OCS Study
MMS 2000-074

Physical/Biological Oceanographic Integration Workshop for the DeSoto Canyon and Adjacent Shelf

October 19-21, 1999

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

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October 19-21, 1999

Editors

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The University of Alabama/
Dauphin Island Sea Lab

and

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ABOUT THE COVER

The cover art depicts the integrative disciplines of research envisioned for the De Soto Canyon and the adjacent continental shelf.

ACKNOWLEDGMENTS

This meeting was a joint effort between the University of Alabama, the Dauphin Island Sea Lab and the U.S. Department of the Interior=s Minerals Management Service. The success of this workshop was due to the individuals below. The professional dedication and skills contributed on behalf of this effort before, during and after the meeting deserve a special note of thanks and appreciation.

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Introduction – The Area

The U.S. Department of the Interior's Minerals Management Service (MMS) conducts all leasing and resource management functions on the Outer Continental Shelf. The MMS sponsors scientific research to effectively manage and protect the environment. While MMS has sponsored substantial oceanographic studies in the northeastern Gulf of Mexico, demand for additional scientific information continues to be high. Recently completed, and ongoing, MMS studies in the northeastern Gulf also suggest that more integration is needed between the physical and biological oceanographic disciplines.

The Northeastern Gulf of Mexico continental shelf is an ecologically heterogeneous marine ecosystem. The shelf region is bounded onshore by a number of estuaries and bays acting as nutrient sources and serving as fertile nursery areas. Offshore, the De Soto Canyon, an area serving as an important fisheries ground and upwelling site, dominates the shelf. The health of the shelf ecosystem depends on physical habitat, environmental and climatic factors, nutrient availability, and oceanographic processes. These physical processes link the biotic components of the ecosystem. Hydrographic and sedimentological information suggest an east-west change of water column nutrients and physico-chemical properties near Cape San Blas; however, the information available is not enough to elucidate and characterize this change. Ongoing oceanographic studies in this region will provide a comprehensive and synoptic data set that can help prove this transition or provide an alternative paradigm. Ongoing biological studies suggest a number of data gaps that need investigating. This includes levels of production, taxonomic and trophic structure of coastal and shelf communities, coupling between water column and benthic communities, impacts of freshwater on shelf ecosystems, impacts of catastrophic events, and status and trends in fisheries resources and management.

To assess our state of knowledge for the area and to address the issue of additional information needs, particularly that of the integration of any future data collection and analysis efforts, a workshop was sponsored by the MMS and co-hosted by The University of Alabama and the Dauphin Island Sea Lab. This workshop brought together experts who summarized what was known about the area; determined critical issues; and provided input to the design of an integrated physical and biological study. Such an integrated study would be intended to bring to closure the *Northeastern Gulf of Mexico Physical Oceanography Program* and the *Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program*.

Specific Area of Discussion

From the perspective of information needs concerning any future OCS activities, the geographic area of interest for this workshop is defined as an area encompassing the western portion of the Florida panhandle westward into the Alabama and Mississippi and includes the De Soto Canyon and adjacent areas going into deeper waters. Figure 1 depicts the area of interest for this workshop, and shows the major physical exchange paths and forcing functions. This geographic area, of course, cannot be studied by itself, it must include the influences from coastal bays and estuaries, as well as the offshore currents including the Loop Current and eddies impinging on the continental shelf. Figure 2 is a depiction of the Eastern Planning area including the area to be available for the proposed lease Sale 181. Part of the proposed lease sale area was brought up during workshop discussion.

Research History of the Area

Physical Oceanography

In 1994, the MMS and the Florida State University hosted the *Northeastern Gulf of Mexico Physical Oceanography Workshop* (Clarke 1995) to assess the state of knowledge of the circulation in the shelf and upper slope region of the Northeastern Gulf, and to develop a strawman plan of possible studies.

Shortly thereafter, the MMS entered into a cooperative agreement with the University of South Florida to conduct the *Northeastern Gulf of Mexico Satellite Oceanography Study.* This study was designed to summarize the meso- to small-scale surface circulation on the continental shelf from the Mississippi River to Cape San Blas, using existing archived sea surface temperature, color camera, and coastal zone color scanner imagery. The three most relevant remote sensing data sets (sea-surface temperature, color photos, and digital color scans) are all now available from Federal archives, and can also be pre-scanned by available browsing routines to reduce search effort. A number of public-domain computer codes are also easily accessible for further analysis.

The project provided charts of selected frontal locations, statistical characterizations of the ensemble of frontal locations (based on the total imagery database); dynamical interpretations of these characterizations, and summary graphics for use by MMS decision-makers. The only previous MMS physical oceanographic study of currents and sea surface characteristics in the area occurred during the *Mississippi-Alabama Marine Ecosystems Study* (Brooks, 1991) which included five current moorings and numerous analyses of satellite images, sea-surface temperature, and currents in the western end of the study area. (A small amount of hydrographic data was taken during the Mississippi-Alabama-Florida study in the early 1970's.) The ultimate product of the work was an atlas of surface current patterns and meso- to small-scale frontal locations in the study area, plus associated documentation of methods, datasets used, and results.

Concurrent with the *Northeastern Gulf of Mexico Satellite Oceanography Study,* the MMS entered into a Cooperative Agreement with the Florida State University to conduct the *Northeastern Gulf of Mexico Inner Shelf Circulation Study* and the *Northeastern Gulf of Mexico Modeling Program.* With the addition of environmental assessment responsibilities for State waters, mandated by the Oil Pollution Act, the MMS is required to analyze oil spill risks within the inner shelf zone, the 3- to 10-mile wide band of marine waters adjacent to the coast. The inner shelf zone has significant differences in circulation from the open shelf, due to the overlap of the benthic and surface Ekman boundary layers, due to complex lateral boundary geometry, and due to wave energy focusing and concentration. An approach to successful assessment of environmental risk in the inner shelf zone adopted by the MMS is the use of actual field measurements (i.e., data, as opposed to model results). This effort involves a mixture of lagrangian drifter measurements, current meter moorings, and synthesis of existing information (through a coordinated Coastal Marine Institute study) to develop an adequate database for these assessments. This field measurement study provided the data for oil-spill risk assessments, skill assessments, and validation of numerical models.

These three efforts formally initiated the highly integrated MMS *Northeastern Gulf of Mexico Physical Oceanography Program* and led to the design of six other studies proposed during the workshop (Clarke 1995):

Meteorology of the Northeast Gulf of Mexico
De Soto Canyon Eddy Intrusion Study
Operational Remote Sensing
Eddy Monitoring & Remote Sensing
Chemical Oceanography & Hydrography, and
Circulation Regimes Affecting Living Marine Resources

Because one of the principal forcing mechanisms for coastal circulation on the continental shelf is wind forcing, and because the shelf is relatively wide area (approximately 100 km), any other physical oceanographic studies for the area would require additional meteorological measurements. If the wind field is not resolved in this way (both in terms of horizontal variations and possible differences in local stress, i.e., forcing strength) then expensive physical oceanographic datasets would be impossible to analyze fully. This being the case, the *Meteorology of the Northeastern Gulf of Mexico* was initiated in 1977 and is scheduled for completion in 2000.

It is well known that the Loop Current (and/or warm-core eddies believed derived from the Loop Current) can be observed to intrude onto the Mississippi-Alabama-Florida shelf in the area of the De Soto Canyon. Speculation on the specific mechanisms involved center on a "steering" effect of the canyon. Observations during the MMS-funded marine ecosystems work offshore Mississippi and Alabama indicate that significant water column effects can be observed during these intrusions. Further, workers in Florida argue that remote sensing images indicate considerable nutrient enrichment (and enhanced primary production) occurring at the head of the Canyon during intrusions. The *De Soto Canyon Eddy Intrusion Study* was conducted to quantify and characterize the physical scales and dynamic mechanisms associated with Loop Current intrusions in this area.

Critical parts of any circulation study attempting to address meso-scale dynamics are sufficient remote sensing. The *Operational Remote Sensing* and the E*ddy Monitoring & Remote Sensing* studies are providing this information. Further, the data gathered constitute a stand-along synthesis of meso-scale features. This study involves satellite analyses of ocean thermal fronts and other relevant thermal structures using AVHRR imagery; satellite analyses of sea surface height; and timely public dissemination of feature analyses and processed images.

