act of 1966, 33 USC 1101 et seq. , PL 89-454 (Agency: National Council on Marine Resources & Engineering Development; Commission on Marine Science, Engineering & Resources) .

National Environmental Policy Act of 1969, 42 USC 4321 et seq., FL 91-190 (Agency: Council on Environmental Quality [CEQ]).

Natural Gas Act [Emergency), PL 95-2, 91 stat. 4 (Agency: Federal Energy Regulatory Commission [FERC]).

Natural Gas Act (Hinshaw) , 15 USC 717, 68 stat. 36 (Agency: FERC).

Natural Gas Policy Act of 1978, 92 stat. 3350, PL 95-621 (Agency: FERC).

National Historic Preservation Act of 1966, 80 stat. 915 (Agency: Advisory Council on Historic Preservation; USGS); amended: 16 USC 470 et seq. , PL 89-665.

Natural Gas Pipeline Safety Act of 1968, 49 USC 1671 et seq. , PL 90-481 (Agency: DOT, Technical Pipeline Safety Standards Committee); amended: 1976, 49 USC 1671, 1674, 1680, 1683 et seq. , PL 94-477; 1974, 49 USC 1674, 1684, PL 93-403.

Oil Pollution Act of 1961, 33 USC 1001 et seq. , PL 87-167 (Agency: Bureau of Customs; DOT, USCG); amended: 1973, 33 USC 1001 et seq., PL 93-119.

Outer Continental Lands Act of 1953, 67 stat. 462 (Agency: DOI, BLM).

Outer Continental Oil Shelf Lands Act of 1978, 43 USC 1331 et seq. , PL 95-372 (Agency: DOI, BLM).

Ports and Waterways Safety Act of 1972, 33 USC 1221, PL 92-340 (Agency: USCG).

In addition to the above cited acts, international agreements have also been executed as a result of the 1954 international Convention for the Prevention of Pollution of the Sea by Oil, the 1958 Geneva Convention on the Continental Shelf, and others. These agreements and acts illustrate the complexities of actions and/or studies and the requirements for executive level decisions on matters related to the oil and gas development process.

With few exceptions, the process includes: 1) exploration by private or public enterprises; 2) leasing by the BLM Outer Continental Shelf (OCS) Office; 3] exploratory and development drilling by the lease owner; 4) completion of units, and production and distribution of hydrocarbons by lease owner; and 5) distribution of funds as per lease agreement.

During the exploration phase, survey cruises are deployed to the proposed OCS leased areas for gathering seismic and geological data. These data are reduced, processed, analyzed, and synthesized by potential lease owners to determine the potential and economics of oil and gas production. To exploit these resources, potential lease owners must bid for the proposed areas through BLM. Bidding is required before exploratory drilling can commence on the federally owned OCS lands.

Other requirements must also be met, including those of BLM, USGS, EPA, DOT, and NOAA.

Once these requirements are met, exploratory drilling can commence, with an average of four exploratory wells per tract being drilled. This exploratory process will confirm the quantity and quality of hydrocarbons to determine the range and extent of the oil and gas reservoirs and also to determine optimal locations for production platforms. Then the lease owner prepares and submits development plans to the USGS and other agencies to determine compliance with safety and environmental specifications. These plans are approved, production platforms are emplaced, and production drilling commences, with the number of platforms and wells per tract dependent on the reservoirs. Normally, the lease owner will build two platforms and drill up to forty wells per tract (personal communication).

BLM is responsible for obtaining biological, geological, ecological, and other data for preparing an Environmental Impact Statement (E IS) prior to awarding a lease. The specific requirements of the aforementioned acts are considered in determining the type, quality, and quantity of data and information necessary. All required data that are not readily available must be collected, reduced, analyzed, and synthesized into meaningful information. This information is subsequently used to make policy and management decisions on OCS matters.

CHAPTER II

PROGRAM MANAGEMENT

J. LeBlanc

INTRODUCTION

Project and data management. on this contract have been directly supervised bv the Program Manager, who is, in the words of the contract, "responsible for the administrative. logistical, financial, and scientific" work efforts and who holds "sufficient authority to insure the timely, efficient, and competent accomplishment of all work. " The Program Manager has worked directly with the two Technical Directors, one geological and one biological, as well as with all Principal Investigators (PIs) in satisfying the tasks or items specified in the Statement of Work .

The requirements in the Statement of Work were specified in order to obtain information that could be used by BLM and others in making policy and management decisions, in developing Environmental Impact Statements, lease stipulations, etc. , and in supporting other mandated requirements. For example, information in this report was used in February 1980 at a public hearing on the Flower Gardens Marine Sanctuary, in the EIS for lease sales 58A, 62A, and 62 (BLM, 1979a, b), in the draft EIS on the Flower Gardens Marine Sanctuary (NOAA, 1979) , in the BLM Fiscal Year Regional Studies Plan (BLM, 1978) , in the development of EPA and NOAA monitoring efforts, etc. Several PIs have also discussed and shared findings and implications at professional and technical conferences and meetings.

The Contractor was obligated to provide all necessary labor, material, supplies, equipment, facilities, and services to accomplish the specified work items. These work items were as follows:

1. Develop and operate from a program management plan.
2* Plan and conduct a field sampling program in the northern Gulf of Mexico and the Florida Middle Ground.
3. Plan and conduct submersible studies and mapping.
4. Reduce, analyze, and synthesize data for the above tasks.
5. Manage and archive scientific data.
6. Prepare and submit plans, maps, and reports.

The Program Manager was also responsible for planning the work tasks and assessing and reporting to BLM the status in terms of accomplishments, cost, and time. Table I l-l provides a list of the plans and reports prepared, and this final report provides the integrated efforts of all contributors. The Management Plan provided the framework for planning and assessing performance in terms of accomplishments, time, and costs. The Logistics Plan provided a similar framework for planning and assessing the field sampling program, submersible studies, mapping, and logistics. The fiscal and personnel resources, materials, facilities, and services were planned and coordinated so as to maximize results. Each Pre-Cruise Plan stated the objectives, expected results, and resources necessary to accomplish the stated objectives. Within thirty days after each cruise, cruise reports were prepared and submitted to BLM. I n each cruise report, the planned activities were described and all deviations from the Pre- Cruise Plan were documented and reported, with appropriate recommendations. Some recommendations were approved by BLM and incorporated as contract modifications and scope changes. Scope changes were also initiated by BLM. Table II-2 provides a breakdown of all contract modifications; all requirements have been addressed in this report.

PROJECT MANAGEMENT

Introduction

To satisfy the requirements of the contract, the Contractor established the BLM Program Office at TAMU and assigned the necessary resources. The Program Manager was delegated the responsibilities and authority for logistical, financial, administrative, and contractual functions, as well as the responsibility for coordinating the scientific work of the PIs accountable for specific tasks.

The Program Manager and TAMRF developed and executed subcontracts and agreements for services, equipment, and materials. The Program Manager and the Technical Directors, in addition to having PI responsibilities, were tasked with the technical review and acceptance of deliverables from PIs and subcontractors.

Personnel, Contracts, and Logistics

Table 1 I-3 provides a list of PIs as well as their associates and subcontractors. Table 11-4 tabulates contract modifications and the associated period of performance for each P] . An analysis of these two tables tends to identify the management and logistics complexities of the contract, as amended. The original Statement of Work “was altered with ten contract modifications. Briefly, the requirements in these modifications were as follows.

Modification #1

The Contractor and the The University of Alabama (UAB) subcontractor were provided overrun funding to complete the “recovery of data and samples from the Florida Middle Ground. Their scheduled cruise had first been delayed by subcontract negotiations, and when the cruise did get underway, bad weather prevented accomplishment of two-thirds of the planned work.

Modification #2

The Contractor and TAMU were provided overrun funding to complete the recovery of data and samples from the East Flower Garden Bank and other banks. Work had been delayed by bad weather.

Modification #3

BLM extended the scope of the contract to include additional work at the East and West Flower Garden Banks. TAMU was required to conduct a submersible and SCUBA diving cruise, collect seasonal data and samples from the two banks, and map the West Flower Garden Bank. Only East Flower Garden data were to be interpreted and included in the present final report. West Flower Garden" data were to be interpreted and reported on the succeeding contract (i.e. , #A A851-CT0-25) .

Modification #4

BLM extended the scope of work to include collection and analysis of post- IXTOC sediment samples at the East and West Flower Garden Banks.

Modification #5

The Contractor and TAMU were provided overrun funding to complete the tasks added under Modifications 3 and 4. This work had been delayed by hazardous atmospheric and oceanographic conditions.

Modification #6

The Contractor and UAB were provided overrun funding to complete "the recovery of data and samples from the Florida Middle Ground. The cruise was shortened due to Hurricane Bob, and deployed instruments had to be recovered.

Modification #7

BLM extended the scope of work to include several sampling, equipment recovery, and SCUBA diving cruises for the collection of seasonal data and samples from the East and West Flower Garden Banks.

Modification #8

BLM extended the scope of work to include organizing and conducting a technical workshop in New Orleans, LA, and publishing the proceedings of this workshop.

Modification #9

BLM extended the scope of work to compensate requirements not properly covered in the original contract nor in subsequent modifications.

TABLE II-1
REPORTS AND PLANS PREPARED FOR TAMRF & BLM
(Contract #AA551-CT8-35)

REPORT	DATE
MANAGEMENT PLAN	Sep 78
LOGISTICS PLAN	Sep 78
QUARTERLY SUMMARY REPORTS	
(1) Aug 78 - Nov 78	Jan 79
(2) Dec 78 -Feb 79	Mar 79
(3) Mar 79 - Jun 79	Aug 79
(4) Jut 79 -Ott 79	Dec 79
PERFORMANCE REPORT	
Nov 79 - Jun 80	Jun 80
SPECIAL REPORT (COFFEE LUMP)	Jan 79
PRECRUISE PLANS	
1st Mapping	Sep 78
2nd Mapping	Jul 79
1st Submersible	Sep 78
2nd Submersible	Aug 79
1st Diving	Sep 78
2nd Diving	Dec 78
3rd Diving	Mar 79
4th Diving	May 79
5th Diving	Dec 79
1st Monitoring	Sep 78
2nd Monitoring	Jan 79
3rd Monitoring	Apr 79
4th Monitoring	Jul 79
1st Seasonal	Dec 78
2nd Seasonal	Mar 79
3rd Seasonal	May 79
Summer Sampling	May 79

REPORT	DATE
CRUISE REPORTS	
Mapping Cruise	
(1) 12 Aug - 4 Oct 78	2 Nov 78
(2) 29 Jul - 4 Aug 79	5 Sep 79
Submersible Cruises	
(1) 26 Sep - 15 Nov 78	20 Feb 79
.(2) 27 Aug - 26 Ott 79	21 Nov 79
Diving Cruises	
(1) 28Sep - 20 Ott 78	15 Feb 79
(2) 15 Jan - 4 Feb 79	9 Mar 79
(3) 26 Mar - 30 Mar 79	25 Apr 79
(4) 18 Jun - 11 Jul 79	15 Aug 79
(5) 15 Jan - 21 Jan 80	Jan 80
Monitoring Cruises	
(1) 25 Sep - 2 Oct 78	31 Ott 78
(2) 7 Feb - 14 Feb 79	9 Mar 79
(3) 28 May - 4 Jun 79	29 Jun 79
(4) 27 Aug - 31 Aug 79	28 Sep 79
Seasonal Cruises	
(1) 11 - 18 Jan 79	13 Feb 79
(2) 18 - 30 Apr 79	28 May 79
(3) 9 - 19 Jul 79	5 Sep 79
Retrieval Cruise	
(1) 31 May - 3 Jun 79	13 Jun 79
Summer Cruise	
(1) 18 Jun - 28 Jun 79	5 Sep 79
PROCEEDINGS: GULF OF MEXICO INFORMATION TRANSFER MEETiNG (12-13 May 80)	Oct 80

TABLE II-2
BREAKDOWN OF CONTRACT MODIFICATION (03 STS/DESCRIPTION)
(BLM-TAMRF Contract #AA551-CT8-35)

Document	Initiator	Description	Effective Date	Amount	Subtotals
Contract #AA551-CT8-35		Contract let 26 Aug 78	5 Aug 78	$1,919,563	$1,919,563
Mod. 1.	UAB*	(a) Overrun funding (weather) (b) Extend period of performance to Feb 80	17 Mar 79	11,290	1,930,853
Mod. 2.	TAMU	Overrun funding (weather)	28 Jun 79	139,198	2,070,051
Mod. 3.	BLM	(a) Add a 79 summer monitoring cruise to EFG/WFG (b) Extend period of performance to May 80	13 Jul 79	397,558	2,467,609
Mod. 4.	BLM	(a) Add sample collection for HMWH analysis	30 Aug 79	50,330	2,517,939
		(b) Redirect funds from Mod 2		-24,990	2,492,949
Mod. 5,	TAMU	Overrun funding (weather)	28 Sep 79	108,444	2,601,393
Mod. 6.	UAB*	Overrun funding (weather and equipment recovery)	2 Feb 80	38,138	2,639,531
Mod. 7.	BLM TAMU	(a) Add funds to continue monitoring (b) Replace current meters (c) Extend period of performance to Dec 80	1 Dec 79	127,157	2,766,688
Mod. 8.	BLM	Conduct workshop	1 May 80	20,808	2,787,496
Mod. 9.	TAMU	Corrections to original contract and Mod. 3	28 Sep 80	73,958	2,861,454
Mod. 10.	TAMU	Transmission of STOCS data to Smithsonian Institute	1 Dec 80	4,900	2,866,354

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*University of Alabama at Birmingham Subcontract #L800166

Table II-3
PI'S, ASSOCIATES, AND SUBCONTRACTORS

1. Texas A&M University (TAMU), College Station, TX
   a. Joseph U. LeBlanc, P.E., C.D.P., Program Manager
   (Rose Norman, Ph.D., Associate)
   b. Richard Rezak, Ph.D., PI and Co-Technical Director
   c. Thomas J. Bright_, Ph.D., PI and Co-Technical Director
   d. C.S. Giam, Ph.D., PI (Subcontractor)
   (Grace Neff, Ph.D., Associate)
   e. Stefan Gartner, Ph.D., PI
   f. Thomas Hilde, Ph.D., PI
   (George Sharman, Ph.D., Associate)
   g. David W. McGrail, Ph.D., PI
   (Doyle Home, Associate)
   h. Bobby J. Presley, Ph.D., PI
   (Paul Boothe, Ph.D., Associate)

2. University of Texas Marine Science Institute (UTMSI), Port Aransas, 'TX, Subcontract #L800167
   a. Patrick Parker, Ph.D., PI
   (Dan Boatwright, Associate)
   b. Richard Scalan, Ph.D., PI
   c. Kenneth Winters, Ph.D., PI

3. University of Alabama at Birmingham (UAB), Dauphin Island Sea Laboratory (DISL), Mobile, AL, Subcontract #L800166
   a. Thomas Hopkins, Ph.D., PI
   b. W.W. Schroeder, Ph.D., PI

4. University of South Florida (USF), Dept. of Marine Science, Tampa, FL, Subcontract #L800165
   a. Larry Doyle, Ph.D., Pi
   b. John Steinmetz, Ph.D., PI

5. LGL Ecological Research Associates, Bryan, TX, Subcontract #L800137
   a. Benny Gallaway, Ph.D., President
   b, Greg Boland, Diving Scientist
   c. Larry R Martin, Diving Scientist

6. Oceanonics, Inc. (01), Houston, TX, P.O. #P36189
   a. Jack O. Hill, President
   b. Lou Andrus, Marine Operations
   c, Thomas Sellers, Hydrologist

7. Sea Ifleet Operators, Inc. (SOI), Galveston, TX, Subcontract #L800164
   a. John Bissell, President

8. Lorac Service Corp., (LORAC), Houston, TX, P.O. #P36846
   a. Max Huff, President

TABLE II-4
CHANGES IN PERIOD OF PERFORMANCE
(TAMRF-BLM CONTRACT AA551-CT8-35)

PI s/co-Pi s	Contract Modifications Changing Scope										Final Period of Performance, Aug 78 to
	1	2	3	4	5	6	7	8	9	10	
Bright, T.J.			X	X	X			X	X	X	Mar 81
Doyle, L.									X	X	Mar 81
Gartner, S.									X		Aug 80
Giam, C.S.											Feb 80
Hopkins, T.	X					X			X	X	Mar 81
Hilde, T.									X	X	Mar 81
LeBlanc, J.U.	X	X	X	X	X	X	X	X	X	X	Mar 81
McGrail, D.W.		X	X	X	X		X	X	X	X	Mar 81
Parker, P.			X						X		Aug 80
Presley, B.J.			X						X		Aug 80
Rezak, R.		X	X	X	X			X	X	X	Mar 81
Scalan, R			X						X		Aug 80
Schroeder, W.	X								X	X	Mar 81
Steinmetz, J.									X	X	Mar 81
Winters, K.			X						X		Aug 80

Modification #10

The Contractor was provided funding for transmission of STOCS data to the Smithsonian Institute.

Services Provided by Subcontractors
(Table II-3]

Chemistry

The researchers from the University of Texas performed the analysis of sediments for high molecular weight hydrocarbons, Delta C-13, and total organic carbon. The Environmental Service Section of the TAMU Department of Chemistry performed analysis of *Spondylus* and macronekton samples for high molecular weight hydrocarbons. (Trace metals analysis of *Spondylus* and sediments was not subcontracted, but handled through a PI in the Chemical Oceanography Section of the TAMU Department of Oceanography.)

Biology

LGL, Inc. , Bryan, TX, conducted all four biological monitoring cruises to the East and West Flower Garden Banks and assisted in the experimental design of the monitoring studies.

Mapping

Oceanonics, Inc., Houston, TX, collected bathymetric, seismic, and other geophysical data, and delivered the bathymetric maps of the Northern Middle Ground and the nine northern Gulf of Mexico banks. PIs at TAMU prepared the seafloor roughness, structure, and other pertinent geological maps.

Florida Middle Ground

Biological and geological studies at the Florida Middle Ground were handled through two subcontractors. Scientists at the University of Alabama at Birmingham, Dauphin Island Sea Laboratory, were tasked with biological reconnaissance and sampling, and conducted all cruises to the Florida Middle Ground. Analysis of geological samples was handled by scientists in the Marine Science Department, University of South Florida. These two subcontractors collaborated in the synthesis of findings. TAMU supported the characterization efforts by mobilizing the M/V RED SEAL and the DRV D IAPHUS for deep submersible operations. TAMU also prepared the geological maps. UAB took responsibility for reporting the integrated work efforts at the Florida Middle Ground.

Cruises

To support the acquisition of geological and biological data, fourteen vessels were leased in connection with eighteen cruises (see

Table II-5). For TAMU cruises, the mobilization of each vessel was accomplished at the docks at TAMU Marine Operations, TAMU/Galveston, Pelican Island, TX. Local welders, plumbers, and electricians, together with TAMU technicians, provided the necessary services. Other facilities in Galveston were used when necessary to satisfy mobilization and logistical requirements. Florida Middle Ground cruises were mobilized by the University of Alabama subcontractor.

Special Equipment

In the course of the contract, special equipment was obtained from a variety of vendors. Nine current meters, Model 550, were obtained from Hydro Products, Inc., San Diego, CA. Six LED transmissometers were obtained from Sea Tech, Corvallis, OR, to be integrated with the current meters (see Volume Two, Chapter VIII.

Time, Funds, Space

The period of performance for all work tasks was originally negotiated at eighteen months, ending in February 1980. Force majeure, changes in the scope of work, and other proposed changes extended the period of performance for some of the work tasks to March 1981 (Table 11-4, above). These changes increased the funding by approximately 49%.

The BLM Program Office was established in the Oceanography and Meteorology building at TAMU. Space was allocated for professional, technical, administrative, and support personnel. Data, records, and samples were stored and processed in the various laboratories on the TAMU campus. The analytical processes leading to the integration and synthesis of data into meaningful information were also performed in these laboratories. The facilities include the following:

Atomic Absorption Laboratory
Cartographic Services Unit
Center for Geodynamics
Center for Sedimentology
Center for Trace Characterization
Data Processing Center with Amdahl 470 V-6 System
DRV DIAPH US
Electron Microscopy Laboratory
Electronic Technician Shop
Gas Chromatography-Mass Spectronomy Laboratory
Geophysical Laboratory
Hydrocarbon Chemical Analytical Laboratories
Hydrology Laboratory
M/V GYRE
Machine Shop
Marine Operations Center
Nuclear Science Center
Photographic Laboratory
Rudder Meeting Center
Sedimentology Laboratory
X-Ray Diffraction Laboratory

DATA MANAGEMENT

Introduction

The management and processing of information and data are critical to overall performance in a contract. The data on this contract have

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SUMMARY OF CRUISES

CRUISE	DATES AT SEA		SHIP	SITE	CHIEF SCIENTIST	REPORT DATE
1st Mapping	Leg 1	12 Aug-29 Aug 78	JOYRO	FMG	Rezak	
	Leg 2	30 Aug-16 Sep 78	JOYRO	FMG	Hilde	2 Nov 78
	Leg 3	17 Sep- 4 Ott 78	JOYRO	NW Gulf	Rezak	
2nd Mapping		29 Jul- 4 Aug 79	PROTON	WFG	Rezak	5 Sep 79
1st Submersible	Leg 1	26 Sep-20 Ott 78	GYRE	COF/EFG	Bright	
	Leg 2	4 Ott- 8 Ott 78	GYRE	EFG	McGrail	20 Feb 79
	Leg 3	9 Ott-25 Ott 78	GYRE	11 banks	Rezak, Bright	
	Leg 4	4 Nov-13 Nov78	RED SEAL	FMG	Hopkins	
2nd Submersible &Boundary Layer	Leg 1	5 Sep-18 Sep 79	BLACK SEAL	EFG/WFG	Rezak, McGrail	
	Leg 2	21 Sep-28 Sep 79	BLACK SEAL	EFG/WFG	Bright	21 Nov 79
	Leg 3	12 Oct-21 Ott 79	ROSS SEAL	EFG/WFG	Rezak, Home	
1st Monitoring		25 Sep- 2 Ott 78	TONYA & JOE	EFG	Martin (LGL)	31 Ott 78
2nd Monitoring		7 Feb-14 Feb 79	TONYA & JOE	EFG	Martin (LGL)	9Mar 79
3rd Monitoring		28 May- 4 Jun 79	TONYA & JOE	EFG	Martin (LGL)	29 Jun 79
4th Monitoring		27 Aug-31 Aug 79	TONYA & JOE	EFG	Martin (LGL)	28 Sep 79
1st Diving		28 Sep-20 Ott 78	BELLOWS	FMG	Hopkins	15 Feb 79
2nd Diving		15 Jan- 4 Feb79	BELLOWS	FMG	Hopkins	9 Mar 79
3rd Diving		26 Mar-30 Mar 79	ROUNSEFELL	FMG	Hopkins	25 Apr 79
4th Diving		19 Jun-11Jul 79	BELLOWS	FMG	Hopkins	15 Aug 79
5th Diving		15 Jan-21 Jan 80	ROUNSEFELL	FMG	Lutz 3	Jan 80
1st Seasonal		11 Jan-18 Jan 79	BERING SEAL	EFG	Home	13 Feb 79
2nd Seasonal		18 Apr-30 Apr 79	MEDITERRANEAN SEAL	EFG	McGrail	28 May 79
3rd Seasonal		6 Jul-19 Jul 79	BERING SEAL	EFG	Home	
Summer Sampling		18 Jun-28 Jun 79	BERING SEAL	6 banks	Rezak	5 Sep 79
Current Meter Retrieval		31 May- 3 Jun 79	PETE & SUE	EFG	Barrow	13 Jun 79
Recovery/Deployment/ Monitoring	Leg 1	7 Dec 79	GYRE	EFG/WFG	Barrow	
	Leg 2	16 Dec 79	INVADER	EFG/WFG	McGrail	
	Leg 3	15 Feb-23 Feb 80	BERING SEAHORSE	EFG/WFG	Viada	May 80
	Leg4	17 Apr-18Apr80	COLD HARBOR	aborted	Home	
	Leg 5	22 Apr-25 Apr 80	GYRE	EFG/WFG	Home	

been voluminous and technical (e.g. , integrated current meter and transmissometer time series data), complicated (e. g., biological data), and crucial (e. g., bathymetric data) . The functions associated with the management of data have included: total system planning, data and sample collection, data reduction, data and sample analysis, data integration and synthesis, data evaluation and reporting, and data base generation and archiving. Once the data and samples were processed by the PIs, scientific techniques were applied, and, in a cognitive manner, data were integrated and synthesized into meaningful information for this report.

