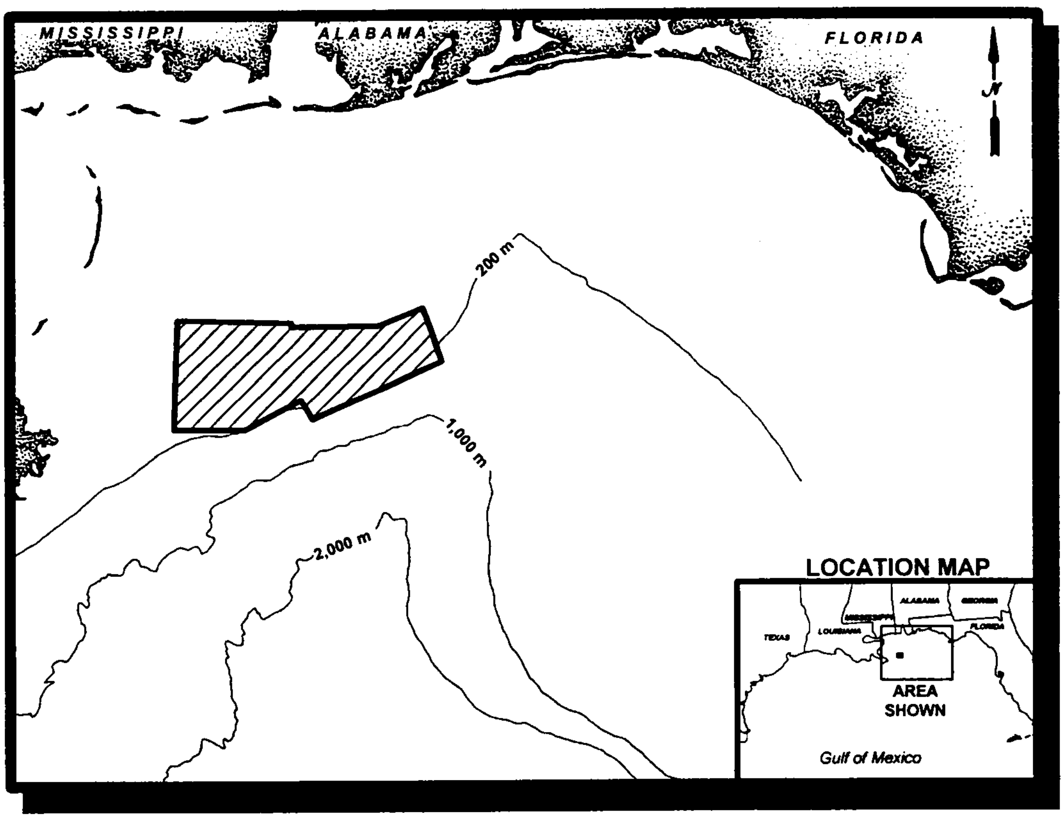
Contractor Report
USGS/BRD/CR-1997-0008
OCS Study MMS 97-0037



Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring, Mississippi/Alabama Shelf; First Annual Interim Report

U.S. Department of the Interior
U.S. Geological Survey
Biological Resources Division

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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OCS Study MMS 97-0037

Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring, Mississippi/Alabama Shelf; First Annual Interim Report

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in cooperation with the

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Acronyms

ADCP	Acoustic Doppler Current Profiler
ANOVA	analysis of variance
AVHRR	Advanced Very High Resolution Radiometer
BLM	Bureau of Land Management
BP	before present
CMAN	Coastal Marine Automated Network
CTD	conductivity/temperature/depth
CVAAS	cold vapor atomic absorption spectrophotometry
DEM	digital elevation model
DO	dissolved oxygen
ELAS	Earth Laboratory Analysis System
EOM	extractable organic matter
EPA	Environmental Protection Agency
FAAS	flame atomic absorption spectrophotometry
GC/FID	gas chromatography/flame ionization detection
GC/MS	gas chromatography/mass spectrometry
GFAAS	graphite furnace or flameless atomic absorption spectrophotometry
GIS	geographic information system
GPS	Global Positioning System
INAA	instrumental neutron activation analysis
KD	Kuderna-Danish
LATEX	Texas-Louisiana Shelf Circulation and Transport Process Program
MAFLA	Mississippi-Alabama-Florida
MAMES	Mississippi-Alabama Marine Ecosystems Study
MASPTHMS	Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study
MDL	method detection limit
MMS	Minerals Management Service
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
OBS	optical backscatter
OCS	outer continental shelf
PAH	polycyclic aromatic hydrocarbon
PAR	photosynthetically active radiation
QA/QC	quality assurance/quality control
ROV	remotely operated vehicle
SAIC	Science Applications International Corporation
SIM	selected ion monitoring
SOP	standard operating procedure
TAMU	Texas A&M University
TIC	total inorganic carbon
TOC	total organic carbon
TPH	total petroleum hydrocarbons
UCM	uresolved complex mixture

Chapter 1
Executive Summary

This Annual Interim Report summarizes the first year of a four-year program to characterize and monitor hard bottom features on the Mississippi/Alabama outer continental shelf (OCS). The "Northeastern Gulf of Mexico Coastal and Marine Ecosystems Program: Ecosystem Monitoring, Mississippi/Alabama Shelf" is being conducted by Continental Shelf Associates, Inc. and the Geochemical and Environmental Research Group of Texas A&M University, for the U.S. Geological Survey (USGS), Biological Resources Division.

The program consists of an integrated suite of reconnaissance, baseline characterization, monitoring, and process-oriented "companion studies." Based on previous studies and new geophysical reconnaissance, nine hard bottom sites in the Mississippi-Alabama pinnacle trend area have been selected for study (Figure 1.1). The central focus of the program is monitoring of hard bottom community structure and dynamics. The potential sensitivity of these communities to OCS oil and gas industry activities is of interest to the Minerals Management Service (MMS), the client agency for whom the USGS is administering this program. Other monitoring components (geological and oceanographic processes) are needed to provide an understanding of the dominant environmental processes that control or influence hard bottom communities. These may include substrate characteristics such as relief, microtopography, sedimentology, and contaminant levels, as well as water column characteristics such as temperature, salinity, dissolved oxygen, near-bottom current patterns, and the presence and extent of the bottom nepheloid layer. Geological characterization is also needed to help understand the origin, status, and probable fate of the pinnacle features. In addition, two companion studies have been designed to complement monitoring by providing information on benthic recruitment and micro-habitat environmental influences on community dynamics.

Objectives

The overall goal of this program is to characterize and monitor biological communities and environmental conditions at three distinct types of topographic features along the Mississippi-Alabama OCS: (1) high relief pinnacles; (2) medium relief pinnacles; and (3) low relief hard bottom. Specific objectives are as follows:

- To describe and monitor seasonal and interannual changes in community structure and zonation and relate these to changes in environmental conditions (i.e., dissolved oxygen, turbidity, temperature, salinity, etc.); and

- To determine the origin, current state, and probable future of these structures, both biologically and geologically.

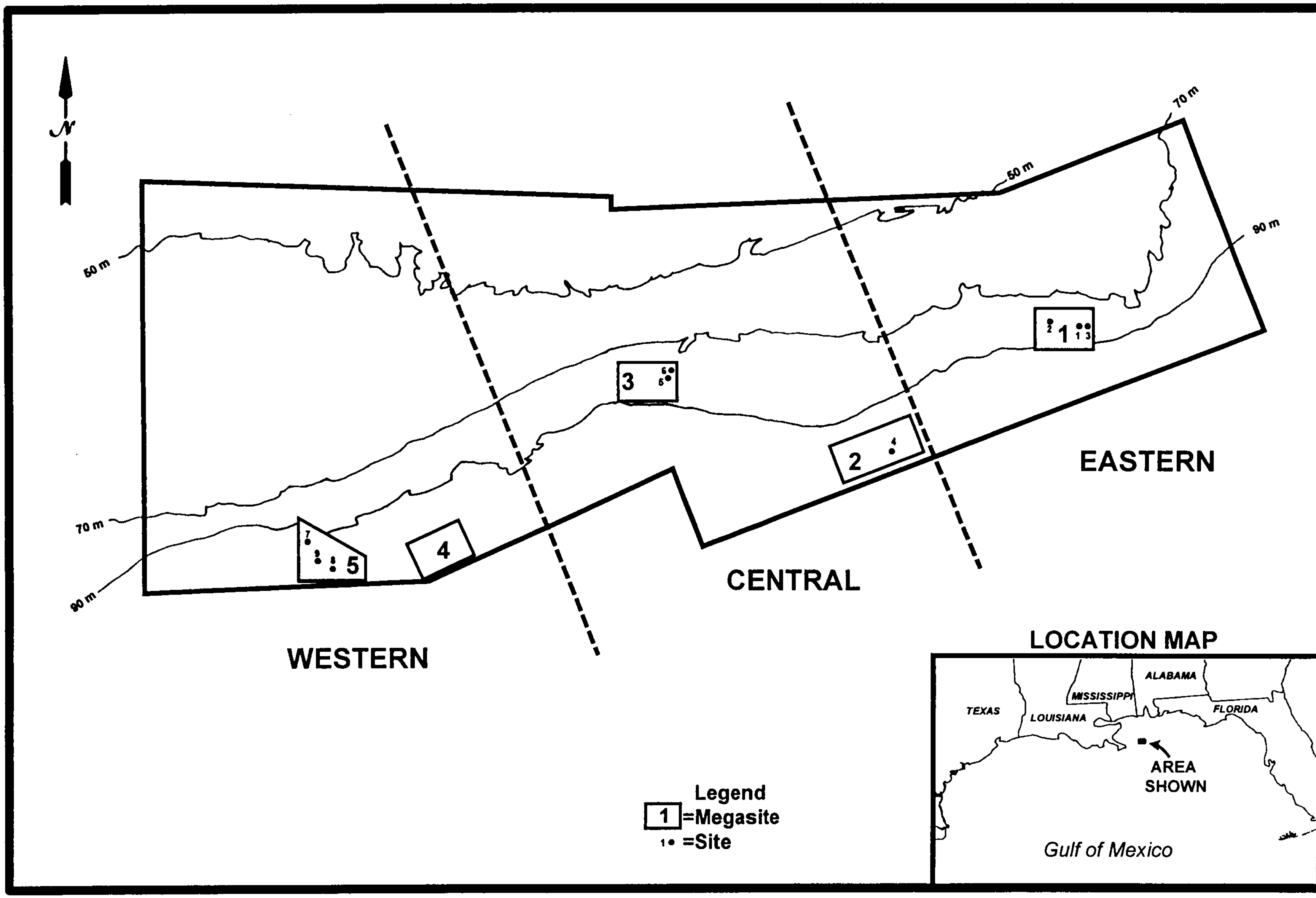

Fig. 1.1. Locations of final monitoring sites.

Phases and Cruise Scheduling

The program consists of four phases, each lasting approximately 12 months:

- Phase 1: Reconnaissance, Site Selection, Baseline Characterization, Monitoring, and Companion Studies;
- Phase 2: Monitoring and Companion Studies;
- Phase 3: Monitoring and Companion Studies; and
- Phase 4: Final Synthesis.

Phase 1, the subject of this report, included three cruises. Cruise 1A (6-22 November 1996) was a geophysical reconnaissance of five megasites containing potential monitoring sites. Cruise 1B (21-24 March 1997) was a visual reconnaissance to check out a few candidate sites that had no previous video or photographic data. The cruise also served to field test the remotely operated vehicle (ROV) and monitoring techniques. Cruise 1C (7-18 May 1997), which was conducted after nine final sites had been selected and approved, was the first of four cruises during which monitoring and companion studies are to be conducted. Activities during this first monitoring cruise included setting up fixed stations, collecting samples and data, and deploying oceanographic and biological moorings.

Monitoring and companion studies will continue during Phases 2 and 3 with Monitoring Cruise 2 (October 1997), Monitoring Cruise 3 (April 1998), and Monitoring Cruise 4 (April 1999). In addition to the monitoring cruises, five Mooring Service cruises will be conducted, with the first occurring in late July 1997.

This report is the first of three Annual Interim Reports summarizing methods and results of Phases 1-3. During Phase 4, a Final Synthesis Report will be produced in which all findings will be summarized, analyzed, synthesized, and discussed in relation to historical data from the region.

Site Selection

The contract specified that a total of nine sites be selected, including high (>10 m), medium (5-10 m), and low (<5 m) relief sites in the eastern, central, and western portions of the study area. Other factors considered in site selection were representativeness, availability of existing video and photographic data, and previous oil and gas industry activities. Site selection involved the following steps:

- *Megasite Selection.* Prior to Cruise 1A, five large areas ("megasites") were selected for geophysical reconnaissance. The selection of the five megasites was based on geophysical data collected during the Mississippi-Alabama Marine Ecosystems Study

(MAMES; Texas A&M University 1990) and the Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS; Continental Shelf Associates, Inc. 1992). The megasites were selected because they were known to contain numerous features of varying relief (candidate sites) and could be surveyed within the time and financial restrictions of the contract.

- *Geophysical Reconnaissance and Preliminary Site Selection.* During Cruise 1A, the five megasites were surveyed using swath bathymetry, high-resolution side-scan sonar, and subbottom profiler to produced detailed maps. After the initial survey of all five megasites, small subsets were chosen for higher resolution mapping. After the cruise, we prepared a list of candidate high, medium, and low relief features within the megasites and tabulated the historical video and photographic data. At this point, three high relief and two medium relief sites were tentatively selected.

- *Visual Reconnaissance.* Three low relief sites and one medium relief site lacking previous video or photographic data were identified as needing visual reconnaissance. During Cruise 1B, these features were surveyed briefly using an ROV to determine whether a hard bottom community was present. All of the sites visited during Cruise 1B were ultimately chosen as final sites.

- *Final Site Selection.* After the completion of Cruises 1A and 1B, the program managers and key principal investigators prepared a final site list. Site selection was discussed and approved during a teleconference with the USGS Contracting Officer's Technical Representative, the Scientific Review Board, and the program principal investigators.

Chapter Summaries

The main body of the Annual Interim Report consists of Chapters 2-11. Chapter 2 (Introduction) discusses the rationale and historical background for the program and summarizes program objectives, phases, components, and report contents and organization. Chapter 3 includes site selection, cruise summaries, and data management. These are followed by chapters describing the individual components of the program:

- Reconnaissance and Megasite Descriptions (Chapter 4);
- Geology/Sediment Dynamics (Chapter 5);
- Geochemistry (Chapter 6);
- Physical Oceanography/Hydrography (Chapter 7);
- Hard Bottom Communities (Chapter 8);
- Fish Communities (Chapter 9);
- Companion Study: Micro-Habitat Studies (Chapter 10); and
- Companion Study: Epibiont Recruitment (Chapter 11).

Chapter summaries are presented below for each component. Because of the time required for data analysis and interpretation following Cruise 1C (May 1997), only preliminary results are available from that cruise (and only for some disciplines).

Reconnaissance and Megasite Descriptions (Chapter 4)

Five survey areas, each containing approximately 20-30 km^2, were chosen for detailed study from within the areas surveyed on the Mississippi-Alabama OCS in previous MMS-funded studies. These areas were termed "megasites" to distinguish them from smaller areas, several hundred meters square, of intensive study. Each contains some combination of small, medium, and high relief carbonate mounds and was chosen to represent typical mounds and their environs. The megasites were surveyed during Cruise 1A, November 1996, using the *TAMU*^{2} digital side-scan sonar and an X-STAR 2-12 kHz chirp subbottom profiler onboard the M/V OCEAN SURVEYOR. Approximately 150 km^2 were covered with 835 km of geophysical track lines spaced 150 to 175 m apart. During Cruise 1C, an additional 200 km of chirp sonar subbottom profiles were collected to enhance the geophysical data grids over detailed study sites. Descriptions of Megasites 1-5 based on the geophysical surveys are presented in Chapter 4.

The *TAMU*^{2} data yield seafloor backscatter images (topographic features and sediment texture differences) as well as digital bathymetry. The X-STAR chirp sonar data show the upper sediment layers. The data show a diverse array of mounds with widths of meters to hundreds of meters and heights from less than a meter to greater than 10 m. In subbottom records, these mounds are typically associated with shelf edge sedimentary structures. Sonar images usually show high backscatter around the mounds, which subbottom profiles indicate are often areas of erosion. Grabs indicate the high backscatter is related to sediment texture. Together, these data imply that the mounds have had an effect on long term sediment distribution leading to differential erosion and deposition in their vicinity.

Geology/Sediment Dynamics (Chapter 5)

The geology/sediment dynamics component concerns the origin and evolution of, characteristics of, and sedimentation regime around carbonate mounds on the Mississippi-Alabama OCS. This work has been divided into three main subtasks: geological characterization, sediment dynamics, and mound history.

The geological characterization subtask seeks to use geophysical mapping and geologic sample analyses to (1) define the seafloor topography at and around each study site; (2) determine how topographic highs affect sediment distribution; (3) geologically characterize the sites, including composition, origin, probable fate, roughness, and friability; (4) determine subtle differences of orientation, size, and morphology; (5) characterize substrate; and (6) determine the distribution of sediment types. This work includes the use of high-resolution side-scan sonar mapping to measure large-scale physical characteristics, such as shape and gross roughness; the use of high-resolution subbottom profiler records to examine long term sedimentation; and examination of ROV videos to characterize the small scale geology. Preliminary geological characterization of megasites has been completed and is presented in Chapter 4. Additional site-specific analyses, mapping, and interpretation are ongoing.

The objectives of the sediment dynamics subtask are to (1) provide quantitative and qualitative measurements of the extent and occurrence of the nepheloid layer; (2) determine sedimentation and resuspension rates; (3) determine how topographic highs affect present-day sedimentation; (4) determine temporal variations in sediment texture; and (5) relate short term sediment dynamics to long term sediment accumulation. These objectives are being addressed by using sediment traps, optical backscatter (OBS) instruments, and conductivity-temperature-depth/dissolved oxygen (CTD/DO) sensors to assess and monitor the extent and variability of the nepheloid layer and resuspension at the study sites in order to assess the impact of these processes on the biological community. Sediment dynamics data collection began with Cruise 1C during May 1997, when 18 sediment traps were deployed on six moorings. These will be recovered on the first servicing cruise in late July 1997. Therefore, no data were available in time for inclusion in this report.

The mound history subtask focuses on the origin, developmental history, and future fate of the calcareous mounds. The long term history and fate of the calcareous mounds is a difficult but important problem to address. This part of the program was originally envisaged as a larger effort with sampling and analyses specifically targeted at obtaining samples from the mounds to be used for dating, isotopic analyses, and other techniques. However, reductions in scope have removed most of the sample gathering and analysis planned for this subtask, so progress in this area will have to rely on clues from the geophysical data and chance recoveries of mound samples in grabs and by collateral ROV collections.

Geochemistry (Chapter 6)

The geochemistry program component includes a combination of hydrocarbon, trace metal, grain size, total organic carbon (TOC), and total inorganic carbon (TIC) measurements of sediments and sediment trap materials. Contaminant measurements are intended to document the current hydrocarbon and trace metal concentrations within the study sites. Sediment characteristics (grain size, TOC, TIC) will aid in the determination of the origins of sediment at the sites and provide a basis for discerning the relationship between sediment texture and biological patterns at the study sites. Trace metals, TOC, TIC, mass, and grain size will be measured in sediment trap materials to aid in determining the origins of sediments at the sites and to document whether contaminants are accumulating at the sites during the duration of the study. No geochemistry data were available in time for inclusion in this report.

Physical Oceanography/Hydrography (Chapter 7)

Physical oceanographic and hydrographic data are needed to understand both the geological and biological processes of the pinnacle features. Data from moored instrument arrays, hydrographic profiles, and collateral sources will allow a characterization of regional and local current dynamics and help understand the dynamics of important environmental parameters including temperature, salinity, dissolved oxygen, and turbidity. Currents and hydrographic variables are potentially important direct and indirect influences on hard bottom communities and could account for differences both within and between sites.

The oceanographic processes effort consists of the following principal elements:

- *Instrument Moorings*. Six, 18-m high, bottom-mounted, instrument moorings have been deployed at selected hard bottom sites to continuously measure current velocity, temperature, conductivity/salinity, dissolved oxygen, and turbidity. The moorings also have sediment traps to accumulate suspended sediment samples.

- *Hydrography*. Vertical profiles are being collected using the same CTD/DO/transmissivity/ light instrument package used during the Texas-Louisiana Shelf Circulation and Transport Process Program (LATEX) to obtain more detailed information about the processes in progress during each monitoring cruise.

- *Collateral Data*. Collateral data, such as satellite images, satellite altimetry, river discharge, coastal wind and sea level data, and buoy observations of wind, waves, barometric pressure, air and sea temperature, are being obtained to define the primary forcing mechanisms.

During Cruise 1C, hydrographic profiling was conducted and six oceanographic instrument moorings were deployed. Four are "permanent" moorings that will be maintained throughout the program to provide continuous long-term, time-series data. The permanent moorings were placed at three medium and high relief features located near the 100 m isobath and at a low relief site in shallower water near the 60 m isobath. The three deeper ones will give us significant along-isobath coverage of the outer shelf, which in turn will provide data about the cross-isobath exchange of water-mass properties between the outer shelf and the slope/open ocean. The shallower site when paired with a deeper site will yield some information about cross-isobath correlation.

The fifth and sixth moorings are re-locatable. They have been placed initially at the eastern-most high relief site to form, in conjunction with the permanent mooring, a triangular pattern. The two re-locatable moorings will be moved at 6-month intervals to each of the other three sites. The objective is to observe any differences in the current flow and water properties around the features.

The instrument moorings were deployed in May 1997 and the first mooring service cruise is scheduled for late July; therefore, no data are available from these instruments. However, hydrographic profiles from Cruise 1C are presented in Appendix A.

Hard Bottom Communities (Chapter 8)

Hard bottom communities at nine sites are being monitored through visual observations and collections from an ROV. These data will help us to understand spatial and temporal variability within sites and will allow statistical comparisons among sites differing in relief, water depth, and proximity to the Mississippi River (among other factors).

At each site, random photographic stations and random video transects are being surveyed during each monitoring cruise. The random quantitative photographs will be used to estimate the abundances of sessile and motile epibenthos, whereas video images will be used to quantify larger and more motile organisms and to broadly characterize substrates and species composition. In addition, fixed video/photoquadrats have been established which will be revisited on subsequent cruises; the data will be used to describe temporal changes including growth, recruitment, and mortality. Voucher specimens are also being collected to aid in species identification. Together with geological and oceanographic data collected during the program, these data will be analyzed and interpreted to describe hard bottom community dynamics, spatial variability, and relationships with the physical environment.

Quantitative data from hard bottom monitoring were not available in time for inclusion in this report. Preliminary, qualitative site descriptions are presented based on ROV observations.

Fish Communities (Chapter 9)

Fish communities are being studied by analyzing photographs and videotapes recorded from the ROV during hard bottom community monitoring. Trophic interrelationships are being studied by reviewing literature from the Gulf of Mexico and South Atlantic Bight. In future reports, these data and literature will be used to describe fish communities associated with the pinnacle features and delineate their ecological roles.

Quantitative fish community data were not available in time for inclusion in this report. However, a preliminary table of fish taxa observed at each site is presented based on ROV observations.

Companion Study: Micro-Habitat Studies (Chapter 10)

The micro-habitat companion study involves independent analysis of photographs and video collected during hard bottom community monitoring in relation to environmental data. The analysis will focus on fine-scale factors such as microtopography, orientation, substrate characteristics, small-scale current patterns, and gradients in chemical contaminants. Geographic information system (GIS) data management and analysis will be used to evaluate and categorize each photograph within the entire data set (about 6,000 photographs in all) with regard to structural and dynamical determinants of micro-habitat. These results will combine the descriptive statistics forthcoming from the hard bottom community structure and dynamics effort with the micro-habitat categorizations in a cross-cutting design. The micro-habitat study will provide a control on the within-site variability of the sessile community that can be used to bound the between-site and temporal comparisons.

The micro-habitat effort will also independently analyze selected sets of photographs and video transects for fine-scale determination of substrate preference. This effort will be combined with the geological interpretation of the side-scan sonar images, any chemical gradients evident from the Phase 1 baseline characterization, and geological descriptions of the sites. The micro-habitat study will also seek to determine indicator species among the hard bottom epifauna that are associated with healthy micro-habitats.

No data from the micro-habitat companion study were available in time for inclusion in this report.

Companion Study: Epibiont Recruitment (Chapter 11)

The goal of this companion study is to support the descriptive and monitoring portions of the program with experiments (based on testable hypotheses) that define the ecological mechanisms responsible for spatial and temporal changes in hard bottom epifauna. The spatial and temporal variation of hard bottom communities is a functional response to primarily three biological processes: recruitment, competition, and predation. Abiotic processes that effect spatial and temporal variability in the shallow coastal zone include seasonal temperature changes, desiccation, abrasion due to waves, turbidity due to resuspended sediments, and stochastic disturbance events. In deep water (e.g., in the pinnacle habitat) temperature and desiccation are not important determinants, but abrasion, turbidity, and stochastic disturbance events may play an important role in the changes of abundance and biomass of epifauna.

A series of settling plate experiments with exclusion, settlement, and control treatments is being used to study the biotic and abiotic interactions that regulate ecological processes. The settling plates are attached to a mooring, and the entire device is called a "biomooring." There are basically two major deployments, one for a spatial and one for a temporal study. The major elements of the settling plate experiment studies are:

- A time series study at one station, with retrieval every 3 months for 2 years;
- A spatial study at four stations to last for 1 year;
- Replication of the spatial study during the second year;
- Two settling surface treatments: hard and soft;
- Three settling plate treatments: uncaged, caged, and partial cage; and
- Two heights or distances from the bottom.

The first biomoorings were deployed in May 1997 and will be retrieved in late July 1997. Therefore, there are no preliminary data to report.

Chapter 2
Introduction

This Annual Interim Report summarizes the first year of a four-year program to characterize and monitor hard bottom features on the Mississippi/Alabama outer continental shelf (OCS). The study area is shown in Figure 2.1. The "Northeastern Gulf of Mexico Coastal and Marine Ecosystems Program: Ecosystem Monitoring, Mississippi/Alabama Shelf" is being conducted by Continental Shelf Associates, Inc. and the Geochemical and Environmental Research Group of Texas A&M University, for the U.S. Geological Survey (USGS), Biological Resources Division.

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Background

The Mississippi-Alabama pinnacle trend area has been described as an important multiple use area for human commerce, fisheries harvest, recreation, and other activities, including oil and gas exploration and development (Texas A&M University 1990). The area has historically been of importance to adjacent states because of heavy demands placed on its natural resources for marine transportation, dredge dumping, and commercial and recreational fishing. Because of the petroleum industry's interest in the area and the potential for environmental impacts, an understanding of hard bottom communities and the dominant environmental processes that influence the system is critical.

Figure 2.2 shows locations of previous hard bottom surveys and studies in the region. The pinnacle trend area was first reported by Ludwick and Walton (1957), who documented a 1.6 km wide band of shelf-edge prominences in water depths ranging from 68 to 101 m.

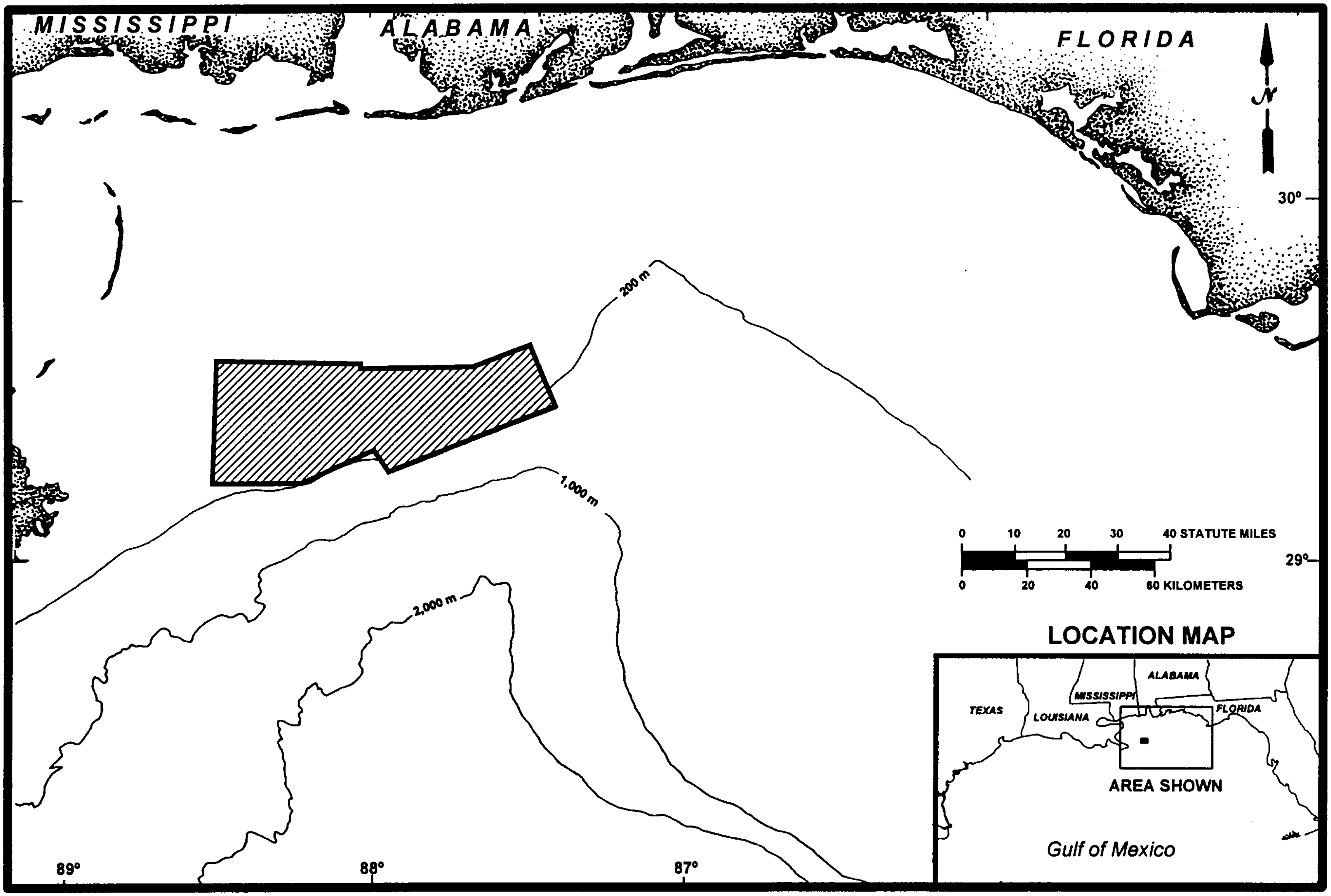

Fig. 2.1. Study area.

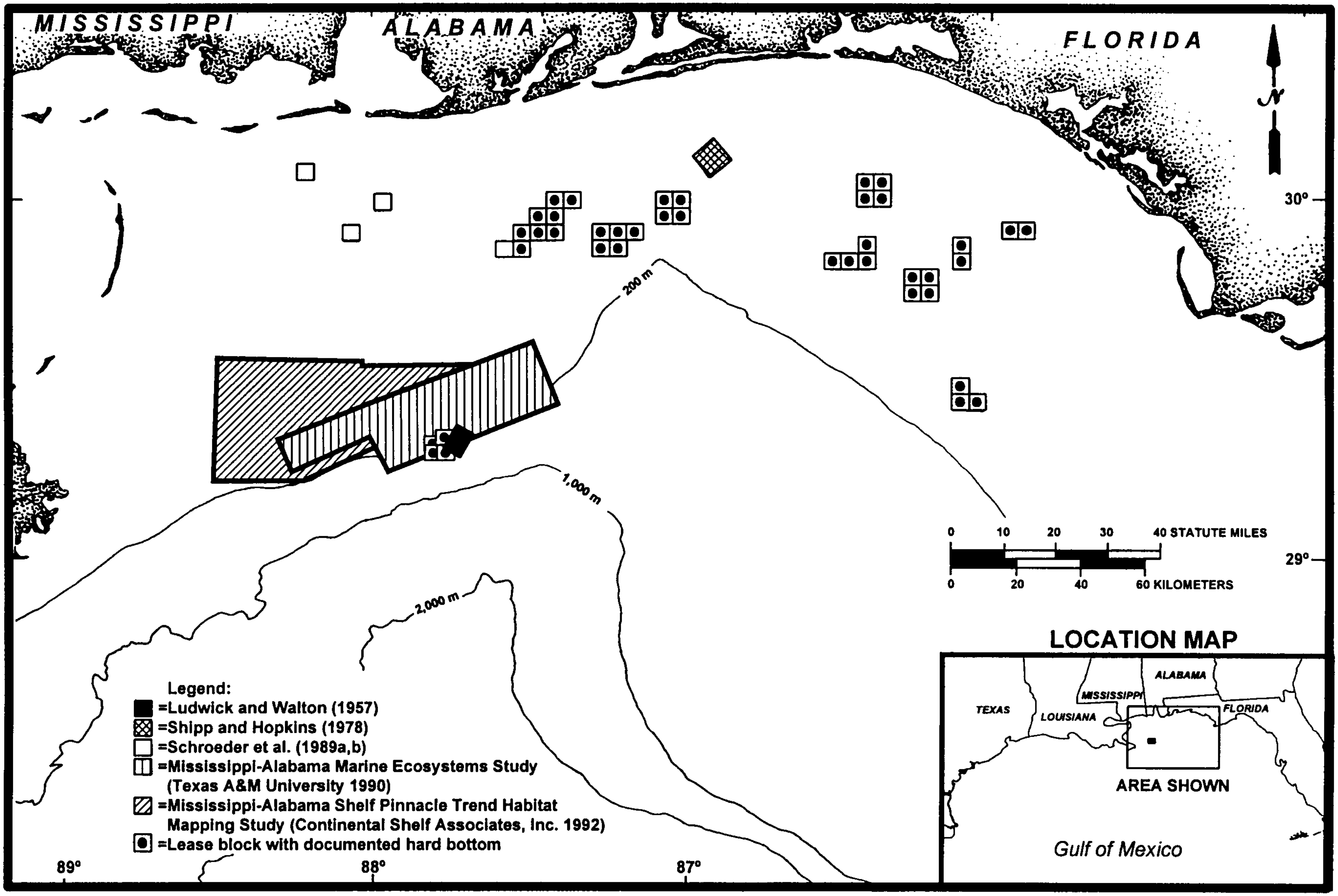

Fig. 2.2. Locations where hard bottom has been documented in the region of the study area.

The pinnacles typically had a vertical relief of about 9 m, with some having over 15 m relief. Subsequent pinnacle observations were reported during oil and gas lease block surveys by Woodward-Clyde Consultants (1979) and Continental Shelf Associates, Inc. (1985a). Two major mapping/characterization studies in the pinnacle region were subsequently funded by the MMS: the Mississippi-Alabama Marine Ecosystems Study (MAMES) (Texas A&M University 1990) and the Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS) (Continental Shelf Associates, Inc. 1992). MAMES included new field studies and provided a detailed synthesis of existing regional information about water masses and circulation, sediment characteristics and contaminants, water column biota, and soft bottom benthic communities including demersal fishes. However, information on pinnacle communities and related hard bottom features consisted mainly of descriptive observations from reconnaissance surveys.

At the conclusion of MASPTHMS, Continental Shelf Associates, Inc. (1992) identified several data needs. These included investigations to determine the origin, current state, and probable future of these structures, both biologically and geologically; investigations concerning the geographic and temporal distribution of turbidity/nepheloid layers that may occur throughout the Mississippi-Alabama shelf; and studies of species tolerance to various abiotic parameters such as turbidity.

The National Research Council (1992) has identified six objectives of obtaining information for assessing the environmental impacts of OCS oil and gas activities:

1. Characterization of major habitat types.
2. Identification of representative species (or major species groups) in the area of interest.
3. Description of seasonal patterns of distribution and abundance of representative species.
4. Acquisition of basic ecological information on key or representative species (e.g., trophic relationships, habitat requirements, and reproduction).
5. Determination of basic information on factors that determine the likelihood that various populations and communities would be affected by OCS activities, and the potential for recovery.
6. Determination of potential effects of various agents of impact (e.g., spilled oil, operational discharges, noise, and other disturbances).

Previous reconnaissance efforts in the pinnacle region have addressed the first two goals, by providing a characterization of major habitat types and identification of representative species. However, information is lacking on seasonal patterns of distribution and abundance, basic ecological information on key or representative species, and factors that determine the likelihood of impacts from OCS activities (e.g., tolerance to natural turbidity due to the presence of a nepheloid layer). The current program is intended to help address goals (3) through (5) above. Goal (6) would involve additional applied studies such as laboratory toxicity tests or monitoring around production platforms, and is beyond the scope of this program.

Commenting specifically on benthic processes, the National Research Council (1992) noted that "understanding of spatial and temporal variability in continental shelf habitats is limited, and there is little understanding of the relative vulnerability of the habitats to environmental impacts of OCS oil and gas activities." The report further noted that, "the need for only broad-scale survey work has passed. Future research should focus on process-oriented programs designed to evaluate mechanisms that control the distribution of populations and communities, such as trophic links between benthic habitats and pelagic communities. The processes by which and the rates at which populations recover from disturbance must be understood in all habitats affected by OCS-related activities."

Multidisciplinary "ecosystem" studies of hard bottom communities have been conducted on the South Atlantic OCS (Marine Resources Research Institute 1984) and Southwest Florida shelf (Continental Shelf Associates, Inc. 1987a; Environmental Science and Engineering et al. 1987; Phillips et al. 1990). These studies provided broad-scale characterization of biological communities, information on seasonal dynamics and relationships to environmental variables, and some understanding of ecological interrelationships and processes. For example, the Southwest Florida Shelf Ecosystems Study included process-oriented studies involving sediment traps, time-lapse cameras, and colonization plates, as well as coordinated primary productivity studies. More recently, an integrated suite of monitoring and process-related studies of hard bottom communities has been conducted during the California OCS Monitoring Program (Steinhauer and Imamura 1990; Hardin et al. 1994; Science Applications International Corporation 1995). The current program similarly involves an integrated, interdisciplinary approach. The results will afford an opportunity to understand processes affecting the dynamics of pinnacle trend hard bottom communities and potentially determining their susceptibility to impacts from OCS activities.

Ultimately, the information from this program may be used to aid in OCS leasing decisions and to evaluate potential lease stipulations to protect pinnacle communities during petroleum exploration and development. A series of studies during the 1970's and 1980's resulted in a biological community-based classification scheme for the Flower Garden Banks and northern Gulf hard banks (Rezak et al. 1985). These studies also documented the extent and importance of the nepheloid layer in controlling the composition of hard bottom communities. Biological, geological, and oceanographic data from these studies were used to develop lease stipulations, including shunting requirements and no-discharge zones near certain banks, which have been used successfully for many years in the northern Gulf of Mexico.

Objectives

The overall goal of this program is to characterize and monitor biological communities and environmental conditions at three distinct types of topographic features along the Mississippi-Alabama OCS: (1) high relief pinnacles; (2) medium relief pinnacles; and (3) low relief hard bottom. Specific objectives are as follows:

- To describe and monitor seasonal and interannual changes in community structure and zonation and relate these to changes in environmental conditions (i.e., dissolved oxygen, turbidity, temperature, salinity, etc.); and

- To determine the origin, current state, and probable future of these structures, both biologically and geologically.

Phases

The program consists of four phases, each lasting approximately 12 months:

- Phase 1: Reconnaissance, Site Selection, Baseline Characterization, Monitoring, and Companion Studies;
- Phase 2: Monitoring and Companion Studies;
- Phase 3: Monitoring and Companion Studies; and
- Phase 4: Final Synthesis.

The flow of events is summarized in Figure 2.3 and the schedule is given in Figure 2.4. Phase 1, the subject of this report, included two reconnaissance cruises (Cruise 1A, November 1996; and Cruise 1B, March 1997) followed by final site selection (April 1997) and the initiation of monitoring and companion studies on Baseline Characterization and Monitoring Cruise 1C (May 1997). Monitoring and companion studies will continue during Phases 2 and 3 with Monitoring Cruise 2 (October 1997), Monitoring Cruise 3 (April 1998), and Monitoring Cruise 4 (April 1999). In addition to the monitoring cruises, five Mooring Service cruises will be conducted, with the first planned for 27 July 1997.

At the end of each of the first three phases, Annual Interim Reports will be produced summarizing methods and results. Finally, during Phase 4, a Final Synthesis Report will be produced in which all data collected during Phases 1 through 3 will be summarized, analyzed, synthesized, and discussed in relation to historical data from the region.

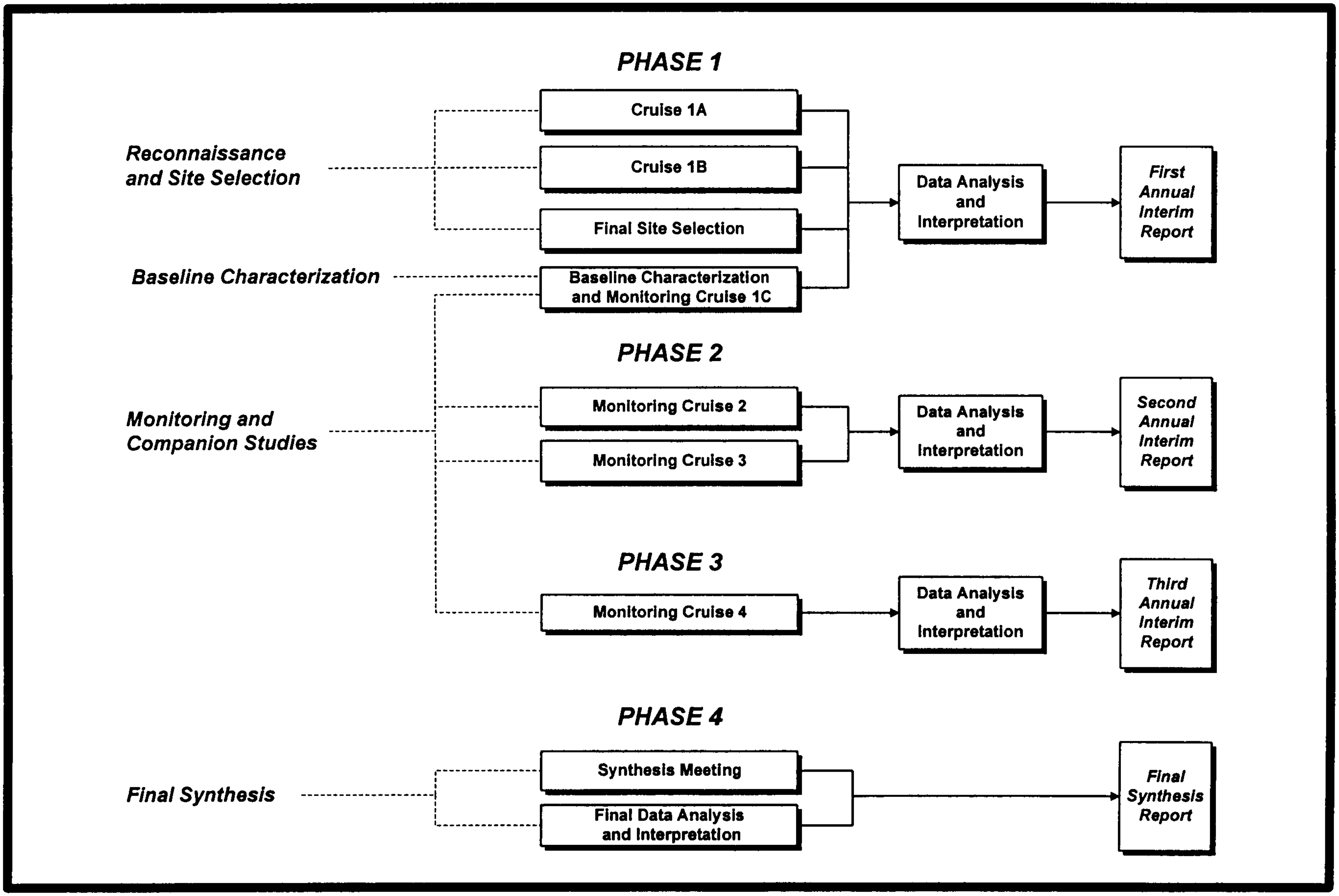

Fig. 2.3. Program flow chart.

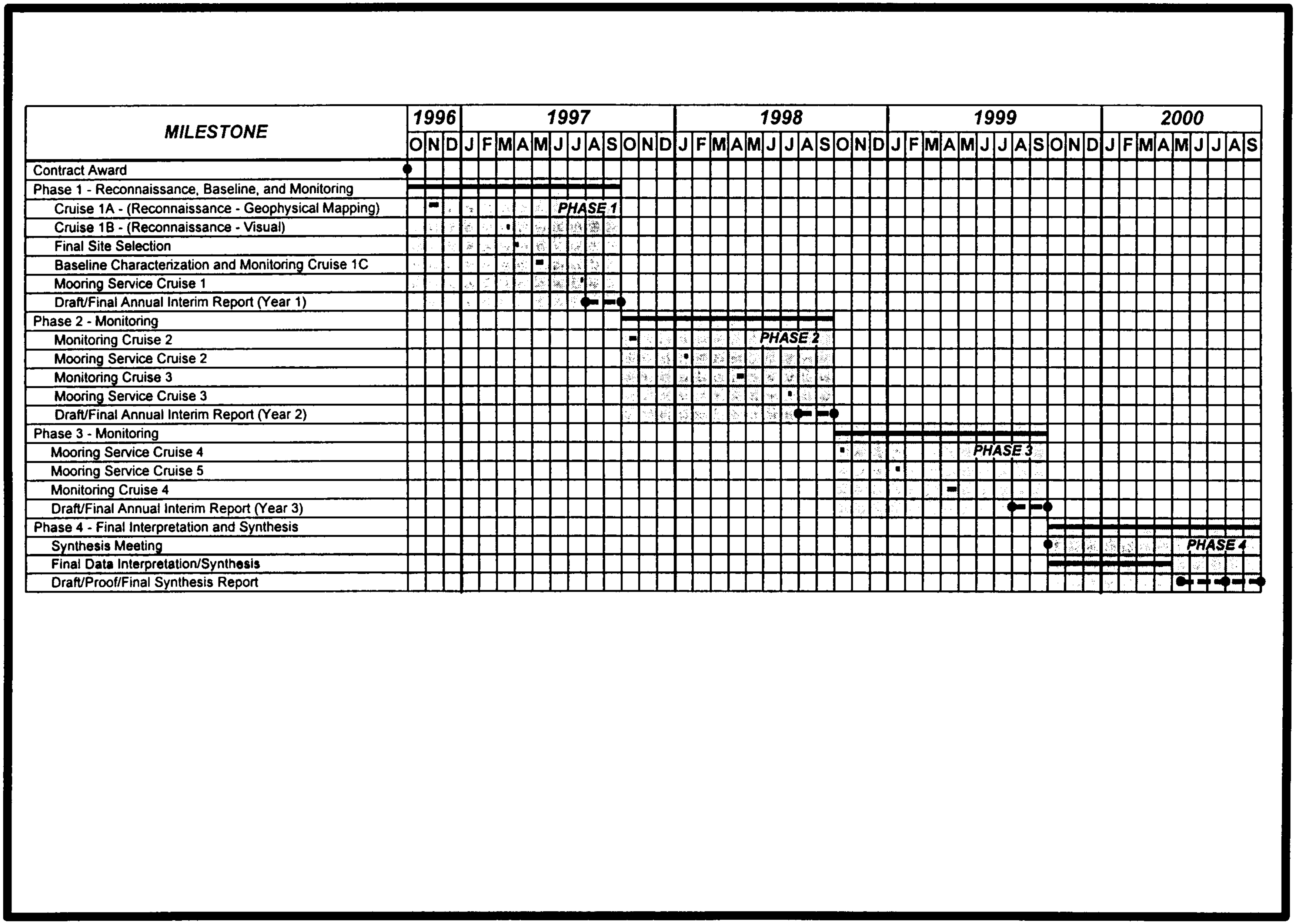

Fig. 2.4. Program schedule and milestones.

Components

The program consists of an integrated suite of monitoring and process-oriented companion studies to be conducted at the nine sites during Monitoring Cruises 1C through 4. Table 2.1 summarizes the monitoring components and companion studies, including objectives, methods, and principal investigators.

Four monitoring components form the core of the program. These are hard bottom communities, fish communities, geology/sediment dynamics/geochemistry, and physical oceanography/hydrography. Hard bottom and fish community monitoring consists mainly of video and photographic sampling at each site. These data will help us to understand spatial and temporal variability within sites and will allow statistical comparisons among sites differing in relief, water depth, and proximity to the Mississippi River (among other factors). Geophysical surveys and data from laboratory analysis of grab samples and rock collections will be used to characterize the seafloor topography, sedimentology, and geochemistry (including contaminant levels) at each site and help to understand the origin, developmental history, and probable fate of the pinnacle features. The geological component also includes monitoring of nepheloid layer dynamics using sediment traps, transmissometer and optical backscatter profiles, and optical instruments on moored arrays. The data will be a critical factor in interpreting hard bottom biology, because the nepheloid layer is known to be a major influence on hard bottom community zonation in the northern Gulf of Mexico (Rezak et al. 1985). Physical oceanographic and hydrographic data are needed to understand both the geological and biological processes of the pinnacle features. Data from moored instrument arrays, hydrographic profiles, and collateral sources will allow a characterization of regional and local current dynamics and help understand the dynamics of important environmental parameters including temperature, salinity, dissolved oxygen, and turbidity. Currents and hydrographic variables are potentially important direct and indirect influences on hard bottom communities and could account for differences both within and between sites.

The two companion studies are designed to complement monitoring by providing information on key ecological processes such as benthic recruitment, growth, and community dynamics. The first, Micro-Habitat Studies, involves independent analysis of photographs and video collected during hard bottom community monitoring in relation to geological and oceanographic data. The analysis will focus on fine-scale factors such as microtopography, orientation, substrate characteristics, small-scale current patterns, and gradients in chemical contaminants. Techniques will include statistical analysis, modeling, and fine-scale mapping using geographic information systems (GIS). The second companion study focuses on Epibiont Recruitment. Through the use of settlement plates deployed on moored arrays, this study will document the process of larval settlement, growth, and community development of hard bottom epibiota. Experimental enclosures will be used to evaluate effects of predation and disturbance.

Table 2.1. Summary of program components.

Component	Objectives	Methods	Principal Investigators
Geology/Sediment Dynamics/Geochemistry			
Site Characterization	• Define seafloor topography at/around each site • Determine how topographic highs affect sediment distribution • Geologic characterization of sites, including composition, origin, probable fate, roughness, and friability • Determine subtle differences of orientation, size, and morphology • Characterize substrate • Determine the distribution of sediment types	• Geophysical surveys (high-resolution side-scan sonar, swath bathymetry, subbottom profiler) • Grain size analysis of grab samples • Visual and laboratory analysis of photographs and rock samples • Analysis of rock samples (thin section petrography, x-ray diffractometry, scanning electron microscopy, electron microprobe, stable isotopes, ^{14}C dating)	W. Sager W. Schroeder D. Benson
Sediment Dynamics	• Provide quantitative and qualitative measurements of the extent and occurrence of the nepheloid layer • Determine sedimentation and resuspension rates • Determine how topographic highs affect present-day sedimentation • Determine temporal variations in sediment texture • Relate short-term sediment dynamics to long-term sediment accumulation	• Vertically separated sediment traps • CTD/transmissometer/OBS profiles • Optical instruments on moored arrays • ROV observations • Trace metal analysis of sediment trap samples	I. Walsh
Mound History	• Determine the origin of calcareous mounds • Determine developmental history of the mounds • Predict the future fate of the mounds	• ROV rock collections • Analyze using thin section petrography, x-ray diffractometry, scanning electron microscopy, electron microprobe, stable isotopes, ^{14}C dating	W. Sager W. Schroeder
Sediment Geochemistry	• Degree of hydrocarbon and trace metal contamination in the benthic environment at each site (Phase 1)	• Hydrocarbon and trace metal analysis of grab samples	M. Kennicutt B. Presley
Physical Oceanography/ Hydrography	• Characterize the regional and local current dynamics in the study area • Determine the dynamics of important environmental parameters including temperature, salinity, dissolved oxygen, and turbidity • Define the relationship of the current dynamics and environmental parameters to the geological and biological processes of the pinnacle features	• Moored instrument arrays (currents, suspended sediments, conductivity, temperature, and dissolved oxygen, sediment traps) • CTD/DO/transmissivity/OBS profiles • Meteorological observations • Collateral data (satellite imagery, etc.)	N. Guinasso F. Kelly

Table 2.1. (continued).

Component	Objectives	Methods	Principal Investigators
Hard Bottom Communities	• Describe hard bottom community structure and seasonal dynamics at each site • Describe differences in hard bottom community structure among sites differing in relief (high/med/low) and location (east/central/west) • Describe relationships between community structure and environmental parameters such as small-scale habitat variability, rock type, sediment cover, turbidity, and other geologic and oceanographic variables	• Random video/photographic transects and stations (ROV) • Fixed video/photoquadrats (ROV) • Collection of voucher specimens (ROV)	D. Hardin K. Spring
Fish Communities	• Describe fish community composition and temporal dynamics at each monitoring site • Identify differences in fish community composition among sites differing in relief and location • Identify relationships between fish communities and environmental parameters such as small-scale habitat variability, rock type, sediment cover, etc. • Identify trophic relationships among fishes, as well as between fishes and the epibenthic community	• Analysis of video and photographs from hard bottom community monitoring (ROV) • Literature review of trophic relationships	D. Snyder
Companion Study #1 **Micro-Habitat Studies**	• Improved understanding of relationships between hard bottom epibiota and microhabitat factors (e.g., microtopography, orientation, substrate characteristics, small-scale current patterns)	• Independent analysis and modeling of data collected during hard bottom community monitoring	I. MacDonald
Companion Study #2 **Epibiont Recruitment**	• Document process of larval settlement, growth, and community development of hard bottom epibiota	• Settling plates on moored arrays; experimental enclosures to evaluate predation and disturbance	P. Montagna

Abbreviations: CTD = conductivity/temperature/depth; DO = dissolved oxygen; OBS = optical backscatter; ROV = remotely operated vehicle.

Report Contents and Organization

This Annual Interim Report covers reconnaissance (Cruises 1A and 1B), site selection, and Baseline Characterization and Monitoring Cruise 1C. Because of the time required for data analysis and interpretation following Cruise 1C, only preliminary results are available from that cruise (and only for some disciplines).

Following this introduction, Chapter 3 describes Site Selection and General Methods. Chapter 4 summarizes the detailed geophysical reconnaissance conducted during Cruise 1A and includes descriptions of the five "megasites" from which the final nine monitoring sites were selected. Subsequent chapters present the historical background, rationale, field and laboratory methods, and preliminary data (if available) for each monitoring component and companion study. The approach for future data analysis and interpretation is also discussed in each chapter.

Chapter 3
Site Selection and General Methods

Detailed methods for each program component are included in the individual chapters. As a general framework, this chapter first discusses site selection. Cruise summaries are then presented describing general field methods. Finally, data management is described.

Site Selection

The contract specified that a total of nine sites be selected, including one of each relief type (high, medium, and low) in the eastern, central, and western portions of the study area. The relief categories were defined as follows:

- high (>10 m)
- medium (5-10 m)
- low (<5 m)

Stratification of sites by relief and longitude is reasonable, based on previous studies. Studies of hard bottom communities in the Gulf of Mexico, South Atlantic Bight, and off Southern California have shown that community structure varies greatly with substrate relief (Marine Resources Research Institute 1984; Rezak et al. 1985; Continental Shelf Associates, Inc. 1987a; Phillips et al. 1990; Hardin et al. 1994). Observations with a remotely operated vehicle (ROV) during the Mississippi-Alabama Marine Ecosystems Study (MAMES) showed that pinnacle community composition varied with relief and proximity to the Mississippi River plume. It was hypothesized that the river plume influences long-term water quality, resulting in diminished community development on hard bottom features close to the Mississippi River delta (Gittings et al. 1992b).

Other factors considered in site selection were representativeness, availability of existing video and photographic data, and previous oil and gas industry activities. The site selection process is described in detail below.

Megasite Selection

Prior to Cruise 1A, five large areas ("megasites") were selected for geophysical reconnaissance (Figure 3.1). The selection of the five megasites was based on geophysical data collected during MAMES (Texas A&M University 1990) and the Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS; Continental Shelf Associates, Inc. 1992).

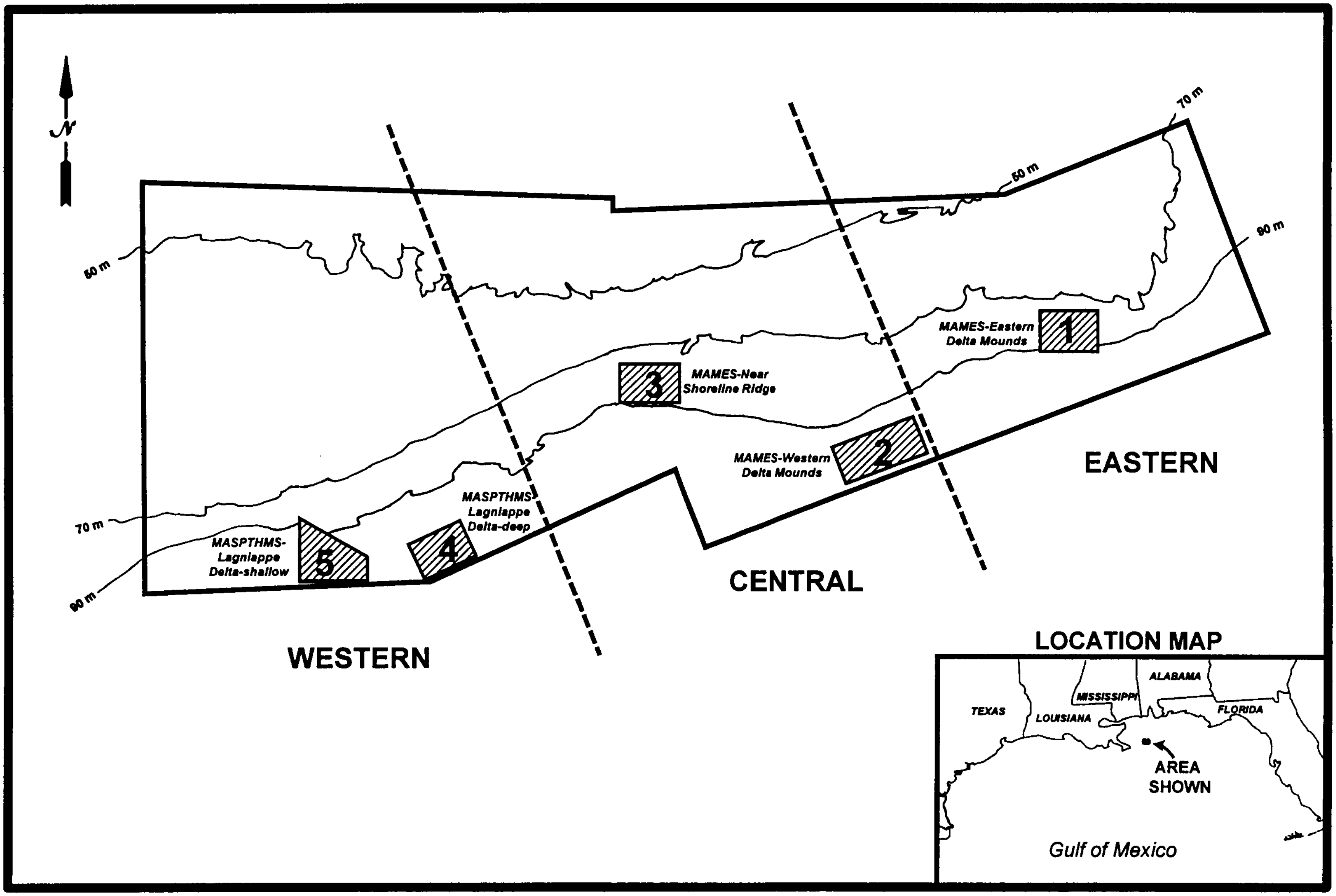

Fig. 3.1. Geographic locations of megasites surveyed during Cruise 1A.

- Megasite 1 - MAMES - Eastern Delta mounds
- Megasite 2 - MAMES - Western Delta mounds
- Megasite 3 - MAMES - Near-shoreline ridge
- Megasite 4 - MASPTHMS - Lagniappe Delta, deep
- Megasite 5 - MASPTHMS - Lagniappe Delta, shallow

The megasites were selected because they are known to contain numerous features of varying relief (candidate sites) and could be surveyed within the time and financial restrictions of the contract.

Geophysical Reconnaissance and Preliminary Site Selection

During Cruise 1A, the five megasites were surveyed using swath bathymetry, high-resolution side-scan sonar, and subbottom profiler to produced detailed maps. After the initial survey of all five megasites, small subsets were chosen within Megasites 1, 2, 3, and 5 for higher resolution mapping. Most candidate sites ultimately selected were located in these high resolution mapping areas. Chapter 4 describes the reconnaissance process in more detail.

After the cruise, we prepared a list of candidate high, medium, and low relief features within the megasites and tabulated the historical video and photographic data (Table 3.1). At this point, candidate high relief Sites 1, 5, and 7 were selected. The sites are located on flat-top mounds in Megasites 1, 3, and 5. The flat-top mounds seemed an obvious choice for the high relief category because these large, striking features were common in all three megasites and video coverage was available from the earlier MAMES and MASPTHMS surveys. Medium relief features were also selected within the high-resolution mapping areas in Megasites 1 and 2 (Sites 2 and 4, respectively). The candidate medium relief sites were located on steep-sided pinnacles, which are common in both megasites and provide a contrast to the flat-top mounds selected for the high relief category. Previous video and photographic data were available from the vicinity of Site 4.

Visual Reconnaissance

After the geophysical reconnaissance and review of historical data, we were able to select all three high relief sites and two of three medium relief sites. The main problem at this point was identifying low relief sites. A visual reconnaissance was necessary because there were no historical video or photographic data from low relief sites and because geophysical data alone cannot indicate whether a biological community is present on low relief hard bottom. For example, although geophysical data may indicate possible hard bottom, a thin sand veneer may be present which can prevent the attachment of hard bottom biota.

Four candidate sites lacking previous video or photographic data were identified as needing visual reconnaissance (Table 3.1). During Cruise 1B, these features were surveyed briefly using an ROV to determine whether a hard bottom community was

Table 3.1. Monitoring site selection in relation to types of hard bottom features and availability of previous video and photographic data. Bullets indicate the presence of each type of hard bottom feature within a megasite and whether video data were available (●) or not available (o) from previous studies. Candidate sites which were visited during Cruise 1B (visual reconnaissance) are shaded. Boxes indicate the final sites (with site numbers next to the bullets).

Type of Feature	Eastern	Central		Western	
	Megasite 1	Megasite 2	Megasite 3	Megasite 4	Megasite 5
High Relief (>10 m)					
Flat-top mounds	●1		●5		●7
Steep-sided pinnacles		●			●
Medium Relief (5-10 m)					
Steep-sided pinnacles	o2	●4[a]	o	o	o8
Low Relief (<5 m)					
Patch reefs/raised hard bottom		o	o6		
Pinnacles/mounds	o3	o	o	o	o9
Linear hard bottom	o				

[a] Previous video data were available for higher relief pinnacles in the area.

present. Candidate Sites 3, 6, and 9 were low relief sites within Megasites 1, 3, and 5. Candidate Site 8 was a medium relief site within Megasite 5. All of the candidate sites visited during Cruise 1B had hard bottom communities present and were ultimately chosen as final sites.

Final Site Selection

After the completion of Cruises 1A and 1B, the program managers and key principal investigators prepared a final site list. Site selection was discussed and approved during a teleconference with the U.S. Geological Survey (USGS) Contracting Officer's Technical Representative (COTR), the Scientific Review Board, and the program principal investigators. The final sites are shown in Figure 3.2 and summarized in Table 3.2. Additional information on determination of site size is presented in Appendix B.

Cruise Summaries

Phase 1 included three cruises. Cruise 1A was a geophysical reconnaissance of five megasites containing potential monitoring sites (as described above under Site Selection). Cruise 1B was a visual reconnaissance to check out a few potential sites that had no previous video or photographic data. The cruise also served to field test the ROV and monitoring techniques. Finally, Cruise 1C was the first of four cruises during which monitoring and companion studies are to be conducted at the nine selected sites. Activities during this first monitoring cruise included setting up fixed stations, collecting samples and data, and deploying oceanographic and biological moorings.

Cruise 1A - Geophysical Reconnaissance

Cruise 1A was conducted from 6-22 November 1996. The survey vessel was the M/V OCEAN SURVEYOR. The cruise was staged out of Pascagoula, MS.

The purpose of the cruise was to collect high-resolution digital side-scan sonar and subbottom profiler data within five megasites believed to contain potential monitoring sites. Equipment used included the *TAMU²* side-scan sonar and an X-STAR 2-12 kHz chirp sonar subbottom profiler. Navigation was accomplished with *Skyfix*, a type of differential global positioning system (GPS) navigation which provides an accuracy of 3-5 m. The position of the sonar towfish relative to the ship was determined using an ultra-short baseline acoustic ranging system.

The main problem during the cruise was poor weather. Gale conditions forced a return to port on 8-9 November and again on 14-18 November. Additional details of Cruise 1A are presented in Chapter 4 (Reconnaissance and Megasite Descriptions).

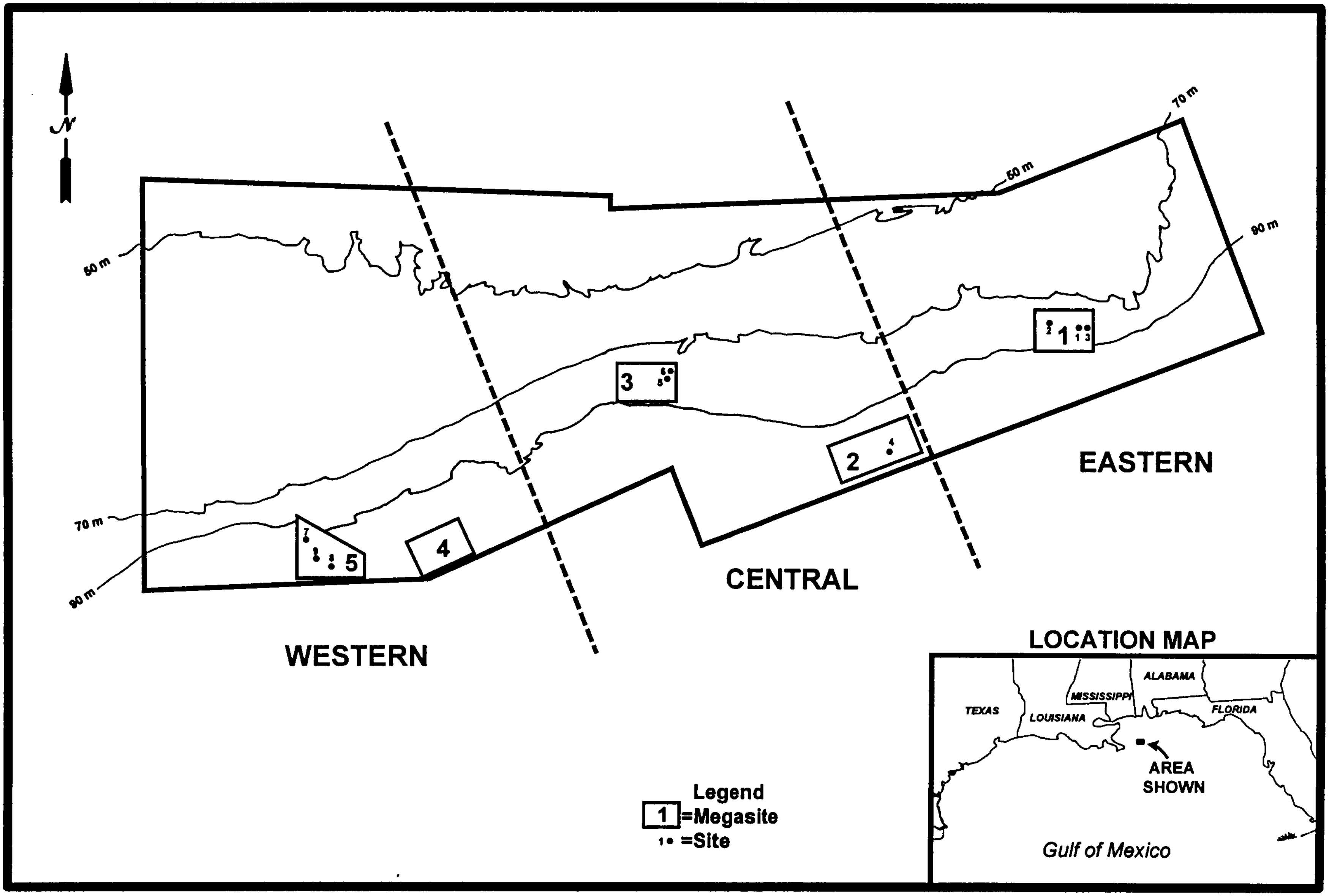

Fig. 3.2. Locations of final monitoring sites.

Table 3.2. Final monitoring sites.

Site	Area and Megasite	Relief Category	Water Depth and Lat/Long	Leasing Status	Previous Video and/or Photographic Data	Notes
1	Eastern (Megasite 1)	High	63-76.5 m 29°26'19.131"N 87°34'27.273"W	In Destin Dome Block 533 which is not leased	MAMES Video Stations 13 and 14	Site diameter 200 m. Flat top feature known as 40 Fathom fishing grounds in eastern high resolution survey area. Site extends across top of pinnacle and down the northeastern and eastern edges
2	Eastern (Megasite 1)	Medium	69.5-81.5 m 29°26'41.053"N 87°36'26.512"W	In Destin Dome Block 532 which is not leased	None	Site diameter 120 m. Steep sided pinnacle is largest within western high resolution survey area. Site includes numerous irregular outcrops with heights ranging from less than 1 m at the periphery up to 10 m toward the site center
3	Eastern (Megasite 1)	Low	76-80.3 m 29°26'15.901"N 87°34'15.266"W	In Destin Dome Block 533 which is not leased	None. First visited during Cruise 1B on 24 March 1997	Site diameter 150 m. Patchy low relief rock outcrops with diameters ranging from 1 to 10 m and relief ranging from <1 to 4.5 m
4	Central (Megasite 2)	Medium	95-107 m 29°19'39.041"N 87°46'7.849"W	In Destin Dome Block 661 which is not leased. May be within 900 m of a previous drillsite to the east-northeast in Destin Dome Block 617	MAMES Video Station 18 is in general area	Site diameter 140 m. Gradual sloping mound of hard bottom with thin sand veneer and low relief rock outcrops (0.5-2 m). Located in southern high resolution survey area
5	Central (Megasite 3)	High	62-78 m 29°23'35.930"N 87°58'51.055"W	In Main Pass Block 223 which has been leased and has a production platform	MAMES Video Station 8 is in general area	Site diameter 160 m. Flat top pinnacle with thin sand veneer in eastern high resolution survey area. Smaller outcrops along edges of pinnacle

Table 3.2. (continued).

Site	Area and Megasite	Relief Category	Water Depth and Lat/Long	Leasing Status	Previous Video and/or Photographic Data	Notes
6	Central (Megasite 3)	Low	75-78 m 29°23'52.887"N 87°58'42.610"W	In Main Pass Block 249 which has been leased and has had many exploratory wells, but no production plans	None. First visited during Cruise 1B on 23 March 1997	Site diameter 150 m. Extensive areas of low-relief rock features ranging up to about 1 m in height and covered with a thin layer of fine sediments
7	Western (Megasite 5)	High	69.5-88 m 29°15'24.844"N 88°20'21.455"W	In Main Pass Block 286 which has been leased, but no drilling plans	MAMES Video Station 33; MASPTHMS ROV Dives 1, 2, and 3	Site diameter 200 m. Flat top pinnacle known as 36 Fathom Ridge, in northern high resolution survey area. Feature has more irregular edges than the two other flat top pinnacles (Sites 1 and 5)
8	Western (Megasite 5)	Medium	88-96 m 29°13'53.857"N 88°19'01.565"W	Just east of boundary between Main Pass Block 285 (not leased) and Block 286 (leased but no drilling plans)	None. First visited during Cruise 1B on 23 March 1997	Site diameter 100 m. Rugged feature with numerous crevices and overhangs, located in the south-central high resolution survey area. Relief 8 to 9 m
9	Western (Megasite 5)	Low	89-95.5 m 29°14'19.499"N 88°19'36.859"W	In Main Pass Block 286 which has been leased, but no drilling plans	None. First visited during Cruise 1B on 21 March 1997	Site diameter 150 m. Small mounds and outcrops in the south-central high resolution survey area. Generally 0.5 to 2 m in height with diameters of 10 to 15 m. A few features with up to 5 m relief had ledges, overhangs, and crevices

Cruise 1B - Visual Reconnaissance

Cruise 1B was conducted from 21-24 March 1997. The survey vessel was the R/V TOMMY MUNRO. The cruise was staged out of Ocean Springs, MS.

The objectives of the cruise were (1) to collect information from potential sites to aid in site selection; (2) to test ROV maneuverability and the various camera, light, and laser configurations; and (3) to check sampling techniques to be used during subsequent monitoring cruises. Four low and medium relief features within Megasites 1, 3, and 5 were visited.

The ROV used during the cruise was the Benthos Openframe SeaROVER with a Python multifunction manipulator arm. The ROV proved to be very maneuverable and capable of conducting all monitoring tasks. Video, photographic, and ancillary equipment included a Sony high-resolution videocamera, DeepSea Power & Light Micro-SeaCam 2000 color videocamera, Photosea 1000 still camera and strobe, DeepSea Power & Light lasers, and a Simrad MS900 color imaging sonar. A Magnavox MX300 differential GPS was used for positioning during the survey.