The marine waters of the Northeastern Gulf are characterized by the transition from the highly turbid Mississippi River effluent (approximately 30% of which flows toward the east) and typical "blue" shelf water. Bottom sediments reflect this gradient, with a marked decrease in clay fraction from west to east. Previous work during the Mississippi-Alabama-Florida studies showed that there may be a sharp boundary between nutrient-rich mid-column water west of Cape San Blas and nutrient-poor water to the east. No studies have attempted to relate these characteristics to the physical circulation regime on the shelf, nor to the presumed periodic injection of new (possibly nutrient-rich) open Gulf water during eddy intrusions. Because the mean circulation in the area is believed to be quite weak, it is possible that the best means to identify any patterns might be through the careful study of the chemical regime. The *Chemical Oceanography & Hydrography of the Northeastern Gulf of Mexico* effort (initiated in 1997) is surveying the region to determine the overall levels and balances of chemical constituents and to identify and describe the chemical, physical, and biological mechanisms responsible for the observed levels, gradients, "sources," and "sinks."

Finally, the area possesses a rich mixture of benthic and pelagic faunas, dependent on the many different types of physical habitat present. As is typical of the coastal environment everywhere, a large part of the offshore fishery is dependent on the presence (and environmental quality) of estuaries for juvenile stage development or spawning. For these reasons, links between physical circulation and the habitat preferences or requirements of living marine resources are important. One notable example (although outside the area of discussion) is the very restricted timing and location for grouper spawning offshore Florida, and the known juvenile recruitment area in the grassbeds of the Florida Big Bend. The general current patterns on the west Florida shelf appear to be entirely contrary to the required transport of eggs and larvae, so unknown circulation mechanisms must be responsible for this critical movement. The study *Circulation Regimes Affecting Living Marine Resources in the Northeastern Gulf of Mexico* was originally scheduled to be the final study if this program. It was intended to make measurements at locations selected for their importance to significant marine resource species, in order to assess the importance of "normal" circulation regimes versus occasional extreme (or anomalous) events.

Biological/Environmental Sciences

Concurrent with the *Northeastern Gulf of Mexico Physical Oceanography Program*, the MMS initiated the *Northeast Gulf of Mexico Coastal and Marine Ecosystem Program.* This program designed with input from the State of Florida and the National Biological Service (now the Biological Resources Division of the USGS) was designed to characterized the environment; identify the biological resources at risk, leading to an understanding of ecological relationships of the area; characterize rare and endangered species and communities; and examine the effects of immediate and long-term impacts.

The component studies of the *Northeast Gulf of Mexico Coastal and Marine Ecosystem Program* include:

Northeastern Gulf of Mexico Offshore Data Search & Synthesis
Northeastern Gulf of Mexico Coastal Characterization and Data Information Management System
Distribution and Abundance of Marine Mammals
Ecosystem Monitoring, Mississippi/Alabama Shelf, and
Ecosystem Monitoring, Northeastern Gulf of Mexico OCS

The *Northeastern Gulf of Mexico Offshore Data Search and Synthesis* (SAIC 1997) was a regional data search and synthesis effort identifying and summarizing important information pertaining to the environmental and socioeconomic characteristics of this area. A conceptual model was drafted to serve as a framework to identify interactions in the ecosystem and look at critical pathways that may be uniquely sensitive to environmental impacts. Source materials were published documents as well as unpublished literature, theses, and dissertations. An annotated bibliography was compiled and a synthesis report brought together physical, chemical, ecological, and socioeconomic information into an ecosystem framework.

The Northeastern Gulf of Mexico Coastal Characterization and Data Information Management System characterized the coastal communities from the Mississippi Delta to Apalachicola Bay. The study area included all coastal counties extending offshore to the Federal leasing boundary. This study furthered our understanding of the coastal environment, how coastal habitats are impacted by offshore processes, and the interrelationship of coastal environmental and socioeconomic factors. The overall study purpose was to collect, organize, and analyze available information from various disciplines that would describe each part of the system in terms of its relation to other parts and to the region as a whole. As an integral component of this coastal characterization, a community profile describing the ecology of live bottom habitats was drafted (Thompson et al. 1999). This synthesis effort summarized available data on the living biological resources between the Mississippi River Delta and Cape San Blas, Florida.

Upon the receipt of the findings of its marine mammal field study, GulfCet I Program (Davis and Fargion 1996), the MMS identified the need for the further study of marine mammals. The *Distribution and Abundance of Marine Mammals* (GulfCet II), initiated in 1996, focused on the distribution, abundance, and behavior of these animals both on the OCS and in the deeper Gulf waters. The study area overlapped somewhat with the GulfCet I study area, but extended into shallower waters and into the area from approximately the Mississippi/Alabama state line eastward at least to Cape San Blas, Florida. The study produced data compatible with and comparable to that of the GulfCet I to produce a larger data set to be re-analyzed together. A 2- to 3-year extension of field observations provided for up to five years of seasonal distribution and abundance data in selected areas. This "cumulative" analysis provides better estimates of population variability, possible trend information, and increased detection for some species.

The study, *Ecosystem Monitoring, Mississippi/Alabama Shelf,* also initiated in 1996, is monitoring environmental conditions at three distinct types of topographic features present along the Mississippi-Alabama OCS. These features include: (1) high profile pinnacles of 2-20 m relief; (2) medium relief, flattop features of approximately 5 m; and (3) low relief hard bottoms of less than 5 m. Seasonal information is being gathered regarding populations and diversity of biological organisms related to turbidity, zonations, and other physical environmental parameters. The program includes observations of reef morphology, as well as sessile organism growth rates and diversity, changes in the nepheloid layer, and general community health. The third interim report for this study was received in 1999 (CSA and TAMU 1999).

As mentioned earlier, the *Offshore Data Search & Synthesis* effort brought together existing data, literature, and information relevant to the marine ecosystem and synthesizing it into a narrative report and conceptual model. This information was intended to identify data gaps and form the basis for planning of the last component of Program, *Ecosystem Monitoring, Northeastern Gulf of Mexico Outer Continental Shelf.* This monitoring study was to be designed to describe this ecosystem, including unique habitats and resources. It was to emphasize delineating processes at work on the OCS and critical processes that may be affected by OCS gas and oil operations.

Future Research

With oil and gas industry interest in the area under discussion (Fig. 1), the results of this workshop will be instrumental in designing the climax to the *Northeastern Gulf of Mexico Physical Oceanography* and *Coastal and Marine Ecosystem Programs*. As noted above, these two final studies, *Circulation Regimes Affecting Living Marine Resources in the Northeastern Gulf of Mexico* and *Ecosystem Monitoring, Northeastern Gulf of Mexico Outer Continental Shelf,* were identified early in the process, long before any preliminary results of the other studies were available. Discussion of such results now suggests that these two studies can not be designed separately. In fact, there is a strong reason to believe that these two efforts are so depended upon one another that a single combined effort is called for. This study (or series of studies), now referred to as *Northeastern Gulf Integrated Study of Physical and Biological Processes*, is now intended to identify and increase the qualitative and quantitative understanding of currents and circulation patterns which help establish links and redistribute primary and secondary productivity within the ecosystem. It may also lead to a better understanding of the distribution of nutrients and sediments; larval dispersal; and the impacts of extreme or occasional events such as eddy intrusions, upwelling, floods, and hurricanes on the ecosystem.

This new venue was used to design Figure 3 which shows how the component studies of the two aforementioned Programs, building upon other research in the area, lead to this meeting.

Workshop Structure

As a basis with which to begin a multidisciplinary discussion, MMS presented a list of "Initial Issues for Discussion" (Table 1) to pre-workshop registrants and workshop participants. On the first day of the workshop invited experts summarized knowledge of the De Soto Canyon and adjacent continental shelf region. Appendix A contains the schedule of invited presentations. Presentation summaries are given in section II.

Table 1. Initial Issues for Discussion.

Integration between the physical and biological components of the northeastern Gulf of Mexico:

1. Consider the transport of inorganic nutrients as these relate to supply and source(s). What are the utilization rates and their residence times on the shelf?

2. Consider the transport, deposition, and resuspension processes of materials (e.g., DOM, POM, POC, fecal pellets, corpses, marine snow, inorganic fines, and organisms) as these relate to supply and source(s). What are the proximate and ultimate fates of these materials?

3. What types and how do the ecosystems utilize the energy as subsidy? For example, how is the flow energy used to orient, disperse, clean, remove, and replenish wastes, oxygen, etc.

4. How, and to what extent, are the benthic assemblages related to substrate type (e.g., hard, soft), quantity (e.g., depth, patch size), and "quality" (e.g., percent organics, metals, depth or reduction potential discontinuity layer, or RPD)? Consider life stages of species and of faunal assemblages.

5. In addition to substrata, what specific physical environments "control" benthic communities?

6. How does the shelf ecosystem respond to prolonged and strong pulses of energy and materials? Is the response similar to those of other areas?

One the second day, three multidisciplinary working groups were formed by equally dividing, by area of expertise, the workshop attendees (Appendix C). Each working group was led by an invited chair and an MMS chair with the assistance from an MMS rapporteur. The participants in each working group are listed in Appendix B.