Data Manager

The functions and responsibilities of the data manager were manyfold, including the following:

1. Assisting Pls with data and information requirements.
2. Defining requirements associated with collection, reduction, analysis, reporting, quality and inventory control, man-machine interfaces, data integration and synthesis, and data base structures for processing and archiving data.
3. Managing the digitizing of data and preparing acceptable tabular and graphical representations of analytical data.
4. Integrating data bases and preparing support computer programs and other software.
5. Assisting the Program Manager and PIs in selecting hardware, software, and firmware. *
6. Verifying the data bases and archiving them in the NOAA Environmental Data Information System (e.g. , NODC and NGSTDC formats).

These functions illustrate the need for total information system planning so that components can be monitored and evaluated. The system components started with the field sampling efforts and culminated with reports and correct data bases.

Data/Sample Collection

To satisfy the field sampling program, vessels were mobilized and deployed to collect samples and data. There were five types of data collection cruises: mapping, submersible, monitoring, seasonal sampling, and diving.

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*"Firmware" refers to hardware computer programs.

Field Mapping Tasks

The field mapping effort consisted of collecting seismic, geophysical, and bathymetric data to prepare maps of nine banks and the Northern Middle Ground area. Lorac Service Corp. provided precision navigation, and Oceanonics, Inc. provided the vessel and survey equipment under fixed price subcontracts. While performing the work tasks, several problems were encountered and were reported in cruise reports.

Submersible Tasks

The submersible tasks consisted of collecting data and samples in deep waters. The TAMU submersible DRV DIAPHUS was used to collect photographic and audio-video data and geological and biological samples (i.e., Spondylus, rocks, sediments, etc.) . Water column data were also collected to help characterize the banks.

Scientists from TAMU collected geological and biological data and samples from eight northern Gulf of Mexico banks, and scientists from UAB and USF collected data and samples from the Florida Middle Ground.

Monitoring Tasks

The monitoring tasks consisted of seasonal SCUBA cruises to the Florida Middle Ground and the East and West Flower Garden Banks to collect biological samples and photographic data and to service station instruments and arrays. These tasks are described fully with the data and/or sample inventories in later chapters.

Seasonal Sampling

Sampling for geological, biological, chemical, and h ydrographic oceanographic data was accomplished on cruises to the East Flower Garden Bank, during three seasons: fall, winter, and spring/summer. To conduct required water column and bottom sediment sampling at Coffee Lump, Fishnet, Diaphus, Jakkula, and Alderdice Banks, a summer sampling cruise was combined with the third seasonal cruise.

Diving at the Florida Middle Ground

Intensive sampling and observational activities were conducted on four SCUBA diving cruises to the Florida Middle Ground. Diving activities involved collection of biological samples and photographic data, as well as installation and servicing of instruments.

Sample Analysis

Samples were transferred to appropriate laboratories for analysis. The Spondylus were delivered to the TAMU Trace Metal Analytical Laboratory for analysis by Drs. Bobby Presley and Paul Boothe and to the TAMU HMWH Analytical Laboratories for analysis by Drs. C.S. Giam and Grace Neff. Sediments were delivered to the TAMU laboratory for textural and mineralogy analysis by Dr. Richard Rezak and to the University of Texas Marine Science Institute for HMWH, Delta-C-13, and total organic carbon analysis by Drs. Partick Parker., Kenneth Winters, R. Scalan, and Dan Boatright. Water samples were analyzed at TAM U by Dr. James Brooks.

The analytical data were documented and delivered to the Program Office for inclusion in this report.

Data Analysis

PIs were individually responsible for the analysis of data in their field of specialization. Techniques were applied and computerized where applicable so as to process the volume-of data and arrive at meaningful graphic or tabular data. Some of the computerized techniques include:

- Cartographic Projection/Grid Programs
- Current Meter Data Analysis
- Gausian-Cascading Butter worth Filter Analysis
- Grain Size Analysis
- Graphics and Plotting Programs
- Report Generator Program
- Rotary Spectral Analysis
- Spectral Analysis
- Standard Fourier Fast Tranform
- Standard Statistical Analysis
- Time Series Analysis
- Variance Tensor Analysis

The TAMU Data Processing Center and other computer facilities were used in the reduction, analysis, and reporting processes. These procedures are described in the appropriate chapters of this report.

Data Synthesis and Integration

PIs analyzed the data in their respective areas, synthesized, and integrated the results, and then prepared Pi Reports. This information was collected and interpreted by the Technical Directors to characterize the areas and banks.

The Florida Middle Ground characterization was directed by UAB, and the characterization of banks in the northern Gulf of Mexico was performed by TAMU.

Data Archiving

Once digitized and anaiyzed, the data were placed on magnetic tapes and/or microfilmed and mailed to the NOAA ED IS in an appropriate format. Analog records were microfilmed to enhance the life of the data.

Data and information Reporting

Table ii-1 (above) provides a complete list of documents prepared in this contract. Management plans provided the framework for reporting. Progress reports provided data and information for the COAR and Contract inspector to monitor the work efforts and provide feedback to the Program Manager and Pls. The progress reviews were held on schedule with positive information exchanges. Cruise reports provided up-to-the-minute status of the data/sample collection efforts with recommendations as appropriate.

DISCUSSION

Introduction

Management of this multi-million dollar contract required surmounting factors and variables affecting the Period of Performance and the associated costs and PI performance. The chief force majeure was weather and its impact on the data collection efforts. Another force majeure was the IX TO C-1 oil and gas spill and its potential effect on the Flower Garden Banks. Part of the FY 1980 monitoring efforts also had to be included as an amendment to satisfy urgent 1980 requirements, underestimated costs, and delays both in releasing the Request for Proposals (RFP) and in evaluating proposals.

Contracts Administration

Service agreements and subcontracts were executed during the contract period, but several tasks had to be initiated prior to obtaining fully executed subcontracts or service agreements. Such delays could be prevented with more advance planning and sufficient lead time to plan and execute these documents and actions.

Federal agencies often have time, fiscal, and other constraints imposed on them which delay the timely award of contracts. It would be highly desirable to have RFPs and realistic estimates on-the-street prior to the start of a fiscal year so as to evaluate proposals, negotiate agreements, and award contracts within a reasonable time after the start of the fiscal year. Each management plan, master schedule, sampling plan, and logistics plan must be prepared, coordinated, and accepted in a minimum amount of time after a contract is awarded. The time is dependent on the size of the contract, and the initial 60 days of a contract are crucial to the efficient scheduling needed to ensure a smooth-running project. For example, some of the reported problems with the mapping tasks were traced to inadequate lead time for performing the tasks and for evaluating and certifying results. Some of the reported problems with the submersible tasks are attributable to inadequate lead time before the cruise. Complaints were also expressed regarding the slow turnaround in obtaining approvals or subcontracts. These problems could be reduced with adequate planning time and sufficient lead time to order, test, and install equipment, to mobilize and deploy data collection efforts, to analyze samples, and to reduce, analyze, integrate, and synthesize data. Results would also be greatly enhanced.

Quality Control and Assurance

All samples and data were labeled, inventoried, and processed as per contractual requirements. Several check points were planned to evaluate performance of PIs and subcontractors and the quality of the intermediate products.

The bathymetric products were prepared by Oceanonics, Inc., and control points were verified by TAMU geophysicists and cartographers. Several errors were discovered and corrected.

Intermediate results from PIs were discussed at progress meetings and reported in the Quarterly Summary Reports. Corrective actions were taken and reported in PI status reports whenever problems were identified.

Analytical results prepared and reported by PIs were reviewed and critiqued by the Technical Directors. Corrections were made to the reports before submittal to BLM.

In the laboratories and in the field, equipment was calibrated according to the specifications. Tasks were performed, checks made, and appropriate corrections incorporated. As a result, the margin for error of the data was minimized and the quality of the information was greatly enhanced. Planning and accomplishing quality control did, however, require additional time and effort.

Planning, Scheduling, and Coordinating

The planning and controlling functions are critical to all projects, especially one with limited resources and with seven subcontractors and fourteen PIs located from Texas to Florida. Requirements were defined and delegated, tasks were planned with successor-predecessor relationships, expected time to complete the tasks was estimated, and a schedule was prepared. Products were subsequently prepared throughout the contract and delivered on time.

The incremental scheduling of tasks along the critical path proved to be very successful except for unanticipated problems encountered with several PI reports. Some PIs performed below expectation, their work efforts were not properly coordinated, and the shortcomings impacted the time and efforts of other PIs, the Technical Directors, and the Program Manager. Other impacts to the period of performance were caused by changes in the scope and by force majeure.

Amendments to the scope of the contract and force majeure resulted in ten modifications to the contract. Not all PIs were affected by these modifications (Table 11-4, above). The major force majeure was weather, especially during the winter and fall of 1979, when several tropical storms and hurricanes (i.e. , Bob, Claudette, David, Elena, Frederic, Henri) caused delays in the data collection efforts. Other force majeure included the failure of components in some of the deployed instruments, the loss of deployed instruments and data; the loss of navigation and bathymetric data from the submersible cruise, etc. These created needs for additional time, efforts, and costs, especially to handle the logistics.

Logistics Administration

The Logistics Plan established the framework for the field logistics. Several vendors were contacted for chartered vessels and navigational services, etc. , and the most cost-effective alternatives were selected. Effective negotiating was also used so as to obtain the least cost for the "best" equipment and services. Pis were successful in all deliberations.

RECOMMENDATIONS

To maximize the future work efforts, minimize costs and time, and obtain qualitative and quantitative results, several recommendations are in order. These include:

1. Assign a Program Manager with technical and managerial abilities and with sufficient authority over the resources for accomplishing timely tasks.
2. Authorize the Program Manager to commit negotiated funds and resources for accomplishing all contractual tasks without additional approval of the Contracting Officer.
3. Minimize or eliminate duplicate efforts of federal agencies, and allocate appropriated funds to maximize results.
4. Provide realistic estimates of time and costs for scope changes.
5. Use acceptable industrial engineering planning and controlling techniques in lieu of PERT.
6. Allow a 60-day project establishment and planning period after letting a contract.
7. Provide archived data in a timely manner so as not to delay the efforts of Pis.
8. Place more emphasis on data management by allocating necessary resources for programming, analysis, archiving, etc.
9. Allow a 90-day period for analyzing data after the data have been processed and reduced to a form usable by Pis.
10. 'Specify for completing all data analysis "a period of at least '60 days before the draft final report is due. "

11. Provide timely critiques and courses of action of all plans and reports.

12. Schedule the draft Executive Summary "30 days after the draft Final Report."

13. Prepare and schedule intermediate segments of the draft reports so as to level resource requirements.

14. Conduct bathymetric mapping tasks at least six months before the products are required.

15. Submit draft report for peer review when draft is submitted to BLM; allow sufficient review time, and provide stipends for reviewers.

CHAPTER III

GEOLOGY

R. Rezak

INTRODUCTION

This chapter summarizes the geological observations and data that have been acquired on TAMU/BLM contracts since 1975. During this period, 38 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 (Figure III-1 and Table Ill-t) . Twenty-one of these banks have been sampled for sediment analyses. Only two of the banks (East and West Flower Garden) 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 38 of the mapped banks. Sub-bottom seismic profiles have also been made for 23 of the mapped banks. These data have been interpreted for only the eight banks mapped under this contract.

SALT DIAPIRISM

General

Salt diapirism has been a recognized feature of the northwestern Gulf of Mexico 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. [n general, these diapirs have much in common. However, there is great variability in the details of the physiographic and structural expression of the diapirs, apparently due to their varying geologic histories.

TABLE III-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	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	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 III-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	x
West Flower Garden (WFG)	1978	Jul 79	X*	x	X**	X
18 Fathom (18F)	1977	May 77		x	x	x
28 Fathom (28F)	1975 & 76	Oct 74	x		X	
28 Fathom, SW Peak	1976	Jul 76		x	x	x
29 Fathom (29F)	1975	Oct 74			X	x
32 Fathom (32F)	1975	May 75	x		x	x

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* = Sediment distribution map constructed
** = Interpreted

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. By Middle-Late Jurassic time, salt deposition had ended and deposition of shallow water, normal marine sediments began. Continued deposition of marine sediments during the Cretaceus and Tertiary 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 weage of post-C setaceous 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 arid 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 discussion is 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 is the most common feature associated with salt tectonics, as can be readily seen on the seismic profiles in Chapters Xl through XVIII . 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. The central graben has been attributed by some authors to the tensional stresses. However, the central graben is a collapse feature that is formed by annular faults that intersect the radial faults and 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, 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 does not fit the observed fault patterns associated with central grabens at the crests of domes. 1 nstead, 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.

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 (see Volume Four, Figures XI II-5 and 6).

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 that are 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. Documentation of one such fault is seen on the east side of Rezak-Sidner Bank (Volume Four, Figures XV II-3 and 4).

ORIGIN OF CAP ROCK

Salt in the diapirs is a mixture of halide minerals having varying volubility. 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 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 NaCl in caprock 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 NaCl. 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 calcium carbonate (calcite] , H_2S, native sulfur, pyrite (FeS_2) , gypsum ($CaSO_4 \cdot 2H_2O$), CO_2 # and methane. 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 $CaSO_4$ 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 (EFG) 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 brine lake is presented in Volume Three, Chapter X, and a graphic representation of the lake is shown on Volume Three, Figure X-C-IS. Examination of the bathymetric chart of the East Flower Garden (Figure III-2) shows clearly that there is no central collapse feature. The West Flower Garden (WFG) has developed a central graben (Figure 1 I 1-4) , and the bathymetry and sub-bottom profiles on 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, 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 $^{0}/00$ 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 it 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 (Volume Four, Chapter XVIII). 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. During a recent conversation with a petroleum company structural engineer, i was told that a platform in the vicinity of the East Flower Garden had experienced an earthquake. The epicenter of the quake is not known, but it is possible that it could have been at the site of a nearby salt dome.

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 (Volume Four, Figure XV III-5c). That figure clearly shows 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 from 1907 through 1956 averaged 8.9 mm/year (Hudson and Robbin, 1980) . 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 reducton 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

Examination of the bathymetric maps and computer-produced perspective diagrams of the banks (Figures III-I through 25) illustrates very clearly the variety of physiographic expression of the banks. The physiography of the banks is controlled primarily by the sub-bottom structure. Unfortunate y, on many banks the core of the dome is seismically transparent. Any one or more of several factors may cause the lack of sub-bottom reflectors in these bank cores: 1) carbonate reefal growths might be thick enough to attenuate the return signal from any reflectors; 2) salt and/or cap rock may be very close to the surface and no sub-bottom reflectors may be present; and 3) sedimentary units in the core may be nearly vertical.

In order to determine the nature of the core, both sub-bottom profiles and side-scan sonar records must be examined critically. In addition, submersible observations may give some clues to the nature of the core. "Both Fishnet and Alderdice Banks have seismically transparent cores. The side-scan sonar records on both banks show outcrop patterns of nearly vertical beds. The side-scan sonar records from Geyer Bank show very little in the way of nearly vertical outcrops. However, submersible observations on the northern part of the bank show extensive areas of vertically dipping sedimentary strata. On the East Flower Garden Bank, no evidence of bedded outcrops in the core of the bank is displayed on the sub-bottom profiles or on the side-scan sonar records. However, submersible observations have revealed brine seeps that indicate that salt in the core must be shallower than 71 m below sea level. Consequently, the seismic transparency of the bank core is probably due to a combination of coral reef growth and proximity of the salt to the surface.

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 (1'379; see his 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 (Figures II I-6 and 7, and Volume Four, Figure Xl-4) . 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 Berry hill, personal communication).

A mature dome is one that has been uplifted, 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 (Figures III-20 and 21, and Volume Four, Figure XIII-S), Jakkula (Figures III-18 and 19, and Volume Four, Figure XIV-4) , Fishnet (Figures III-14 and 15, and Volume Four, Figure XII-4) , and Elvers

(Figures III-10 and 11, and Volume Four, Figures XV-4, 5, and 6). Previously surveyed banks (1977 contract) belonging to this category are: Claypile, Sonnier, Parker, Bright, 18 Fathom; Bouma, and Ewing (see Table III-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 [Figures II I-2 and 3) , Geyer (Figures II I-8 and 9, and Volume Four, Figures XV I-4 and 5) , and Alderdice (Figures III-16 and 17, and Volume Four, Figure XVIII-6) (see Table III-2). Alderdice is the only bank where direct evidence of rejuvenation is displayed on the subbottom 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 I-2
CLASSIFICATION OF SALT DOMES

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

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 places major emphasis on the presence of even minute quantities of gravel because he feels that the proportion of gravel is a function of the highest current velocity at the time of deposition. Consequently, even a trace of gravel (0.01%) is enough to term the sediment "slightly gravelly." This emphasis on the importance of gravel creates a problem when dealing with sediments that are mixtures of land-derived sediment and locally produced skeletal matter. 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 (Volume Three, Chapter X of this report) 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 non-deposition 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.

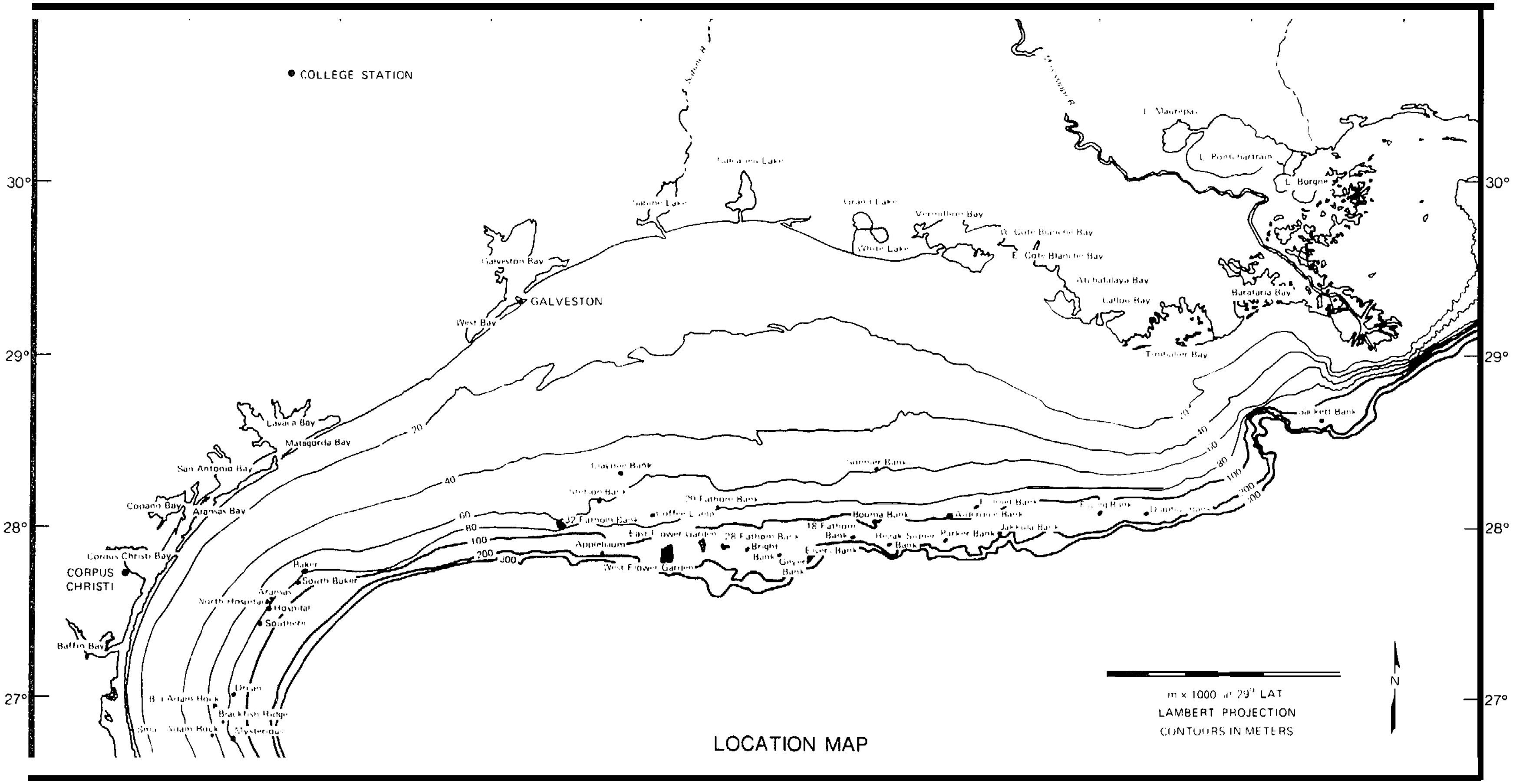


Figure 1-. Location map of topographic features mapped since 1974.