Problems encountered during the cruise included additional mobilization time to integrate extra cameras and lasers with the ROV system, minor flooding of the ROV during one dive, and the loss of several ship anchors during anchor recovery operations.

Cruise 1C - Baseline Characterization and Monitoring

Baseline Characterization and Monitoring Cruise 1C was conducted from 7-18 May 1997. The survey vessel again was the R/V TOMMY MUNRO. The ROV, associated equipment, and navigation were the same as for Cruise 1B. The cruise was staged out of Ocean Springs, MS.

Each of the nine final sites was sampled during the cruise (Table 3.3). Subbottom profiling was conducted to geophysically characterize each site in more detail than was possible with the broad-scale geophysical reconnaissance cruise. Grab samples were collected for geological and geochemical analyses (see Chapters 5 and 6). Hydrographic profiling was also conducted at each station, including conductivity/temperature/depth (CTD), dissolved oxygen (DO), and transmissivity/optical backscatter (see Chapter 7).

Hard bottom and fish community monitoring was conducted at each site using the ROV. Monitoring included random video/photographic transects and stations and establishment of fixed video/photoquadrats. Voucher specimens were also collected at some sites to aid in species identification. See Chapter 8 for details of the hard bottom community methods.

Table 3.3. Baseline characterization and monitoring activities at each site during Cruise 1C. Closed circles (●) indicate activities to be repeated on Monitoring Cruises 2, 3, and 4. Open circles (o) indicate activities that will not be repeated. For oceanographic and biological moorings, the table indicates the number of moorings deployed.

	Eastern Area			Central Area			Western Area		
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Relief category -->	High	Medium	Low	Medium	High	Low	High	Medium	Low
Subbottom profiling	o	o	o	o	o	o	o	o	o
Grab sampling	●	●	●	●	●	●	●	●	●
Hydrographic profiling	●	●	●	●	●	●	●	●	●
ROV video/photo transects, stations, quadrats	●	●	●	●	●	●	●	●	●[a]
Oceanographic mooring(s) deployed	3[b]	--	--	1	1	--	--	--	1
Biological mooring(s) deployed	1[c]	--	--	8[d]	1[c]	--	--	--	1[c]

[a] Turbidity prevented the establishment of fixed video/photoquadrats at Site 9.

[b] Two of these are re-locatable moorings which will subsequently be redeployed for an interval at each of the other three oceanographic mooring sites. See Chapter 7.

[c] Biological moorings at Sites 1, 5, and 9 will be recovered after one year (Monitoring Cruise 3) and redeployed for another year (finally recovered on Monitoring Cruise 4). See Chapter 11.

[d] The biological moorings at Site 4 are for a time-series experiment. One mooring will be recovered on each subsequent Mooring Service Cruise and Monitoring Cruise until all eight have been retrieved. See Chapter 11.

Six physical oceanographic/sediment dynamics moorings were installed during the cruise. Three moorings were installed at Site 1, and one each at Sites 4, 5, and 9. Two of the moorings at Site 1 are re-locatable moorings which will subsequently be redeployed for an interval at Sites 4, 5, and 9. See Chapter 7 for further information on the moorings.

Eleven biological moorings were also deployed as part of the companion study of epibiont recruitment (see Chapter 11). Eight biological moorings were deployed at Site 4 and one mooring each at Sites 1, 5, and 9. The moorings at Sites 1, 5, and 9 will be recovered after one year (Monitoring Cruise 3) and redeployed for another year (finally recovered on Monitoring Cruise 4). The biological moorings at Site 4 are for a "time-series" experiment; one will be retrieved on each subsequent Mooring Service Cruise and Monitoring Cruise until all eight have been retrieved.

Problems encountered during the cruise included ROV cable connectors breaking, the loss of two ROV thruster motors due to use of the ROV in high currents, the stripping of gears in the manipulator arm on two occasions, high currents at Site 4 during our first site visit, high turbidity at Site 9 preventing the initial establishment of fixed video/photoquadrats, and the presence of fishing boats on Site 7 preventing the collection of additional subbottom profile data.

Data Management

A data management program has been established to monitor, control, and facilitate data flow and ensure the integrity of the data through each phase of the program. As part of this process, a program data management plan has been developed which consists of four interrelated elements: (1) data administration; (2) data control; (3) data utilization; and (4) data archiving submission.

The purpose of data administration is to ensure continuous tracking and custody of samples and data. Evidence of data possession, comparison, and security with signatures, dates, times, and location of data are noted. This element also ensures proper formatting and reporting of all data and distribution of data as required among the principal investigators.

Data control consists of monitoring the progress of data flow to identify data gaps and to facilitate further processing. The data control procedures adopted for the data management plan document data availability, data reduction, and data analysis.

Data utilization includes processing and validating data as they are submitted. The processed data are then made available to all study participants.

Finally, available data are being routinely archived to insure permanency. Procedures and protocols for data submittal to the National Oceanographic Data Center (NODC) are being developed and implemented.

Data types, formats, and procedures have been discussed and established to insure reliable and accurate data receipt and distribution. Sample inventories from the completed cruises have been developed, and a master inventory of samples received and analyses required has been completed. Data management has received cruise notes, sampling information, and position data. A sample inventory for all project components has been finalized. This includes expected cruise dates, sampling schedules, and standardized cruise, site, and station nomenclature for all work elements. This will ensure the smooth acquisition of data into the project database.

An inventory of the expected program data has been developed to insure appropriate processing and availability of data. Magnetic tape copies of the side-scan sonar, digital elevation data, and subbottom data have been submitted to data management. These data are being archived and will shortly be made available to study participants.

Chapter 4
Reconnaissance and Megasite Descriptions

Five small survey areas, each containing approximately 20-30 km^2, were chosen for detailed study from within the areas surveyed on the Mississippi-Alabama outer continental shelf in previous studies. These areas were termed "megasites" to distinguish them from smaller areas, several hundred meters square, of intensive study. Each contains some combination of small, medium, and high relief carbonate mounds and was chosen to represent typical mounds and their environs. The megasites were surveyed during Cruise 1A, November 1996, using the *TAMU*^{2} digital side-scan sonar and an X-STAR 2-12 kHz chirp subbottom profiler onboard the M/V OCEAN SURVEYOR. This chapter describes these reconnaissance surveys and their general results.

Historical Background

Prior to the late 1980's, non-proprietary geologic data from the Mississippi-Alabama outer continental shelf were sparse. Nevertheless, it was known that carbonate mounds and hard bottoms occur in this region (Ludwick and Walton 1957). Although described as partially-drowned carbonate banks, these features are nevertheless the locus of ecosystems containing abundant marine life. To assess these ecosystems, the Minerals Management Service (MMS) funded two high-density surveys of the region: the Mississippi-Alabama Marine Ecosystems Study (MAMES; Brooks 1991) and the Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS; Continental Shelf Associates 1992). Both studies mapped the occurrences of carbonate mounds, hard bottoms, and other features within an area approximately 40 x 100 km, in water depths from about 50 m to just below the shelf-edge (Figure 4.1). In general, it was discovered that there are two main trends of mounds, one near the shelf-edge in water depths of about 100-110 m and another in a band at about 75-80 m depth (Sager et al. 1992). Mound heights were found to range from less than 1 m to 15-18 m whereas diameters vary from a few meters to nearly a kilometer (Laswell et al. 1992; Sager et al. 1992).

In the MAMES and MASPTHMS surveys, geophysical data used to describe the study sites were high-frequency (100 kHz) side-scan sonars and lower frequency (3.5-4.0 kHz) subbottom profilers. Although precision navigation systems were used, resolution was limited by the spacing of the ship's tracks (typically 500-750 m), use of standard, military-degraded global positioning system (GPS) navigation in the MASPTHMS survey, lack of navigation transponders on the side-scan towfish during the MAMES survey, and large towfish laybacks owing to high ship's speeds (typically 6-8 knots). These usually limited positional accuracy to several tens of meters or more.

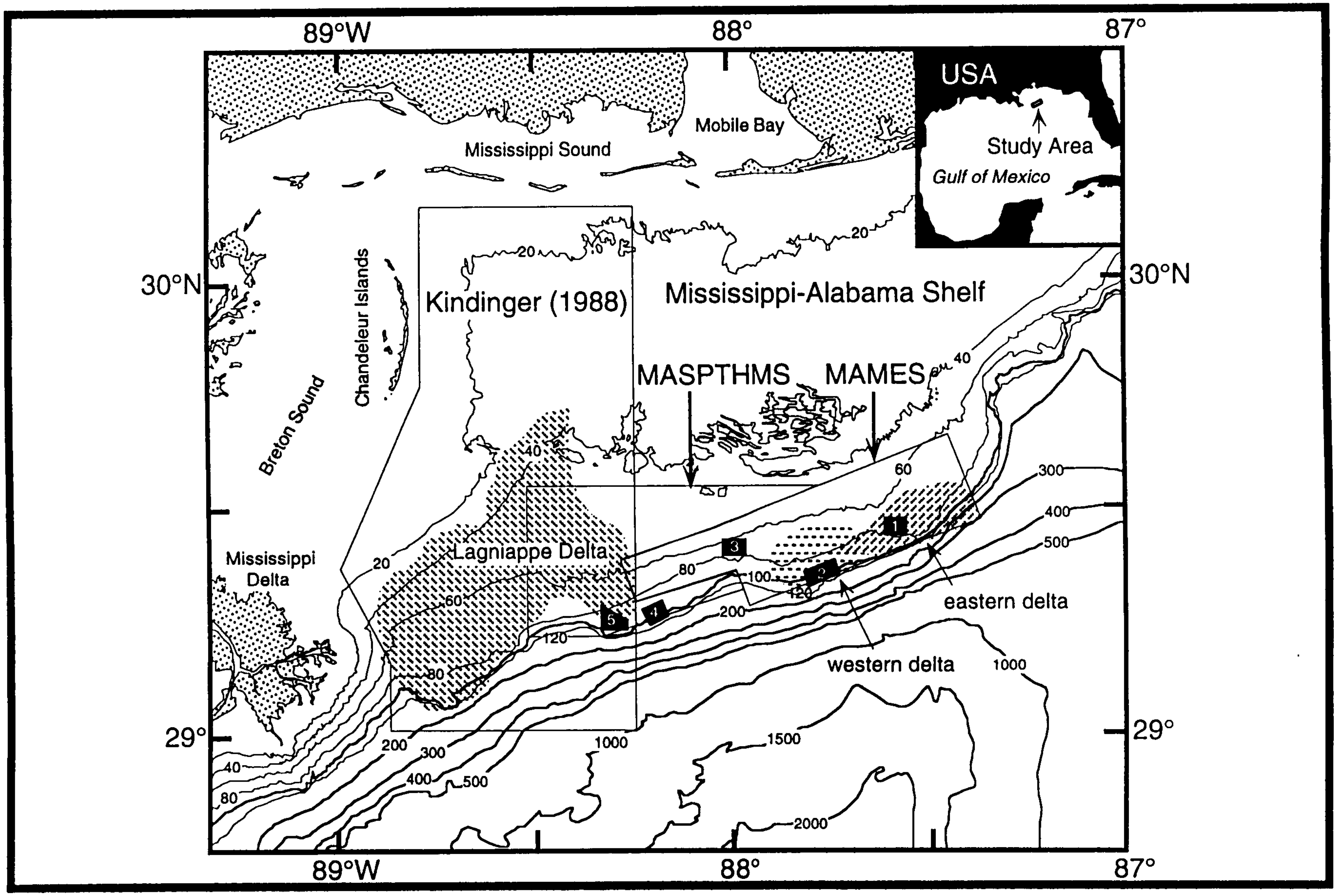

Fig. 4.1. Locations of MAMES, MASPTHMS, USGS study, and Megasites 1-5. Boxes show areas surveyed by MMS-funded MAMES and MASPTHMS studies along with the area encompassed by USGS survey (Kindinger 1988; 1989a; 1989b). Small, numbered black boxes show megasite survey areas from this study. Hachured areas show locations of shelf-edge fluvial deltas mapped with high-resolution seismic reflection data (Kindinger 1988; 1989a; 1989b; Sager et al. in preparation). Isobaths at 20 m intervals to 120 m and 100 m for deeper depths are shown for reference.

Approach and Rationale

A quantum leap over previously available data, the MAMES and MASPTHMS surveys did an adequate job of mapping the general distribution of features on the outer shelf. Nevertheless, a desire for a more detailed knowledge of the ecosystems profiled in these two surveys spurred MMS to request higher resolution data be collected in the current project. This was accomplished by three main improvements: (1) surveying on tracks spaced only 175 m apart with >100% side-scan sonar overlap; (2) using a digital side-scan sonar, *TAMU²*, to collect acoustic image and bathymetry data that can be co-located and computer processed to enhance accuracy, precision, and details; and (3) using an ultra-short baseline acoustic transponder system and a short layback to precisely determine the position of the sonar towfish relative to the ship. The *TAMU²* sonar is capable of producing sub-meter image resolution and bathymetry arrays with similar precision whereas the acoustic transponder locates the sonar within several meters. When combined with differential GPS, which has an accuracy of about 5 m, this allows the absolute horizontal location accuracy to be less than 10 m.

To balance greater survey detail with reasonable cost, it was decided that surveys for the current project would map small areas (termed "megasites") from the original MAMES-MASPTHMS study area. Project requirements dictated that low, medium, and high relief mounds be surveyed in the western, central, and eastern part of the original survey areas. Five "megasites" were chosen to contain sufficient numbers of typical mounds within an area of about 20-30 km^2 to allow an adequate characterization (Figures 4-2 to 4-6 presented at the end of this chapter). Five megasites were chosen because it was possible to survey low, medium, and high relief features in one area of the eastern region, but two megasites each were needed to characterize mounds in the central and western parts. In both of these areas, mounds are located in two depth bands and it was necessary to characterize both sets. Megasite 1, at depths of 75-95 m, is in the eastern part of the study area, Megasites 2 and 3, at depths of 100-120 m and 70-85 m, respectively, are in the central part of the study area, whereas Megasites 4 and 5, at depths of 110-140 m and 90-110 m, respectively, are in the western part of the study area (Table 4.1; Figures 4-2 to 4-6).

In addition to more-or-less north-south lines spaced 175 m apart, subsets of the five megasites were surveyed with more-or-less east-west lines spaced 150 m apart. During these "detailed" surveys the sonar swath width was cut in half and the digitization rate doubled to increase the amount of detail available in the data (Figures 4-2 to 4-6). Subbottom profiler data were collected along both sets of tracks to form a rectangular grid of closely spaced seismic reflection profiles. Furthermore, during the first monitoring cruise (Cruise 1C) an additional set of perpendicular subbottom profiler lines were collected over the "detailed" survey areas to create a data grid with 88 m (east-west) and 75 m (north-south) spacing.

Table 4.1. Megasite boundaries.

Corner	Latitude (°N)	Longitude (°W)
	Megasite 1 (east)	
NW	29° 27.455'	87° 37.213'
SW	29° 25.018'	87° 37.215'
NE	29° 27.454'	87° 33.854'
SE	29° 25.016	87° 33.857'
	Megasite 2 (central deep)	
NW	29° 29.191'	87° 49.493'
SW	29° 18.079'	87° 48.528'
NE	29° 21.840'	87° 44.775'
SE	29° 19.731'	87° 43.808'
	Megasite 3 (central shallow)	
NW	29° 24.540	88° 02.000'
SE	29° 22.268	88° 02.005'
NE	29° 24.540'	87° 58.543'
SE	29° 22.265'	87° 58.543'
	Megasite 4 (west deep)	
NW	29° 15.094'	88° 15.565'
SW	29° 12.875'	88° 13.162'
NE	29° 16.350'	88° 11.897'
SE	29° 14.035'	88° 10.638'
	Megasite 5 (west shallow)	
NW	29° 16.411	88° 20.992
SW	29° 12.836'	88° 20.993
NE	29° 14.458'	88° 17.102'
SE	29° 12.834'	88° 17.096'

Field Methods

Data were collected with the *TAMU*^{2} digital side-scan sonar system (operated by C&C Technologies, Inc. of Lafayette, LA) and an digital X-STAR 2-12 kHz chirp sonar subbottom profiler (operated by Continental Shelf Associates, Inc.). The purpose of the former was to produce swath bathymetry soundings as well as sonar backscatter images of topographic and sedimentary features. This instrument has sonar arrays using both 11/12 kHz and 72 Hz. Although the lower frequency arrays are not suitable for high-resolution imagery at shallow depths and narrow swaths, data at both frequencies were collected for comparison of backscatter signatures because this seafloor property is dependent partly on sediment texture and acoustic signal frequency. The purpose of the subbottom data was to collect images of shallow subsurface sedimentary layers. This instrument was modified from its original configuration to limit its frequency sweep to 2-10 kHz so that the upper end would not impact 11/12 kHz sonar data acquisition. Navigation was accomplished with *Skyfix* differential GPS positioning. This system provides positions with an accuracy of 3-5 m. The sonar towfish was positioned relative to the ship using an ultra-short baseline acoustic ranging system.

All of the initial surveys were done with a line spacing of 175 m and a sonar swath-width of 400 m so that the data are over 100% redundant (i.e., the sonar image from one track overlaps the adjacent tracks by 25 m on each side). This allowed features in the nadir "blind-zone" of the sonar to be mapped. Bathymetry data can only be calculated in a swath 3.5 times the towfish altitude, and in most parts of the survey this gives an overlap of 25%-50%. Most data were collected at a ping rate of 0.4 sec with 1,650 bins, giving along track and across track resolutions of about 1.25 m and 0.24 m, respectively. The binning was limited to 1,650 because at greater densities the data stream would overwhelm the computers that collected the data. During the middle of the cruise, the method of operation was slightly changed so that higher resolution data were collected in Megasites 1 and 2. In the Megasites 3-5 surveys, both 11/12 kHz and 72 kHz data were collected simultaneously on all tracks. For Megasites 1 and 2, one pass (odd or even numbered lines) was shot with both frequency sonar arrays collecting data, but the second pass was made with double the number of bins (3,300) and without collecting 11/12 kHz data. In all, 180 lines were shot totaling 797.4 trackline kilometers and covering an area of 144.5 km^2 (Table 4.2).

After the initial mapping of all five megasites, small subsets were chosen within Megasites 1, 2, 3, and 5 for higher resolution mapping using a 200-m swath width, 3,300 bins (pixels) per swath, and a track spacing of 150 m. Whereas the initial survey lines were all run either north-south or north-northwest-south-southeast, the detailed lines were run perpendicular. Within Megasite 1, two detailed surveys were carried out, one consisting of two swaths (1A-1B) over medium mounds in the northwest corner and the other consisting of six lines (1C-1H) over two large flat-topped mounds in the eastern part of the area. Two of these lines were extended to cover a portion of a field of small mounds to the east of the larger mounds.

Table 4.2. Megasite survey dimensions.

Mega-site	No. Lines	Line Nos.	Line Length	Total Length (km)	Line Trend	Dimensions (meters NS x EW)	Area (km^2)
				Main Surveys			
1	32	1-32	4,599	144,9	0°	4,500 x 5,825	26.21
2	48	33-80	4,200	201.6	348°	4,200 x 8,625	36.23
3	33	81-13	4,200	138.6	0°	4,200 x 6,000	25.20
4	29	117-145	4,500	130.5	345°	4,500 x 5,300	23.85
5	38	147-183	6,600-3,000	182.4	0°	6,600-3,000 x 6,875	33.00
				Detailed Surveys			
1	8	1A-1H	875-1,575	8.4	90°	var	1.19
2	8	2A-2H	1,225-1,400	10.7	78°	var	1.73
3	8	3A-3H	525-1,575	5.8	90°	var	1.02
5	11	5A-5K	700-3,063	12.5	90°	var	1.65

Notes: Megasites 1-4 are rectangular whereas Megasite 5 is a trapezoid. Total lines number of lines = 180. Trackline distance: main = 797.1 km; detailed = 37.4 km; total = 834.5 km. Area covered: main = 144.5 km^2; detailed = 5.6 km^2; total = 150.1 km^2.

Because it was not clear which survey megasite would provide better sites for monitoring in the central part of the study area, higher detail lines were run in both Megasites 2 and 3. The detailed surveys in Megasite 2 were also concentrated in two areas: three lines (2A-2C) over small mounds in the northeast corner and five lines (2D-2H) over large low mounds and "pinnacles" in the south-central part. Three areas were sampled in the detailed mode within Megasite 3. Two were single lines (3A, 3H) over extensive "patch reef" hard bottoms where many small mounds surmount a slightly elevated hard bottom. Six lines were run over a cluster of small flat-topped mounds and another cluster of medium mounds, both in the eastern part of the survey area. Within Megasite 5, three detailed survey lines (5A-5C) were run over medium and small mounds in the eastern part of the survey area and seven lines (5E-5K) were collected over the large, linear ridge ("36-fathom ridge") in the northwest corner of the megasite. One line, 5D, was run between the two sites along the linear trend which contains many of the mounds in that megasite. No higher detail lines were run in Megasite 4 because it is near to Megasite 5 and the features in Megasite 5 appear more interesting. A total of 37.4 km of tracklines were shot in the detailed mode, covering an area of 5.6 km^2 (Table 4.2).

Megasite Descriptions

Megasite 1

Megasite 1 was surveyed with 32 north-south trending lines each 4,500 m in length. The east-west coverage is 5,825 m (Table 4.2). The survey covers all but the westernmost 450 m of lease block Destin Dome 532 and the western 1,050 m of block Destin Dome 533. This area is within Mosaic 10 of the 1990 MAMES geophysical atlas (Laswell et al. 1990).

The most notable element of the survey is a crescentic band of large mounds (Figure 4.2), many with flat-tops, stretching from line 20, shotpoint 28, to line 13, shotpoint 18, to line 5, shotpoint 17. These mounds are surrounded by seafloor with high backscatter as well as many small and medium size mounds. The large flat-top mound at shotpoint 17 of line 7 is the one that has been visited on previous remotely operated vehicle (ROV) and submersible dives. It has a remarkably flat top, is about 400 m in length, and over 10 m in height. Small and medium sized mounds are scattered around different parts of the survey area. A field of hundreds of small mounds stretches east from the large mound. Many small mounds are scattered in the southeast part of the survey. Medium sized mounds are scattered throughout the northwestern and southwestern part of the site.

North of the large mound band are three linear hard bottoms that appear dark on the records. They have the appearance of longshore features and the subbottom profiler records suggest that their foundations may be deeper than the erosional unconformity upon which all the other mounds appear to be built.

A common feature of many mounds, large and small, is a dark area of high backscatter beginning at the mound and trending southwest. Many small and medium mounds have these features and many of these streaks are many hundreds of meters long. Many are more-or-less linear or rounded whereas some actually fan out with distance from the source mound.

Subbottom records show good penetration, typically 10-15 m, often to the unconformity formed during the last glacial period. The records typically show a thin and variable transparent layer overlying layered delta muds that dip seaward. The erosional nature of the contact between these two layers is evident on many records.

Megasite 2

Megasite 2 contains the deep (100-120 m) pinnacles originally described by Ludwick and Walton (1957). The megasite survey consists of 48 lines (33-80) oriented north-northwest, each 4,200 m in length. The east-west dimension of the survey is 8,625 m (Table 4.2). The survey completely covers lease block Viosca Knoll 654 and parts of lease blocks Destin Dome 617, Destin Dome 661, Viosca Knoll 698, Main Pass 255, and Main Pass 254 (Figure 4.3). This area was covered in Mosaic 8 of the 1990 MAMES geophysical atlas (Laswell et al. 1990).

Megasite 2 contains many steep-sided mounds with vertical relief greater than 10 m, as shown by the previous survey of the area. What was not generally appreciated before is the presence of large areas of buried mounds. In the geophysical atlas, a mound was shown in block Main Pass 255 at the western end of the survey megasite, and indeed it was into the margin of this mound that the well in that block was drilled. However, the present survey has shown that these mounds are widespread throughout the survey area (Figure 4.3).

A first glance at sonar records from the megasite shows many small to medium mounds. In the western part of the survey area, they are widely scattered and have shapes reminiscent of those in Megasite 4. In general, the mounds become larger eastward. Many of the mounds, particularly in the eastern part of the megasite, are lineated along the track direction or form curvilinear chains that have an overall trend in the same direction. These mounds and chains often enclose areas of slightly elevated backscatter (higher acoustic return). Indeed, high acoustic backscatter is associated with and encloses many mound groups. As detailed below, these higher backscatter areas are usually the summit or flanks of buried mounds.

In the western part of the survey area, the *TAMU²* sonar often shows areas of slightly greater seafloor roughness, including some small mounds, typically with a shadow on the south side, but an indistinct northern edge. In many respects these areas are like the "patch reef" hard bottoms in Megasite 3 and they probably have similar origins. Subbottom profiles and *TAMU²* bathymetry show that these are mounds and their indistinct northern edges are a result of burial. As shown in the sketch, there are many of these buried or partially buried mounds in the western part of the survey area. They typically have 3-4 m relief on their southern edges and are a few hundred to about 500 m across. In the central and western part of the survey area, the size of these features is generally smaller and there are a number of mounds that appear transitional between the large, elevated hard bottoms in the western part and smaller features that look like more typical mounds. This suggests that there is in fact a continuum of features from large, low mounds to smaller mounds. In general, the larger mounds seem to be located in a curved band from about shotpoint 16 on line 80 to shotpoint 6 on line 53 to shotpoint 12 on line 33. Although this band is somewhat isobath parallel, it does not seem to be related to the position of the shelf edge.

Interestingly, many of the steeper mounds, or pinnacles, seem to rise from the large, low relief mounds. As we suggested in our prior publications, this may indicate two phases of growth (Sager et al. 1992). Because many of the smaller mounds are either lineated, in curvilinear chains, or make subcircular patterns, it is probable that many of the smaller mounds in this area sit atop low, buried bases.

In the southern part of the survey area is a curvilinear band of higher seafloor backscatter that correlates to an indentation in the shelf break. In our previous interpretations, we hypothesized this to be a slump scarp. The higher reflectivity areas may be slump scars and indeed many of them have shapes that "point downhill" as if they are sedimentary slide features. Unfortunately, these features do not give a clear indication in the subbottom records of a slump scar.

The subbottom profiler records typically show 5-10 m penetration with highly variable sediment thickness. An unconformity, with delta foreset beds beneath, is usually the deepest reflection feature noted. Above this the mounds occur with sediment aprons of variable thickness. In most of the area, the uppermost sediments show three layers: upper transparent, middle turbid, and lower transparent. The upper transparent layer drapes the topographic features and seems to have a relatively consistent thickness. The turbid and transparent layers beneath do not. These layers form the aprons of the mounds.

In most cross sections of the mounds, the pinnacles are seen atop a reflective feature with steep sides which corresponds to the core of the mound. On its flanks are sediment aprons and these often correspond to the higher reflectivity areas that surround the mounds. One particularly good example is the mound which trends northeast across the northeastern part of the survey, from shotpoint 12 on line 45 to shotpoint 26 on line 33. This mound shows large sediment aprons with 6-8 m thickness close to the mounds. What is more, it is possible to see the turbid layer thickening towards the mound cores, implying this layer may have to do with shedding from the mounds.

Megasite 3

Megasite 3 covers 4200 m in the north-south direction and 6,000 m in the east-west direction (Table 4.2). It consists of 33 north-south lines (81-113) each 4,200 m in length. The survey is located at the junction between lease blocks Main Pass 224, 223, 249, and 250, covering the southern parts of the first two and the northern parts of the last two (Figure 4.4). The survey area was covered in the 1990 MAMES Geophysical Atlas in Mosaics 1 and 12 (Laswell et al. 1990).

The megasite contains several dozen medium sized mounds in its western portion, many small mounds in the central part, and about 14 flat-topped mounds in the northeast corner (Figure 4.4). The mounds in the western part are distributed along an isobath-parallel band trending east-southeast. The larger mounds in this group are located at the western end, although there are small mounds even there, and the mounds generally become smaller eastward. In the central part of the survey are many small mounds including an area of hundreds of small mounds, a few meters to 10-20 m across, on an apparent hard bottom. In the 1990 atlas, this field was identified as a "patch reef" area because of the many small, subcircular mounds. The *TAMU*^{2} side-scan shows that these features are associated with an area of different seafloor reflectivity and somewhat greater roughness. Another such area is found at the northeast corner of the survey. At this location, the mounds are less prominent than in the patch reef area in the center of the survey, and the seafloor appears to have a greater difference in acoustic backscatter and roughness. This area looks more like a hard bottom. The flat-top mounds are one of the most distinctive features of the survey. They have very flat tops, steep sides with rubble, are typically more than 10 m high, and are about 50-150 m in width. Another feature noted during the survey was a small field of shallow pockmarks, each 10-15 m across, in the southwest corner of the survey area.

Subbottom profiler data showed little penetration in this area, probably owing to geologic factors such as moderate to high-seafloor reflectivity reducing the transmitted acoustic energy. Generally surficial sediments are thin (1-2 m) and form a relatively uniform layer. The "patch reef" areas show a slight elevation, indicating they are raised hard bottoms.

Megasite 4

Megasite 4 covers much of lease block Viosca Knoll 734, the northwestern part of Viosca Knoll 778, and the eastern part of Main Pass 283 (Figure 4.5). A chart from the MASPTHMS survey (Continental Shelf Associates 1992) shows symbols for mound locations scattered across the megasite. Part of the megasite was also covered in the 1990 MAMES geophysical atlas (southwestern Mosaic 14; Laswell et al. 1990). The atlas shows scattered small mounds only and seafloor reflectivity varying from uniform low to high as well as areas of patchy backscatter. According to the MASPTHMS chart, depths range from 110-140 m. The Megasite 4 survey consists of 29 north-south lines (numbers 145-117), each 4,500 m in length (Table 4.2). This gave an east-west coverage of 5,300 m.

The most notable features of the *TAMU²* sonar images are areas of patchy seafloor reflectivity and low mounds and pockmarks (Figure 4.5). Most mounds are small, apparently a few meters in diameter. A few larger mounds range up to a maximum diameter of about 20 m. Apparent pockmarks are seen in several locations. However, feature identification is often difficult because spots on the image do not show definite shadow characteristics that would distinguish them as either mounds or pockmarks (depressions).

On the southwest part of the survey, a band of dark seafloor (high reflectivity) trends northwest-southeast from about shotpoint 16 on line 145 to shotpoint 9 on line 133. Dark patches to the east, at shotpoints 6-8 on lines 126-122 appear to be continuations of this trend. The dark band usually has a sharp southwest side and an irregular north side, suggestive of barrier island morphology. To the north of this band the seafloor has patchy reflectivity and areas of pockmarks. These features generally stretch north to shotpoints 19-20 from line 145 on the west, to about 125 on the east. Most of the mounds are found between the dark band and the northern edge of the patchy seafloor. Their distribution seems nearly random, but there is a tendency towards loose clustering.

Some mounds are found to the south of the dark band and some to the north of the patchy seafloor. To the south only about 10-15 mounds were identified. To the north of the patchy seafloor there is a gap, usually of about 3-5 shotpoints (450-750 m) between mounds, although there are a few isolated mounds within the gap. The northern mounds are scattered, but tend to cluster in west-northwest-east-southeast trending linear groups, typically 600-1,000 m in length.

Subbottom profiler records rarely show mounds, owing to their small sizes. Acoustic penetration was generally good, generally 5-15 m. Layering in the records shows a thin transparent layer, probably relict transgressional sand deposited as sea level rose from the last ice age. The layers show a seaward thinning delta wedge with low-angle seaward prograding layers. Some of these reflectors are truncated up-dip, indicating that the unconformity beneath the thin surface layer is an erosional surface. The subbottom records imply that the mounds were built on a delta front near the shelf edge.

Megasite 5

The Megasite 5 survey covers the western edge of a bulge in the contours of the shelf edge. In this region, the shelf edge is shallow, about 90-100 m, owing to the deposition of a delta lobe at this location. This delta was named the Lagniappe Delta by Kindinger (1989a). Depths in the survey area, according to the MASPTHMS chart (Continental Shelf Associates 1992), are 90-110 m. This chart shows a diagonal band of mounds trending northwest-southeast across the survey area. The survey area lies mostly within the southern 80% of block Main Pass 286 and the southern half of block Main Pass 285 (Figure 4.6). The southern parts of the lines, however, go over into the northern parts of Viosca Knoll 775 and 776. The survey is a polygon with north-south east and west boundaries, an east-west south boundary, and a northwest-southeast trending northern boundary (Figure 4.6). The survey contains 38 lines spaced 175 m apart, yielding an east-west coverage of 6,875 m (Table 4.2). The westernmost line is 6,600 m in length whereas the easternmost is 3,000 m in length.

The most notable feature of the *TAMU²* sonar data is a crescentic band of large to small mounds across the megasite (Figure 4.6). The band runs north-south at its western end, along lines 177-176 from shotpoints 33-26. South of there it bends eastward, having a northwest-southeast trend in its middle, and finishing with a nearly east-west trend at its eastern end, around shotpoint 10 on line 148. This band looks like a reef, so we call it the "reef trend." It contains the largest mounds, a linear multi-part ridge called "36-fathom ridge" on lines 177-176, and two small flat-top mounds, 50-120 m across, at lines 167-168. Most of the reef trend, however, is made up of medium to small mounds and mound clusters. Notably, some of the mounds in this trend are in lines trending northeast-southwest and many also have dark seafloor (high reflectivity) bands trending southwest from them, particularly in the portion between 36-fathom ridge and the two flat-top mounds (lines 177-167). These bands of dark seafloor suggest current action.

Only a few mounds are located southwest of the reef trend. More, however, are located landward of the trend. These "back-reef" mounds range from medium to small in size. Some of them have areas or stripes of dark seafloor trending to the southwest from their location. Although these mounds are scattered in clumps as far as 1,000 m landward of the reef trend, most are located near the reef trend. Interestingly, some are in linear clusters with the same northeast-southwest trend seen in the dark seafloor and in the reef trend mounds.

The other notable features in the *TAMU²* records are more or less linear areas of dark (high-reflectivity) seafloor located seaward of the reef trend mounds. The dark seafloor is often a band about 250-400 m across, often with darker narrow bands, a few tens of meters across, within it. This band is seen landward of the western and southeastern reef trend, but there is a 1 km gap in the middle. The band is most notable and continuous on its eastern end. Comparison with the subbottom profiler records shows that this band occurs along the upper slope, just seaward of the shelf break. It is not obvious what it represents.

Subbottom profiler records from Megasite 5 typically show 5-10 m penetration. A thin transparent layer, probably consisting of relict transgressional sands, overlies an unconformity. Beneath the unconformity, usually truncated, seaward-dipping reflectors are seen. These are probably foreset beds of the Lagniappe delta. As noted above, this unconformity is considerably shallower, 90 m, than is typical of erosional surfaces produced by the last sea level lowstand.

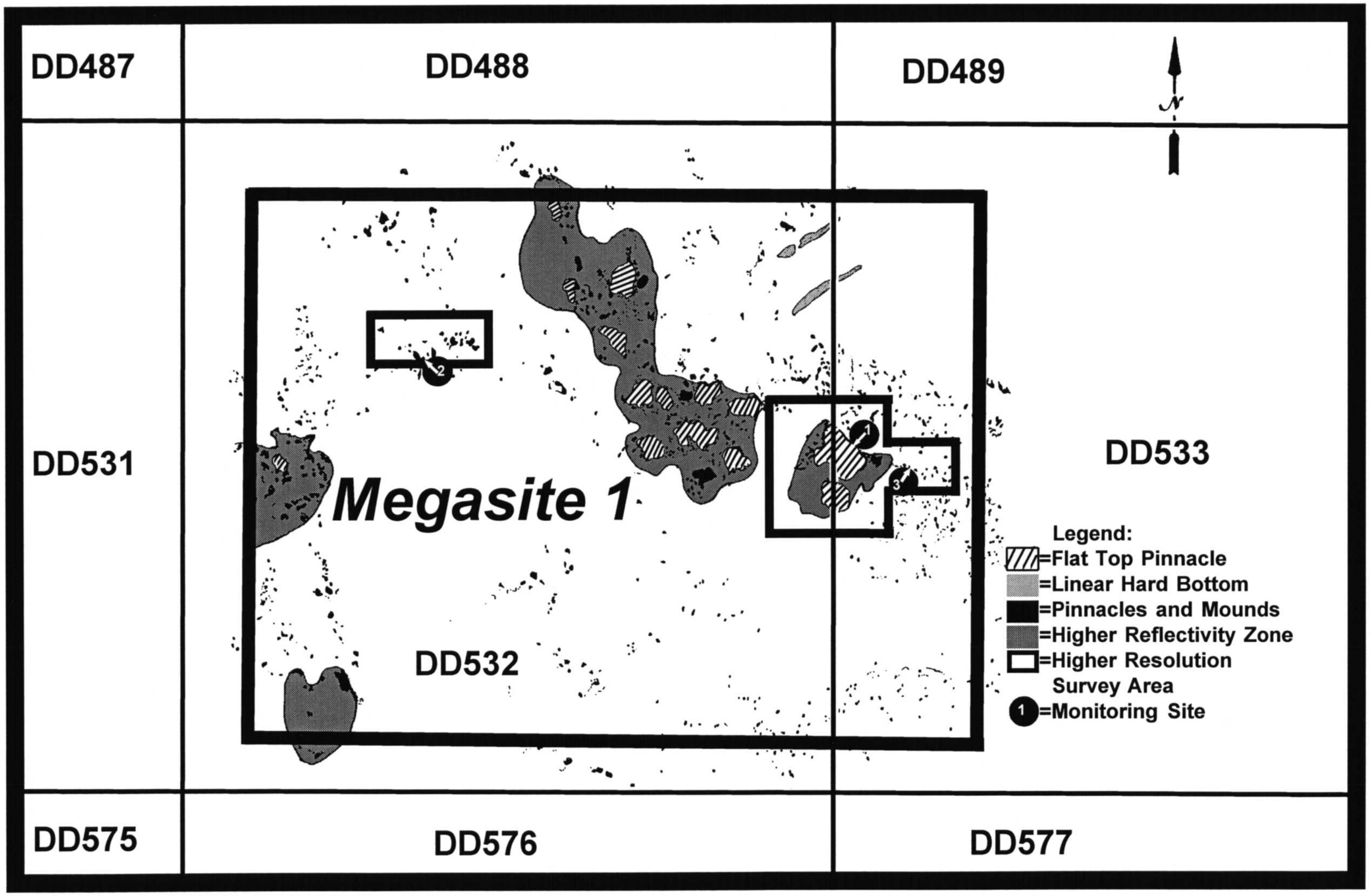

Fig. 4.2. Megasite 1 preliminary geophysical interpretation chart.

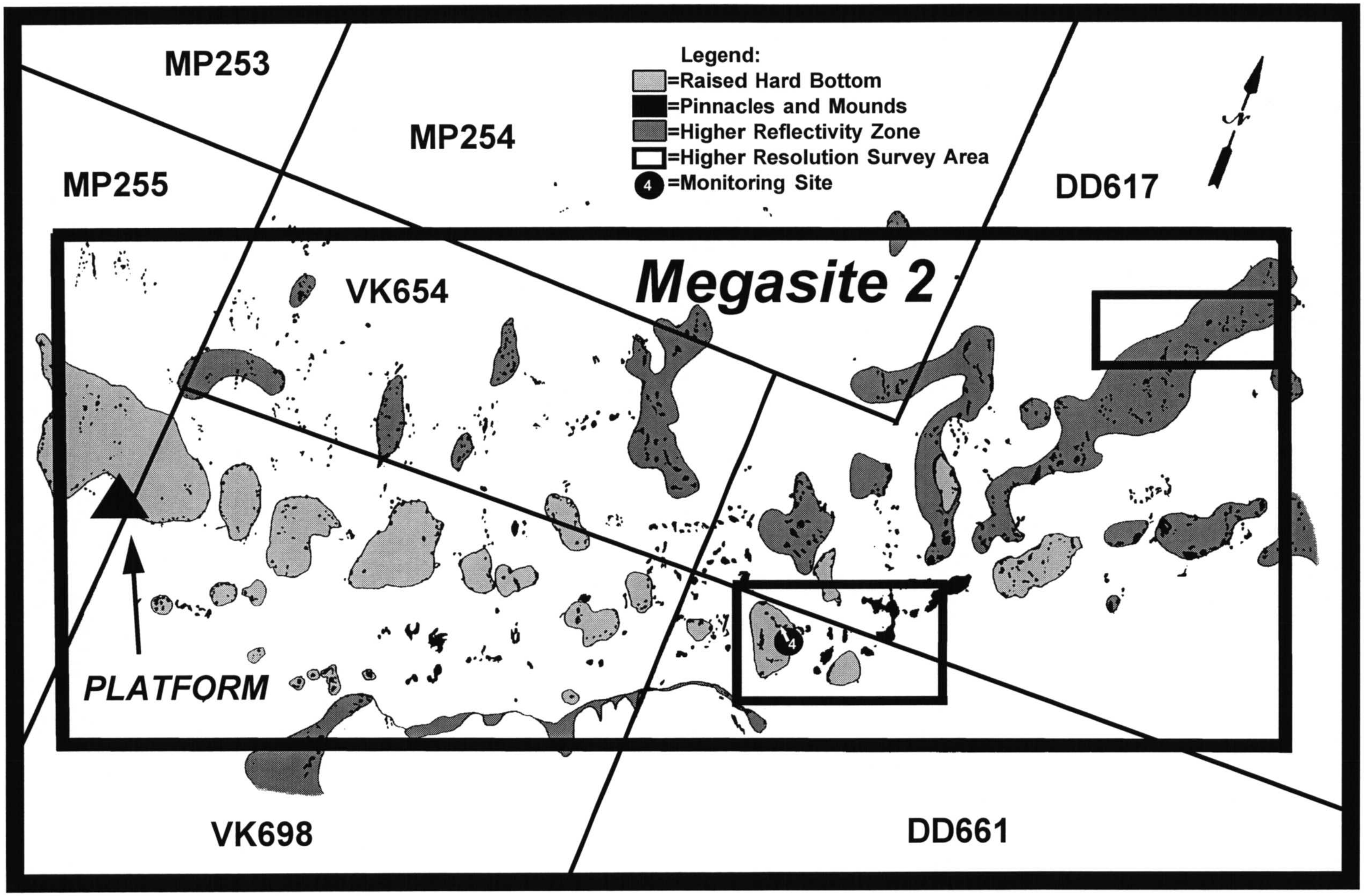

Fig. 4.3. Megasite 2 preliminary geophysical interpretation chart.

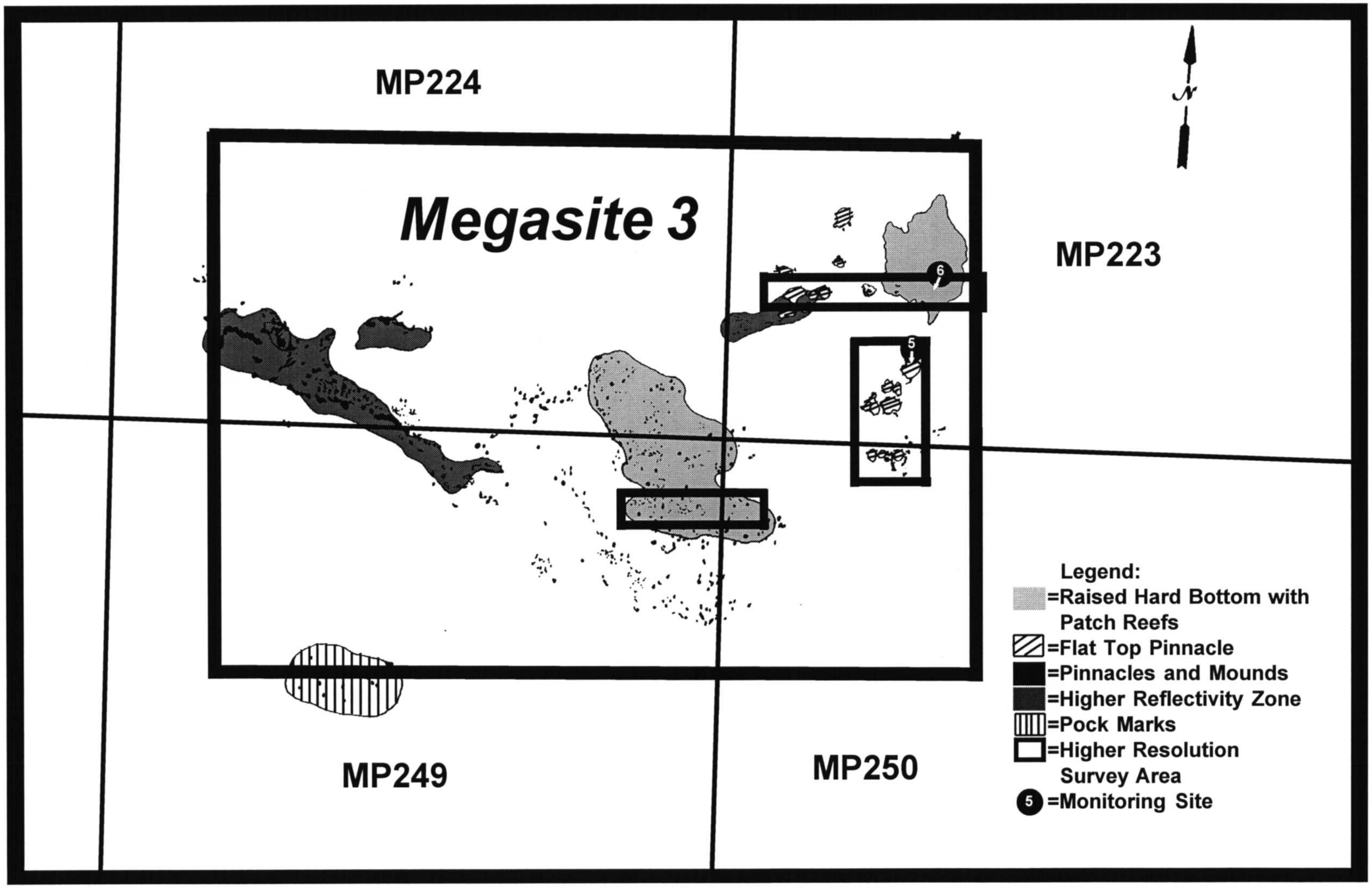

Fig. 4.4. Megasite 3 preliminary geophysical interpretation chart.

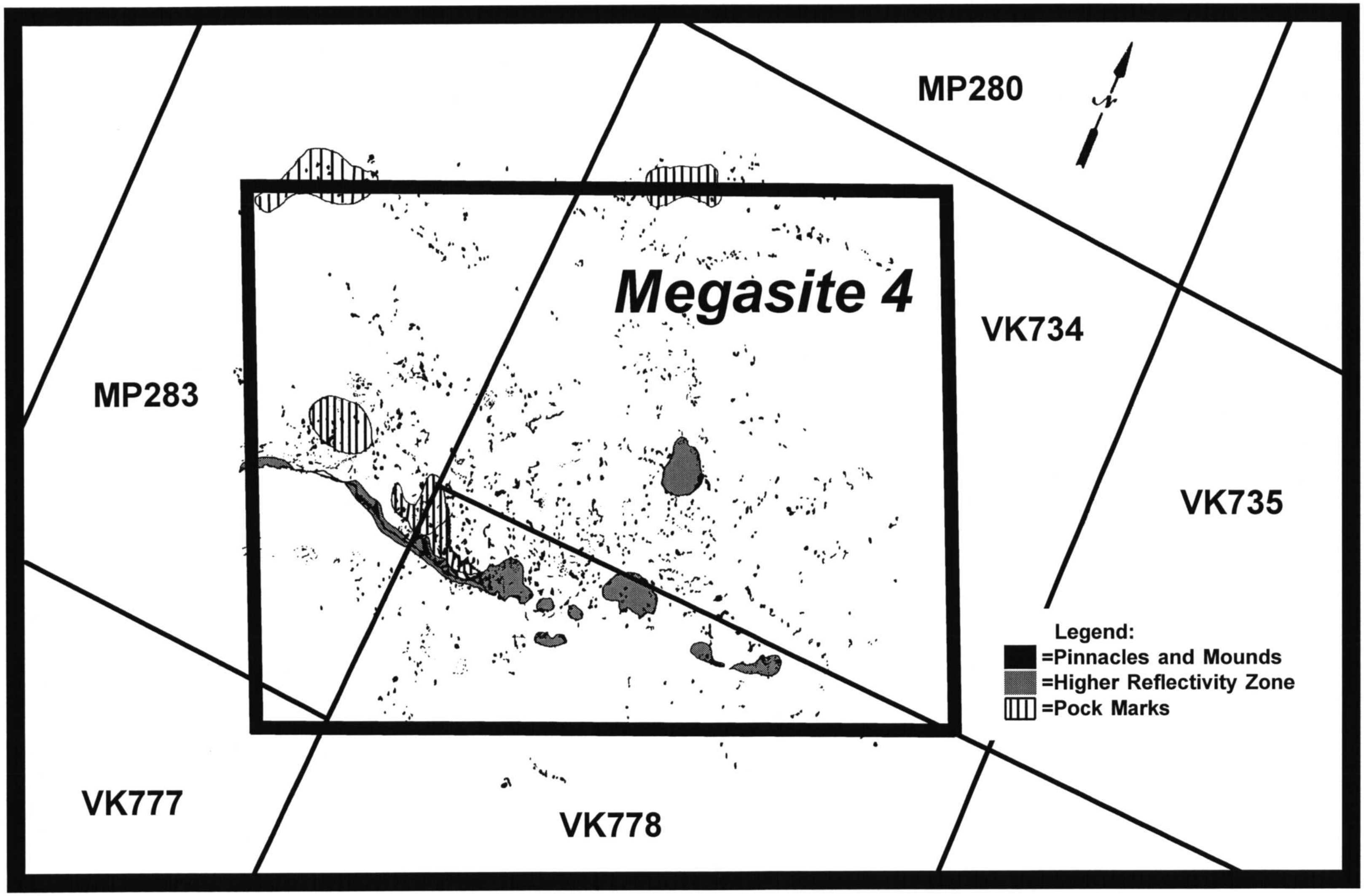

Fig. 4.5. Megasite 4 preliminary geophysical interpretation chart.

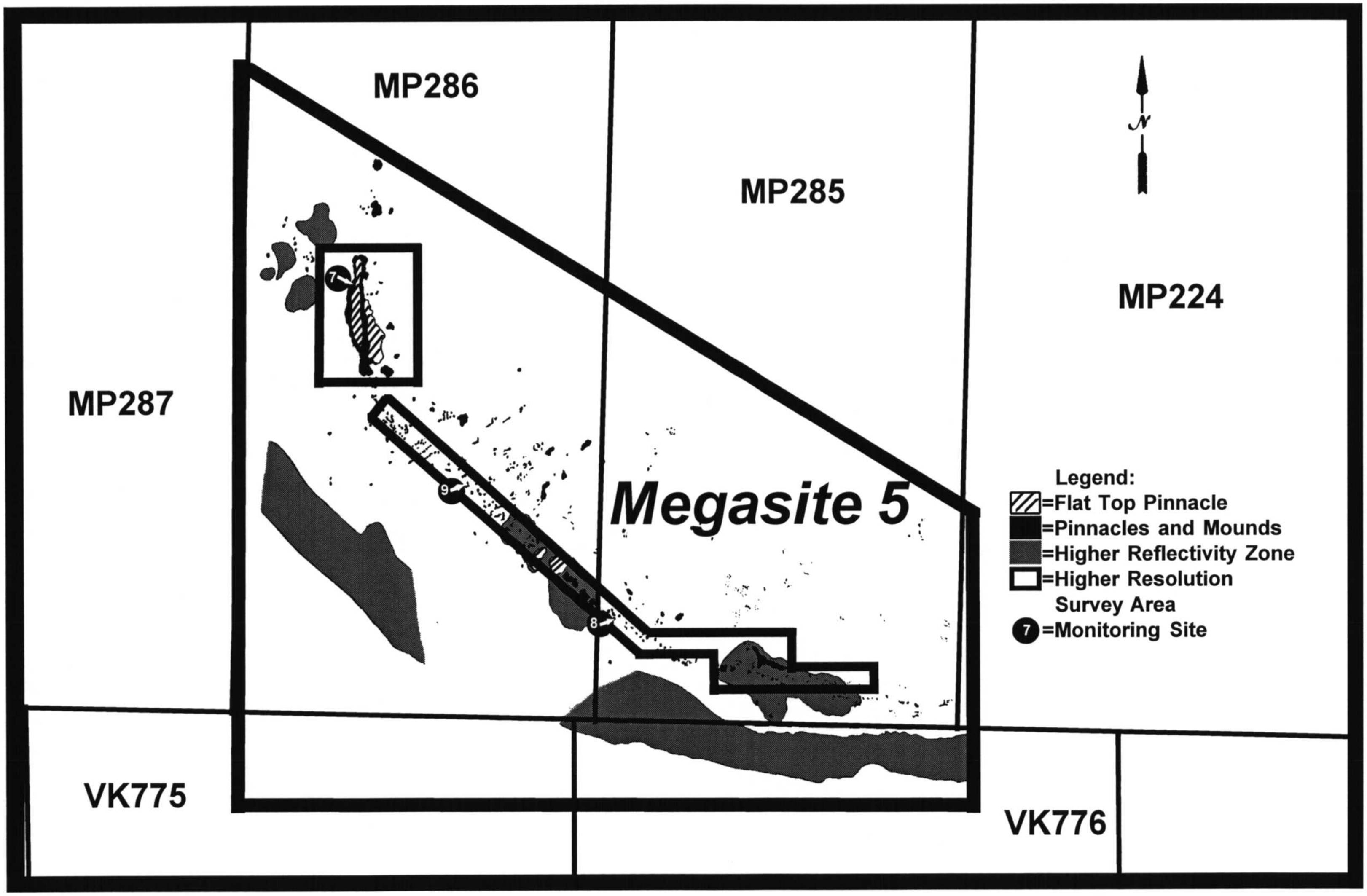

Fig. 4.6. Megasite 5 preliminary geophysical interpretation chart.

Chapter 5
Geology/Sediment Dynamics

The geology/sediment dynamics portion of this project concerns the origin and evolution of, characteristics of, and sedimentation regime around carbonate mounds on the Mississippi-Alabama outer continental shelf. These mounds formed in an unknown manner at lower sea level stands of the Pleistocene-Holocene transgression (Sager et al. 1992) and they have become a substrate upon which a diverse marine ecosystem has evolved (Gittings et al. 1992b).

The objectives of the geological characterization subtask are (1) to use high-resolution side-scan sonar mapping to measure the large-scale physical characteristics, such as shape and gross roughness; (2) to use high-resolution subbottom profiler records to examine long term sedimentation; and (3) to use remotely operated vehicle (ROV) videos to characterize the small scale geology. Although understanding the origin and evolution of the mounds is also an aim of this project, little funding has been specifically allotted for this goal, so progress will rely on clues gleaned from other program elements.

The objectives of the sediment dynamics component are to (1) to provide quantitative and qualitative measurements of the extent and occurrence of the nepheloid layer; (2) to determine sedimentation and resuspension rates; (3) to determine how topographic highs affect present-day sedimentation; (4) to determine temporal variations in sediment texture; and (5) to relate short term sediment dynamics to long term sediment accumulation. To address these objectives, the sediment dynamics subtask is using sediment traps, optical backscatter (OBS) instruments, and CTD/DO (conductivity, temperature, depth, dissolved oxygen) sensors to assess and monitor the extent and variability of the nepheloid layer and resuspension at the study sites in order to assess the impact of these processes on the biological community of the mounds area. Sediment dynamics data collection began in earnest with Cruise 1C during May 1997, when 18 sediment traps were deployed on six moorings. These will be recovered on the first servicing cruise in late July 1997.

Historical Background

The first systematic study of the Mississippi-Alabama outer continental shelf was reported by Ludwick and Walton (1957) and Ludwick (1964). The former described calcareous "prominences" along the shelf edge between the Mississippi River mouth and De Soto Canyon. Although reported earlier by Trowbridge (1930), these features were found by Ludwick and Walton (1957) to be concentrated on the Mississippi-Alabama shelf. The calcareous mounds, termed "pinnacles" owing to their spire-like character in vertically-exaggerated echosounder profiles, were found mainly in a cluster at the shelf edge near 88°W (Ludwick and Walton 1957). These mounds did not appear similar in character to others in the northwestern Gulf of Mexico, which are often the tops of salt or shale diapirs (Rezak et al. 1985). Instead, Ludwick and Walton proposed the

Mississippi-Alabama pinnacles are calcareous reefs, formed just after the end of the last ice age, when sea level was lower and the mounds closer to sea level. Furthermore, they suggested that the pinnacles were no longer actively growing, but are instead in a stage of decline owing to the fact that sea level has risen and the mounds are now deep in the photic zone. Other geologic studies have been carried out in the region, but typically these investigated small portions of the shelf or specific sediment properties (van Andel 1960; van Andel and Poole 1960; Moore and Bullis 1960; Upshaw et al. 1966; Shipp and Hopkins 1978; Woodward-Clyde Consultants, Inc. 1979; Fairbank 1979; Doyle and Sparks 1980; Continental Shelf Associates, Inc. 1985a; Schroeder et al. 1988a, b; Kindinger 1988, 1989a, b).

Ludwick (1964) described the gross surface sediment distribution across the Mississippi-Alabama shelf as consisting of five major zones: (1) the Mississippi-Alabama sand sheet (the most extensive unit); (2) the Mississippi-Alabama reef and interreef facies (associated with the carbonate pinnacles); (3) the St. Bernard prodelta facies; (4) Chandeleur (sand) facies; and (5) Mississippi prodelta facies. The latter three units are laterally limited and located along the eastern shore of the Louisiana delta. Other publications have further illuminated the distribution of surface sediments (Pyle et al. 1975; Dames and Moore 1979; McBride and Byrnes 1995; McBride et al. 1996), component mineral provenance (van Andel 1960; van Andel and Poole 1960; Fairbank 1979; Doyle and Sparks 1980; Mazullo and Bates 1985) or paleogeomorphology (Ballard and Uchupi 1970; McBride et al. 1996), but Ludwick's fundamental classification has remained unchanged.

The area immediately east of the Chandeleur Islands has been the focus of several geologic studies based on dense grid of geophysical acoustic profile data collected by the U.S. Geological Survey (USGS), industry, and other sources (Figure 4.1; Kindinger 1988, 1989a,b; Kindinger et al. 1989; Sydow et al. 1992; Roberts et al. 1993). These data and a well bore from lease block Main Pass 303 were used to describe the deposition and sequence stratigraphic implications of a Late Pleistocene shelf edge river delta, the Lagniappe Delta, which was probably a product of the Mobile River (Kindinger 1989a, b; Sydow and Roberts 1994; Winn et al. 1995). Although no calcareous pinnacles were described, several small salt diapirs were mapped near the shelf-edge (Kindinger 1988). This stands in contrast to the Mississippi-Alabama outer shelf slightly farther to the east, where there are no known diapirs but many calcareous mounds (Sager et al. 1992).

During the late 1980's, Minerals Management Service (MMS) commissioned two high resolution geophysical mapping studies of the Mississippi-Alabama outer continental shelf region where Ludwick and Walton (1957) had earlier reported carbonate pinnacles (Figure 4.1). The first was the Mississippi-Alabama Marine Ecosystems Study (MAMES; Brooks 1991) and this was followed by the Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS; Continental Shelf Associates 1992). Both were tasked with assessing the locations and distributions of calcareous mounds and hard bottoms.

The MAMES study surveyed a 1,620 km^2 region of the outer continental shelf using high-resolution seismic profiling (3.5 and 4.0 kHz) and 100 kHz side-scan sonar collected on tracks spaced typically 500-750 m apart (Laswell et al. 1990; 1992; 1994; Sager et al. 1992). In addition, photography obtained by an ROV and geologic samples collected at grab and dredge stations served to ground-truth the geophysical data as well as to characterize the biological committees (Laswell et al. 1992; Gittings et al. 1992b). Three general types of features were observed: (1) reef-like mounds (RLM); (2) isobath-parallel ridges (IPR); and (3) shallow depressions (Rezak et al. 1989; Sager et al. 1992). The bases of the RLM cluster in two isobath bands, 105 to 120 m and 74 to 82 m and their origin appears to be of a biogenic nature based on limited samples recovered from these features. Depth relationships suggest the shallower RLM (e.g., large flat-top reefs and fields of thousands of small patch reef-like mounds) and most IPR formed about the time of the mid-deglacial Younger Dryas cooling episode. The deeper RLM (i.e., principally from the Ludwick and Walton (1957) pinnacles region) probably formed during a slow sea level rise at the beginning of the late Wisconsinan deglaciation. Radiocarbon ages of 12,000 ±90 yr BP and 11,380 ±110 yr BP were obtained from carbonate rock fragments (composed mostly of coralline algae, serpulid worms and bryozoa) collected from the exterior of one of the tall pinnacles. The dates suggest that the most recent production of exterior frame-building occurred 12 to 11 kyr BP. This is consistent with Ludwick and Walton (1957) who described the pinnacles as intermediate in stage between active growth and fossilization and report that no living representatives of calcareous algae were found on the pinnacles.

The MASPTHMS study surveyed the outer continental shelf and upper slope north and west of the MAMES study area (Continental Shelf Associates 1992). The first of two surveys geophysically mapped topographic structures using a 3.5 kHz echosounder and 100 kHz side-scan sonar on track lines spaced typically 500-600 m apart. The second MASPTHMS survey characterized biological communities associated with these hard bottom features. Two physiographically different zones were identified from the geophysical data in terms of bottom slope gradient, topographic feature morphology and seafloor acoustic backscatter. The first was the relatively flat outer shelf in the depth range of 40 to 75 m. There small outcrops of low relief hard bottom occur scattered over an otherwise relatively featureless bottom consisting of sand, silt, and clay. The second zone was a more steeply inclined shelf-edge to upper slope region in 75 to 210 m of water. Two types of hard-bottom shelf edge prominences were mapped in the latter zone: (1) a region of large pinnacles between 80 to 90 m; and (2) a region of low relief hard bottom and small pinnacles/RLM's at 110 to 130 m. The large pinnacle region occurs on the outer edge of one of the lobes of the shelf-margin Lagniappe Delta (Kindinger 1989a). These pinnacles are up to 20 m tall, appear to occur in clumps and are surrounded by sand, silt and carbonate debris. Area 2 is characterized by low relief pinnacles or RLM's generally 2-6 m in height. Some are as tall as the pinnacles in Area 1 but have broader bases. Continental Shelf Associates, Inc. (1992) classified the sediments in and adjacent to this region as continuous, low relief hard bottom.

Another site within the MAMES area was investigated by the USGS and MMS during a study to document environmental impacts of drilling exploratory wells on selected offshore locations in the northeastern Gulf of Mexico (Shinn et al. 1993). The survey site, Main Pass Block 255, is at the western end of the Ludwick and Walton (1957) deep pinnacles trend. Shinn et al. (1993) report that a well drilled in 1990 was located 1 m south of the base of a 4- to 5-m-tall pinnacle. They also document the presence of two 2-3 m wide and up to 1 m deep trenches cut into a carbonate crust extending from the wellhead template to the northwest for an unknown distance. The trenches are thought to be the result of the legs of the jack-up rig dragging across the bottom when the rig was originally positioned at the site. Post-drilling impact is evident by the presence of high concentrations of barium (>20,000 ppm within 100 m south of the wellhead template) and drill cuttings (observed and photographed from a submersible within 175 m southwest of the wellhead template; Shinn et al. 1993).

Approach and Rationale

The current project seeks to pick up where the MAMES and MASPTHMS programs left off. Those projects were reconnaissance efforts to broadly characterize the Mississippi-Alabama outer continental shelf seafloor and to describe the general characteristics and distribution of carbonate mounds such as those reported by Ludwick and Walton (1957). Current project aims are to provide greater detail in the characterization of the mounds and their geologic environment. As dictated by the contract, the current program has three main goals: (1) to characterize the geology, morphology, and sedimentation regime of calcareous mounds in their current state; (2) to monitor seasonal and interannual changes in the geologic environment of the mounds; and (3) to determine the origin and probable future of the mounds. Given the stated goals, we divide the geologic study into three subtasks with somewhat different approaches: (1) geological site characterization; (2) sediment dynamics; and (3) calcareous mound history.

Geological Characterization

The site characterization subtask seeks to use geophysical mapping and geologic sample analyses to address the following goals:

(1) define the seafloor topography at and around each study site;
(2) determine how topographic highs affect sediment distribution;
(3) geologically characterize the sites, including composition, origin, probable fate, roughness, and friability;
(4) determine subtle differences of orientation, size, and morphology;
(5) characterize substrate; and
(6) determine the distribution of sediment types.

Site characterization consists of mapping the geological variables of the study sites and their environs. Geophysical data will be used to address goals of mapping mound morphology, large scale roughness, sediment thickness and texture, and understanding mound origin. Digital high-resolution side-scan sonar, swath bathymetry, and subbottom profiler data were collected around study sites on Cruises 1A and 1C and these will be the basis of much of the investigation. Bathymetry and side-scan backscatter mosaics will be used to define the size, shape, and overall morphology of each study site and to compare the study sites with similar nearby features. Closely-spaced subbottom profiler acoustic reflection records will be used to determine long term sedimentation patterns by mapping the thickness of Holocene sediments around the calcareous mounds. Such data will also be useful to characterize the seafloor and shallow subsurface layers by their reflection characteristics, a property which is related to roughness, induration, and layer thickness.

Sediment Dynamics

The sediment dynamics subtask is examining particulate matter in bottom waters and on the seafloor to address these goals:

(1) provide quantitative and qualitative measurements of the extent and occurrence of the nepheloid layer;
(2) determine sedimentation and resuspension rates;
(3) determine how topographic highs affect present-day sedimentation;
(4) determine temporal variations in sediment texture; and
(5) relate short term sediment dynamics to long term sediment accumulation.

The goals as outlined above will be met by assessing particle distributions and dynamics with several techniques. Data on the spatial and vertical distribution, intensity and short time-scale variability of the nepheloid layer are being acquired with a transmissometer and an OBS instrument interfaced to the CTD/DO system to obtain profiles of beam attenuation and optical backscatter during the cruises. Extended temporal sampling and monitoring of the intensity and temporal variability of the nepheloid layer in conjunction with the current regime at the study sites are being measured with the OBS instruments interfaced with current meters on moorings. Sediment traps have been deployed on the moorings to quantify resuspension flux. Samples from grabs and sediment traps will be used to determine sediment patterns on the seafloor and to understand present-day sedimentation. Grids of grab samples will allow us to determine sediment types and provide ground truth data for the side-scan sonar backscatter images. Together these data delineate seafloor sediment patterns. Vertically-separated sediment traps are being used to sample particulates from the nepheloid layer and higher waters and to thereby derive short term sedimentation and resuspension rates. Particles from the traps will be compared with sediments from the seafloor to characterize deposition. Grabs and sediment trap samples will be part of the routine monitoring program, so that time variations can be monitored. The extent and occurrence of the nepheloid layer will be determined using grids of CTD/DO/transmissometer/OBS casts around the study sites during biannual monitoring cruises. Long term variations will be addressed by OBS instruments deployed on mooring stations, providing comparisons with current meter records.

Most of the changes in optical properties of seawater are caused by particles suspended or settling through the water. Light attenuation as measured with a beam transmissometer is one of the easiest to use and most versatile optical instruments now in use to measure inherent optical properties in seawater. The Sea Tech 25 cm pathlength transmissometer is widely used because of its ease in interfacing with CTDs, which provides a real-time shipboard readout of beam attenuation. Gross large-scale measurements can be made easily with this instrument, but to make precise quantitative measurements considerable care must be exercised in cleaning the optical windows, in correcting for the decay of the LED light source, and in calibration with in-situ particle concentration from filtered samples (Bartz et al. 1978; Gardner et al. 1983). Beam attenuation is an inherent property of seawater and is the sum of light scattering and absorption (Gordon et al. 1984). At the 660 nm wavelength used in the Sea Tech transmissometer, the scattering function is small. Attenuation is usually considered to be the sum of attenuation of seawater (c_w), yellow matter (c_y), and particles (c_p). In the open ocean c_y is negligible and c_w is constant, so changes in total attenuation result from changes in particles (Morel 1974; Jerlov 1976; Pak et al. 1988; Gardner et al. 1995; Walsh et al. 1995). The properties of particles that affect attenuation are their concentration, size distribution, index of refraction, and shape, with concentration and size being most important. If the size distribution, index of refraction and shape of particles are constant, beam attenuation is linearly related to particle concentration (Spinrad et al. 1983; Baker and Lavelle 1984; Moody et al. 1986). Particle characteristics vary between regions, however, so in order to estimate particle mass concentration from attenuation data it is necessary to calibrate the data from each area by filtering water for total particle concentration.

Transmissometers are also effective in locating areas of resuspension of bottom sediments and production of bottom and intermediate nepheloid layers (Walsh 1990; Gardner and Walsh 1990). Since resuspended sediments form the bulk of the nepheloid layer particles (Gardner et al. 1983; Gardner et al. 1985), monitoring of the nepheloid layer by use of beam attenuation data can be used to infer spatial and temporal variability of both particle concentrations and resuspension (Walsh 1990; Gardner and Walsh 1990; Walsh et al. 1995).

Mound History

The mound history subtask has three main goals:

(1) determine the origin of the calcareous mounds;
(2) determine the development history of the mounds; and
(3) predict the future fate of the mounds.

The long term history and fate of the calcareous mounds is a difficult but important problem to address. This part of the project was originally envisaged as a larger effort with sampling and analyses specifically targeted at obtaining samples from the mounds to be used for dating, isotopic analyses, and other techniques. However, reductions in project scope have removed most of the sample gathering and analysis planned for this subtask, so progress in this area will have to rely on clues from the geophysical data and chance recoveries of mound samples in grabs and by collateral submersible programs.

Field and Laboratory Methods

Geological Characterization

High-Resolution Geophysical Baseline Data

One hundred eighty track lines, totaling 797 km in length and covering an area of 144.5 km^2 with side-scan sonar swaths, were collected at the five megasites (see Chapter 4) with the *TAMU*^{2} digital side-scan sonar and an X-STAR 2-12 kHz chirp sonar on Cruise 1A. Ship's tracks were spaced 175 m apart and the ship's speed was approximately 5.5 knots with a sonar layback of about 85 m continuously measured with an ultra-short baseline acoustic tracking system. Navigation was done using *Skyfix* differential global positioning system (GPS), with an accuracy of less than 5 m. On these tracks, which were either oriented at a heading of 0° or 30°, an image swath of 400 m was used to provide >100% coverage of the seafloor. This allowed features directly beneath the sonar on one ship track to be imaged by adjacent tracks. This duplication was important because features have different appearances depending on the incidence angle of the acoustic waves and because the *TAMU*^{2} sonar has a "blind spot" directly beneath the track. Because the sonar bathymetry swath is limited by the first bottom multiple to 3.4 times water depth, the bathymetry swaths overlapped by 25%-50% in these surveys.

The sonar digitization rate was typically 1,650 pixels per ping at a ping rate of 0.4 seconds. This configuration implies that each pixel is representative of an area of seafloor 1.25 by 0.24 m. Both 70 kHz and 11/12 kHz data were collected along each of the tracks so that the two frequencies could be compared to highlight differences in sediment texture. In addition to these data, higher resolution data were collected during Cruise 1A on tracks oriented perpendicular to the main survey tracks over areas of particular interest. These "detailed" surveys typically had track spacings of 150 m, sonar swath widths of 200 m, and were digitized with 3,300 pixels per ping, and at up to 0.2 pings per second. The goal of these data were to provide higher resolution images of likely sites for more detailed study. In all, 34.7 km of data were collected on these "detailed survey" lines covering an area of 5.6 km^2 with side-scan swaths.

Additional chirp sonar data were collected on Cruise 1C. A grid of perpendicular lines was run between the lines collected over the "detailed" survey sites in the geological baseline cruise (1A). Because the original grid had tracks with an east-west spacing of 175 m and north-south spacing of 150 m, the Cruise 1C data filled in the grids at spacings of 87.5 and 75 m. Cruise 1C subbottom lines were positioned by differential GPS with an accuracy of less than 5 m. The total length of subbottom data collected on Cruise 1C was 199.8 km.

Ground Truth Data

ROV video tapes and grab samples were collected during Cruise 1C and will be collected on subsequent monitoring cruises. The grabs provide samples of the surficial sediments insonified by the side-scan sonar. These are being described for gross characteristics and are also analyzed for particle size distribution (see below). Ten grabs were collected at each site during Cruise 1C to provide a baseline and five will be collected at each site during each subsequent monitoring cruise to look for variations. ROV videos also provide valuable geologic information concerning seafloor features, sediment types, and texture. These are presently being viewed and characterized.

Grain size measurements will be done by standard techniques (Folk 1974). Samples will be homogenized, treated with an aliquot of 30% hydrogen peroxide to oxidize organic matter, and washed with distilled water to remove soluble salts. Sodium hexametaphosphate will be added to deflocculate each sample before wet-sieving with a 62.5 micron (4 phi) sieve to separate the sand and gravel from the mud fraction. The sand and gravel fraction will be dried, weighed, and sieved at 1/2 phi intervals from -1.5 to 4.0 phi. Each fraction will be examined for aggregates and those found will be disaggregated. Fractions will be weighed to three significant figures. The mud fraction will be analyzed for particle size by the pipette settling method at intervals of 4.5, 5.0, 5.5, 6.0, 7.0, 8.0, 9.0, and 10.0 phi intervals.

Characterization of Rock Samples

If suitable carbonate rock samples are recovered by grab samplers, ROV, or other means, a battery of tests may be applied to describe the composition, age, and other characteristics. These include thin section petrographic description, x-ray diffractometery, scanning electron microscopy, electron microprobe analysis, all of which characterize particle content and composition, carbon and oxygen isotope ratio measurements to yield clues about the formation of the carbonate, and radiocarbon dating to determine age.