The members of each working group were asked to utilize the information syntheses provided by the speakers, combined with their own expertise, to: 1) identify the critical components and processes which need to be delineated, measured and modeled in order to understand the important physical and biological phenomena that occur in De Soto Canyon and adjacent continental shelf region; 2) identify significant knowledge and/or data gaps germane to these components and processes; and 3) formulate recommendations for research elements, based on the results from items 1) and 2). These discussions would then be used to assist MMS in designing an integrated physical and biological study to complete the *Northeastern Gulf of Mexico Physical Oceanography Program* and the *Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program.*

Each of the working groups employed different, but effective, approaches in their deliberations. The full day allocated for this phase of the workshop permitted sufficient opportunity for all conferees to present their views and interact constructively. The chairs and rapporteurs organized and recorded all the relevant material from discussions for inclusion in the working groups written reports. On the morning of the third day a plenary session was convened. This session began with the invited chairs presenting preliminary summaries of the draft reports being prepared by each of the working groups. The workshop ended with an open floor general discussion that allowed conferees to comment on the working group reports and/or to present any additional information or views. The working group reports appear in the last section of these proceedings.

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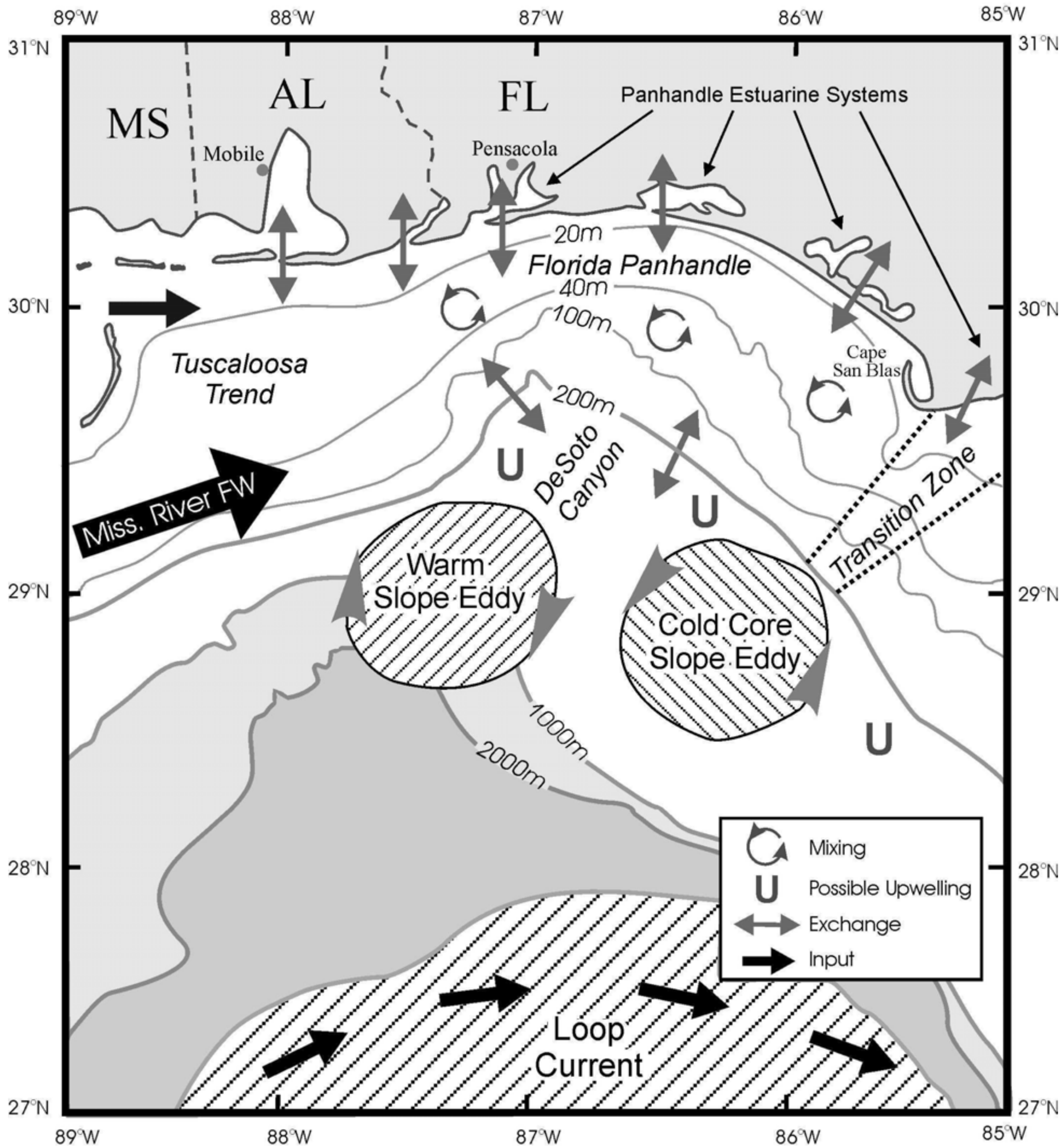

Figure 1. The geographic area of interest for this workshop is defined as an area encompassing the western portion of the Florida panhandle westward into Alabama and Mississippi and includes the De Soto Canyon and adjacent areas going into deeper waters.

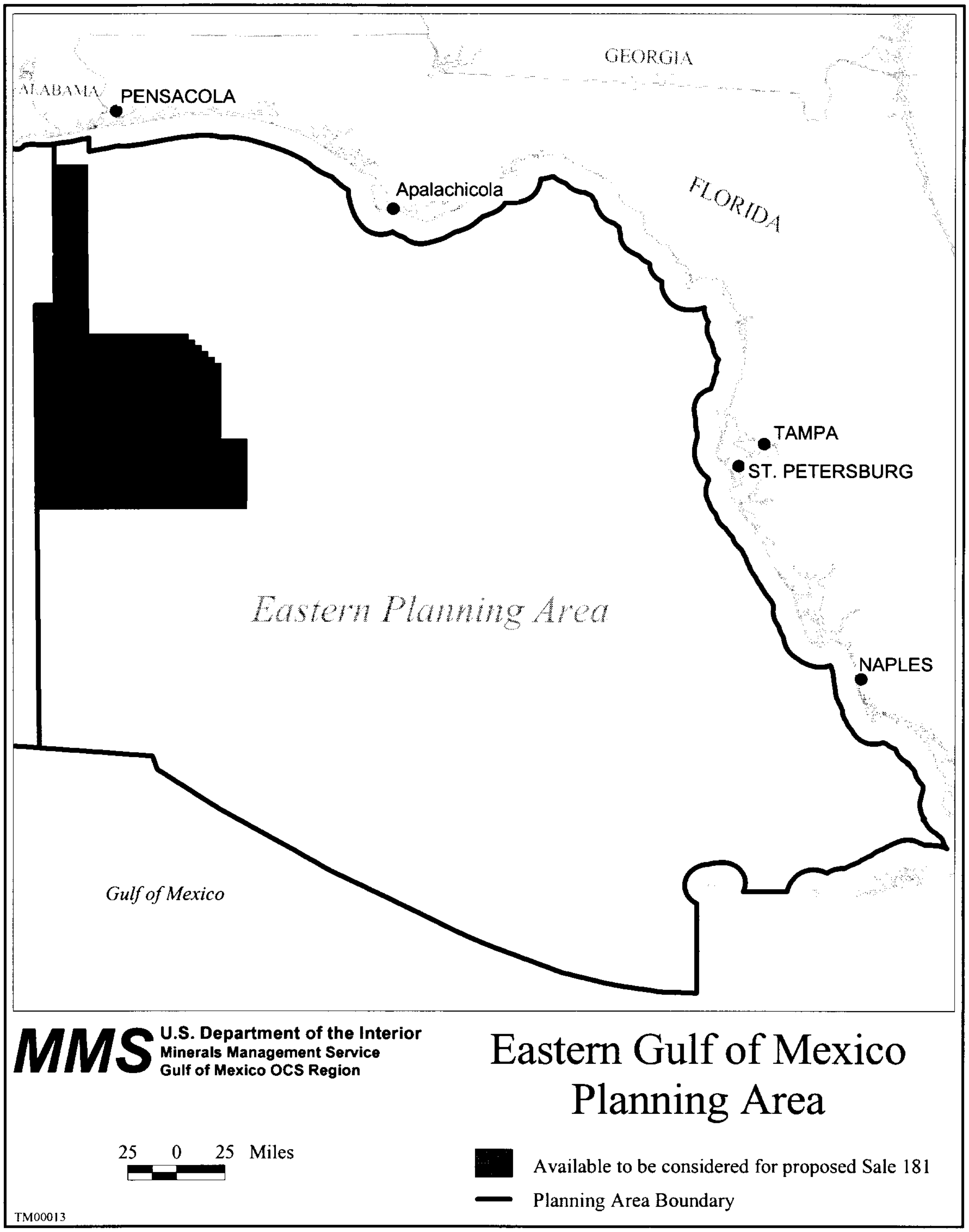

Figure 2. This is a depiction of the Eastern Planning Area including the area to be available for proposed lease Sale 181. Part of the proposed lease sale area was brought up during workshop discussion.