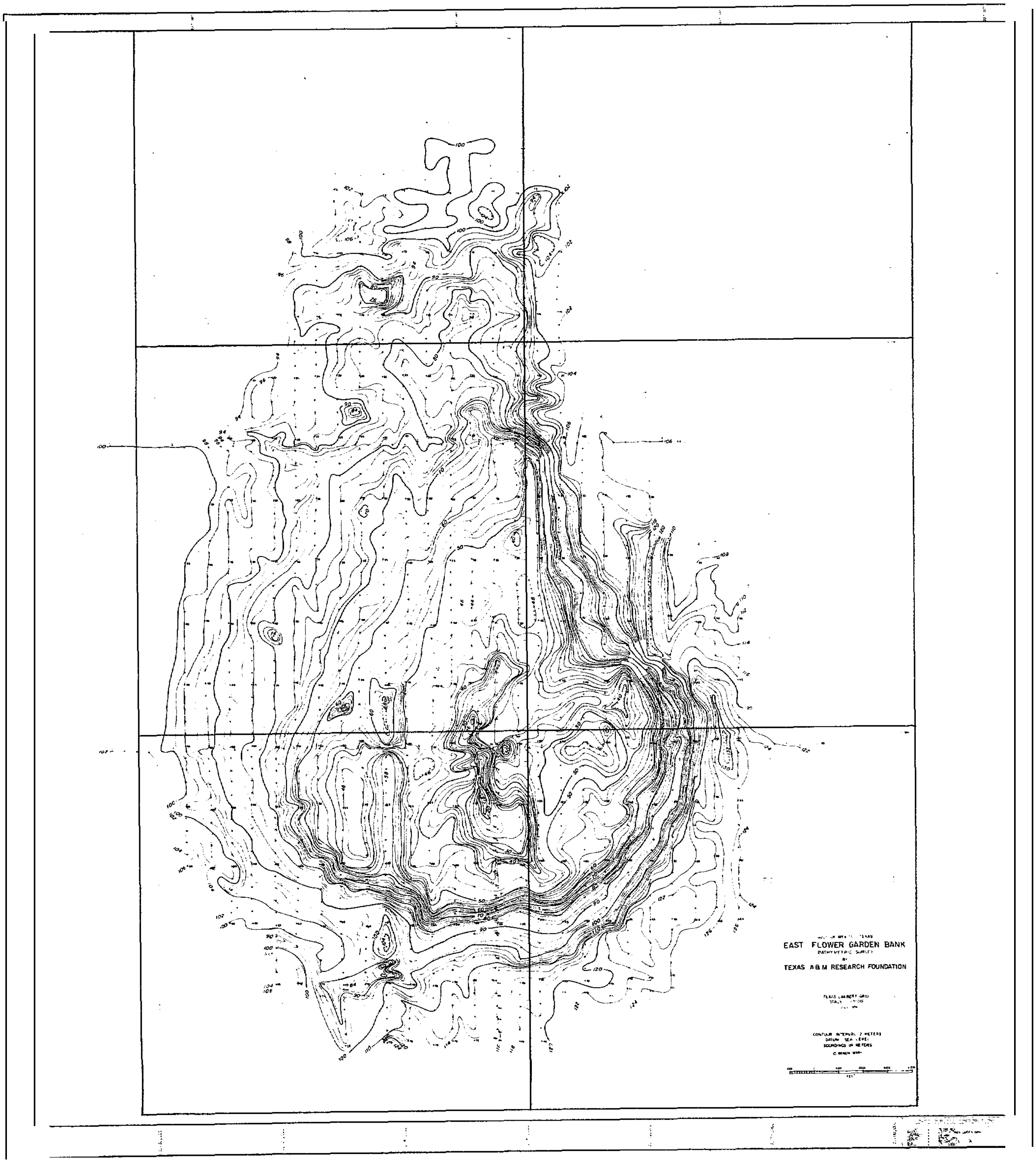


Figure III-2. East Flower Garden Bank **bathymetry.**

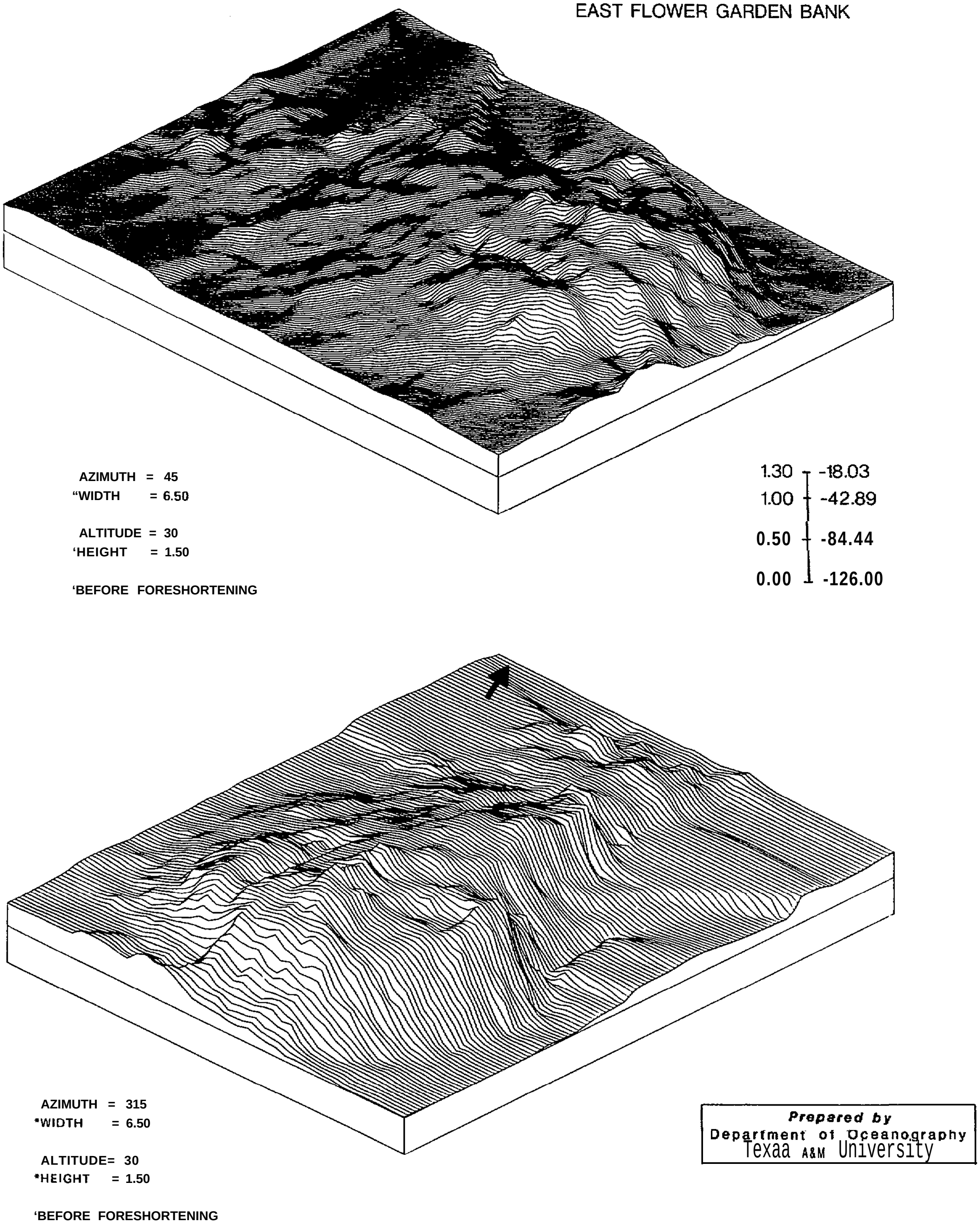


Figure III-3. Three-dimensional perspective views, East Flower Garden Bank. (Arrow points toward north.)

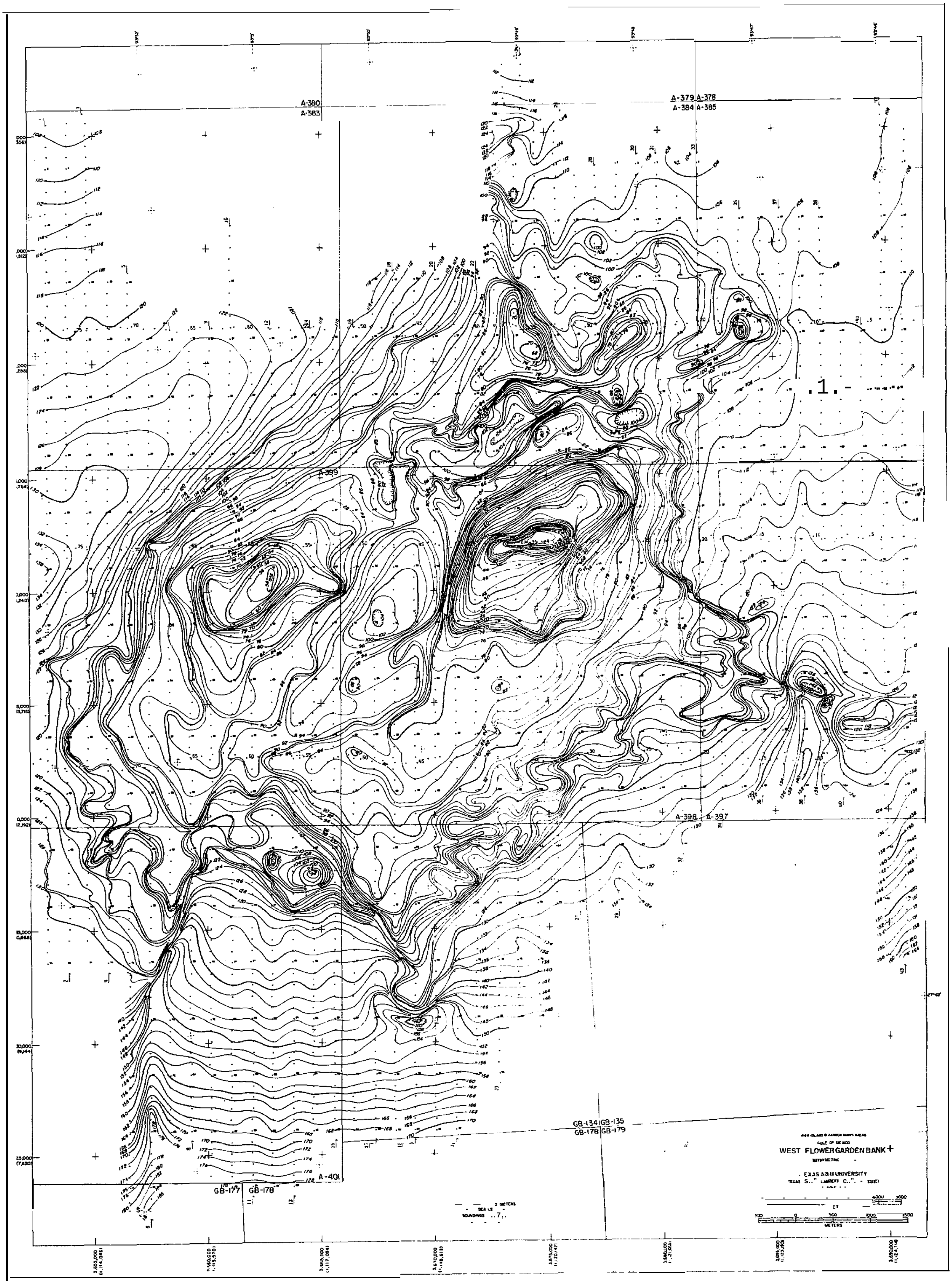
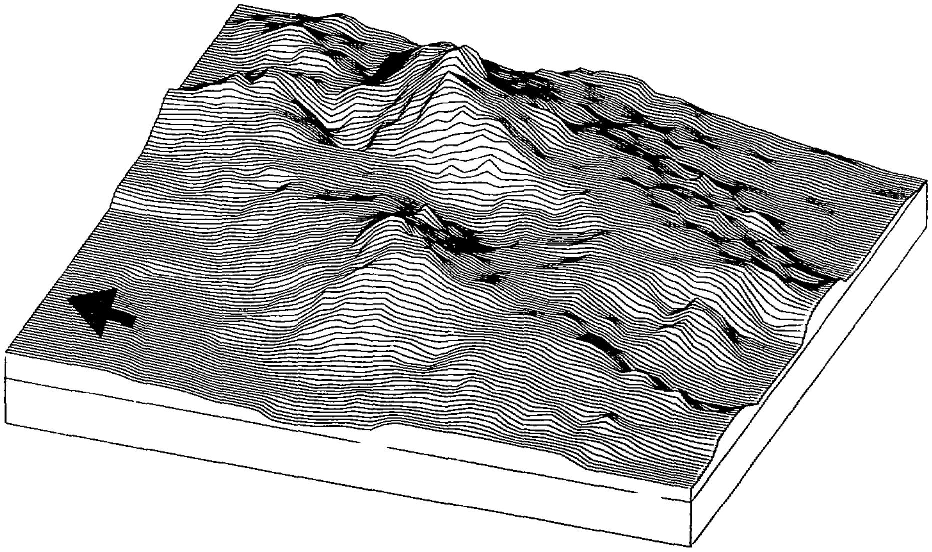
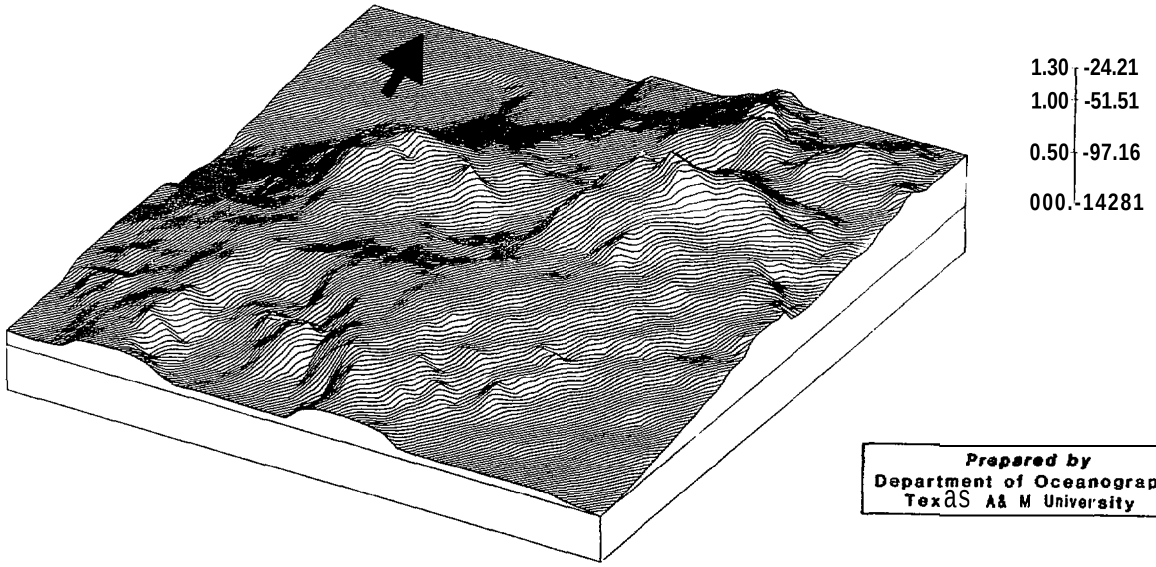


Figure III-4. West Flower Garden Bank bathymetry.

WEST FLOWER GARDEN BANK



AZIMUTH = 70 ALTITUDE = 30
*WIDTH = 6.50 ‘HEIGHT = 1.50
‘BEFORE FORESHORTENING



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AZIMUTH = 330 ALTITUDE =30
‘WIDTH = 6.50 ‘HEIGHT = 1.50
“BEFORE FORESHORTENING

Figure III-5. Three-dimensional perspective views, West Flower Garden Bank. (Arrow points toward north.)

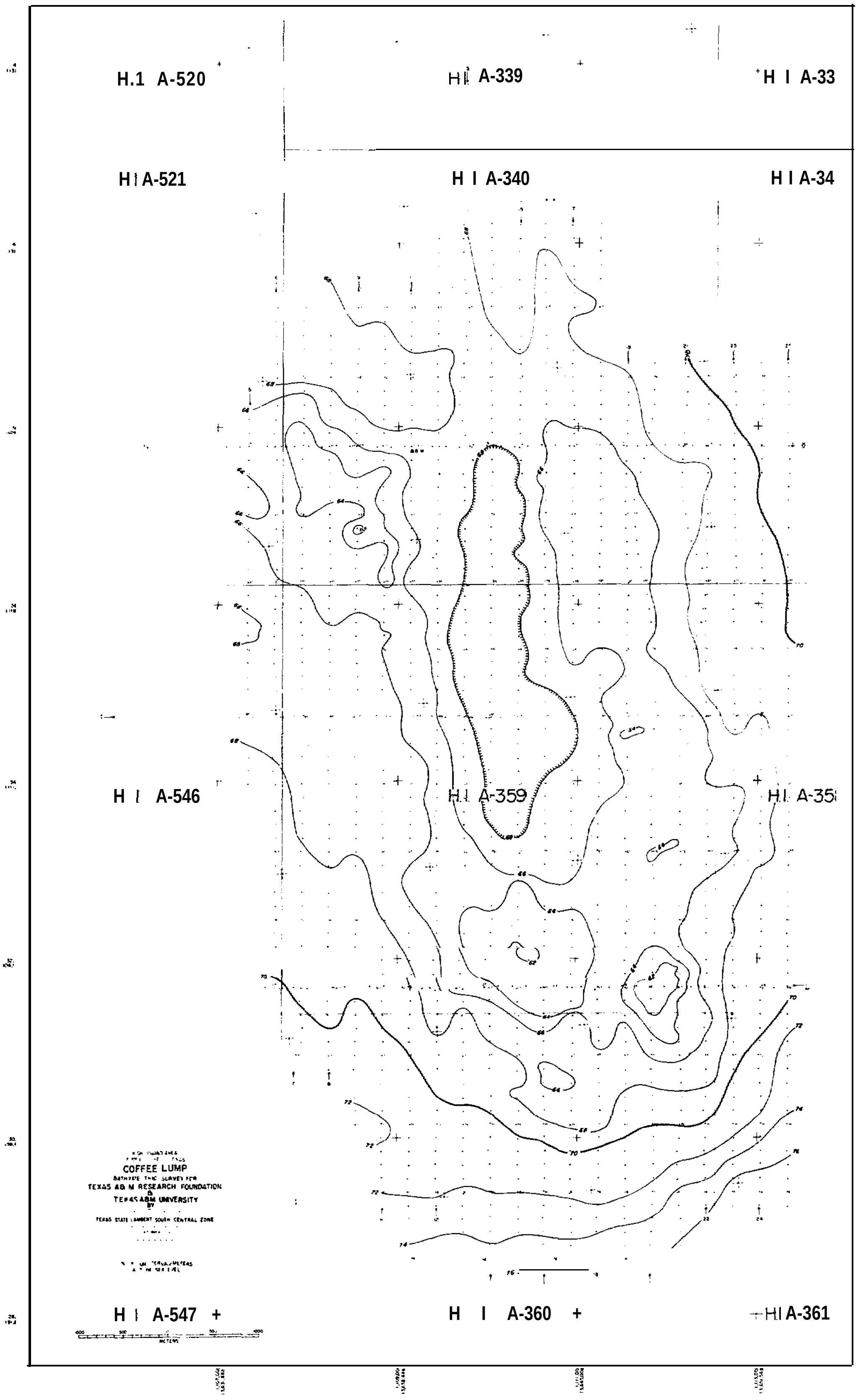


Figure III-6. Coffee Lump bathymetry.

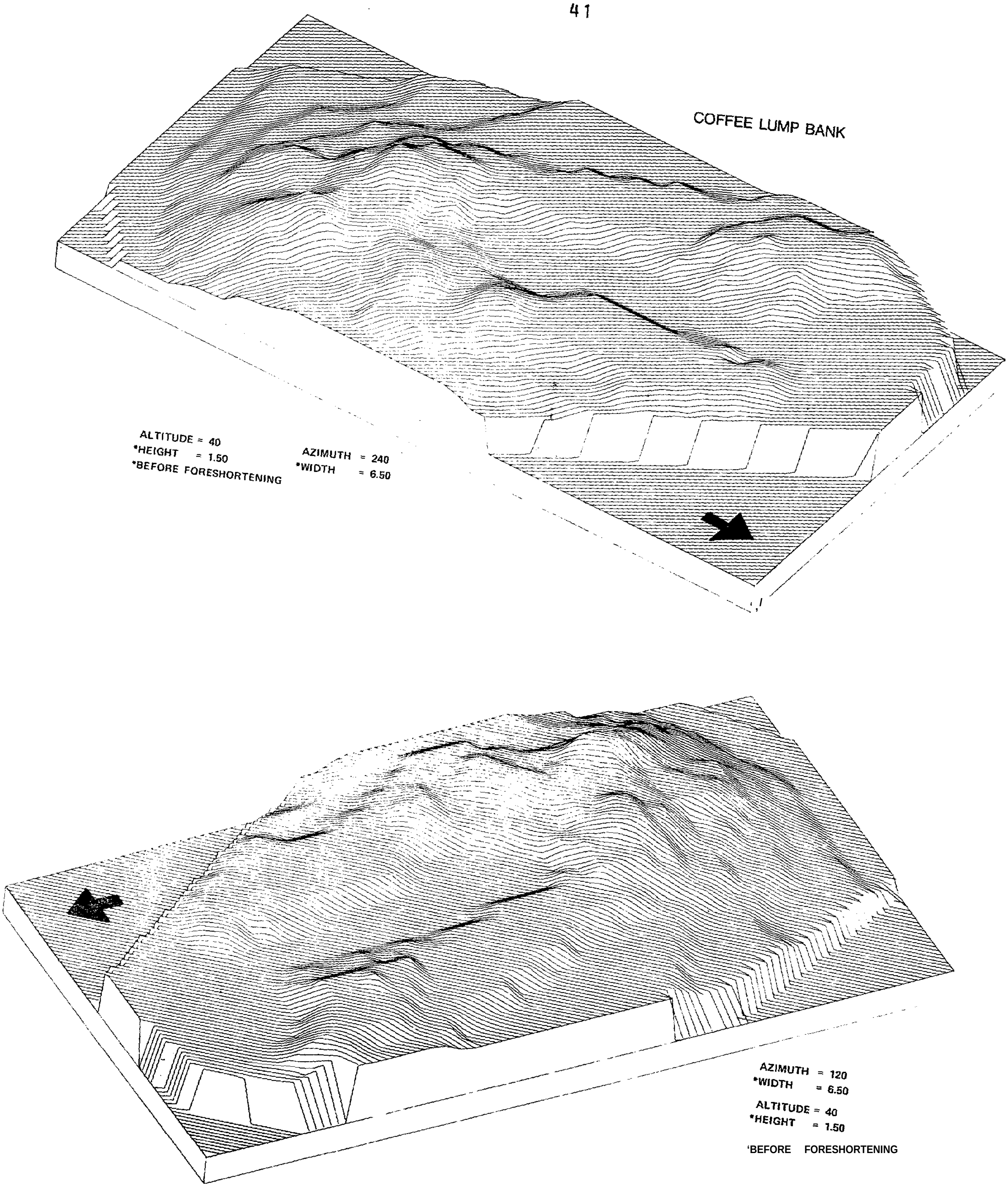


Figure III-7. Three-dimensional
(Arrow points toward north.) Perspective views,
coffee Lump.