Sediment Dynamics

CTD/DO/Transmissometer/OBS Data Sets

Using the transmissometer interfaced to the CTD/DO, we plan on a minimum of three profiles at each of the monitoring sites per monitoring cruise. These profiles will include profiles at mooring locations if they are present at a site. The CTD/DO will also be equipped with an OBS instrument used on the moorings so that a robust correlation can be made between the transmissometer signal and the OBS instrument used on the mooring.

Transmissometer data from a Sea-Tech 25 cm pathlength transmissometer will be collected with each CTD/DO cast as will data from OBS instruments deployed on the moored current meters. CTD data are plotted graphically in real time on board ship to help determine rosette bottle sampling depths and to monitor the quality of the data stream. It is particularly helpful to denote the thickness of the nepheloid layer and in the bottom boundary layer the vertical extent of mixing.

Particle concentration profiles for calibration will be made at each site by in-line filtration from Niskin bottle samples. Filter heads holding 47 mm 0.4 µm pore size Poretics or similar filters are attached in-line between the Niskin bottle spigot and a glass carboy which holds a vacuum. The filters are pre-weighed on a micro-balance before the cruise. Subsequent to filtration, the filters are rinsed with distilled water in a laminar flow hood to remove salts and dried in the hood. On shore, the filters are weighed again, and the difference between the pre- and post-weighings yields the particle mass. Concentration is determined by dividing by the filtrate volume collected in the carboy for each filtration. Blank filters are used for quality control at all stages of the analysis.

Mooring Data Sets

Six moorings have been deployed during the monitoring study to provide long term data sets and characterize the flow fields, near-bottom oxygen concentrations, and nepheloid layer dynamics with respect to the flow field. Four of the moorings will be used for regional coverage, with the remaining two rotating among the study sites for intensive spatial/temporal sampling. An OBS instrument is located a few meters above the bottom of each mooring and interfaced with a current meter to supply power and record data. The nepheloid layer OBS data will characterize the intensity and temporal relationships between the current velocities and the nepheloid layer. Simple particle modeling and observational records will be used to determine whether observed nepheloid layer fluctuations are the result of near field (active) resuspension or are advective features. Combining the point source records of the current meters and optical instruments with the wider areal coverage and discrete full water column profiles from the CTD/DO/transmissometer/OBS work will yield a robust data set describing the temporal and spatial variability of the nepheloid layer over the area and at each of the monitoring sites.

ROV Observations

On each of the monitoring cruises an ROV will be used to gather biological data sets from video camera transects of the study sites (see Chapter 8). The camera records, along with the position and altitude records will be used to develop a near-field variability record of the nepheloid layer at each of the sites with respect to the bottom morphology, flow field and time. In particular, the video observations will yield data on the structure of the nepheloid layer with respect to the features of interest (e.g. mounds, pinnacles) at a level of detail with respect to the flow field that would be prohibitively expensive to obtain by any other method.

Sediment Traps

The sinking flux of particulate material is being collected using sediment traps. Simple core-tube sediment traps have been deployed on each of the moorings to monitor particle flux and resuspension during the monitoring period. This type of sediment trap has been proven both effective and cost-effective during the Texas-Louisiana Shelf Circulation and Transport Process (LATEX) Program on the shelf of the western Gulf of Mexico (Zhang 1997). The traps have been placed at 2, 7, and 15 m above the bottom. We will derive the resuspended component of the bulk sedimentation rate by partitioning the bulk sediment sample in the 2 m and 7 m traps using the 15 m trap and the surface sediment samples as end members. Partitioning will be based on bulk sedimentation rate, grain size, and the suite of chemical analysis that is also made on the sediment samples [e.g., total inorganic carbon (TIC), total organic carbon (TOC), metals from instrumental neutron activation analysis (INAA); see Chapter 6]. This partitioning scheme has been used effectively in previous sediment trap studies (Walsh et al. 1988; Walsh and Gardner 1992).

Sediment trap materials will be collected during three monitoring cruises and five servicing cruises. Sediment traps have been placed on moorings at three depths (2, 7, and 15 m above bottom). All samples will be analyzed for mass and grain size. TOC and TIC will also be done on the materials from the eight cruises (3 depths x 6 moorings x 8 cruises = 144 samples).

The sediment trap samples will be photographed upon recovery. Decanting and refrigeration of the samples will occur at sea, subsequent processing will occur in the laboratory ashore. In the lab the supernatant will be drawn off and the samples will be wet sieved through a 1 mm nylon screen. The >1 mm fraction will be visually inspected during processing, but our experience, including traps in the Gulf of Mexico and the upper slope off Cape Hatteras, has been that the >1 mm fraction is a small proportion (<5%) of the total sample and is almost entirely composed of zooplankton. "Obvious swimmers" will also be removed from the sieved sample. The <1 mm fraction will be split into six fractions using a forced air, constant stirring splitter. One split will be archived at this stage (dark refrigeration). Depending on sample size, one or two splits will be used for grain size analysis. The remaining splits will be recombined into pre-weighed centrifuge tubes and centrifuged at 15 krpm for 100 minutes. The supernatant will be drawn off and the tubes weighed. The salinity of the supernatant is recorded using a hand-held optical salinometer. The samples are frozen and freeze dried for 24 to 48 hours depending on the volume of sample. After freeze drying the tubes are reweighed to measure the water loss. The samples are removed from the centrifuge tubes and ground to a powder in a mortar. Ground samples are placed into pre-weighed petri dishes and reweighed. The empty centrifuge tubes are also reweighed to estimate the remaining sample on the wall and as a double check on the petri dish weight. Mass flux is calculated using the total weight of the sample adjusted by calculating the salt mass in the sample. Dry splits of the ground samples will be made to provide subsamples for chemical analysis. The concentrations of TIC and TOC will be measured from the subsamples (methods are described in

Chapter 6). Depending on the amount of subsample available, aluminum, barium and other trace metals in the samples will be analyzed from:

(1) each mooring and depth from
  (a) Mooring Service 1 and Monitoring Cruise 2,
  (b) Mooring Service 2 and Monitoring Cruise 3, and
  (c) Mooring Service 3, 4, and 5 and Monitoring Cruise 4 will be combined and analyzed for INAA trace metals (3 depths x 6 moorings x 3 combined cruises = 54 samples); or

(2) each mooring and depth from the samples collected on the three monitoring cruises (3 depths x 6 moorings x 3 monitoring cruises = 54 samples).

Preliminary Results

Geological Characterization

Summaries and sketches of features found in the survey sites are given in Chapter 4. In general, carbonate mounds of various sizes from several meters wide and tall to >500 m wide and 15 m tall were seen in the west, central, and east parts of the study area. In all areas, the mounds are often found clustered along isobaths and associated with erosional unconformities on the fronts of deltas. In Megasite 5 there is a striking crescentic band of mounds that follows the shelf edge with a lesser number of scattered mounds just landward of the main band. From its morphology, it looks much like a coral reef complex. Megasites 2 and 3 are characterized by zones containing many small mounds 5-10 m across and a few meters tall, which have been called "patch reefs" previously owing to their appearance. Some of these are atop of what appear to be hard bottoms which are slightly elevated and have sizes ranging from several tens of meters across to hundreds of meters across. In Megasite 2, some of these hard bottoms are the bases of the steep-sided "pinnacle" features and imply that the hard bottoms may be an initial stage of mound formation. Flat-topped mounds are found in Megasites 1, 3, and 5. They typically form in clusters, often along an isobath, and have diameters ranging from about 50 to 400 m and heights greater than 10 m. The largest are in an isobath-parallel band in Megasite 5. Megasite 3 contains several clusters with no apparent trend. Additionally, Megasite 5 contains two in the shelf edge band as well as the 36-Fathom Ridge, which may also be a flat-topped mound. Megasite 4 is different from the others in that it contains only small mounds, the largest being only about 20 m across, and these are scattered over most of the megasite.

Ninety-eight grabs and 13 box cores were collected during Cruise 1C. Ten from each site will be analyzed for particle size distributions and this analysis is ongoing. A preliminary examination of samples shows that most contain mud and sand in varying amounts, but there is a general trend of greater amounts of mud proceeding westward across the study area. This is likely due to proximity from the Mississippi River mouth. The grabs contain varying amounts of carbonate debris, often shell and other fragments from infauna, but occasionally carbonate fragments from the mounds themselves. In general, the grabs appear to contain more larger fragments on the southwest sides of the mounds, from seafloor showing higher backscatter. This implies currents have winnowed those sediments on the southwest or preferentially deposited larger fragments there.

Sediment Dynamics

Eighteen sediment traps were deployed on the six moorings on the first monitoring cruise. These will be recovered on the first servicing cruise in late July. CTD/DO/transmissometer/OBS profiles were made on the monitoring cruise and preliminary data processing of these profiles is underway. The delays of the first monitoring cruise resulted in a conflict with a cruise for another project, and filtration samples were not collected on the monitoring cruise. More intensive sampling on subsequent monitoring cruises will compensate.

Data Analysis and Interpretation

Geological Characterization

TAMU^2 Side-scan Sonar and Bathymetry

TAMU^2 side-scan sonar data were digitally recorded for shore-based processing. However, because of the volume of data and the time required for processing, initial interpretations have been based on uncorrected monitor records produced on board ship. These records were characterized and synthesized to produce preliminary site feature maps (see Chapter 4).

Processing of the *TAMU^2* data includes noise filtering, correction of bad pings and striping, filling in the nadir on the backscatter image, and correction for ray-bending. The ray-bending correction is extremely important as this is one of the great differences between *TAMU^2* and conventional side-scan data. By taking a CTD cast at the beginning and end of a survey to get a profile of sound speed versus depth, the paths of the *TAMU^2* acoustic rays can be calculated. This allows the exact locations of image pixels and bathymetry points to be calculated.

Preliminary processing is being done by C&C Technologies, Inc. Subsequent processing will be done at Texas A&M University with a Silicon Graphics Indigo High Impact workstation using ELAS (Earth Laboratory Analysis System) software, developed by NASA for map and 3D visualization. Products of the processing include backscatter image mosaics (at 11 and 72 kHz), bathymetry maps, and 3D perspective views.

Our analysis of *TAMU^2* data will include interpretations of side-scan sonar mosaics as well as quantitative studies of mound morphology and roughness from the backscatter images and bathymetry. We will characterize backscatter patterns (see Chapter 4), using as a starting point the analysis we did for the MAMES and MASPTHMS studies, and from these we will make interpretation maps for the megasites and detailed monitoring sites. Morphology will be examined using several techniques. To define aspect ratio (length/width) and trends, we will digitize the mound outline and calculate the best fitting ellipse. Bathymetric gradients will be used to characterize the slopes of these features. In addition, Fourier spectra will be used to examine the trends and characteristics of the bathymetry. Roughness will be quantified in several ways. We will calculate the difference between 11 kHz and 72 kHz backscatter as an indicator of seafloor roughness because the backscatter depends partly on the relation of the wavelengths of the seafloor roughness and the acoustic signal. This difference data can be plotted in map form and compared with the backscatter image and bathymetry. We will also calculate inter-pixel variability as a measure of roughness. For example, flat seafloor will have little pixel variability whereas rough seafloor will have a high degree of variability.

Subbottom Profiles

Data from the chirp echosounder will be used to map the thickness and character of shallow sediments in the study areas. These data are recorded digitally and also plotted in analog manner as monitor records during the cruise. We will probably use monitor records for most interpretation, but will reprocess data where it seems useful. Reprocessing may include expanding parts of the sediment column and using different frequency filters to emphasize different reflection characteristics. We do not anticipate extensive reprocessing as this is time consuming and we believe that most of the information we need to understand sedimentation around the carbonate mounds will be visible in the initial records.

Subbottom profiles will be analyzed using standard seismic stratigraphic techniques (e.g., Mitchum and Vail 1977). This involves (1) recognition and correlation of acoustic reflectors by their characteristics and (2) mapping and interpretation of seismic facies. The latter step assumes that sediments of different sedimentary facies give a common, recognizable acoustic response. We will interpret each subbottom line and plot the features and sedimentary layer thicknesses on charts with survey navigation. In addition, our experience with the MAMES data suggests that the seafloor will have different reflection characteristics depending on the surface sediment. Therefore, we will generalize and plot seafloor reflection character. This technique proved very useful in our study of the geologic response of surficial sediments to hydrocarbon seeps (Sager et al. 1994; Lee 1995).

Isopachs, facies interpretations, and seafloor reflection characters will be plotted, contoured, and digitized. We anticipate producing a map of Holocene sediment thickness, seafloor reflection character, and the topography of the underlying Pleistocene erosional surface for each megasite and monitoring site.

Maps and Data Interpretation

TAMU² bathymetry data will be used to make contour maps and three dimensional perspective views of each megasite and each monitoring site. These data will address our goals of describing seafloor topography and mound morphology, orientation, and large scale roughness. Depending on data quality, larger scale maps will be contoured at 2-4 m intervals and smaller maps at 1 m intervals or less. Bathymetry will be used to address a number of characterization issues. Slope angles and aspect ratios (length/width and diameter/height) will be calculated for mounds and compared statistically. The MAMES survey found that mound diameter and height are related and that the number of features decreases logarithmically with increasing diameter (W. Sager, unpublished data). Such statistics have implications for how typical are monitoring sites and will help us understand mound growth and origin.

TAMU² backscatter images will be used to map surficial sediments as well as surface characteristics of the mounds. These data will address our goals of describing mound morphology, orientation, and roughness. We will make mosaics of the side-scan images to allow mapping of sediments with similar backscatter patterns, which are related to texture. From the MAMES survey, we found backscatter patterns to be quite variable and possibly influenced by storm waves (Laswell et al. 1992). These data will also give higher resolution images of mounds in general and the study sites in particular. These images will help biologists better understand the habitat structure. We will also use the backscatter images to help understand roughness. The *TAMU²* system makes images at two frequencies, 11/12 kHz (wavelength = 14 cm) and 72 kHz (wavelength = 2 cm), and since backscatter character depends on surface texture and scattering within the volume of substrate penetrated by the acoustic waves (Johnson and Helferty 1990), we will compare the two images for information about surface roughness.

Chirp profiler records will be analyzed using standard seismic interpretation techniques (e.g., correlating reflectors and their characteristics). These data will be used to address our goals of understanding mound origin as well as long term sedimentation rates, sediment distribution, and the effects of mounds on sedimentation. We will digitize layer thicknesses to make maps of sediment distribution. Of particular interest are the uppermost sediments, which consist of Holocene transgressive sands and recent mud from the nepheloid layer. We believe the mounds formed on a surface formed by sea level lowstand erosion of delta forset beds. The Holocene sediments were therefore deposited around the mounds and their uneven distribution shows the effects of currents perturbed by mound topography. With the chirp profiler data, we will map the thicknesses of Holocene and the most recent sediments within the megasites and detailed study areas to give information about long term deposition. Horizon characteristics and structure will give clues about the mound origin. In addition, because seismic reflections depend on interface and sediment texture, induration, and layer thicknesses, we can map areas of similar reflection character to derive the distribution and type of sediments on the seafloor and buried beneath.

To address the goal of assessing sediment texture changes and sedimentation processes around the mounds, we will compare the new geophysical data to existing reconnaissance survey data. We expect there may be changes because the sediment backscatter patterns in some areas suggest sediment waves created by storm waves (Laswell et al. 1992) and several hurricanes have passed over the study site since the reconnaissance surveys. Reconnaissance subbottom profiler records were precisely navigated and can be compared with new profiles for changes in surficial character owing to changes in seafloor sediments. Likewise, we can compare the reconnaissance side-scan images with the 72 kHz *TAMU²* images, but to do this we will have to match features and bathymetry in the two data sets since the old side-scan images are not as accurately positioned as the new data will be.

Grain Size Characterization of Sediments

Important environmental variables for each monitoring site are the type and grain size distribution of the sediments. Side-scan sonar backscatter patterns from previous surveys indicate that sediment variability can be expected on scales from tens of meters to kilometers (Laswell et al. 1990; 1992) so grain size measurements are crucial ground truth for the geophysical data. To address goals of characterizing site sediment variations and substrate characterization, we used a grab to obtain a grid of approximately 10 surface samples per site during the baseline cruise. From these and the geophysical data, we can make maps of sediment type. We will also measure the grain size of sediments collected in sediment traps at each site to characterize the grains supplied by the nepheloid layer.

Roughness and Friability Characterization

Roughness is a factor that may affect substrate suitability for biologic communities, but not knowing what scale is important, we take several approaches to measuring this factor. To derive large scale roughness patterns, we will analyze *TAMU²* bathymetry and side-scan sonar backscatter images. This will define roughness to approximately meter scale. From video records taken by the ROV, we will describe, at least qualitatively, the roughness apparent in those images. This scale should be on the order of centimeters to millimeters. Rock samples recovered by grabs will be photographed from several angles for documentation purposes. The photographs will be scanned and the edges digitized. Additionally, selected samples not needed for other analyses will be slabbed with a rock saw and similarly photographed and digitized. These digital outlines will be analyzed to quantify their roughness. A diameter/circumference ratio is a simple, easily calculated measure of the surface tortuosity. Another method of obtaining a single measure of roughness is to calculate the fractal dimension of the digitized circumference. Such single-value measures of roughness will be useful for statistical comparison with biologic and other data.

If suitable rocks are recovered, we will attempt to quantitatively determine friability using 1.25-inch cylinders, approximately 1 inch in length, cored from rocks. The ends will be cut and smoothed perpendicular to the cylinder axis. The cylindrical sample will be placed in a hydraulic press and pressure applied until the rock fails under compression. The pressure at which the failure occurs will be a measure of friability; more friable rocks will fail at lower pressures.

Sediment Dynamics

Preliminary data reduction of the transmissometer and OBS instrument data will be done by the physical oceanographic group using Seabird software routines. Calibration of the transmissometer and OBS instrument will be performed by linear regression of particle concentration data from in-line filtration of Niskin bottle samples taken during the cruise to beam attenuation output from the transmissometer and the output from the OBS instrument. The mooring records of the OBS instrument will be calibrated to the cross-calibration of the transmissometer and CTD mounted OBS instrument.

Chapter 6
Geochemistry

The geochemistry program component includes a combination of hydrocarbon, trace metal, grain size, total organic carbon (TOC), and total inorganic carbon (TIC) measurements of sediments and sediment trap materials. Contaminant measurements are intended to document the current hydrocarbon and trace metal concentrations within the study sites. Sediment characteristics (grain size, TOC, TIC) will aid in the determination of the origins of sediment at the sites and provide a basis for discerning the relationship between sediment texture and biological patterns at the study sites. Trace metals, TOC, TIC, mass, and grain size will be measured in sediment trap materials to aid in determining the origins of sediments at the sites and to document whether contaminants are accumulating at the sites during the duration of the study (see Chapter 5).

Historical Background

Sediment characteristics on the Mississippi-Alabama shelf are dynamic and change on time scales varying from less than 6 months to more than 2 years (Kennicutt et al. 1995). Some sediment properties have been shown to vary by more than an order of magnitude over a 2-year period. Individual sediment components vary independently and can be described as cyclic, steadily increasing, random, or unchanging. Many of the variations are linked to influxes of terrestrial material associated with river discharge, non-point terrestrial runoff and/or outflow from coastal environments during storm events. Carbonate content and grain size vary from clay rich fine-grained sediments associated with the Mississippi River delta complex to coarse-grained shell hash on the eastern shelf. Organic carbon content, extractable organic matter, and hydrocarbons are elevated in sediments near the Mississippi River delta complex and in a band of sediments between the 100 and 200 m isobaths. TOC values in excess of 2% have been observed; however, average TOC concentrations are 0.8%. Hydrocarbons in sediments are present at low concentrations and are a mixture of biological and petroleum hydrocarbons. Terrestrial plant biowaxes are ubiquitous and, when present, petroleum hydrocarbons are associated with elevated barium concentrations. Aromatic hydrocarbon compositions are indicative of unprocessed petroleum and are dissimilar to combustion polycyclic aromatic hydrocarbons (PAHs) detected in adjacent bays. PAH concentrations in the outer continental shelf (OCS) are as much as six times lower than adjacent coastal sediment concentrations. Spatial and temporal heterogeneity in sediments is due to variations in inputs, preservation, diagenetic alteration, and oceanographic setting.

Studies of sediment hydrocarbons in the Mississippi-Alabama shelf are best represented by four reports (Gearing et al. 1976; Boehm 1979; Brooks et al. 1988; Kennicutt et al. 1995). Gearing et al. (1976) reported the analysis of 60 sediments from the northeastern Gulf of Mexico continental shelf. Total extractable organic matter (EOM) averaged 133 ppm (±80%) and 232 ppm (±53%) for sediments off Florida and the Mississippi River, respectively. Aliphatic hydrocarbons were determined gravimetrically and accounted for only a small percentage of the EOM. The aliphatic hydrocarbons were dominated by a series of branched or cyclic unsaturated C_{25} isomers, n-C_{17}, high molecular weight odd carbon number n-alkanes, and an unresolved complex mixture (UCM). The relative abundances of these compounds varied regionally and represented a mixture of biological (marine and terrestrial) and petroleum hydrocarbons. Gas chromatograms (flame ionization detection) of aromatic fractions exhibited sharp peaks on top of a moderate envelope of unresolved compounds. The large number of peaks in the aromatic fractions did not correspond to the available aromatic standards (no mass spectrometric confirmation was available). It was concluded that a western zone, which encompasses the present study area, extending eastward to the Alabama shelf, was dominated by terrigenous and petroleum hydrocarbons from the Mississippi River delta complex.

A similar conclusion was reached by Boehm (1979) based on the analysis of sediments from the Mississippi, Alabama, Florida Outer Continental Shelf (MAFLA) baseline environmental study conducted for the Bureau of Land Management (BLM). A region on the Mississippi-Alabama Shelf and the more offshore areas of the Florida OCS showed strong petroleum and terrigenous biogenic influences. Petroleum contamination was inferred from chromatograms with a double "hump" of unresolved compounds and a regular series of n-alkanes. Total hydrocarbons as estimated by gas chromatography averaged 1.6 ppm on the Mississippi-Alabama Shelf.

Sediment PAH concentrations on the shelf are on average six times lower than PAH concentrations in sediments in adjacent coastal embayments (Brooks et al. 1988). The aromatic compounds detected on the shelf are evenly distributed among 2, 3, 4 and 5 ring PAHs, typical of unprocessed petroleum. Unprocessed petroleum can result from natural seepage, runoff, leakage from industrial complexes, offshore oil production, and shipping or tanker activities. The association between sediment texture and some of the PAHs detected provides a clue to the origins of the PAHs (Brooks 1991). In general the higher PAH levels are associated with sediments containing low amounts of sand. Higher hydrocarbon concentrations are generally in sediments between the 100 and 200 m isobaths with the stations closest to the Mississippi River delta complex containing the highest concentration of hydrocarbons. The composition of PAHs on the shelf differs from those in adjacent coastal embayments suggesting little input of sediment contaminants onto the shelf from these areas. The association of PAHs with fine particulates suggests that non-point source terrestrial runoff combined with river discharge material is a significant source of sedimentary PAHs in the study area.

Approach and Rationale

There are two objectives related to the geochemistry program component. One objective is to document the presence of any contaminants in the study area due to energy exploration and exploitation. The second objective is to characterize the benthic abiotic environment at the study sites to aid in determining the origins of sediment at the study sites and to define the relationship between sediment texture and biological patterns.

The two most common contaminants associated with platforms are hydrocarbons and metals (Middleditch 1981; Boesch and Rabalais 1987; Boothe and Presley 1987; Continental Shelf Associates 1983, 1985b, 1989). The release of petroleum from a platform to the surrounding environment can occur during drilling as well as in the production phase of a platform's lifetime. Petroleum hydrocarbons are potentially present in a variety of discharges including drilling fluids, cuttings, produced water, spills, deck drainage, and other releases (Kendall 1990). Petroleum-derived hydrocarbons released to the environment can be differentiated from naturally occurring background biogenic hydrocarbons (Brassell et al. 1978; Philp 1985; Boehm and Requejo 1986; Kennicutt and Comet 1992). Petroleum contains (1) a homologous series of n-alkanes with 1 to more than 30 carbons with odd and even carbon number n-alkanes present in nearly equal amounts; (2) a complex mixture of branched and cycloalkanes; and (3) an extensive suite of PAHs. Aliphatic hydrocarbons synthesized by organisms (both planktonic and terrestrial) include a suite of normal alkanes with odd numbers of carbons from 15 to 33. Complex branched and cycloalkanes are rare in organisms. Petroleum PAH mixtures are easily differentiated from PAHs synthesized by organisms by the structural complexity of the mixture and the presence of substantial amounts of alkyl substituted PAHs. PAHs are some of the more toxic components of oil and as such indicate the potential for biological effects. Based on considerations of petroleum chemistry, biological occurrences, and toxicological effects, aliphatic and aromatic hydrocarbons were chosen as tracers of petroleum contamination (Kennicutt 1995).

Trace metals are also released in discharges from offshore drilling activities (Lake Buena Vista Symposium 1981; Boesch and Rabalais 1987; Boothe and Presley 1987). Metal contamination can potentially affect both infauna and epifauna in the vicinity of platforms (Southwest Research Institute 1978). Many trace metals are priority pollutants (silver, arsenic, cadmium, chromium, copper, mercury, nickel, lead, antimony, selenium, and zinc) and are known to be toxic to organisms. These metals are often constituents of drill muds (Houghton et al. 1981; Rubinstein et al. 1981; Tornberg et al. 1981). Tin is known to be toxic and is present in antifouling paints used on platform structures. Barium is an ideal tracer of the settleable particulate fraction of discharged drilling fluids and cuttings because it occurs in high concentrations in drilling muds and has a low, natural background in ambient sediments (200 to 500 ppm dry weight; Chow and Snyder 1981; Boothe and James 1985; Boothe and Presley 1987). Barium (as barite, barium sulfate) is the dominant component of drill mud (up to 90% on a dry weight basis). Aluminum and iron are major constituents of alumino-silicate minerals and can be used to detect changes in sediment type. Vanadium is another metal of interest because it can occur in significant concentrations in crude oil.

In order to characterize the benthic geochemical environment at the proposed study sites, a variety of inorganic and organic attributes will be measured. The origins and regional distribution of sediment characteristics are ultimately a function of abiotic and/or biotic processes and anthropogenic activity. Some characteristics tend to covary due to common origins and thus can confirm or contradict the importance of an inferred process. For example, TOC and silt/clay content covary and may suggest the prevailing depositional environment. Other parameters are indicators of the origins of materials that have accumulated at the site. For example, PAHs are a measure of petroleum contamination. The origins and movement of sediments and their associated constituents on continental shelves are particularly important in predicting the impact of human activities with reference to the longevity of an "unnatural" perturbation and possible "natural" mitigation or enhancement of environmental effects (i.e., removal or concentration of a contaminant; disruption of sedimentary processes). The detection of perturbations due to anthropogenic activities can only be recognized if the natural variability of the system is understood. The benthic setting is a key determinant in defining the ecology of biological communities.

Measures of sediment characteristics can provide quite different information. Often bulk characteristics, the chemistry of a select subfraction of the sediment, or compositional information is determined. Each type of measurement provides important information, however, each has its limitations in inferring origins and processes. Bulk measurements characterize a large percentage of the total sample. However, depending on the measurement, these characteristics can be generic in nature with multiple inputs unresolved (e.g., TOC). On the other hand more specific tracers can be useful in defining the origins of materials (e.g., $\delta^{13}C$). If a subfraction of the sample is characterized, the subfraction may or may not be representative of the bulk of the associated materials (e.g., alkanes). Often a specific chemical composition is preferentially associated with a single or unique source of materials (e.g., PAHs and petroleum). Quantitative determinations are needed if the relative importance of multiple inputs is to be determined. It is also key to measure flux to the benthos based on analyses of sediment trap materials in conjunction with measurements on the accumulated sediment.

The approach and rationale for the geochemistry portion of the study optimizes application of resources by using prior study information and a hierarchical approach to analysis selection. For hydrocarbons, a simple cost effective measure of the presence or absence of oil is needed. Total petroleum hydrocarbons (TPH) determined by gas chromatography/flame ionization detection (GC/FID) and a gravimetric measurement of EOM has been shown to accurately reflect oil contamination on the Gulf of Mexico continental shelf (Kennicutt et al. 1996). The best application of resources is to provide simple, cost effective measurements and increase sample coverage to assure representativeness. The origin of hydrocarbons within a site is of interest and will be determined on a single composite of all samples collected at a site. Fingerprinting techniques using PAH composition are the method of choice. In addition it is clear from previous studies that many indicators of platform discharges covary, providing equivalent information about the presence or absence of drilling discharges. A select set of metals (barium, cadmium, chromium, lead, mercury, and zinc), most closely related to platform discharges, will be measured. As an indicator of sediment mineralogy, aluminum and iron will also be measured. Crustal elements are used to normalize the concentration of trace metals to detect anthropogenic additions.

Field and Laboratory Methods

Sediments are collected by grab as described in Chapter 5, Geology/Sediment Dynamics. The top 5 cm are sampled. Samples for geochemistry are collected concomitantly with geological samples. The collection of sediment trap materials is also described in Chapter 5.

Total Inorganic and Organic Carbon

Sediment carbonate content (0.2-0.5 g) is determined by treatment with concentrated HCl. Residual organic carbon is converted to CO_2 and analyzed with a non-dispersive infrared spectrophotometer (Leco WR-12 Total Carbon System). Calcium carbonate is determined as the difference between a treated (acidified) and untreated carbon determination. The acidification is carried out in the crucible used for analysis and the residual acid is evaporated in place to avoid loss of acid soluble organic matter.

Hydrocarbon Analyses

The analytical procedures that provide quantitative hydrocarbon concentrations in sediments have been described in detail elsewhere (Wade et al. 1988; Brooks et al. 1990). The method was adapted from MacLeod et al. (1985) as modified by Wade et al. (1988). Sediment samples are freeze-dried, ground, and stored frozen until analysis. Each set of samples (six to eight) are accompanied by a complete system blank and a spiked blank, which is carried through the entire analytical scheme in a manner identical with the samples. System blanks only include reagents and internal standards. Spiked blanks are system blanks plus known amounts of the analytes of interest. Approximately 15 g of sediment (dry weight) is extracted with methylene chloride for 12 h in a Soxhlet apparatus. Extracts are concentrated with a Kuderna-Danish (KD) evaporative concentrator to 0.5-1 mL (60°C) and stored refrigerated (4°C), if not immediately fractionated by column chromatography.

Aromatic hydrocarbons are separated from interfering lipids by alumina/silica gel chromatography. Copper powder is added to the column to remove sulfur. The CH_2Cl_2 is replaced with hexane, and the extract, in 1 mL of hexane, is transferred to the column. The column is then eluted with 50 mL of pentane (f_1, aliphatic), and 200 mL of 1:1 CH_2Cl_2-pentane (f_2, aromatic). The aliphatic fractions are analyzed by gas chromatography with flame ionization detection. The detector is calibrated by triple injections of authentic standards (n-C_{11} to n-C_{34}). The aliphatics are separated on a DB-5 fused-silica capillary column by using the following temperature program: T_1 = 60°C, t_2 = 0 min, rate = 12°C/min, T_2 = 300°C, and t_2 = 10 min.

Quantitation of the aromatic (f_2) fraction is by gas chromatography/mass spectrometry (GC/MS) using the selected ion monitoring (SIM) mode. Mass fragmentation is accomplished by electron impact at 70 eV. Sample components are separated on 30-m (DB-5, 0.25 mm i.d.) fused-silica capillary columns with carrier flow (He) of 2-3 mL/min. Sample injections are cold trapped on the capillary column for 1 min at 40°C. The oven is then heated to 300°C at 12°C/min. The detector is calibrated for the molecular ion of each analyte. Deuterated surrogates are readily differentiated with no interferences due to differences in the molecular ions monitored (i.e., naphthalene, m/z 128; naphthalene-d_8, m/z 136). Two GC/MS systems are used: Hewlett-Packard (HP) 5996 GC/MS/DS and HP 5970 GC/MSD/DS. The HP Aquarius software is calibrated at five concentrations for each component of interest. Blanks and spiked blanks are run with each sample set. Analyte concentrations are corrected for blank levels and surrogate recovery.

Surrogate recoveries are maintained between 60% and 90%. Method detection limit (MDL) calculations are based on 15-g sample size, 1 mL final volume, and 1-µL injections provide values of 1-4 ppb for all aromatic analytes. Blanks are maintained at less than 3 times the MDL or corrective action is taken (i.e., reinjection or reextraction as necessary). Analytical precision of ±20% for individual analytes on replicate samples is maintained at a concentration of 5 times MDL.

Trace Metal Analyses

All labware is pre-cleaned by soaking for 24 hours in Micro® cleaning solution followed by extensive rinsing with distilled water. The rinsed labware is then soaked for 24 hours in a 50% nitric acid, rinsed with reagent water and air-dried. Each set of samples is accompanied by quality assurance/quality control (QA/QC) samples (i.e., method blank, spiked blank, duplicate, matrix spike duplicate, and standard reference material).

The method to be utilized involves wet digestion of a dry homogenized sample in a closed Teflon® bomb. Three mL of Ultrex nitric acid are added and the lid loosely replaced. The Teflon® bomb is allowed to react for 24 hours at room temperature with the lid securely tightened and digestion proceeds at 130°C. Following digestion, 17 mL of ultrapure water is added to the Teflon® bombs and the samples are transferred to clean 1 ounce Nalgene® sample bottles.

The analytical methods are optimized for each element/matrix type to ensure high quality data. The analytical methods to be used are summarized in Table 6.1.

All sediments are stored frozen. Sediment samples are thawed, homogenized, and a representative aliquot is taken for freeze-drying. After freeze-drying, the samples are homogenized by grinding to a powder prior to digestion.

For most elements in sediments, National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Mussel Watch methodologies, which incorporate a closed Teflon bomb acid digestion, are used (Lauenstein et al. 1993). These are sensitive (low detection limit), total digestion methods (i.e., MDLs for most elements in the 0.01 to 1.0 ppb dry weight range) developed for use in baseline monitoring programs. These methods are capable of accurately measuring trace element levels in uncontaminated, pristine areas. Mercury is determined according to U.S. Environmental Protection Agency (EPA) method 245.1 (U.S. EPA 1991), which involves a separate sulfuric/nitric acid and permanganate/persulfate digestion followed by cold vapor atomic absorption spectrophotometry (CVAAS).

Table 6.1. Trace element analytical methodologies[a].

Element	Grab Samples	Sediment Trap Samples
Barium (Ba)	INAA	INAA
Cadmium (Cd)	GFAAS	--
Chromium (Cr)	INAA	INAA
Iron (Fe)	INAA	INAA
Lead (Pb)	FAAS	--
Zinc (Zn)	FAAS	--
Mercury (Hg)	CVAAS	---

[a]Analytical methods are flame atomic absorption spectrophotometry (FAAS), graphite furnace or flameless AAS (GFAAS), instrumental neutron activation analysis (INAA), and cold vapor AAS (CVAAS).

For certain elements of special interest to this study (e.g., barium), specialized analytical techniques are needed. For example, sediment barium is the most important elemental tracer of drilling mud discharges and is a critical parameter for interpreting the chemical gradients observed in the vicinity of drilling locations. To maximize data quality, sediment barium concentrations are determined by instrumental neutron activation analysis (INAA). INAA is the analytical method of choice for sediment barium determination because barium is difficult to dissolve by normal acid digestion procedures. INAA is a nuclear technique that is free of chemical interferences, and has an essentially unlimited linear dynamic range. INAA determinations are made using the method of Boothe and James (1985), which is optimized for marine sediments. Other elements (chromium, iron) will be determined simultaneously by this multi-element technique.

Trace element analyses are conducted under a comprehensive QA project plan designed to consistently produce high quality, verifiable data. All sample processing and analysis procedures are performed to minimize contamination and maximize data quality (accuracy and precision). All procedures are conducted by properly trained personnel according to approved laboratory standard operating procedures (SOPs). Good laboratory practices (e.g., daily refrigerator/freezer temperature checks, balance calibrations, etc.) are consistently followed.

All sample handling is done using new or acid-cleaned, metal-free containers and implements. Cleaning procedures and sample processing are performed in a clean room to avoid sample contamination. Also, all containers are kept closed or covered except when material is being added or removed. Distilled-deionized high purity water is used to prepare all detergent and acid cleaning solutions and for all rinses during cleaning procedures. Double-distilled, ultra-pure water is used for all dilutions and to prepare all sample digestion/processing reagents. Ultra-pure reagents are used whenever necessary to ensure that the procedural blank for a given analytical procedure is below the method detection limit for that procedure.

A detailed log is prepared for each digestion, specifying all aspects of the procedure (e.g., SOP to be used, matrix spike levels, QA samples, etc.). As the digestion is performed, all information is recorded in a bound, pre-printed logbook for the specific digestion procedure being used. A full suite of laboratory QA samples is analyzed with each set of 30 to 45 samples digested. These include certified reference materials, laboratory control samples (blank spikes, matrix spikes, laboratory duplicates ±5%), and procedural blanks.

All standards are traceable to National Institute of Standards and Technology standards and are replaced when expiration dates are exceeded. The preparation of all standard solutions (including lot numbers, measuring devices, and amounts used, etc.) are recorded in a single log book and all solutions are clearly labeled and traceable to a logbook entry.

During each analytical procedure, the instrument will be calibrated at the beginning of the analysis and the calibration will be checked (or re-calibrated) frequently during the analysis. Full re-calibrations will be performed as necessary if the calibration changed more than 5% between any two checks. All data entered will be verified independently by a second person.

Each analytical batch is evaluated based on the results of the QA samples and stringent QA acceptance criteria consistent with those recommended by the EPA (U.S. EPA 1989). The acceptance criterion for percent recovery (i.e., QA parameter for CRM, matrix spikes, blank spikes) is 80% to 120%. The acceptance criterion for relative percent difference for duplicates at 10 times the MDL is ±20%. The acceptance criterion for procedural blanks is less than twice the MDL. Finally, 95% of all QA analyses performed for each batch of samples must meet the acceptance criteria. When one or more QA parameters fall outside the acceptance criteria for a given digestion set and element, the samples are re-analyzed. If re-analysis does not bring the QA parameter(s) within acceptable ranges, the samples are re-digested and re-analyzed.

Preliminary Data

As of this report, no preliminary data are available.

Data Interpretation and Synthesis

The geochemistry work element will provide a series of independent abiotic indicators of contaminant levels (hydrocarbons-TPH, EOM, and PAH; trace metals-Ba, Cd, Cr, Hg, Pb, and Zn), sediment grain size, TOC, and sediment composition (Al, Fe, and TIC) to be incorporated into the overall statistical design. Intersite and intrasite comparisons will be made to highlight changes in the geochemical patterns. These abiotic parameters will be used to interpret the associated biological patterns.

Chapter 7
Physical Oceanography/Hydrography

The purpose of this component of the program is to monitor environmental conditions (i.e., dissolved oxygen, turbidity, temperature, salinity, etc.) at the three distinct types of topographic features along the Mississippi-Alabama outer continental shelf (OCS). Other program elements can then relate observed seasonal and inter-annual changes in community structure and zonation to changes in environmental conditions. The specific objectives that focus on the details of this relationship are:

- to characterize the regional and local current dynamics in the study area, which lies on the outer portion (60-100 m water depth) of the Mississippi-Alabama continental shelf;

- to determine the dynamics of important environmental parameters, including temperature, salinity, dissolved oxygen and turbidity; and, most important,

- to define the relationship of the current dynamics and environmental parameters to the geological and biological processes of the hard bottom features.

Historical Background

Because the pinnacles are relatively narrow low relief features, this oceanographic study focuses on the bottom portion of the water column. The Mississippi-Alabama Marine Ecosystems Study (MAMES; Brooks 1991) provides the best available background information. For example, two MAMES current meter moorings were located in 60-m water depth in an area that corresponds to the northern side of the present study area. The physical oceanography portion of the MAMES program concluded that four primary forcing mechanisms drive the continental shelf and slope waters of this region: synoptic scale wind stress, Loop Current related intrusions, river discharge, and tropical cyclones. The first is a stochastic process, and the other three are non-stochastic events that strongly modulate the first. The response to wind forcing is relatively mild, except during tropical storms and hurricanes, and results in a shelf wide circulation that is cyclonic on a seasonal-mean basis. This latter conclusion is speculative because of the small number of MAMES moorings and hydrographic surveys. The intrusion of Loop Current related waters onto the shelf is chaotic in occurrence. However, intrusions are an important factor for the present study because of the frequency of occurrence, the marked contrast in water mass properties, and the large shelf area affected.

During MAMES, satellite imagery was used to monitor the Loop Current and the filaments that meander northward from it. A census of the images found warm intrusions in the MAMES region to be frequent; an exact count for the whole study period could not be made by thermal imagery because intermittent cloud cover and the relatively isothermal sea surface conditions during July through September interrupted the continuity of observations. Therefore, the search for intrusive events was supplemented by studying the 40-hour, low-passed time series of temperature recorded at 150 and 426 m by two current meter moorings on the 430-m isobath. Every intrusion counted in the census by satellite corresponded to a temperature increase above the mean of one or more of the subsurface temperature series. The increase persisted for at least 10 days and reached a peak deviation of at least 1 degree. Using these criteria additional periods of warm intrusions were identified. The combination of satellite imagery and sub-surface temperature data covered a total of 798 days. Intrusions were found during 11 periods of time, totaling 355 days, or 44% of the time. A combination of satellite imagery, hydrographic surveys, and sub-surface moorings suggested that the east-west spatial scale of the intrusions was on the order of 30-45 km.

The years of 1988 and 1989 were contrasting extremes in Mississippi River discharge that demonstrated the effect of this river's discharge on vertical stability in the study area. A decrease in vertical stratification of the shelf water increased its response to stochastic wind forcing. Coherence between wind stress and bottom currents during the drought of 1988 was stronger than in 1989 when Mississippi River discharge increased to above average rates. The MAMES study also found that (a) near bottom currents at the 60-m sites were more strongly coherent with wind stress than the surface currents, regardless of the degree of stratification, and (b) the coherence between wind stress and currents was most commonly observed at frequencies near 0.08 and 0.2 cpd. Since wind stress exhibited a broad energy peak around 0.09 cpd, the results suggest that a wind-forced wave mode dominates the middle and outer shelf response.

MAMES found that mean bottom currents at one 60-m site and two 430-m sites were persistently toward the southwest. At the other 60-m site significant cross-isobath mean currents caused persistent southeastward mean flow from February through May 1989, while from June through October the mean was weaker and variable in direction. The persistent southwestward flow at three of the sites suggests the existence of a large scale east-to-west pressure gradient.

In general, the MAMES results are in agreement with Dinnel's (1988) surface circulation schema over the inner and middle shelf, where the current meter observations suggest a cyclonic circulation pattern. Over the outer shelf and slope, Dinnel's seasonal maps of dynamic height, computed relative to a level of no motion at 500 m, suggest an anticyclonic circulation cell with southwestward surface flow over the slope. The MAMES direct observations of current, however, do not support the existence of the anticyclonic cell. The MAMES results suggest that the mean surface circulation on the shelf consists of only a cyclonic circulation cell, the south side of which extends to the outer shelf and slope.

Approach and Rationale

To address the objectives, the oceanographic-processes effort consists of the following principal elements:

- Instrument Moorings. Six, 18-m high, bottom-mounted, instrument moorings are deployed at selected hard bottom sites to continuously measure current velocity, temperature, conductivity/salinity, dissolved oxygen, and turbidity. The moorings also have sediment traps to accumulate suspended sediment samples.

- Hydrography. Vertical profiles are collected by the same conductivity/temperature/depth/dissolved oxygen (CTD/DO)/transmissivity/ light instrument package used during the Texas-Louisiana Shelf Circulation and Transport Process Program (LATEX) to obtain more detailed information about the processes in progress during each monitoring cruise.

- Collateral Data. Collateral data, such as satellite advanced very high resolution radiometer (AVHRR) images, satellite altimetry, river discharge, coastal wind and sea level data, and buoy observations of wind, waves, barometric pressure, air and sea temperature, are being obtained to define the primary forcing mechanisms.

Instrument Moorings

Moored instruments provide information about the temporal scales of physical processes that affect the biota associated with the bottom features in the study area. The variables of greatest interest are currents, suspended sediments, water temperature, dissolved oxygen, and salinity. Time scales associated with the interaction among these variables and the biological communities of the hard bottom features cannot be adequately measured by the semi-annual monitoring cruise. The MAMES results suggest that important changes could be caused by events, such as passage of a hurricane or an intrusion associated with the Loop Current. Continuous time-series measurements will capture the details of such events and yield statistically significant averages of the variables. The time series must include near-bottom measurements at the hard bottom features and the collateral data (discussed in a succeeding section) that document the forcing functions.

The hard bottom features addressed here include pinnacles that extend up to 15 m above the bottom. Water depth in the region ranges from 70 to 120 m. One of the study objectives is to examine the local effect of these features on the currents and, therefore, on sediment and water property dynamics. We believe the orographic effect will be small. Studies of the flow perturbation by small, circularly symmetric topography on idealized, baroclinic flow show that the vertical influence depends on three parameters: a stratification measure, a topographic size parameter, and the scaled upstream shear (e.g., Hogg 1973). Parameter values computed using MAMES data suggest a small orographic effect. The stratification and current shear get as large as the "moderate" category, but the topographic parameter is very small because of the small width of the pinnacles. The Flower Garden Banks, on the other hand, have similar stratification and current shear parameters, but a substantially larger topographic parameter because width is on the order of 4 km. The result is that flow is measurably perturbed by the Flower Garden Banks (Rezak et al. 1985).

Six moorings are deployed in the study area to measure currents, conductivity/salinity, temperature, dissolved oxygen, turbidity, and sediment flux. Figure 7.1 illustrates the mooring design. The dissolved oxygen and turbidity sensors are located as close to the bottom as possible. Time-series measurements of dissolved oxygen and turbidity are difficult to obtain because even minor fouling degrades data quality. However, they are important ecological parameters, and the new technologies used by the instruments may provide time series of up to 3 months duration. Sediment traps are attached at three heights above the bottom. Current, temperature, and conductivity/salinity are recorded about 2.5 m above the bottom and at 16 m above the bottom.

One mooring is placed at each of four of the nine pinnacle sites. Three of the sites (Sites 1, 4, and 5) are medium and high relief features located near the 100 m isobath. The fourth (Site 9) is a low relief site in shallower water near the 60 m isobath. These four moorings locations are permanent, i.e., they will be maintained throughout the program to provide continuous long-term, time-series data at each of the four sites. The three deeper ones will give us significant along-isobath coverage of the outer shelf, which in turn will provide data about the cross-isobath exchange of water-mass properties between the outer shelf and the slope/open ocean. The shallower site when paired with a deeper site will yield some information about cross-isobath correlation.

The fifth and sixth moorings are re-locatable. They have been placed initially at the eastern-most high relief site (Site 1) to form, in conjunction with the permanent mooring, a triangular pattern. The two re-locatable moorings will be moved at 6-month intervals to each of the other three sites. The objective is to observe any differences in the current flow and water properties around the features.

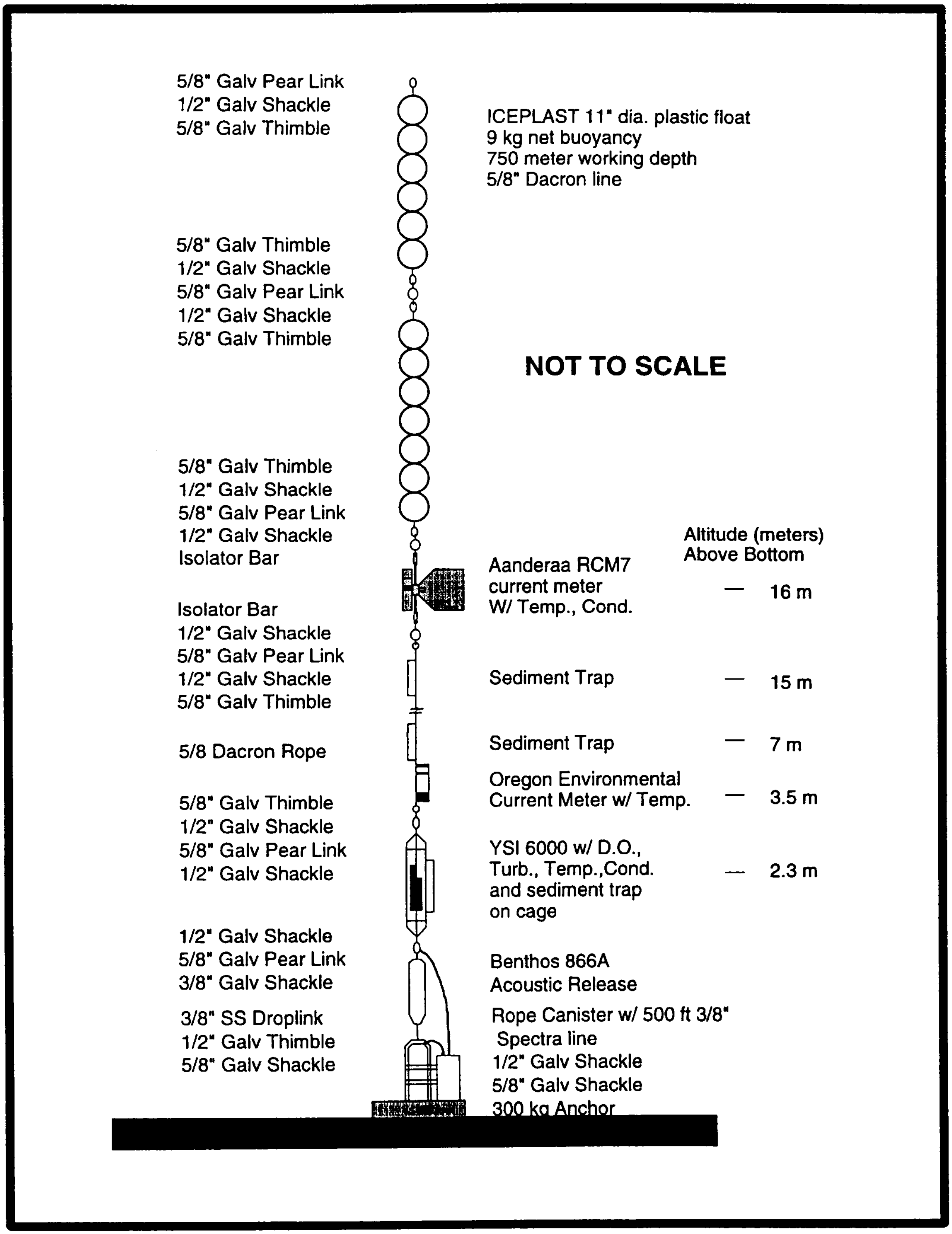

Fig. 7.1. Schematic drawing of the instrument mooring.

Hydrography

Physical factors that affect the biota in the region include currents, temperature, salinity, dissolved oxygen, turbidity, and light levels. Moored instruments will produce time series of all these variables except light levels, but only at two depths for current, temperature, and salinity and one depth for dissolved oxygen and turbidity and only at a few discrete locations. Vertical profiles of these variables taken during the monitoring and servicing cruises will give valuable information on the vertical distribution of these properties. Previous studies (Kelly 1991) indicate that water masses in the study area can undergo changes both at the surface and at depth. CTD profiles indicate the presence of near bottom nepheloid layers that vary quite markedly over the area.

Vertical variations are induced by Loop Current intrusions, seasonal heating and cooling, wind forcing, fresh water input from both the Mississippi and local rivers, and the passage of storms. To assess the effect of these variations at each study site, we are collecting multiple vertical profiles of conductivity, temperature, photosynthetically active radiation (PAR), transmissivity, backscattered light, and oxygen concentrations. Vertical profiles are made at three locations around each site to determine if changes in water properties are induced by flow past the topographic features. Water samples are collected for determination of total suspended matter and for calibration of the oxygen sensor. Salinity samples are used as a check on the depth at which the bottle actually closed. Sampling depths focus on the depth from feature height to the regional bottom depth, with fewer samples in the overlying water. From these measurements, we hope to infer the depth of the nepheloid layer and characterize the water masses enveloping the features. The basic measurements of temperature, salinity, light levels, oxygen, and suspended sediment loads will be available for use as environmental variables in statistical models applied to the biological assemblages. These data will also be useful for calibration and quality control of the time series measurements made at the moorings.

Collateral Data

Kelly (1991) found that the coherence between wind stress and bottom currents in the region was consistent with a wind-driven shelf model. Bottom currents were coherent with wind stress at most of the sites he studied. Any interpretation of the current data must consider the wind data. There are six National Oceanic and Atmospheric Administration (NOAA) and Coastal Marine Automated Network (CMAN) buoys in or near the study area. Collectively they will provide good indication of the wind field over the region during the field program. River discharge and sea level are other collateral variables that must be examined and related to currents in the study area. In MAMES, we found significant correlation with these variables at low frequency. Satellite AVHRR data is critical to the study of Loop Current related events that reach the shelf. Altimetry data is a newer resource that we will evaluate. It proved useful to the LATEX studies.

The primary source for our collateral data will be the Minerals Management Service (MMS) funded project being conducted by Science Applications International Corporation (SAIC) entitled "Northeastern Gulf of Mexico Physical Oceanography Program: De Soto

Canyon Eddy Intrusion Study." MMS has tasked that project with collecting, archiving, and disseminating to concurrent MMS studies all collateral data. In addition, we will incorporate into our analyses and interpretation the relevant data collected by the SAIC field program. Our two projects are concurrent and interface along the 100-m isobath.

Hydrographic measurements by other programs will aid us in the interpretation of our own data. The Gulfcet II program will conduct cruises in September 1996, Spring 1997, and Fall 1997. They will make CTD casts and acoustic Doppler current profiler (ADCP) measurements in water depths as shallow as 100 m near our study area. The measurements should provide snapshots of the influence of physical processes originating from currents, rings and filaments on the continental slope. Another MMS project will overlap in time an location with our study will be the "Northeastern Gulf of Mexico Physical Oceanography Program: Chemical Oceanography and Hydrography," which should begin in late 1997. At least a portion of it should overlap our study and provide additional data to augment our interpretive effort.

Field and Laboratory Methods

The May 20-24 leg of Cruise 1C deployed six instrument moorings and conducted 29 casts with the CTD system. In addition, 11 bio-moorings were deployed in support of the Epibiont Recruitment Study (Chapter 11). Chapter 2 provides the details of the cruise's operations and logistics. Table 7.1 provides the locations, dates, and times of deployment of the instrument moorings

Equipment

Moorings

Six, multiparameter, physical oceanography moorings are deployed, and three additional moorings are available as spares. All nine are identical. Their principal components are shown schematically in Figure 7.1. The spare moorings will be used during servicing to speed up the operation and to replace losses as they occur.

A mooring is constructed using 5/8" Dacron rope. The linkage between the acoustic release and the anchor is rope rather than chain so that it can be cut by the remotely operated vehicle (ROV) should the release fail. ICEPLAST Model 1102 plastic floats provide flotation. Each float has 9 kg of net buoyancy and a maximum working depth of 750 m. Static mooring analysis was computed for the mooring using the program BUOY2.41 developed by Specialty Devices Inc. The amount of flotation has been selected to assure that mooring "blow-over" is less than 1.0 m for current profiles up to 40 cm/s. The rope canister contains 152 m of 3/8" Spectra line, a length that will permit the mooring to rise to the surface and be recovered before pulling the anchor up.

Table 7.1. Coordinates for current meter (CM) moorings deployed on Cruise 1C.

Date and Mooring No.	Time In	Easting	Northing	Latitude	Longitude	Depth (m)
5/21/97						
CM 4A	21:21	426583.3	3244597.2	29° 19' 47.66"	87° 45' 22.15"	115
5/22/97						
CM 1A	22:39	444520.7	3256839.9	29° 26' 28.75"	87° 34' 19.32"	78
CM 1B	23:57	444544.5	3256163.9	29° 26' 06.79"	87° 34' 18.31"	79
5/23/97						
CM 1C	01:09	443761.2	3256406.8	29° 26' 14.56"	87° 34' 47.43	82
CM 5A	13:03	405132.8	3251628.7	29° 23' 30.94"	87° 58' 39.59	82
CM 9A	20:30	371417.2	3235151.9	29° 14' 24.89"	88° 19' 23.29	93

NOTES: 1) All times are in local time - Central Time Zone.
2) All distances and depths are in meters.
3) Geodetic parameters: Ellipsoid = Clarke 1866, Zone = 16, CM = -87, Projection = UTM, Units = meters.

Acoustic Releases

Benthos Model 866A Continental Shelf Releases are used on the current moorings. Billings Industries, Inc. Model ATR-397 acoustic releases are used on the bio-moorings.

Current Meters

The bottom current meter on each mooring is an Oregon Environmental, Inc. (OEI) Model 9407 with temperature sensor. The top current meter on each mooring is an Aanderaa Model RCM7 with conductivity and temperature sensors. Both types vector average currents, record into battery-backed solid-state memory, and download directly to PC-type computers.

Dissolved Oxygen and Turbidity Recorders

A YSI Model 6000 recording system with oxygen, turbidity, temperature, and conductivity sensors lies immediately below the OEI current meter. This unit records internally. It includes an external battery pack to extend battery life up to 4 months. The oxygen system uses rapid pulse technology. This measures oxygen current in small pulses only when the measurement is actually being made, which not only limits power drain but also reduces the effect of fouling on the measurement. The turbidity sensor is of the backscatter type. It contains a small wiper that cleans the optical window before each sample. The rapid-pulse technology and the wiper have proven to significantly extend the period of good data collected by these types of sensors before biofouling finally takes hold.

To further reduce biofouling, we have replaced the standard sensor-guard of the YSI6000 (conceptually, a cup with holes in it) with a "poison sensor-guard" custom manufactured by Oceanographic Industries of Miami Beach, FL. The inside of the guard is covered with a poisoned jell. The poison slowly diffuses from the gel into the small interior region surrounding the sensors. Freshly coated guards are installed during each service cruise. Used guards are returned to the manufacturer for re-coating.

CTD/DO/Transmissivity/Light-Profiling Instruments

The primary system for continuous measurements is a Sea-Bird Electronics, Inc. SBE-9 CTD system used with a SBE-11 deck unit. This is essentially the same system used during the MMS LATEX A program. The Sea-Bird SBE-9 CTD is a research grade CTD system which offers high quality profiles of oceanic temperature, salinity, and density to all ocean depths. The SBE-9 uses ultra-stable time-response matched sensors and fast, high-resolution parallel sampling for data acquisition.

In addition to providing-precise measurements of temperature and salinity with depth, the Sea-Bird CTD is also used as a general-purpose data acquisition and telemetry system. Dissolved oxygen is measured with a "Beckman" polarographic type *in situ* dissolved oxygen sensor connected to the Sea-Bird Electronics SBE-9 CTD. Downwelling irradiance is measured with a Biospherical Instruments, Inc. Model QSP-200L irradiance profiling sensor. Particle scattering is measured with a Sea Tech light scattering sensor. In addition to the light scattering sensor, the CTD is equipped with a SeaTech, Inc. 25-cm transmissometer.

Water Samples

Samples for discrete measurements of dissolved oxygen and salinity are drawn from the 10-liter PVC Niskin bottles mounted on the General Oceanics Rosette sampler, which is part of the CTD profiling system.

Samples for dissolved oxygen analysis are collected in 125-mL, calibrated glass-stoppered bottles. Samples are collected from all stations. At least 10% of the oxygen analyses are duplicated to establish sampling and analytical precision, and assure data reliability. Samples are collected and analyzed for dissolved oxygen by the reliable microwinkler technique (Carpenter 1965). This method has been the world standard for major oceanographic programs for decades. The microwinkler method has a precision of 0.01 mL/l oxygen at STP. Most analyses were performed aboard ship. Some of the samples from the last few stations plus duplicates from samples analyzed aboard ship were analyzed in the laboratory after the cruise.

Samples for salinity analysis are collected in 350-mL citrate bottles that have been triple rinsed with sample water before collection. These bottles are air tight. A salinity sample is collected from every Niskin bottle that is tripped. Samples are taken for salinity analysis from at least half of the stations during a given cruise and returned to the laboratory for analyses.

Preliminary Data

The instrument moorings will be recovered on a cruise scheduled for 27-30 July 1997. The data from the instruments will not be available in time to be included in this report.

Twenty-nine CTD casts were conducted during the deployment cruise. Appendix A provides the locations, dates, and times of the casts. Three casts were made around each of the nine pinnacles. However, Sites 1 and 3 are located so closely together that their CTD casts form a group of six rather than two distinct groups of three. Therefore, these casts are designated H1A1 through H1F1; there are no casts with the ID's H2A1, H2B1, and H2C1. There are two locations where duplicate casts were conducted because of problems with bottles closing correctly, e.g., H4B1 is duplicated by H4B2, and H7A1 is duplicated by H7A2.

Appendix A contains plots of the vertical profiles of salinity, temperature, sigma-theta, percent transmissivity, OBS, and irradiance. There are two pages of graphics per station. The first page shows the profiles for temperature, salinity, and sigma-theta, and the second page shows the data for the optical properties.

Data Analysis and Interpretation

No analysis or interpretation of the data is attempted for this report because of the limited amount of data and the limited time since their collection and processing.

Chapter 8
Hard Bottom Communities

Hard bottom communities at nine sites are being monitored through visual observations and collections from a remotely operated vehicle (ROV). At each site, random photographic stations and random video transects are being surveyed during each monitoring cruise. The random quantitative photographs will be used to estimate the abundances of sessile and motile epibenthos, whereas video images will be used to quantify larger and more motile organisms and to broadly characterize substrates and species composition. In addition, fixed video/photoquadrats have been established which will be revisited on subsequent cruises; the data will be used to describe temporal changes including growth, recruitment, and mortality. Voucher specimens are also being collected to aid in species identification. Together with geological and oceanographic data collected during the program, these data will be analyzed and interpreted to describe hard bottom community dynamics, spatial variability, and relationships with the physical environment.

Historical Background

Previous biological surveys within the pinnacle trend area have used rock dredges and combinations of dredges and video and still cameras (Ludwick and Walton 1957; Woodward-Clyde Consultants 1979; Continental Shelf Associates, Inc. 1985a). ROVs have been used for studies which focused on the biological characterizations of some of these features. A combination of video and still photography and discrete collections of conspicuous epibenthic biota were made during these surveys (Brooks 1991; Continental Shelf Associates, Inc. 1992).

From these previous surveys, it is generally known that the biotic assemblages are of tropical Atlantic origin and consist mainly of suspension feeding invertebrates typical of hard bottom habitats at these depths in other areas of the Gulf of Mexico (Gittings et al. 1992b). Studies conducted by Continental Shelf Associates, Inc. (1985a) found that these communities were comparable to the transitional "Antipatharian Zone" described by Rezak et al. (1985) at depths below 82 m at the Flower Garden Banks on the outer continental shelf edge off Texas-Louisiana. Studies made by Texas A&M University scientists found that dominant epibenthos included gorgonacean octocorals, ahermatypic scleractinian corals, antipatharian corals, sponges, comatulid crinoids, bryozoans, alcyonacean octocorals, and oysters (roughly in order of abundance) (Brooks 1991). Encrusting coralline algae were also common constituents of those exposed hard bottom features which were located at depths shallow enough for adequate light penetration and with sufficient vertical relief to prevent or minimize the effects of smothering by fine sediments. Filamentous and leafy algae were not significant constituents of the hard bottom communities.

Epibenthic community development is known to vary significantly between features. Influential factors may include the amount of exposed hard bottom, substrate texture (rugosity), topographic complexity, and water quality (Brooks 1991; Gittings et al. 1992b). Studies conducted by Continental Shelf Associates, Inc. (1992) found that the relative densities and species diversities of epibenthos on pinnacle features were considerably greater on relatively horizontal reef flat areas than on adjacent vertical reef faces, suggesting that the horizontal surface may be more suitable for colonization and subsequent growth. Longitudinal variability in certain species such as ahermatypic corals was observed (Brooks 1991; Gittings et al. 1992b). It was suggested that the Mississippi River plume may influence chronic, average water quality in these areas, and may become limiting for conspicuous, hard bottom biota. It was estimated that the longitudinal extent where water quality is suboptimal for hard bottom community development, termed the "Mississippi Threshold," extends east of the Delta about 70 km.

Approach and Rationale

The hard bottom monitoring approach includes a combination of random and fixed video/photographic sampling using an ROV. Random video/photographic transects are appropriate for broad characterization of substrates and epibiota, and for estimating abundances to compare among sites. Because of the high spatial variability within hard bottom communities, repetitive video/photographic sampling of fixed quadrats is the preferred method for studying temporal changes within a site.

The depths of the study area are below the practical limit using SCUBA diving, and the limited maneuverability of ROVs reduces the precision in collecting small scale repetitive photographs. Therefore, a modification of the fixed 8 m^2 photoquadrat methods used during the long-term monitoring study of the Flower Garden Banks National Marine Sanctuary is being used (Gittings et al. 1992a). The Flower Gardens method compared the relative dimensions or outlines of individual epibenthic organisms seen within fixed photographic quadrats over time. The repetitive quadrat photographs were taken with a camera equipped with a wide angle (15 mm) lens and mounted on a T-shaped framer with a fixed camera-to-subject distance of 2 m to reduce the effects of camera parallax. Despite the relatively large size of the photographic images, analysis of temporal changes in photoquadrat epibiota was still feasible at this camera-to-subject distance because of the large size of the dominant epibiota at the Flower Garden Banks (consisting of massive hermatypic scleractinian corals and hydrocorals).

In contrast, the dominant epifauna within the study area consist of more numerous, smaller organisms (e.g., ahermatypic scleractinian corals, octocorals, antipatharian corals, and sponges) than those occurring on the Flower Garden Banks. The rates of growth or detectable change in these communities may also be much slower than those observed in shallower areas such as the Flower Garden Banks. In addition, because of depth limitations, an ROV must be used to collect photographic data at all sites. Therefore, the methods described in Gittings et al. (1992a) have been modified for this environment and sampling device. In the study area, it is not feasible for the ROV to carry a photographic framer device to assist in positioning the camera at each fixed photoquadrat. Therefore, precise repositioning of the vehicle depends upon the strategic placement of multiple, permanent quadrat markers (instead of a single marker post) and the use of a paired laser device on the ROV. The camera-to-subject distance of photoquadrats taken within the study area will be much shorter than the 2 m distance used in the Flower Gardens study. The image size of each photoquadrat will be the same as that used for random photographs. Because of the problems of camera angle and distance in repetitive photography, the videocamera is the main sampling device for fixed photoquadrats.

Field Methods

Field sampling includes qualitative data collection, random photographic stations and video transects, fixed video/photoquadrats, and voucher specimen collection. The ROV being used for field sampling is the Benthos Openframe SeaROVER with a Python multifunction manipulator arm. Video, photographic, and ancillary equipment include a Sony high-resolution videocamera, DeepSea Power & Light Micro-SeaCam 2000 color videocamera, Photosea 1000 still camera and strobe, DeepSea Power & Light lasers, and a Simrad MS900 color imaging sonar.

Qualitative Data Collection

Both qualitative and quantitative video and still photographic data are being collected at each site during the monitoring program. During Cruise 1B qualitative data were collected from four potential monitoring sites (3, 6, 8, and 9) to aid in site selection. Additionally, quantitative still photographs were taken at various heights above the substrate to augment the video data and determine the optimal still camera-to-subject distance for identifying individual species during the monitoring surveys. Due to the small sizes of many of the more abundant species the camera-to-subject distance for still photographs was set at 60 cm, the closest distance from which an in-focus photograph could be taken. This provided the highest detail for discerning small biota which was possible with the Photosea camera system. Qualitative video and still photographic data were also collected at each monitoring site during Cruise 1C, the first monitoring survey.

During Cruises 1B and 1C, the ROV equipped with two independent videocamera systems and one still camera system was used to collect video and still photograph data. One of the videocameras was aimed forward and was used to maneuver the ROV and collect qualitative video images for identifying substrates, epibiota, and fish. The second videocamera and the still camera were used to collect either qualitative or quantitative video and still photographs. These two cameras were aligned to have the same field of view and were able to be remotely positioned to be perpendicular to the targeted substrate or subject. The second videocamera and still camera also allowed the scientific observer and ROV pilot to observe the four lasers which were used to determine distance above the bottom and scale within the video and still photographs. Video and photographic data and ROV position were correlated using the Mission Manager software system and observations concerning specific features of interest were noted using Mission Manager and written logs.

Random Photographic Stations and Video Transects

At each of the nine monitoring sites, the ROV equipped with two videocameras and a still camera is being used to collect video footage and still photographs at pre-selected random locations and along transects between these locations. Prior to the monitoring cruise, 100 locations were randomly selected at each of the nine monitoring sites. These random locations were selected using the digital elevation models for each of the sites which were created from the detailed bathymetric data collected during Cruise 1A.

The results of an analysis of the digital elevation data were considered in determining the size of the nine sites (Appendix A). In this analysis, the standard deviation of the slope magnitude, slope direction, and depth were iteratively calculated for progressively larger areas of each feature, starting at the center of the study site. Plots of these calculated standard deviations versus area were examined to ascertain the areas around the study site central locations over which the standard deviations stabilized. This insured that the variability in elevation that the feature added to the surrounding background elevation was appropriately considered in the site boundary evaluation process.

During the first monitoring survey (Cruise 1C) each of the nine monitoring sites was defined as a circular area with a site-specific diameter. Each circular site was then divided into eight sectors (Figure 8.1), with 16 points randomly positioned in each sector. The ROV maneuvered between each of the random locations in a sector, collecting a quantitative still photograph with a camera orientation perpendicular to the substrate at each random location. Both qualitative and quantitative video data were collected along the transects between each of the random still photo locations, with one videocamera (qualitative) aimed ahead for navigating the ROV and the second videocamera (quantitative) oriented perpendicular to the substrate. Upon the completion of a sector, the ROV moved to the next adjacent sector and resumed collecting video and still photo data until each of the eight sectors were covered. Additional photographs were taken of specific features or biota along the transects to aid in bottom characterization or individual species identifications.

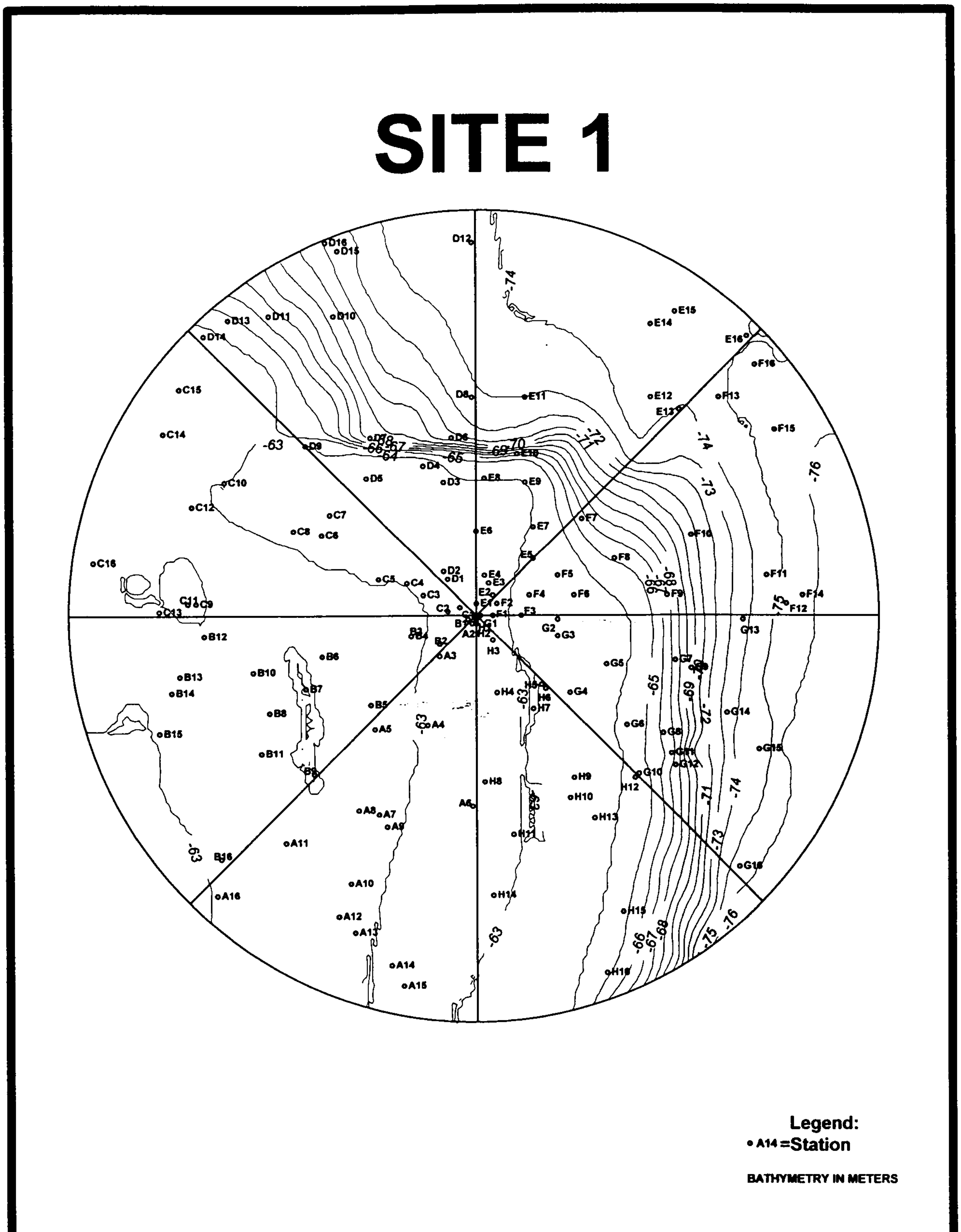

Fig. 8.1. Example of random point allocation within eight sectors of a site. A quantitative photograph was taken at each random point. Qualitative and quantitative video and additional photographs were collected along transects between random points.