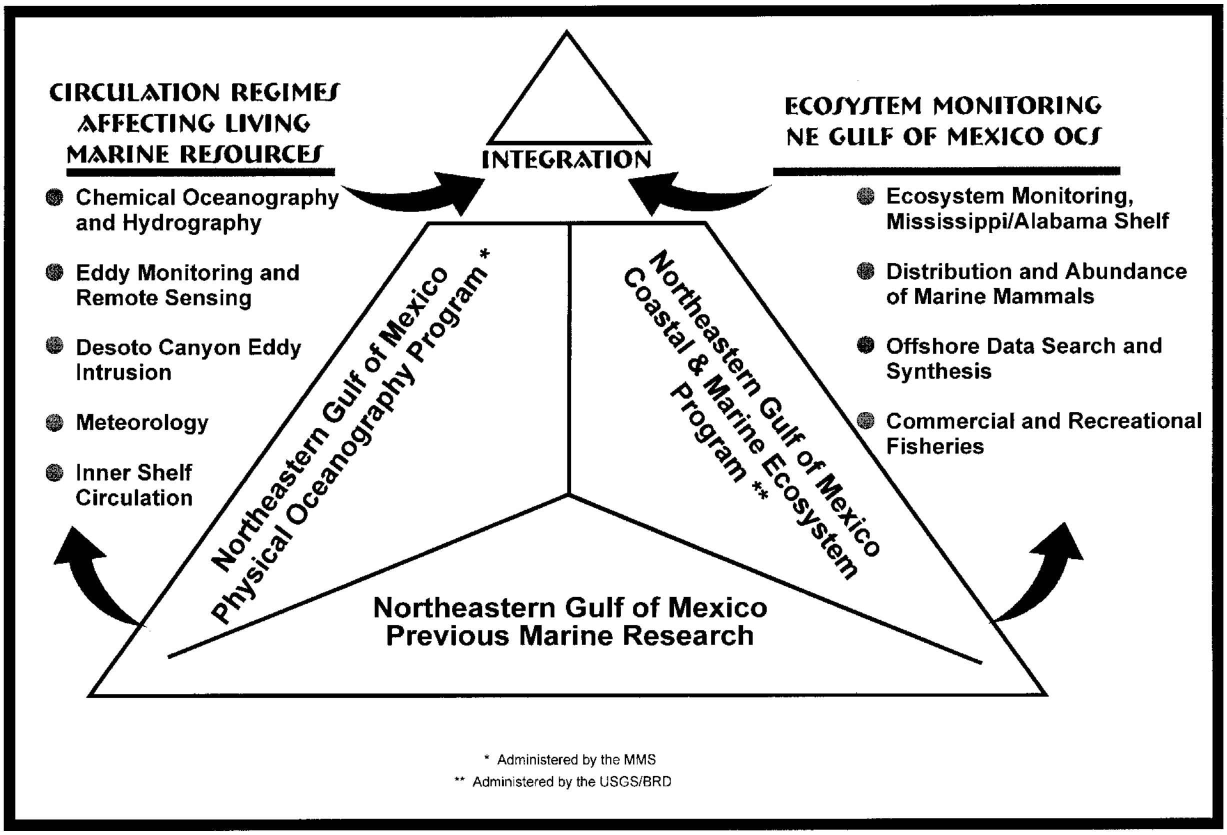

Figure 3. The physical/biological interaction workshop for the De Soto Canyon and adjacent shelf: the culmination of two regional research programs built on previous research.

II. INVITED PRESENTATIONS

MARINE METEOROLOGY AND AIR-SEA INTERACTION OVER THE DE SOTO CANYON AND ADJACENT SHELF - A SUMMARY

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Louisiana State University
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Marine meteorology and air-sea interactions are integral parts in the total systems approach to study oceanographic processes. This presentation intends to cover the characteristics of mesoscale marine meteorology, air-sea interactions, and the physics of the atmospheric boundary layer over the northeast Gulf of Mexico. Emphases are placed on marine cyclogenesis, heat flux, wind-wave interaction, and the way(s) in which these phenomena influence the oceanographic regime or could affect physical/biological systems. They are summarized as follows:

1) From a synoptic climatological viewpoint, the march of seasons can be represented by four major weather types: the Gulf Return for spring, Gulf High for summer, Continental High for fall, and Frontal Overrunning for winter.

2) Analyses of total heat fluxes (sensible and latent) shown in Figure 4 are based on the following equations:

$$H_{Total} = H_{Sensible} + H_{Latent} = \left(1 + \frac{1}{B} \right) H_{Sensible} \quad \textbf{(1)}$$

where

$$H_{Sensible} = \rho \; C_p \; C_T \; (T_{sea} - T_{air}) \; U_{10} \quad \textbf{(2)}$$

$$H_{Latent} = L_T \; E = \frac{H_{Sensible}}{B} \quad \textbf{(3)}$$

and

$$B = 0.077 \; (T_{sea} - T_{air})^{0.70} \quad \textbf{(4)}$$

It can be seen that approximately from November through March the largest total heat flux is found in the shelf break area (represented by buoy #42009) rather than over the Loop Current region as represented by buoy #42003. The lowest values are found in the shallow water region represented by buoy #42007.

3) Monthly characteristics of precipitation (P) and evaporation [E, computed from Eq. (3)] over the shelf break (at buoy #42009) and shallow water environments (buoy #42007) are provided in Figure 5. For comparison purposes, the rainfall rate at Mobile, Alabama is also

delineated. It can be seen that approximately from September through April the evaporation in the shelf break region is persistently higher than in the shallow water area. Note that from September through March, E > P over the shelf break region whereas similar conditions exist from September through January over the shallow water areas.

4) Monthly characteristics of geostrophic vorticity and Ekman pumping are shown in Figure 6. Due to winter cyclogenesis and frontal overrunning, both curves peak in the winter season. For example, approximately 1.8 m per day exists for the Ekman pumping in December. This directly impacts primary productivity. Comparison of these characteristics to other regions in the Gulf will be discussed.

5) From an atmospheric boundary layer physics viewpoint, the free convective regime is found along the shelf break region. Also, because the wave conditions in the study area are mainly fetch-limited, an evaluation of nine related wind-wave interaction formulas is made. It is found that the formula suggested by Dobson et al. (1989) performed the best, which relates U_{10}, the wind speed at 10 m, F, the fetch, H_s and T_p, the significant wave height and its corresponding period that

$$\left(\frac{g\ T_p}{U_{10}} \right) = \frac{1}{1.7} \left(\frac{g\ F}{U_{10}^2} \right)^{0.24} \quad \textbf{(5)}$$

and

$$\left(\frac{g\ H_s}{U_{10}^2} \right) = 0.00897 \left(\frac{g\ T_p}{U_{10}} \right)^{1.65} \quad \textbf{(6)}$$

For the wind-wave-current interaction, the following formula is suggested for momentum flux (τ) and surface drift (u_s) studies in our area:

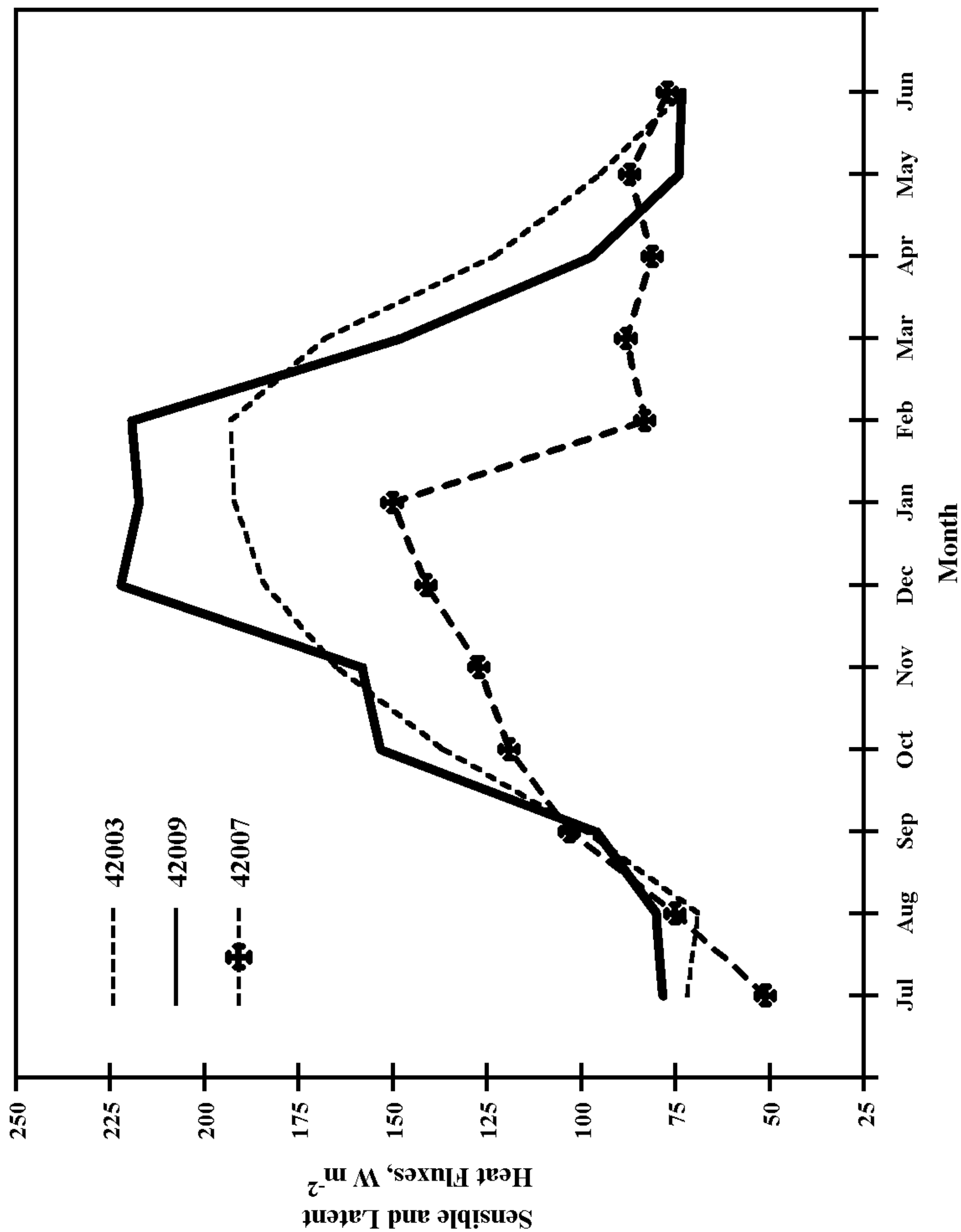
$$\tau = \rho\ u_*^2 \quad \textbf{(7)}$$

$$u_* = \frac{0.4\ U_{10}}{11.0 - \ln \left[\dfrac{H_s}{\left(\dfrac{C_p}{U_{10}} \right)^{2.6}} \right]} \quad \textbf{(8)}$$

and

$$u_s = 0.55\ u_* \quad \textbf{(9)}$$

where C_p (=gT_p / 2π) is the phase speed of the waves at the spectral peak. Note that the wave age C_p / U_{10} is related to Eq. (6). Other implications to wind-wave-current interaction and dispersion meteorology will also be discussed.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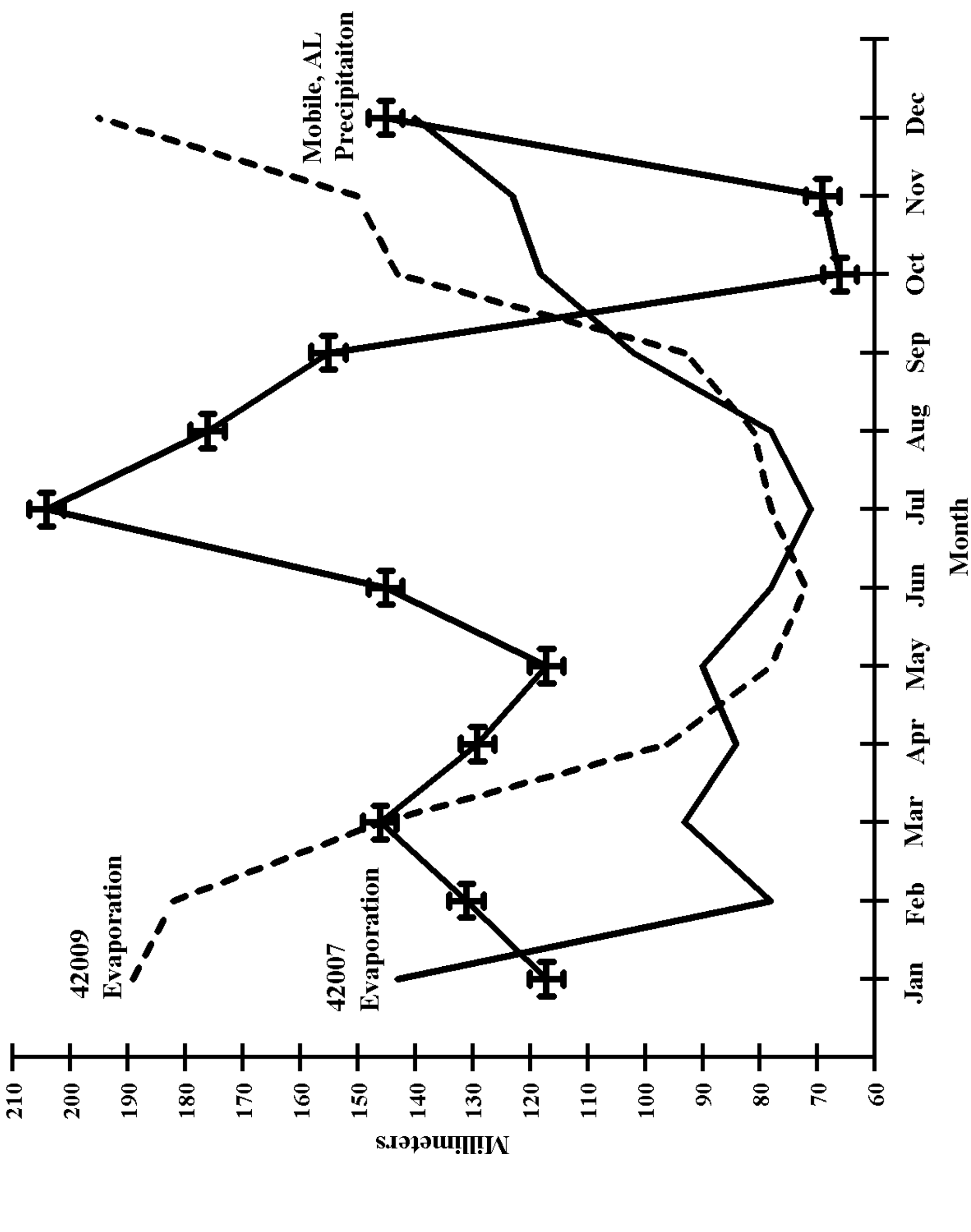
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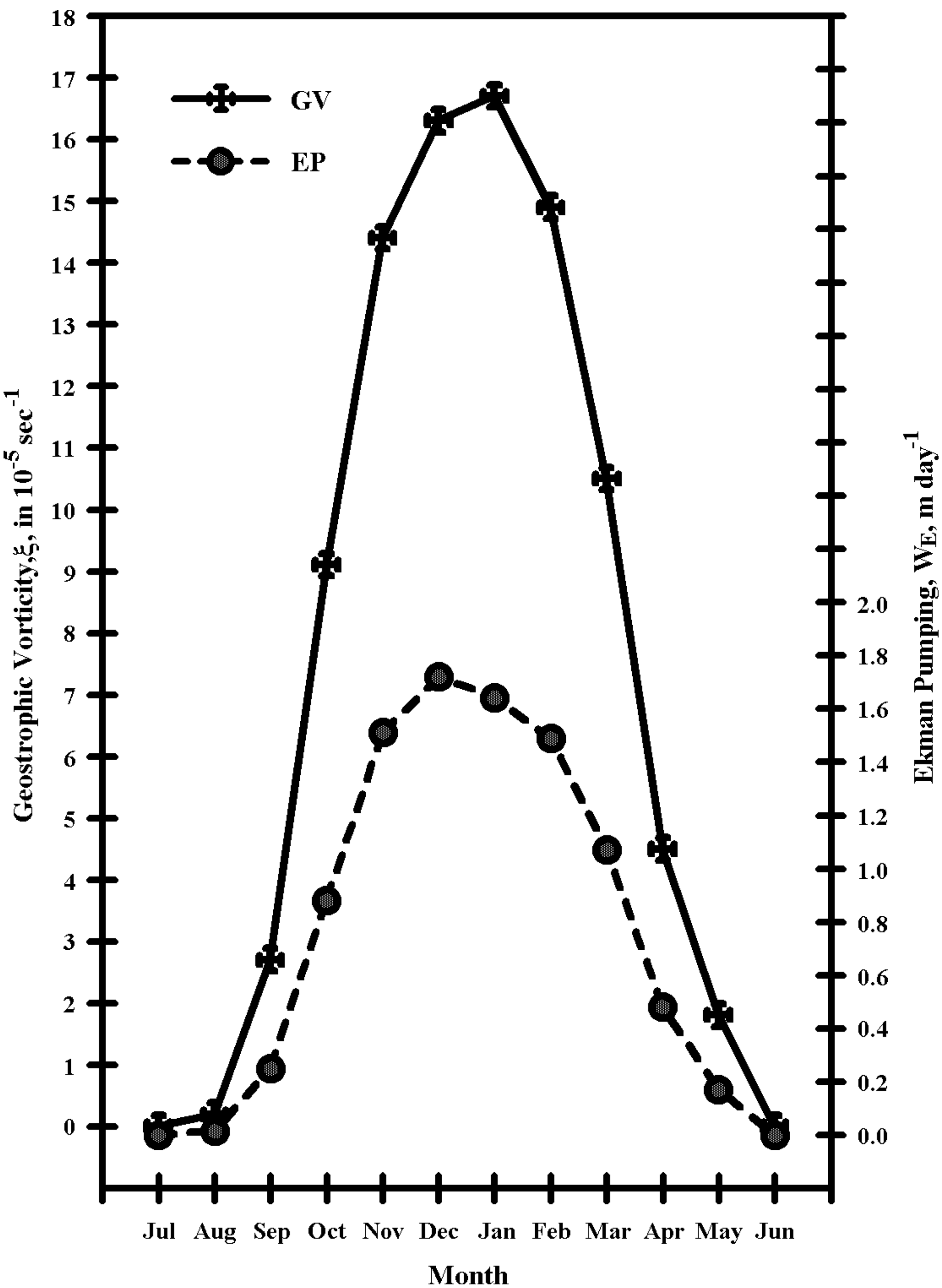