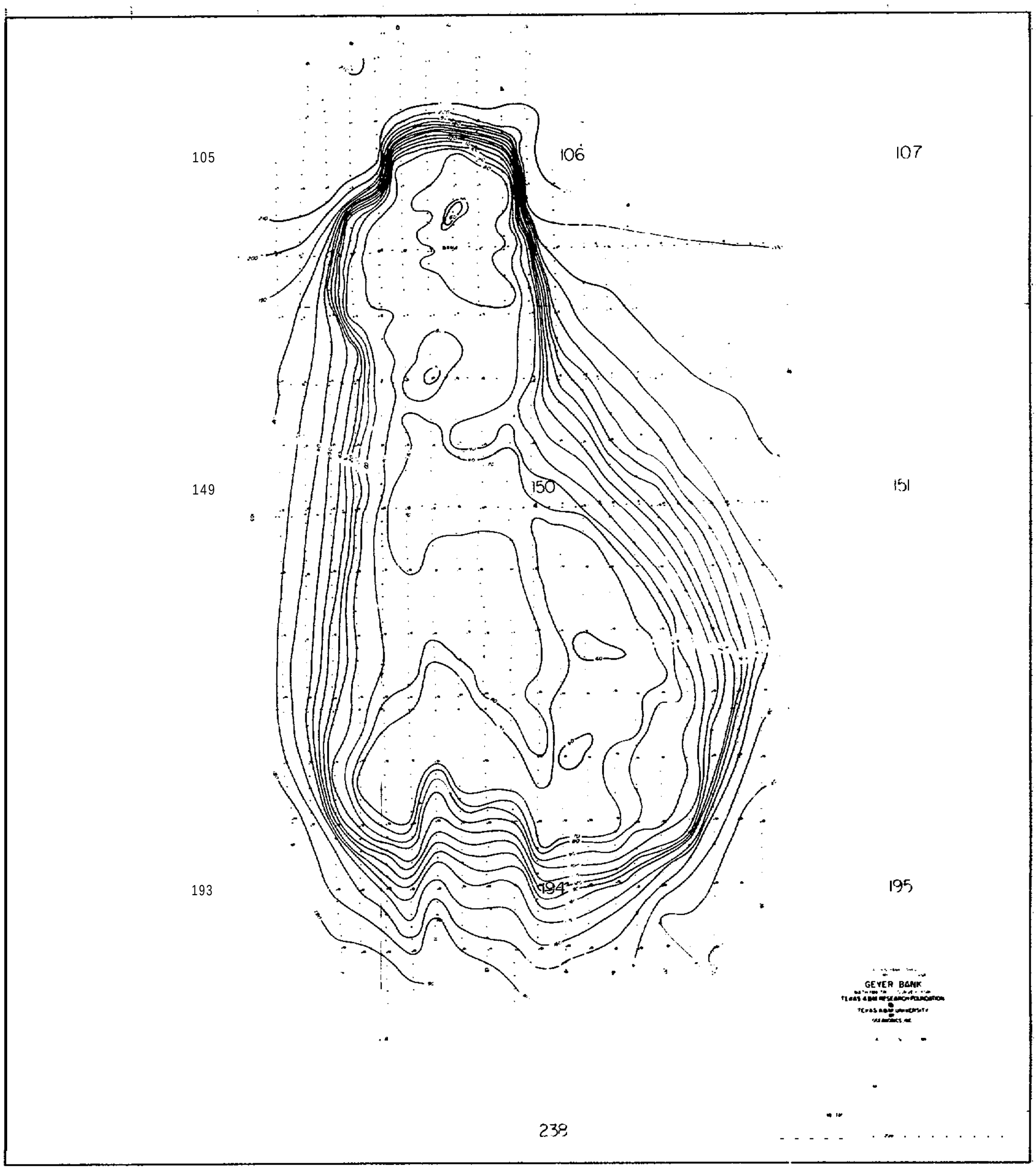


Figure III-8. Geyer **Bank bathymetry.**

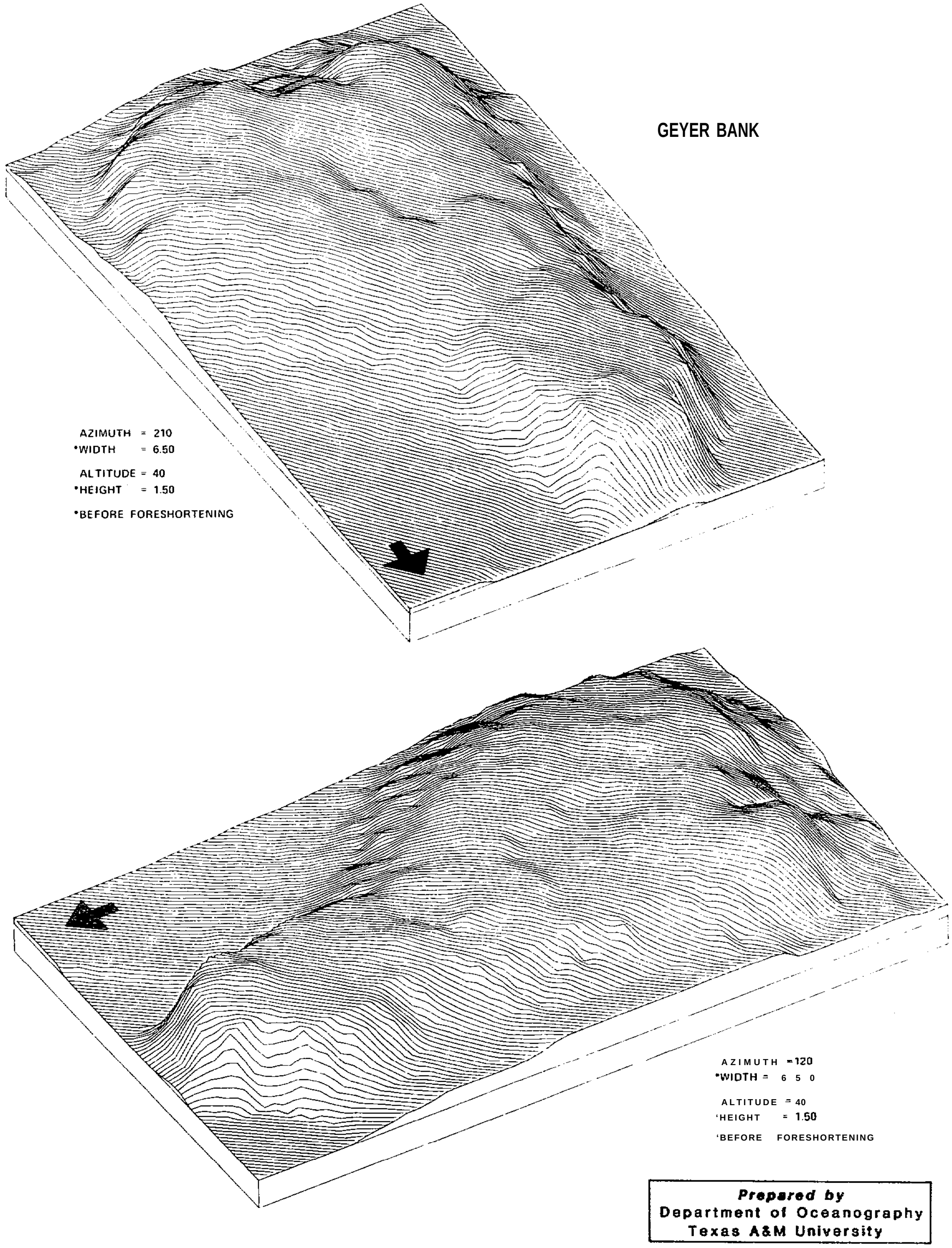


Figure III-9. Three-dimensional perspective views, Geyer Bank. (Arrow points toward north.)

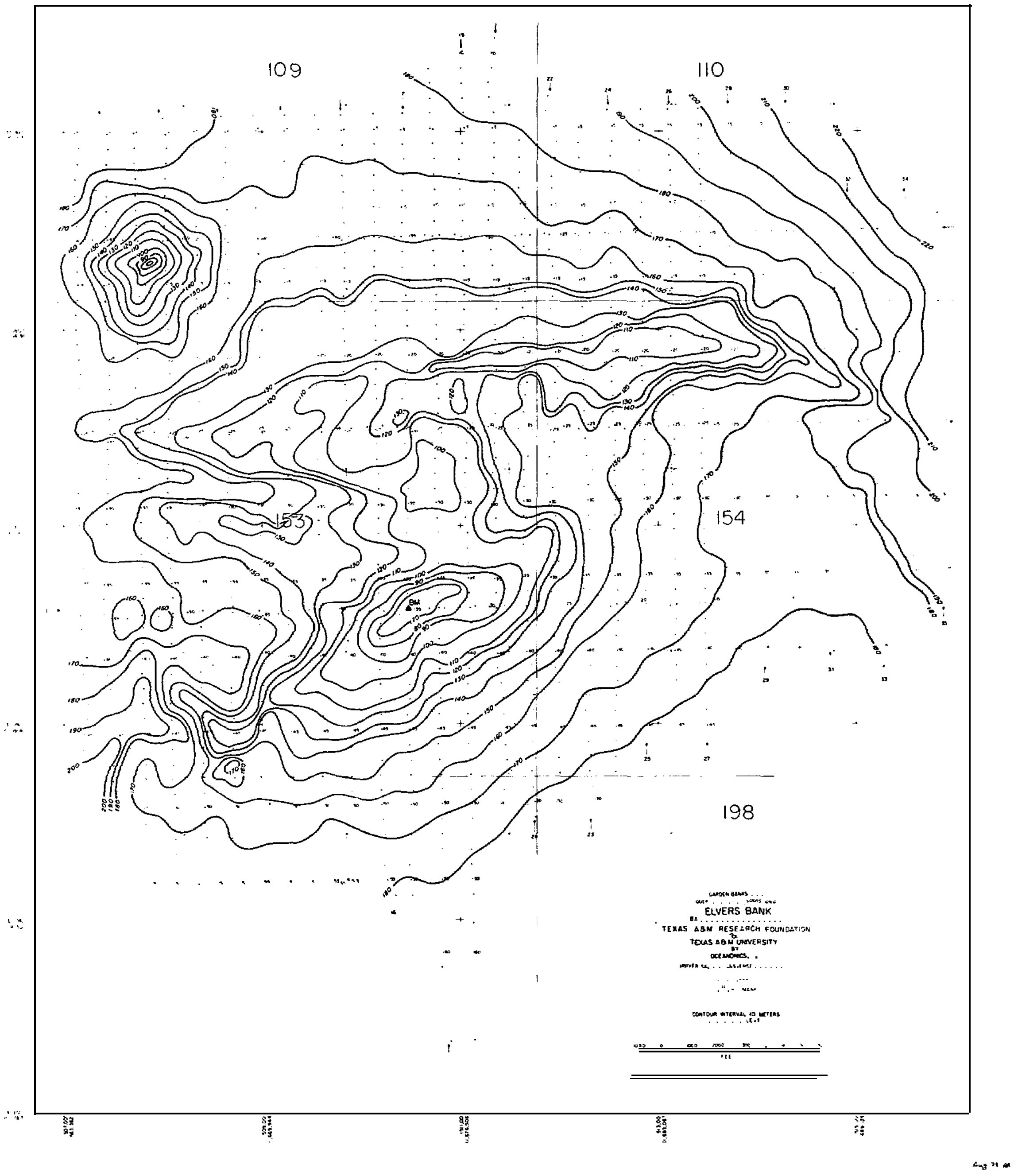


Figure III-10. Elvers Bank bathymetry.

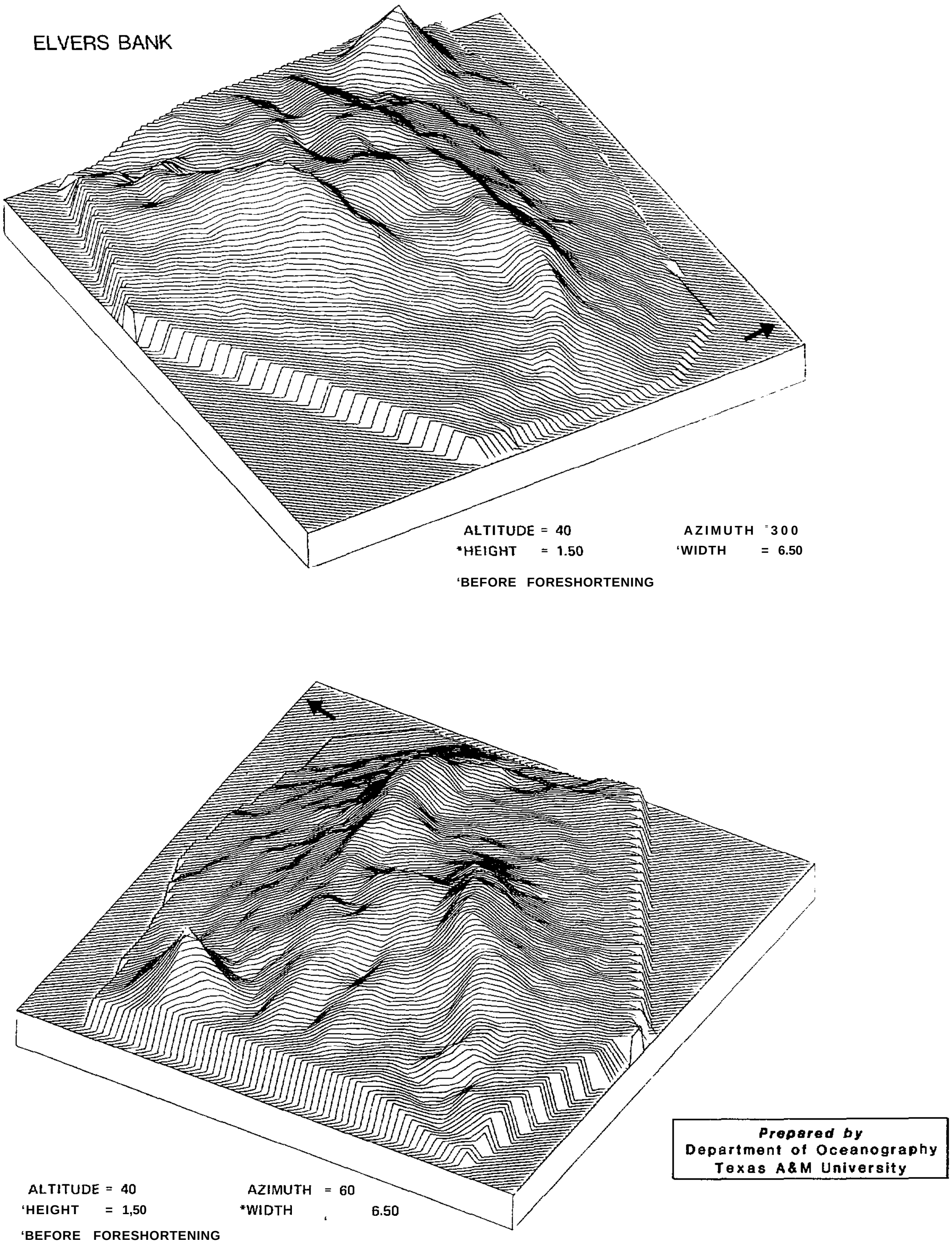


Figure III-11. Three-dimensional perspective views, Elvers Bank. Apparent cliffs near margins of blocks indicate limits of data. (Arrow points toward north.)

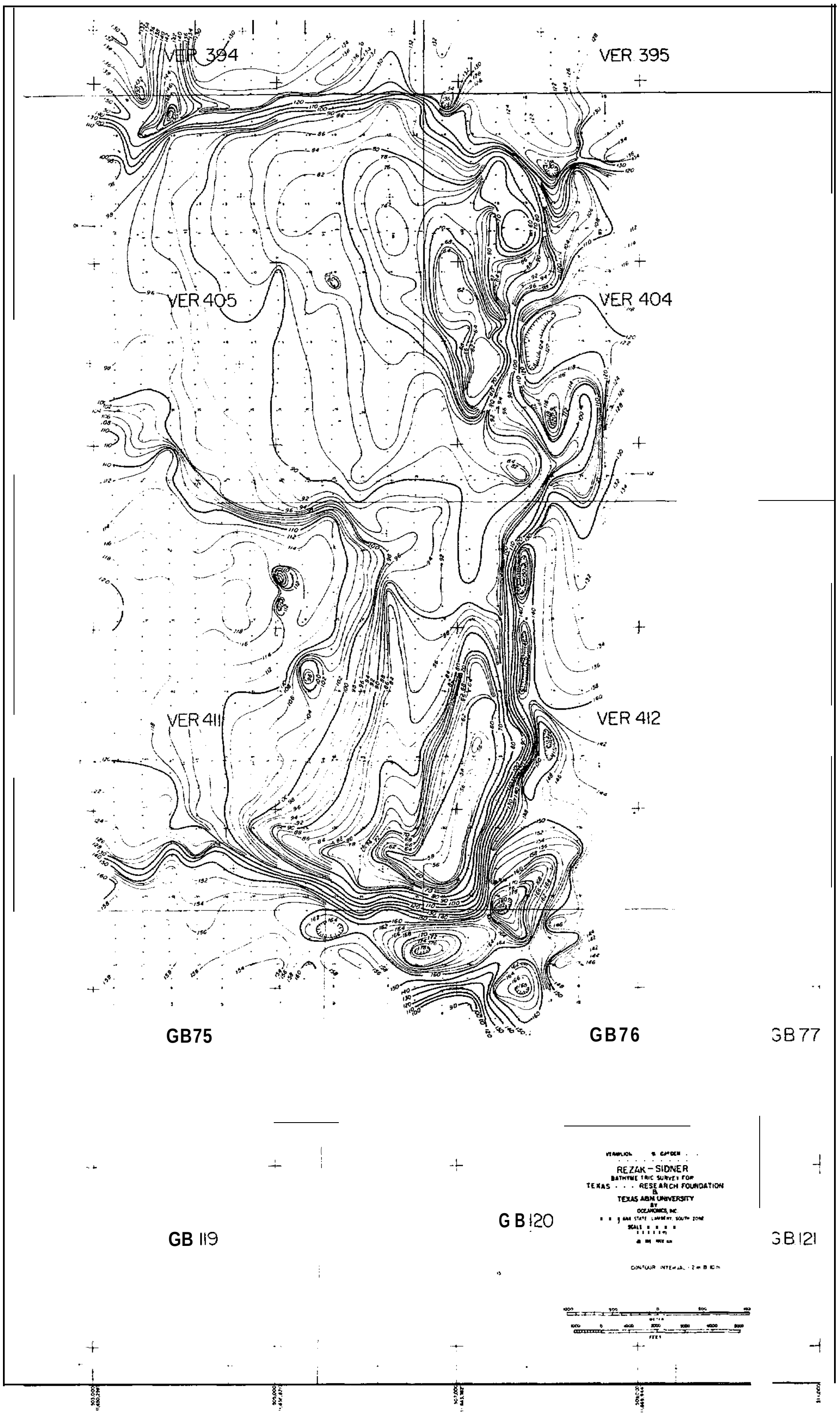


Figure III-12. Rezak-Sidner Bank bathymetry.

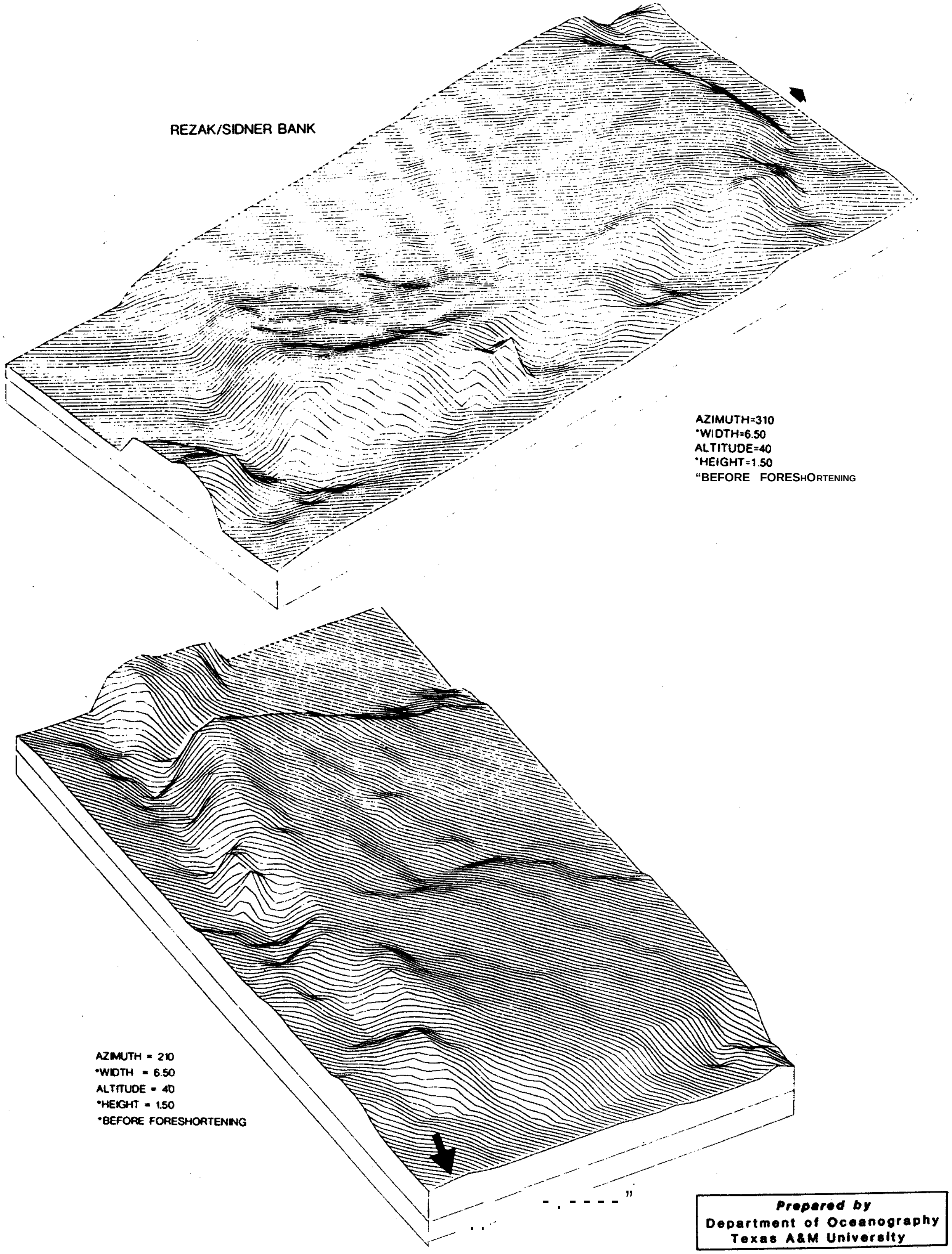


Figure III-13. Three-dimensional perspective views, Rezak-Sidner Bank. (Arrow points toward north.)