The quantitative video and still cameras were able to be maintained at a specific distance from the bottom by the use of four lasers mounted on the ROV. This laser system consisted of three lasers mounted with their beams in parallel around the video and still cameras and aimed to fall within the cameras' fields of view. The three lasers were oriented in the shape of an equilateral triangle with the resultant beam pattern providing a constant scale in all video and still photo data. The fourth laser was mounted at a convergent angle which overlapped one of the three parallel lasers when the quantitative videocamera and still camera lenses were 60 cm from the bottom. All four lasers were visible to the ROV pilot in the quantitative videocamera field of view, enabling him to maneuver the ROV at a constant height above the bottom along the transects.

The sampling procedures and criteria for the collection of random still photographs changed slightly during the monitoring survey based upon the type of feature being surveyed. Initially, for all of the low, medium, and high relief pinnacle sites, if a sandy or sediment-covered bottom was present at the pre-selected random photograph location a photograph was not taken, and using the ROV's forward looking sonar the ROV moved to the nearest adjacent hard bottom location within the sector and took the photograph. If sufficient hard bottom was not present in the sector, additional random points were sampled in subsequent sectors. This worked well until surveying sites where the bathymetry data collected during Cruise 1A did not match up well with the features actually present at the site, as at Sites 2, 5, or 8. The sizes of the circular sampling areas established at these sites were significantly larger than the actual diameter of the features, causing a majority of the random photograph locations in some sectors to fall on sand bottom areas tens of meters from the edge of the pinnacles. Additionally, the features at Sites 5 and 8 were also offset to the north relative to the positions shown in the bathymetry data set. Because of the lack of nearby adjacent hard bottom in many of the random photograph locations at these sites, additional random positions were regenerated for the site following the completion of the eight sectors and the ROV collected photographs at these new locations.

Fixed Video/Photoquadrats

During Cruise 1C five fixed video/photoquadrats were established at random locations within each site. The video/photoquadrat markers for each site consisted of the numbers 1 through 5 made from lead, with dimensions of approximately 10 cm in height by 6 cm in width. The numbers were deployed at the random locations using the manipulator arm of the ROV. The actual position of each video/photoquadrat marker was recorded with the precision navigation system to allow relocation of the markers on subsequent monitoring surveys. For each of the first two monitoring sites visited, Sites 1 and 3, the five fixed video/photoquadrat markers were deployed at five different random locations. Due to silty conditions observed while deploying several of the markers at subsequent sites and concerns the markers may become covered with sediments and not be found during the later monitoring surveys, it was decided to deploy the markers around a single random location identified by a 12 cm diameter buoy coated with antifouling paint and highly reflective tape. The fixed video/photoquadrat markers for six of the seven subsequent monitoring sites (Sites 2, and 4 - 8) were deployed in this manner. Fixed video/photoquadrat markers were not deployed at Site 9 due to high turbidity levels present at the site which would have prevented the collection of acceptable quality video or photographic images of the quadrats. At Site 7, only fixed video/photoquadrat markers 1 and 2 were deployed and only marker 1 was photographed due to ROV videocamera problems and the subsequent loss of use of the ROV manipulator arm upon recovery of the vehicle.

After each fixed video/photoquadrat marker was deployed, a series of still photographs and video image grabs were made of the marker and the surrounding substrate from a distance of 60 cm. Video images were also taken at distances of up to about 2 m from the markers, providing a wider view of the surrounding features to facilitate fixed video/photoquadrat relocation during future surveys. During the collection of the still photographs and video images the cameras were oriented perpendicular to the substrate and the heading or orientation of the ROV was recorded in the log for each shot or image grab.

Voucher Specimen Collection

Epibiota and rock samples were collected when feasible during the first monitoring cruise to begin the compilation of a specimen inventory to aid in the identification of species appearing on video and in photographs and to provide information to help characterize the substrates. Selected specimens were picked up with the manipulator arm, placed in the sample basket which had been lowered to the bottom, and the basket was returned to the surface by the ROV. At the surface the specimens were assigned a unique identification number, photographed, and then labeled and preserved.

Laboratory Methods

Random Photographic Stations and Video Transects

For analysis purposes a replicate video transect consists of a standardized time increment of visually acceptable video data. Time is counted only when the ROV is in motion and remains at the proper distance from the bottom, and when visibility is acceptable. Video images recorded along each replicate transect are reviewed to characterize substrates and determine species composition. Video data are reviewed using an S-VHS videocassette recorder interfaced with a 20-inch color monitor and Mission Manager software system. All recognizable substrate features and epibenthos are listed as either present or absent. Individual biota are identified to the lowest practical taxonomic grouping. Substrate types are separated into the following categories:

- soft bottom;
- hard bottom with a sediment veneer;
- low relief hard bottom;
- medium relief hard bottom (vertical to irregular topography);

- high relief hard bottom (flat-topped); and
- high relief hard bottom (vertical to irregular topography).

Areal coverage of substrate and epibiota within the random quantitative photographs is estimated using the quantitative analysis method developed by Bohnsack (1976, 1979). Each photograph (slide or Photo CD image) is analyzed in one of two ways. If using the original slide film, the image is projected onto the 30 cm by 40 cm screen of a slide viewer and a clear acetate overlay containing 50 randomly selected points is superimposed on the screen over each frame. If using Photo CD's made from the original slide film, the stored image is pulled up onto the screen of a high-resolution monitor and a set of 50 randomly generated points is added to the display.

For each analysis method the number of points that covers each organism and/or substrate is recorded for each frame or image. The areal coverage of each organism and substrate is proportional to the number of points overlaying the particular image. Since some points may fall on deep shadows and be unreadable, the denominator in the percent cover calculations is reduced by the number of points overlaying shadowed areas. These percentages are combined for all frames from each site to obtain the average areal coverage for each species and substrate type. The numbers of individuals of solitary species are also counted and all species that are present in the photographic frame are recorded. The data for point contacts, numbers of individuals, and species presence are directly entered into a computer database for subsequent calculation of percent cover, density, and diversity.

Many epifauna such as sponges, hydroids, octocorals, and antipatharians are attached at a single point and their morphologies are commonly ascending and branched or expansive above the point of attachment. This morphology creates a canopy effect when viewed from above during quantitative photography. Therefore, their cover as viewed in quantitative photographs is more correctly termed "areal cover" rather than percent cover of substrate provided by the individual biota.

Due to difficulties in taxonomic identification, certain epifauna observed in the photographs may be given descriptive names only, which are being assigned to specific morphological forms that can be consistently distinguished. Groupings based on specific morphology can result in either overestimation or underestimation of the abundance of the correct species. Conversely, because some descriptive groupings may contain several species that cannot be distinguished from one another, an underestimation of the species richness may result. These uncertainties are unavoidable, and are being minimized by the careful collection and identification of voucher specimens and the construction of the voucher photographic image catalogue.

Fixed Video/Photoquadrats

Fixed video/photoquadrats are being analyzed using a method similar to that used by Gittings et. al. (1992a) for fixed photoquadrats on the Flower Garden Banks. A single representative video frame is being selected from data collected at each fixed video-photoquadrat location to serve as a baseline image. The selected image is projected on a high resolution color monitor and the areal cover of epibiota and substrates types is estimated using the same random point quantitative analysis method used for the random photographs. The thickness of the sediment veneer is estimated, if possible, when it is present. Supplemental photographs of the fixed quadrats taken at the same time as the video images were collected are also used to assist in the identification of epibiota. The number of species in the projected images are counted and their densities are calculated. The borders of all conspicuous epibiota and distinctive physical features are traced onto a sheet of clear mylar. The mylar overlay will be used as a baseline template for selecting identical video images collected during subsequent monitoring cruises and as a means to detect temporal change within each video/photoquadrat. Changes in the border dimensions of each colony or individual species from the baseline tracing may represent growth or retreat and possible evidence of disease or stress, sediment inundation, or inter- and intraspecific competition. All changes in border dimensions will be categorized and enumerated during each future analysis. New colonies which appear within the video/photoquadrats during the program will be documented and traced on the mylar overlay. The small sizes, three dimensionality, and possibility of parallax error in video/photoquadrat images may preclude the measurement or estimation of epibiota growth rates.

Determination of Specimen Biomass

Voucher specimens are being collected by the ROV to aid in species identifications in the still photograph and video data sets, as noted under the Field Methods. In the laboratory, the wet weight biomass of these specimens is being determined using standard methodologies.

Preliminary Data

Preliminary data obtained during Cruise 1C include the following brief descriptions of the nine monitoring sites visited during the survey. These data may be subject to revision following the completion of the Cruise 1C data analyses.

Site 1

Site 1 is a high relief site situated on a large flat-top pinnacle feature in Megasite 1 along the western edge of Destin Dome Area Block 533. The coordinates of the site center are 29°26'19.131" N latitude and 87°34'27.273" W longitude. Water depths ranged from 63 to 76.5 m in the site, which consists of a circular area with a diameter of 200 m extending across the top of the pinnacle and down the northeastern and eastern edges of the feature.

A total of 12.75 hr of video data were collected with each videocamera from 2000 hr on 7 May 1997 through 1412 hr on 11 May 1997. In addition, 173 still photographs were taken. Underwater visibility was excellent, exceeding 15 m, and ambient light levels during daylight hours were high enough to observe the feature with or without artificial lighting. The top of the pinnacle ranged from 63 to 65 m depth, with significant areas of coarse sediments present in shallow depressions or lower relief hard bottom areas. Octocorals, sponges, coralline algae, and small solitary hard corals were quite abundant on the flat-topped area of the pinnacle, while the relatively vertical edges or faces, which dropped 10 m down to low relief rock and sandy areas, were relatively bare.

Site 2

Site 2 is a medium relief site located in the northwestern portion of Megasite 1, with water depths ranging from as shallow as 69.5 m at the crest down to 81.5 m in rubble areas around the main pinnacle structure. The circular study site is centered at 29°26'41.053" N latitude and 87°36'26.512" W longitude and has a diameter of 120 m.

About 5.5 hr of video data were collected with each videocamera from 1400 hr to 2000 hr on 12 May 1997. A total of 195 still photographs were taken. Visibility was greater than 10 m. This pinnacle feature consists of numerous irregular outcrops with heights ranging from less than 1 m at the periphery up to 10 m toward the site center. The outcrops had a somewhat "rounded off" upper surface with fairly vertical sides. Biotic cover consisted primarily of solitary hard corals and octocoral whips with considerably fewer sponges than were observed at Site 1.

Site 3

Site 3 is a low relief site located along the eastern side of Megasite 1, about 345 m east-southeast of Site 1, and centered at 29°26'15.901" N latitude and 87°34'15.266" W longitude. The study area has a diameter of 150 m and water depths ranged from 76 to 80.3 m.

About 5.5 hr of video data were collected with each videocamera, and 141 still photographs were taken. Visibility was excellent, exceeding 10 m. The site was characterized by patchily distributed low relief rock outcrops with diameters ranging from 1 m to about 10 m. The larger rock outcrops were characterized by an irregular surface and varying amounts of undercutting. The rock outcrops supported an epibiota dominated by octocorals, solitary and colonial ahermatypic hard corals, and crinoids. Biotic coverage of the outcrops was variable and seemed related to size and amount of vertical relief.

Site 4

Site 4 is a medium relief site situated in the south-central segment of Megasite 2, centered at 29°19'39.041" N latitude and 87°46'7.849" W longitude. The site diameter is 140 m and water depths ranged from 95 to 107 m.

About 5.75 hr of video data were taken with each videocamera from 2015 hr on 17 May through 0210 hr on 18 May 1997. A total of 161 photographs were taken. Visibility was excellent, limited only by the ROV light penetration. The site consists of a gradually sloping mound of low relief hard bottom with a thin sand veneer, over which are distributed rock outcrops ranging in height from 0.5 m to greater than 2 m. The most common epifauna included solitary hard corals, antipatharians, and crinoids, with higher densities present on those outcrops exhibiting the greatest vertical relief.

Site 5

Site 5 is a high relief flat-top pinnacle located along the eastern side of Megasite 3 at 29°23'35.930" N latitude and 87°58'51.055" W longitude. The diameter of the site is 160 m and water depths ranged from 62 to 78 m.

About 5.5 hr of video data were collected with each videocamera, and 221 still photographs were taken. Visibility was greater than 10 m. The top of the pinnacle is relatively flat with a fine sediment veneer, and large octocorals are the most common epifauna. Along the edges of the pinnacle at a distance of several meters from the main flat-top are smaller outcrops which appear to have broken off from the main pinnacle. These smaller outcrops as well as the vertical faces and upper edges of the main pinnacle are covered with the ahermatypic hard coral *Rhizopsammia manuelensis*.

Site 6

Site 6 is a low relief pinnacle site situated about 550 m to the north-northeast of Site 5 in Megasite 3. The site is 150 m in diameter and is centered at 29°23'52.887" N latitude and 87°58'42.610" W longitude. Water depths ranged from 75 to 78 m.

About 4.3 hr of video data were recorded with each videocamera and 157 still photographs were taken. Visibility was at least 4 to 5 m, which was the limit of the ROV light penetration. This site is located in an area of low relief hard bottom with outcrops protruding up to approximately 1 m above the bottom. There was a layer of silt covering the rock outcrops and bottom areas between the exposed rock. The outcrops cover extensive amounts of the bottom and appear to be somewhat continuous. The associated epifauna include octocorals, antipatharians, bryozoans, and ahermatypic hard corals, with higher epifaunal density occurring on the highest relief rock.

Site 7

Site 7 is a high relief, somewhat flat-topped pinnacle known as 36 Fathom Ridge, located in the northwest corner of Megasite 5. The site, with a diameter of 200 m, is positioned at the northern end of the elongate feature and centered at 29°15'24.844" N latitude and 88°20'21.455" W longitude. Water depths ranged from 69.5 m at the pinnacle top down to 88 m in rubble areas to the west.

About 5 hr of video data were collected with each videocamera, and 170 still photographs were taken. Visibility was about 3 to 4 m, with higher amounts of particulate matter in the water column than observed at the previously described sites. This site had more irregular edges than the two previously described flat-top pinnacles in the study. The sides did not appear to rise straight up to the top from the surrounding seafloor, but rather came up in a more broken and irregular manner. The relatively flat top of the feature at depths of 69.5 to 72 m was populated mainly by octocoral whips and fans, antipatharians, sponges, and crinoids. The edges and inclined areas down to depths of 85 m had higher numbers of hard corals, particularly *Rhizopsammia manuelensis*, as well as crinoids and octocorals.

Site 8

Site 8 is medium relief pinnacle situated in the south central region of Megasite 5. The study site has a diameter of 100 m and is centered at 29°13'53.857" N latitude and 88°19'01.565" W longitude. Water depths ranged from 88 m at the pinnacle crest to 96 m at the base.

About 6.25 hr of video data were collected with each videocamera, and 167 still photos were taken. Visibility was 3 to 4 m. This pinnacle has a very rough and irregular surface with numerous crevices and overhangs. There was also a thin layer of silt covering the rock surfaces, with this layer appearing thicker near the base than at the top. The hard coral *Rhizopsammia manuelensis* was the dominant animal at the site with higher densities present as depth decreased. Also fairly common were both large and small octocoral fans and whips, antipatharians, and basket stars.

Site 9

Site 9 is a low relief pinnacle site located in the southwestern segment of Megasite 5, approximately 1.3 km northwest of Site 8. The survey site has a diameter of 150 m and is centered at 29°14'19.499" N latitude and 88°19'36.859" W longitude. Water depths at the site ranged from 89 to 95.5 m.

Visibility was minimal -- about 0.5 m during the first site visit on 16 May which resulted in no data collection. During a return to the site on 17 May, visibility was initially about 1.3 m but decreased to less than 0.3 m within a few hours, preventing the collection of fixed video/photoquadrat data. Approximately 5 hr of video data were recorded on each videocamera and 129 still photographs were taken. The low relief rock features of this site generally were from 0.5 to 2 m in height, with a few up to 4 to 5 m high. They were silt-covered and appeared somewhat continuous, although due to limited visibility this may be questionable. Epifaunal coverage was higher on those rock outcrops with the greater vertical relief, with octocoral whips and fans and basket stars relatively common. *Rhizopsammia manuelensis* and other solitary hard corals also were present in higher abundance on the larger rock features.

Data Analysis and Interpretation

As noted in Chapter 2, a major objective of this program is "to describe and monitor seasonal and interannual changes in community structure and zonation and relate these to changes in environmental conditions (i.e., dissolved oxygen, turbidity, temperature, salinity, etc.) at three distinct types of topographic features within the Mississippi-Alabama pinnacle trend area." Data analysis and interpretation will address this objective through a combination of qualitative description, mapping, exploratory analyses, and statistical hypothesis testing.

Data from the random video/photographic transects will be used to characterize substrates and biological communities and to estimate quantitative abundance of epibiota. Mission Manager software will be used to aid in mapping features of interest along the transects.

Summary statistics including tables of ranked species abundances will be prepared. These summary statistics will also be recalculated after the assemblages are objectively determined using multivariate methodology to highlight possible subtleties in the distributions. For example, one species could contribute only a moderate amount to the overall biota for a high relief pinnacle, but because of its distribution, this species could dominate within one specialized assemblage, such as within the zone consistently exposed to a nepheloid layer.

A tiered analysis strategy is planned (Figure 8.2). Generally, abiotic variables will be reduced/simplified using canonical and partial correlation analysis. Ordination and classification analyses will be used to explore patterns and structure in the biological data and to identify species groupings for further analysis. Strong relationships between biological groupings and abiotic variables will be identified through discriminant analysis and canonical correlation analysis. Finally, statistical testing for relationships to environmental variables will be conducted using a general linear/non-linear models approach. Prior to statistical analyses, assumptions will be tested and, if necessary, data will be transformed or nonparametric methods will be used, depending on the nature of the data.

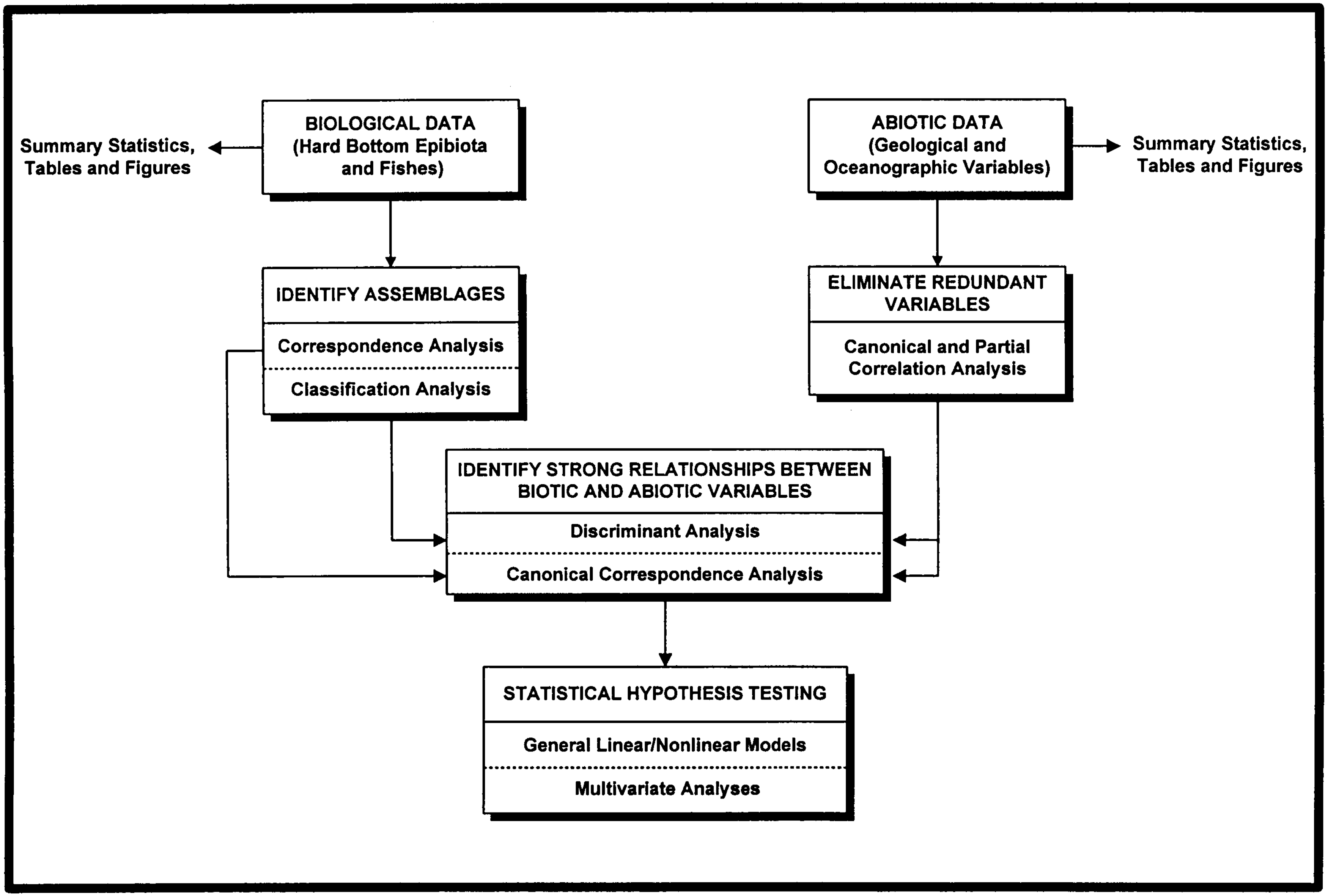

Fig. 8.2. Overall approach to analyzing relationships between biological communities and abiotic environmental variables.

Chapter 9
Fish Communities

In this program component, fish communities are being studied by analyzing photographs and videotapes recorded from a remotely operated vehicle (ROV) during hard bottom community monitoring (see Chapter 8). Trophic interrelationships are being studied by reviewing literature from the Gulf of Mexico and South Atlantic Bight. In future reports, these data and literature will be used to describe fish communities associated with the pinnacle features and delineate their ecological roles.

Historical Background

The ichthyofauna inhabiting the pinnacle features consists of a mixture of tropical and subtropical reef fishes derived from Gulf of Mexico and Caribbean faunal regions. Seventy reef fish species were reported during remote video reconnaissance of the pinnacles (Darnell 1991). Thirty-nine of these were primary reef fishes (those obligatively associated with hard bottom or reef habitats; Starck 1968), while the remaining 31 were secondary reef species (i.e., not intimately associated with hard bottom). During another remote photodocumentation of pinnacle features in Destin Dome Area Block 617, various fish taxa were observed in video and still photographs of high and low relief features (Continental Shelf Associates, Inc. 1985a). Although neither Darnell (1991) nor Continental Shelf Associates, Inc. (1985a) were specifically studying fishes, these two studies provide all of the information available on fishes associated with the pinnacle features. Despite the limited sampling effort, the known fish assemblage for the pinnacle features contains just less than half of the 150 reef fishes known from the hard banks and reefs of the northern Gulf of Mexico (Cashman 1973; Bright and Pequegnat 1974; Smith et al. 1975; Smith 1976; Sonnier et al. 1976; Boland et al. 1983; Dennis and Bright 1988a, 1988b). The species composition of the pinnacle fish assemblage resembles that of deep-reef fish assemblages (e.g., 55-100 m water depths) off the southeastern U.S. (Miller and Richards 1980; Parker and Ross 1986; Gilmore et al. 1987), within the lower portion of the Algal-Sponge zone of the west Flower Garden Banks in the northwestern Gulf of Mexico (Bright and Pequegnat 1974; Boland et al. 1983; Dennis and Bright 1988a), or near the head of De Soto Canyon (Shipp and Hopkins 1978; Continental Shelf Associates, Inc. 1987b).

The sea bass family (Serranidae) is the most speciose group associated with the deep-reefs. The anthiin serranids (*Holanthias martinicensis*; *Hemanthias* spp.), known as streamer basses, often numerically dominate deep reef habitats and undoubtedly serve as forage for a number of piscivorous species. Other serranids typically found in these habitats range from small species such as the tattler (*Serranus phoebe*), and the wrasse bass (*Liopropoma eukrines*), to some of the larger groupers such as the snowy grouper (*Epinephelus niveatus*), and the warsaw grouper (*Epinephelus nigritus*). Other species frequently occurring on deep reefs include bank butterflyfish (*Chaetodon aya*), yellowtail reeffish (*Chromis enchrysurus*), bar drum (*Paraques iwamotoi*), short bigeye (*Pristigenys alta*) and amberjacks (*Seriola* spp.). This program should contribute additional species to the list of 70 presently compiled for the pinnacles.

Approach and Rationale

The objectives of this program component are to:

- describe fish community composition and temporal dynamics at each site;
- identify differences in fish community composition among sites differing in relief and location;
- identify relationships between fish communities and environmental parameters such as small-scale habitat variability, rock type, sediment cover, etc.; and
- identify trophic relationships among fishes, as well as between fishes and the epibenthic community.

These objectives are being addressed by analyzing photographs and videotapes recorded by the ROV during routine hard bottom monitoring (see Chapter 8). The program does not include any "dedicated" fish censusing or sampling. Nevertheless, the photographs and video collected while performing other tasks will provide images suitable for qualitative analysis fish assemblages. The data obtained will consist of species occurrences that can be partitioned by site, time (cruise), and habitat (substrate).

Methods

Field Methods

Because qualitative data are being extracted opportunistically from all video transects not specifically made for fishes (i.e., epibiota), the field methods are identical to those described for hard bottom communities in Chapter 8. Only the aspects of these methods most important to fish assessment need to be restated. Two videocameras simultaneously record the path taken by the ROV during its operations; one is forward-viewing for piloting the ROV, the other is downward-viewing, perpendicular to the substrate for recording quantitative data. A 35 mm Benthos camera equipped with a Nikkor 28 mm lens and a 200 watt-second electronic strobe is being used to collect the photographs. The camera is aligned perpendicular to the substrate for all quantitative photographs, and aligned parallel with the downward viewing videocamera. A coordinate laser system mounted on the ROV is used to estimate proper distance. Still photographs have the resolution needed for accurate identifications of fishes, particularly small ones, and video provides redundant images should the still camera fail during a dive.

The most important field task pertaining to the fish data is the collection of random photographs (Chapter 8). Random photographs are collected within eight sectors of a circular plot located within each site. The paths recorded on video by the ROV as it moved from photograph to photograph provides the best data available for characterizing the fish taxa present at each site.

Laboratory Analysis

In the laboratory, videos from both videocameras (forward-viewing and downward-viewing) were examined simultaneously for the presence of fishes. Videotapes from both of these cameras are useful because they produce complementary observations. The forward-viewing camera will often record larger fishes such as amberjacks, snappers, groupers, or sharks that are not seen by the downward camera. On the other hand, the downward-viewing camera records small reef associated species (anthiins, damselfishes, squirrelfishes) not discernable by the forward-viewing camera. The paths taken by the ROV were recorded by the two videocameras while collecting random photographs from eight sectors of an imaginary circle plot at each site (see Chapter 8). For each random path fish species occurrences were recorded for each sector within a site. Also, within each sector the time spent by the ROV over soft bottom and hard bottom was recorded; and, when on hard substrate, the time spent along the vertical face, the surface, or the base of a feature was also recorded. The photographs (35 mm transparencies) are viewed on a large screen film viewer. All fish in the quantitative photographs are identified to the lowest practical taxon and added to the species list for a particular site or sector from which the photograph was taken. All photographic data collected during ROV operations are reviewed for new species to add to the master species list for the hard bottom features. The final data include frequency of occurrence of all fish taxa by site and cruise.

Preliminary Data

Based on preliminary analysis of two sets of videotape recorded at each site during Cruise 1C, we observed 48 fish taxa from 22 families (Table 9.1). The species list may change after the still photographs are examined. The higher resolution of still photographs will allow us to identify some of the smaller or more cryptic taxa not easily discerned in video images.

Most of the observed taxa were hard bottom forms expected for the eastern Gulf of Mexico. The seabasses (Serranidae), represented by 13 taxa, were the most diverse family. Other families were not as diverse; the squirrelfishes (Holocentridae), jacks (Carangidae), and puffers (Tetraodontidae) contributed three taxa each while the remaining families contained only one or two taxa each. The most frequently observed species across all sites was the short bigeye *Pristigenys alta* which was followed by roughtongue bass *Holanthias martinicencis*, bank butterflyfish *Chaetodon aya*, wrasse bass *Liopropoma eukrines*, greater amberjack *Seriola dumerili* and blackbar drum *Equetus iwamotoi*. Eighteen taxa were observed only at one site.

The number of fish taxa per site ranged from 29 taxa at Site 1 to 5 taxa at Site 9. Sites 2, 5, and 6 yielded 17, 17, and 19 taxa respectively. The number of taxa per site averaged 17 for the nine sites.

Data Analysis and Interpretation

As only preliminary data from Cruise 1C were available for this report, detailed analysis and interpretation is not appropriate. Anticipated future analysis and interpretation is summarized below.

Fish Community Description and Dynamics

The characterization of the fish communities will focus upon taxonomic composition, taxonomic richness, and biogeography of the feature-associated fishes. Tables of fish taxa will be generated for all sector, site, and time combinations. We will analyze the final taxa by site-time incidence (presence-absence) matrices with multivariate ordination. These analyses will objectively reveal broad patterns in species occurrence and identify any underlying spatial and temporal variation in the data set.

Trophic Interrelationships

Data from the literature will be used to construct food webs. Description of trophic interrelationships for the hard bottom associated fish assemblages will minimally require data on food habits of the component species. Unfortunately, there is little information available on the feeding ecology of hard bottom fishes from the northern Gulf of Mexico (e.g., Bradley and Bryan 1975). Darnell (1991) and Rogers (1976) have analyzed the trophic spectra of trawl-caught demersal (soft bottom) fishes from the northern Gulf of Mexico and elucidated the general trophic structure in these assemblages. Some of the species analyzed in these studies were secondary reef fishes and could provide some insight into the trophic relationships of the pinnacle-associated fishes. In contrast with the northern Gulf of Mexico, there have been a number of studies on the feeding habits of hard bottom fishes inhabiting the South Atlantic Bight (Manooch 1977; Grimes 1979; Grimes et al. 1982; Sedberry 1983, 1985, 1993). Because of the similarity in the hard bottom ichthyofaunal composition between the South Atlantic Bight and the northern Gulf of Mexico, some major trophic designations may also be extrapolated from the South Atlantic Bight studies.

Table 9.1. Preliminary list of fish taxa observed in videotapes from each site during Cruise 1C.

Taxa	Site 1	2	3	4	5	6	7	8	9
Relief Category:	H	M	L	M	H	L	H	M	L
MURAENIDAE									
Gymnothorax kolpos	--	--	--	●	--	--	--	--	--
Muraenid sp.	--	●	--	--	--	--	--	--	--
SYNODONTIDAE									
Synodus sp.	--	--	●	--	--	●	--	--	--
BATRACHOIDIDAE									
Opsanus pardus	●	--	●	--	--	--	--	●	--
OGCOCEPHALIDAE									
Ogcocephalus sp.	●	--	--	●	--	--	--	●	●
HOLOCENTRIDAE									
Corniger spinosus?	--	--	--	●	--	--	--	--	--
Holocentrus adscensionis	●	--	--	--	--	--	--	--	--
Holocentrus bullisi	●	--	--	--	--	--	--	--	--
FISTULARIIDAE									
Fistularia sp.	●	--	--	--	--	--	--	--	--
SCORPAENIDAE									
Scorpaena sp.	--	●	--	●	--	--	●	--	--
SERRANIDAE									
Anthiin sp.	--	●	--	--	●	●	--	●	●
Centropristis ocyurus	--	--	--	--	●	●	--	--	--
Epinephleus niveatus	--	--	--	--	--	●	--	●	--
Gonioplectrus hispanus	--	●	●	--	--	--	--	●	--
Hemanthias sp.	●	●	--	●	●	--	●	--	--
Holanthias martinicensis	●	●	●	●	●	--	●	●	●
Liopropoma eukrines	●	●	--	--	●	●	●	●	--
Mycteroperca phenax/interstitialis?	●	●	--	--	--	●	●	--	--
Paranthias furcifer	●	--	--	--	--	--	--	--	--
Rypticus saponaceous	--	--	--	--	--	●	--	--	--
Rypticus sp.	--	--	--	--	--	●	--	--	--
Serranus atrobrancus?	--	●	--	●	--	--	--	--	--
Serranus phoebe	●	●	●	--	●	●	--	--	--
PRIACANTHIDAE									
Priacanthus arenatus	●	--	--	--	●	--	--	--	--
Pristigenys alta	●	●	●	●	●	●	●	●	●
APOGONIDAE									
Apogon pseudomaculatus	●	--	--	--	--	●	--	--	--

Table 9.1. (continued).

Taxa	Site 1	2	3	4	5	6	7	8	9
Relief Category:	H	M	L	M	H	L	H	M	L
MALACANTHIDAE									
Caulolatilus sp.	--	--	--	●	--	--	--	--	--
CARANGIDAE									
Seriola dumerili	●	●	--	●	●	●	●	--	--
Seriola rivoliana	●	●	--	--	--	--	●	--	--
Trachurus lathami	●	--	●	--	--	--	--	--	--
LUTJANIDAE									
Lutjanus campechanus	--	--	--	--	●	●	●	--	●
Rhomboplites aurorubens	●	--	--	--	●	●	--	--	--
SPARIDAE									
Calamus sp.	--	●	--	--	●	--	--	--	--
SCIAENIDAE									
Equetus iwamotoi	●	●	--	●	●	●	--	●	--
Equetus umbrosus	--	--	--	--	--	●	--	--	--
CHAETODONTIDAE									
Chaetodon aya	●	●	●	--	●	●	●	--	--
Chaetodon sedentarius	●	--	--	--	●	--	●	--	--
POMACANTHIDAE									
Holacanthus bermudensis	●	--	--	--	●	●	●	--	--
Holacanthus tricolor	●	--	--	--	--	--	--	--	--
POMACENTRIDAE									
Chromis enchrysurus	●	--	--	--	●	●	●	●	--
LABRIDAE									
Bodianus pulchellus	●	●	--	--	--	--	--	--	--
Halichoeres sp.	●	--	●	--	--	--	--	--	--
BOTHIDAE									
Bothid sp.	--	--	●	●	--	--	--	--	--
Cyclopsetta sp.?	--	--	--	--	--	--	●	--	--
OSTRACIIDAE									
Lactophrys polygonia	●	--	--	--	--	--	--	--	--
TETRAODONTIDAE									
Canthigaster rostrata	●	--	--	--	--	--	●	--	--
Chilomycterus sp.	--	--	--	●	--	--	--	--	--
Sphoeroides spengleri	●	--	--	--	--	--	--	--	--
TOTAL TAXA	29	17	10	13	17	19	15	10	5

Chapter 10
Companion Study: Micro-Habitat Studies

The Micro-Habitat Companion Study will incorporate appropriate physical measurements with biological observations at every stage of program design, execution of field sampling, and data synthesis. Geographic information system (GIS) data management and analysis will be used to evaluate and categorize each photograph within the entire data set (approximately 6,000 photographs in all) with regard to structural and dynamical determinants of micro-habitat. These results will combine the descriptive statistics forthcoming from the hard bottom community structure and dynamics effort with the micro-habitat categorizations in a cross-cutting design. The micro-habitat study will provide a control on the within-site variability of the sessile community that can be used to bound the between-site and seasonal comparisons.

The micro-habitat effort will also independently analyze selected sets of photographs and video transects for fine-scale determination of substrate preference. This effort will be combined with the geological interpretation of the side-scan sonar images, any chemical gradients evident from the Phase 1 baseline characterization, as well as geological descriptions of the sites.

The micro-habitat study will also seek to determine indicator species among the hard bottom epifauna that are associated with healthy micro-habitats. Such indicator species might be used in a predictive sense to measure impact.

Historical Background

The physical environment exerts considerable control over the composition, abundance, and health of a marine, hard bottom ecosystem. The hard bottom community structure and dynamics effort for this program (see Chapter 8) will establish key findings regarding composition, diversity, and density of hard bottom epifauna. Study sites consist of bottom regions, approximately 1 to 5 ha in area, centered on structures that belong to the low, medium or high relief categories. Measurements for hard bottom community structure and dynamics will include fine-scale photographs collected in a randomized design across the sites during each cruise. Hard bottom community structure and dynamics results will be suitable for general description of the individual sites as a whole, for determination of ecosystem health, and for statistical comparison among sites and seasons. However, differences in the biological indices among sites and within sites will, it is proposed, result from specific abiotic factors and will be manifest at a meter or sub-meter scale. Testing for these causative effects, i.e., for temporal and spatial changes in hard bottom epifauna, small-scale variability in epifauna, and the relationship between community structure and the physical environment, will require a level of study design, data management, and analysis beyond the monitoring effort.

The following section considers relevant structural and dynamical factors in terms of the published literature and with reference to previous work in the study area.

Water Circulation

Water circulation influences the flux of food particles, the dispersion of propagules, and rates of sedimentation; it is therefore one of the key processes that determines the local distribution of epibenthic fauna in the offshore environment. There is a rich literature describing physical influences on community patterns among hermatypic and alcyonarian corals in shallow water (Kinzie III 1973; Rezak et al. 1985; Sammarco and Andrews 1988; Yoshioka and Yoshioka 1989). Effects of water circulation will also vary with light levels, temperature, and substrate availability, competition, predation, or other interactions. Previous research has also shown clearly how the abrupt topographic relief of sea mounts generates distinctive circulation patterns (Genin et al. 1989; Noble and Mullineaux 1989; Noble et al. 1994; Zhang et al. 1994) that are reflected in the distribution of corals and other fauna (Genin et al. 1986; Kaufmann et al. 1989; Rogers 1994). Results from sea mounts, where current meter records and numerical simulation often have provided detailed physical information, have also been invoked to explain anomalous distribution or abundance of epibenthic fauna in deep-sea habitats where no direct measurements of bottom current were available (Messing et al. 1990; Genin et al. 1992).

The direct influence of current direction upon benthic fauna has been documented in several previous studies. Rowe and Menzies (1968) predicted the seafloor extent of the Gulf Stream on the continental slope off North Carolina based on photographs of two decapod species that tended to face into the current. Heezen and Hollister (1971) published numerous photographs in which fish, sponges, or other deep-sea animals act as current vanes. Time-averaged effects become evident when sessile animals have a fixed and axially asymmetric growth form that enhances survival if turned into prevailing currents. Such effects have been noted in scleractinian corals such as *Agaricia agaricites*, which can display bifacial growth forms (Helmuth and Sebens 1993). Orientation is particularly distinctive among the fan-shaped gorgonians in which the colony of polyps occupy ramie arrayed from a central holdfast along a predominant vertical axis or blade (Barham and Davies 1968). Early investigators proposed that turning the plane of the fan normal to a current would minimize tortional stress to the holdfast (Wainwright and Dillon 1969; Grigg 1972). Subsequent work showed that it also maximized feeding efficiency by the colony of polyps (Leversee 1976; Velimirov 1983; Dai and Lin 1993). MacDonald et al. (1996) have recently measured precisely the distribution and orientation of almost 1,000 gorgonians in an area of approximately one square kilometer and therefore compiled a more comprehensive data set than had been previously available. They also obtained a diverse set of physical measurements to validate and complement the biological observations. Together, these results demonstrated the influence of circulation patterns at a community level and considered the role of fine-scale topographic features in determining this effect.

Previous results concerning water circulation obtained along the Texas-Louisiana coast (Cochrane and Kelly 1986) and in the study area (Brooks 1991) demonstrate considerable seasonal dynamics at a regional scale. Seasonal effects observed during the Mississippi-Alabama Marine Ecosystems Study (MAMES) include protracted episodes of offshore surface flow through the study area. Such events would have consequences for fish and larvae populations and could strongly influence sedimentation rates. Effects of the Mississippi-Alabama pinnacles in determining local circulation anomalies are not well-documented. However, inspection of the current meter records from the MAMES mooring array clearly shows variation in the speed and direction of surface currents over a spatial scale of <25 km, which is probably related to eddy passage.

Temperature

Temperature is a well-documented stressor on hermatypic corals. These effects have received particular attention in recent years because of concerns that global warming may threaten coral health. Temperature excursions above 28°C have been associated with coral "bleaching" events in which coral species such as *Agaricia* spp., *Madrepora* spp., and others have sloughed their symbionts as a result of thermal stress. This effect has been observed in the Gulf of Mexico at the Flower Garden Banks reefs (Gittings et al. 1992a). Effects of thermal stress on soft corals, sponges, or calcareous algae are not well documented. Observations during the MAMES program documented a thermal excursion to above 28°C during October 1989. The important feature of thermal stress is that short-term events are sufficient to produce a lasting biological effect. Also, because temperature is strongly depth dependent, high topographic relief at a pinnacle could determine the proportion of the sessile community that was stressed by high temperatures. Finally, circulation patterns previously observed at the study area might produce a heterogeneous distribution of temperatures across the region.

Light

Light levels will affect calcareous algae and soft corals that contain zooxanthellae. Light levels may also affect fish. Light is strongly determined by depth and depth-dependent effects such as sediment transport/resuspension or formation of a nepheloid layer.

Dissolved Oxygen

Bottom hypoxia could have catastrophic effects on the sessile community, and possibly on the nekton (Harper et al. 1981). Although probability of severe hypoxia within the study area is judged to be low, previous studies indicate it is possible (Rabalais et al. 1991, 1992; Rabalais and Harper 1992). Monitoring bottom oxygen levels can also supply information useful for determining variation in local primary productivity.

Substrate Characteristics

The taxa emphasized (soft corals, sponges, echinoids, crinoids, antipatharians, and calcareous algae) will be the most abundant taxa attached on carbonate rock. The properties of the rocky habitat will determine the extent and characteristics of the hard bottom community.

Hemipelagic Sediment/Erosional Material/Rubble and Bioaccumulation

Fish, echinoids, sponges, and antipatharians will also occur on sandy or silty bottoms surrounding the hard bottom features. Sediment grain size and depth of sediment over hard bottom are important factors for the sessile antipatharians and sponges. Note that in addition to suspended/transported sediments, the structures are eroding and contributing to the sediments at the base of structures. Likewise, shells and some coral materials contributed to the sediments at the base of some structures.

Relief

For rocky structures, the height above bottom is important because of differences in temperature, light levels, dissolved oxygen concentrations, and circulation in the near-bottom water column. In low structures, the stratification is minimal: e.g., on-structure vs. off-structure. In medium structures, we can distinguish the off-structure, structure base, structure wall, and the top. In high-relief structures, the structure wall may be sub-divided.

Orientation

Currents influence the biological community by flushing sediments off the sessile organisms and by increasing the flux (not the concentration) of suspended food particles. The direction, intensity, and seasonal variation in current speed and direction will therefore influence the characteristics of the community. It is therefore important to control for the direction faced by colonized portions of the medium and high relief structures.

Approach and Rationale

Brooks (1991) proposed a descriptive division of substrate characteristics appropriate to video and photographic analysis. Selected subsets of the photographic and video data sets will be independently analyzed for substrate characteristics. In addition, selected video and photographic data will be independently analyzed to test for biological associations with the geological characterizations of the sites made by use of side-scan sonar and other techniques. Selected video and photographic data may also be independently analyzed to test for biological associations with chemical gradients (if any) found at the sites during Phase 1 sampling.

A major contribution of the micro-habitat study will be to compile the characteristics and sample location in a GIS with use of ARC Info and MAP-X software. A typical GIS consists of map layers that are overlain on each other to represent graphically and analytically the results of a geographically characterized data collection.

In GIS parlance, layers are either vector or raster. Vector refers to points, lines, and polygons, which are scale-independent. Raster refers to a digital image in which scale is defined by the dimension of the individual pixels that make up the image. Locations of photographs, remotely operated vehicle (ROV) track lines, and mooring locations are all potential vector layers. Considering that each cruise will produce an independent set of such locations, it is clear that there will be many vector layers for each site. A digital elevation model (DEM), on the other hand, is conveniently represented as a raster layer in a GIS because it comprises a grid of pixels covering the entire site and each pixel has a value (depth) that can be represented as a pixel intensity (from 0 to 255 in an 8-bit image). The row and column address of the pixel gives its geographic location. Slope angle and direction will also be represented as raster layers. Side-scan sonar images, and their interpretation, are inherently raster layers.

The power of GIS is that it makes it possible to sort and combine all data according to the independent variable of location for rapid and convenient comparison. For example, the mean depth of the nepheloid layer could be represented as a raster layer by combining the depth-dependent physical data with the DEM. It would then be possible to search the photographic data set for all occurrences of particular species and to map where they were located with respect to the nepheloid layer. Affinities evident from such a comparison can be tested statistically with straight-forward analysis of variance (ANOVA) techniques.

Field and Laboratory Methods

The results obtained during Cruise 1C indicate that micro-habitat studies can be undertaken at many of the nine monitoring stations. To complete this work, the orientation of numerous gorgonians will be measured by analysis of the videotape records. To complete this work, the videotapes will be reviewed to locate images that show a gorgonian taken from a vertical orientation of the camera. The orientation of the flat portion of the colony will be determined by comparison to the compass display in the video overlay. The position of the video image on the pinnacle will be determined by matching the time of the image to the log of the ROV's position. This comparison will be sufficient to show the location of the gorgonian within 5 m on the pinnacle. These orientation data as well as the distribution of overall colonies, combined with the current meter results, will indicate the long-term adaptation of the bottom fauna to circulation patterns.

Preliminary Data

No preliminary data were available at the time of this report.

Chapter 11
Companion Study: Epibiont Recruitment

The goal of this companion study is to support the descriptive and monitoring portions of the program with experiments (based on testable hypotheses) that define the ecological mechanisms responsible for spatial and temporal changes in hard bottom epifauna. The spatial and temporal variation of hard bottom communities is a functional response to primarily three biological processes: recruitment, competition, and predation. Abiotic processes that effect spatial and temporal variability in the shallow coastal zone include seasonal temperature changes, desiccation, abrasion due to waves, turbidity due to resuspended sediments, and stochastic disturbance events. In deep water (e.g., in the pinnacle habitat) temperature and desiccation are not important determinants, but abrasion, turbidity, and stochastic disturbance events may play an important role in the changes of abundance and biomass of epifauna.

The dynamics of nearshore, intertidal hard bottom communities are well known, but experimental studies in deep hard bottom habitats are rare. Consequently, the design of the ecological study in the pinnacle habitat closely follows the design of studies to elucidate similar processes in the intertidal zone.

Historical Background

The mechanisms that control biotic processes (e.g., recruitment, competition, and predation) in shallow environments are well known. Recruitment involves the substrate selection, settlement, and growth of invertebrate larvae onto hard bottom habitats. Larval supply is controlled by the size of the adult reproductive population and reproductive rates. Substrate selection and settlement are controlled by various environmental cues, which include biofilms and interactions with adults of the same and different species. But open space is the currency that controls the supply of recruitable habitat space. Competition for space is thus the foremost process regulating successful recruitment (Connell 1961a,b). Competition comes in mainly two forms: interference competition and resource competition. In interference competition, a superior competitor can produce an action that interferes with the competitive inferior. Examples include production of a chemical that kills or inhibits a competitor, and abrasive activities of long branches that sweep a rock as the current moves to and fro. The later is a common mechanism in which plants and Bryozoa can compete with barnacles, sponges, and other encrusting fauna. In resource competition, a resource is limiting and the competitive dominant can sequester more of the resources by its activities. An example is a barnacle with growth rate higher than its competitive inferior. Normally, one would expect that competitive dominants should completely exclude all other species, but of course this does not occur. The main reason it does not occur is predation by keystone species. A keystone species can graze or crop the members of a competitive dominant, thus allowing competitively inferior species to occupy space that might otherwise be taken by the competitively superior species (Paine 1966). An example is starfish grazing on mussels. If starfish are not present, mussels will dominate the intertidal community. When starfish are present, they eat mussels, which free habitat space for other species, e.g., barnacles. In this manner, keystone predators are also important in maintaining diversity on hard bottom habitats. Finally, the climax state of the community development through succession may differ from time to time due to differential larval supply, recruitment, growth, or predation activities (Sutherland 1974).

The mechanisms that control abiotic processes (e.g., abrasion, turbidity, and stochastic disturbance events) are also relatively well known in shallow water environments. Abrasion and disturbance play a role in removing epifauna or retarding the natural succession of community development. Abrasion can be caused by the movement of currents across the surface, and stochastic disturbance events are generally related to storms (Dayton 1971). Whereas both of these processes are very important in the intertidal zone, they are probably of minimal importance in the deep habitat of the pinnacle area. Turbidity may be the one physical process that has an effect in the deeper waters. Turbidity can affect filter feeders by clogging feeding apparatus with particles, and thus is a kind of trophic amensalism. If turbidity is having a negative effect on filter feeders, then we would expect their populations to decline. Turbidity currents may or may not be important in the pinnacle area, but turbidity caused by drilling related activities may also exist.

The net result of the interactions between biotic and abiotic processes is the development of the epibiont community. Following the creation of open niche space, as simulated by the placement of an artificial surface for colonization, a community of organisms colonizes the substrate and develops through time by the process of succession. Succession is a directional process in where pioneering species alter the environment, which is then amenable to colonization by climax species. Generally, early succession is characterized by low diversity, opportunistic (or *r*-selected) species, high growth rates, and small animals (Odum 1969; Rhoads et al. 1978). In contrast, late succession communities are characterized by high diversity, specialized slow-growing (or *k*-selected), and large species (Odum 1969; Rhoads et al. 1978). Community succession on deep-sea hard substrata will be slow compared to coastal areas (Levin and Smith 1984). A community can be eliminated, or its development retarded by disturbance events. In the pinnacle habitat, settlement rates of larvae will decrease with depth and distance from shore (DePalma 1972).

Approach and Rationale

A series of settling plate experiments with exclusion, settlement, and control treatments is being used to study the biotic and abiotic interactions that regulate ecological processes. The settling plates are attached to a mooring, and the entire device is called a "biomooring." There are basically two major deployments, one for a spatial and one for a temporal study. The major elements of the settling plate experiment studies are:

- a time series study at one station, with retrieval every 3 months for 2 years;
- a spatial study at four stations to last for 1 year;
- replication of the spatial study during the second year;
- two settling surface treatments: hard and soft;
- three settling plate treatments: uncaged, caged, and partial cage; and
- two heights or distances from the bottom.

The first experiment is designed to test for recruitment and growth over time. The current sampling schedule will allow us to retrieve settling plates every 3 months and perform a balanced long-term recruitment experiment to examine temporal trends. The temporal experiment required that eight moorings be deployed at one location during the first cruise and one will be retrieved on each of the subsequent cruises (Table 11.1).

The second major experiment is designed to test for spatial trends. Moorings have been deployed at three pinnacles sites, one each with low, medium, and high relief, in approximately the same water depths. The experiment will be run twice, for a 1-year period both times (Table 11.1).

Table 11.1 Time line and sampling schedule for experimental studies. For each cruise, the table gives the study, number of stations being sampled, and the duration of the deployment, where D = deployed, --- = submerged, and R = retrieved.

	Cruise (#, Date, and Months Exposed)								
	1C	S1	M2	S2	M3	S3	S4	S5	M4
	5/97	7/97	10/97	1/98	4/98	7/98	10/98	1/99	4/99
Study	0	3	6	9	12	16	18	21	24
Time	D	R							
Series	D	---	R						
1 Station	D	---	----	R					
	D	---	---	---	R				
	D	---	---	---	---	R			
	D	---	---	---	---	---	R		
	D	---	---	---	---	---	---	R	
	D	---	---	---	---	---	---	---	R
Spatial	D	---	---	---	R				
3 Stations					D	---	---	---	R
Total Deployed	11	0	0	0	3	0	0	0	0
Total Retrieved	0	1	1	1	4	1	1	1	4

Field and Laboratory Methods

There are three experimental treatments for settling plates at each of the sampling units. The three manipulations are an unenclosed settling plate (U), an enclosed settling plate (E), and an enclosure-control settling plate (C). The unenclosed settling plate is the experimental treatment to measure larval settling, recruitment, growth, and community development (S) with biotic and abiotic interactions. The enclosed settling plate is the experimental treatment to exclude ecological effects due to biotic interactions (e.g., predation) and disturbance (P). A common problem with enclosures is that water flow at the settling plate surface is changed, therefore we must include an enclosure-control treatment to subtract effects due to the enclosure. The control consists of a partial enclosure that would have the same effects on water flow (W), but would allow predators access to the experimental treatment. Thus, the control treatment includes water mass interactions. The experimental treatments (U, E, and C) contain the following ecological processes (S, P, and W) described above:

$$U=S+P$$
$$E=S+W$$
$$C=S+P+W$$

The effects due to the three ecological processes (no exclusions, predation and disturbance excluded with water flow disruption, and water flow disruption with predation and disturbance) are estimated by subtraction.

$$W=C-U$$
$$P=C-E$$
$$S=U-E-C$$

Each experimental treatment (U=unenclosed, E=enclosed, and C=control) consists of 12 settling plates or replicates attached to a biomooring. Each biomooring consists of an anchor, float, and 12 replicate settling plates. A common pitfall in these types of experiments is pseudoreplication, where the treatment levels (U, E, and C) are not replicated. To avoid pseudoreplication, there are three replicate treatments (U, E, and C) for each mooring. The replicate treatments are placed on the wire so that there is no vertical bias in sampling. Each replicate treatment contains four replicate settling plates, three of which are hard surfaces made of ceramic tiles and one of which is a soft surface made of outdoor carpet. Therefore each treatment contains a total of 12 replicates (3 treatment replicates x 4 pseudoreplicates). Altogether, each replicate set consists of 36 samples (3 treatments x 3 replicate treatments x 4 replicate plates). Therefore, the biomooring consists of 72 samples (2 depths x 36 samples). The experimental treatments were placed within 2 m of the bottom and within 10 m of the bottom. The "Y" consists of the three arms, each containing four replicate settling plates. Upon retrieval, the settling plates are moved from the "Y," placed in a separate container with 2% formalin for preservation, and exact location on the biomooring is recorded.

Settling plates will be scored for abundance as percent cover by species to the lowest taxonomic level possible. Taxonomic validation will be ensured by comparing organisms on the settling plates with organisms found on the remotely operated vehicle (ROV) transects. A transparent scoring card is created with 100 cells. Presence of a species in any part of a cell counts for the entire cell. The size of non-colonial organisms will also be measured. Diversity is calculated by the Shannon (H') diversity index and the exponential transformation ($e^{H'}$), which indicates the total number of dominant species (Hill 1973).

Preliminary Data

The first set of biomoorings were deployed in May 1997 (Table 11.2) and will be retrieved in late July or early August of 1997. Therefore, there are no preliminary data to report.

Data Analysis and Interpretation

Analysis and synthesis of the data is a multi-step process that starts with data collection, coding, and proofreading, followed by statistical analysis and interpretation, and culminating with report writing.

The first step is data analysis. Data quality is checked by proofreading data sets. This is ensured by a chain-of-custody procedure that has been used effectively in the past. Raw data is written on sheets by hand, and each person associated with raw data evolution signs the bottom of the raw data sheets. The data is then coded into a database, and again the data coder signs the bottom of the data sheets. Finally, the data is proof-read, primarily by a technician familiar with similar data, and this person also signs the data sheet. After data sets are complete, there are simple procedures, e.g., frequency analysis and summary statistics, that check for outliers.

Statistical analysis is performed with a two-way factorial analysis of variance (ANOVA), or a three-way factorial ANOVA for the time series data. Some of the responses are multivariate. For example, biological responses will be measured in the same places that environmental variables will also be measured. One key variable is turbidity, and depth of the turbidity layer. Multivariate analyses, e.g., factor analysis is used to find underlying structure in these data sets that is a result of collection of data using the experimental design. The general null hypothesis of the multivariate test is that there is no response for the independent variables in response to the dependent variables in the experimental design. Trends in the data will also be displayed graphically.

The last phase of data analysis is interpretation. This step involves presenting the data graphically, writing the results, and writing a section discussing the trends in the data set, how the variables measured relate to one another, and comparing the results to those found in other studies. One important comparison for the experimental studies will be with the monitoring data being collected in the core program.

Table 11.2. Coordinates for biological (BIO) moorings deployed on Cruise 1C.

Date and Mooring No.	Time In	Easting	Northing	Latitude	Longitude	Depth (m)
5/21/97						
BIO 4A	11:30	425829.0	3243793.6	29° 19' 21.39"	87° 45' 49.92"	122
BIO 4B	12:49	425547.3	3243765.9	29° 19' 20.43"	87° 46' 00.36"	126
BIO 4C	13:23	425328.4	3243693.2	29° 19' 18.02"	87° 46' 08.45"	124
BIO 4D	13:56	425252.2	3243878.2	29° 19' 24.02"	87° 46' 11.32"	118
BIO 4E	15:17	426701.5	3244662.2	29° 19' 49.79"	87° 45' 17.78"	115
BIO 4F	15:43	426558.0	3244471.9	29° 19' 43.58"	87° 45' 20.90"	115
BIO 4H	16:07	426669.8	3244455.5	29° 19' 43.07"	87° 45' 18.91"	116
BIO 4G	16:39	426819.7	3244588.5	29° 19' 47.42"	87° 45' 13.39"	116
5/22/97						
BIO 1B	21:27	444632.7	3256066.5	29° 26' 03.64"	87° 34' 15.02"	83
5/23/97						
BIO 5A	13:25	405134.0	3251781.0	29° 23' 35.89"	87° 58' 39.59	82
BIO 9A	21:05	371422.1	3234977.9	29° 14' 19.24"	88° 19' 23.03	94

NOTES: 1) All times are in local time - Central Time Zone.
2) All distances and depths are in meters.
3) Geodetic parameters: Ellipsoid = Clarke 1866, Zone = 16, CM = -87, Projection = UTM, Units = meters.

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Appendix A

Hydrographic Data From Cruise 1C

Appendix A

Hydrographic Data From Cruise 1C

Twenty-nine conductivity-temperature-depth (CTD) casts were conducted during Cruise 1C in May 1997. This appendix lists the locations, dates, and times of the casts. Three casts were made around each of the nine pinnacle sites. However, Sites 1 and 3 are located so closely together that their CTD casts form a group of six rather than two distinct groups of three. Therefore, these casts are designated H1A1 through H1F1; there are no casts with the numbers H2A1, H2B1, and H2C1. There are two locations where duplicate casts were conducted because of problems with bottles closing correctly, e.g., H4B1 is duplicated by H4B2, and H7A1 is duplicated by H7A2.

Following the tabular listing are plots of the vertical profiles of salinity, temperature, sigma-theta, percent transmissivity, optical backscatter (OBS), and irradiance. There are two pages of graphics per site. The first page shows the profiles for temperature, salinity, and sigma-theta, and the second page shows the data for the optical properties.

CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
21 May 1997					
		SITE 4			
		H4B1 (H4A1) (Average depth - 122m)			
IN WATER	10:06	425332.8	3243766.3	29 19 20.38	87 46 8.29
START DOWN		425332.8	3243766.3	29 19 20.38	87 46 8.29
START UP		425294.4	3243745.9	29 19 19.74	87 46 9.73
SURFACE		425246.5	3243730.6	29 19 19.23	87 46 11.49
ON DECK	10:35	425242.5	3243727.5	29 19 19.12	87 46 11.64
		H4B2 (Average depth - 115m)			
IN WATER	14:12	425433.9	3243811.1	29 19 21.86	87 46 4.58
START DOWN		425414.2	3243838.4	29 19 22.76	87 46 5.30
BOTTOM		425389.7	3243897.7	29 19 24.67	87 46 6.24
START UP		425382.2	3243913.7	29 19 25.21	87 46 6.52
FIRE 2		425373.7	3243932.7	29 19 25.82	87 46 6.81
FIRE 3		425378.0	3243940.3	29 19 26.07	87 46 6.96
FIRE 4		425364.5	3243953.4	29 19 26.47	87 46 7.17
FIRE 5		425362.3	3243966.4	29 19 26.90	87 46 7.24
FIRE 6		425354.8	3243984.4	29 19 27.48	87 46 7.53
FIRE 7		425352.6	3243998.7	29 19 27.94	87 46 7.64
FIRE 8		425351.4	3244008.9	29 19 28.27	87 46 7.68
FIRE 9		425344.9	3244023.7	29 19 28.77	87 46 7.93
ON DECK	14:40	425332.4	3244055.5	29 19 29.78	87 46 8.40
		H4C1 (Average depth - 107m)			
START DOWN	17:00	425375.1	3244487.0	29 19 43.82	87 46 6.92
START UP		425379.1	3244563.4	29 19 46.30	87 46 6.78
FIRE 1		425380.6	3244576.4	29 19 46.74	87 46 6.74
FIRE 2		425381.2	3244594.0	29 19 47.17	87 46 6.70
FIRE 3		425381.8	3244615.8	29 19 48.00	87 46 6.70
FIRE 4		425383.3	3244636.3	29 19 48.68	87 46 6.63
FIRE 5		425383.3	3244656.7	29 19 49.33	87 46 6.63
FIRE 6		425385.2	3244684.8	29 19 50.26	87 46 6.60
FIRE 7		425386.0	3244701.8	29 19 50.80	87 46 6.56
FIRE 8		425386.6	3244715.4	29 19 51.24	87 46 6.52
FIRE 9-SURFACE		425386.6	3244727.8	29 19 51.63	87 46 6.56
ON DECK	17:21	425387.9	3244744.1	29 19 52.17	87 46 6.49
		H4A1 (Average depth - 115m)			
IN WATER	21:35	426429.7	3244434.2	29 19 42.34	87 45 27.79
ON BOTTOM		426423.3	3244621.0	29 19 48.36	87 45 28.08
UP TO 100M		426415.9	3244705.1	29 19 51.13	87 45 28.36
FIRE 4		426426.9	3244733.5	29 19 52.06	87 45 27.97
FIRE 3		426422.0	3244719.9	29 19 51.60	87 45 28.15
FIRE 5		426437.3	3244758.7	29 19 52.86	87 45 27.61
FIRE 6-45M		426454.7	3244804.0	29 19 54.33	87 45 26.96
FIRE 7-25M		426462.9	3244833.8	29 19 55.30	87 45 26.67
FIRE 8-15M		426464.8	3244852.1	29 19 55.92	87 45 26.60
FIRE 9-SURFACE		426469.1	3244874.2	29 19 56.64	87 45 26.46
ON DECK	22:00	426474.7	3244900.4	29 19 57.50	87 45 26.24
		SITE 1			
		H1D1 (Average depth - 83m)			
IN WATER	20:31	444790.1	3256581.4	29 26 20.40	87 34 9.26
START DOWN		444778.6	3256608.1	29 26 21.26	87 34 9.69
BOTTOM		444765.6	3256623.8	29 26 21.76	87 34 10.20
FIRE 1-76M		444763.7	3256625.9	29 26 21.84	87 34 10.27
FIRE 2-70M		444759.3	3256627.1	29 26 21.87	87 34 10.41
FIRE 3-60M		444752.4	3256635.0	29 26 22.12	87 34 10.66
FIRE 4-51M		444748.3	3256643.7	29 26 22.41	87 34 10.84

CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
FIRE 5-43M		444748.0	3256648.6	29 26 22.56	87 34 10.84
FIRE 6-27M		444748.2	3256655.1	29 26 22.77	87 34 10.84
FIRE 7-12M		444748.0	3256662.0	29 26 22.95	87 34 10.84
FIRE 8-SURFACE		444746.6	3256664.4	29 26 23.06	87 34 10.92
ON DECK	21:00	444746.5	3256667.5	29 26 23.17	87 34 10.92
		H1A1 (Average depth - 78m)			
IN WATER	23:00	444411.1	3256796.4	29 26 27.31	87 34 23.37
START DOWN		444417.6	3256864.2	29 26 29.50	87 34 23.16
BOTTOM		444421.0	3256896.3	29 26 30.55	87 34 23.01
FIRE 1-75M		444421.2	3256898.0	29 26 30.62	87 34 23.01
FIRE 2-73M		444421.9	3256910.4	29 26 31.02	87 34 23.01
FIRE 3-67M		444421.7	3256930.3	29 26 31.66	87 34 23.01
UP TO SURFACE		444421.4	3256942.4	29 26 32.06	87 34 23.01
ON SURFACE	23:15	444423.5	3256980.2	29 26 33.28	87 34 22.94
23 May 1997					
		H1B1 (Average depth - 81m)			
IN WATER	00:10	444293.4	3255923.1	29 25 58.90	87 34 27.58
ON BOTTOM		444298.2	3255939.2	29 25 59.44	87 34 27.40
FIRE 1-81M		444298.7	3255940.4	29 25 59.48	87 34 27.40
FIRE 2-78M		444303.8	3255951.1	29 25 59.84	87 34 27.19
FIRE 3-73M		444306.4	3255959.7	29 26 00.13	87 34 27.12
START UP		444308.8	3255969.4	29 26 00.42	87 34 27.01
SURFACE		444317.9	3255995.8	29 26 01.28	87 34 26.68
ON DECK	00:25	444320.9	3256004.3	29 26 01.57	87 34 26.58
		H1C1 (Average depth - 82m)			
IN WATER	01:17	443795.3	3256341.8	29 26 12.44	87 34 46.16
START DOWN		443821.0	3256397.8	29 26 14.28	87 34 45.19
BOTTOM		443855.7	3256456.5	29 26 16.18	87 34 43.93
FIRE 1-79M		443857.1	3256459.0	29 26 16.26	87 34 43.89
FIRE 2-75M		443883.4	3256502.7	29 26 17.70	87 34 42.92
FIRE 3-70M		443908.3	3256541.7	29 26 18.96	87 34 41.98
SURFACE		443938.6	3256585.1	29 26 20.36	87 34 40.87
ON DECK	01:35	443948.1	3256597.8	29 26 20.79	87 34 40.51
		H1E1 (Average depth - 73m)			
IN WATER	02:03	444216.9	3256540.8	29 26 18.99	87 34 30.54
START DOWN		444257.2	3256570.5	29 26 19.96	87 34 29.06
BOTTOM		444307.7	3256603.6	29 26 21.04	87 34 27.19
START UP		444334.3	3256619.8	29 26 21.55	87 34 26.18
SURFACE		444375.2	3256641.0	29 26 22.27	87 34 24.67
ON DECK	02:09	444387.1	3256646.2	29 26 22.45	87 34 24.24
		H1F1 (Average depth - 78m)			
IN WATER	02:32	443807.2	3256809.4	29 26 27.63	87 34 45.80
START DOWN		443829.8	3256799.5	29 26 27.31	87 34 44.94
BOTTOM		443860.8	3256813.5	29 26 27.78	87 34 43.82
FIRE 1-74M		443864.4	3256815.2	29 26 27.85	87 34 43.68
FIRE 2-70M		443881.4	3256825.4	29 26 28.17	87 34 43.03
FIRE 3-65M		443894.6	3256835.3	29 26 28.50	87 34 42.56
FIRE 4-56M		443907.5	3256843.6	29 26 28.75	87 34 42.09
FIRE 5-42M		443937.2	3256864.2	29 26 29.43	87 34 40.98
FIRE 6-38M		443954.9	3256875.3	29 26 29.79	87 34 40.33
FIRE 7-21M		443972.1	3256886.5	29 26 30.19	87 34 39.68

CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
FIRE 8-SURFACE		443989.3	3256898.8	29 26 30.58	87 34 39.03
ON DECK	02:44	444000.1	3256907.4	29 26 30.84	87 34 38.64
		SITE 2			
		H2A1 (Average depth - 80m)			
IN WATER	07:50	441580.4	3257234.7	29 26 41.10	87 36 8.53
START DOWN		441597.5	3257244.7	29 26 41.42	87 36 7.88
BOTTOM		441614.2	3257257.0	29 26 41.82	87 36 7.27
FIRE 1-76M		441614.8	3257257.4	29 26 41.85	87 36 7.27
FIRE 2-69M		441621.4	3257260.5	29 26 41.92	87 36 7.02
FIRE 3-58M		441628.6	3257265.0	29 26 42.07	87 36 6.73
FIRE 4-50M		441635.6	3257268.7	29 26 42.21	87 36 6.48
FIRE 5-45M		441639.4	3257271.8	29 26 42.32	87 36 6.33
FIRE 6-27M		441642.6	3257277.0	29 26 42.46	87 36 6.22
FIRE 7-15M		441645.0	3257284.0	29 26 42.72	87 36 6.15
FIRE 8-SURFACE		441647.6	3257289.8	29 26 42.90	87 36 6.04
ON DECK	08:10	441651.1	3257294.0	29 26 43.04	87 36 5.90
		H2B1 (Average depth - 81m)			
IN WATER	09:01	440359.9	3257237.4	29 26 40.99	87 36 53.82
START DOWN		440365.5	3257237.4	29 26 40.99	87 36 53.64
BOTTOM		440369.0	3257239.0	29 26 41.02	87 36 53.49
FIRE 1-77M		440369.5	3257239.6	29 26 41.06	87 36 53.46
FIRE 2-75M		440372.1	3257239.7	29 26 41.06	87 36 53.38
FIRE 3-70M		440374.4	3257239.5	29 26 41.06	87 36 53.28
FIRE 4-SURFACE		440380.2	3257234.6	29 26 40.88	87 36 53.06
ON DECK	09:14	440382.5	3257233.9	29 26 40.84	87 36 52.99
		H2C1 (Average depth - 79m)			
IN WATER	09:53	441072.8	3257560.4	29 26 51.57	87 36 27.43
START DOWN		441069.8	3257569.4	29 26 51.90	87 36 27.54
BOTTOM		441070.2	3257572.9	29 26 52.00	87 36 27.54
FIRE 1-76M		441070.5	3257574.9	29 26 52.04	87 36 27.54
FIRE 2-73M		441071.1	3257577.7	29 26 52.15	87 36 27.50
FIRE 3-SURFACE		441072.4	3257578.2	29 26 52.18	87 36 27.46
ON DECK	10:02	441073.1	3257578.1	29 26 52.15	87 36 27.43
		SITE 5			
		H5C1 (Average depth - 80m)			
IN WATER	13:38	404469.6	3251858.2	29 23 38.22	87 59 4.27
START DOWN		404410.2	3251779.4	29 23 35.62	87 59 6.43
BOTTOM		404383.7	3251740.8	29 23 34.36	87 59 7.40
START UP		404378.2	3251731.1	29 23 34.04	87 59 7.62
SURFACE		404363.4	3251697.1	29 23 32.96	87 59 8.16
ON DECK	13:51	404358.3	3251683.7	29 23 32.49	87 59 8.34
		SITE 6			
		H6B1 (Average depth - 80m)			
IN WATER	14:10	404750.2	3252320.8	29 23 53.30	87 58 54.01
START DOWN		404721.4	3252282.7	29 23 52.08	87 58 55.05
BOTTOM		404688.2	3252256.7	29 23 51.21	87 58 56.28
START UP		404681.1	3252252.7	29 23 51.07	87 58 56.53
SURFACE		404664.1	3252244.4	29 23 50.82	87 58 57.18
ON DECK	14:20	404658.7	3252240.6	29 23 50.67	87 58 57.36
		H6C1 (Average depth - 78m)			
IN WATER	14:33	405122.9	3252704.2	29 24 5.86	87 58 40.29
START DOWN		405098.0	3252690.6	29 24 5.43	87 58 41.19

CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
BOTTOM		405076.5	3252677.4	29 24 5.00	87 58 41.98
START UP		405071.2	3252673.9	29 24 4.86	87 58 42.20
SURFACE		405050.9	3252659.6	29 24 4.39	87 58 42.96
ON DECK	14:42	405046.0	3252655.5	29 24 4.28	87 58 43.14

H6A1 (Average depth - 81m)

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	14:55	405434.6	3252286.4	29 23 52.40	87 58 28.59
START DOWN		405415.2	3252284.6	29 23 52.33	87 58 29.31
BOTTOM		405384.3	3252278.7	29 23 52.11	87 58 30.46
FIRE 1-77M		405380.5	3252278.4	29 23 52.11	87 58 30.61
FIRE 2-75M		405368.5	3252278.7	29 23 52.11	87 58 31.04
FIRE 3-69M		405356.2	3252278.5	29 23 52.11	87 58 31.51
FIRE 4-59M		405345.8	3252278.4	29 23 52.11	87 58 31.87
FIRE 5-46M		405334.2	3252279.1	29 23 52.11	87 58 32.30
FIRE 6-32M		405323.2	3252280.1	29 23 52.15	87 58 32.73
FIRE 7-11M		405312.0	3252282.3	29 23 52.22	87 58 33.13
FIRE 8-SURFACE		405302.3	3252283.1	29 23 52.26	87 58 33.49
ON DECK	15:10	405292.8	3252282.8	29 23 52.22	87 58 33.85

SITE 5

H5A1 (Average depth - 81m)

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	15:51	405200.4	3251699.8	29 23 33.25	87 58 37.09
START DOWN		405171.5	3251714.3	29 23 33.72	87 58 38.17
BOTTOM		405144.9	3251734.4	29 23 34.36	87 58 39.18
FIRE 1-78M		405142.9	3251735.4	29 23 34.40	87 58 39.25
FIRE 2-75M		405136.2	3251740.7	29 23 34.58	87 58 39.50
FIRE 3-68M		405126.1	3251750.6	29 23 34.90	87 58 39.86
FIRE 4-50M		405115.9	3251763.3	29 23 35.30	87 58 40.26
FIRE 5-40M		405104.9	3251772.2	29 23 35.59	87 58 40.65
FIRE 6-20M		405090.1	3251784.7	29 23 35.98	87 58 41.23
FIRE 7-10M		405081.5	3251792.4	29 23 36.24	87 58 41.55
FIRE 8-SURFACE		405066.5	3251806.7	29 23 36.70	87 58 42.09
ON DECK	16:06	405052.0	3251819.9	29 23 37.14	87 58 42.63

H5B1 (Average depth - 80m)