Figure 6. Monthly characteristics of geostrophic vorticity (GV) and Ekman pumping (EP) over the northeast Gulf of Mexico.

Biographical Sketch

Dr. S. A. Hsu has been a Professor of Meteorology at LSU since 1969, after he received his Ph.D. in Meteorology from the University of Texas at Austin. He is the author of *Coastal Meteorology* (Academic Press 1988) and numerous papers on coastal and marine meteorology and air-sea interaction. Dr. Hsu is also an AMS Certified Consulting Meteorologist.

Shelf Hydrography Over the Northeastern Gulf of Mexico

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Texas A&M University is conducting the Chemical Oceanography and Hydrography Study (NEGOM-COHS), which is one of the components of the Northeastern Gulf of Mexico Physical Oceanography Program, supported by the U.S. Minerals Management Service (MMS). The major objective of NEGOM-COHS is to describe the spatial and temporal distribution and variation of hydrographic variables and the processes responsible. The variables of interest are sea water salinity, temperature, dissolved oxygen, nutrients, particulate material, particulate organic carbon, transmissivity, fluorescence, pigments, and light penetration. The objective is being met through the completion of a field program of nine hydrography/acoustic Doppler current profiler (ADCP) cruises, one in each of the spring (May), summer (August), and fall (November) seasons over three years. The observations, together with collateral data, will be synthesized, interpreted, and reported to provide a more complete understanding of circulation and transport of properties over the study area.

The study area encompasses the east Louisiana, Mississippi, Alabama, and west Florida continental shelf and upper slope from the Mississippi River Delta to Tampa Bay in water depths of 10 to 1000 m. The first cruise was conducted in November 1997, the last will be in August 2000. Approximately 100 CTD and 90 XBT stations, in a configuration of 11 cross-shelf lines and one alongshelf line on the 1000 m isobath, are occupied on each cruise (Fig. 7). Station locations are approximately the same for each cruise to facilitate comparisons between cruises. Additionally, ADCP, thermosalinograph, and 3 m flow-through fluorescence measurements are made continuously along the track.

Although the final year of hydrographic surveys remains to be done, the six cruises already completed provide a preliminary look at the seasonal variability of the properties and inferred circulation over the region. To examine the circulation over the shelf at the time of the cruises, we constructed gridded current vector fields from the ADCP data for the near surface (10-14 m) and several subsurface layers. We compared the near-surface ADCP fields to the geopotential anomaly fields computed from the hydrographic data and to sea surface height anomaly fields derived from satellite altimeter data.

We examined the seasonal circulation on three sub-regions: the western inner shelf, eastern inner shelf, and outer shelf/upper slope. Here "inner shelf" extends from approximately 10 m to 100 m and "outer shelf" is seaward of 100 m. The western inner shelf consists of the region west of Cape San Blas. The eastern inner shelf includes that part of the shelf southeast of Cape San Blas in the Big Bend region to Tampa. The outer shelf/upper slope is that region in water depths from about 100 m to 1000 m. The focus of this paper is on the near-surface circulation and property distributions.

Spring (May 1998 and May 1999*)*

Western Inner Shelf: The springtime near-surface currents flow downcoast from Mississippi toward Tampa (Fig. 8a). This is mainly in response to the eastward alongshelf component of the wind, which also induces some nearshore coastal upwelling. The currents moved fresh water being discharged onto the shelf from the Mississippi and other rivers along the inner shelf to the east (Fig. 8b). In 1998, both the Mississippi and Tombigbee Rivers were discharging at above their record-length mean discharges, resulting in salinities at 3 m of <32 over much of the western inner shelf extending east to Cape San Blas. The salinity pattern shows large volumes of fresh water coming from the Mississippi and out of Mobile Bay. In 1999, however, the salinity pattern shows a smaller region with salinity of <32, extending only to Choctawhatchee Bay.

River water carries nutrients into the Gulf. The 3 m silicate (silicate at a 3 m depth), which is not a limiting nutrient for biological activity, had high concentrations (>3 mM) all along the western inner shelf during both spring cruises. The 3 m nitrate values, however, were high (>1 mM) mainly in the region adjacent to the Mississippi River Delta and seaward off the Chandeleur Islands. Concentrations near the mouth of the Mississippi were exceedingly high (>30 mM) in 1999 as compared to ~15 mM in 1998. There were localized high nitrate concentrations adjacent to Choctawhatchee Bay in 1998. The 3 m phosphate values were <0.1 mM everywhere except immediately off the mouth of the Mississippi River; concentrations in 1999 were higher than in 1998. Chlorophyll *a* concentrations showed response to the nutrients from the river water and were relatively high (>500 $ng{\cdot}L^{-1}$) along the entire western inner shelf in 1998 and from Choctawhatchee Bay west in 1999. The near-bottom dissolved oxygen concentrations in spring 1998 generally were lower and less variable than those in spring 1999, although lowest, hypoxic values occurred in 1999. Lowest values, at 2.1 $mL{\cdot}L^{-1}$ in 1998 and 1.5 $mL{\cdot}L^{-1}$ in 1999, were off the Chandeleur Islands.

Eastern Inner Shelf: In spring 1998, near-surface currents were weak and directed mainly downcoast over the broad middle shelf, possibly in response to the northeastward-directed winds (Fig. 8a). Inshore of about the 20 m isobath, currents were directed mainly toward the shore. The pattern of spring 1999 currents in this region is very different. Here there is indication of a cyclonic circulation over the broad middle shelf centered at about 28.75°N, 84.5°W, with flows inshore of this feature directed mainly westward. Salinities at 3 m were fresher in 1998 than 1999, with lowest values in 1998 being <32 inshore of the 20 m isobath off the Suwannee River (Fig. 8b) and lowest in 1999 being ~35. The salinity contours in 1998 generally parallel the isobaths with salinities increasing offshore, but in 1999 they indicate a tongue of higher salinity (>36) water moving upcoast from the south. This likely is due to the cyclonic circulation drawing saltier water to the north and east, possibly from offshore.

Nutrient, chlorophyll *a*, (chl *a*) and dissolved oxygen patterns also differ between the two springs. In 1998, a tongue of locally high silicate extended from Cape San Blas south over the broad eastern inner shelf. This likely was due in part to the downcoast movement of waters associated with the river discharges over the western inner shelf, coupled with the downcoast movement of discharge from the Apalachicola River. Nitrate and phosphate concentrations, however, were very small. Much of the eastern inner shelf in 1998 had chlorophyll *a* concentrations in excess of 300 $ng{\cdot}L^{-1}$, increasing inshore. Bottom oxygen concentrations were generally less than 4 $mL{\cdot}L^{-1}$, except inshore of the 10 m isobath where they were <5 $mL{\cdot}L^{-1}$. In contrast, the 1999 concentrations of all nutrients, including silicate were very small everywhere over the eastern inner shelf, and near-bottom dissolved oxygen concentrations were approximately 5 mL·L^{-1}. There was a local high in chl *a* (300-500 ng·L^{-1}) centered about 29.3°N, 84°W offshore of the Suwannee River.