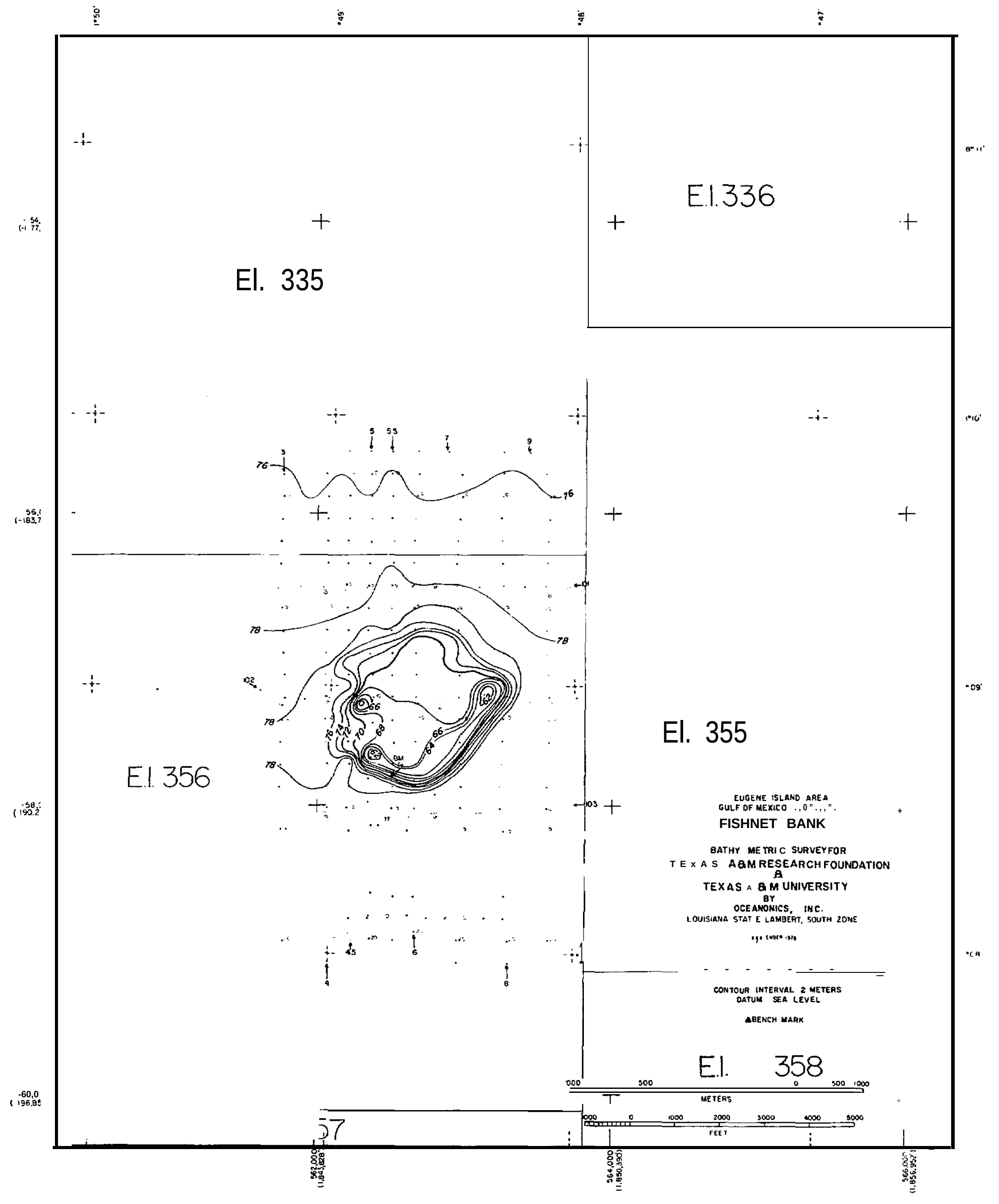
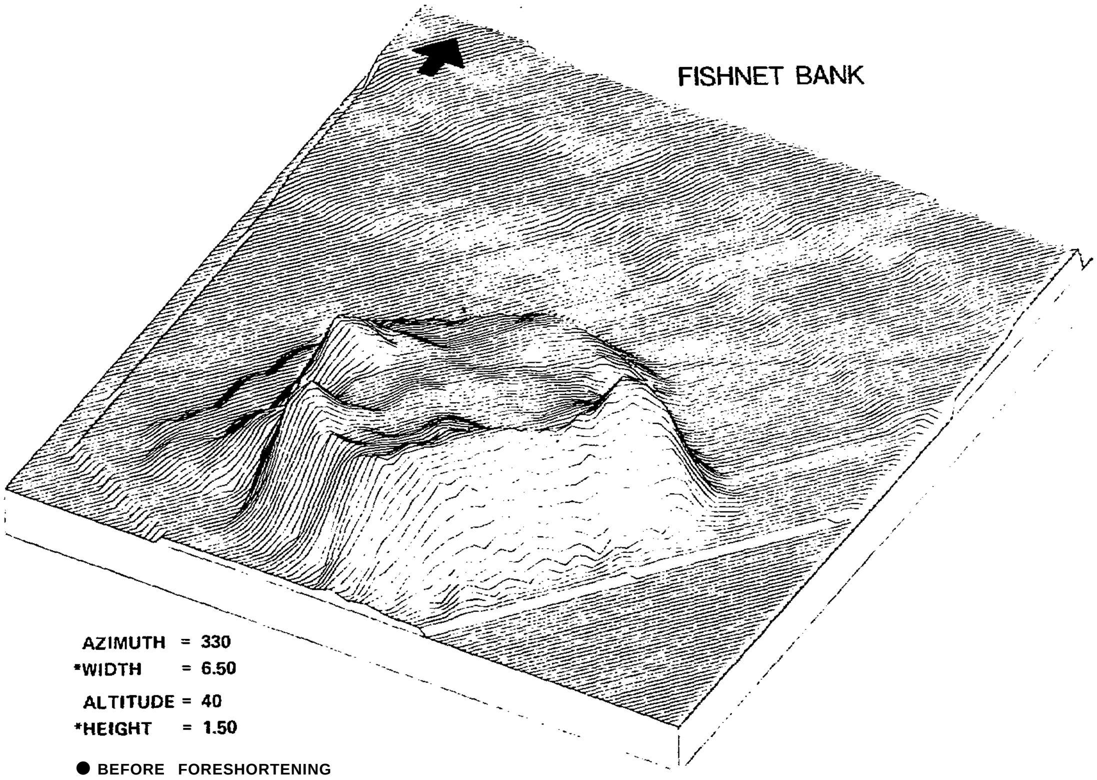


Figure III-14. Fishnet Bank bathymetry.



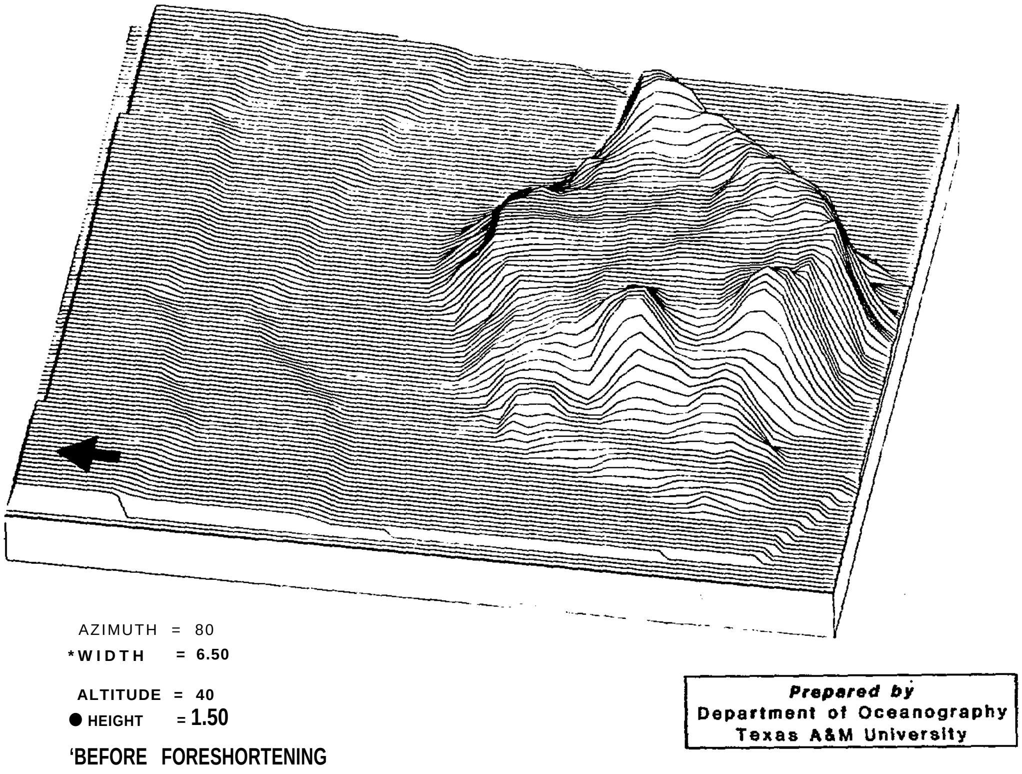


Figure III-15. Three-dimensional perspective views, Fishnet Bank. Apparent cliffs near margins of block are limits of data. (Arrow points toward north.)

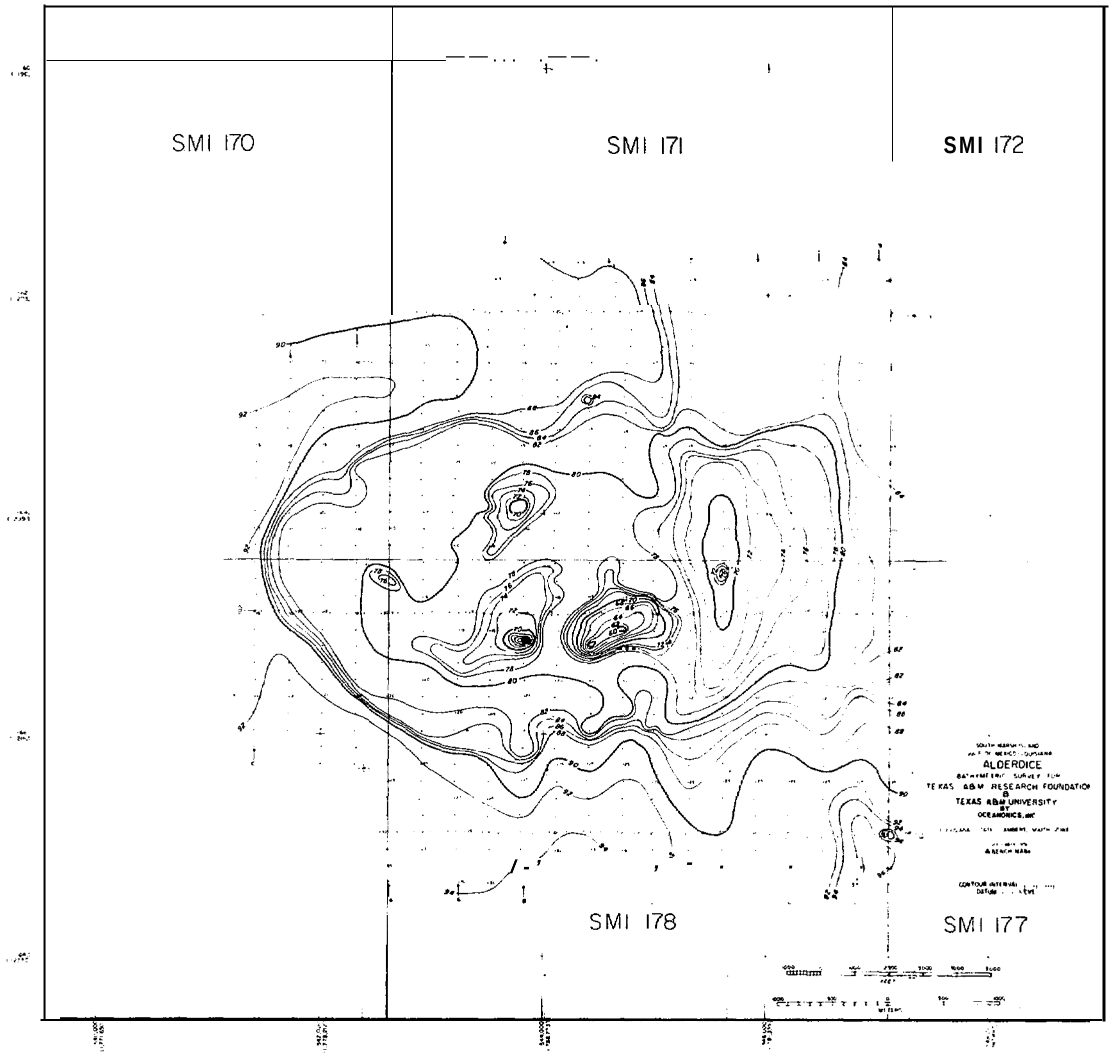


Figure III-16. Alder dice Bank bath ymetry.

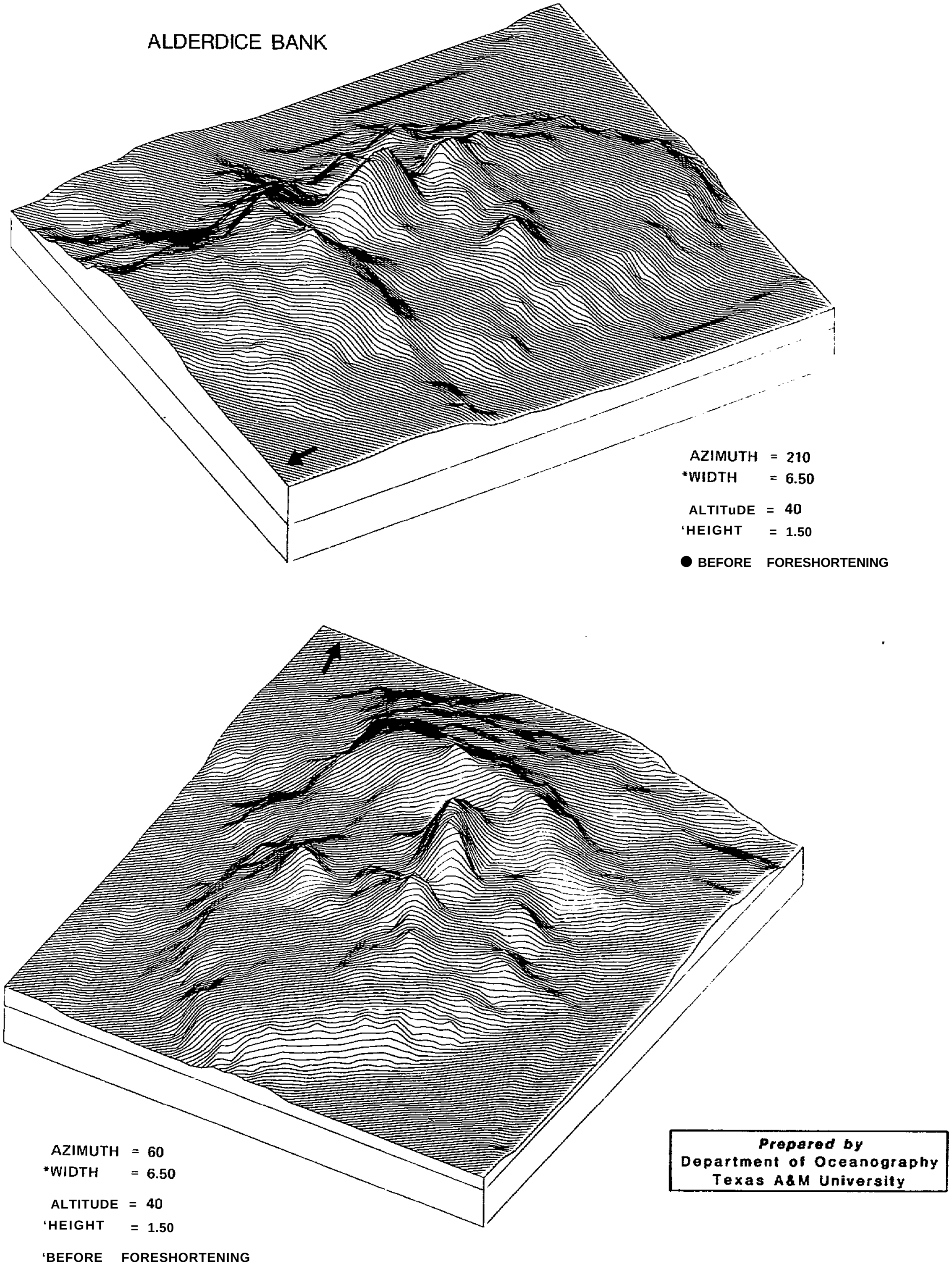


Figure III-17. Three-dimensional perspective views, Alderdice Bank. (Arrow points toward north.)

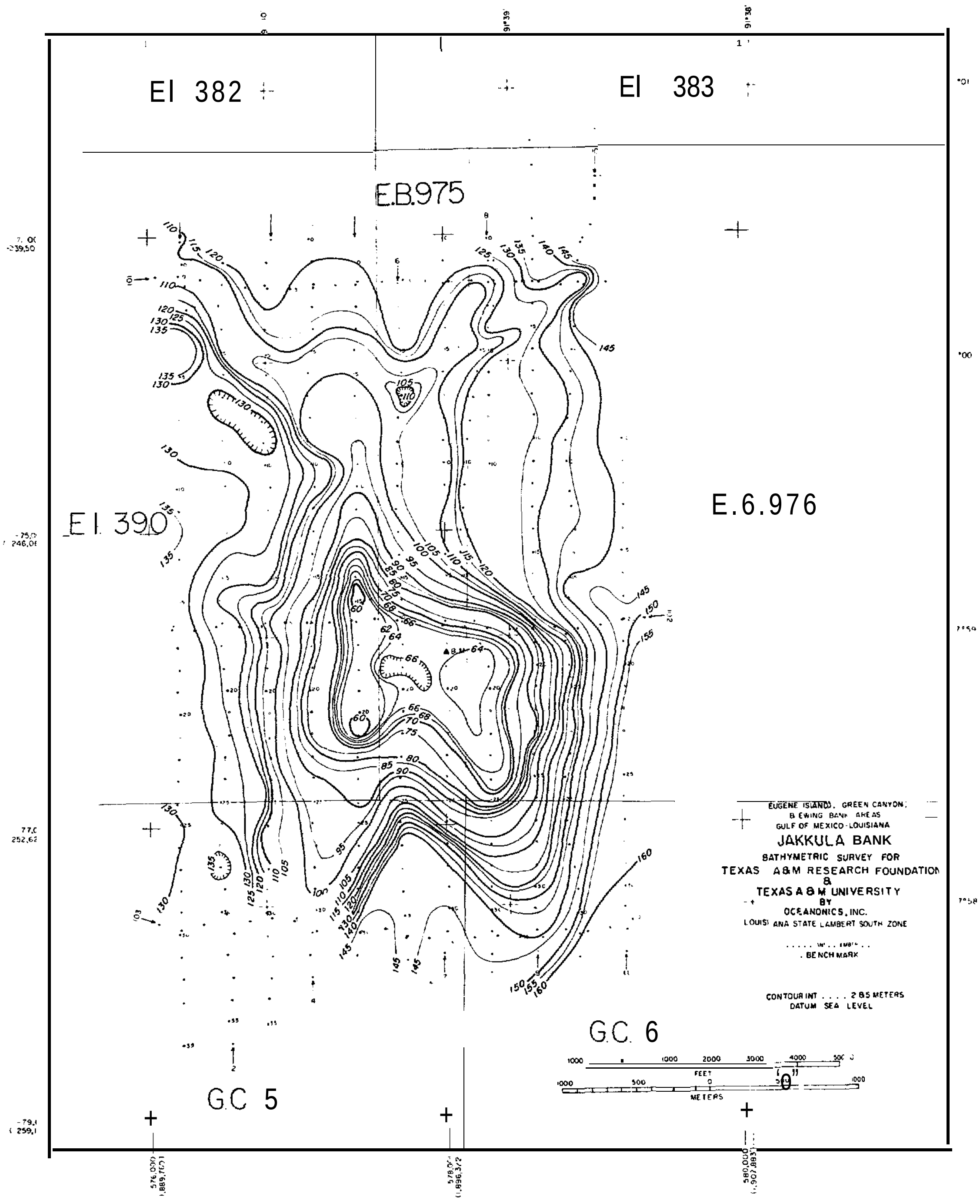


Figure III-18. Jakkula Bank bathymetry.

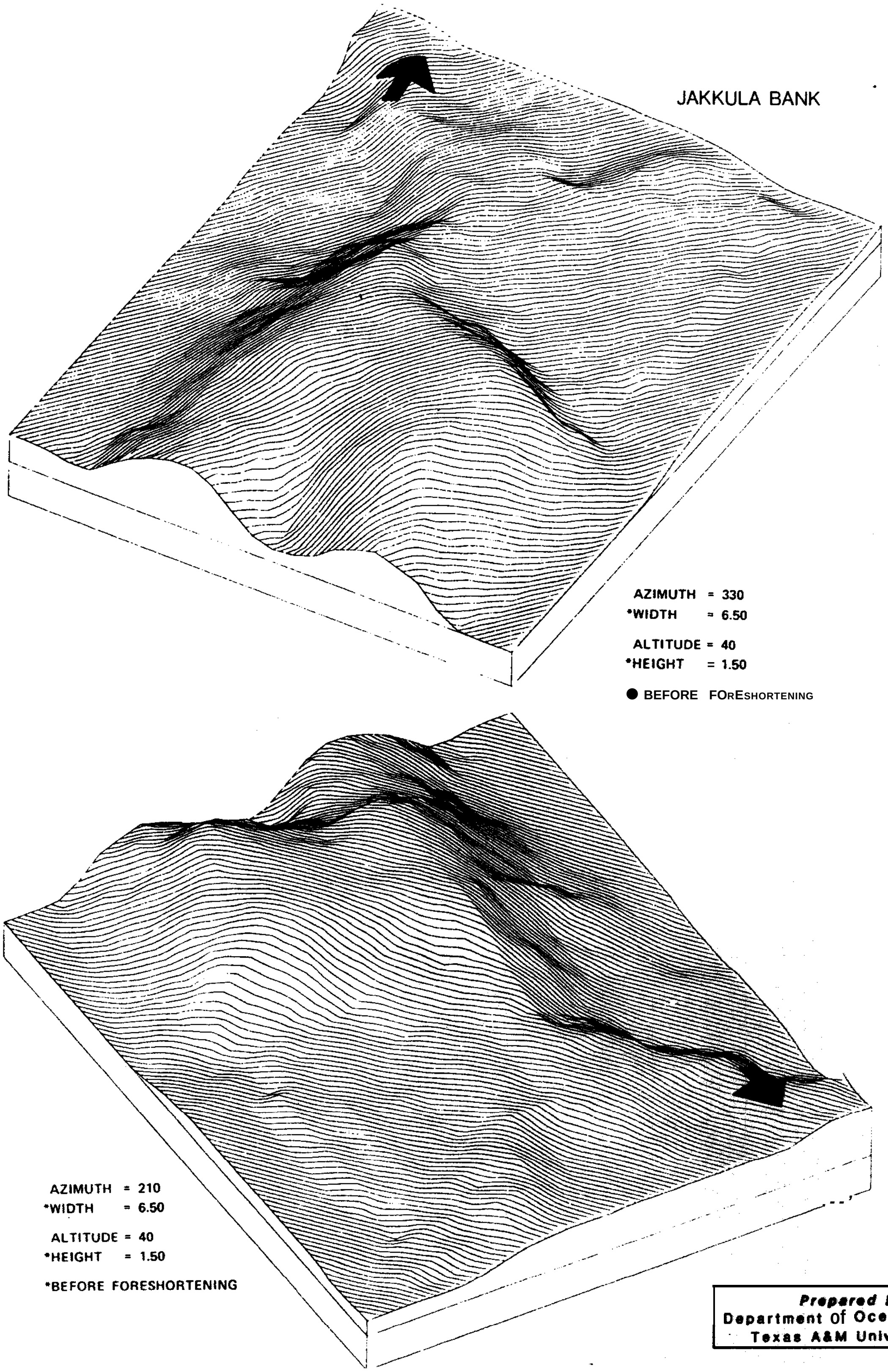


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Figure III-19. Three-dimensional perspective views, Jakkula Bank. (Arrow points toward north.)