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	16:42	404767.6	3251337.4	29 23 21.37	87 58 53.04
START DOWN		404745.8	3251387.1	29 23 22.99	87 58 53.86
BOTTOM		404736.5	3251405.9	29 23 23.60	87 58 54.22
FIRE 1-77M		404735.4	3251408.4	29 23 23.67	87 58 54.26
FIRE 2-74M		404730.6	3251417.9	29 23 23.96	87 58 54.44
FIRE 3-SURFACE		404718.1	3251440.7	29 23 24.72	87 58 54.91
ON DECK	16:54	404711.9	3251449.0	29 23 24.97	87 58 55.12

SITE 9

H9A1 (Average depth - 91m)

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	21:33	371607.5	3234825.9	29 14 14.38	88 19 16.10
START DOWN		371598.8	3234932.3	29 14 17.84	88 19 16.46
BOTTOM		371580.1	3235019.6	29 14 20.65	88 19 17.18
FIRE 1-89M		371579.2	3235023.2	29 14 20.76	88 19 17.22
FIRE 2-86M		371573.1	3235052.4	29 14 21.73	88 19 17.47
FIRE 3-79M		371560.7	3235104.8	29 14 23.42	88 19 17.94
FIRE 4-64M		371551.4	3235145.5	29 14 24.72	88 19 18.30
FIRE 5-45M		371541.9	3235206.5	29 14 26.70	88 19 18.69
FIRE 6-25M		371534.9	3235247.0	29 14 27.81	88 19 18.98
FIRE 7-9M		371526.1	3235278.1	29 14 29.04	88 19 19.30
FIRE 8-SURFACE		371516.5	3235332.7	29 14 30.80	88 19 19.66
ON DECK	21:50	371513.8	3235368.8	29 14 31.99	88 19 19.81

H9B1 (Average depth - 95m)

CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	22:33	370746.8	3234629.7	29 14 7.69	88 47.89
START DOWN		370759.2	3234783.2	29 14 12.66	88 47.49
BOTTOM		370780.1	3234932.2	29 14 17.52	88 46.77
FIRE 1-93M		370781.4	3234938.7	29 14 17.73	88 46.74
FIRE 2-90M		370786.4	3234972.4	29 14 18.81	88 46.56
FIRE 3-SURFACE		370802.8	3235056.1	29 14 21.55	88 46.02
ON DECK	22:46	370808.2	3235093.0	29 14 22.77	88 45.80
		H9C1 (Average depth - 95m)			
IN WATER	23:03	371110.6	3235135.0	29 14 24.25	88 19 34.64
START DOWN		371137.5	3235248.4	29 14 27.92	88 19 33.67
BOTTOM		371162.0	3235362.9	29 14 31.66	88 19 32.84
START UP		371163.5	3235369.2	29 14 31.84	88 19 32.77
SURFACE		371177.3	3235442.4	29 14 34.26	88 19 32.30
ON DECK	23:10	371179.3	3235469.1	29 14 35.12	88 19 32.23
		SITE 8 **H8C1 (Average depth - 92m)**			
IN WATER	23:27	371962.1	3234389.2	29 14 0.31	88 19 2.78
START DOWN		371978.2	3234501.3	29 14 3.94	88 19 2.24
BOTTOM		372001.2	3234582.0	29 14 6.61	88 19 1.41
START UP		372003.4	3234589.7	29 14 6.82	88 19 1.34
SURFACE		372022.4	3234645.5	29 14 8.66	88 19 0.66
ON DECK	23:35	372032.5	3234677.6	29 14 9.70	88 19 0.30
		H8B1 (Average depth - 96m)			
IN WATER	23:52	371588.2	3233682.4	29 13 37.23	88 19 16.35
START DOWN		371614.2	3233803.1	29 13 41.16	88 19 15.42
BOTTOM		371632.0	3233938.7	29 13 45.55	88 19 14.84
START UP		371632.0	3233948.1	29 13 45.87	88 19 14.84
SURFACE		371633.4	3234022.5	29 13 48.28	88 19 14.80
ON DECK	00:01	371632.8	3234052.3	29 13 49.26	88 19 14.84
24 May 1997					
		H8A1 (Average depth - 95m)			
IN WATER	00:20	372370.7	3234003.0	29 13 47.9	88 18 47.48
START DOWN		372383.3	3234083.3	29 13 50.5	88 18 47.05
BOTTOM		372406.9	3234213.3	29 13 54.7	88 18 46.26
FIRE 1-91M		372408.7	3234241.8	29 13 55.7	88 18 46.18
FIRE 2-89M		372410.3	3234281.5	29 13 57.0	88 18 46.15
FIRE 3-87M		372410.8	3234314.7	29 13 58.0	88 18 46.15
FIRE 4-80M		372413.0	3234352.7	29 13 59.3	88 18 46.08
FIRE 5-65M		372415.3	3234395.1	29 14 0.67	88 18 46.00
FIRE 6-30M		372421.5	3234454.4	29 14 2.61	88 18 45.79
FIRE 7-12M		372425.7	3234489.7	29 14 3.76	88 18 45.64
FIRE 8-SURFACE		372432.3	3234544.7	29 14 5.53	88 18 45.43
ON DECK	00:36	372439.0	3234589.7	29 14 7.00	88 18 45.21
		SITE 7 **H7C1 (Average depth - 89m)**			
IN WATER	01:04	370277.9	3236922.5	29 15 21.99	88 20 6.21
START DOWN		370301.9	3237016.5	29 15 25.05	88 20 5.38
BOTTOM		370320.9	3237154.5	29 15 29.55	88 20 4.74
START UP		370321.8	3237159.7	29 15 29.70	88 20 4.70
SURFACE		370334.5	3237248.4	29 15 32.61	88 20 4.27
ON DECK	01:14	370337.8	3237273.0	29 15 33.40	88 20 4.16

H7B1 (Average depth - 93m)

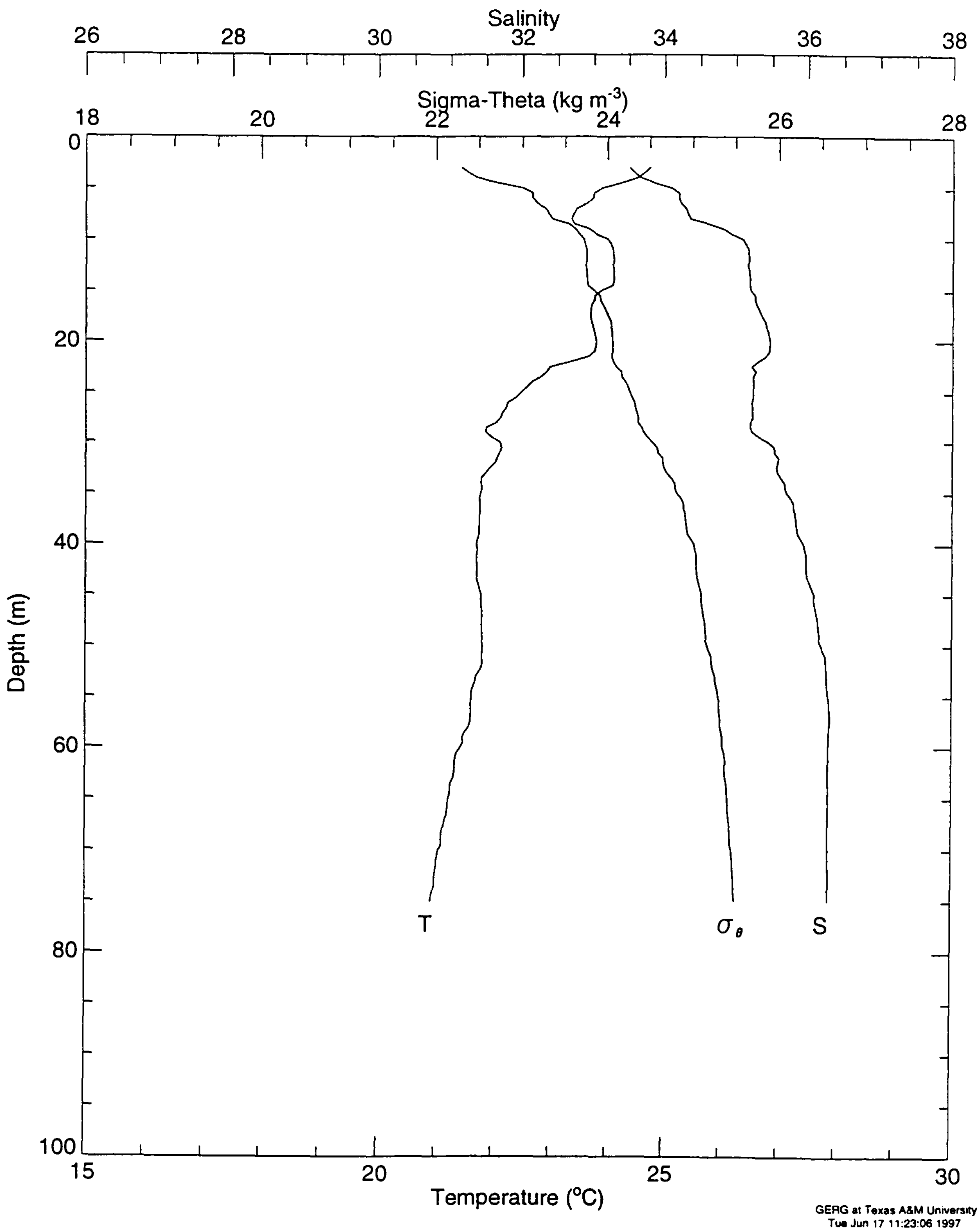
CTD CASTS
PINNACLES CRUISE 1C

EVENT	TIME	EASTING (meters)	NORTHING (meters)	LATITUDE (DD MM SS.SS)	LONGITUDE (DD MM SS.SS)
IN WATER	01:28	369520.9	3236782.0	29 15 17.13	88 20 34.22
START DOWN		369529.1	3236870.2	29 15 20.01	88 20 33.93
BOTTOM		369544.9	3236988.5	29 15 23.86	88 20 33.39
START UP		369545.7	3236995.5	29 15 24.08	88 20 33.39
SURFACE		369561.6	3237101.7	29 15 27.54	88 20 32.85
ON DECK	01:39	369567.5	3237127.6	29 15 28.40	88 20 32.64
		H7A1 (Average depth - 92m)			
IN WATER	01:57	370224.1	3236484.6	29 15 7.74	88 20 8.05
START DOWN		370242.0	3236619.4	29 15 12.13	88 20 7.44
BOTTOM		370276.8	3236756.5	29 15 16.59	88 20 6.21
FIRE 1-88M		370278.7	3236762.6	29 15 16.81	88 20 6.14
FIRE 2-85M		370289.0	3236795.9	29 15 17.89	88 20 5.78
FIRE 3-80M		370305.6	3236840.9	29 15 19.36	88 20 5.17
FIRE 4-50M		370323.5	3236892.1	29 15 21.02	88 20 4.52
FIRE 5-15M		370337.5	3236931.5	29 15 22.32	88 20 4.02
FIRE 6-SURFACE		370347.2	3236961.2	29 15 23.29	88 20 3.69
ON DECK	02:13	370393.7	3237084.6	29 15 27.28	88 20 2.00
		H7A2 (Average depth - 92m)			
IN WATER	02:48	370186.0	3236333.0	29 15 2.80	88 20 9.38
START DOWN		370257.2	3236509.8	29 15 8.56	88 20 6.82
BOTTOM		370294.4	3236621.3	29 15 12.20	88 20 5.49
FIRE 1-88M		370295.0	3236628.5	29 15 12.45	88 20 5.46
FIRE 2-84M		370309.0	3236682.4	29 15 14.22	88 20 4.99
FIRE 3-80M		370326.2	3236727.5	29 15 15.66	88 20 4.34
FIRE 4-50M		370353.5	3236786.0	29 15 17.56	88 20 3.37
FIRE 5-10M		370389.8	3236848.1	29 15 19.62	88 20 2.04
ON DECK	03:05	370439.6	3236931.8	29 15 22.35	88 20 0.24

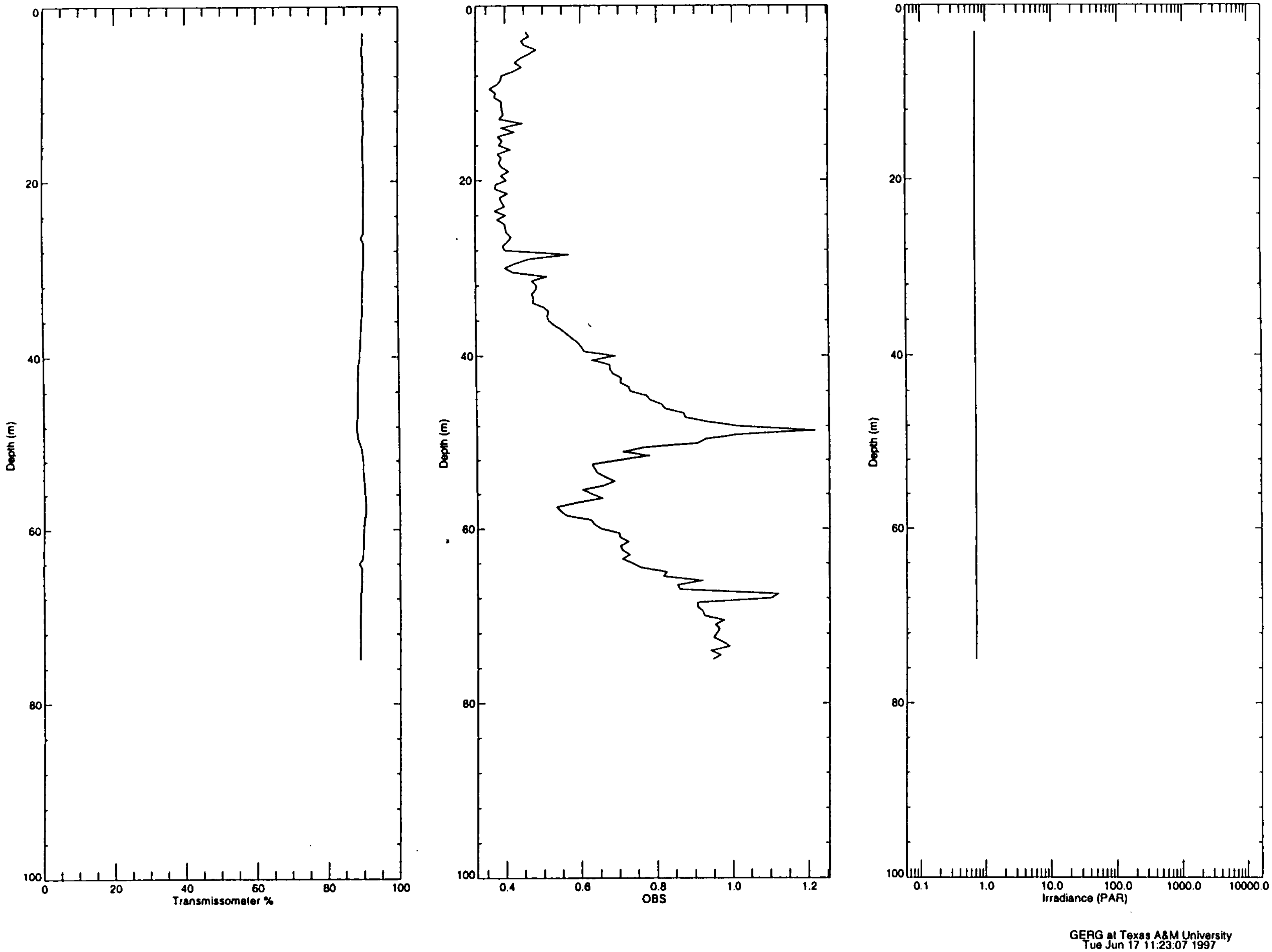
NOTES:

1) All times are in local time - Central Time Zone.
2) All distances and depths are in meters.
3) Geodetic parameters:
   - Ellipsoid = Clarke 1866
   - Zone = 16
   - CM = -87
   - Projection = UTM
   - Units = Meters