Outer Shelf/Upper Slope: Satellite altimeter data allow the estimation of the sea surface height anomaly (SSHA) fields that can provide information on the presence or absence of anticyclonic (highs in SSHA) or cyclonic (lows in SSHA) features seaward of the shelf edge. SSHA maps indicate that during spring 1998, an anticyclonic eddy was located seaward of the western shelf edge. The anticyclone had two centers: one situated over De Soto Canyon and the other centered at 27.5°N, 86.3°W. The stronger SSHA gradients were over the outer shelf/upper slope adjacent to the eastern inner shelf. The centers from the SSHA data match reasonably well the centers in geopotential anomaly, although those of the SSHA are offset mainly to the west. The SSHA gradients, which are greatest adjacent to the eastern inner shelf, match well with the regions of stronger currents in ADCP (Fig. 8a). The 3-m salinity field shows a tongue of more saline water extending up the axis of DeSoto Canyon. This is in the region where the anticyclone generates northeastward currents. The resulting chl *a* field shows a region of lower concentrations up the axis of the canyon. The circulation and property distributions over the outer shelf/upper slope, therefore, were responding to the presence of this anticyclonic eddy. During spring 1999, a cyclonic eddy was located southwest of De Soto Canyon with weak lows adjacent to the shelf edge. The Loop Current was adjacent to the upper slope south of Tampa. The ADCP field shows the circulation over the outer shelf/upper slope was not as well organized as in spring 1998. The influence of the Loop Current was apparent in strong, anticyclonic, southward currents over the upper slope west of Tampa; these currents extended at least to 100 m as measured by the ADCP. In both springs, the salinity was higher over the outer shelf/upper slope than over the inner shelf (Fig. 8b). The region with the higher nutrients and chlorophyll *a* concentrations was off Louisiana, Mississippi, and Alabama and was associated with the discharge of the Mississippi River.

Summer (August 1998 and August 1999)

Western Inner Shelf: Summertime currents over the western inner shelf were weak and not well organized, but with some indication of reversal of the springtime downcoast flow conditions to upcoast flow (Fig. 9a). Winds were weaker than in spring, and differed in direction between the two cruises with a westward component during 1998 and an eastward component during 1999. During 1998, there was a low in geopotential anomaly over the head of De Soto Canyon associated with a cyclonic circulation along the 100 m isobath. In 1999, the currents show no such cyclonic circulation, but rather exhibit downcoast flow along the 100 m isobath. The salinity at 3 m in both summers was freshest off the Mississippi River Delta and was generally greater than 32 elsewhere (Fig. 9b). Off Panama City, salinities were highest nearshore; this was related to the offshelf circulation discussed below. Silicates were high off the Mississippi River and also off Pensacola Bay. Nitrates and phosphates were elevated only off the Mississippi River Delta, where chl *a* concentrations also were the highest over the western inner shelf. Lowest bottom oxygen concentrations (<3 mL·L^{-1}) were associated with the region of highest chl *a*. Hypoxia at the bottom occurred along line 4 in about the 25 m water depth (Fig. 10).

Eastern Inner Shelf: Summertime near-surface currents over the eastern inner shelf were weakly cyclonic, with a center at about 28.5°N, 84°W in 1998 (Fig. 9a). The pattern extended into the water column, but with the center shifted westward. In contrast, the near-surface currents in 1999 (not shown) were weakly anticyclonic, mainly north of 28.7°N, with a center at about 29°N, 84.3°W. Inshore of the

20 m isobath south of 28.7°N, currents were directed south. The 1999 pattern did not extend into the water column. The contours of salinity at 3 m in 1998 generally paralleled isobaths, with higher salinities inshore (Fig. 9b). Preliminary results indicate a similar pattern for 1999. This pattern is related to the conditions at the outer shelf. In 1998, nutrients were low and bottom dissolved oxygen concentrations were high over all the eastern inner shelf. Chlorophyll *a* values were less than 300 $ng \cdot L^{-1}$ everywhere except between the Apalachicola and Suwannee rivers. This is consistent with the movement of Suwannee River water northwest in association with the cyclone located over the shelf.

Outer Shelf/Upper Slope: The SSHA map for the summer cruise 1998 shows an anticyclonic eddy was located seaward of the western shelf edge, with its center near 28.5°N, 87.5°W and elongated NW-SE between the Mississippi River Delta and the west Florida terrace. The ADCP near-surface currents show the strong anticyclonic response of the upper slope circulation to this eddy (Fig. 9a). The eddy drew water from the Mississippi River along the outer shelf/upper slope from the delta eastward. The effect can be seen in the 3 m salinity map (Fig. 9b) which shows very fresh waters (<30) over the eastern flank of De Soto Canyon and along the 1000-m isobath. This results in the condition of saltier water being located inshore over the shelf east of about 87°W. Silicates are high (up to 10 mM) over the upper slope east of De Soto Canyon as compared to the inner shelf values of order 1. Other nutrients are very small, due to consumption as indicated by the region of high chl *a* (>500 $ng \cdot L^{-1}$) co-located with the low salinities/high silicates at the outer shelf/upper slope. Indications are the results for 1999 will be similar, which might be expected from the presence of anticyclonic features adjacent to the 1000-m isobath during the summer 1999 cruise.

Also present over the outer shelf/upper slope in summer 1998 was a small cyclone located at the head of De Soto Canyon (Fig. 9a). Associated with this feature is an uplift in the various water properties, including dissolved oxygen as shown in Figure 10. This is an example of localized upwelling. The presence of small cyclones near the shelf edge with associated upwelling was seen in other seasons as well.

Fall (November 1997 and November 1998)

Western Inner Shelf: The near-surface circulation over the western inner shelf in fall was highly variable in direction and magnitude, most likely due to the frequent passage of cold fronts through the area (Fig. 11a). During both cruises, the average winds were directed approximately west to southwest over the western inner shelf. In each, the fall pattern of circulation included an elongated, but weak cyclone over the Mississippi-Alabama shelf. This pattern was strongest in 1998 (not shown). In fall, when river discharge is smaller than spring, the salinity concentrations at 3 m were lowest immediately adjacent to the Mississippi River Delta (Fig. 11b). However, in contrast to the two summer cruises, the salinity east of the delta went from lower nearshore to higher offshore. The contours also approximately follow the isobaths, except near the Mississippi River Delta. The gradient was steeper in 1998 than in 1997, reflecting the higher river discharge in 1998. This difference also is reflected in the patterns and concentrations of nutrients at 3 m. The 1998 conan order of magnitude or more off the delta than in 1997. In both years, localized high silicates occurred offshore of Pensacola and Choctawhatchee Bays. Nitrate and phosphate were low (generally less than 0.1 mM) over the western inner shelf except adjacent to the Mississippi River Delta in 1998. Chlorophyll *a* concentrations were less than 500 $ng \cdot L^{-1}$ except adjacent to the delta. Bottom dissolved oxygen concentrations were high over the western inner shelf, as expected from vertical mixing induced by passage of cold fronts through the area in fall.

Eastern Inner Shelf: Geopotential anomalies over the eastern inner shelf in fall exhibited pairs of high and low features, where the dynamic range was approximately 5 dyn cm. In 1997, the low was centered near 28.5°N, 83.5°W and the high near 28.5°N, 85°W. The near-surface currents, however, do not indicate that these were well-developed circulation features (Fig. 11a). Rather, flows over the eastern inner shelf tended to bifurcate at about 29°N, with flows directed northwestward north of that latitude and flows directed southward to the south of it. The north-south order of the high-low pair in 1998 was reversed from that of 1997, with the low centered at about 28.3°N, 83.7°W and the high at about 29°N, 84°W. No near-surface currents are available for this cruise. The 3 m salinities in both years are between 34 and 36, with lower values inshore (Fig. 11b). Nutrient values are low. Bottom dissolved oxygen concentrations are high, although the values in 1997 are generally higher than in 1998. The chlorophyll *a* patterns are somewhat different in the two years. The concentrations in 1998 are lower, ranging from <100 to ~400 $ng{\cdot}L^{-1}$, compared to 1997, which range from about 200 to 3000 $ng{\cdot}L^{-1}$. The highest values in 1998 were inshore just northwest of the Suwannee River; winds in this region during the cruise were toward the west. The highest values in 1997 were inshore south of the Suwannee River; winds during this cruise were directed to the south-southwest. Thus, these chl *a* patterns may reflect movement of Suwannee River water by the winds.

Outer Shelf/Upper Slope: During both fall cruises, a weak anticyclonic eddy was located seaward of the western shelf edge, with lows in SSHA adjacent to the west Florida shelf. The currents over the outer shelf/upper slope indicate a response to the presence of these SSHA patterns. For example, associated with the anticyclone in 1997 were eastward currents over the outer shelf/upper slope just west of the delta and southward flow associated with the SSHA lows over the upper slope off Tampa (Fig. 11a). Except where influenced by the discharge from the Mississippi River in the west, property distributions in this region show patterns of low nutrients and chl *a* and salinities that are higher than those over the adjacent inner shelf.