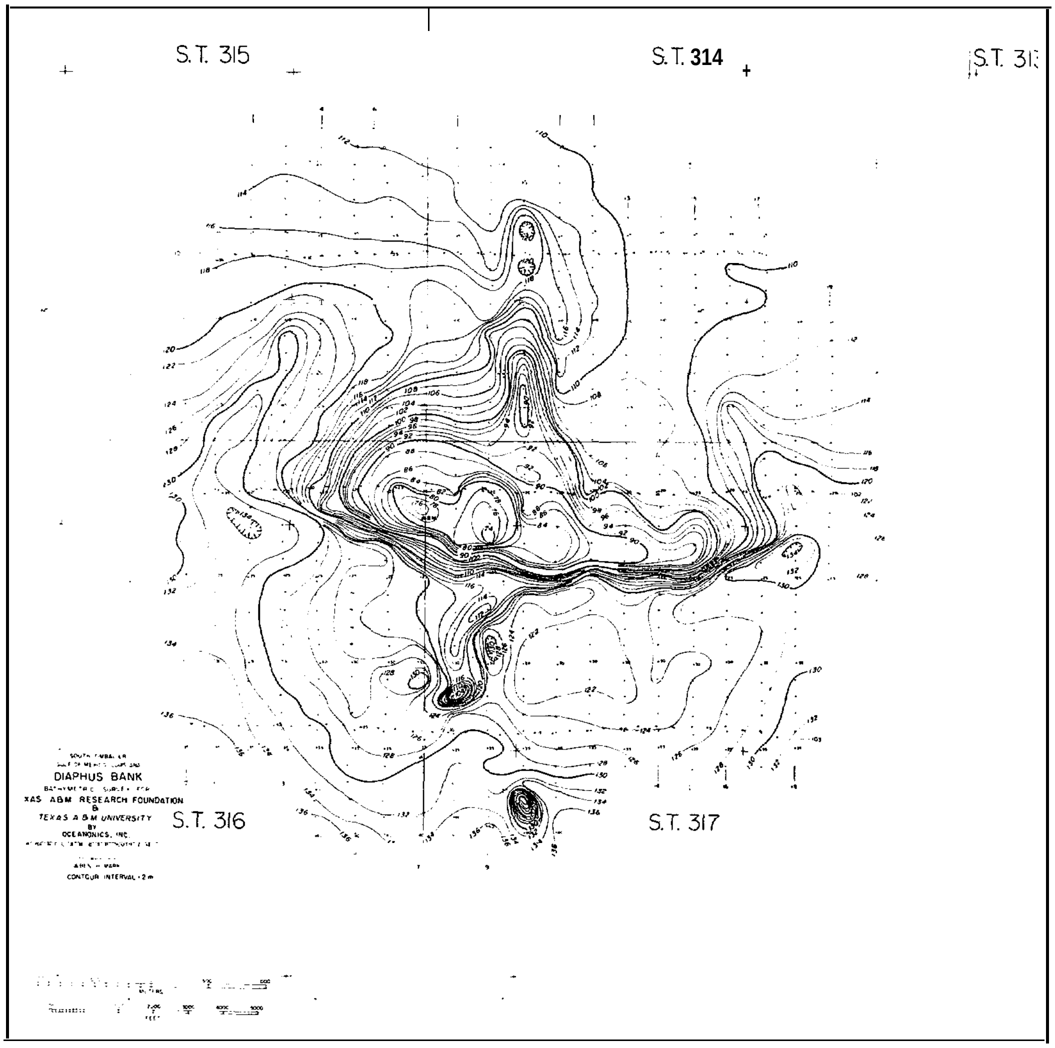

Figure 111-20. **Diaphus Bank bathymetry.**

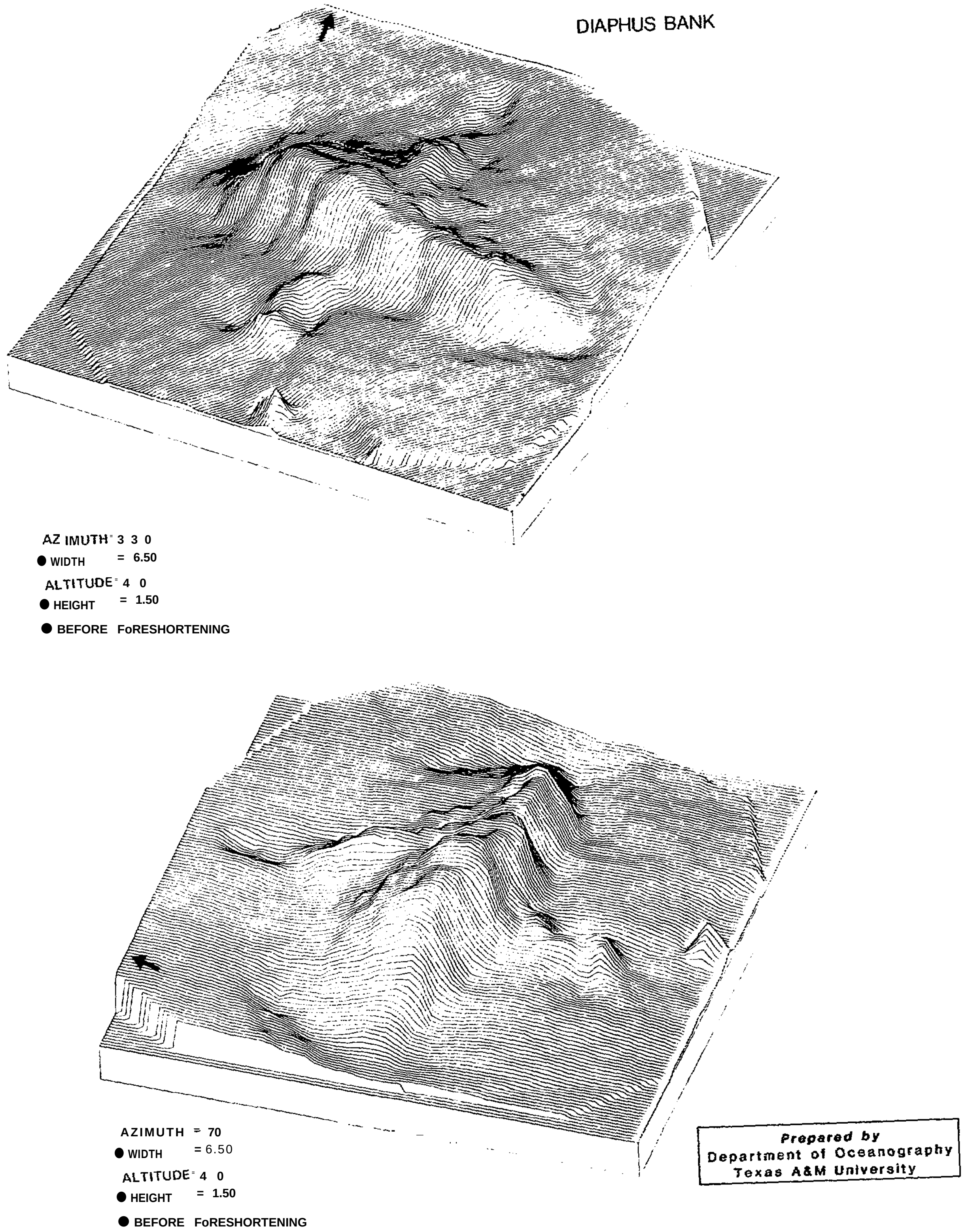

Figure III-21. Three-dimensional perspective views, Diaphus Bank. Apparent cliffs near margins of blocks indicate limits of data. (Arrow points toward north.)

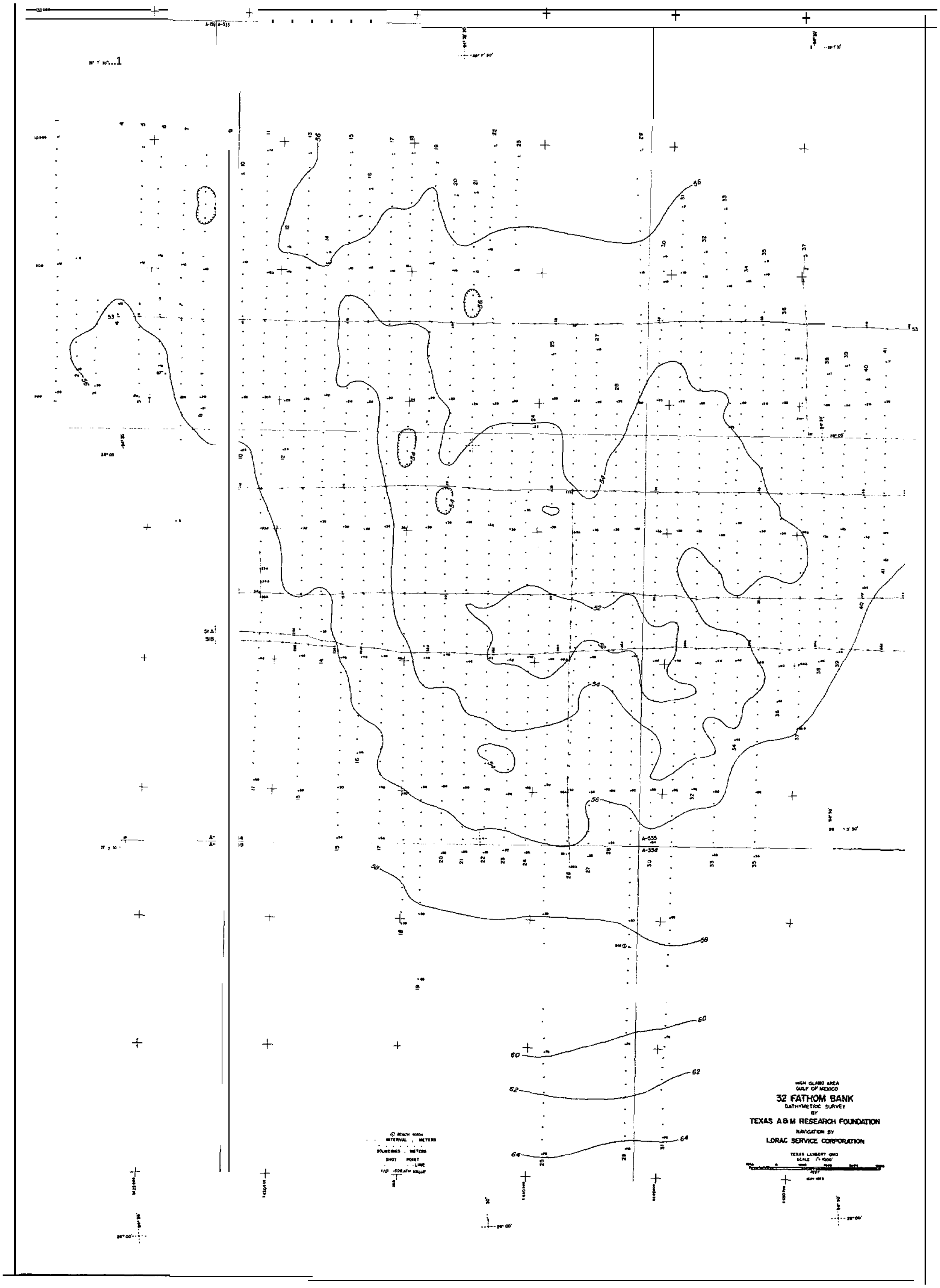

Figure II-22. 32 Fathom Bank bathymetry.

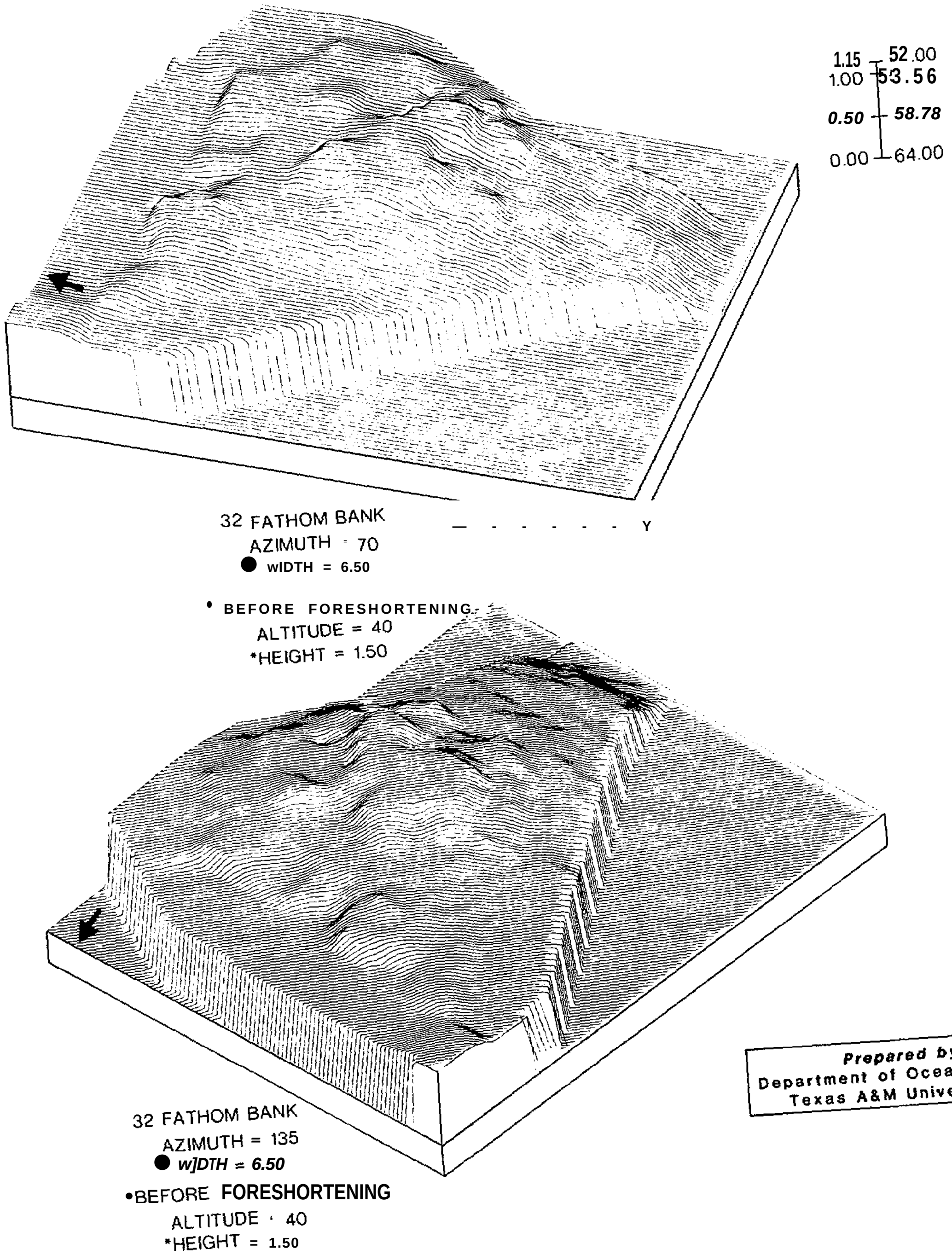

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Figure III-23. Three-dimensional perspective views, 32 Fathom Bank. Apparent cliffs near margins of blocks indicate limits of data. (Arrow points toward north.)

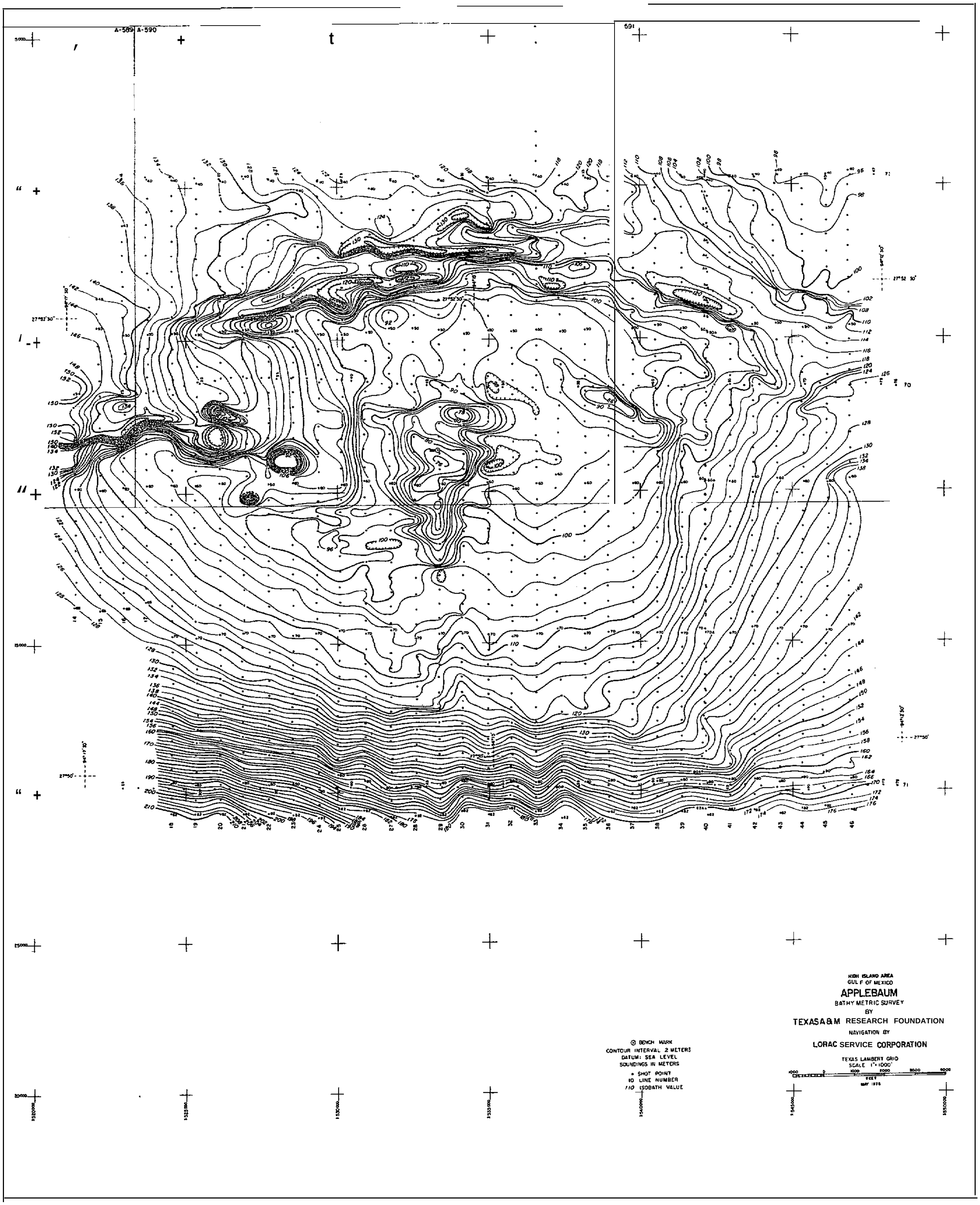

Figure III-24. Applebaum Bank bathymetry.

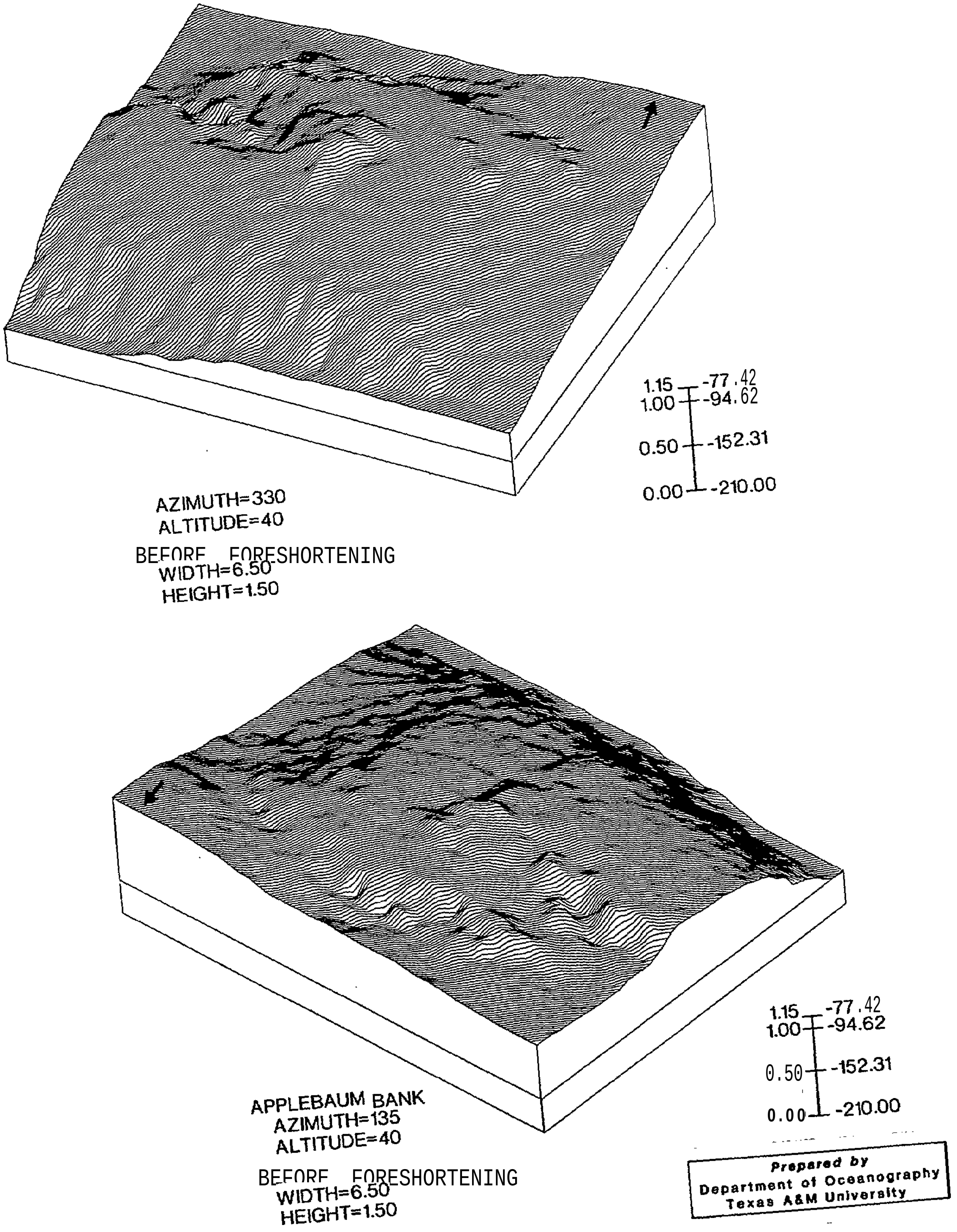

Figure III-25. Three-dimensional **perspective views, Applebaum** Bank. **(Arrow** points **toward** north .)

TABLE IV-I
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 tank zones. Comparable to an Antipatharian Zone.

CHAPTER IV

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

T. Bright

INTRODUCTION

Results of the biological work performed are reported in Volumes Three and Four, Chapters X-XX, and summarized in the Executive Summary. This chapter describes a method for biological categorization and "environmental ranking" of biotic zones and banks which we think will be useful for management purposes.

The categorization and ranking system presented below is an attempt to provide BLM with a more "tangible" means of assessing biotic zones and banks in the decision-making process. We have had frequent requests from federal employees concerning the "value" of one bank in comparison to others, and it has often been difficult to convey clear and simple opinions. The following should help ease the confusion concerning the "environmental priority" and the contemporary biotic zones of the banks.

BANK CATEGORIES

In past reports we presented a system of bank categorization which is now obsolete and should be replaced (Bright and Rezak, 1978a, b). The revised categorization is not meant to 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 zones' depth ranges on each bank. This system of categorization seems more functional than the previous one insofar as certain banks are more complex biologically than 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 IV-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 quantities" 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 is 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 IV-1.

The Category D zone is:

VII* Nepheloid Zone: A zone located at the bases 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 IV-1, above) .

ENVIRONMENTAL PR1ORITY 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 IV-2 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 IV-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, V II) 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 may increase the known depth ranges somewhat.

TABLE IV-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	Area1 Extent	
1. <u>D-M-P</u>	8	8	8	7	6	7.4
II. <u>Madracis</u>	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. <u>Millepora</u>	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.

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

BANKS	D-M-P I 7.4	MAD. II 7	STEPH. III 5.8	AL.SP. IV 5.0	MILLEP. V 4.8	ANTIP. VI 3.0	NEPH. VII 1.8	Surrounding Mud Bottom 1.2	BANK PRIORITY RATING (Sum of Priority Indices)
East Flower Garden	X	X	X	X		X	X	X	36
West Flower Garden	X	X	X	X		X	X	X	36
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 V

WATER AND SEDIMENT DYNAMICS

D. McGrail

INTRODUCTION

In terms of management requirements, the most critical issue addressed by our hydrodynamic research concerns the Flower Garden Banks, in particular whether water from the base of the bank can flow up to the living reef. This 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 is a discourse presenting 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.

No reasonably intelligent person should be surprised 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 x 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.