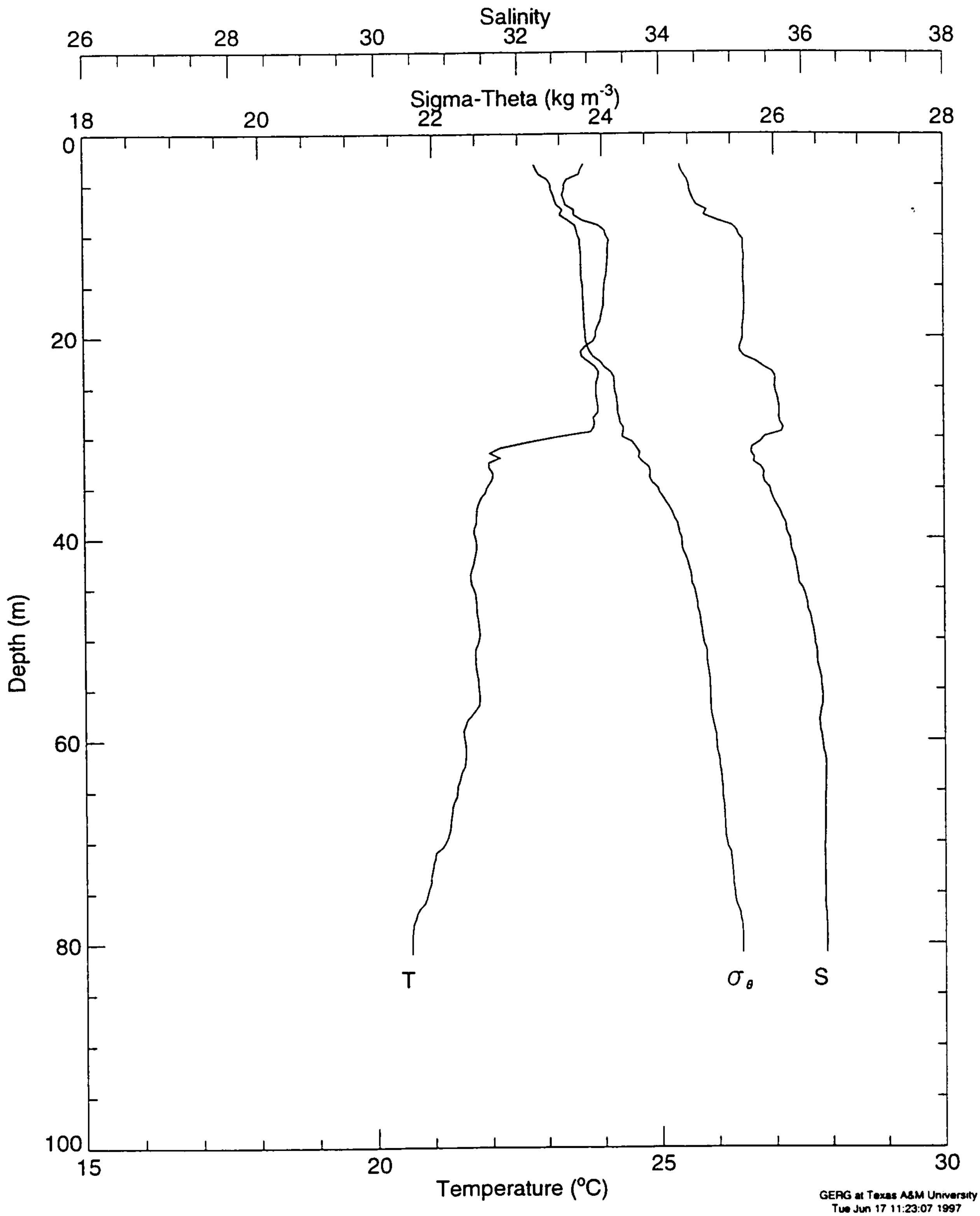
Station: H1A1



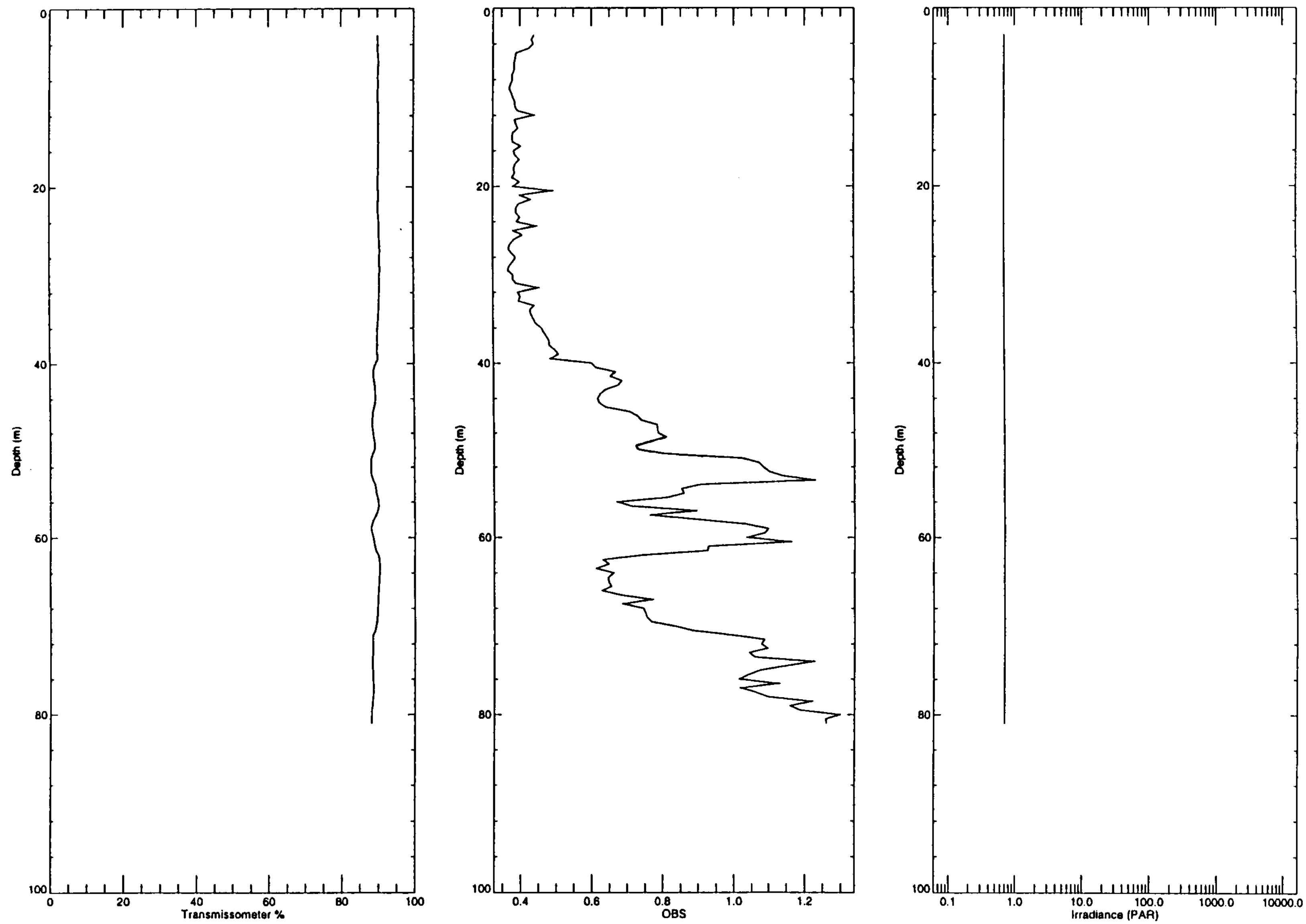
Station: H1A1



Station: H1B1

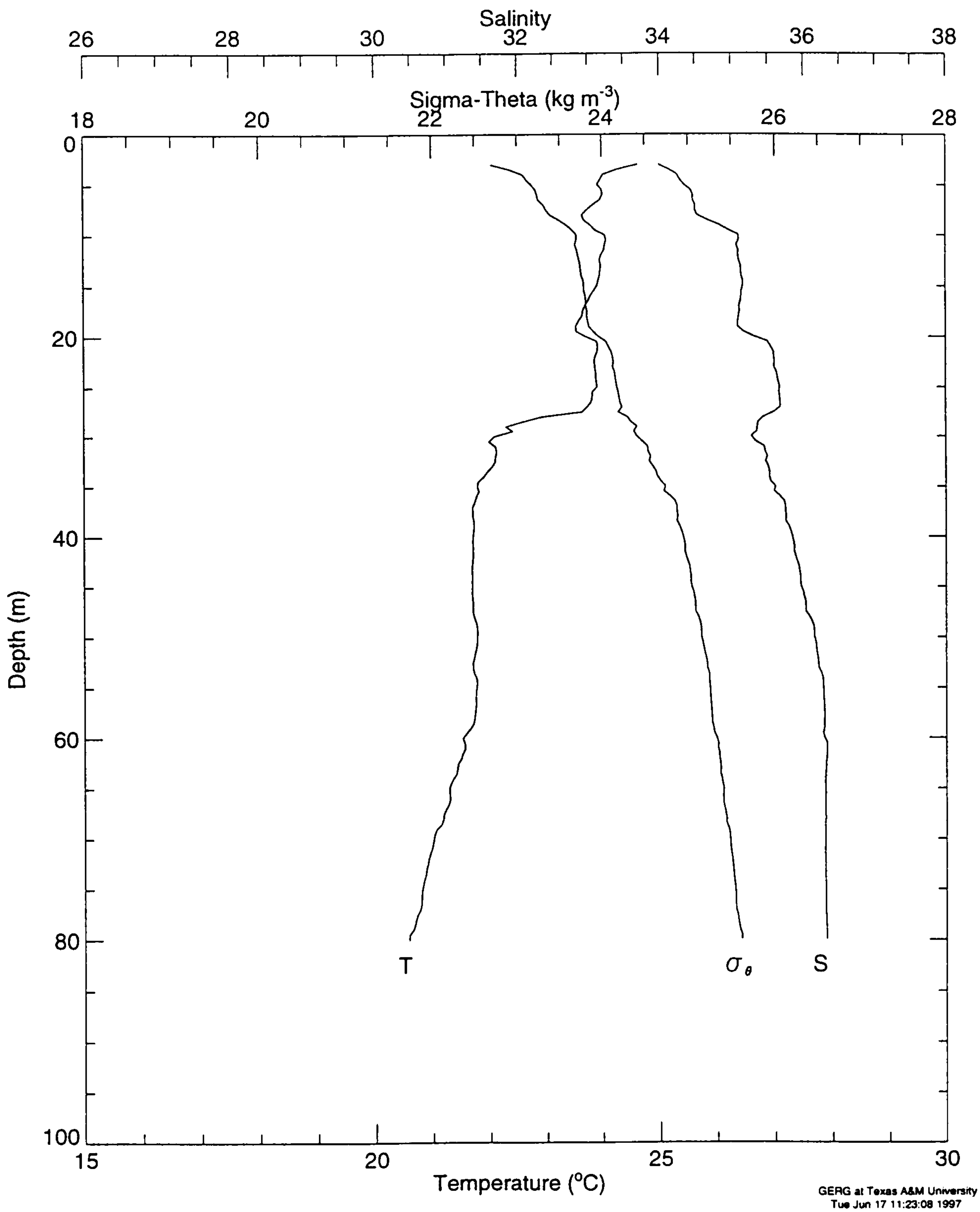


Station: H1B1

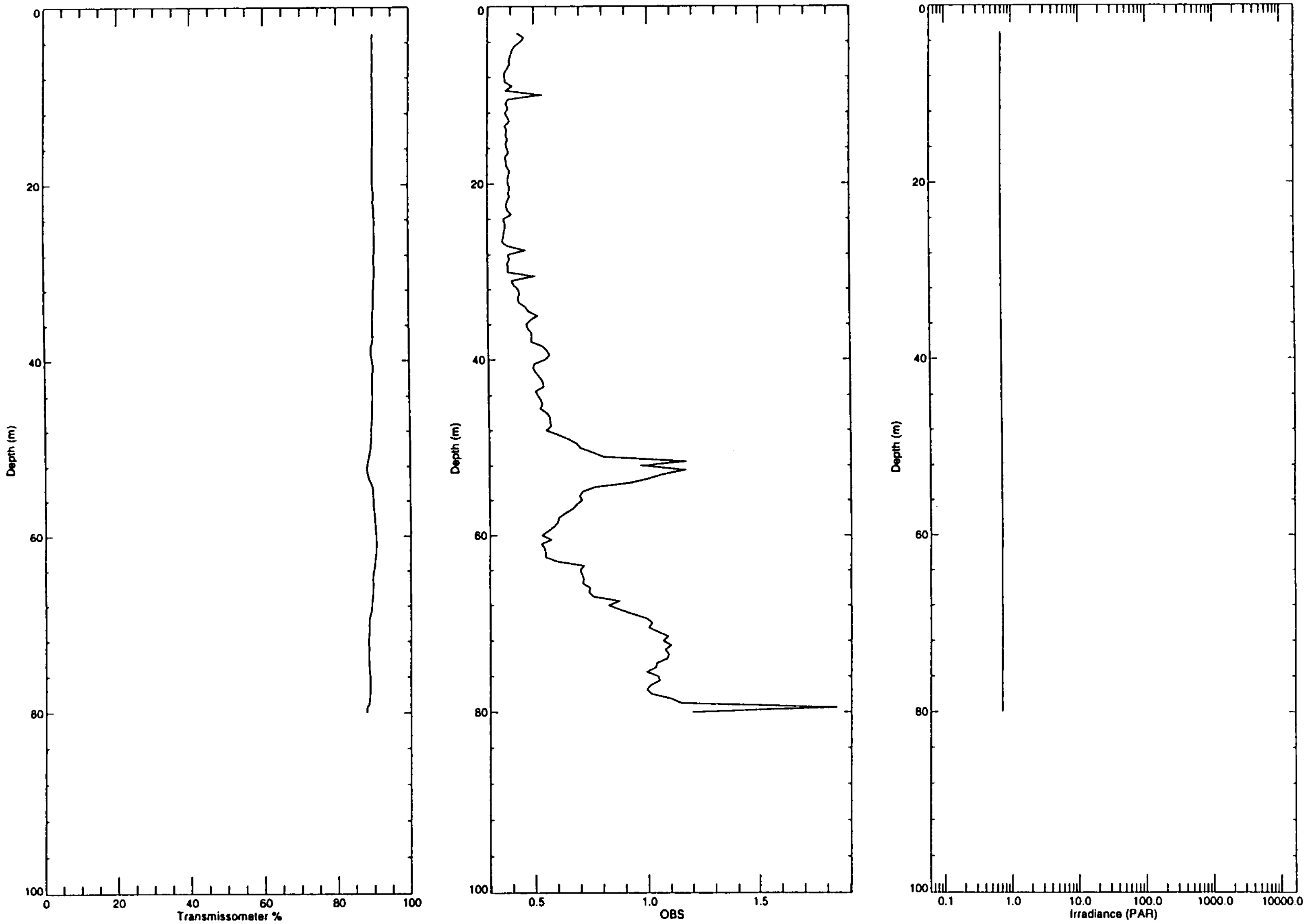


GERG at Texas A&M University
Tue Jun 17 11:23:07 1997

Station: H1C1

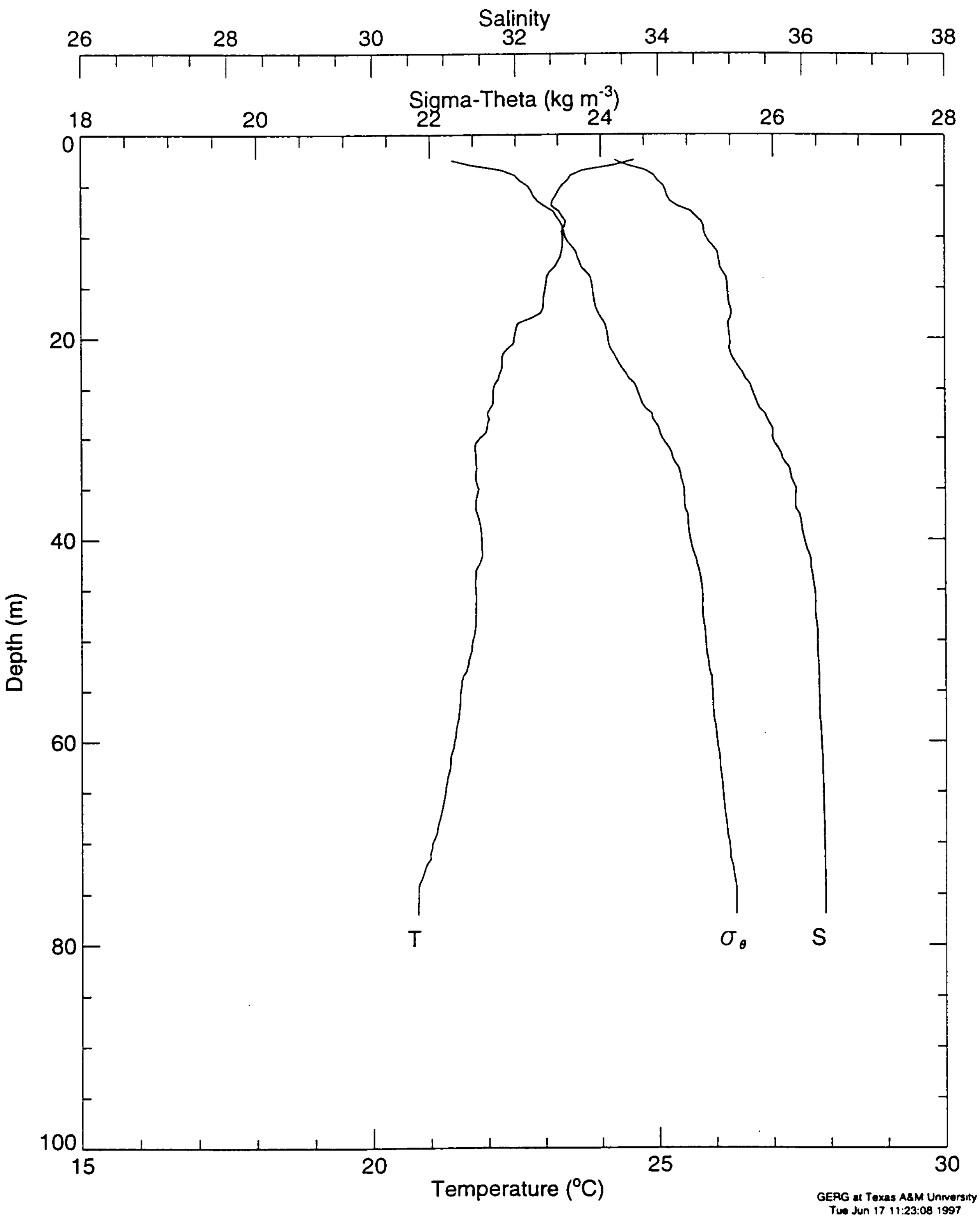


Station: H1C1

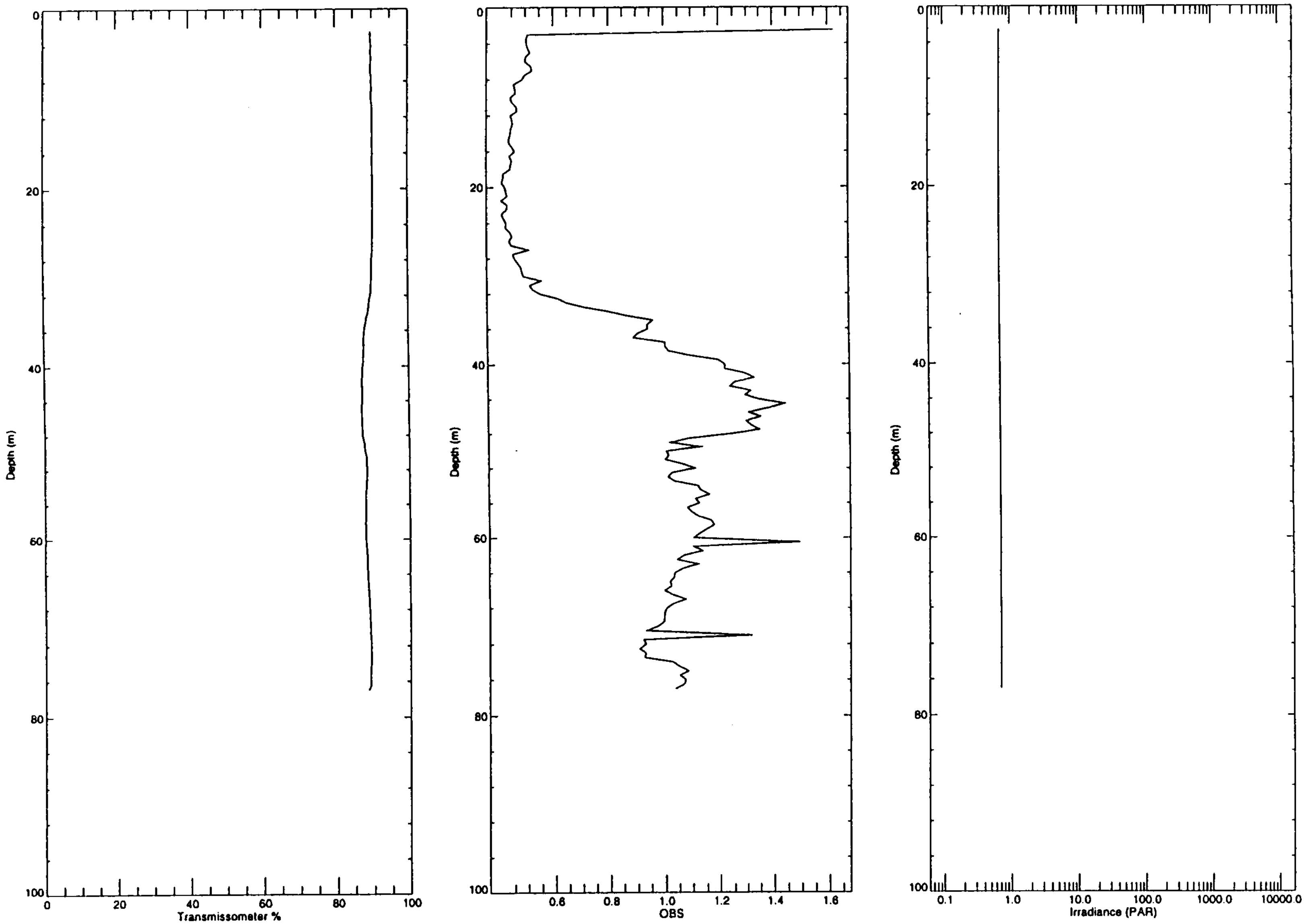


GERG at Texas A&M University
Tue Jun 17 11:23:08 1997

Station: H1D1

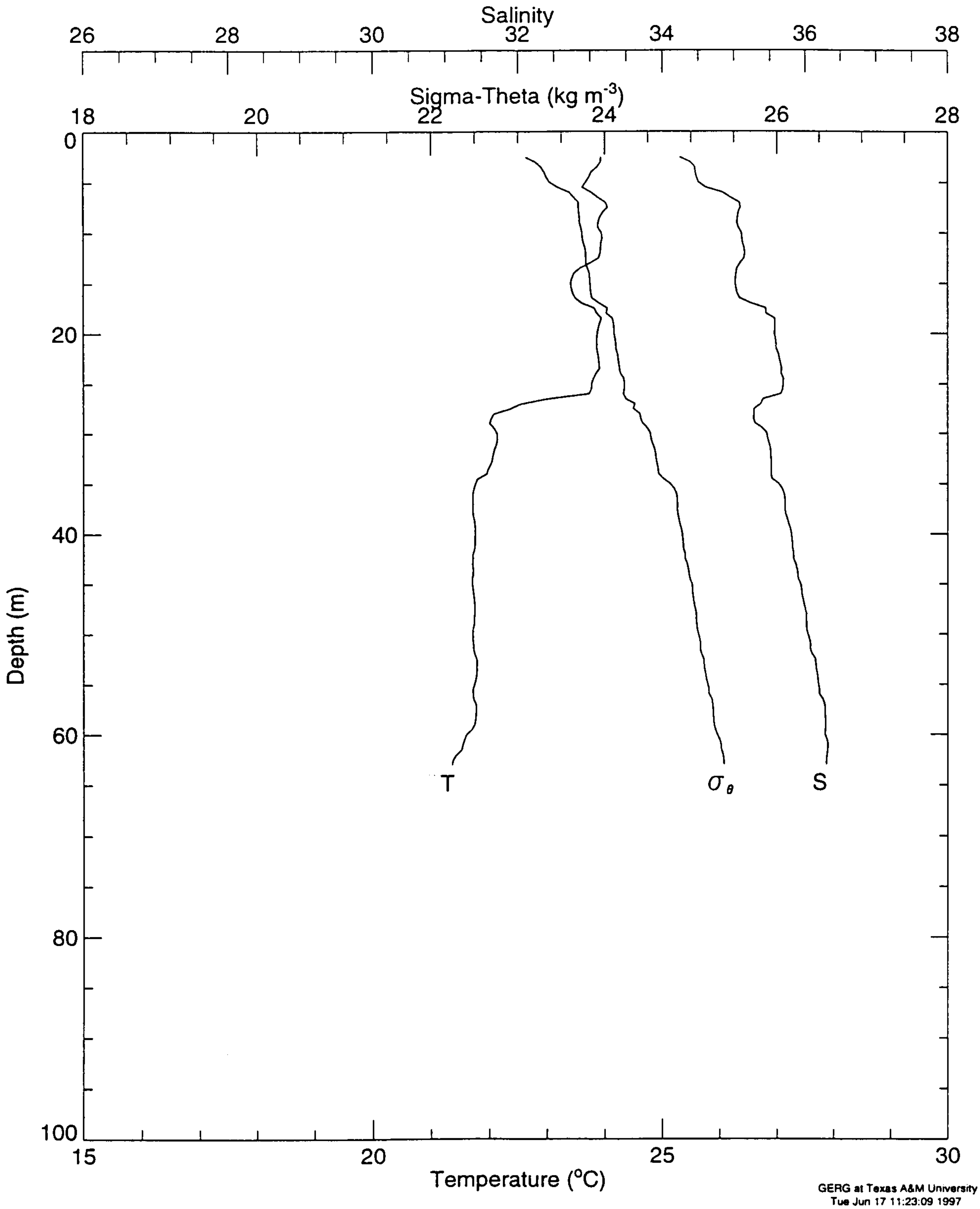


Station: H1D1

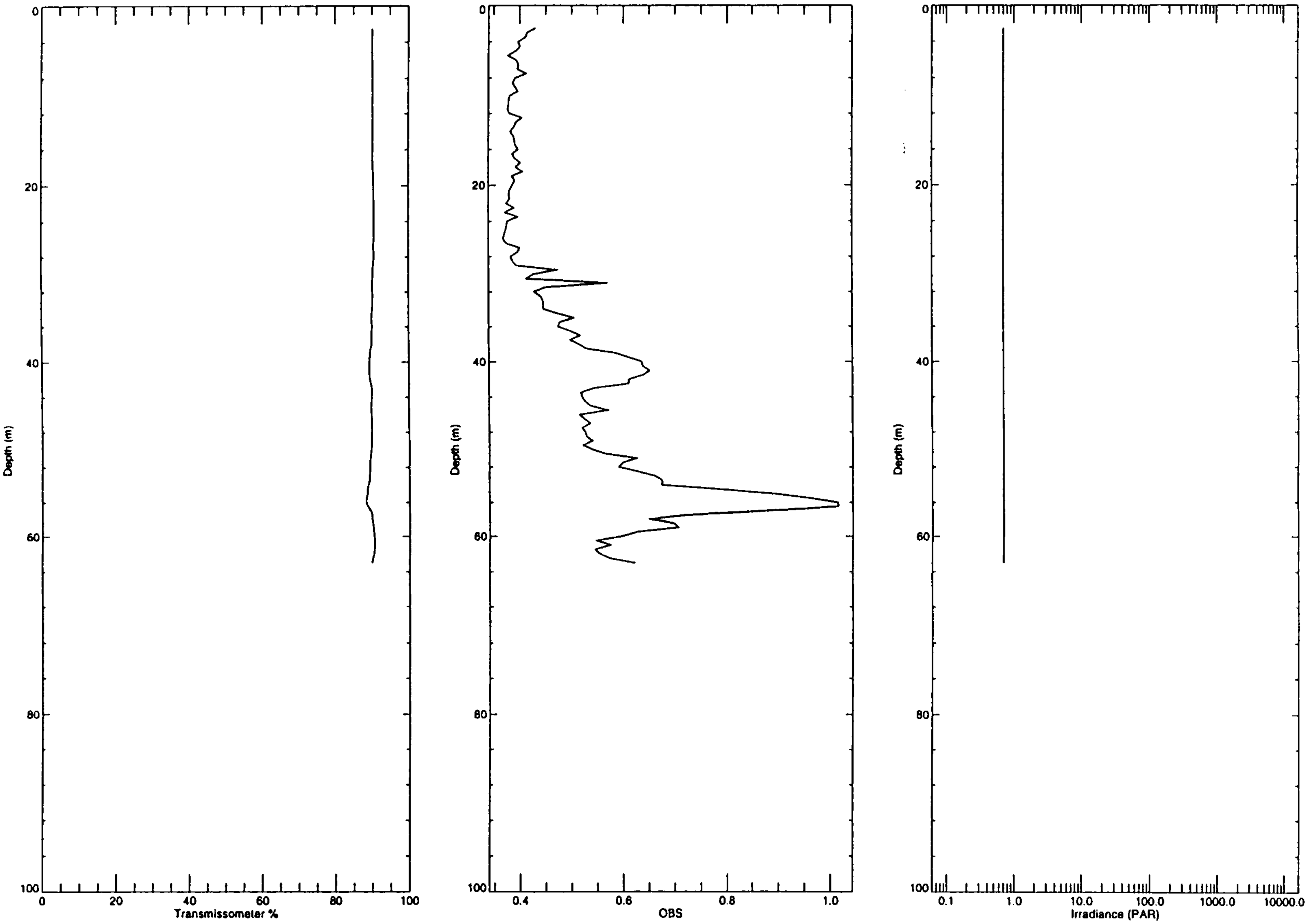


GERG at Texas A&M University
Tue Jun 17 11:23:08 1997

Station: H1E1

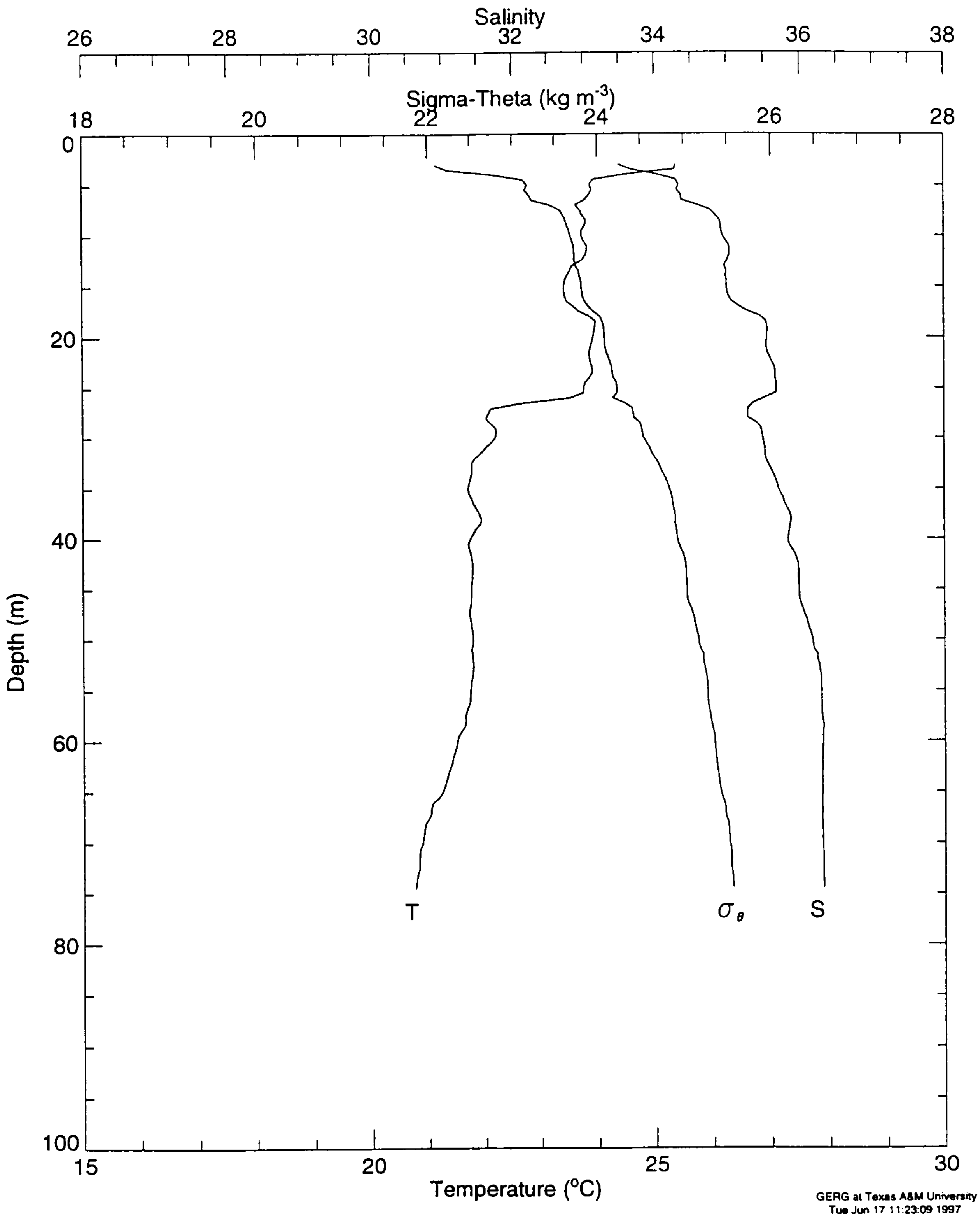


Station: H1E1

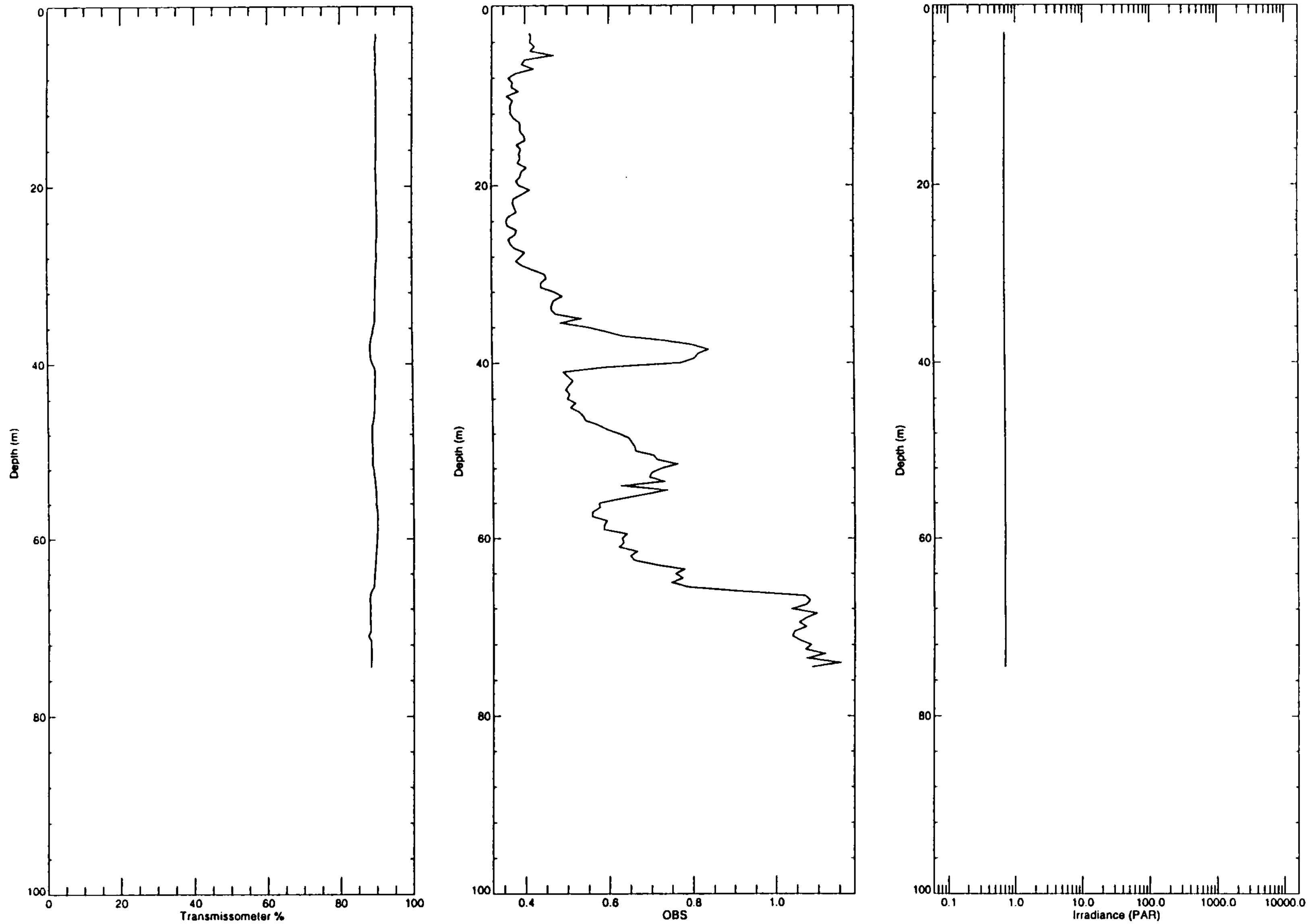


GERG at Texas A&M University
Tue Jun 17 11:23:09 1997

Station: H1F1

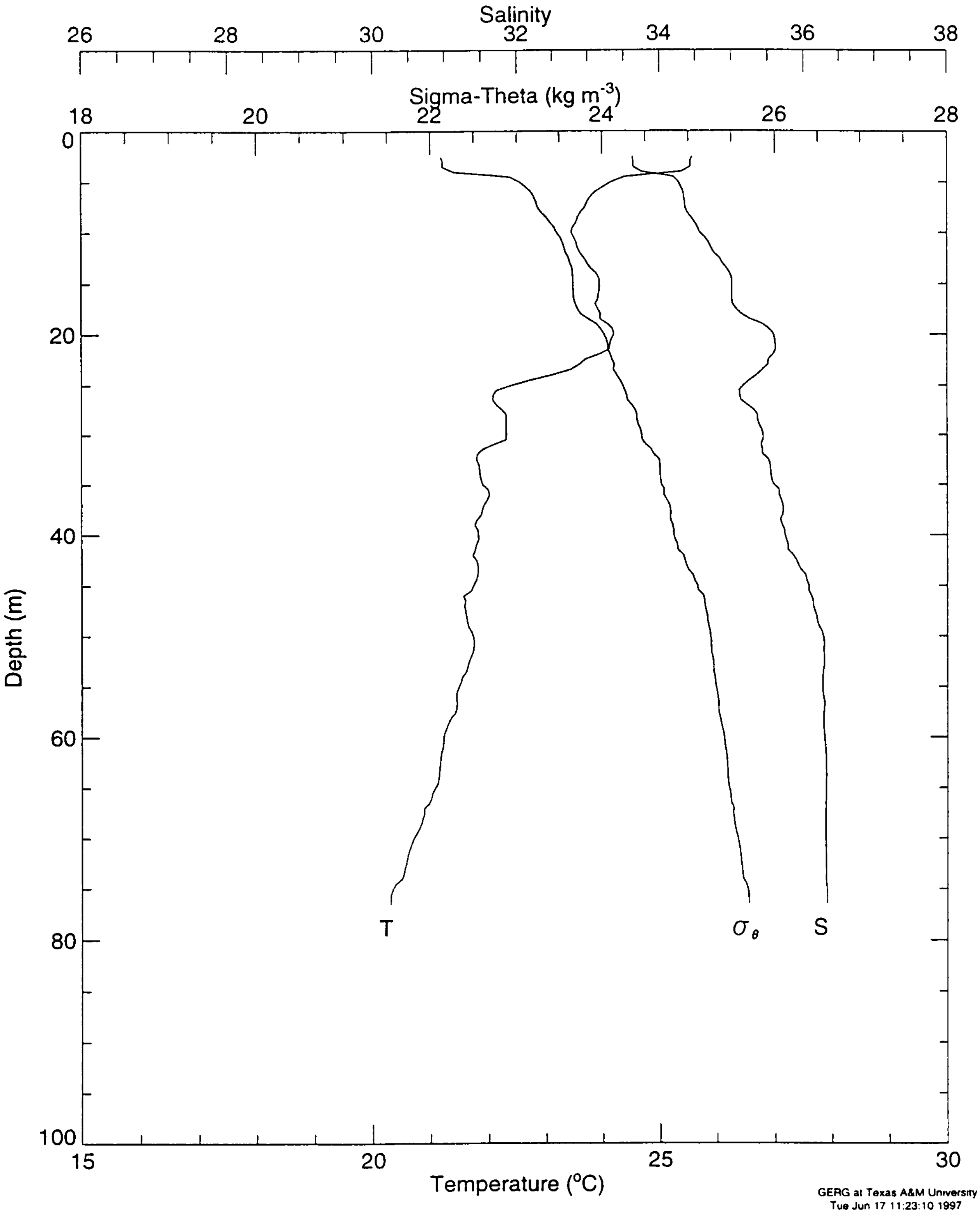


Station: H1F1

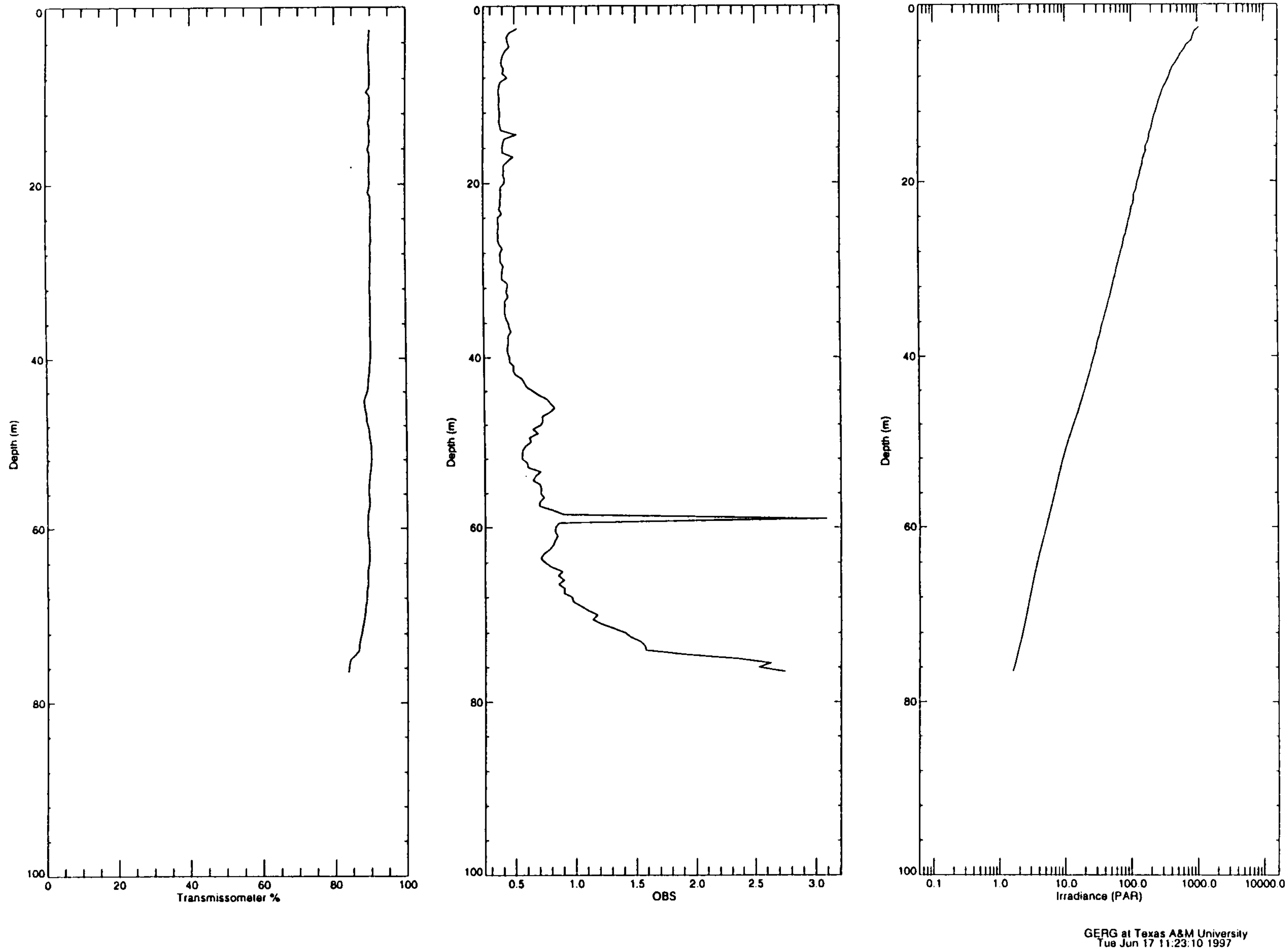


GERG at Texas A&M University
Tue Jun 17 11:23:09 1997

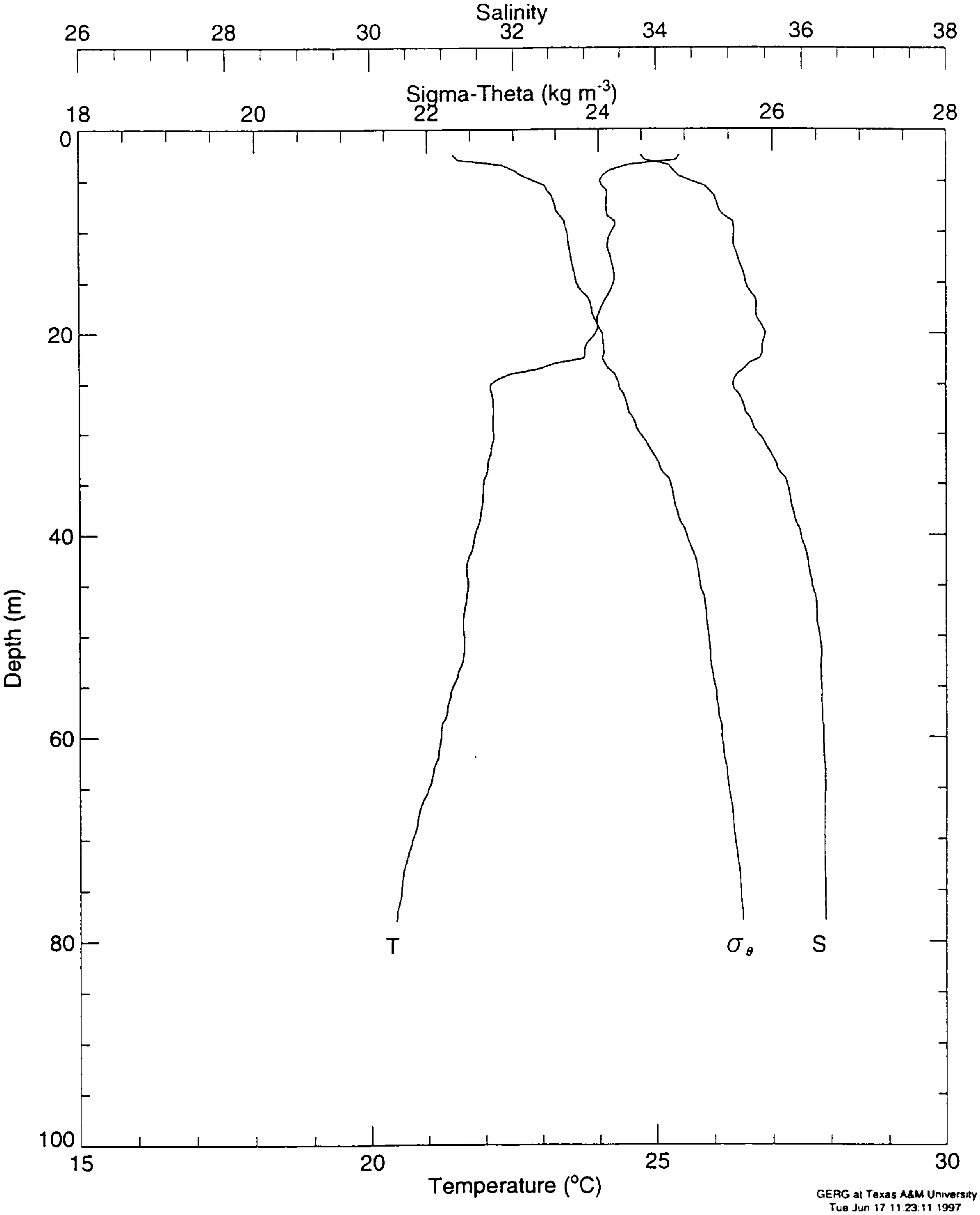
Station: H2A1



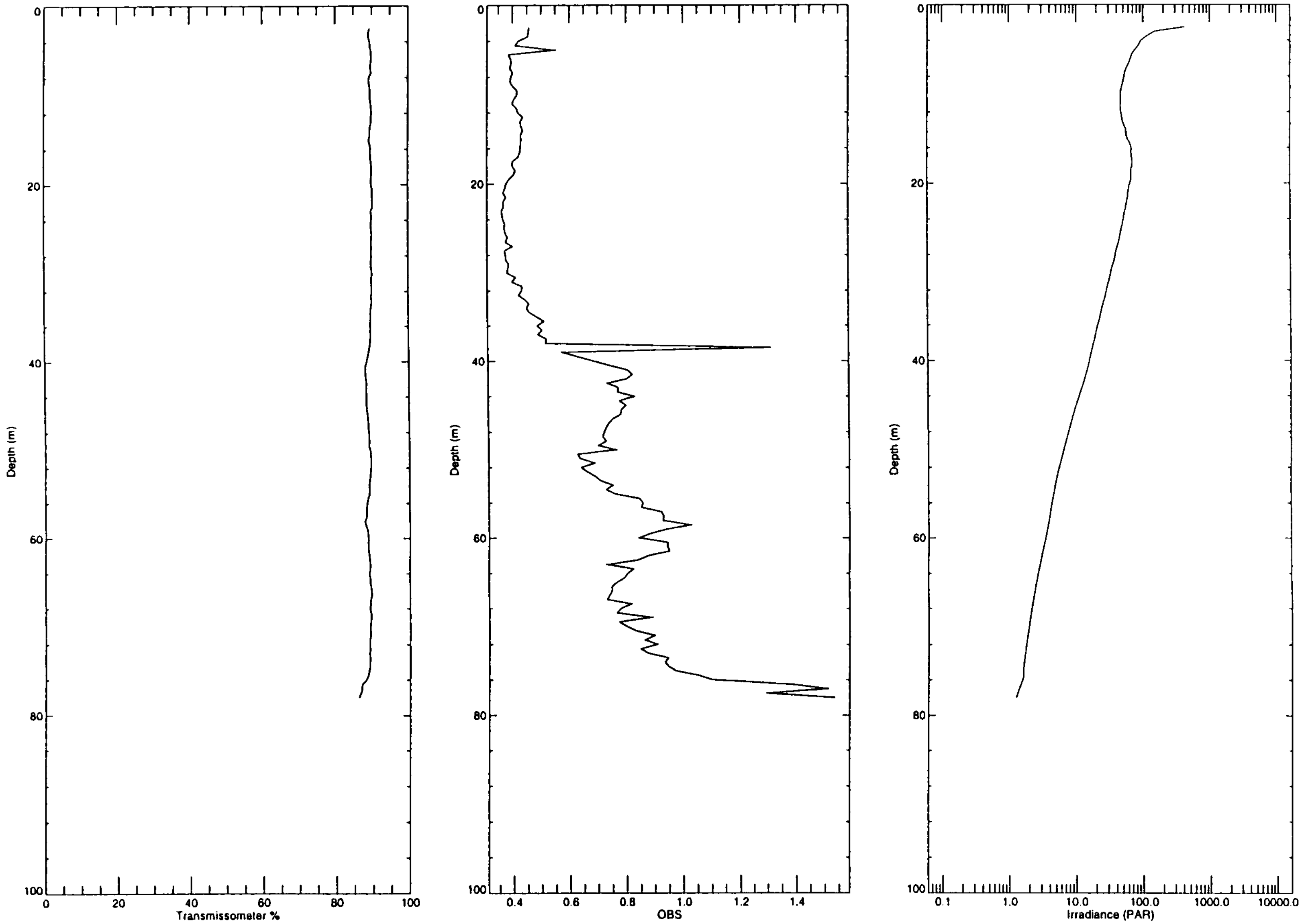
Station: H2A1



Station: H2B1

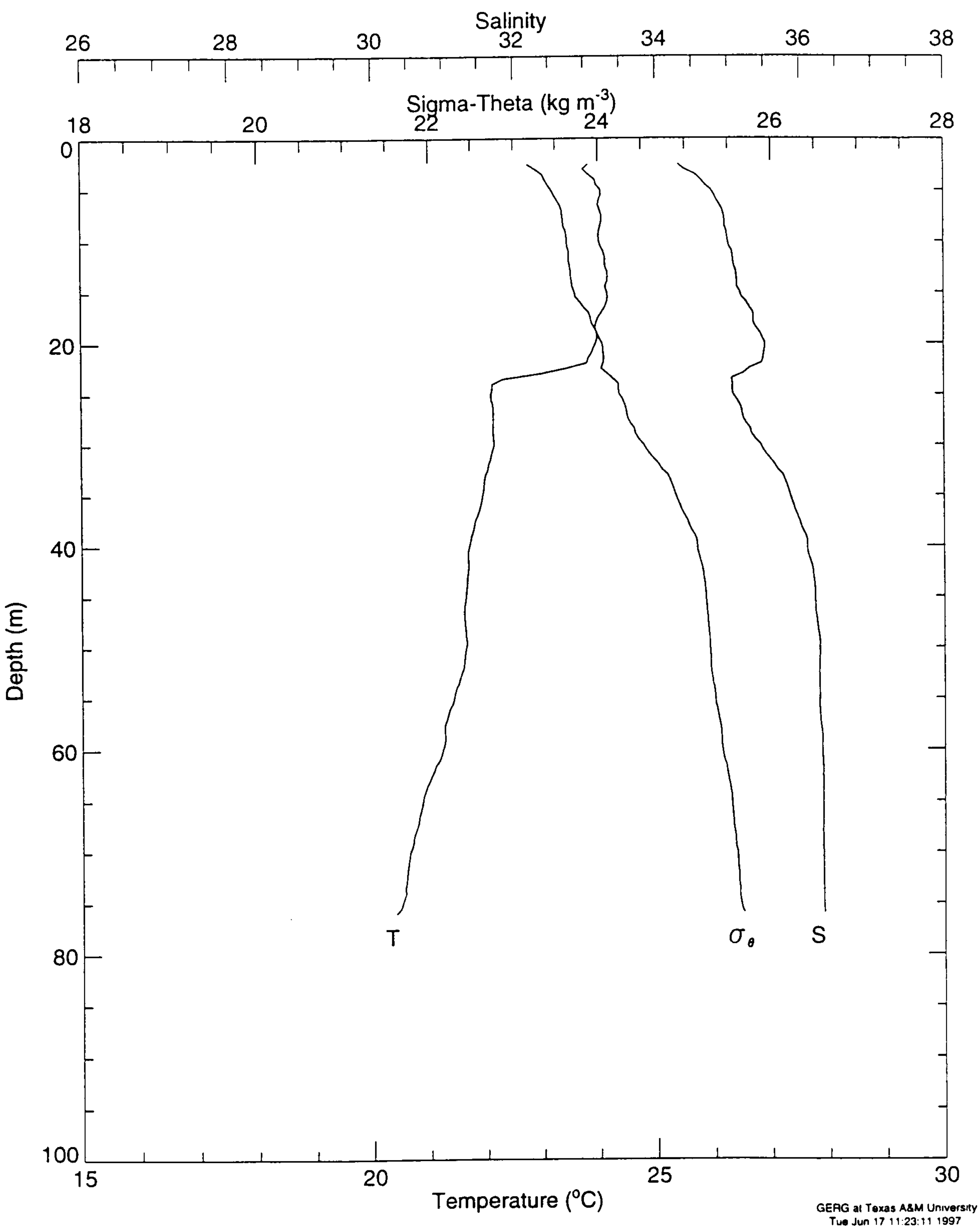


Station: H2B1

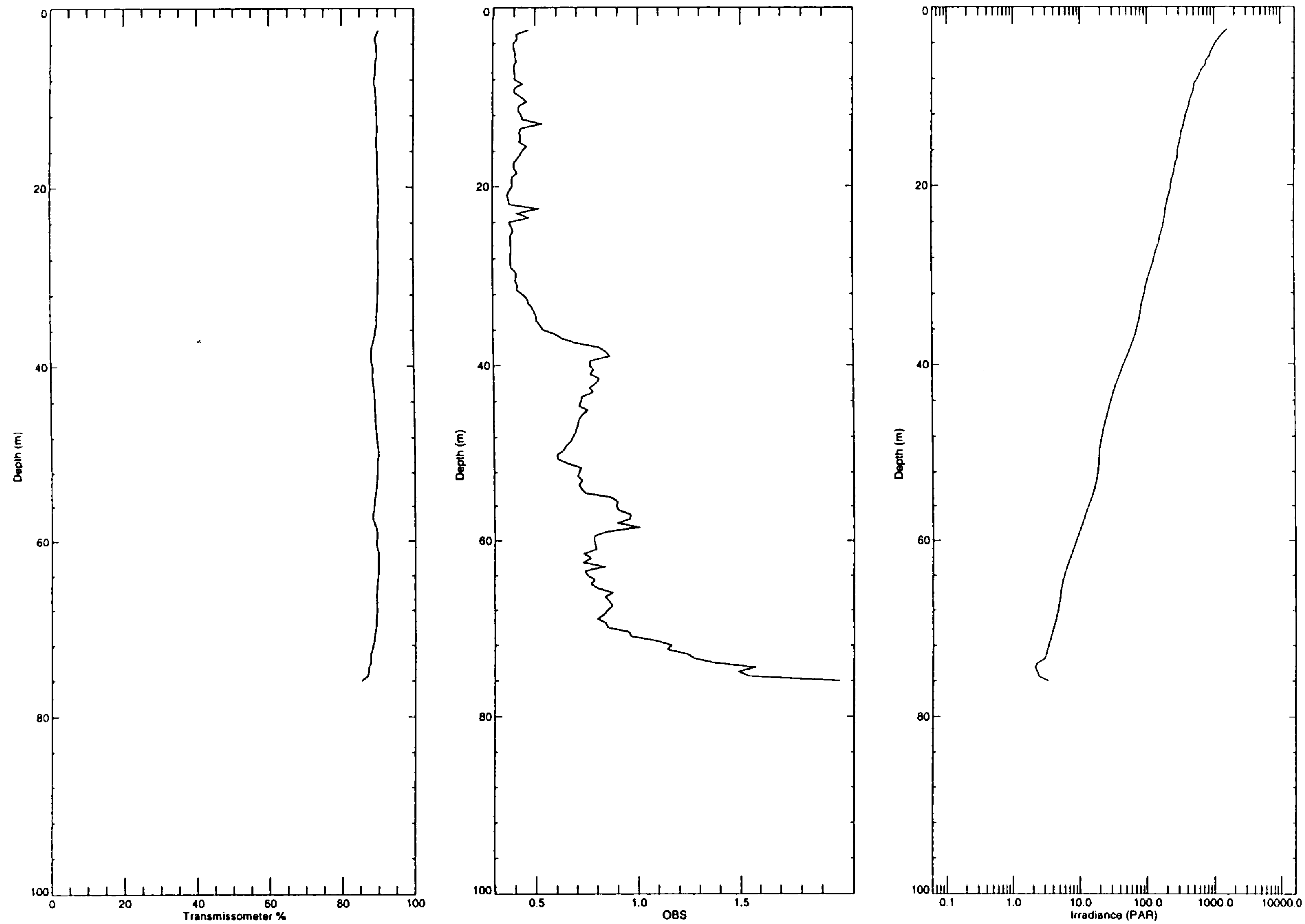


GERG at Texas A&M University
Tue Jun 17 11:23:11 1997

Station: H2C1

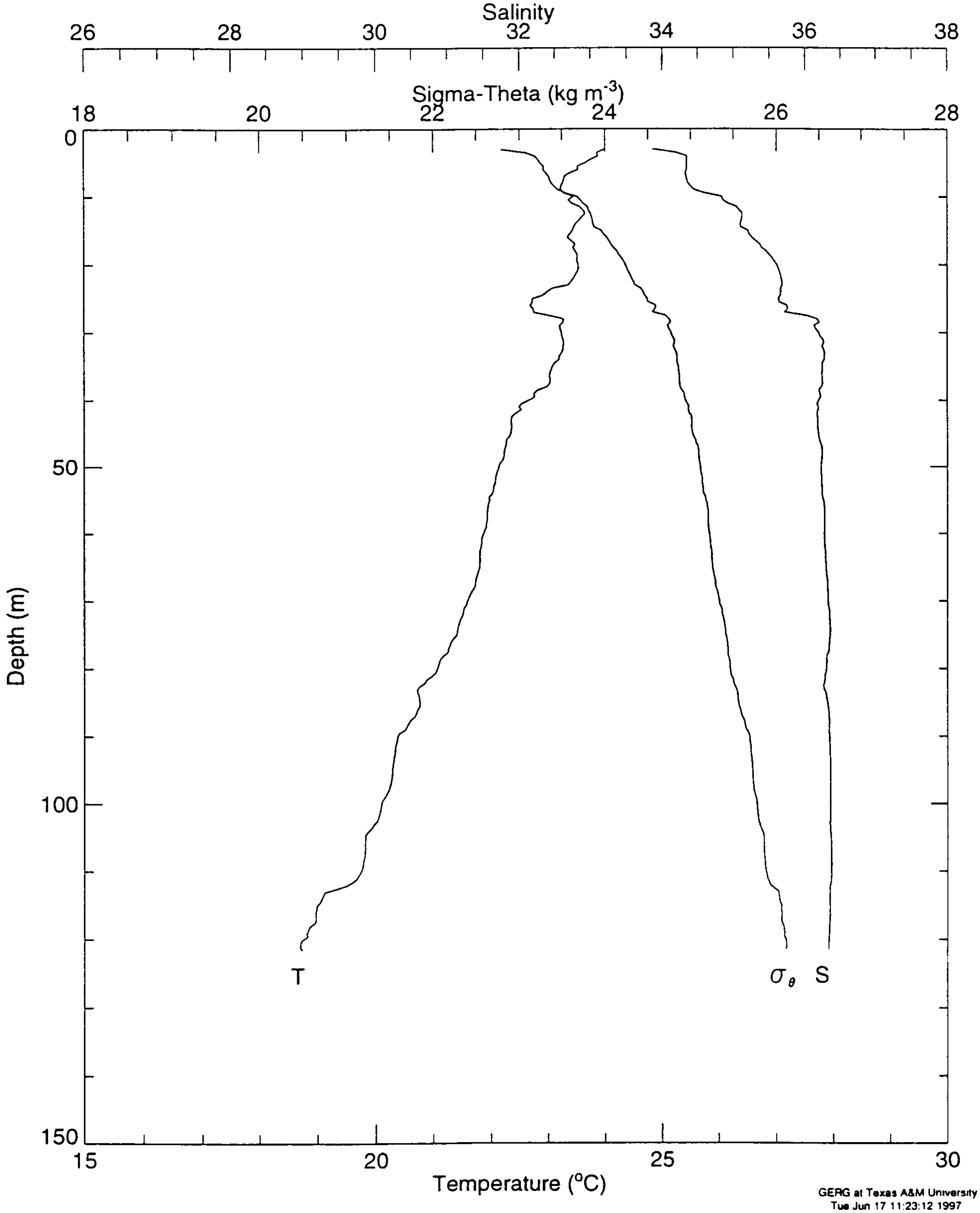


Station: H2C1

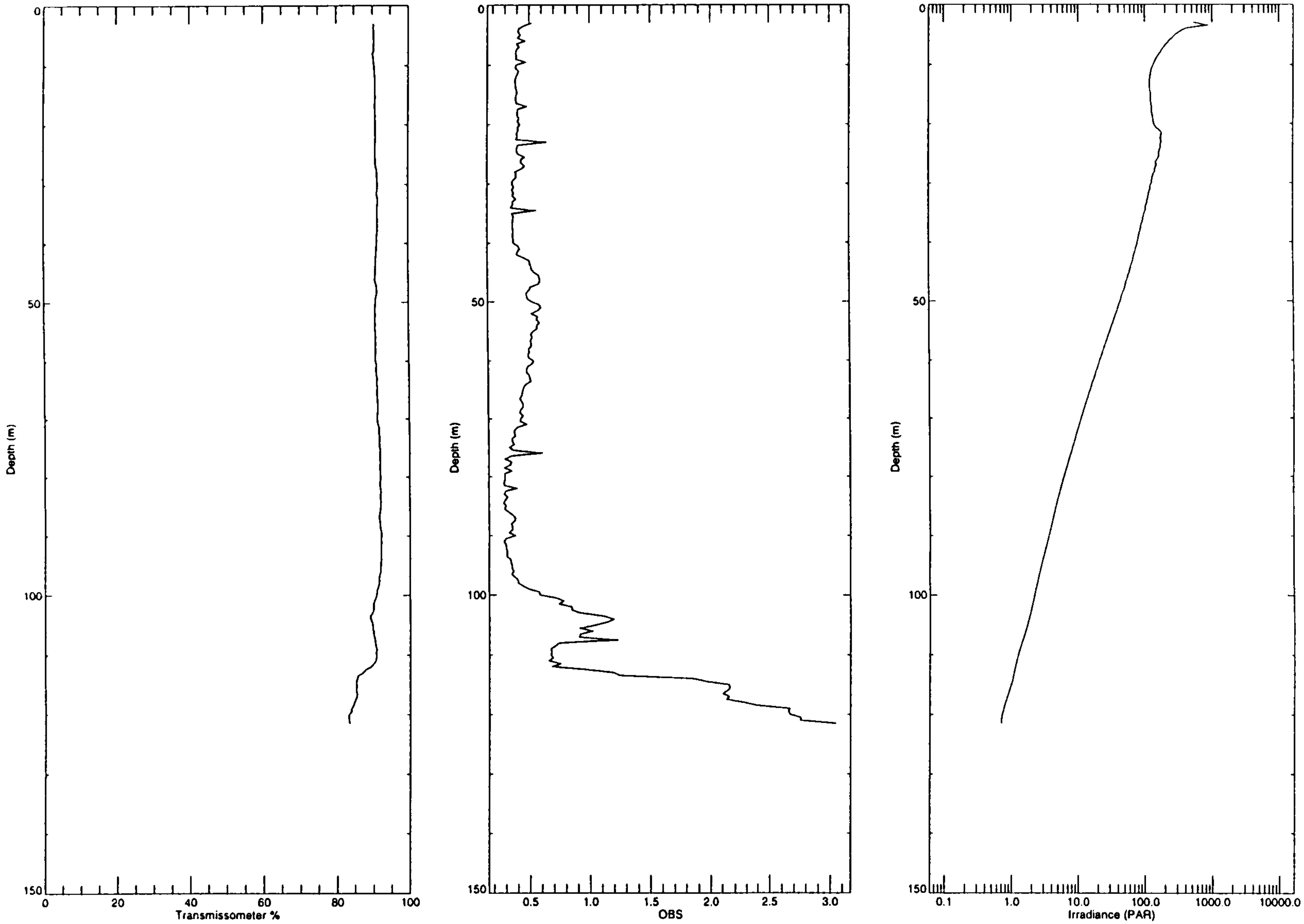


GERG at Texas A&M University
Tue Jun 17 11:23:11 1997

Station: H4A1

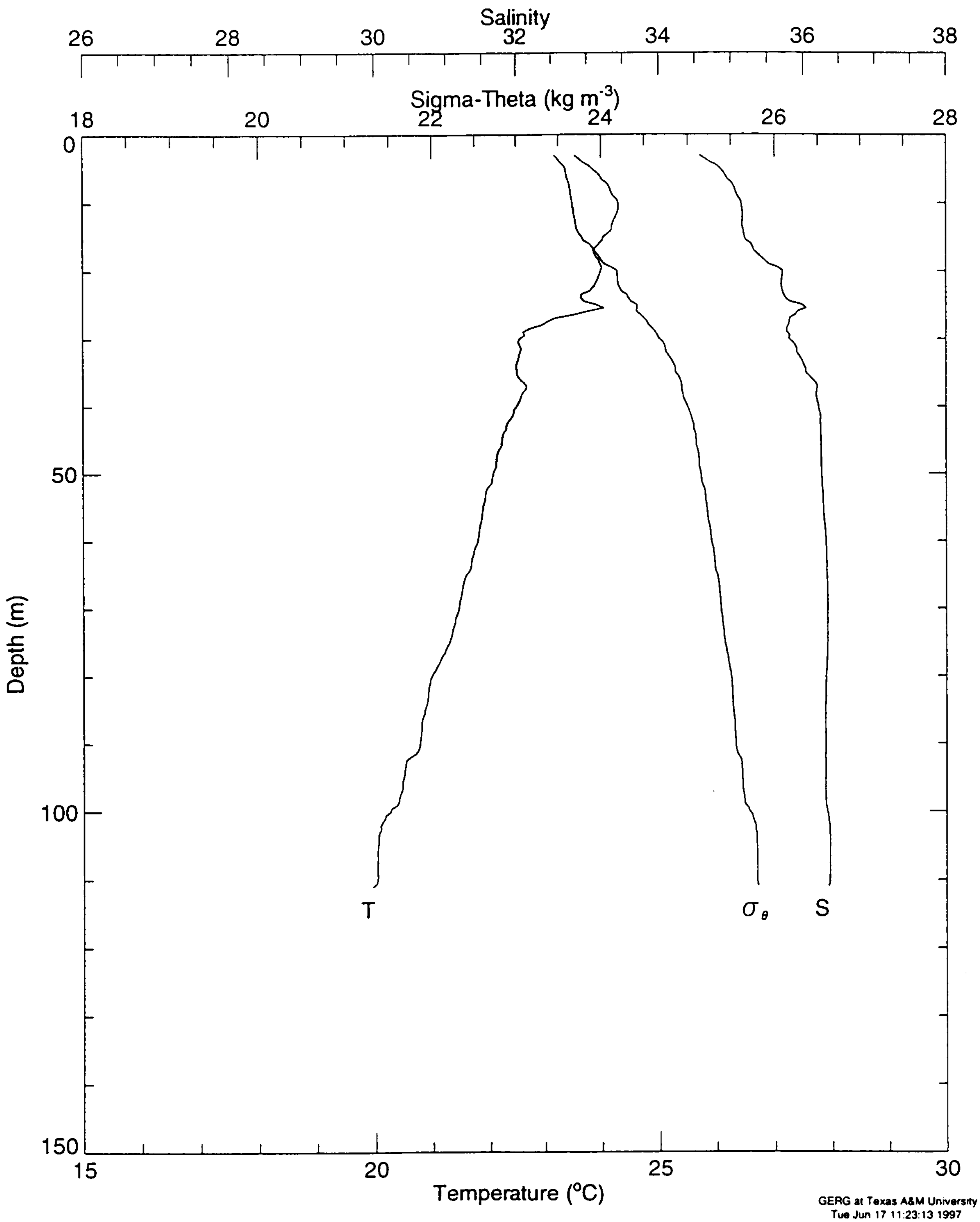


Station: H4A1

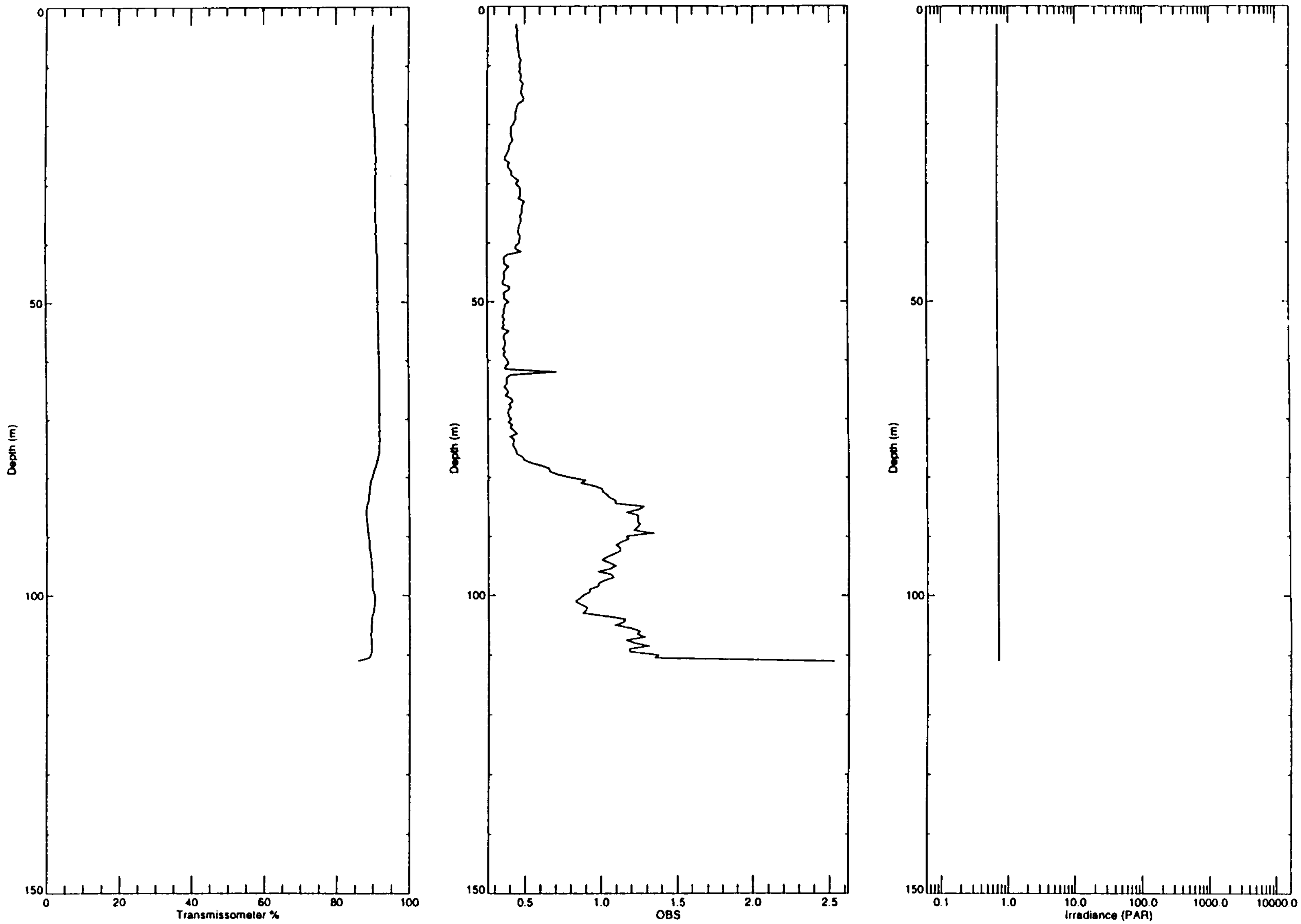


GERG at Texas A&M University
Tue Jun 17 11:23:12 1997

Station: H4A2

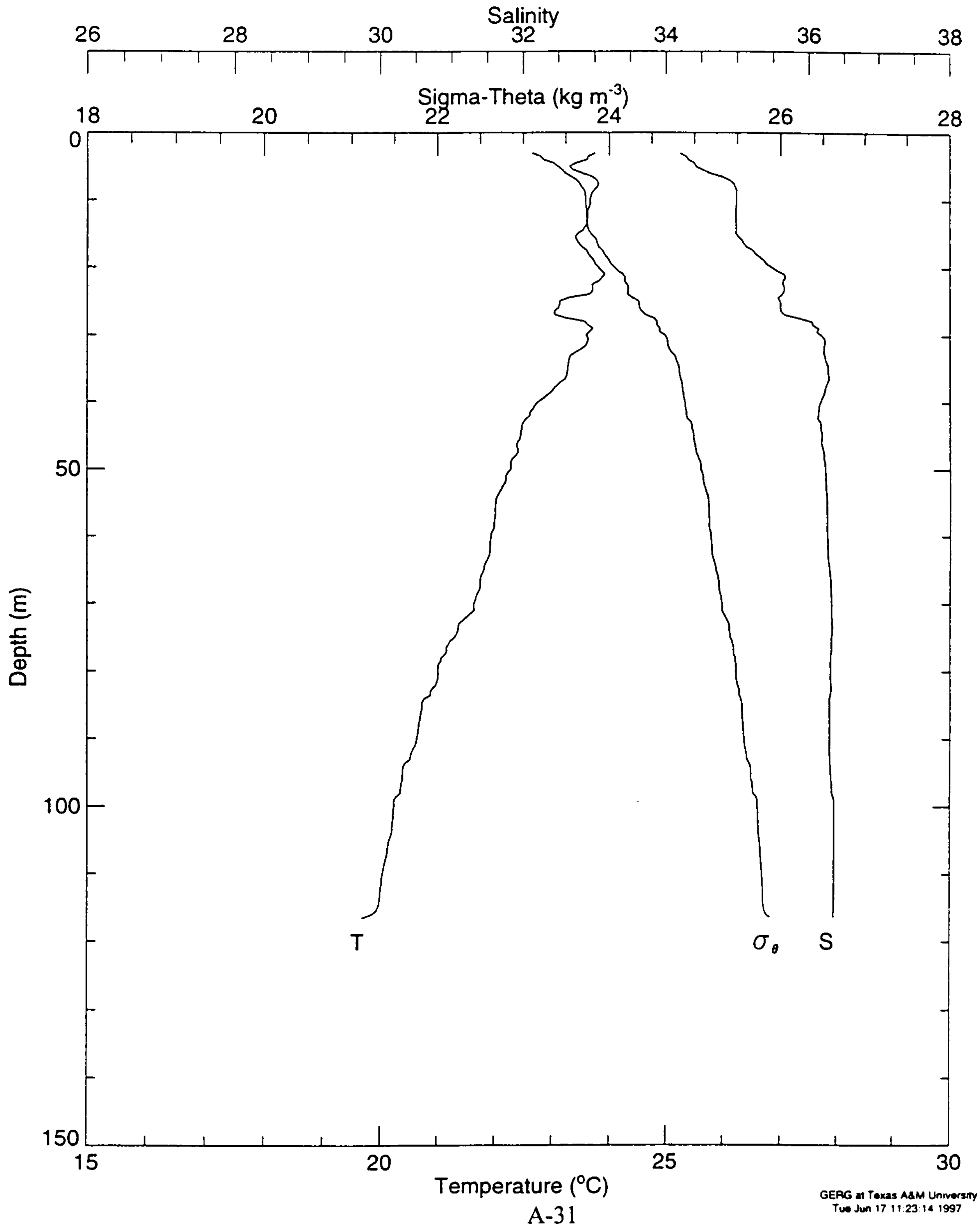


Station: H4A2

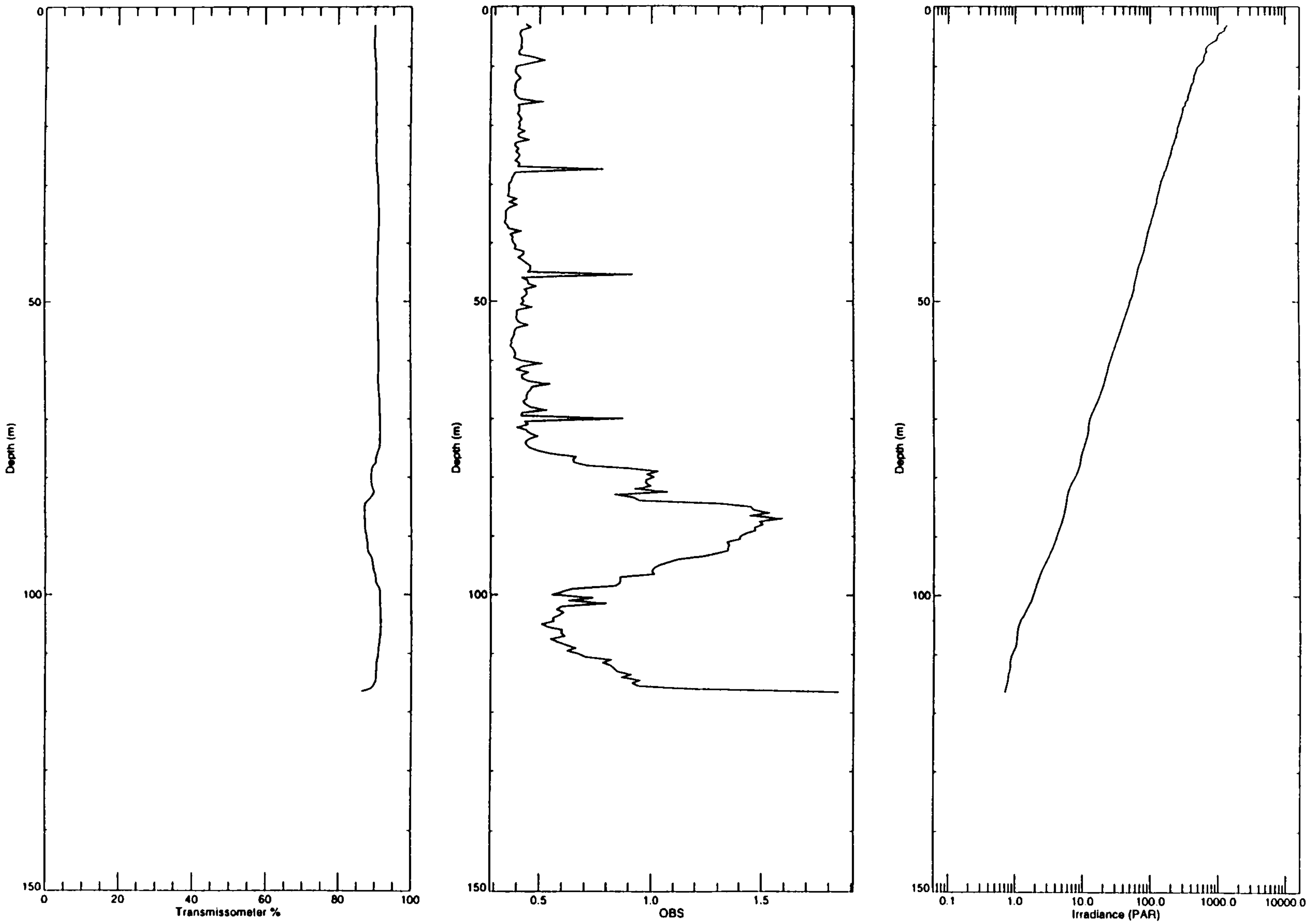


GERG at Texas A&M University
Tue Jun 17 11:23:13 1997

Station: H4B2

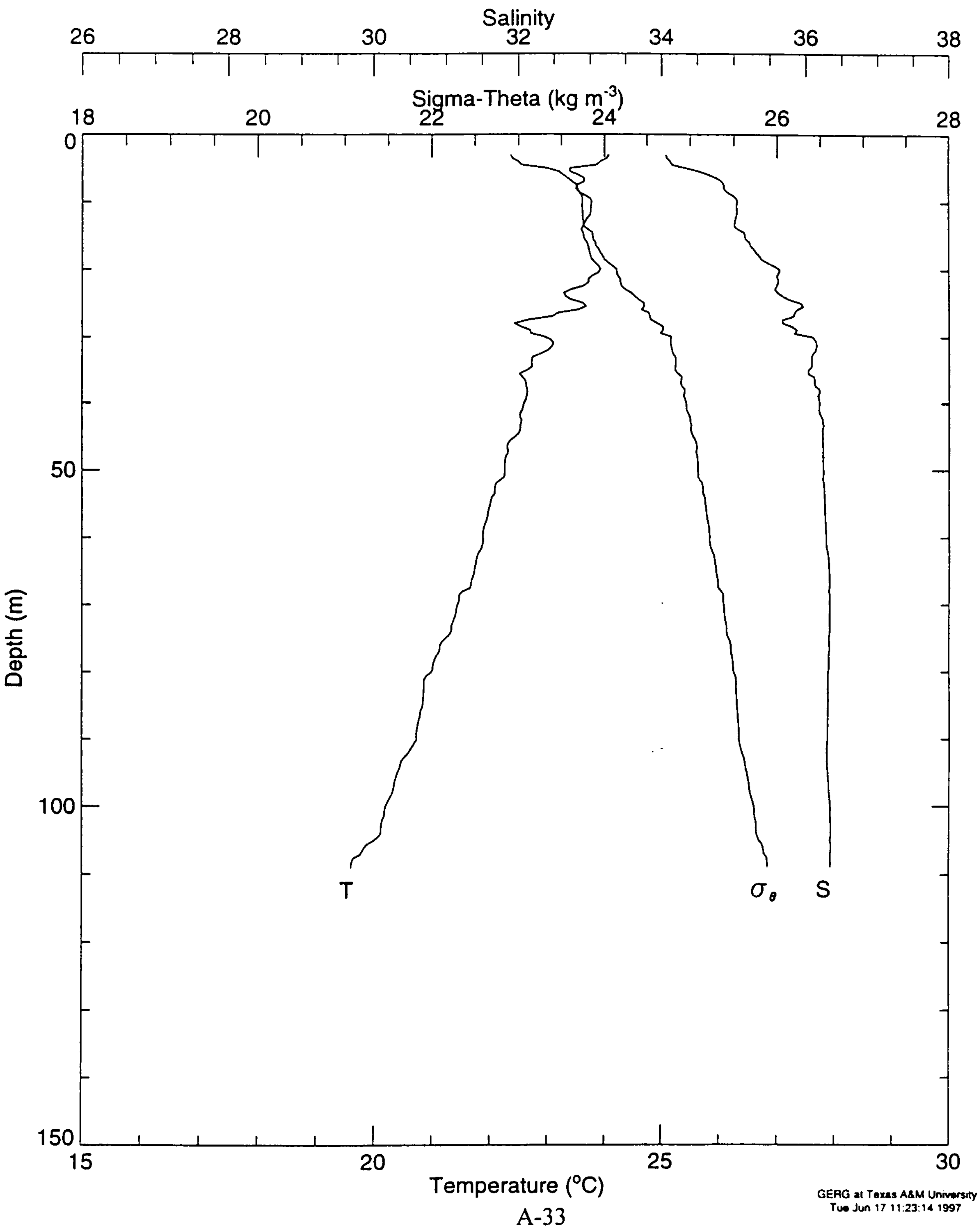


Station: H4B2

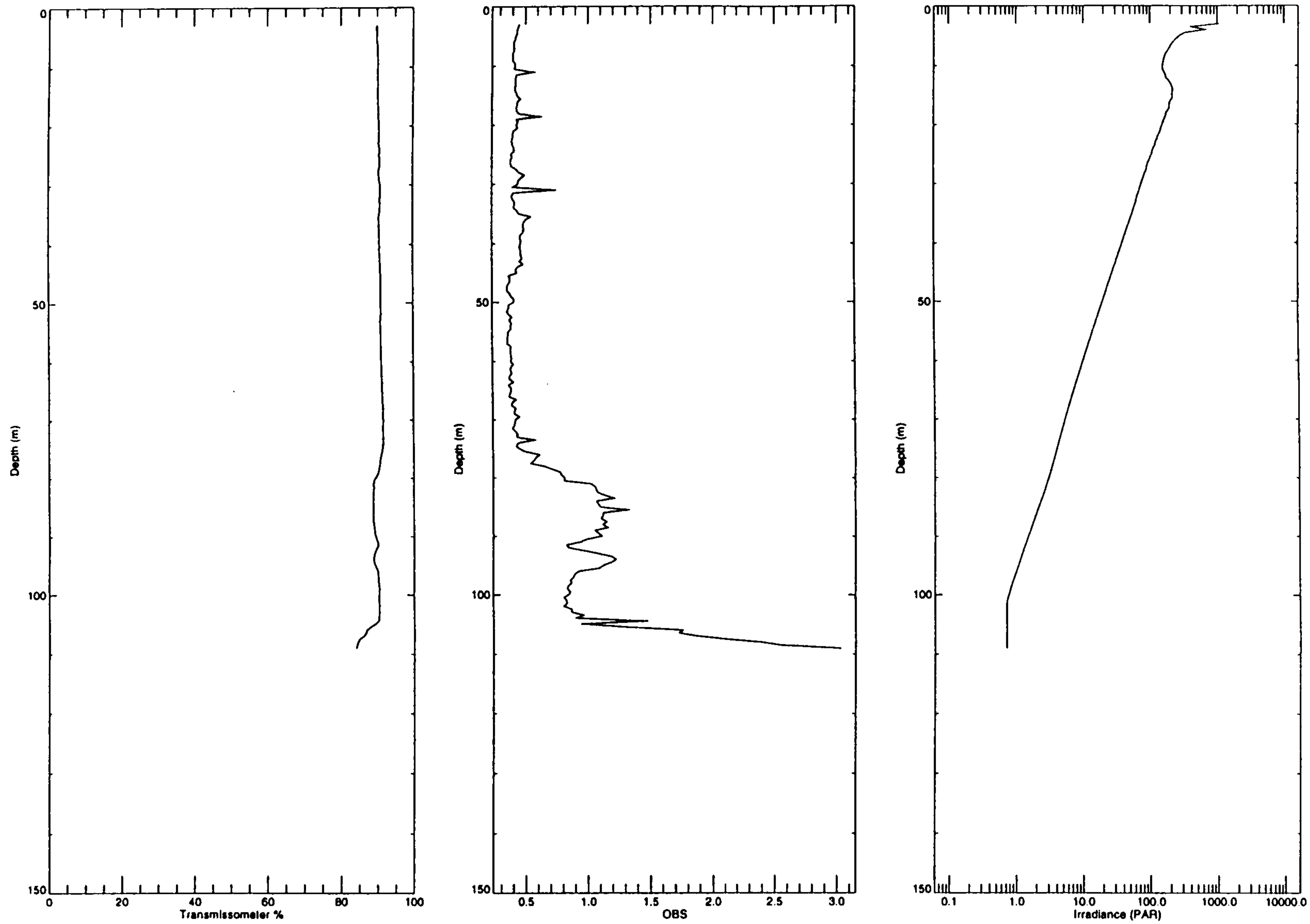


GERG at Texas A&M University
Tue Jun 17 11:23:14 1997

Station: H4C1

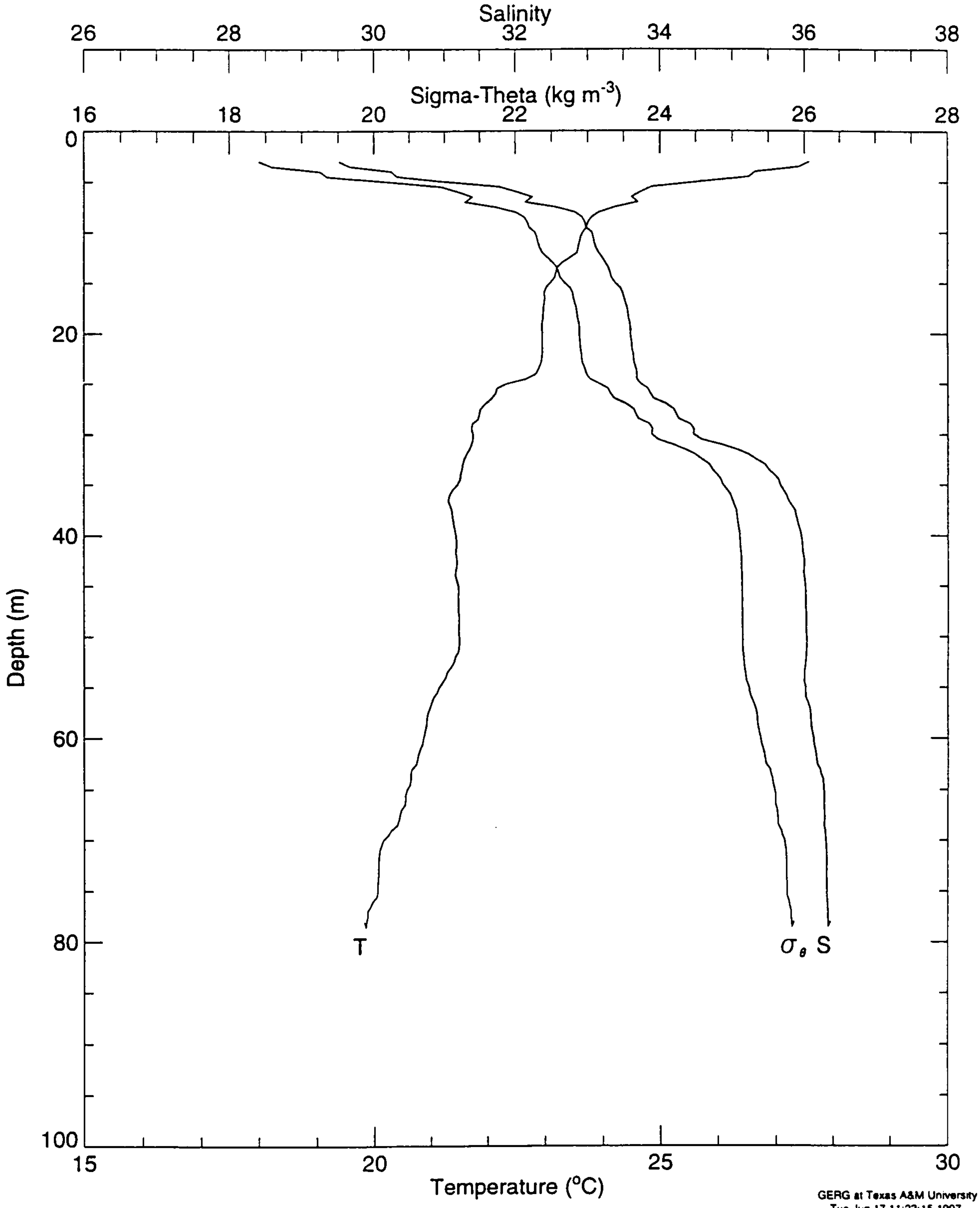


Station: H4C1

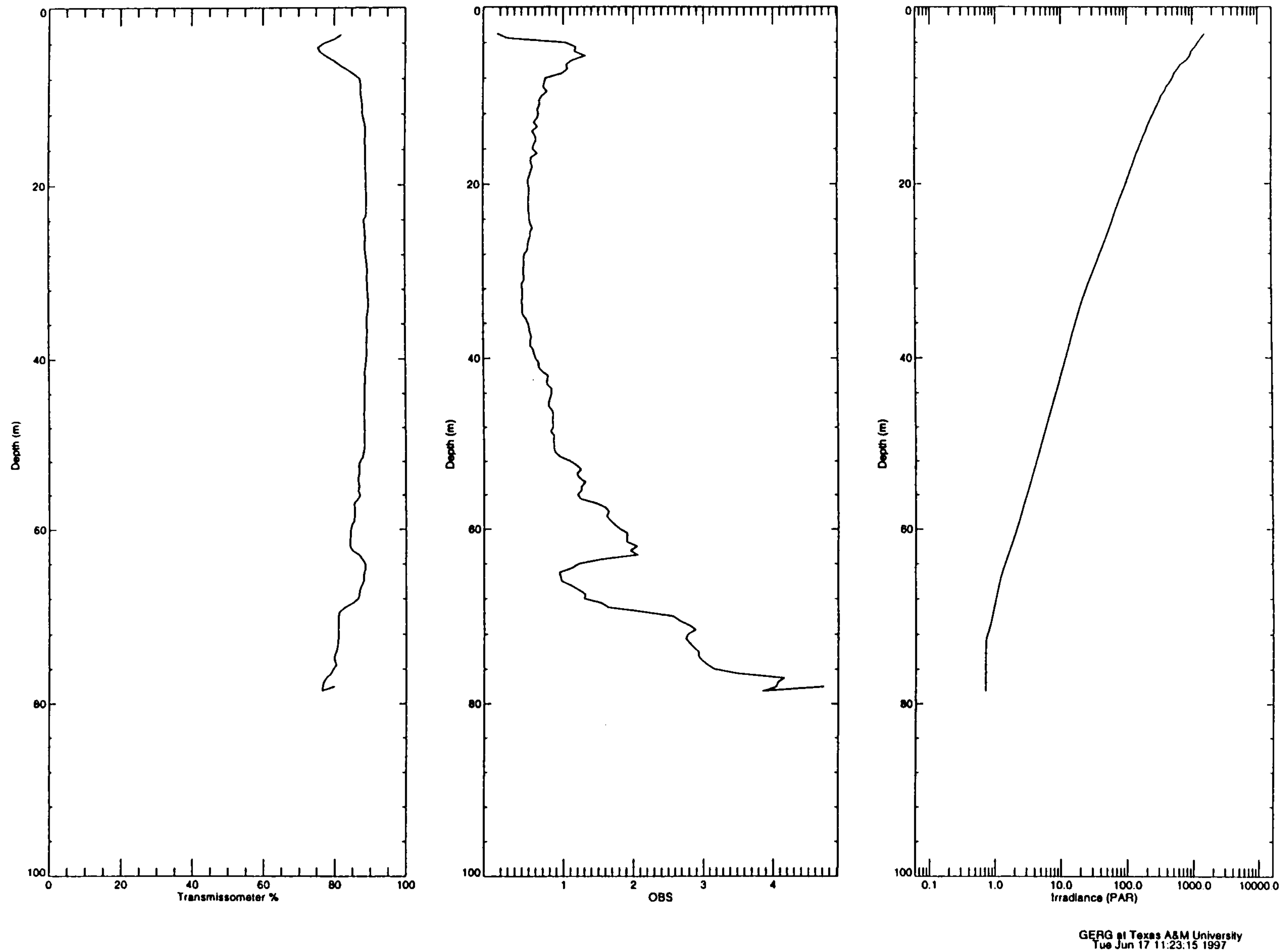


GERG at Texas A&M University
Tue Jun 17 11:23:14 1997

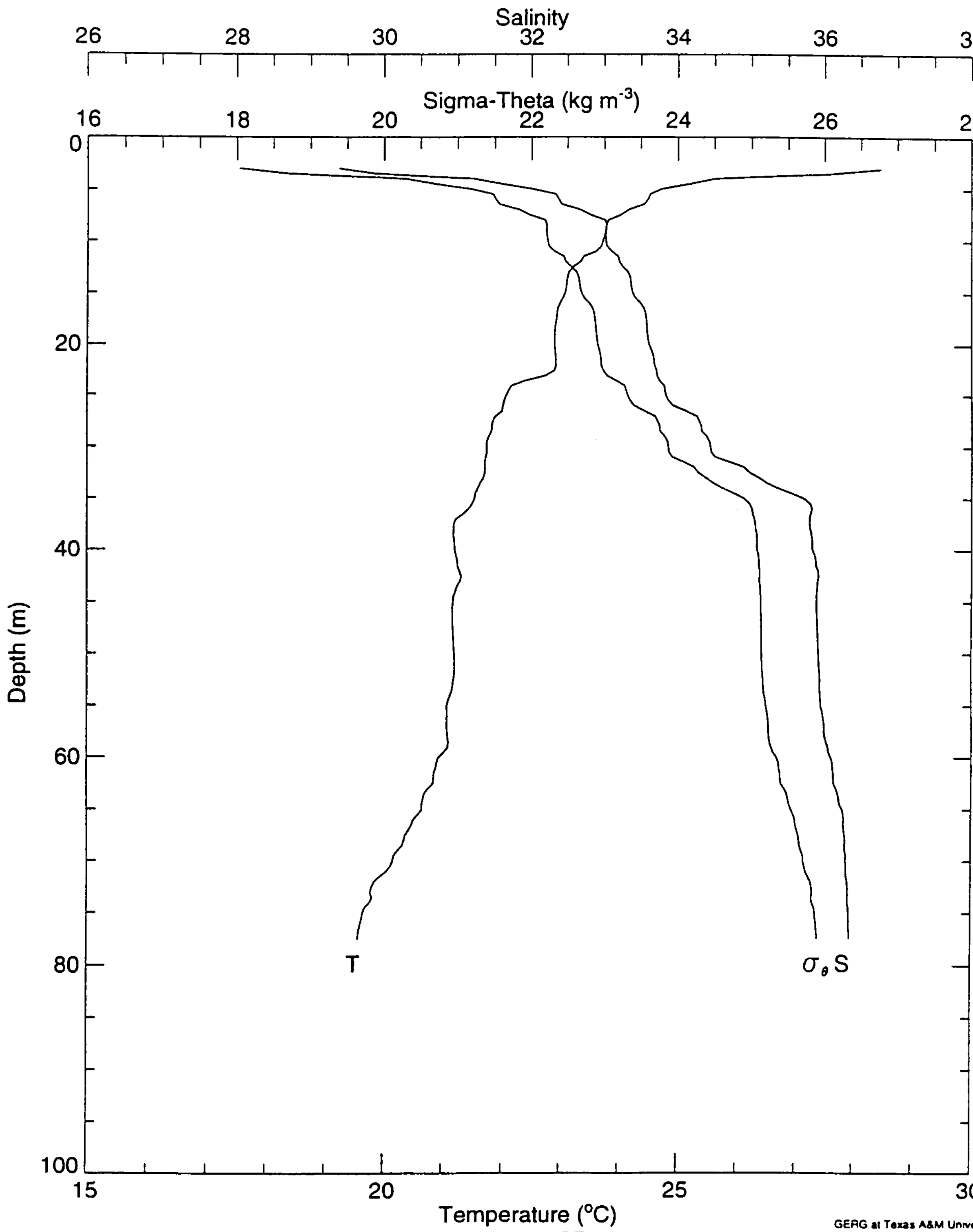
Station: H5A1



Station: H5A1

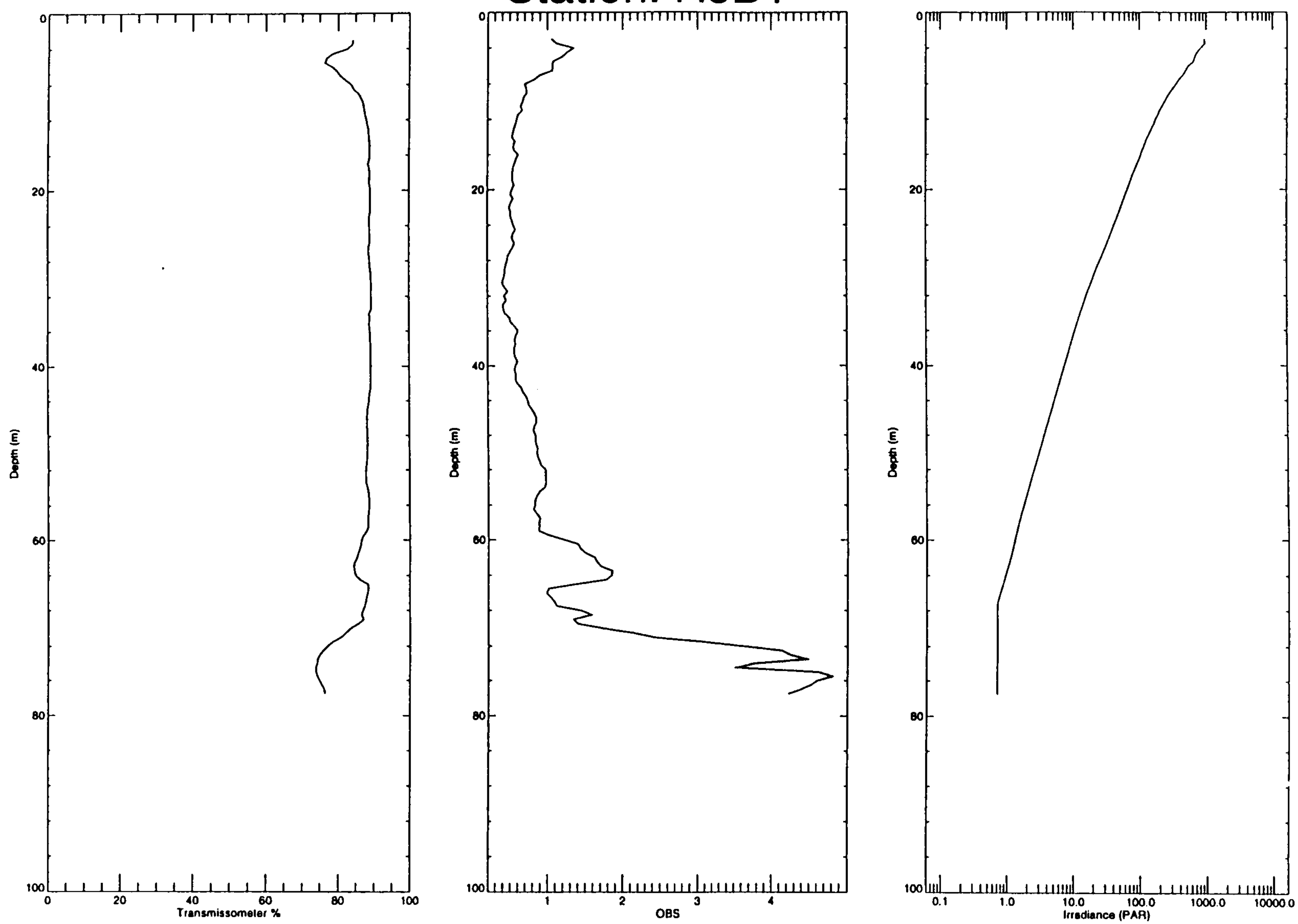


Station: H5B1



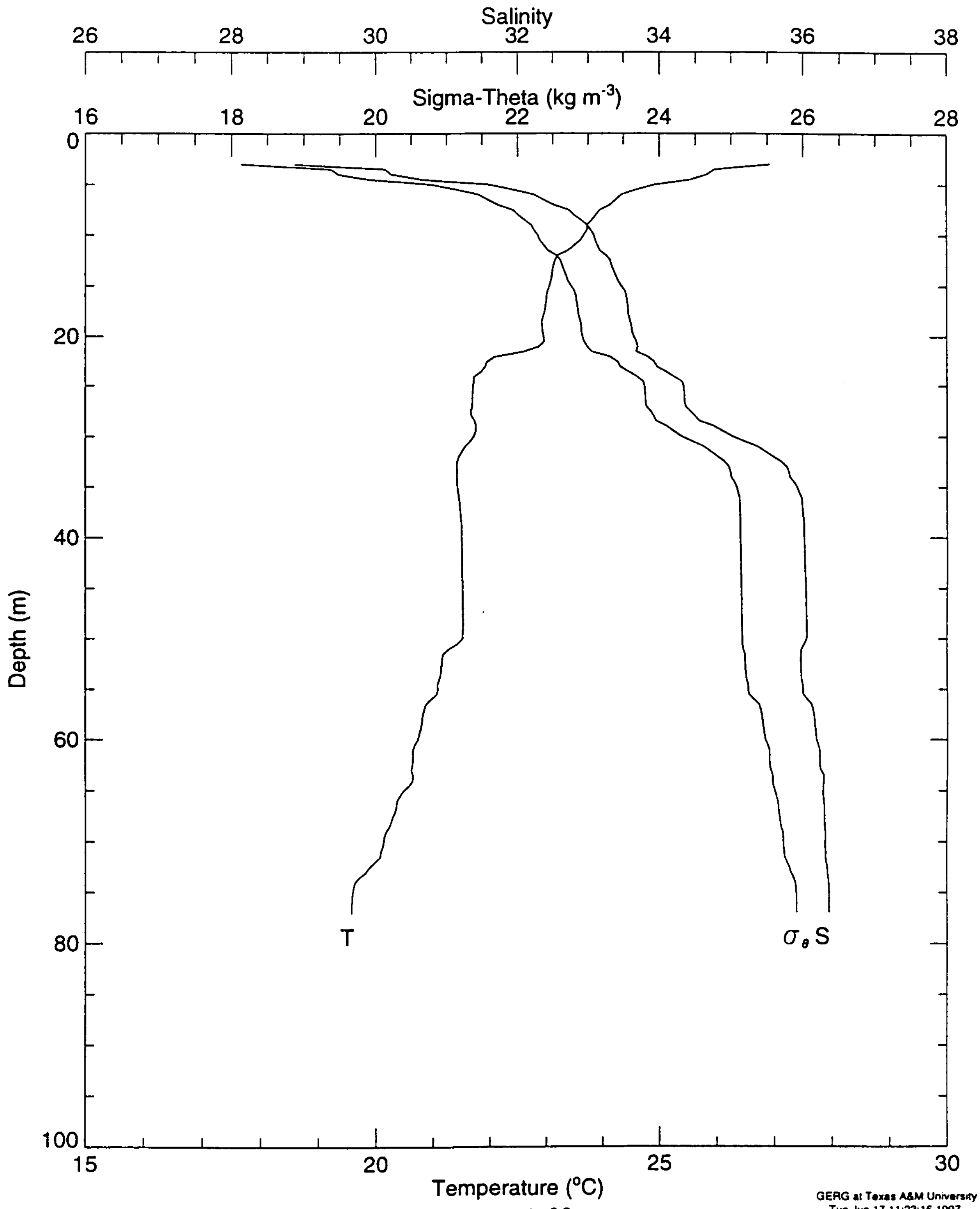
GERG at Texas A&M University
Tue Jun 17 11:23:15 1997

Station: H5B1



GERG at Texas A&M University
Tue Jun 17 11:23:15 1997

Station: H5C1



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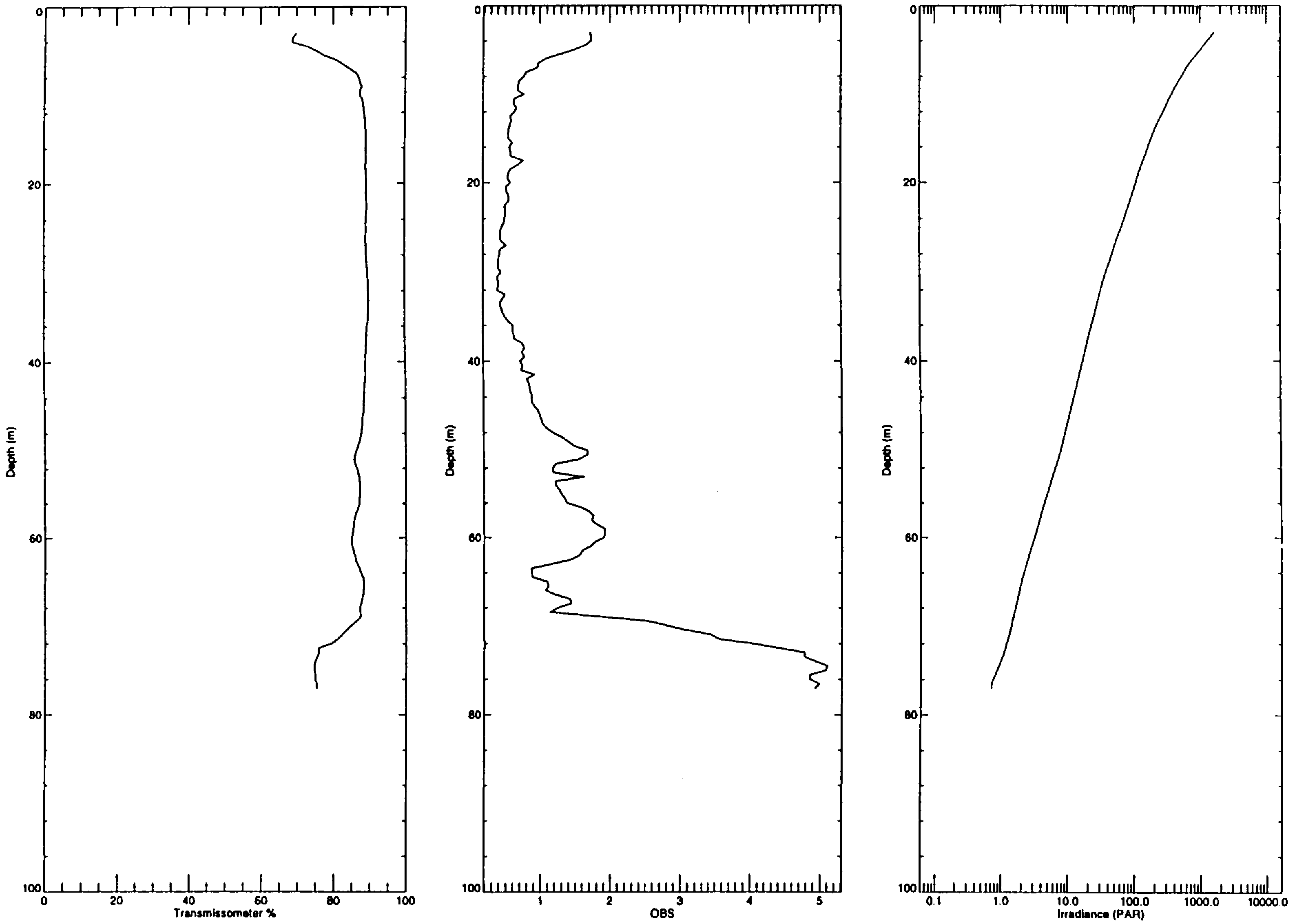
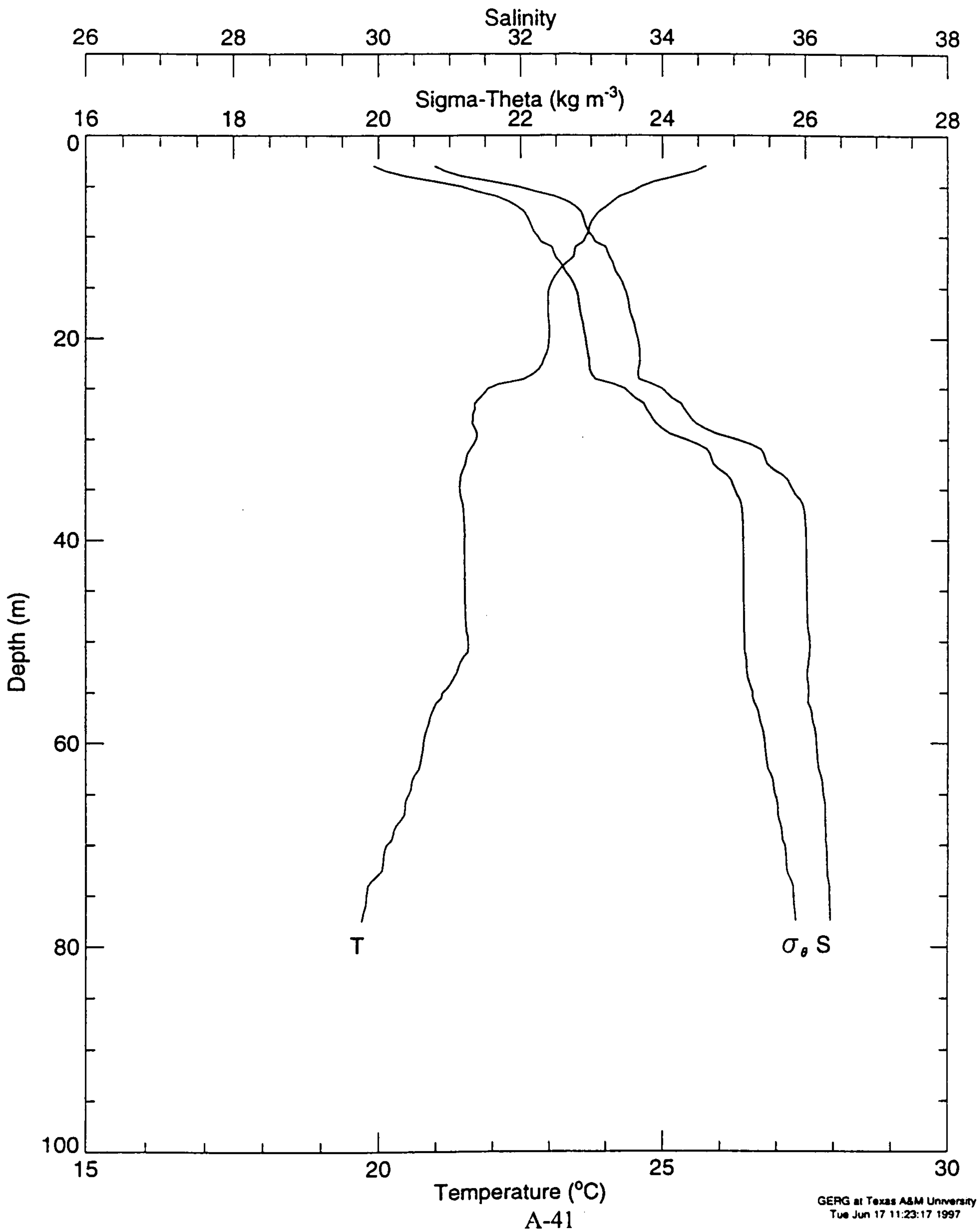
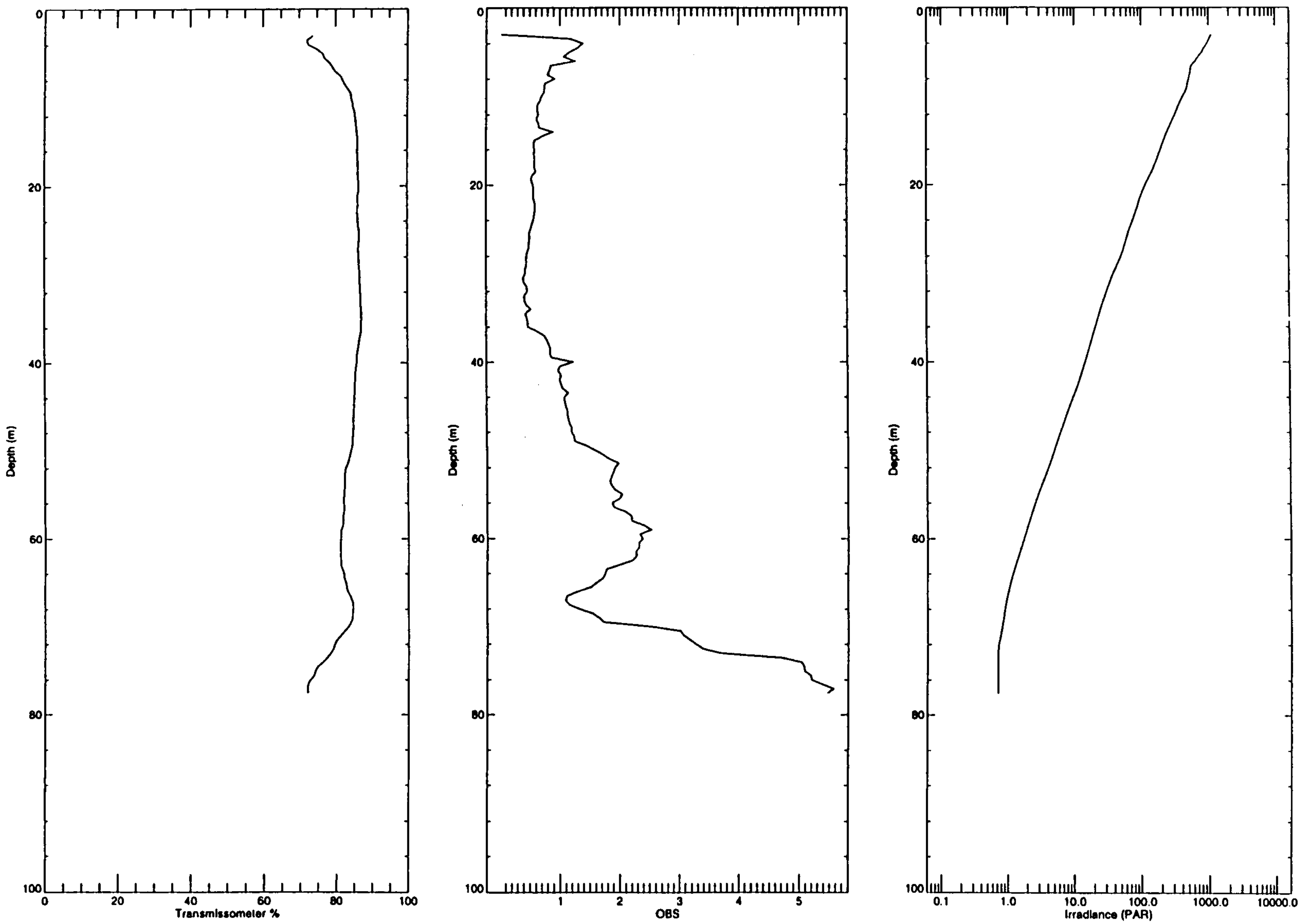


GERG at Texas A&M University
Tue Jun 17 11:23:16 1997

Station: H6A1

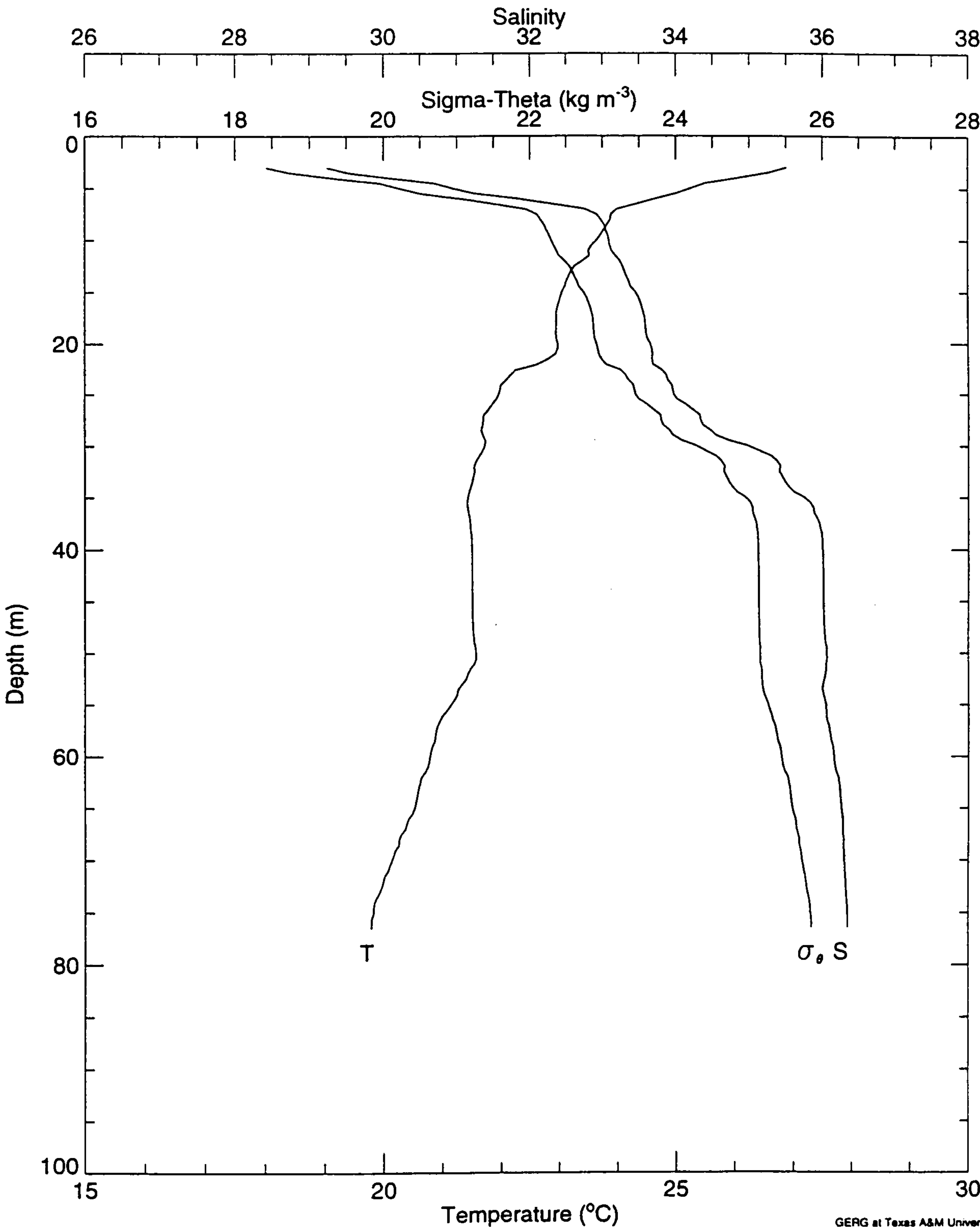


Station: H6A1



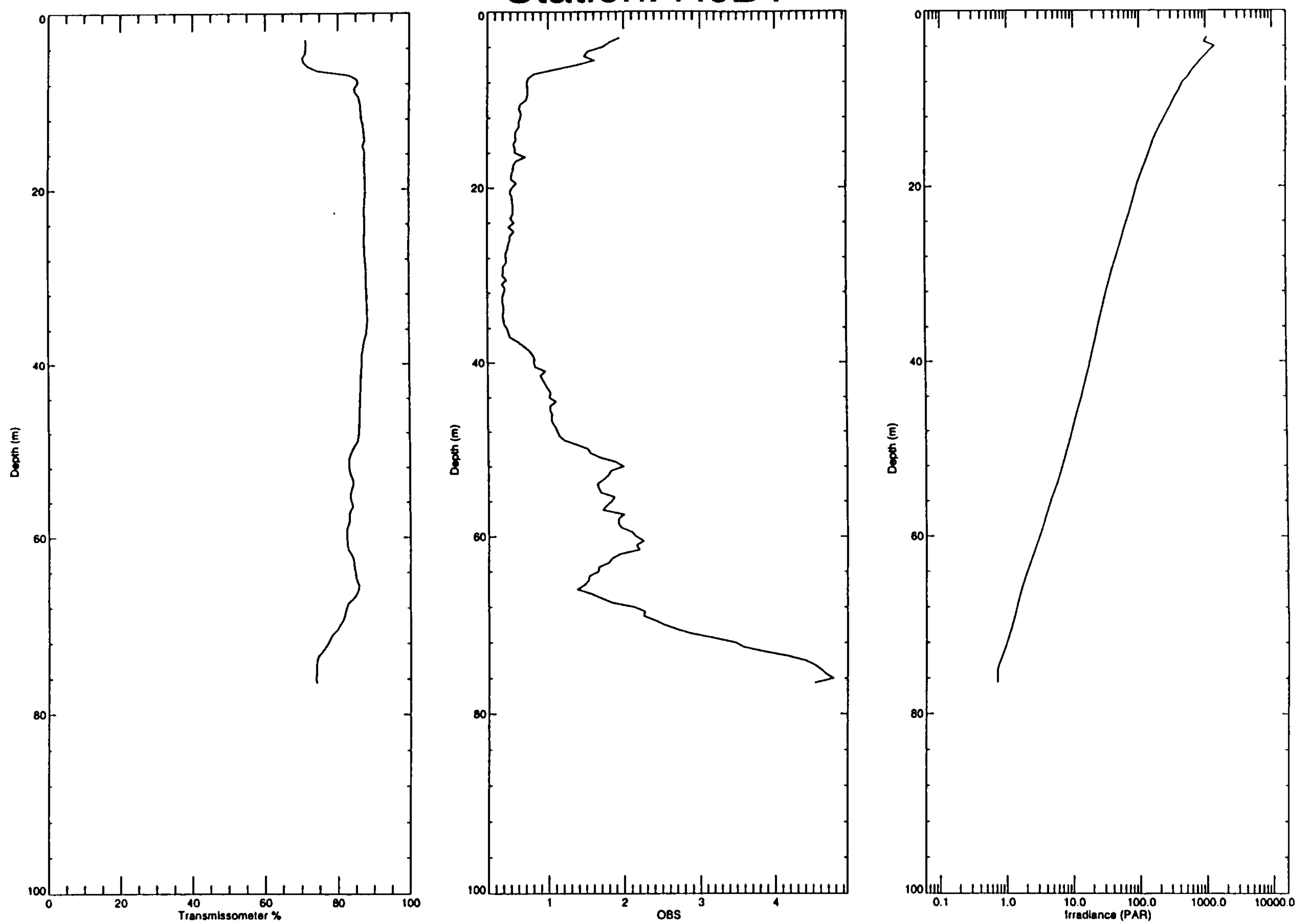
GERG at Texas A&M University
Tue Jun 17 11:23:17 1997

Station: H6B1



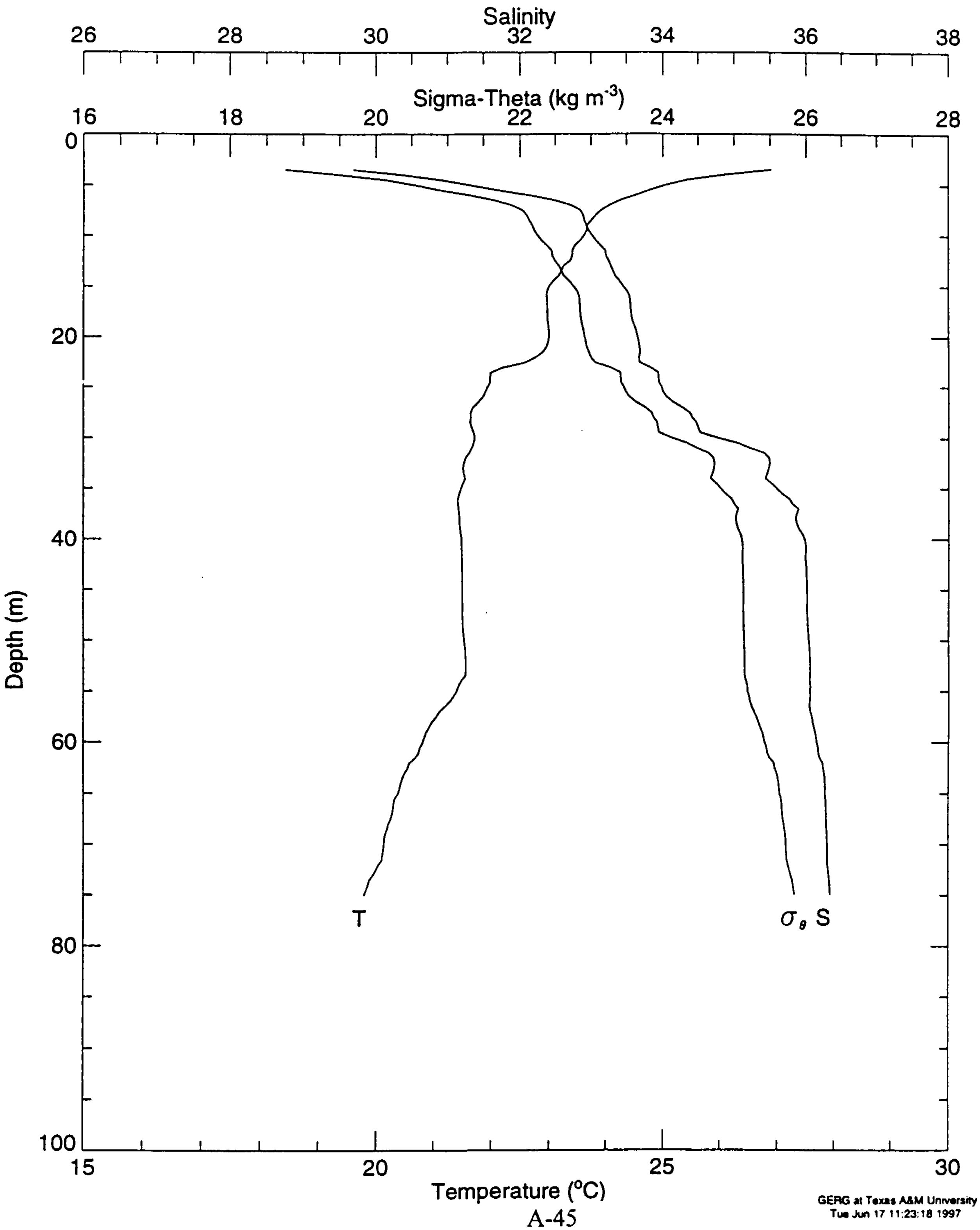
GERG at Texas A&M University
Tue Jun 17 11:23:17 1997

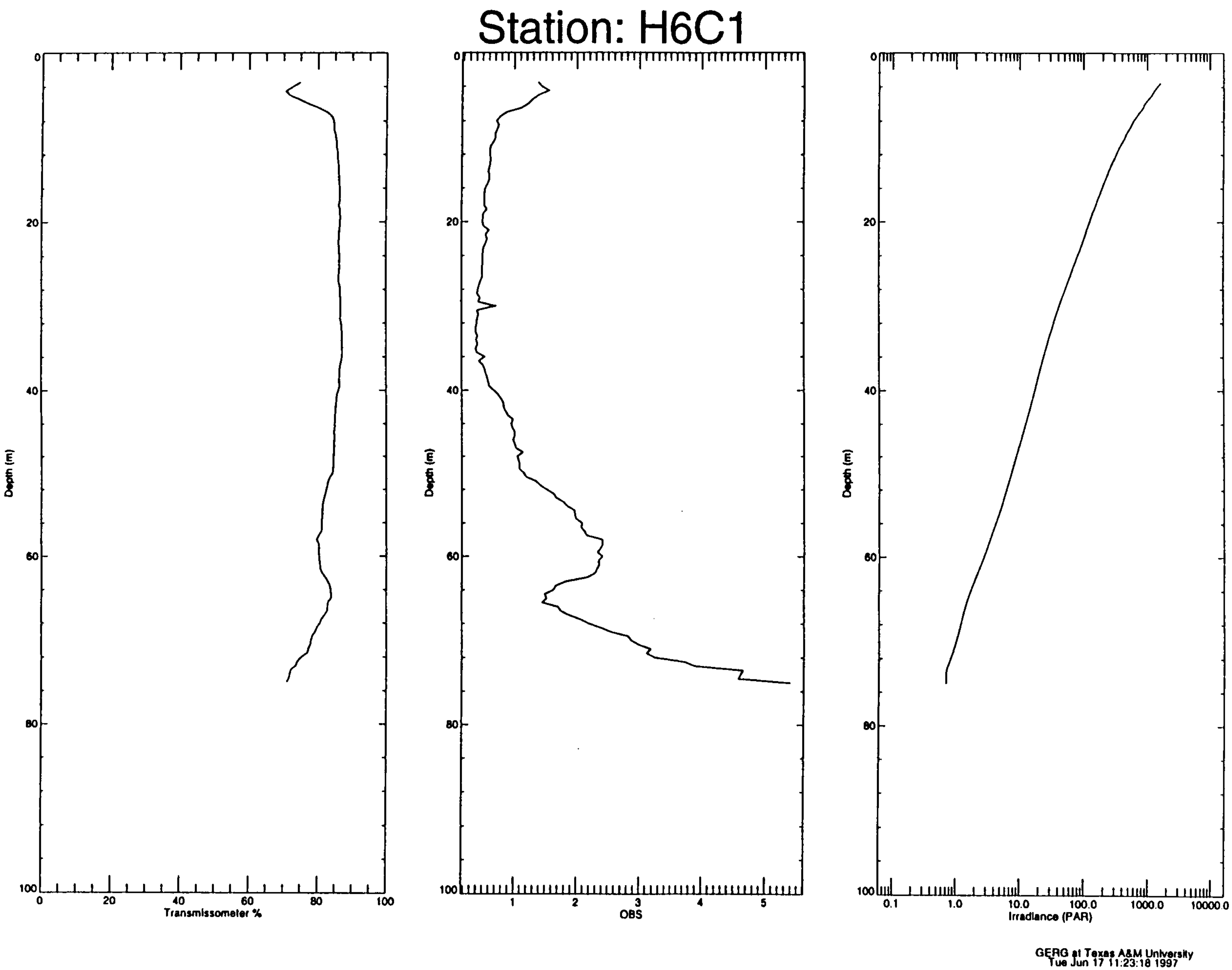
Station: H6B1



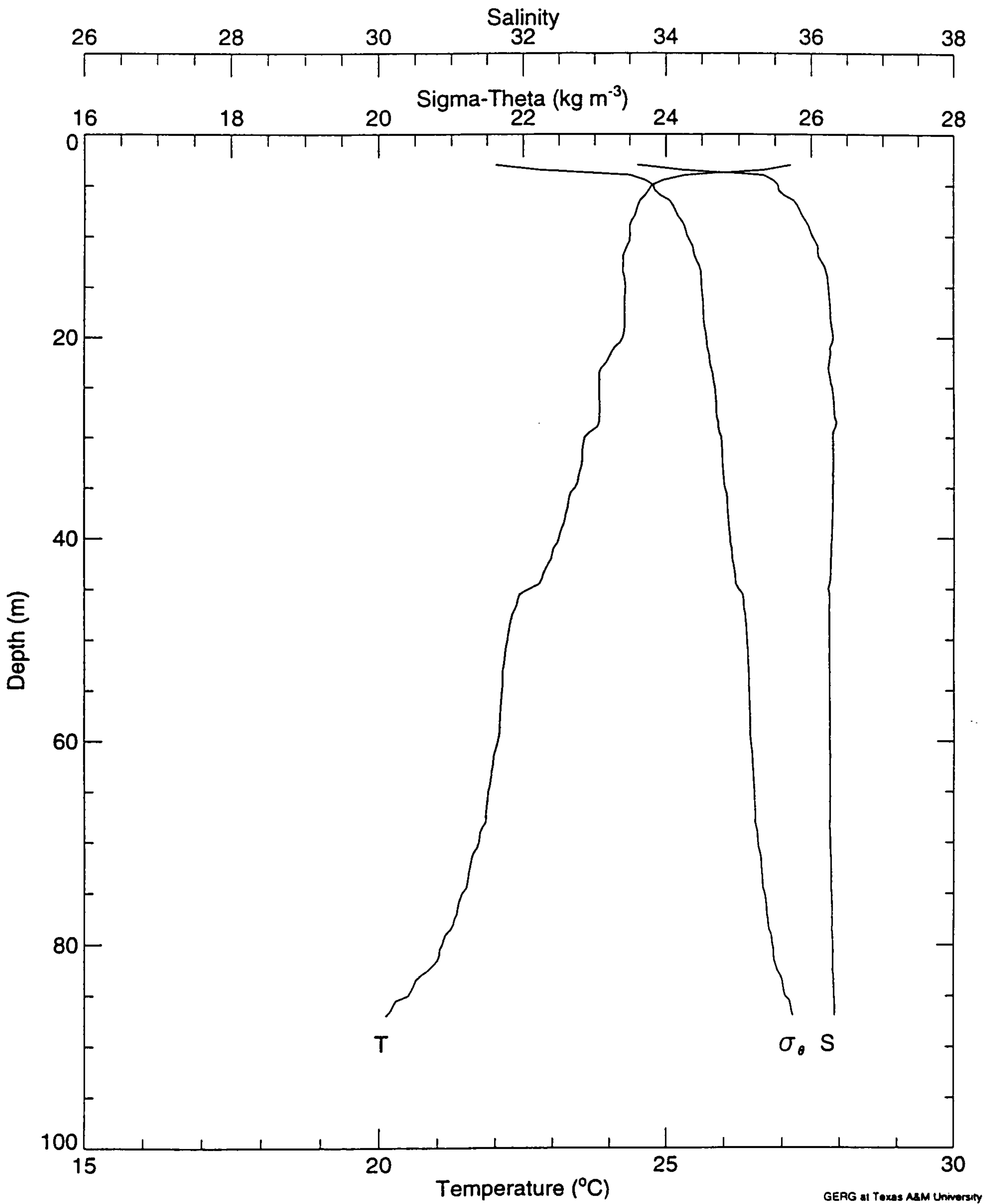
GERG at Texas A&M University
Tue Jun 17 11:23:17 1997

Station: H6C1

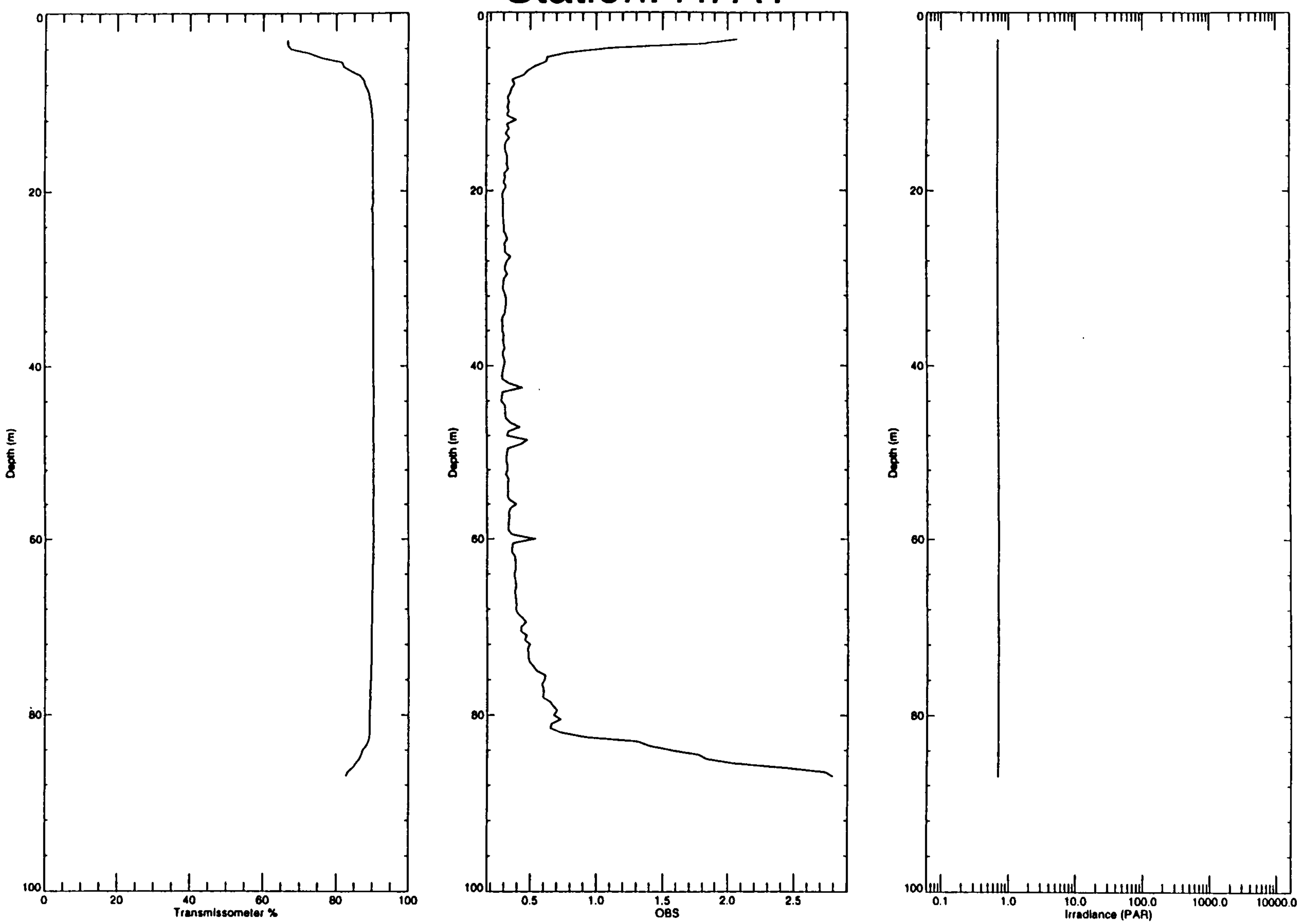



Station: H6C1
Depth (m)
Transmissometer %
OBS
Irradiance (PAR)
GERG at Texas A&M University
Tue Jun 17 11:23:18 1997

Station: H7A1

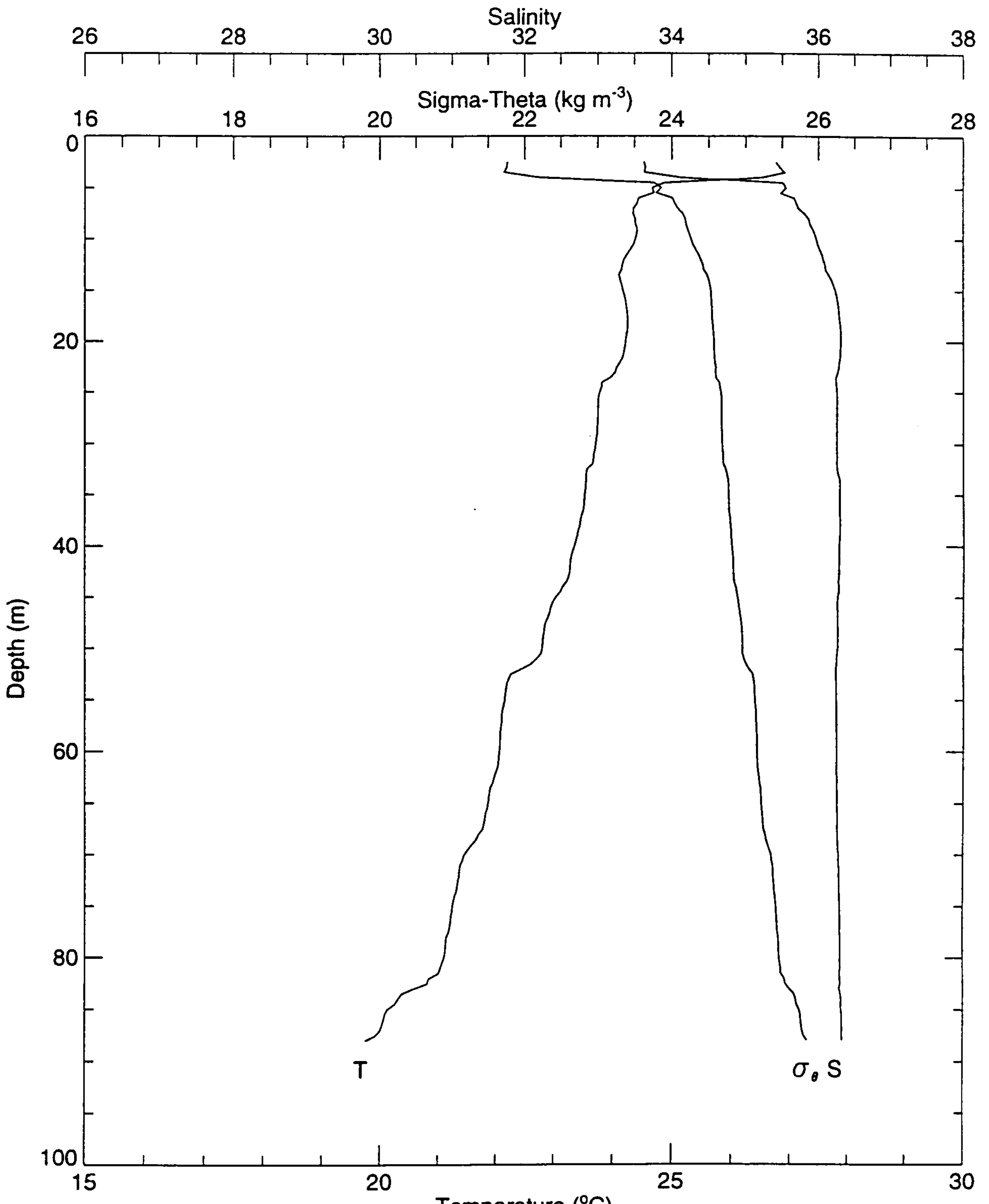


Station: H7A1



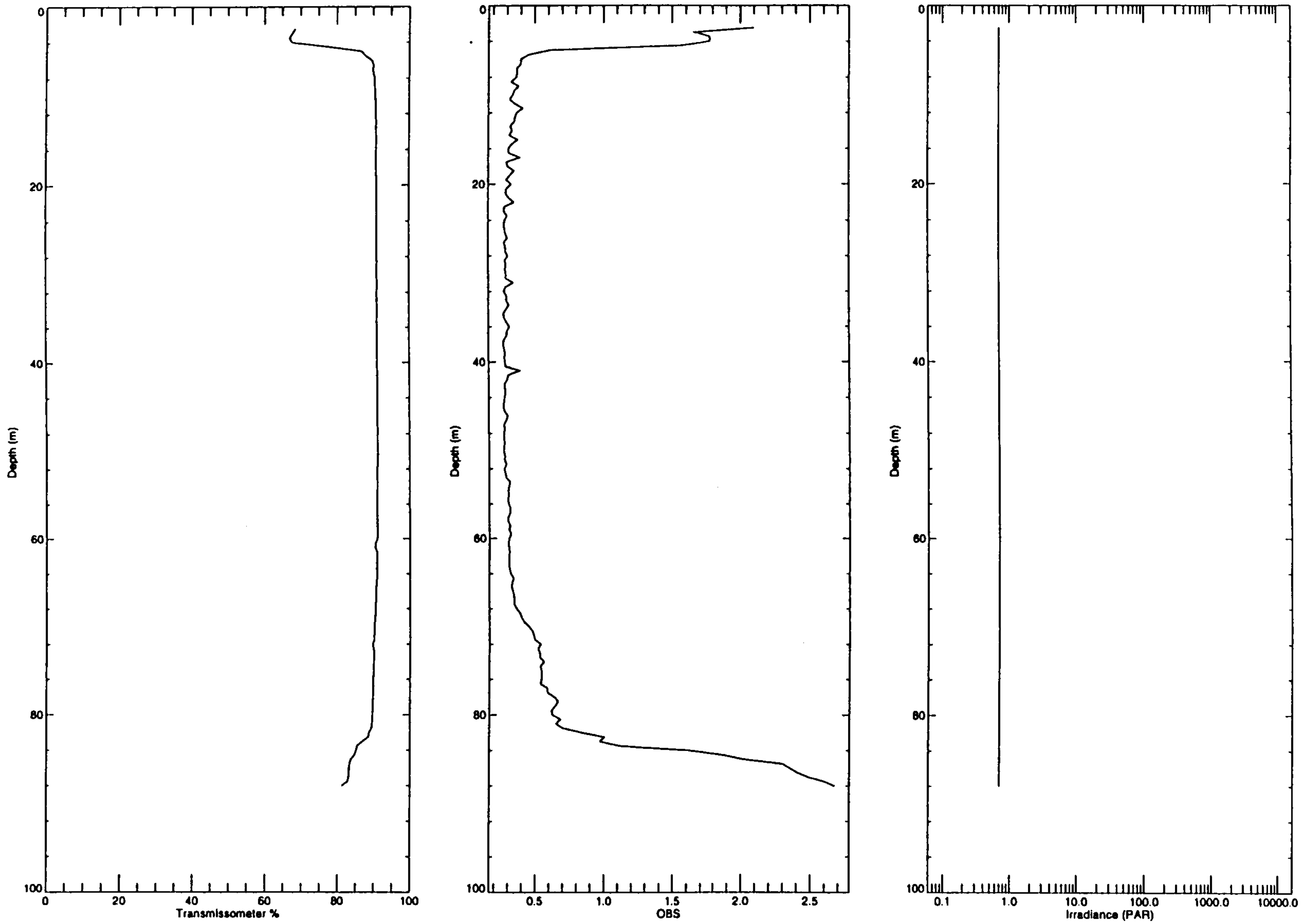
GERG at Texas A&M University
Tue Jun 17 11:23:19 1997

Station: H7A2



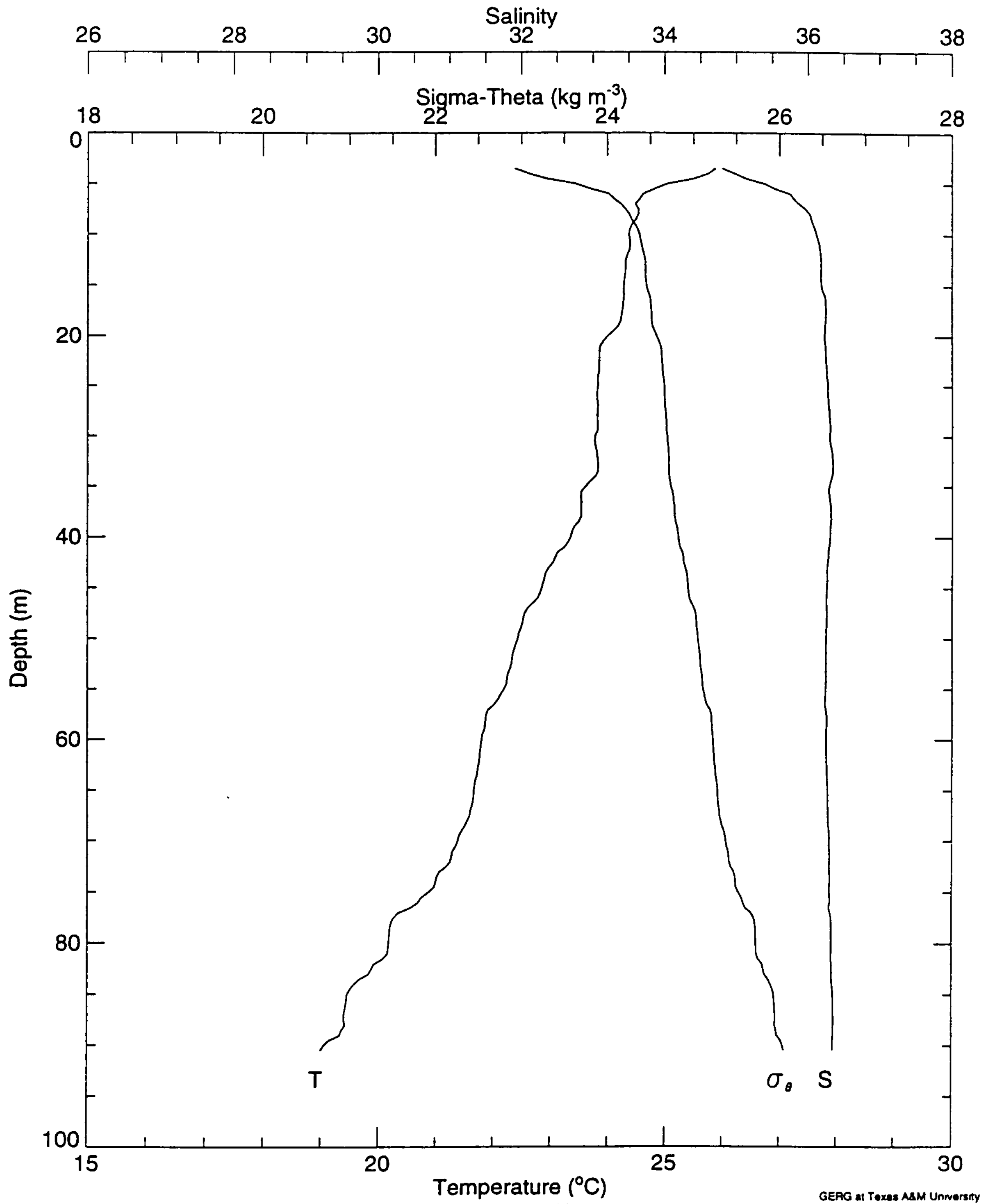
GERG at Texas A&M University
Tue Jun 17 11:23:19 1997

Station: H7A2

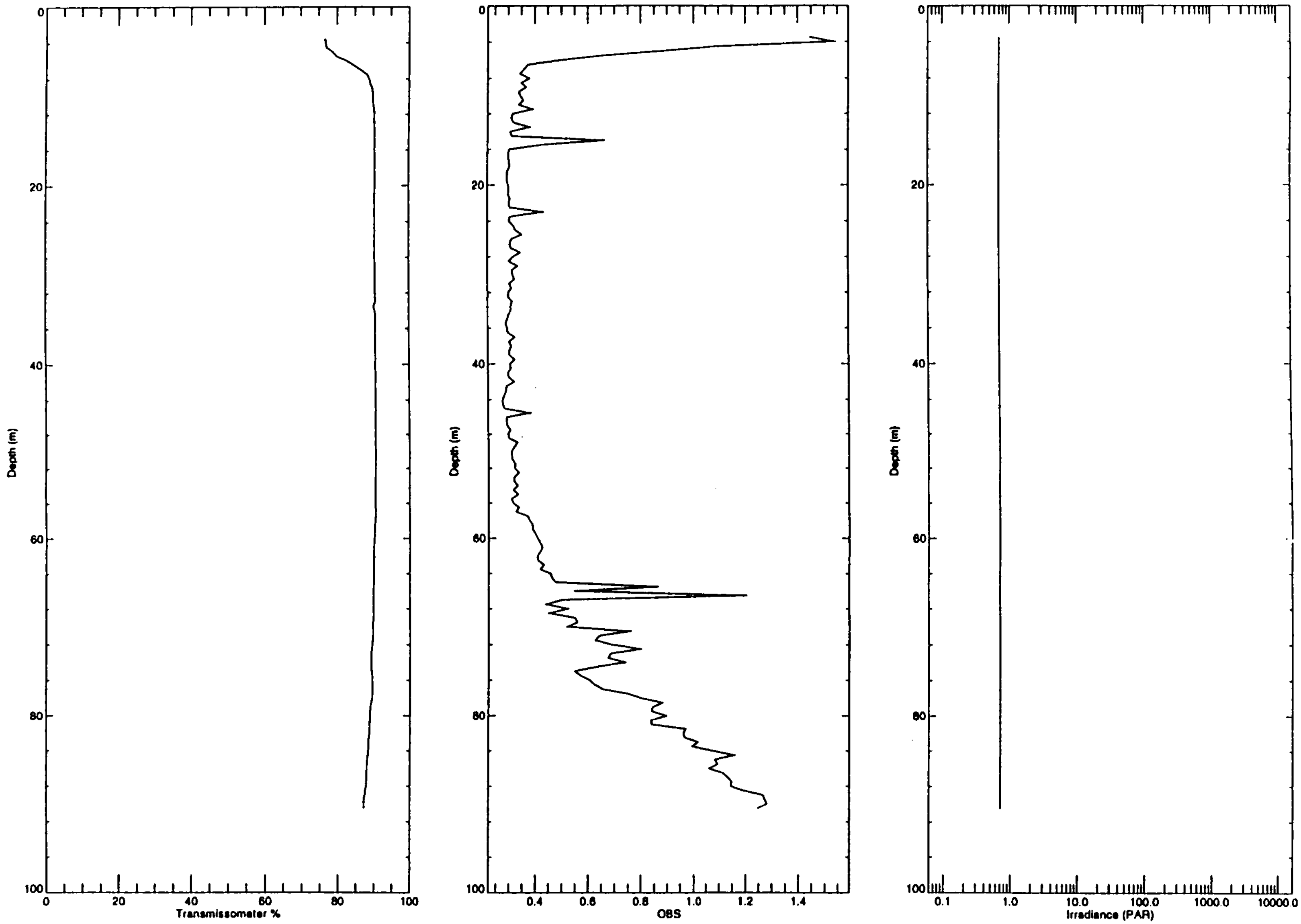


GERG at Texas A&M University
Tue Jun 17 11:23:19 1997

Station: H7B1

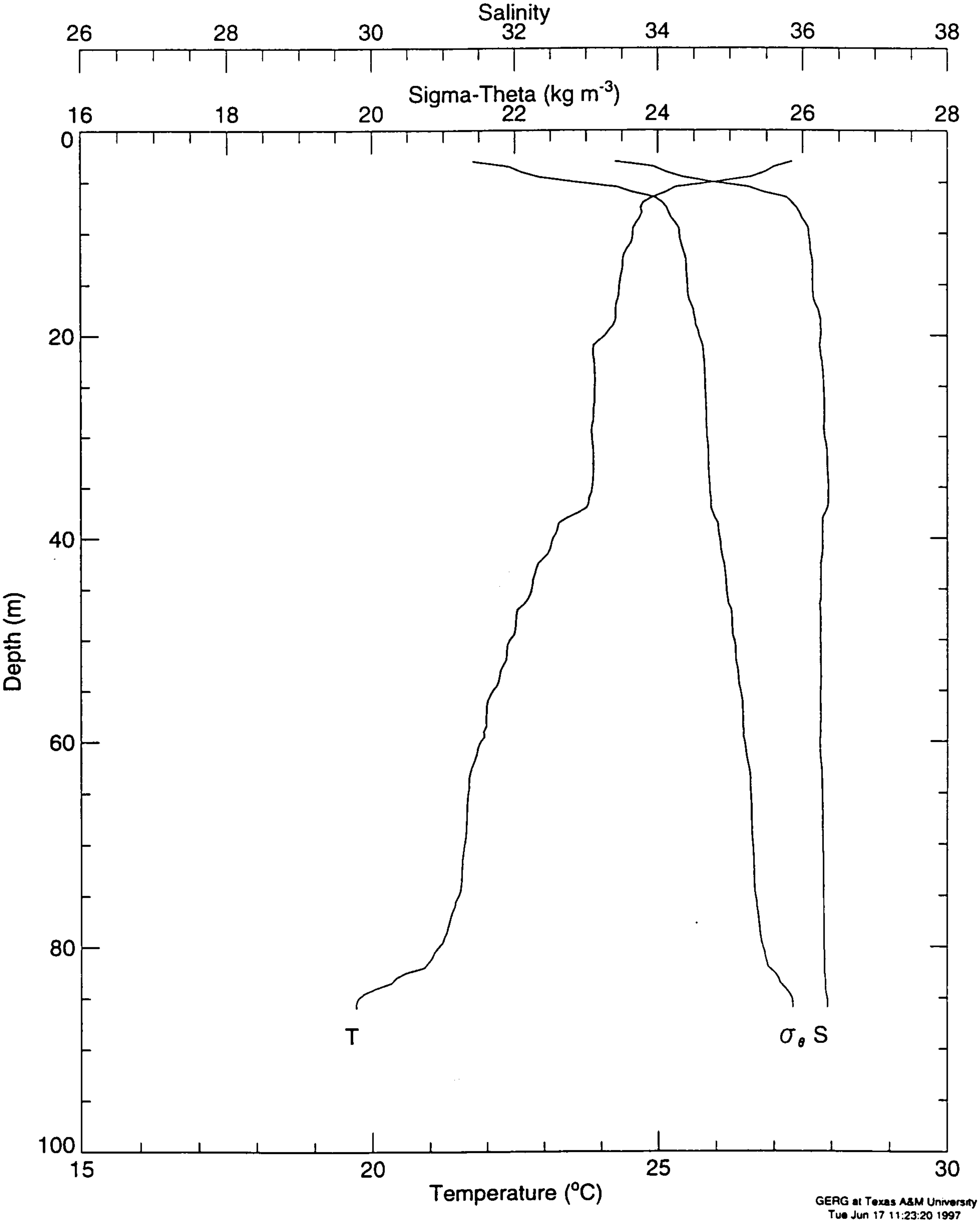


Station: H7B1

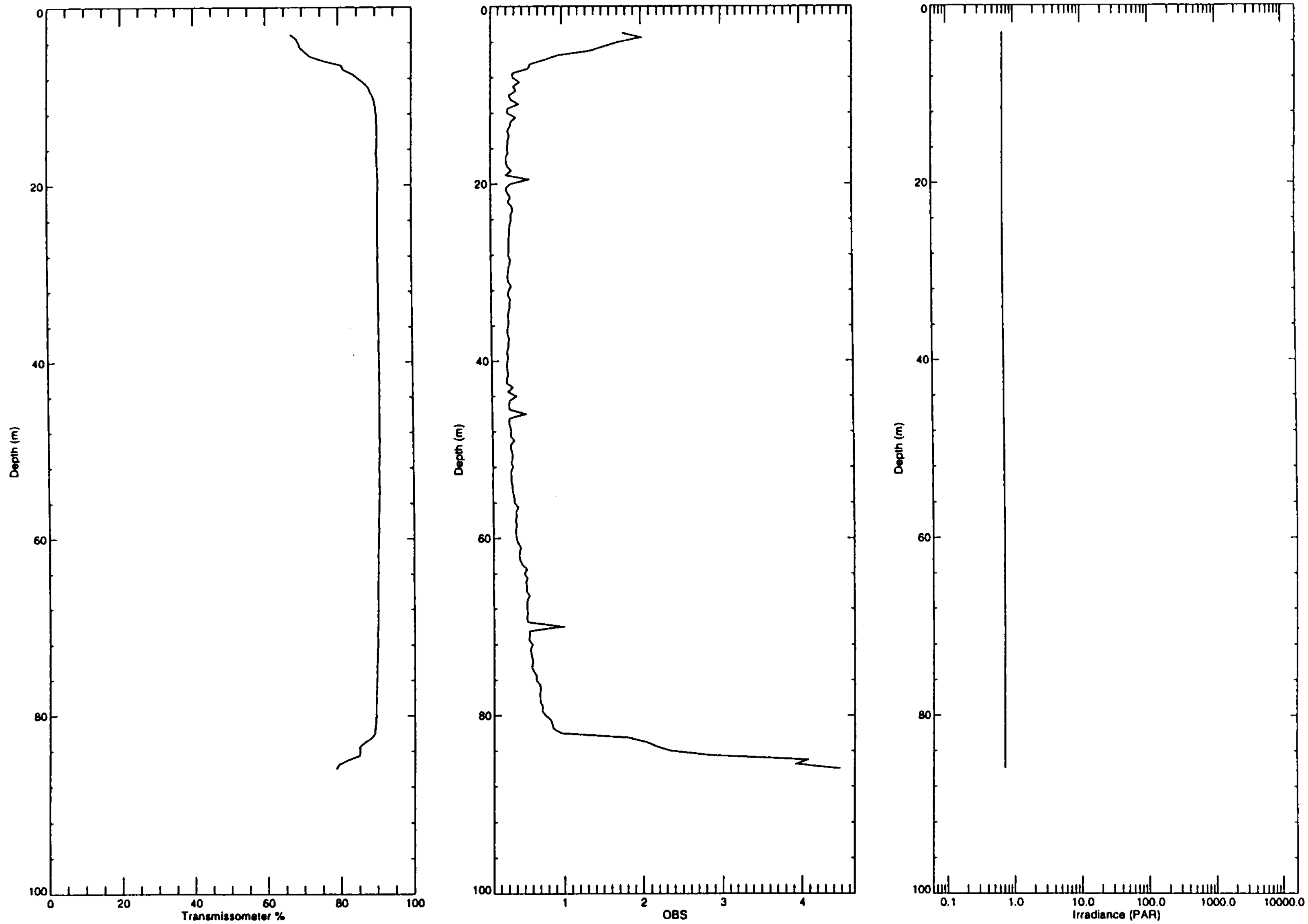


GERG at Texas A&M University
Tue Jun 17 11:23:20 1997

Station: H7C1

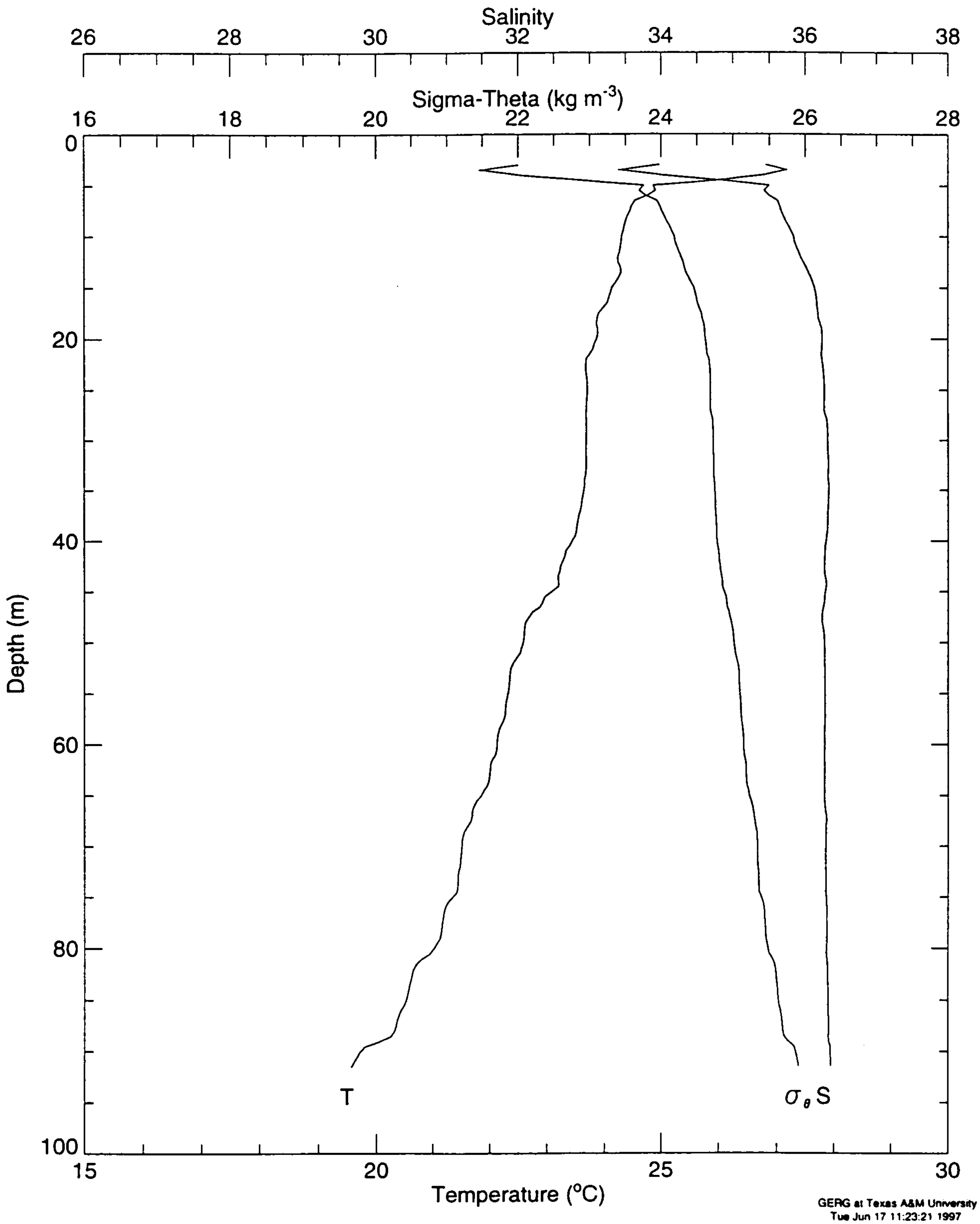


Station: H7C1

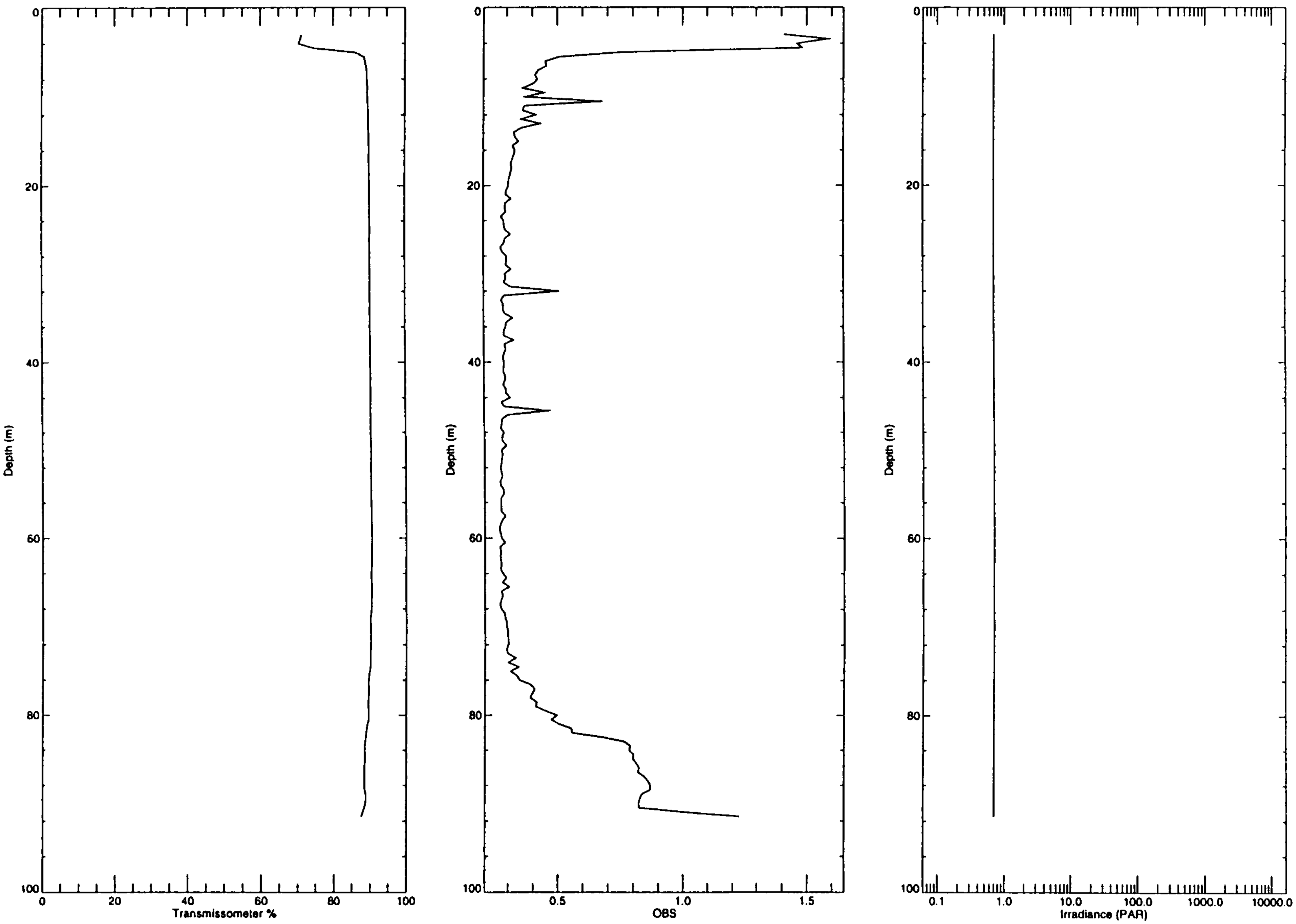


GERG at Texas A&M University
Tue Jun 17 11:23:21 1997

Station: H8A1

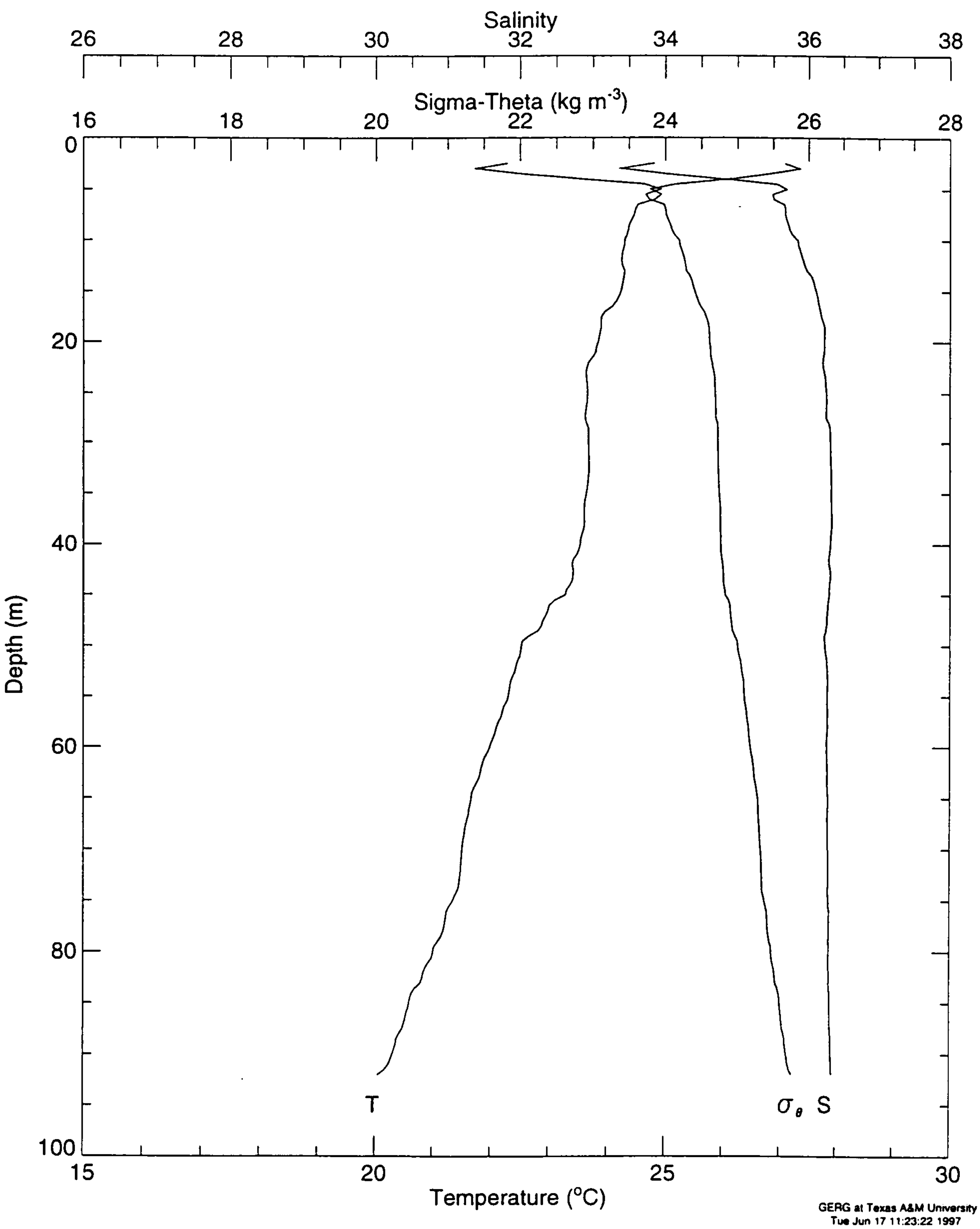


Station: H8A1

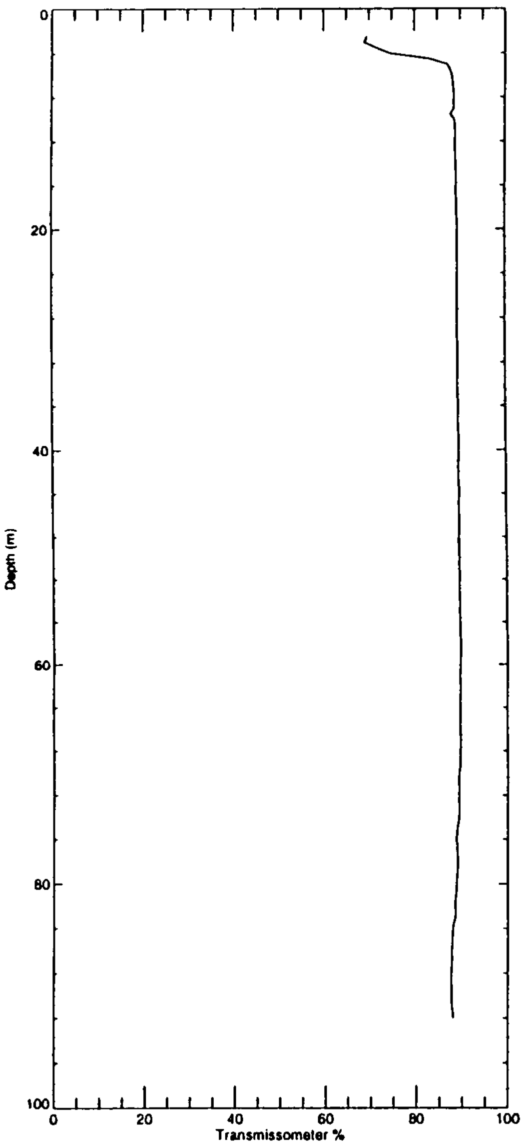


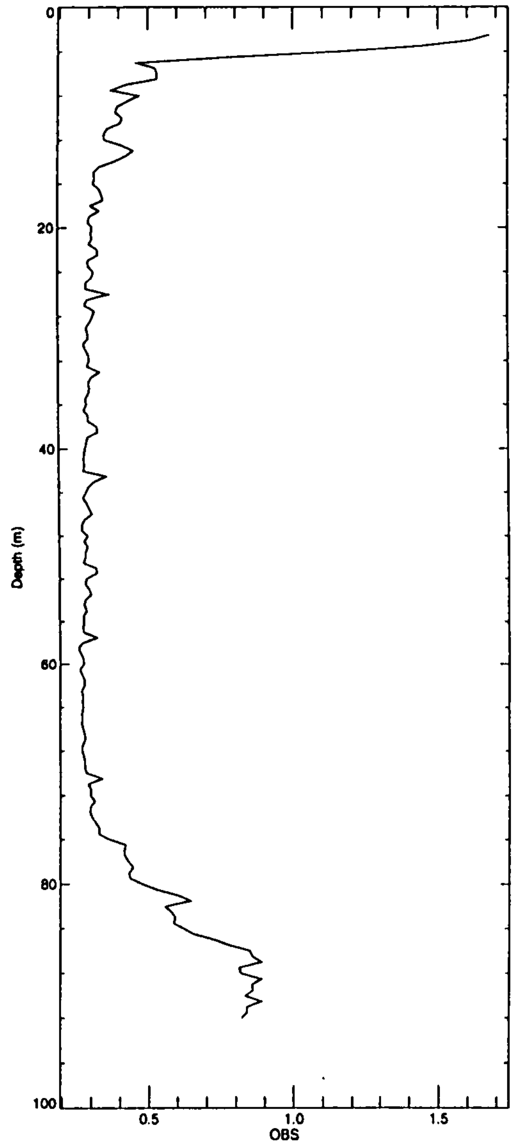
GERG at Texas A&M University
Tue Jun 17 11:23:21 1997

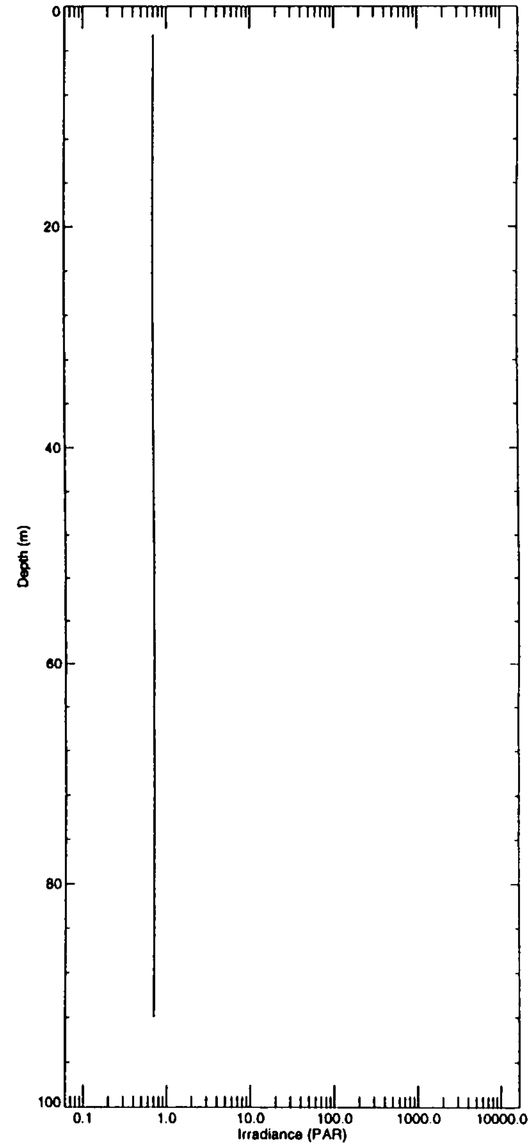
Station: H8B1



Station: H8B1







GERG at Texas A&M University
Tue Jun 17 11:23:22 1997

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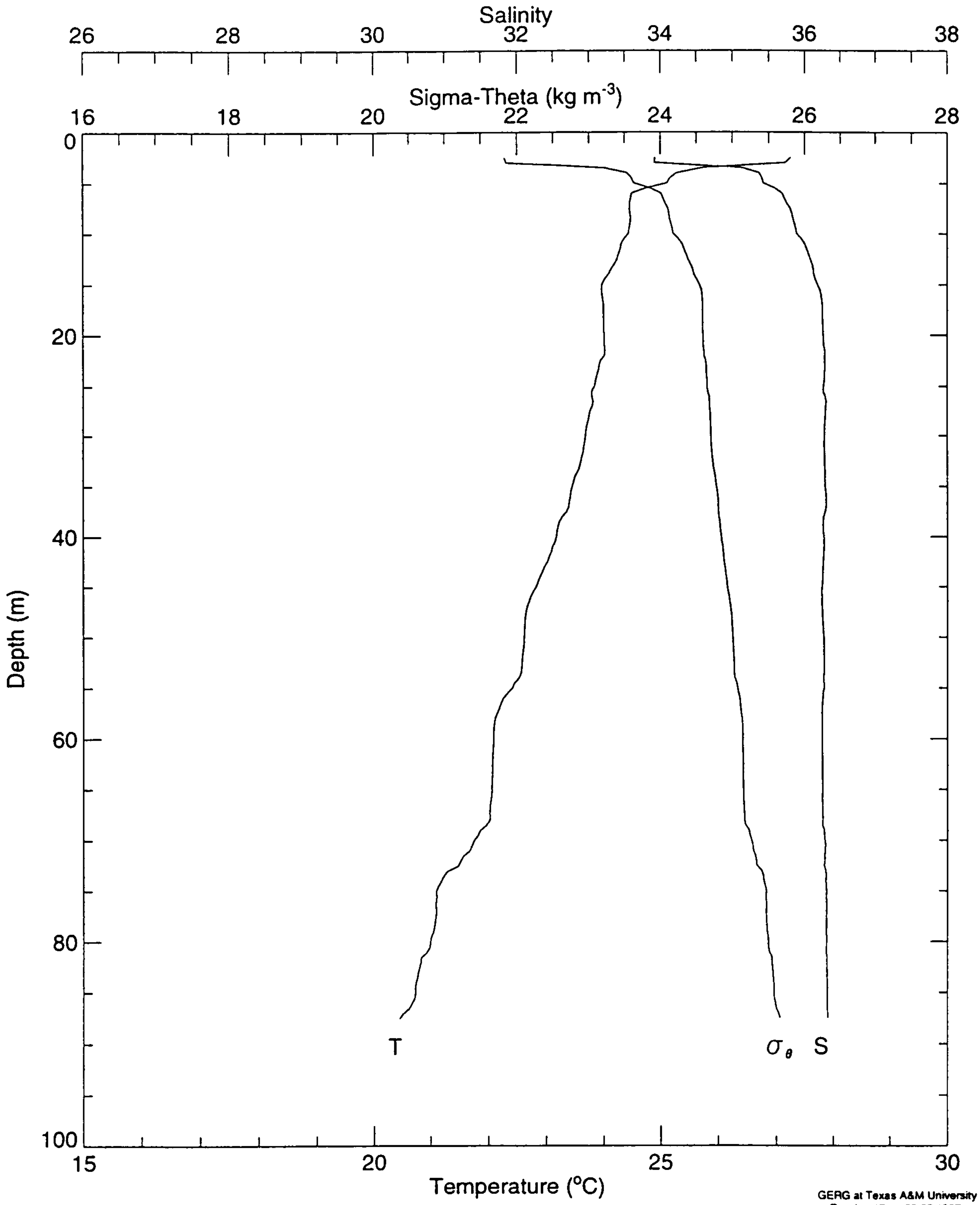

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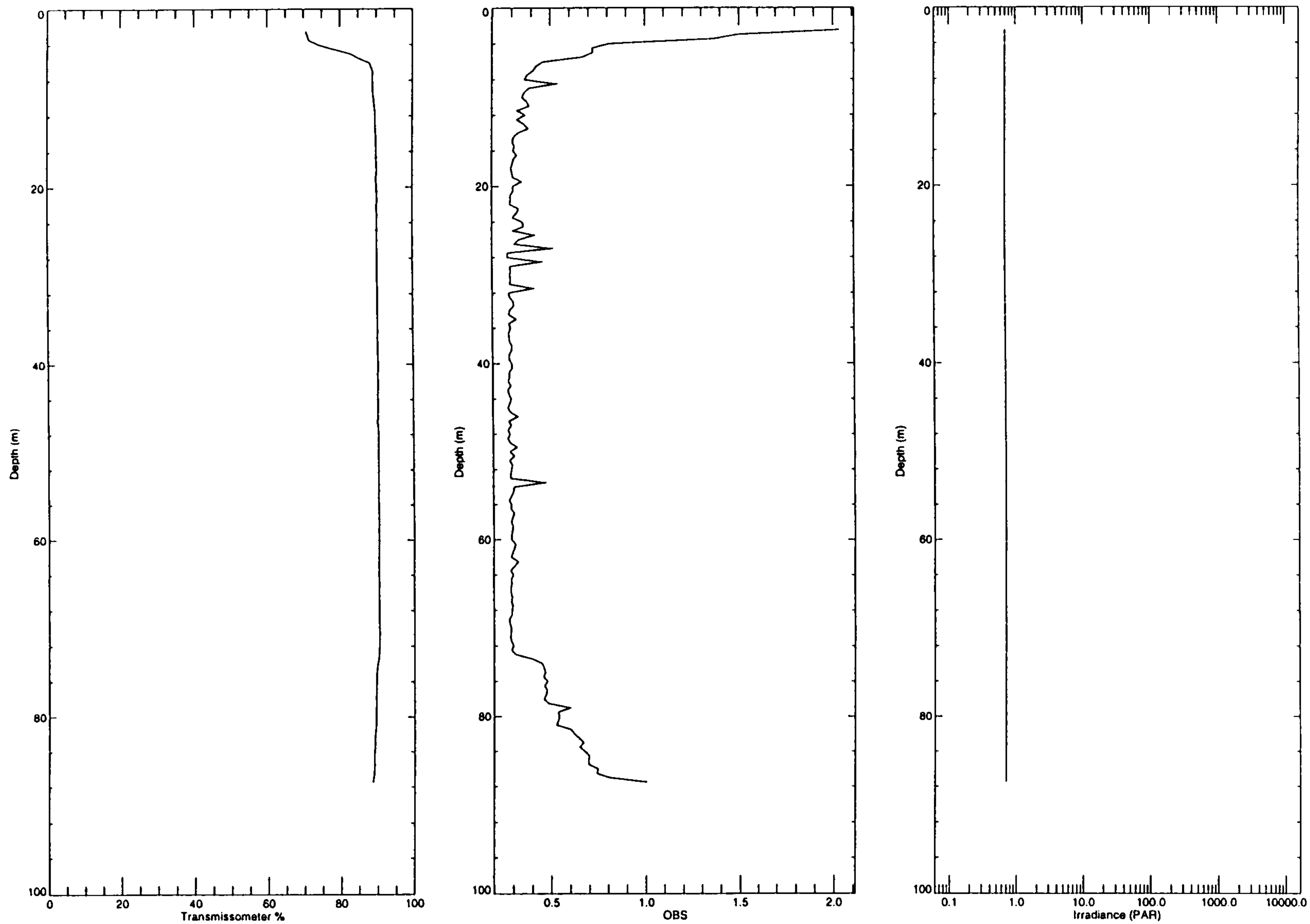

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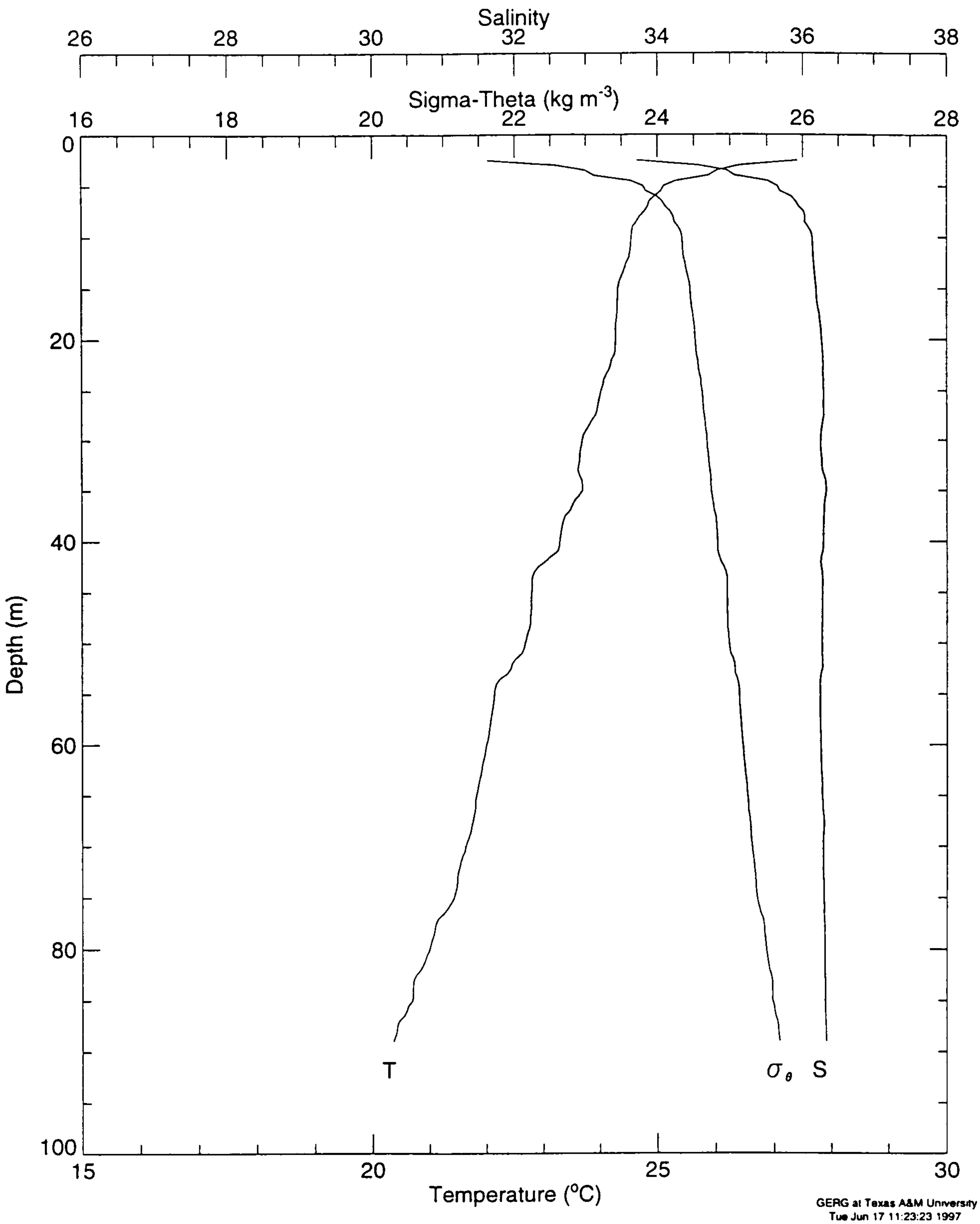

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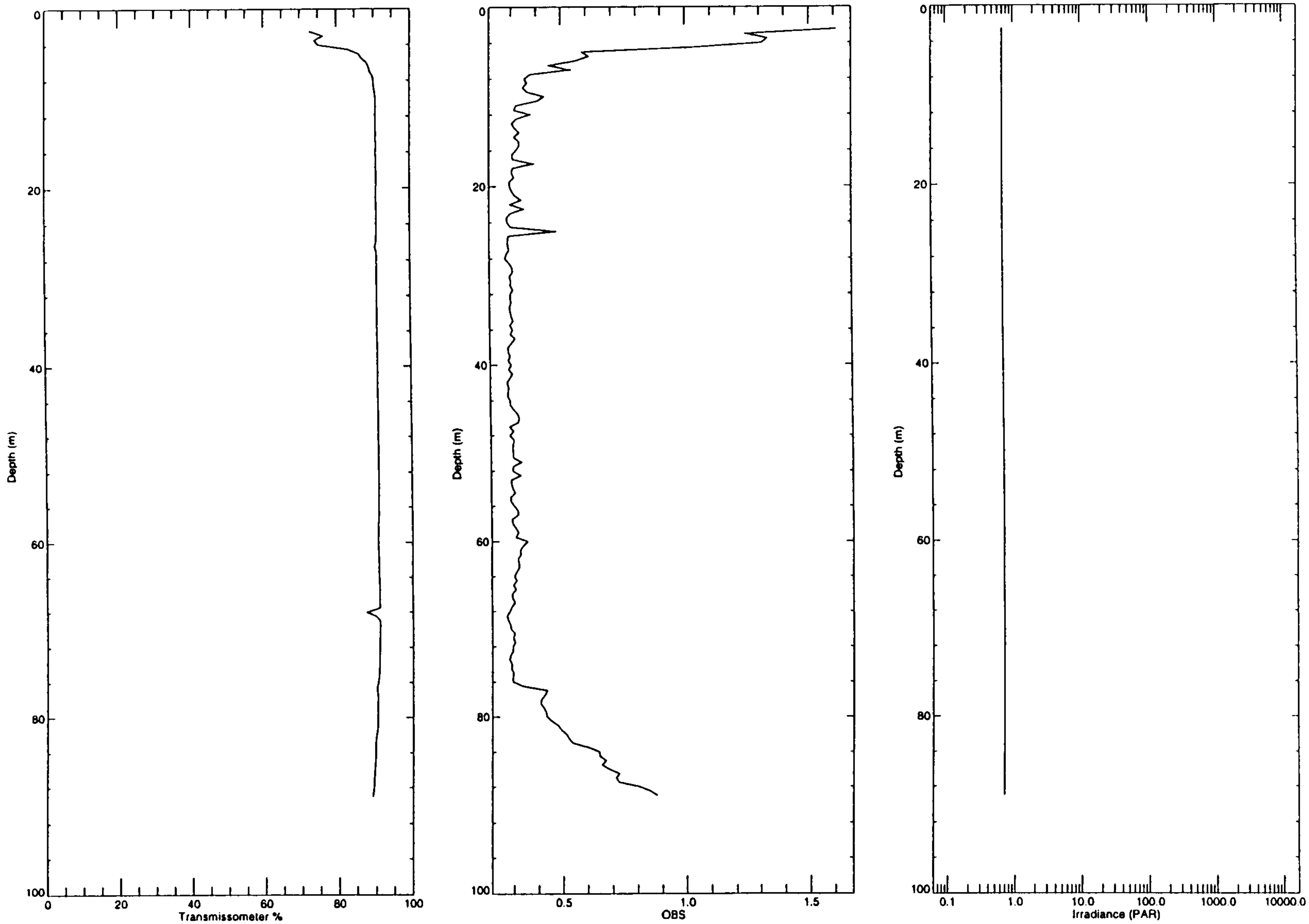

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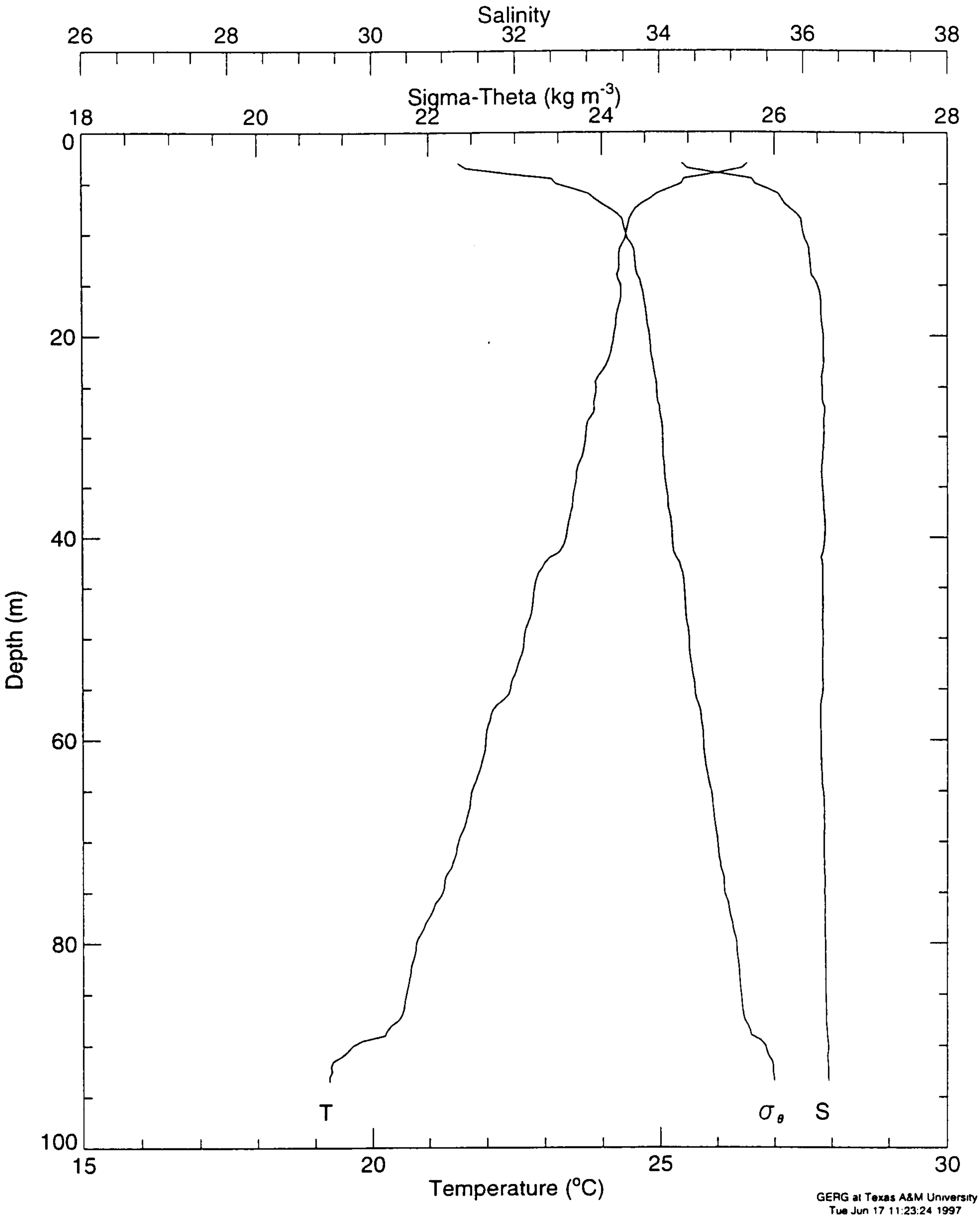

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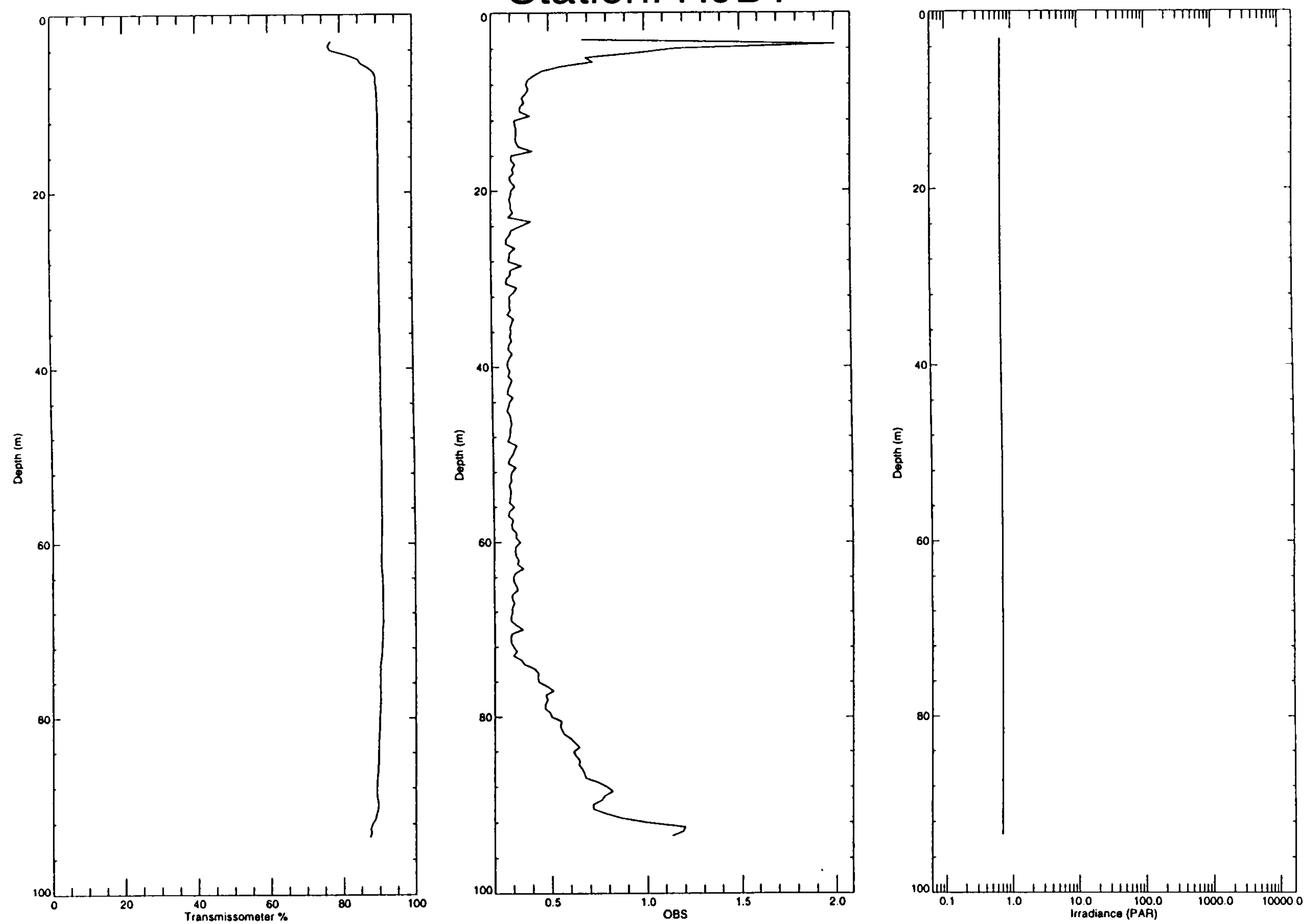