The pertinent geophysical fluid motions are “governed by the following equations:

- Continuity - for an incompressible fluid (conservation of mass)

$$\nabla \cdot \vec{q} = 0 \qquad (1)$$

where

$\vec{q} = u +$ vi-w

and

u, v, w are the velocity components in the x, y, z directions, respectively.

- Conservation of momentum (appropriately scaled and dimensionless form)

$$F \frac{\partial \vec{q}}{\partial t} + \varepsilon \vec{q} \cdot \nabla \vec{q} + 2 (\hat{k} \times \vec{q}) = - \nabla P - E \nabla \times \nabla \times \vec{q} \qquad (2)$$

where

P = pressure
$\hat{k}$ = unit vector in z direction
t = time
V = differential operator,
E = $\nu L^{-2} f^{-1}$, the Ekman Number
ν = kinematic viscosity of the fluid
L = a characteristic length scale of the flow
f = $2w \sin \phi$, the local vertical component of rotation
$\varepsilon = |q| L^{-1} f^{-1}$, the Rossby Number
F = $(\tau f)^{-1}$, ratio of characteristic time scale of flow (τ) to rotational frequency.

Density distribution is approximated by

$$\rho = \rho_m - \alpha_{\cdot} (T - T_m) + \alpha_s (S - S_m) \qquad (3)$$

where m denotes the mean value

P = mean density of the fluid

α_* = coefficient of thermal expansion $\frac{\partial \rho}{\partial T}$

T = temperature

S = salinity

as = coefficient of density increase per unit increase in salinity $\frac{\partial \rho}{\partial s}$

An approximation for the pressure distribution is

$$\nabla P(d) = -g \int_d^0 \frac{\partial \rho}{\partial z}\left(\tan \alpha - \tan \beta\right) dz \qquad (4)$$

where

α = the slope of the isopycnals against the geopotential surface (depth dependent)

β = the slope of the sea surface against the geopotential surface (depth independent)

d = any given depth.

From these it is possible to estimate the height (h) to which a flow would rise if it struck a barrier. First, assume that the flow is entirely along one horizontal axis, x for example, and assume further that the flow is constrained to remain two-dimensional in the x-z plane. The continuity equation becomes

$$\frac{\partial u}{\partial z} + \frac{\partial w}{\partial z} = 0 \qquad (5)$$

Now assume that the fluid is inviscid (1) = 0] , so that no momentum is lost to friction at the bounding surface of the barrier, and that the fluid is vertically stratified

$$\frac{\partial \rho}{\partial z} \neq 0 \qquad (6)$$

Finally, assume that all of the vertically displaced water can be accommodated by accelerated flow over the barrier so that the free surface η_{fs} remains undisturbed (η_{fs} = 0 at x,y, 0) .

One method of estimating h is to examine the instantaneous conversion of the kinetic energy of the flow into potential energy by raising a particle above its equilibrium

$$\frac{\hat{\rho}\vec{q}^{\,2}}{2} = \hat{\rho} g h \qquad (7)$$

Since it was assumed that the free surface would remain rigid, the conversion to potential energy is accomplished by raising the isopycnals or internal surfaces $\eta_I = \hat{\rho}$ where $\hat{\rho}$ is a constant density. Then ρ in (7) may be replaced by $h\frac{\partial \rho}{\partial z}$ because that gives the relative density of a particle on η_I at a position h above its equilibrium level in a fluid with stratification $\frac{\partial \rho}{\partial z}$. Then (7) becomes

$$\frac{\hat{\rho}\vec{q}^{\,2}}{2} = g h^2 \frac{\partial \rho}{\partial z} \qquad (8)$$

Using the mean density gradient observed in April 1979 for $\frac{\partial \rho}{\partial z}$ (2×10^{-7} gm/cm^4) and 100 cm/sec for $\vec{q}$, (8) yields a value of 5.05×10^3 cm, or 50.5 m for h.

A physical example of this situation would be a 100 m deep channel capped by a rigid lid with a 70 m high barrier representing the East Flower Garden Bank somewhere in the channel. A 100 m wall of inviscid fluid having the density structure of the water column observed at the East Flower Garden in April would be run down the channel and into the barrier. Fluid from the base of the column would rise 50 m as its kinetic energy was converted to potential energy. The lowest 20 m of fluid would be completely blocked by the barrier and the remaining 50 m of the fluid striking the barrier would be accelerated through the 30 m gap at the top of the barrier. Since the fluid is assumed to be incompressible, the velocity through the gap would be 100 cm/sec • (1 + 50/30), or 267 cm/sec (5.3-knots).

Notice that even under these absurdly adverse "conditions, fluid from the bottom boundary layer still could not reach the height of the living reef.

If the fluid were viscid, flow over the reef would be retarded and the fluid could not move horizontally fast enough to accommodate that displaced from below. This of course would reduce the vertical distance that the lowest level fluid could rise because of the adverse pressure gradient created. If the rigid lid restriction were removed, some of the excess displaced fluid could be accommodated by raising the fluid surface. As shown in (7) , however, the elevation of the fluid surface would require approximately 20% of the flow's kinetic energy for each 1 cm of rise. Thus, the addition of viscosity to the problem leads inevitably to a reduction in the height (h) to which the bottom waters could rise.

Removing the stricture against three-dimensional motion would further reduce h. The build up of dense water on the upstream side of the bank would produce a pressure gradient which would cause a divergence of the flow around the hank. That portion of the flow so diverted would not be available for conversion to vertical motion.

In summary, 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: the flow would rise 15 to 20 m along the upstream face of the bank; flow over the top of the reef would be sharply accelerated to accommodate the excess volume; and 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.

Note that this analysis does not require recourse to arguments involving the conservation of vorticity or strong stratification.

A large body of literature regarding orographic effects in geophysical fluid dynamics has evolved, but the range of parameters studied is not applicable to the problem at hand. Studies of orographic effects in the atmosphere, such as that of Kasahara (1980), for example, are inapplicable because the fluid is compressible. McCartney (1975) analyzed theoretical studies of obstacles in both rotating and rotating stratified fluids. In the nine investigations summarized, the Rossby number, ε, was assumed to be zero or <<1, the Ekman Number, E, was assumed to be zero, and the stratification parameter,

$$S = \frac{gH}{f^2 \rho_0} \frac{\Delta\rho}{L^2} = \frac{\delta^2 N^2}{f^2}$$

where

H = the water depth

$\Delta\rho = H\frac{\partial\rho}{\partial z}$

$S = H/l$

L = horizontal length scale of the obstacle

and

N = Brunt-V aisala frequency

was assumed to be ≤ 1. It was also assumed in these studies that, ho the height of the obstacle, was <<H.

In the case at hand, $\varepsilon = 3.68$, $h_o = .7H$, $E << 1$, and $S = 25.8$. For problems in which the parameters are suitably small, the obstacle would be isolated in the flow by closed streamlines known as a Taylor

Column. If stratification is important ($S \sim 1$), the column becomes a cone (Hogg, 1980). The key parameter according to Hogg (1980) is

$$\beta_T = \frac{h_o}{H} \cdot \frac{fL}{|\vec{q}|}$$

He shows that for β_T smaller than 1, no Taylor column can form. For the East Flower Garden Bank in April, β_T was found to be approximately 2×10^{-1}. Greenspan (1969) states that the pluglike flow of the Taylor column is a consequence of upward propagating waves over the obstacle and that if the Rossby number were large, the waves would be advected downstream so that the column could not form. Hogg's criterion (β_T) would indicate that, for velocities of up to about 27 cm/see, a Taylor Column or cone could develop over the East Flower Garden Bank for flow of sufficient duration for rotational effects to be important (approximately 24 hours). Still, the stratification is so strong, even in April, that the cone would be compressed to the height of the bank. However, flow around the bank would still be completely two-dimensional in horizontal planes.

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 (this report) 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 (this study) 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, Rossby, and Rhines (1975) was performed on the records from the meters moored on Arrays 1 and 2 (Figure V-1). This analysis determines the major and minor axes of variance relative to true north. The

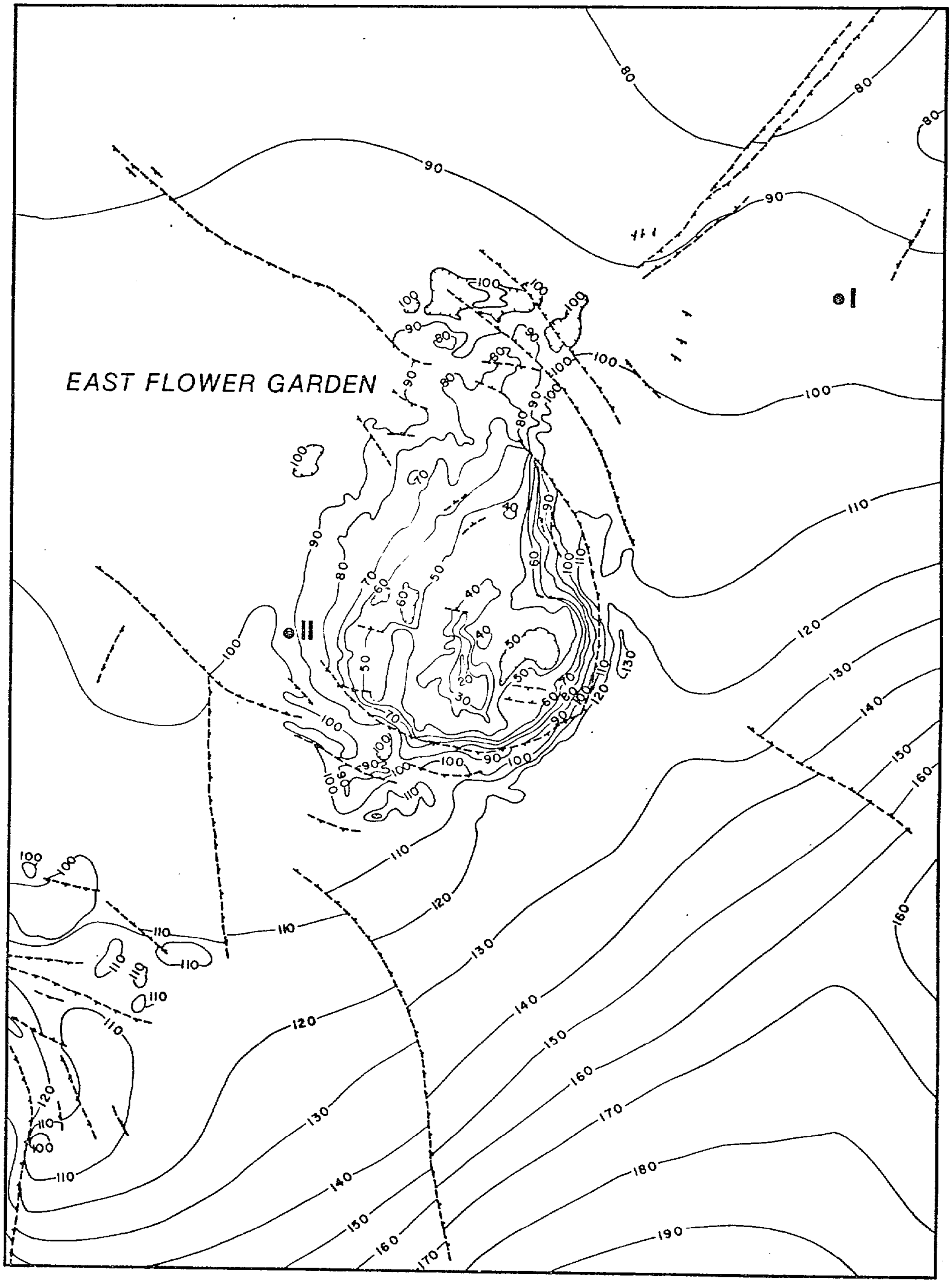

Figure V-I. Location of current meters, East Flower Garden Bank results were that the records from all of the meters at array 2 showed strong polarization along the local isobaths. Even the meter at 60 m depth showed very little cross-isobath flow. The meters at 94 m and 96 m showed even stronger topographic steering and an acceleration commensurate with that required to accommodate the excess volume of 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 VI

SUMMARY AND RECOMMENDATIONS

R. Rezak

INTRODUCTION

Eleven banks (East Flower Garden, Coffee Lump, Rezak-Sidner, Diaphus, Jakkula, Alder dice, Elvers, Geyer, 32 Fathom, and Applebaum) were characterized biologically and geologically using observations and samples taken by surface vessel, research submersible, and 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.

Five banks bear reef-building populations of coralline algae within well developed Alga! -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 the 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.

EAST FLOWER GARDEN BANK

Geology

P-lo significant normal faulting has occurred at the East Flower Garden Bank. The crests! 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 he 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.

B iology

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 have been observed in the population levels of corals or in their dominance ranking during the years 1978 arid 1979.

Current accretionary growth of *M. annularis* may average 7 mm/yr. 2 and that of *Stephanocoenia intersepta*, 5.8 mm/yr. There appear to have been no changes in rate of accretionary growth of these twodominant 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 norreal.

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 coral line 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.

In general, there is no indication of a significant change in benthic community structure or condition during 1978 and 1979. 3

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 em bayment.

COFFEE LUMP

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 to 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 is 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 "clarity 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. As can be seen in Volume Four, Figure XVI-1, only a very small part of the bank has been observed from the submersible. 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 XV I-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

Geyer Bank possesses four distinct biotic zones characterized by differences in substratum, depth and structure of biotic communities: Millepora-Sponge Zone (37-61 m, bedrock 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, gravel, nodules and fines at top, grading to mud with carbonate gravel at bottom); and the Mud Zone (189-213+ m) .

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, coral line algae are significant to depths of 113 m or so and occur as deep as 123.5 m.

The great depth to which coralline algae grow at Geyer Bank (123.5 m, observed) is a feature held in common with Elvers Bank

(122.5 m, observed) but not other shelf -edge banks. Physiographically, Geyer and Elvers Banks rise from greater surrounding depths (215 m or more) than do the others. As indicated in the description of Elvers Bank, we speculate that the survival and growth of coralline algae populations at great depths on Geyer and Elvers Banks is related to the banks' high relief and the relief's influence on bottom hydrography and sedimentation on and adjacent to the banks. In effect, compared to banks of lesser relief, clearer water favoring algal growth exists at greater depths on the flanks of high relief banks. Water clarity was good even at depths over 185 m at both banks during reconnaissance dives.

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, as illustrated by Figure XV II I-6c (Volume Four) 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 ex petted. 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 spectacular basalt outcrops 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 that has been 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 coral gal 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) .

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APPENDIX A
RAW DATA TABLES

TABLE III-1
SEDIMENT PARTICLE TYPES AND PERCENT CARBONATE

Sample	Planktonic Foraminifers	Benthic Foraminifers	Amphistegina	Echinoderms	Molluscs	Coralline Algae	Coral	Bryozoans	Worm Tubes	Lithoclasts	Quartz	Miscellaneous	% Carbonate
EFG1-1G	62.6	20.0	0.5	2.5	2.0	0.5	0.0	0.0	0.0	0.0	0.0	2.0	18.1
EFG2-1G	68.2	8.0	0.0	8.0	2.0	0.5	0.0	0.0	0.0	0.0	13.3	0.0	20.0
EFG3-1G	1.6	5.5	8.7	7.1	35.0	4.4	3.3	7.1	4.4	23.0	0.0	0.0	59.8
EFG4-1G	13.3	10.2	0.0	14.8	15.3	9.7	0.0	5.6	5.1	6.6	10.2	9.2	72.1
EFG5-1G	24.2	7.1	0.0	8.1	11.4	6.2	0.0	0.0	0.0	5.2	34.1	3.8	12.5
EFG6-1G	9.3	2.0	0.0	1.5	5.9	0.0	0.0	0.5	1.0	0*0	76.6	3.4	34.4
EFG7-1G	0.0	1.4	13.0	12.6	22.7	22.7	1.0	3.4	5.8	17.4	0.0	0.0	91.3
EFG8-1G	9.1	7.1	0.5	9.1	35.5	22.8	0.0	1.0	2.5	0.0	10.2	2.0	27.1
EFG9-1G	9.4	7.4	0.0	7.4	25.1	9.9	0.0	1.0	1.5	0.0	34.5	3.9	59.7
EFG10-1G	50.5	12.5	0.0	2.9	5.8	0.0	0.0	0.0	0.0	0.0	26.0	2.4	22.2
EFG11-1G	79.6	7.6	0.0	2.4	3.8	0.9	0.0	0.0	1.4	0.0	3.3	0.9	16.8
EFG12-1G	65.7	23.5	0.0	4.4	2.0	0.0	0.0	0.0	0.0	1.0	2.5	1.0	17.4
EFG13-1G	41.2	20.4	0.0	2.4	3.8	0.0	0.0	0.0	0.0	0.0	29.9	2.4	18.4
EFG14-1G	50.7	15.5	0.0	2.4	6.3	3.4	0.0	0.0	0.0	1.4	17.9	2.4	19.0
EFG15-1G	40.2	20.1	0.0	2.5	3.5	5.0	0.0	0.0	1.0	0.0	24.1	3*5	19.2
EFG16-1G	57.7	16.9	0.0	3.5	2.5	0.5	0.0	0.0	0.0	2.5	12.4	4.0	16.6
EFG17-1G	60.0	20.0	0.0	7.0	1.0	0.0	0.0	*0.0*	0.0	0.0	8.5	3.5	19.3
EFG18-1G	11.1	4.5	0.5	*4.0*	9.1	1.5	0.0	1.5	0.0	5.6	56.1	6.1	24.3
EFG19-1G	17.5	5.5	0.0	5.5	2.5	0.5	0.0	0.5	0.0	7.0	56.5	4.5	26.4
EFG20-1G	3.8	9.6	0.0	3.8	33.5	2.9	1.4	4.8	1.0	16.3	18.2	4.8	67.4
EFG21-1G	0.5	3.6	0.0	4.6	27.6	0.0	0.0	0.0	0.0	62.8	1.0	0.0	39.8
EFG22-1G	0.9	3.0	16.2	2.1	11.9	3.4	0.0	'2.6	1.7	58.3	0.0	0.0	72.2
EFG23-1G	2.4	1.6	1.6	12.4	25.1	1.2	0.4	6.0	8.0	40.6	0.0	0.8	73.3
EFG24-1G	3.3	5.1	4.5	10.3	54.7	6.5	0.0	7.0	0.5	6.5	0.0	1.4	83.7
EFG25-1G	1.0	3.9	15.0	9.2	33.8	8.2	0.0	3.4	1.9	23.2	0.5	0.0	92.1
EFG26-1G	0.0	0.5	44.5	1.8	4.5	2.3	0.0	0.9	2.7	40.5	0.5	2.3	93.1
EFG27-1G	1.0	1.0	1.5	11.8	51.8	7.2	2.1	4.6	4.6	10.8	0.0	3.6	84.2
EFG28-1G	0.0	0.6	41.5	5.7	0.0	11.4	4.0	1.7	10.2	20.5	1.7	2.8	90.9
EFG29-1G	9.2	4.1	0.0	4.1	4.6	4.1	0.0	0.5	0.0	7,1	66.3	0.0	37.1
EFG30-1G	10.3	8.4	1.0	2.0	6.9	3.4	0.0	0.0	0.0	7.4	59.1	1.5	23.9
EFG31-1G	7.8	11.1	4.5	13.5	33.2	3.3	8.2	8.2	6.1	0.0	3.7	0.4	64.0
EFG32-1G	8.0	8.8	0.4	7.3	36.4	26.1	0.8	1.5	0.0	5.0	5.7	0.0	70.4
z-1	0.0	0.0	23.6	4.4	12.1	52.7	1.6	0.0	4.4	1.1	0*0	0.0	98.8
z-2	0.5	1.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0*0	95.4	1.5	5.2
z-3	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	97.0	1.5	5.4
z-4	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	97.5	2.0	2 . 9
z-.5	0.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	5.4
z-6	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.5	1.0	3.4
DS1-1G1	43.3	32.0	0.0	6.4	1.0	0.0	0.0	0.0	0.5	3.0	13.8	0.0	0.0
DS1-2G1	37*3	30.3	0.0	8.0	6.5	2.0	0.0	0.0	0.0	1.0	14.9	0.0	0.0
0S1-3G1	39.5	29.5	0.0	2.3	5.0	0.0	0.0	0.0	0.0	1.4	22.3	0.0	0.0
DS1-4G1	31.9	25.6	0.0	3.9	3.9	0.0	0.0	0.0	0.0	1.4	33.3	0.0	0*0
DS1-5G1	44.3	36.6	0.0	7.7	8.8	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0
DS1-6G1	30.4	22.5	0.5	8.8	16.7	3.4	1.5	5.9	7.4	0.0	2.0	1.0	0.0
DS1-7G1	36.9	25.2	0.0	10.3	7.9	0.0	0.0	0.0	I)*9	0.0	18.7	0.0	0.0
DS1-8G1	32.5	32.0	0.0	7.1	5.6	0.0	0.0	0.0	1.0	0.0	21.8	0.0	0.0

TA8LE 11 I-1 (Continued)

Sample	Planktonic Foraminifers	Benthic Foraminifers	Amphistegina	Echinoderms	Molluscs	Coralline Algae	Coral	Bryozoans	Worm Tubes	Lithoclasts	Quartz	Miscellaneous	% Carbonate
DS1-9G1	40.8	28.0	0.0	13.7	7.6	o* o	0.0	0.0	0.0	0.0	5.2	0.0	0.0
DS1-1021	52.2	15.4	0,0	15.4	11.4	0.0	0.0	0.0	2.0	0.0	3.5	0.0	0 . 0
DS1-11G1	67.4	10.2	0.0	10.7	7.0	2.3	0.0	0.0	2.3	0.0	O*O	0.0	0.0
DS1-12G1	50.7	20.5	0.0	22.0	6.3	0.0	0.0	0.5	O*O	0.0	0.0	0.0	0.0
0S2-1	28.1	22.6	0.0	4.5	14.6	0.5	0.0	0.0	0.0	0.0	27.6	2.0	0.0
DS2-2	29.3	16.2	0.0	2.3	5.0	2.3	0.0	0.5	0.5	0.0	41.9	2.3	O*O
0S2-3	26.1	13.8	0.0	4.9	13.3	0.0	0.0	0.0	1.5	0.0	39.4	1.0	0.0
DS2-4	28.2	23.6	0.0	2.1	3.2	8.2	0.0	0.0	1.1	0.0	32.1	1.4	0.0
DS2-5	45.5	31.5	0.0	2.8	10.3	1.4	0.0	o" o	0.0	0.5	7.5	0.5	0.0
0s2-6	20.6	11.3	2.0	4.9	19.1	1.5	0.5	0.0	1.0	0.0	38,7	0.5	0.0
DS2-7	38.0	27.7	0.0	6.1	3.8	0.0	0.0	o* o	0.5	2.8	21.1	0.0	0.0
DS2-8	43.6	27.0	0.0	7.6	13.7	0.5	0.0	0.0	0.0	0.0	7.6	0.0	0.0
DS2-9	16.9	36.2	0.0	7.7	12.9	0.9	0.0	0.0	0.0	0.0	15.5	0.0	0.0
0s2-1 o	16.9	23.4	O*O	3.0	25.9	1.0	0.0	1.0	0.0	1.0	27.9	0.0	0.0
0S2-1 1	40.3	35.0	0.0	5.8	9.7	0.0	0.0	0.0	0.0	1.0	9.2	o* o	0.0
0s2-12	23.1	14.6	3.0	5.0	37.2	7.0	0.0	1.5	5.0	0.0	1.5	2.0	0.0
JAK 1	30.1	7.4	1.4	5.1	31.0	11.1	0.0	1.4	3.7	0.0	0.0	8.8	70.6
JAK 3	65.4	27.7	0.0	3.7	2.1	0.5	0.0	0.0	0.0	0.0	0.5	0.0	14.8
JAK 4	9.8	2.6	17.5	7.7	6.7	46.4	0.0	2.6	3.1	3.1	0.0	0.5	92.4
DIA 1	5.4	3.4	23.9	4.9	17.1	26.8	0.0	14.1	3.4	0.0	O*5	0.5	87.7
DIA 2	12.0	5.2	2.6	7.3	28.8	24.6	0.0	6.3	8.9	1.6	0.0	2.6	53*4
DIA 3	65.7	18.2	0.0	5.1	4.5	4.5	0.0	0.0	0.5	0.0	1.5	0.0	14.9
DIA 4	51.8	14.4	0.5	6.7	9.7	8.7	0.0	2.6	3.6	0.0	2.1	0.0	22.6
ALD 1	6.3	3.2	4.2	12.2	20.1	27.5	3.2	7.9	11.6	0 . 0	0.0	3.7	83.0
ALD 2	4.0	2.5	2.5	14.1	13.6	39.2	1.5	8.5	2.5	5.5	4.5	1.5	58.3
ALD 3	3.7	6.0	0.9	8.3	24.9	17.5	0.0	8.8	3.2	6.5	6.5	13.8	50.7
ALD 4	8.6	1.9	20.5	10.0	16.7	9.5	1.0	15.2	15.2	0.0	0.0	1.4	78.2
FIS 1	16.7	9.7	1.1	1.6	26.3	12.4	0.0	3.8	2.2	15.1	3.8	7.5	53.9
FIS 2	10.2	7.1	0.0	4.6	36.0	4.6	o* o	10.2	2.0	2.0	12.7	10.7	34.4
FIS 3	6.1	6.6	1.0	3.0	25.4	5.1	0.0	7.6	4.1	7.6	5.1	28.4	57.8
FIS 4	11.0	7.3	1.0	4.2	16.2	7.3	0.0	11.5	5.8	6.8	8.9	19.9	28.7
COF ?	1.0	1.0	0.0	O*5	3.0	0.0	0.0	0.0	0.0	1.5	90.5	2.5	12.9
COF 2	2.5	1.5	o* o	1.0	4.0	0.5	0.0	0.0	0.5	1.0	88.1	1.0	21.8
COF 3	0.5	0.0	0.0	0.5	4.0	0.0	0.0	0.5	0.5	0.0	91.5	2.5	40.2
COF 4	0.0	0.5	0.0	0.5	3.5	0.0	0.0	0.0	0.0	0.0	94.5	1.0	36.7
32F 1	0.5	1.0	0.0	0.5	2.0	0.5	0.0	0.5	0.0	0.0	95.0	0.0	0.0
32F 2	1.0	0.5	0.0	1.5	5.0	0.0	0.0	1.0	1.0	0.0	90.0	0.0	0.0
32F 4	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	1.0	0.0	95.5	0.0	0.0
32F 5	0.5	0.0	0.0	0.0	2.5	0.0	0.0	0.5	0.5	0.0	96.0	0.0	0.0
AFP	18.1	7.3	18.1	7.8	23.3	6.2	1.0	2.6	5.7	0.0	5.2	4.7	0.0

TABLE III-2
X-RAY DIFFRACTION OF SUSPENDED SEDIMENTS (Tenneco)

SAMPLE	%SMECTITE	%EXPANDABLE MIXED LAYER CLAYS	%ILLITE	%KAOLINITE	%CHLORITE
STA-1	27	- -	38	35	--
STA-2	37	—	31	32	TR
STA-3	36	- -	34	30	TR
STA-4	42	- -	39	19	TR
EFG-1	42	- -	27	31	TR
EFG-2	31	- -	28	42	--
EFG-3	NOT ENOUGH SAMPLE, BUT K >I > S				
EFG-4	- -	17	37	46	
EFG-5	38	- -	32	20	--
EFG-6	47	- -	26	27	--
EFG-7	41	—	31	28	--
EFG-8	NOT ENOUGH SAMPLE, BUT I > K (NO SMECTITE)				
EFG-9	45	—	29	26	--
EFG-10	53	- -	27	20	--
EFG-11	43	- -	31	26	--
EFG-12	29	---	33	48	
EFG-13	52	- -	28	20	TR
EFG-14	47	- -	30	23	
EFG-15	34		33	33	--
EFG-16	39	- -	38	23	--
EFG-17	42		27	31	TR
EFG-18	41	- -	37	22	TR
EFG-19	31	..-	35	34	
EFG-20	41	- -	42	17	

SAMPLE	%SMECTITE	% EXPENDABLE MIXED LAYER CLAYS	%ILLITE	%KAOLINITE	%CHLORITE
EFG-21	16		27	57	TR
EFG-22	42		28	30	--
EFG-23	14	--	44	42	--
EFG-24	15		41	44	--
EFG-25	20	--	26	54	--
EFG-26	16		36	48	TR
EFG-27	30		38	32	TR
EFG-28	—	8	42	50	
z-l	10		52	38	--
z -2	3	--	55	42	TR
z-3	39	--	36	25	
z-4-1	- -	12	55	33	--
z-4-1 I	13	--	50	37	T R ”
z-5	25		42	33	TR
Z-6	8		58	34	TR
COF-1	36	--	41	23	TR
COF-2	29		47	24	
COF-3	32		31	37	--
COF-4	- -	33	45	22	TR
ALD-1	54	--	30	16	TR
ALD-2	37		38	25	TR
ALD-3	29		43	28	
ALD-4	23		40	37	
FIS-4	35		41	24	TR

TABLE II I-5
BOTTOM SEDIMENT TEXTURE

SAMPLE	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
JAI(-1	9.95	72.83	5.06	12.17	1.79	0.72	3.29	1.48	0.91
JAK-3	0.07	1.63	56.52	41.77	7.51	7.67	1.73	-0.81	1.48
JAK-4	14.27	84.23	0.40	1.10	0.16	0.05	1.42	3.34	19.45
DIA-1	12.62	86,50	0.30	0.58	0.04	0.02	?.15	3*54	27.00
D IA-2	15.44	56.56	13.67	14.33	2.29	0.87	3.67	0.92	-0.54
D I A-3	0.72	11.62	48.08	39.58	6.66	7.31	2.74	-0.69	-0.25
D IA-4	0.79	20.69	37.28	41.24	6.56	7.56	3.11	-0.90	-0.40
ALD-1	30.57	68.04	0.52	0.86	0.03	-0.16	1.61	2.10	9.18
ALD-2	28.22	46.04	14.05	11.69	1.88	0.60	3.64	0.96	-0.34
ALD-3	52.41	27.81	8.82	10.96	0.93	-1.08	3.69	1.39	0.51
ALD-4	26.16	73.43	0.24	0.18	0.09	0.01	1.33	0.96	4.23
FIS-1	14.24	42.74	15.55	27.47	3.62	1.79	4.29	0.29	-1.58
F I S-2	7.58	36.54	33.93	21.95	4.22	4.44	3.74	0.04	-1.33
FIS-3	19.59	43.84	15.80	20.76	2.88	1.21	4.12	0.57	-1.23
F IS-4	46.29	10.39	24.40	18,92	2.55	-0.06	4.48	0.42	-1.53
COF-1	0.24	86.30	8.21	5.25	3.19	2.77	1.76	2.44	6.85
COF-2	13.56	67.02	12.35	7.08	2.59	2.67	2.76	0.66	0.70
COF-3	32.47	49.32	8.37	9.85	1.72	1.22	3.43	1.00	0.15
COF-4	0.58	98.05	0.66	0.72	2.33	2.29	0.87	3.50	34.73
32F-1	8.96	73.66	6.54	10.85	3.15	2.52	2.75	0.89	0.92
32F-2	14.42	71.91	4.21	9.46	2.69	2.45	2.90	0.76	0.68
32F-4	3.09	96.22	0.22	0.47	2.25	2.35	1.13	-0.17	10.06
32F-5	3.99	89.00	1.60	5.40	2.80	2.45	2.00	1.45	4.54
LIS-1	2.38	22.55	31*19	43.88	6.33	7.46	3.47	-o.70	-0.80
EFG1-1G	0.0	2.52	45.82	51.66	7.93	8.06	1.70	-1.00	1.99
EFG1-2G	0.0	0.01	32.74	67.24	8.50	8.63	1.37	-0.60	-0.25
EFG2-1G	0.0	4.00	39.02	56.98	7.96	8.34	1.96	-0.84	0.14
EFG2-2G	0.02	5.55	44.81	49.62	7.59	7.98	,2.10	-0.68	-0.15
EFG3-1G	23.88	52.02	5.82	18.28	2.08	0.42	3.98	1.00	-0.54
EFG3-2G	34.96	40.24	5.66	19.14	1.96	0.38	4.09	0.94	-0.72
EFG4-1G	0.11	88.47	3.30	8.12	2.68	2.06	2.25	2.08	3.65
EFG4-2G	1.65	86.53	5.27	6.56	2.61	2.09	2.23	1.80	3.23
EFG5-G	0.0	0.04	26.17	73.80	8.66	8.82	1.22	-0.66	-0.04
EFG6-G	1.69	66.16	5.90	26.25	4.67	3.62	3.12	0.49	-0.95
EFG7-G	0.10	96.48	0.82	2.60	2.11	1.72	1.54	2.84	10.91
EFG8-G	0.0	86.73	2.92	10.35	3.48	2.83	2.21	1.91	2.60
EFG9-G	O*O	85.20	4.08	10.72	3.39	2.47	2.34	1.80	2.02
EFG1O-G	0.16	9.85	36.33	53.66	7.62	8.17	2.22	-0.92	0.29
EFG1 1-G	0.0	0.07	25.17	74.76	8.73	9.03	1.35	-0.95	0.46
EFG12-G	0.0	0.0	30.82	69.18	8.54	8.76	1.40	-0.77	0.10
EFG13-G	0.04	3.24	44.99	51.74	7.86	8.07	1.81	-0.89	1.09
EFG14-G	0.08	4.73	42.13	53.07	7.85	8,13	1.92	-1.15	1.77
EFG15-G	0.10	5.00	28.79	66.11	8.26	8.61	1.87	-1.61	3.24
EFG16-G	0.0	0.02	51.98	48.00	7.90	7.92	1.52	-0.14	-0.88
EFG17-G	0.0	7.22	32.93	59.85	7.95	8.47	2,10	-1.01	0.30
EFG18-G	0.02	60.53	15.13	24.32	4.78	3.21	3.06	0.56	-1.24
EFG 19-G	0.31	32.30	23.02	44.38	6.57	7.56	3.01	-0.39	-1.22
EFG20-G	2.42	77.07	7.39	13.12	2.61	1.51	3.14	1.29	0.36
EFG21 -G	4.10	34.82	24.62	36.46	5.37	6.60	3.87	-0.34	-1.37
EFG22-G	6.21	69.46	9.99	14.34	2.51	1.04	3.43	1.09	-0.24
EFG23-G	50.18	29.73	7.31	12.79	1.19	-1.01	3.85	1.24	0.06
EFG24-G	4.31	82.86	7.33	5.49	2.68	2.28	2.15	1.52	3.48
EFG25-G	0.15	98.35	0.54	0.96	1.69	1.62	1.08	3.80	25.76
EFG26-G	30.70	69.19	0.04	0.07	-0.31	-0.34	1.06	0.79	4*55

TABLE III-5 (Continued)

SAMPLE	GRAVEL	SAND	SILT	CLAY	MEAN	MEDIAN	STD DEV	SKEWNESS	KURTOSIS
EFG27-G	0.19	94.43	2.72	2.66	2.34	2.14	1.58	2.57	9.20
EFG29-G	0.38	75.25	10.22	14.15	3.93	3.10	2.63	1.11	0.19
EFG30-G	0.18	30.66	32.70	36.45	6.32	7.09	2.89	-0.40	-1.09
EFG31 -G	17.64	48.07	15.21	19.08	3.26	2.15	3.91	0.43	-1.20
EFG32-G	10.47	63.77	11.62	14.15	2.76	1.80	3.47	0.82	-0.53
DS1-1G1	0.0	0.03	30.59	69.38	8.62	8.72	1.25	-0.47	-0.48
DS1-1G2	0.19	4.48	25.68	69.65	8.41	8.84	1.93	-1.99	5.18
DS1-2G1	0.0	0.0	47.95	52.05	8.01	8.08	1.48	-0.25	-0.77
DS1-2G2	0.04	2.01	42.83	55.12	8.08	8.21	1.68	-1.12	2.80
DS1-3G1	0.0	0.10	38.49	61.41	8.34	8.44	1.40	-0.44	-0.49
DS1-3G2	0.07	3.43	29.73	66.76	8.36	8.65	1.78	-1.85	5.11
DS1-4G1	0.39	3.07	54.55	41.99	7051	7.64	1.93	-1.07	2.61
DS1-4G2	0.88	5.78	32.08	61.25	8.02	8.49	2.25	-1.90	4.31
DS1-5G1	0.29	3.53	44.38	51.80	7.84	8.07	1.90	-1.44	3.60
DS1-5G2	0.17	3*93	32.40	63.50	8.15	8.51	1.96	-1.60	3.35
DS1-6G1	2.92	28.04	30.88	38.16	5.84	7.32	3.76	-0.64	-1.12
DS1-6G2	9.44	42.90	17.41	30.24	4.38	2.84	4.10	0.09	-1.54
DS1-7G1	0.27	3.71	42.87	53.15	7.91	8.13	1.96	-1.54	3.86
DS1-7G2	0.0	0.06	34.49	65.45	8.47	8.57	1.36	-0.57	-0.15
DS1-8G1	0.36	6.61	53.39	39.64	7.23	7*43	2.24	-1.03	1.48
DS1-8G2	0.53	7.68	35.52	56.26	7.76	8.23	2.29	-1.67	3.00
DS1-9G1	0.12	1.59	50.50	47*79	7.78	7.90	1.75	-0.82	1.71
DS1-9G2	0.0	0.02	51.32	48.65	7.88	7.94	1.57	-0.20	-0.84
DS1-10G1	0.21	3.11	32.93	63.74	8.27	8.51	1.79	-1.94	6.00
DS1-10G2	0.06	2.21	32.14	65.58	8.35	8.61	1.72	-1.54	3.87
DS1-11G1	0.08	2.75	35.12	62.05	8.25	8.48	1.74	-1.54	4.03
DS1-11G2	0.02	1.57	28.24	70.17	8.54	8.73	1.50	-1.60	4.85
DS1-12G1	0.72	2.59	29.26	67.43	8.32	8.80	1.98	-2.01	5.86
DS1-12G2	0.0	0.02	41.39	58.59	8.23	8.33	1.45	-0.39	-0.64
DS2-1-2G	0.06	3.69	47.42	48.83	7.79	7.96	1.75	-1.26	3.05
DS2-2-2G	0.54	15.05	40.24	44.16	7.08	7.69	2.61	-1.02	0.45
DS2-3-2G	1.26	10.61	36.46	51.67	7*44	8,07	2.59	-1.48	1.92
DS2-4-2G	2.76	16.82	35*94	44.48	6.81	7.71	3.09	-1.15	0.39
DS2-5-2G	0.05	2.00	40.33	57.62	8.14	8.27	1.62	-1.30	3.57
DS2-6-2G	48.48	34.56	6.42	10.54	0.81	-0.91	3.63	1.53	0.87
DS2-7-2G	1.92	18.02	27.87	52.20	7.03	8.11	3.13	-1.16	0.22
DS2-8-2G	0.35	8.49	35.96	55.19	7.71	8.23	2.34	-1.51	2.27
DS2-9-2G	0.95	2.02	34.35	62.68	8.19	8.46	1.86	-2.27	8.31
DS2-10-2G	9.12	25.06	27.16	38.66	5.58	7.15	3.97	-0.57	-1.20
DS2-11-2G	0.08	3.74	40.14	56.04	7.97	8.21	1.82	-1.57	3.91
DS2-12-2G	37.05	39.41	8.38	15.16	1.50	-0.31	4.02	1.14	-0.35
z-1	48.31	49.90	1.24	0.54	-0.74	-0.96	1.36	4.16	24.60
z-2	0.20	62.34	13.24	24.22	4.89	3.34	2.89	0.67	-1.09
z-3	0.11	71.79	9.80	18.31	4.40	3.06	2.62	1.14	-0.20
z-4	0.05	58.44	18.58	22.93	4.87	3.42	2.82	0.66	-1.13
z-5	11.63	69.10	8.16	11.11	3.12	2.68	2.90	0.72	0.49
Z-6	0.02	10.35	33.36	56.27	7.69	8.26	2.18	-0.96	0.02

TABLE III-3
X-RAY DIFFRACTION OF BOTTOM SEDIMENT < .002 mm

SAMPLE	SMEC	ILL	KAOL	CHLOR
JAK-1	74	18	8	--
JAK-2	ALGAL NODULE GRAVEL			
JAK-3	76	16	8	--
JAK-4	69	20	11	
DIA-1	73	17	10	TR
DIA-2	61	18	21	TR
DIA-3	70	19	11	--
DIA-4	71	21	8	--
ALD-1	61	28	11	TR
ALD-2	70	21	9	TR
ALD-3	75	17	8	TR
ALD-4	71	18	11	--
FIS-1	75	16	9	TR
FIS-2	71	20	9	--
FIS-3	71	19	10	TR
FIS-4	74	15	11	--
COF-1	68	19	13	
COF-2	69	10	21	TR
COF-3	79	12	9	TR
COF-4	70	18	12	TR
z-1	ALL COARSE MATERIAL			
Z-2	65	23	12	--
z-3	70	20	10	--
z-4	59	26	15	TR
z-5	75	11	14	--
Z-6	69	21	10	TR
32FM-1	30	39	31	
32FM-2	23	40	37	--
32FM-3	33	33	34	
32FM-4	29	36	35	--
EFG-1	65	22	13	TR
EFG-2	70	20	10	TR
EFG-3	75	16	9	TR
EFG-4	71	19	10	--
EFG-13	74	17	9	TR
EFG-14	73	17	10	TR
EFG-15	77	16	7	TR
EFG-16	73	17	10	TR
EFG-17	73	17	10	TR

SAMPLE	SMEC	ILL	KAOL	CHLOR
EFG-18	76	15	9	TR
EFG-19	72	18	10	TR
EFG-20	77	12	11	TR
EFG-21	71	18	11	TR
EFG-22	75	15	10	TR
EFG-23	68	20	12	TR
EFG-24	64	22	14	TR
EFG-25	67	19	14	TR
EFG-26	61	24	15	TR
EFG-27	74	17	9	TR
EFG-28	67	20	13	
EFG-29	84	12	4	TR
EFG-30	73	18	9	TR
EFG-31	77	15	8	TR
EFG-32	62	26	12	—
0S 1-2	55	26	19	TR
0S 1-3	66	21	13	TR
0s 1-4	64	19	17	TR
DS1-5	69	15	16	TR
0S1-6	66	23	11	TR
DS 1-7	61	20	19	TR
0S 1-8	68	19	13	TR
DS 1-9	68	22	10	TR
DS1-10	64	21	15	TR
DS1-11	67	21	12	TR
0S1-12	69	19	12	TR
0S2-1	70	18	12	TR
0S2-2	67	20	13	TR
DS2-3	75	14	11	TR
0S2-4	69	20	11	TR
0S2-5	63	24	13	TR
0S2-6	68	18	14	TR
DS2-7	67	21	12	TR
0S2-8	67	19	14	TR
DS2-9	66	19	15	TR
DS2-10	63	24	13	TR
DS2-11	63	23	14	TR
0S2-12	68	21	11	TR

TABLE III-4
X-RAY DIFFRACTION OF BOTTOM SEDIMENT > .0≤2 mm

Sample	Minerals (In Decreasing Relative Abundance)
Z-1	high-Mg > arag
Z-2	qtz >> feld > low-Mg
Z-3	qtz >> feld
Z-4	qtz >> feld
Z-5	qtz >> feld > low-Mg
Z-6	no coarse fraction
JAK-1	high-Mg > low-Mg > arag > qtz
JAK-2	high-Mg >> arag > qtz
JAK-3	low-Mg > qtz > arag≈high-Mg > dolo
JAK-4	high-Mg > low-Mg > arag
DIA-1	high-Mg > low-Mg > arag
DIA-2	high-Mg > low-Mg > arag > qtz
DIA-3	qtz≈low-Mg > feld≈high-Mg≈arag
DIA-4	low-Mg > high-Mg > qtz > arag > dolo
ALD-1	high-Mg > low-Mg > arag > qtz
ALD-2	high-Mg > low-Mg > arag > qtz
ALD-3	high-Mg > arag > low-Mg > qtz
ALD-4	high-Mg > low-Mg > arag > qtz
FIS-1	low-Mg > high-Mg > arag > qtz
FIS-2	low-Mg > high-Mg > arag > qtz > dolo
FIS-3	low-Mg > high-Mg > arag > qtz > dolo
FIS-4	low-mg > arag > high-Mg > qtz
COF-1	qtz >> feld > low-Mg > arag
COF-2	qtz >> low-Mg≈arag
COF-3	qtz > arag > low-Mg > feld high-Mg dolo
COF-4	qtz > arag≈feld≈low-Mg > high-Mg
32F-1	qtz >> arag≈low-Mg > feld
32F-2	qtz >> arag > feld > low-Mg
32F-3	qtz >> arag > feld > low-Mg
32F-4	qtz >> feld >> arag >> low-Mg
32F-5	coralline algae qtz > high-Mg
32F-5	branched form qtz > high-Mg

Sample	Minerals (In Decreasing Relative Abundance)
EFG-1G1	no coarse fraction
EFG-2G1	no coarse fraction
EFG-3G1	high-Mg > arag≈low-Mg > qtz
EFG-4G1	low-Mg > high-Mg > arag≈qtz > dolo
EFG-5	low-Mg >> qtz > high-Mg > arag
EFG-6	qtz > low-Mg > feld > high-Mg≈arag
EFG-7	high-Mg >> arag > feld
EFG-8	qtz > high-Mg > low-Mg > arag > feld
EFG-9	qtz > low-Mg > feld > high-Mg > arag
EFG-10	low-Mg > qtz > feld > high-Mg > arag
EFG-11	low-Mg >> qtz > arag
EFG-12	low-Mg >> qtz > high-Mg > arag
EFG-13	low-Mg > qtz > feld > arag
EFG-14	no coarse fraction
EFG-15	no coarse fraction
EFG-16	no coarse fraction
EFG-17	no coarse fraction
EFG-18	qtz > low-Mg≈feld > arag≈high-Mg
EFG-19	qtz > low-Mg > feld > arag≈high-Mg
EFG-20	qtz > low-Mg > high-Mg > arag > dolo
EFG-21	high-Mg > low-Mg > arag > qtz
EFG-22	high-Mg > low-Mg > arag > qtz
EFG-23	high-Mg > low-Mg > arag > qtz
EFG-24	high-Mg > low-Mg≈arag > qtz
EFG-25	high-Mg > low-Mg > arag
EFG-26	high-Mg > low-Mg > arag
EFG-27	high-Mg > low-Mg > arag > qtz > dolo
EFG-28	high-Mg > low-Mg≈arag > qtz
EFG-29	low-Mg > qtz > feld > dolo≈high-Mg > arag
EFG-30	qtz > low-Mg > feld > high-Mg > arag
EFG-31	high-Mg > arag > low-Mg > qtz
EFG-32	high-Mg≈arag > low-Mg > qtz > dolo

≈ = approximately the same concentration.