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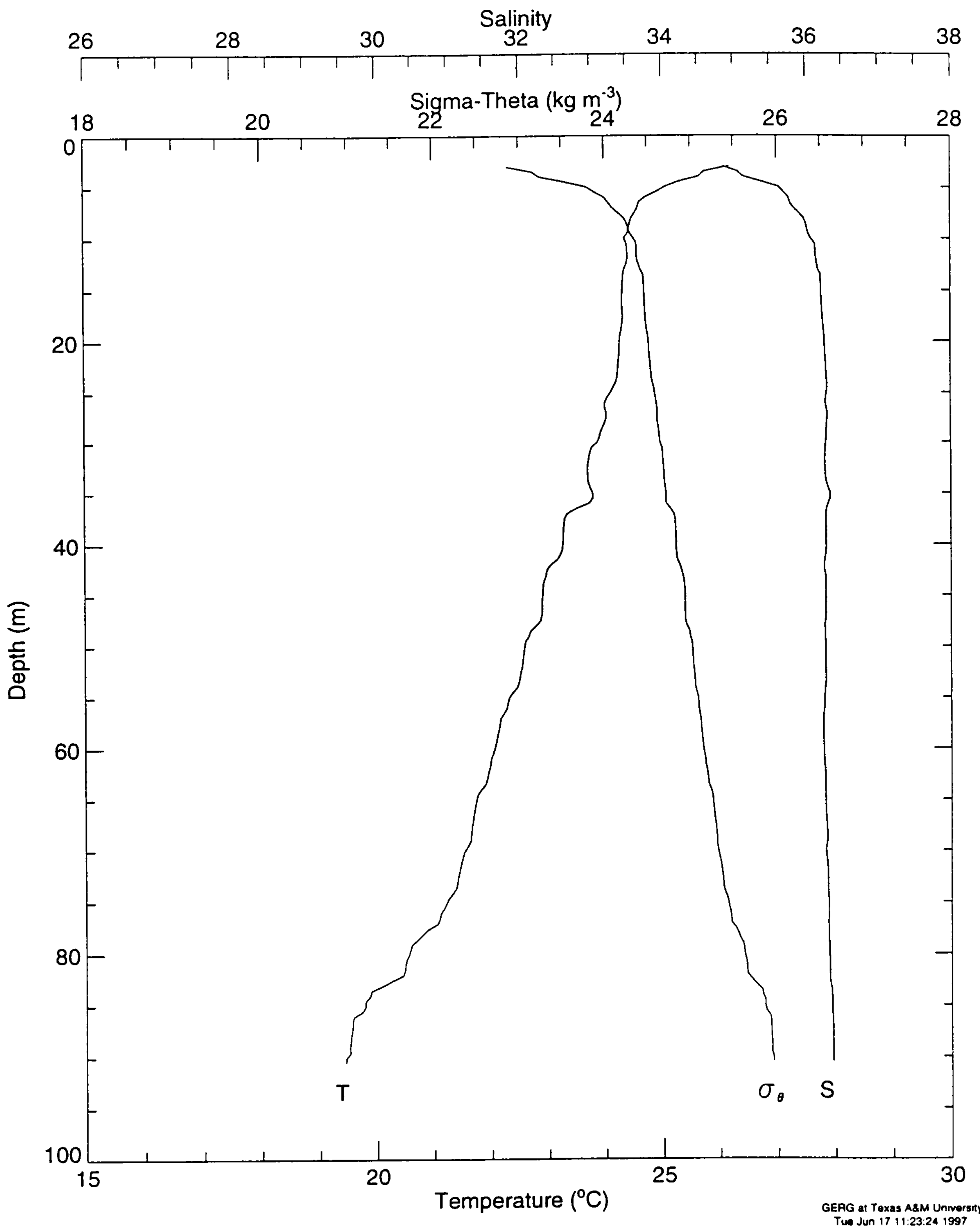

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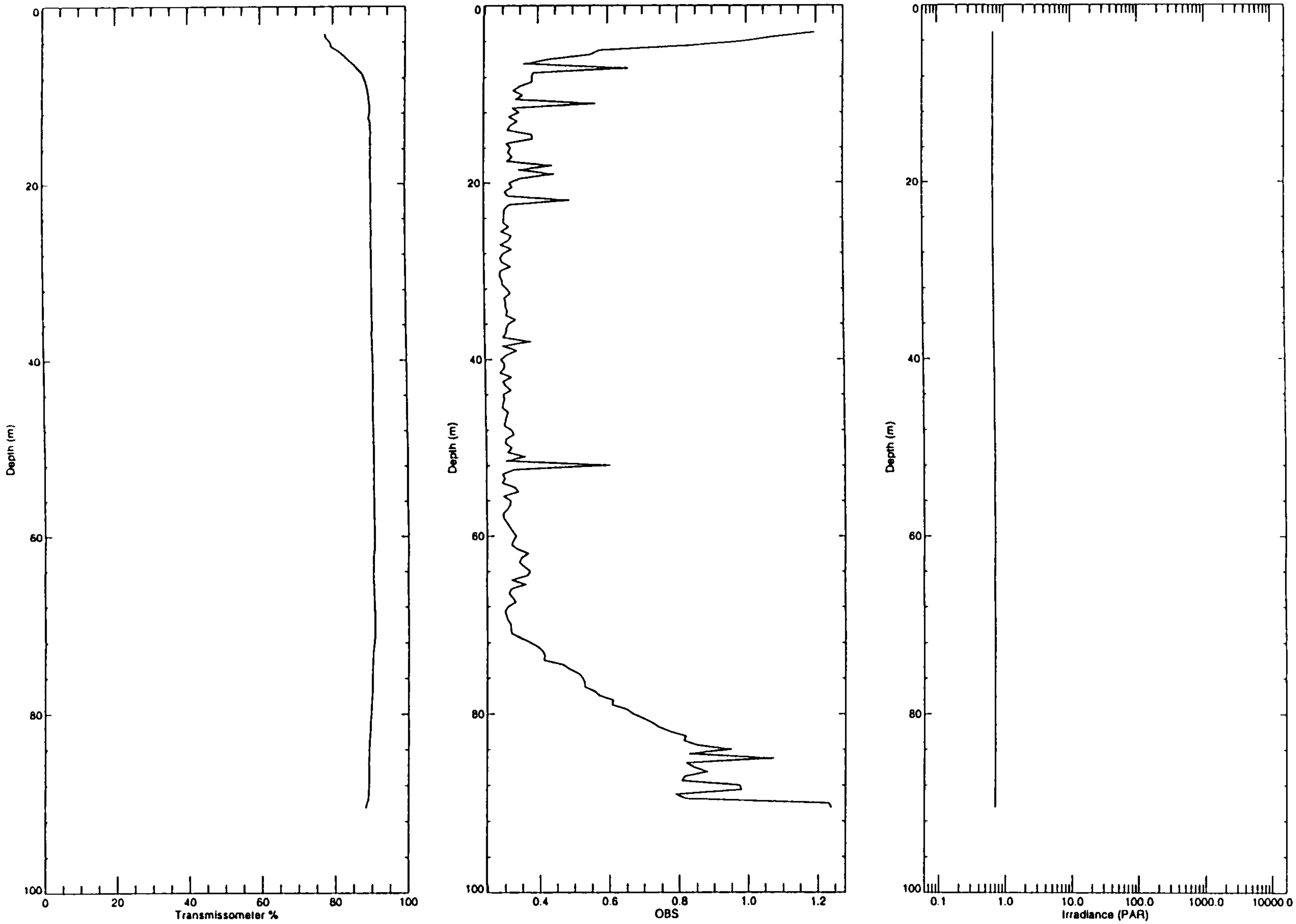

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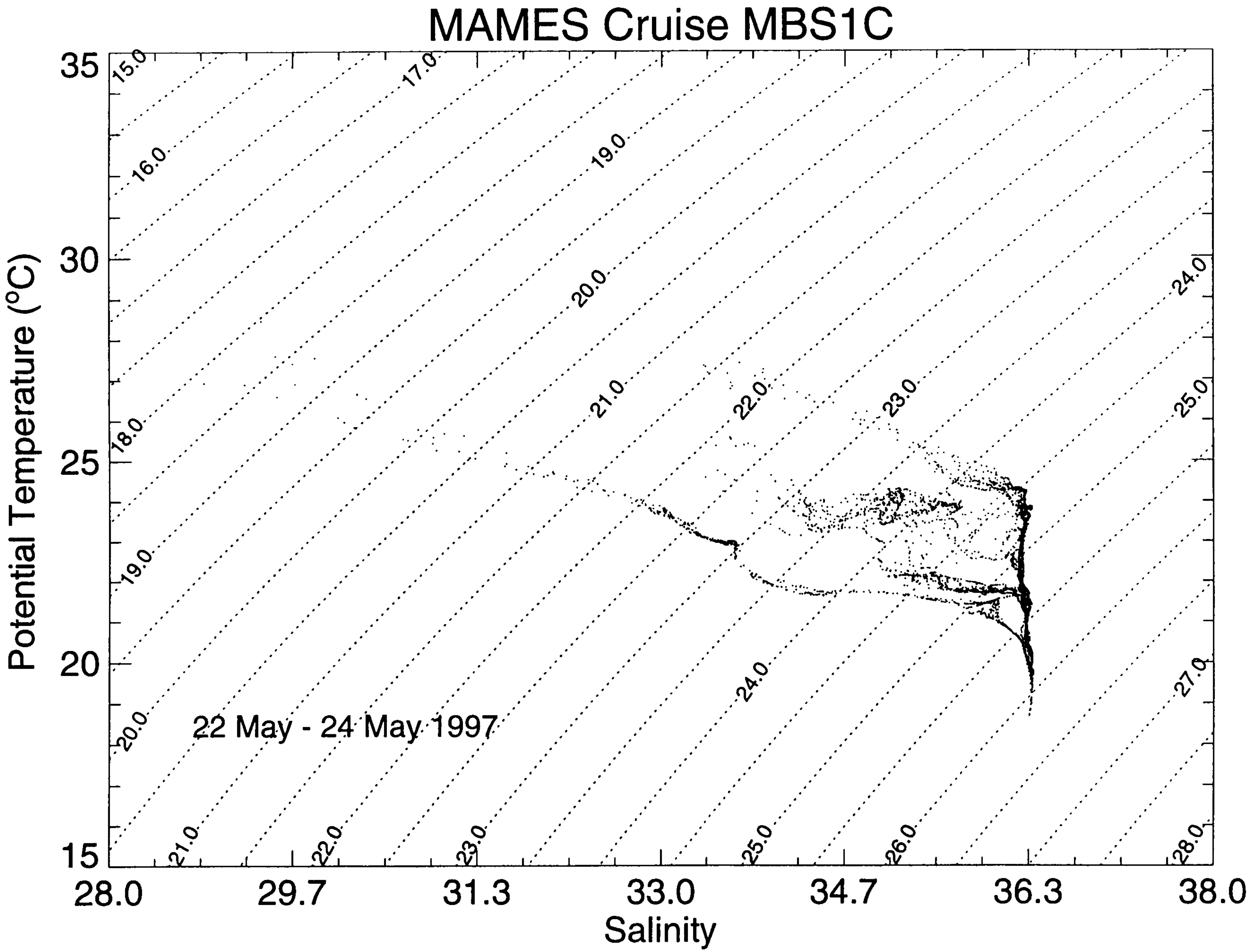
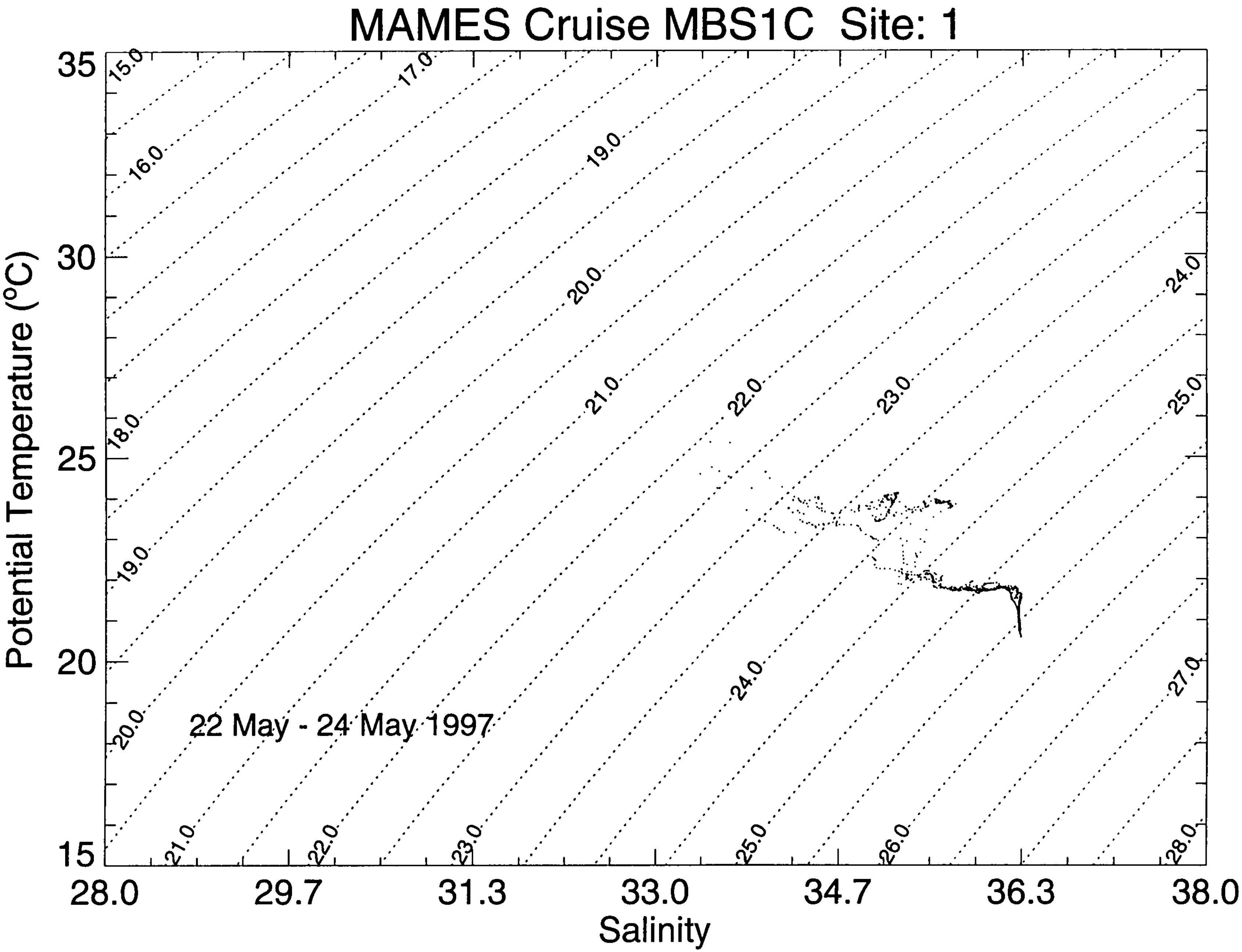
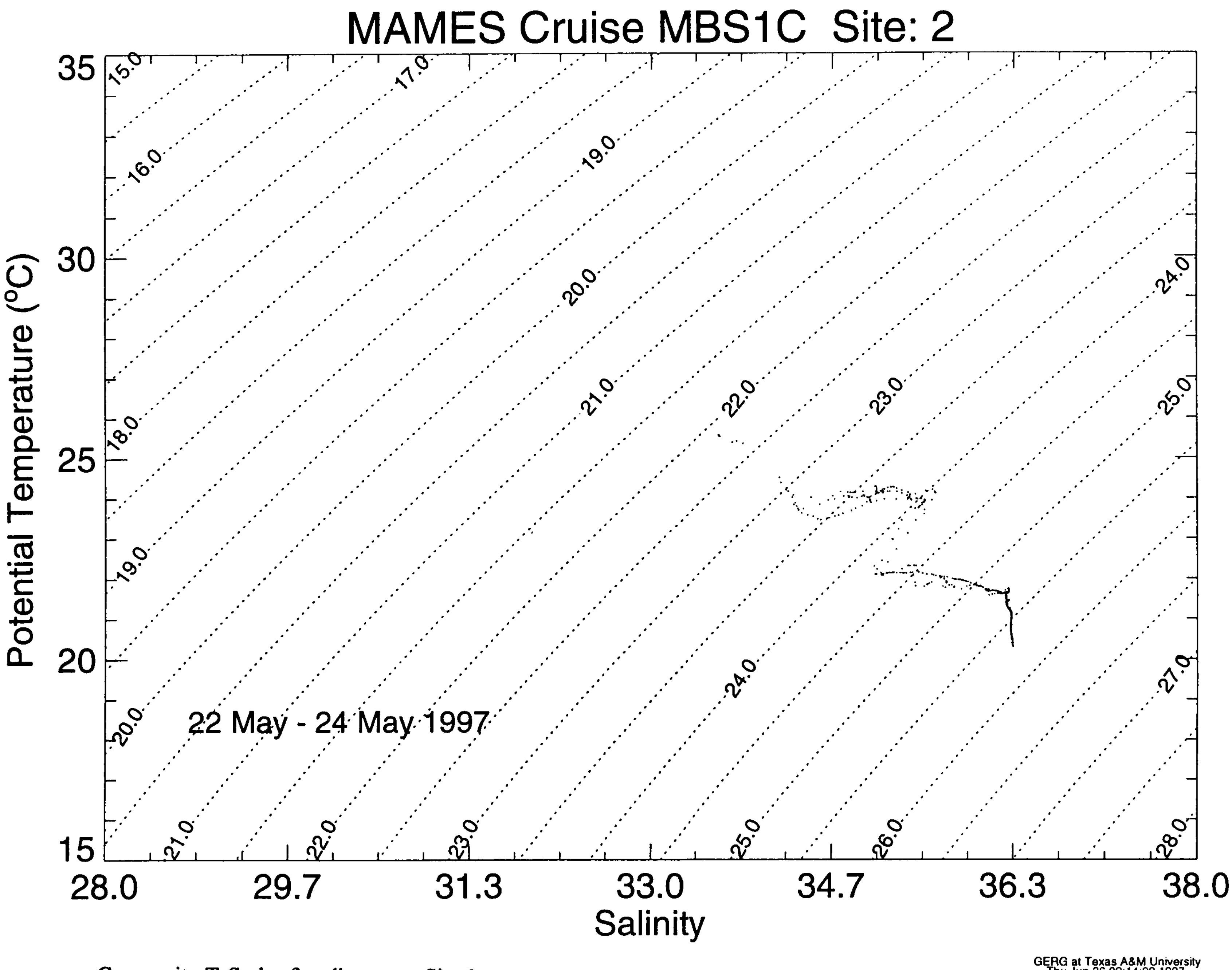


Composite T-S plot for all casts.

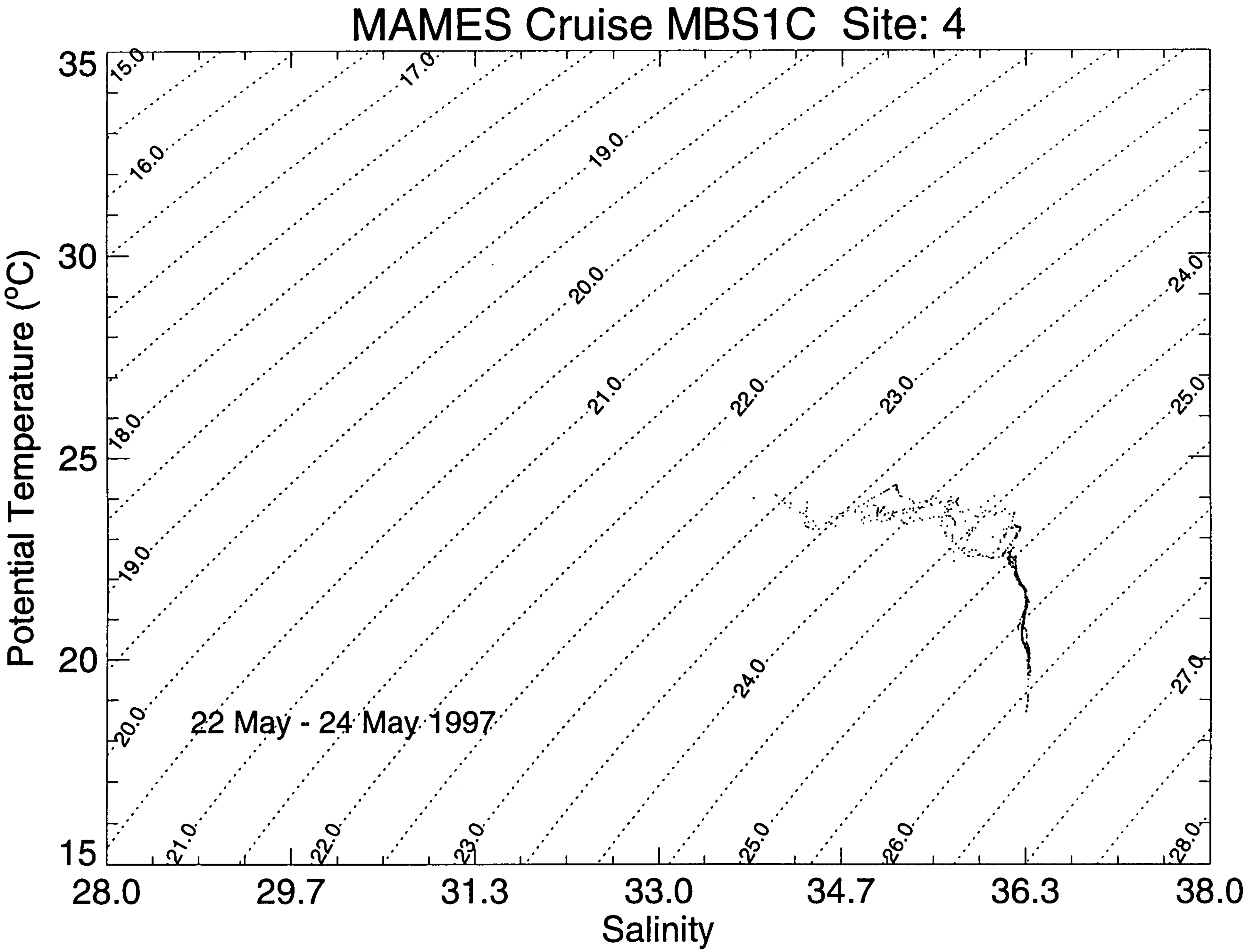
GERG at Texas A&M University
Wed Jun 25 15:40:49 1997



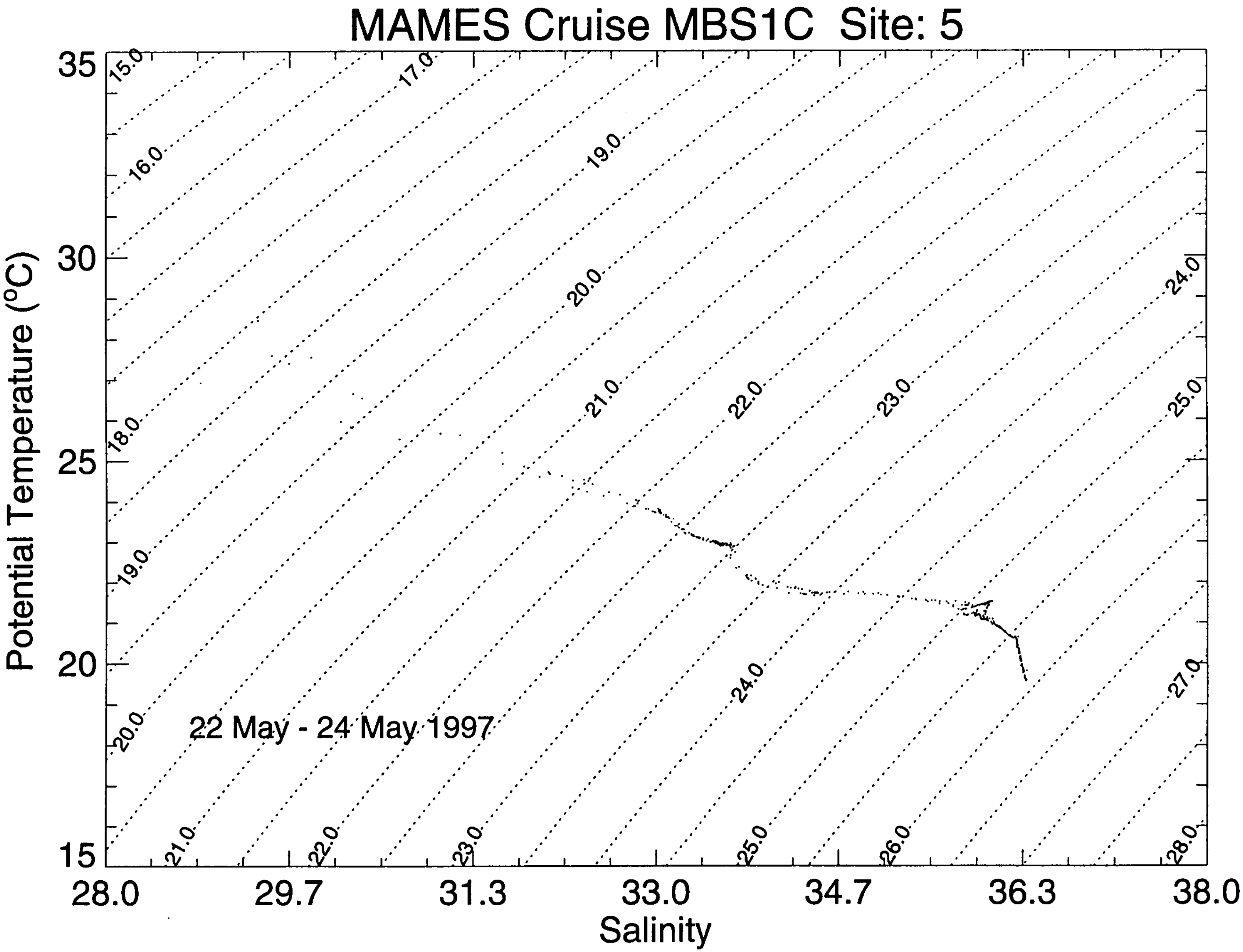
Composite T-S plot for all casts at Sites 1 and 3.



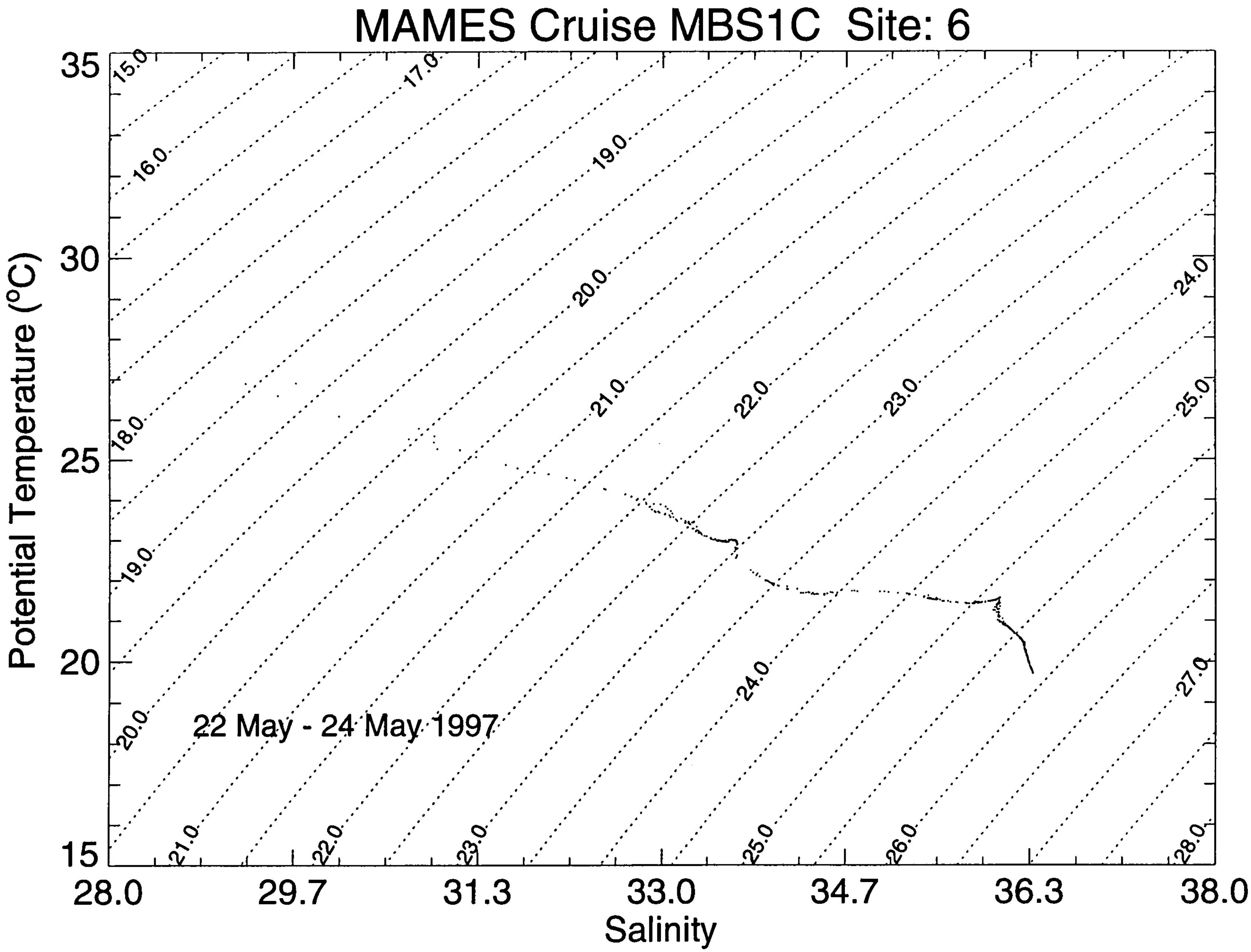
Composite T-S plot for all casts at Site 2.



Composite T-S plot for all casts at Site 4.

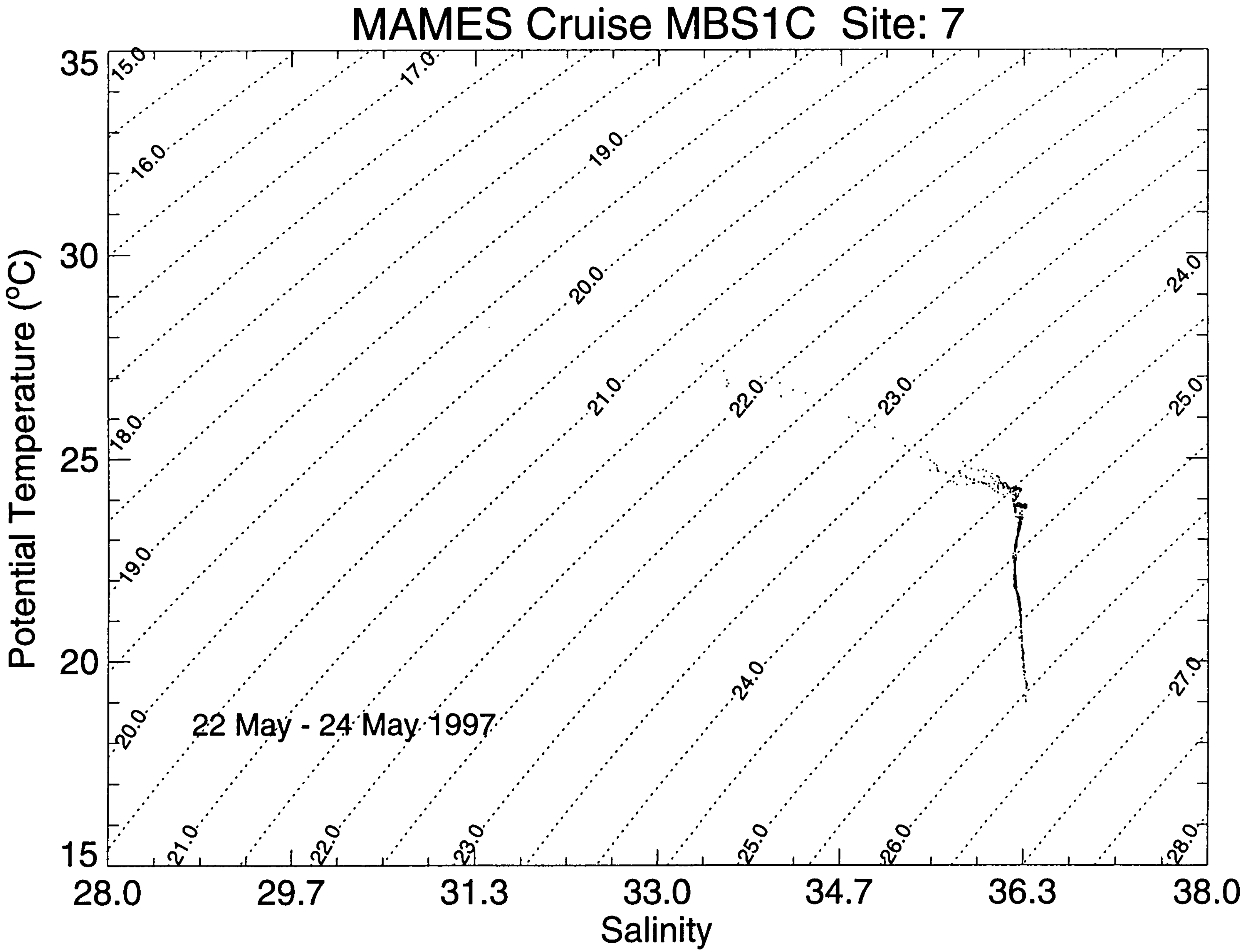


Composite T-S plot for all casts at Site 5.



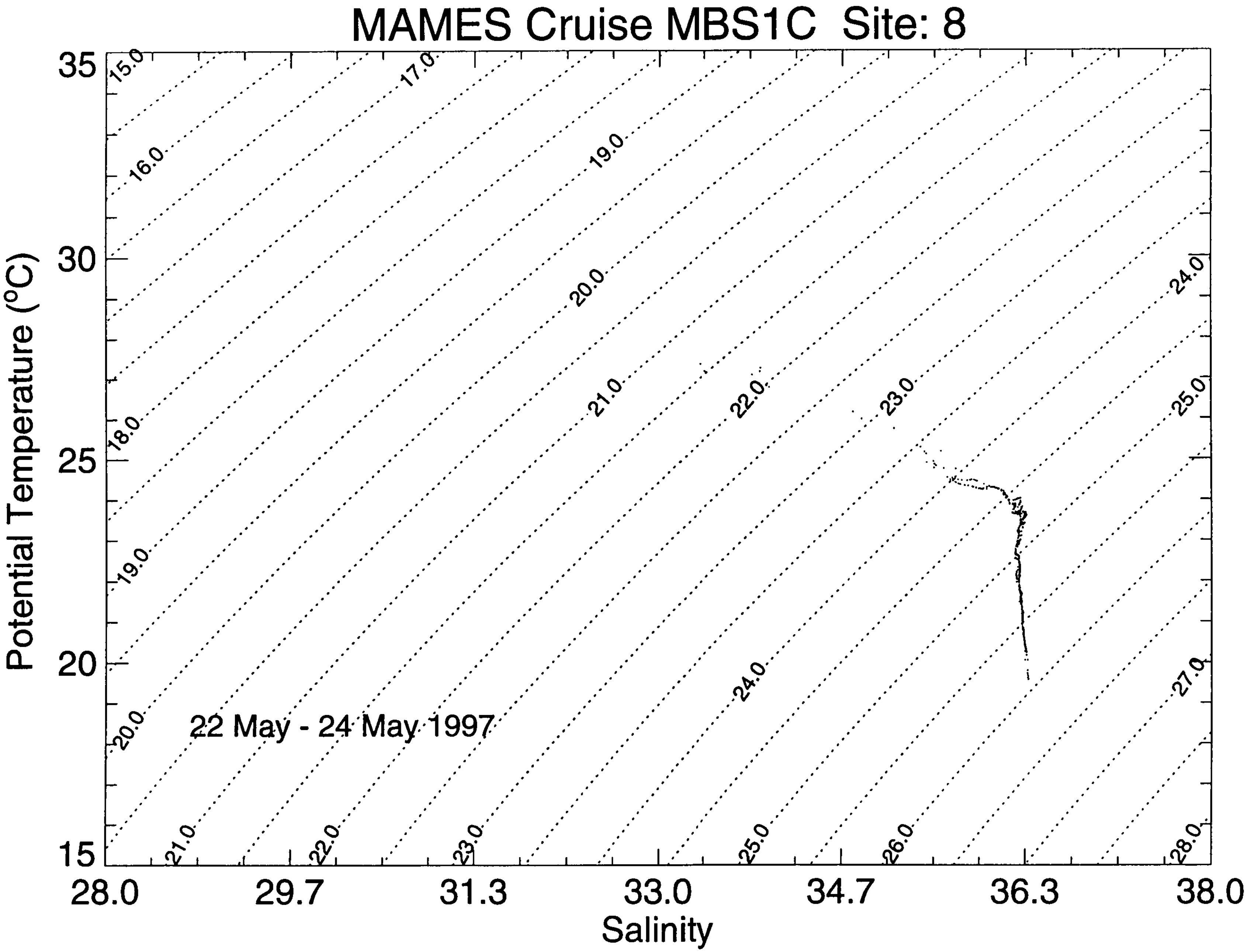
GERG at Texas A&M University
Thu Jun 26 09:14:11 1997

Composite T-S plot for all casts at Site 6.



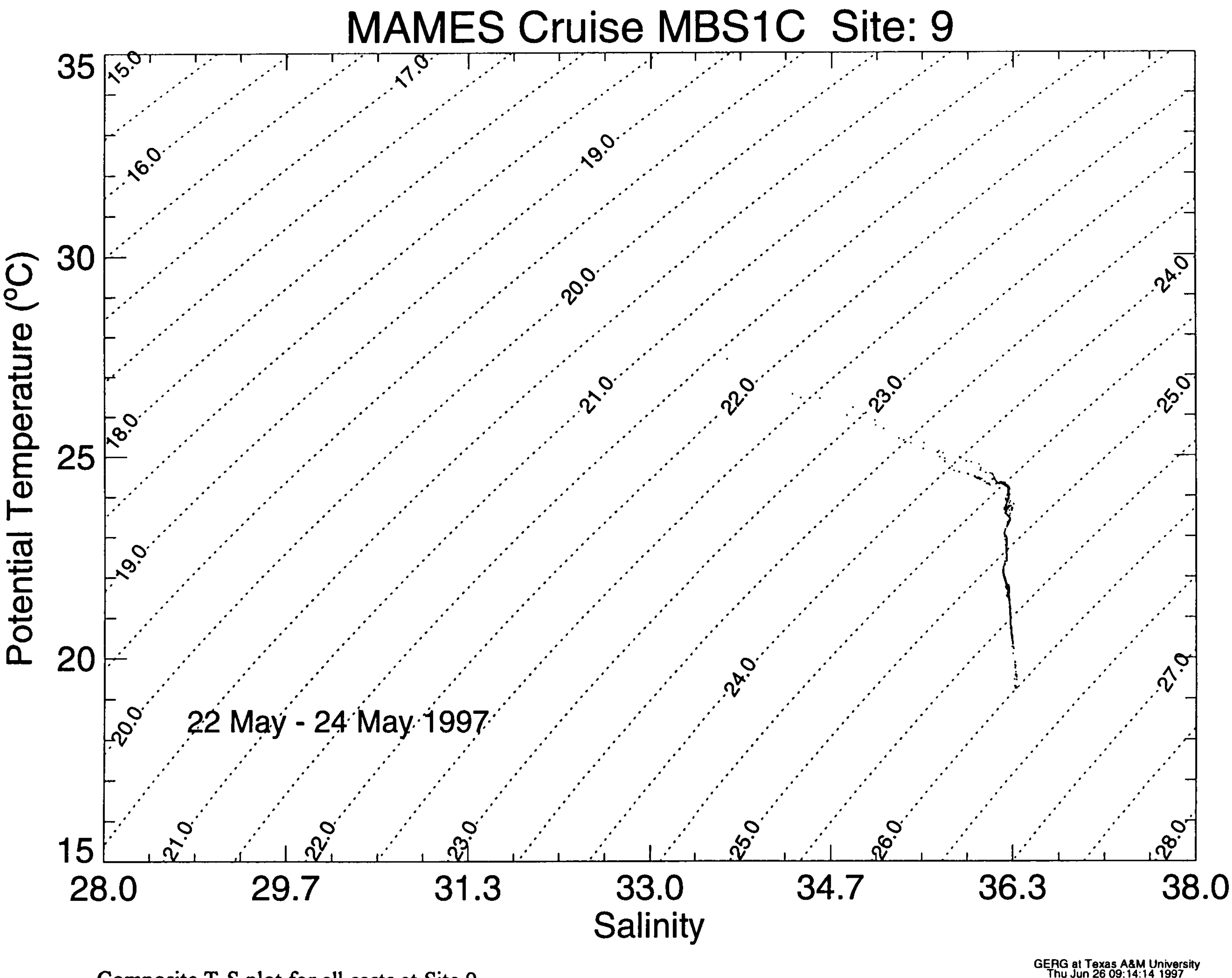
Composite T-S plot for all casts at Site 7.

GERG at Texas A&M University
Thu Jun 26 09:14:11 1997



Composite T-S plot for all casts at Site 8.

GERG at Texas A&M University
Thu Jun 26 09:14:14 1997



Composite T-S plot for all casts at Site 9.

Appendix B

Choosing an Unbiased Site Size

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Intuitively, it is clear that there will be a different proportion of substrate type, slope steepness, and slope direction at each pinnacle site. To develop a statistically robust sampling plan, it is critical that site heterogeneity be taken into account to balance sample collection for hypothesis testing. For example, if one were to propose an arbitrary and constant site size--100 by 100 m for example (as was suitable for the Gittings et al. 1992a Flower Gardens Monitoring study), then the study design would be seriously flawed because sampling would not control for the differing proportions of level, sandy substrate, of near-vertical faces, of pinnacle top, etc. that will be found at the different sites. The study design requires characterization of spatial and temporal factors in the biological community that are determined by these variables. To avoid this bias, an objective and site-specific set of criteria were used to fix the boundaries of each sampling site.

Each of the study sites can be represented as a population of depths, slope magnitudes, and slope orientations within each 300 by 300 m subset of the bathymetry data. Beginning at the a point centered on a pinnacle or cluster of pinnacles and interactively increasing the width of the site, the variance in these variables increases the site size increases until the site is fully characterized. Making the site too small or too large will bias the results of biological sampling. To determine the site boundaries, the slope magnitude, the slope direction, and the water depth were determined for each point in the matrix of depths, based on a 'neighborhood' of 5 by 5 points.

The standard deviation of slope magnitude, slope direction, and depth were then interactively calculated for blocks centered on the mid-point of 300 by 300 m area. Block width was increased with step of 10 m. Figures B.1-B.8 show these results for each of the study sites with the exception of Site 2, where the pinnacle feature was located too close to the limit of the available bathymetric data to permit analysis. These results were combined with logistic considerations to fix the final site boundaries cited in Chapter 8.

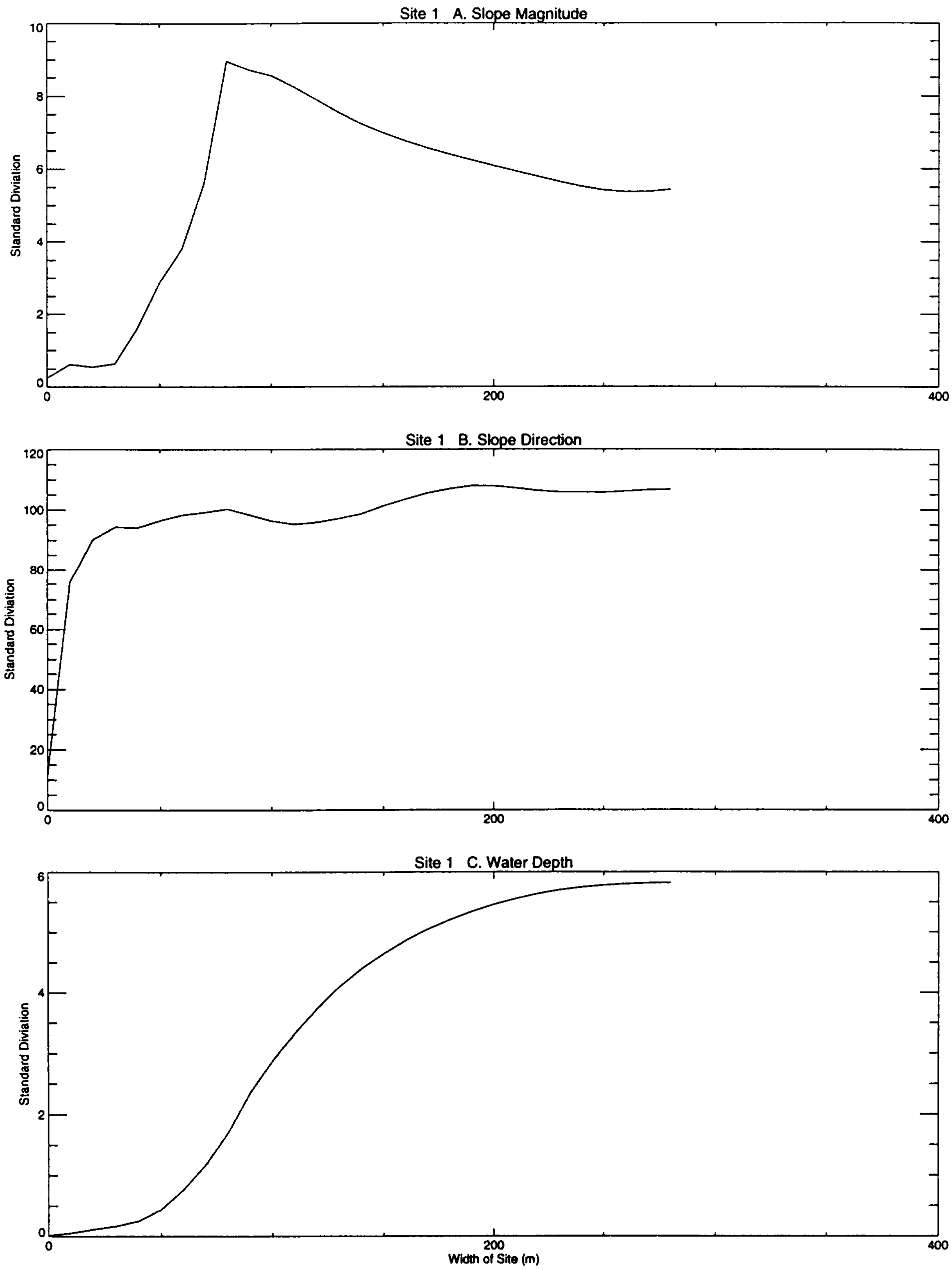

Figure B.1. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 1.

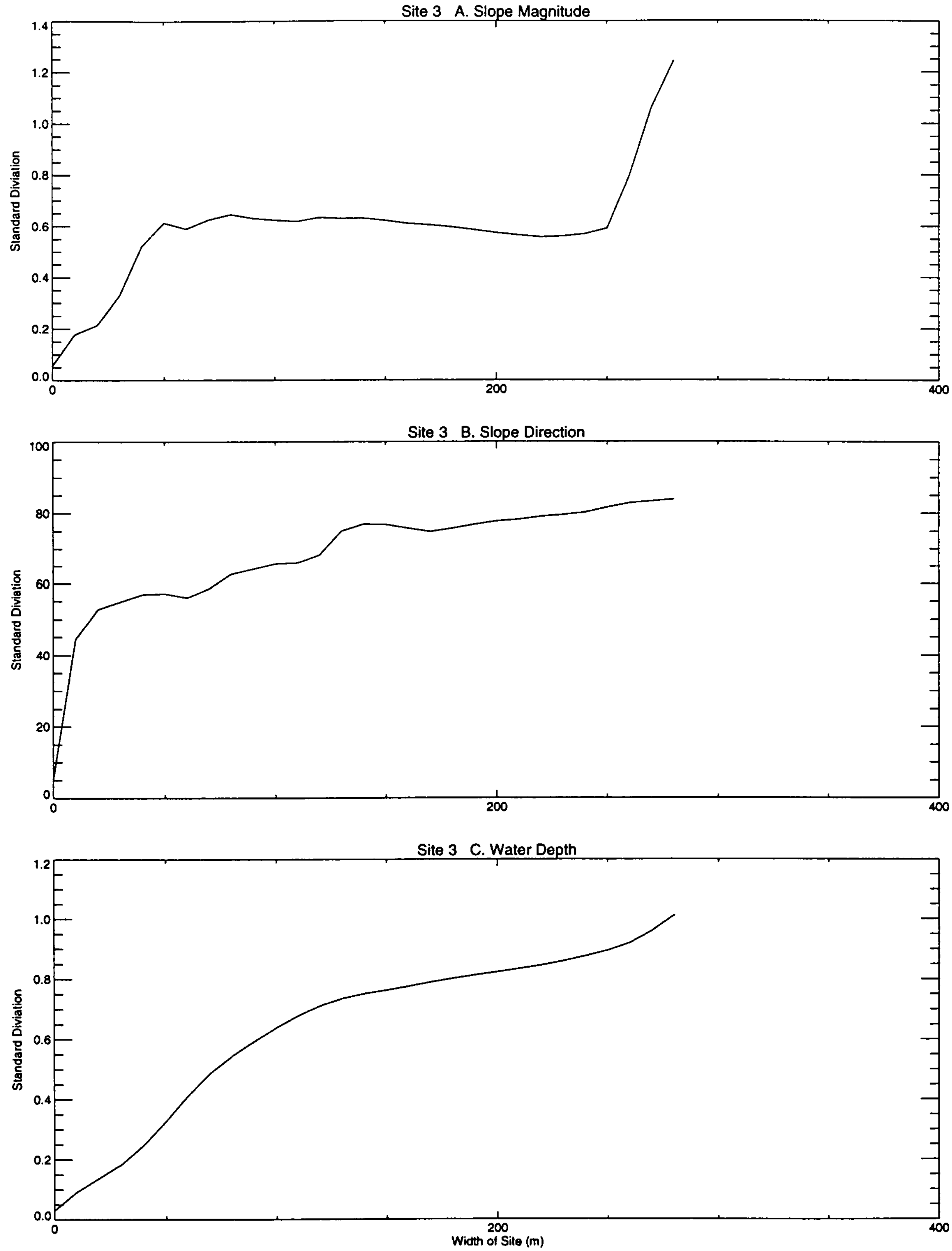

Figure B.2. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 3.

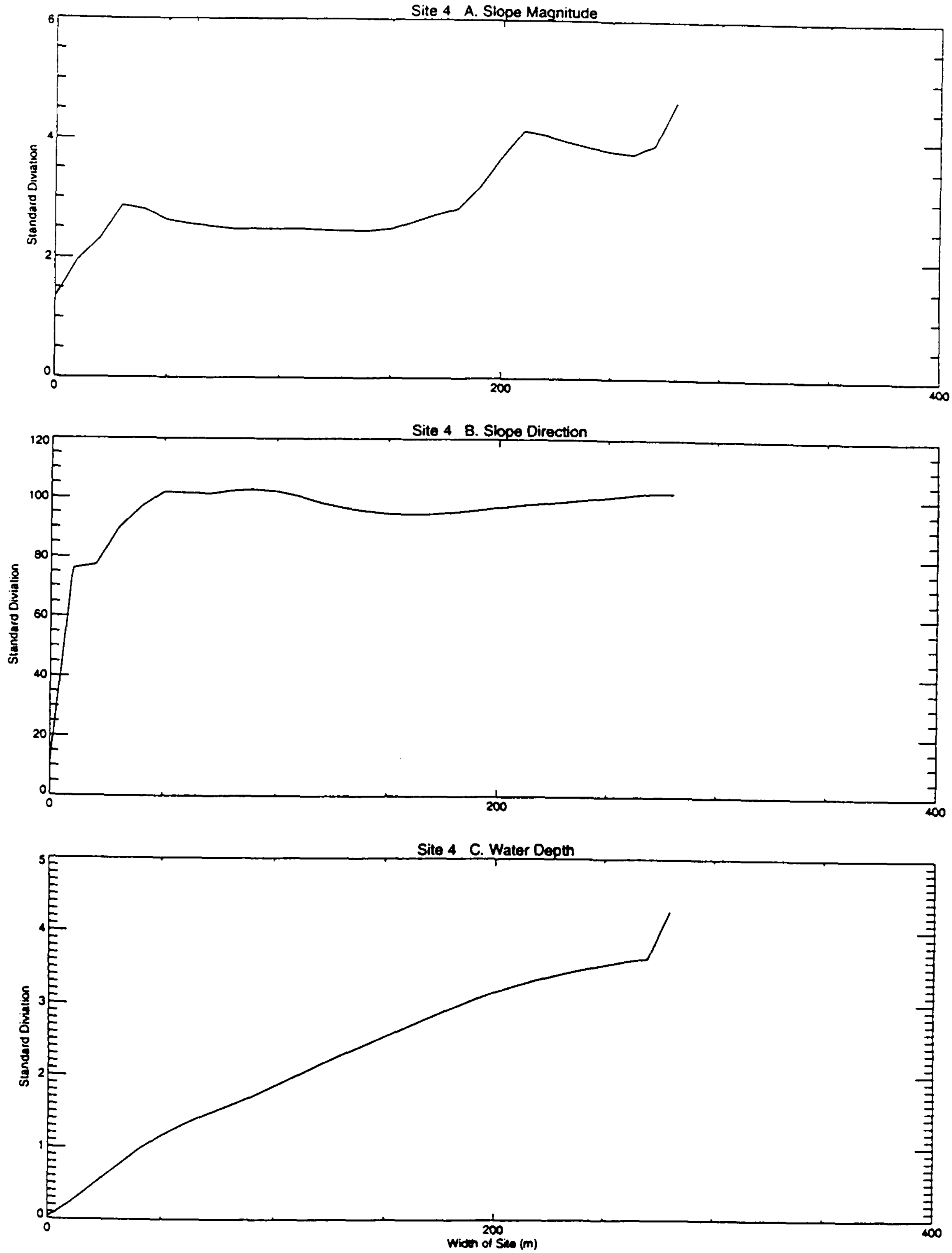

Figure B.3. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 4.

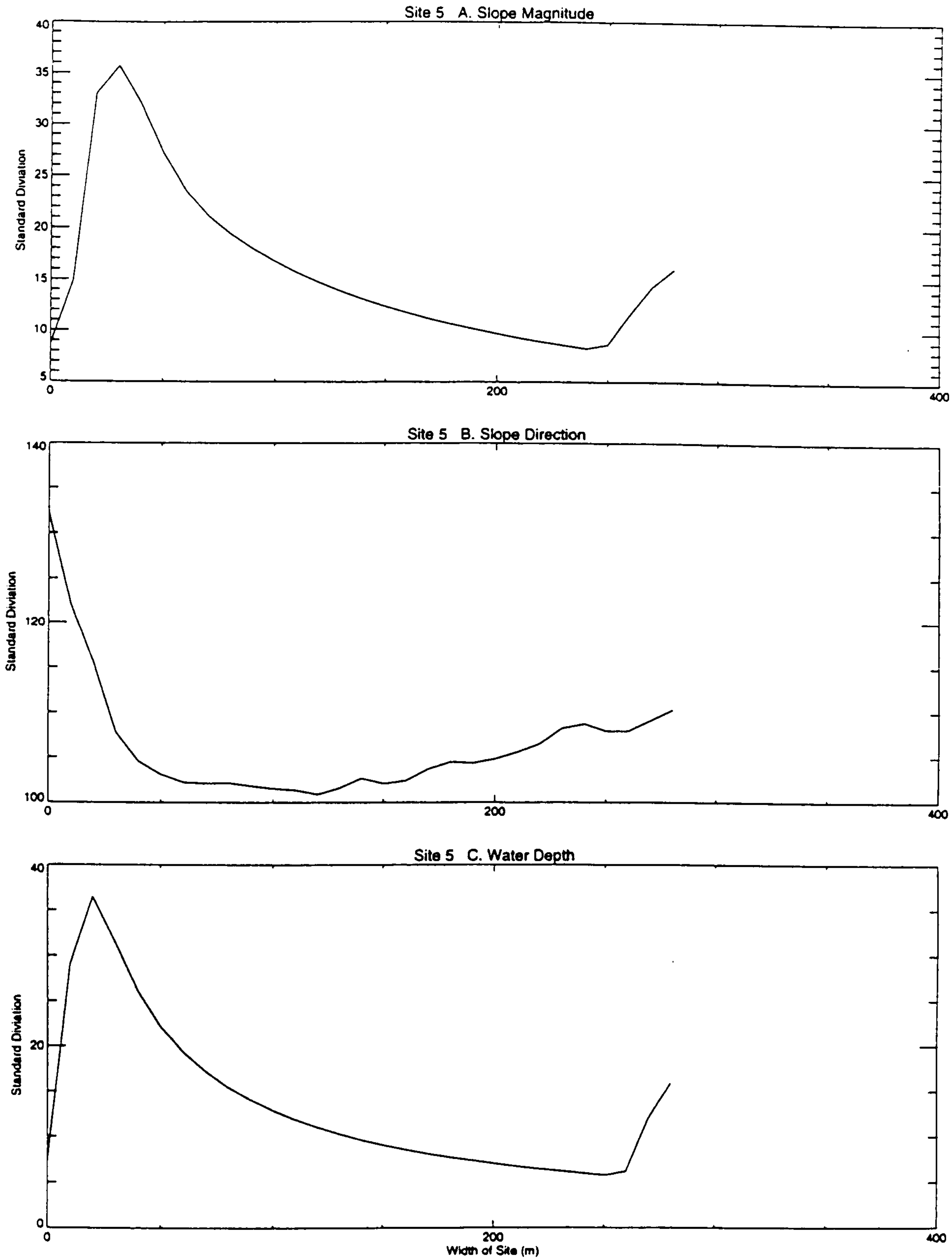

Figure B.4. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 5.

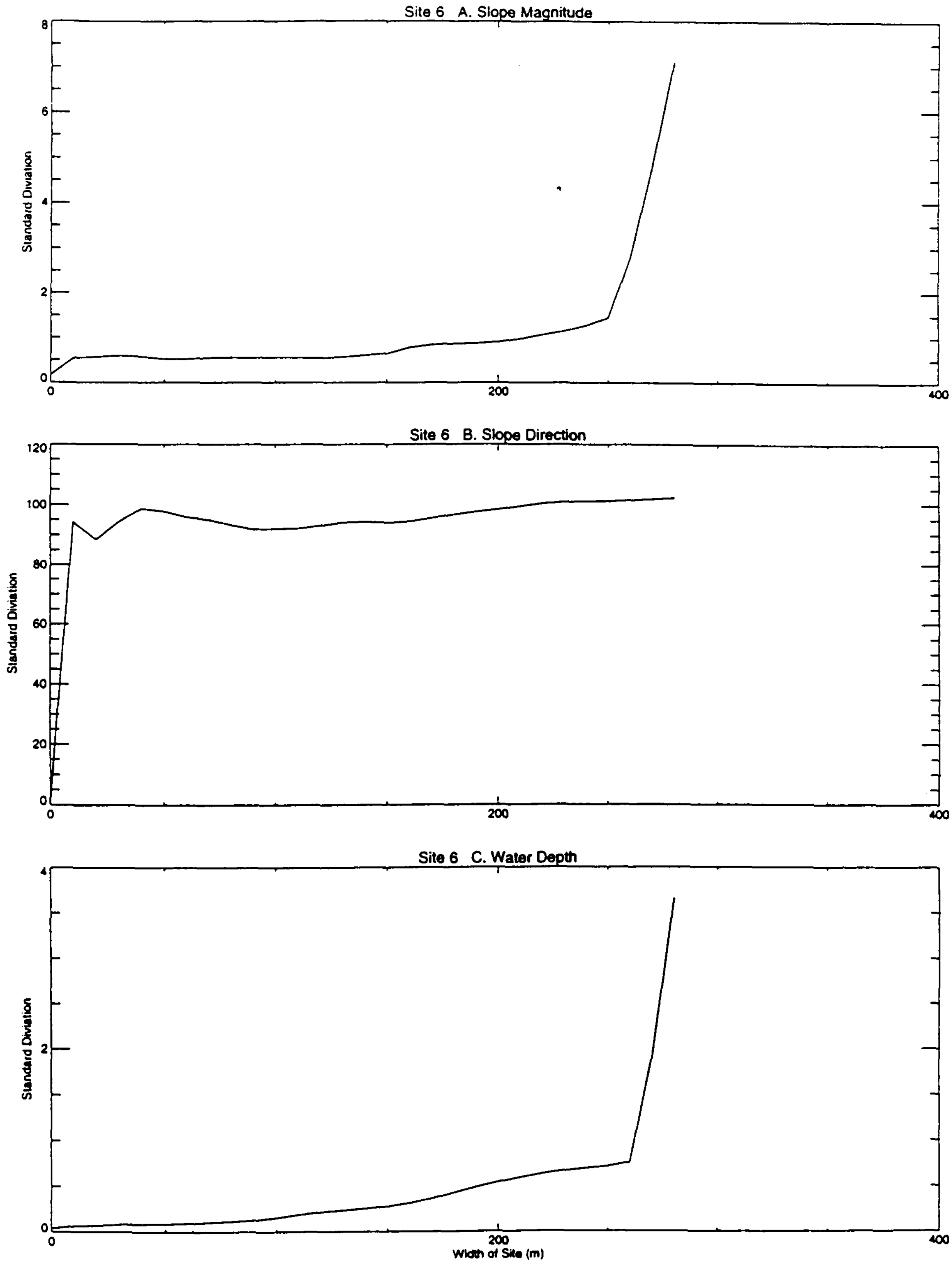

Figure B.5. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 6.

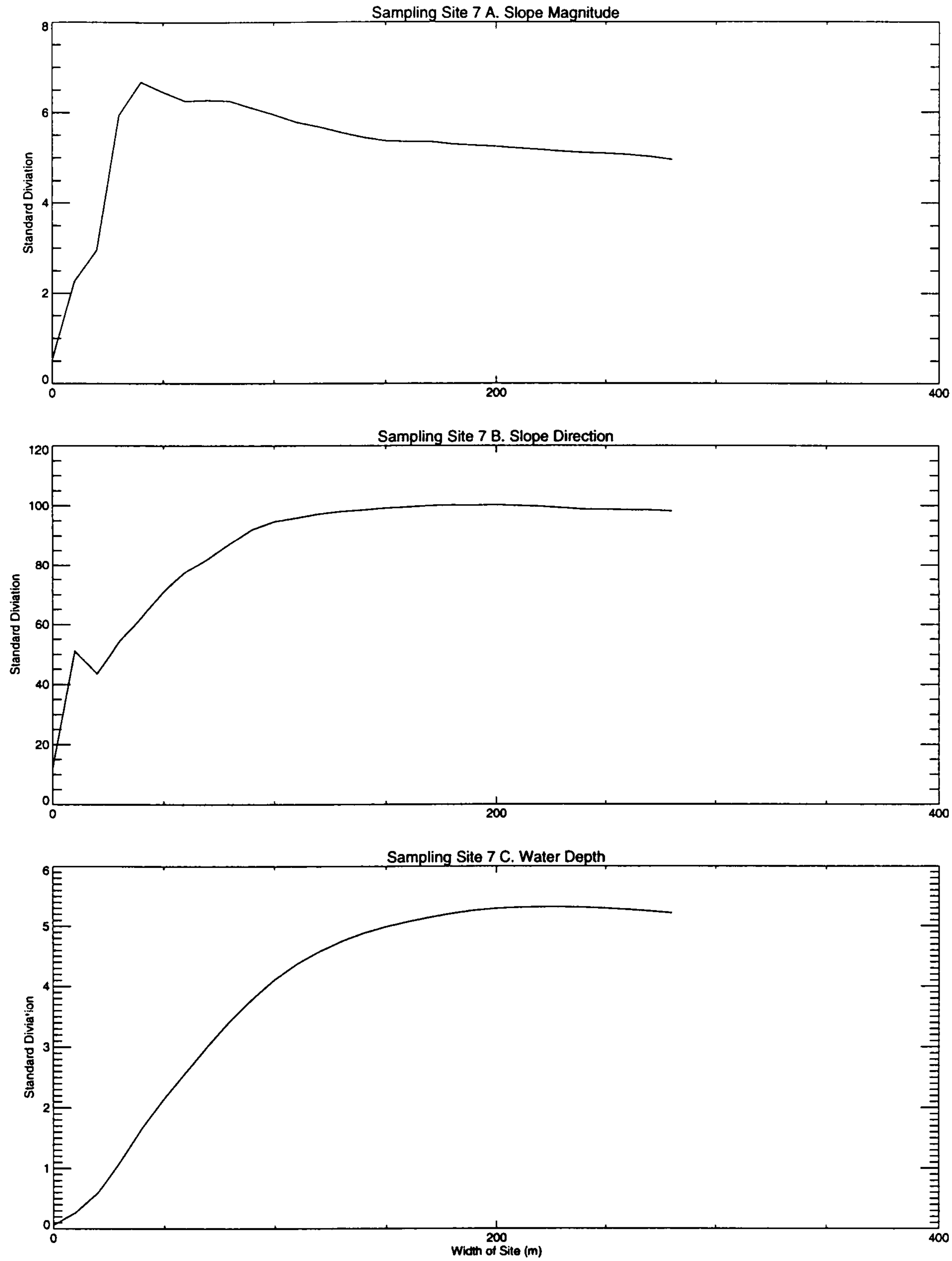

Figure B.6. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 7.

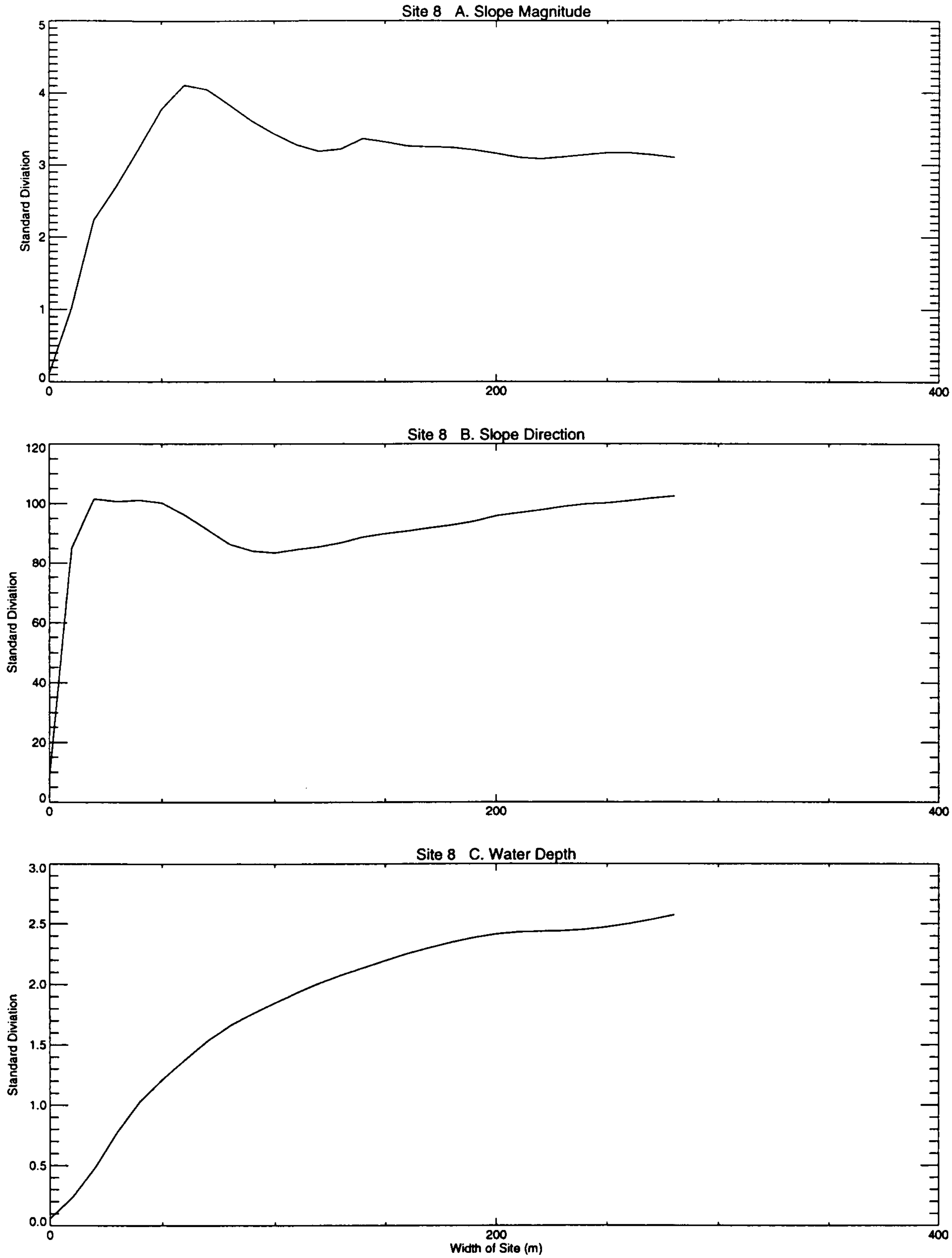

Figure B.7. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 8.

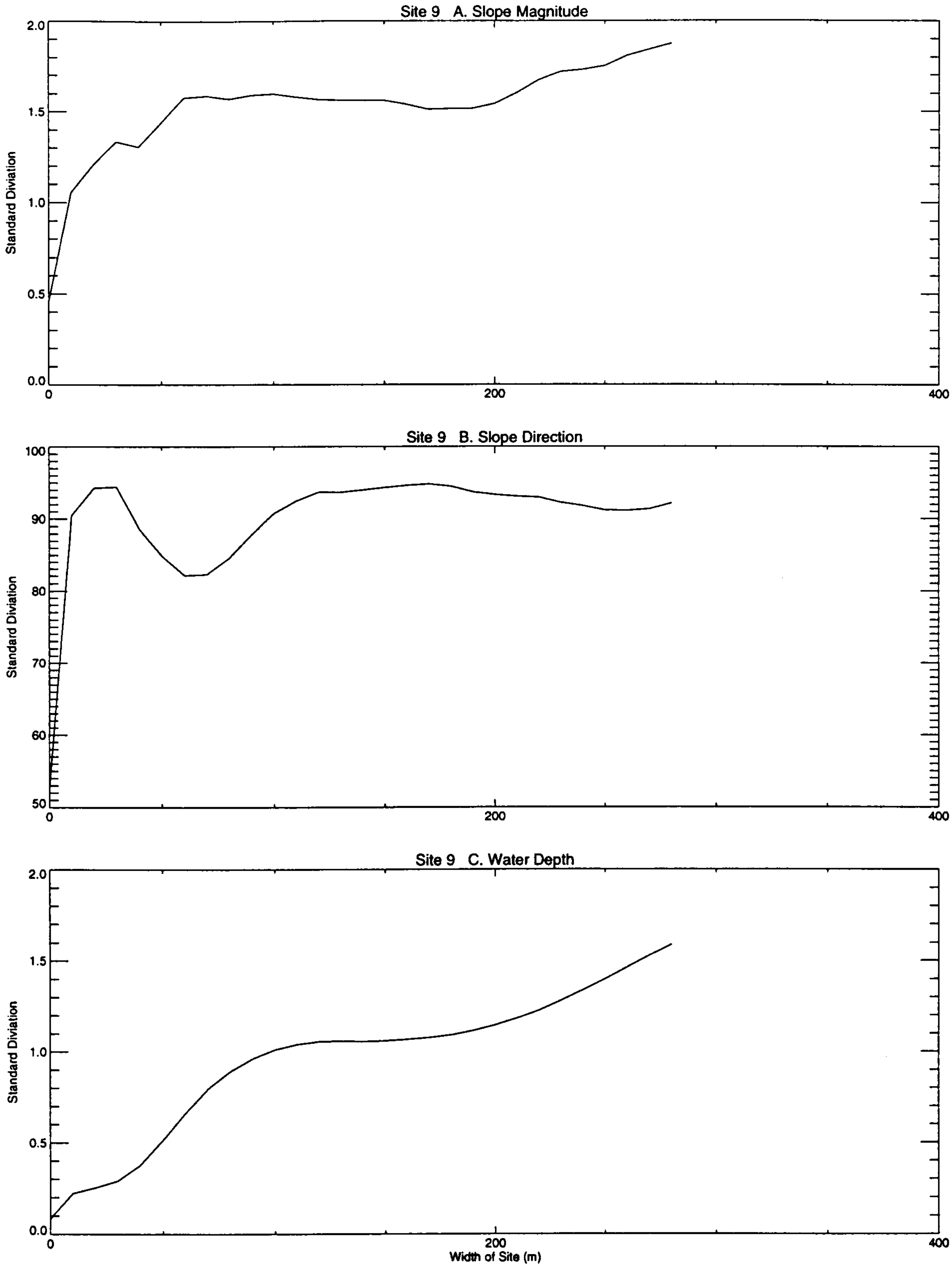

Figure B.8. Standard deviation of slope magnitude, slope direction, and water depth as a function of increasing study site diameter in the vicinity of Site 9.

The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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