Summary

The preliminary results of the first six NEGOM-COHS cruises indicate a seasonal pattern to the circulation over the shelf. In spring, the wind field generally forces an eastward flowing coastal current over the inner shelf west of Cape San Blas. This transports nutrient-rich, fresh river water eastward along the coast. East of Cape San Blas there is no indication of an anticyclonic circulation in the Big Bend region; rather, there are indications of possible cyclonic flow. In contrast to the spring, there is no large alongshelf flow over the inner shelf in the fall season. Flows over the outer shelf were not strong either. This caused the effects of the discharge of the Mississippi and other rivers to be localized near the river mouths and offshore of the sounds, as apparent in property distributions. In summer, the major circulation feature seen on the NEGOM cruises was fresher water being drawn along the outer shelf in response to the presence of anticyclonic and cyclonic eddies over the slope adjacent to the shelf edge. In all seasons, the presence of such anticyclonic or cyclonic eddies adjacent to the shelf edge influenced the circulation, and hence the property distributions, over the outer shelf and upper slope.

Figure 8. Spring NEGOM Cruise N2, 5-16 May 1998, (a) gridded ADCP-measured currents at 14 m and geopotential anomaly (4db re 800db) and (b) salinity at ~3.5 m.

Figure 9. Summer NEGOM Cruise N3, 25 July - 7 August 1998, (a) gridded ADCP-measured currents at 14 m and geopotential anomaly (4db re 800db) and (b) salinity at ~3.5 m.

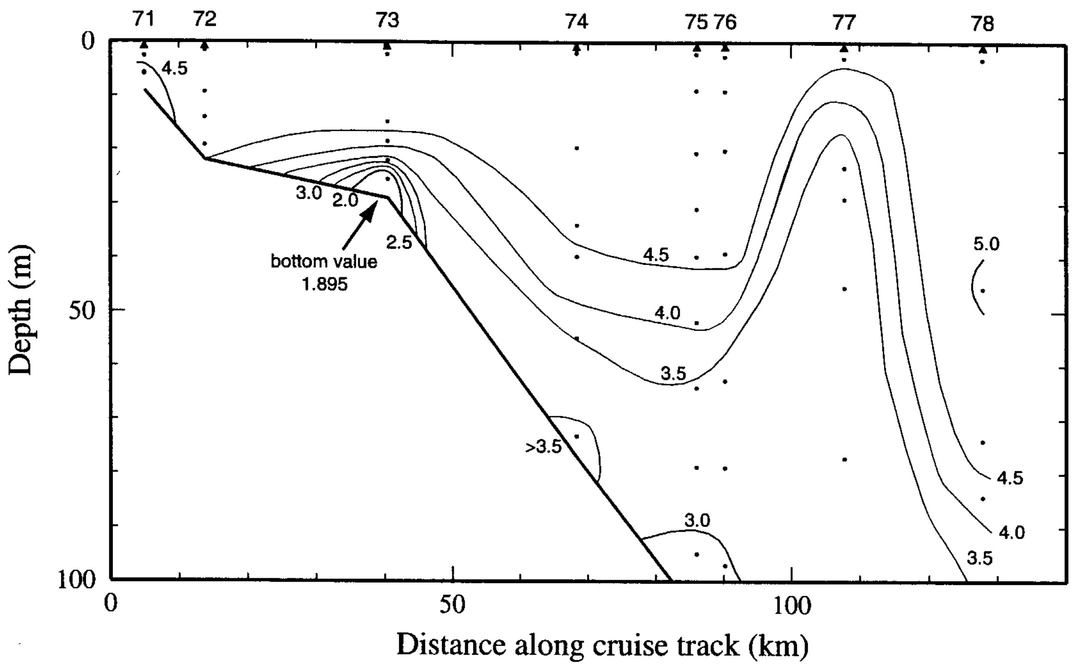

Figure 10. Dissolved oxygen (mLA L^{-1}) on line 4 of NEGOM cruise N3, 26 July-6 August 1998.

Figure 11. Fall NEGOM Cruises (a) N1, 16-27 November 1997, gridded ADCEP-measured currents at 10 and 12 m and geopotential anomaly (4db re 800db) and (b) N4, 13-24 November 1998, salinity at ~3.5 m.

Biographical Sketches

Dr. Ann E. Jochens is an Associate Research Scientist in Oceanography at Texas A&M University. She came to physical oceanography as a mathematician and attorney with extensive experience in environmental safety and permitting in the oil and gas and minerals industries. She received the J.D. from the University of Oregon and the M.S. and Ph.D. in Oceanography from Texas A&M University. She was Deputy Program Manager for the MMS-sponsored Texas-Louisiana Shelf Circulation and Transport Processes Study (LATEX A) of the Louisiana-Texas Shelf Physical Oceanography Program (LATEX). She presently serves as Deputy Program Manager of the MMS-sponsored Northeastern Gulf of Mexico Physical Oceanography Program: Chemical Oceanography and Hydrography Study (NEGOM-COHS) and as a Principal Investigator for the MMS-sponsored Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data Study (Deepwater). Her research interests are processes at the boundary of coastal and open oceans; Gulf of Mexico physical oceanography; meso- and large-scale ocean circulation and property distributions, with emphasis on shelf and slope regions; ocean law and policy; and research planning and management.

Dr. Worth D. Nowlin, Jr., is a Distinguished Professor of Oceanography at Texas A&M University. He has served over 35 years in teaching and research, including extensive experience in managing ocean research programs and in formulating and carrying through large, long-term physical oceanographic field studies. He was Program Manager for LATEX A, and is the Program Manager for NEGOM-COHS and Deepwater. His principal professional interest areas, in which he has authored or co-authored over 50 refereed publications and many more reports, are meso- and large-scale distributions of oceanic properties and circulation, long-term and systematic ocean observations for climate studies, and research planning and management. He received the M.S. in Mathematics and the Ph.D. in Oceanography from Texas A&M University.

Dr. Steven F. DiMarco is an Assistant Research Scientist in Oceanography at Texas A&M University. He was a member of the LATEX A scientific team, is a scientist on NEGOM-COHS, and is a Principal Investigator for Deepwater. His research interests include large-scale ocean transport, continental shelf physical oceanography, mixed layer dynamics, nonlinear surface wave interaction, impact of extreme events on shelf circulation, tidal currents and heights in the Gulf of Mexico, oceanographic database management, Texas decadal scale climatic variation, and directional wave measurement. He received his M.S. and Ph.D. in Physics from the University of Texas at Dallas.

Dr. Matthew K. Howard is an Assistant Research Scientist in Oceanography at Texas A&M University. He has served as scientist on the LATEX A program and serves as a Principal Investigator on NEGOM-COHS and Deepwater. His research interests include coastal and blue-water oceanography, especially of the Gulf of Mexico, data quality control and data base management, near real-time data delivery systems, numerical models of ocean circulation, circulation over steep topography, and computer visualization and Internet information delivery systems. He took his B.S. in Physical Oceanography from Humboldt State University and his Ph.D. in Oceanography from Texas A&M University.

Professor Robert O. Reid is Distinguished Professor of Oceanography, Emeritus, at Texas A&M University. He has 48 years of service in teaching and research spanning the fields of physical oceanography, meteorology, and coastal engineering. He received his M.S. in Oceanography from Scripps Institution of Oceanography. He is a Principal Investigator for LATEX A, NEGOM-COHS, and Deepwater. His research interests, as reflected by over 80 publications, range from analytical and numerical studies of ocean circulation, storm surges, tide and tsunamis to surface waves dynamics, estuarine circulation, modeling of dense plumes, wave forces on structures, and stochastic modeling.

Mr. Ou Wang is a Graduate Assistant-Research in Oceanography at Texas A&M University. He received his B.S. in Oceanography from Ocean University of Qingdao, Qingdao, China, with graduate studies at the Second Institute of Oceanography, State Oceanic Administration, Hangzhou, China. He presently is enrolled as a doctoral student in Oceanography at Texas A&M University, where his research is focused on examination of pycnobathic effects over the shelf and slope using hydrographic and ADCP observations.

Dr. Joseph Yip is an Assistant Research Scientist in Oceanography at Texas A&M University. His research interests are continental shelf dynamics, coastal oceanic and atmospheric prediction system implementation, and data assimilation. He has developed and implemented an automated shelf circulation now/forecast system for the Texas-Louisiana shelf region for an oil spill prevention and response program sponsored by Texas General Land Office and is a scientist on NEGOM-COHS. He received his Ph.D. in Oceanography at Texas A&M University.

DE SOTO CANYON CIRCULATION AND EXCHANGE

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Introduction

The De Soto canyon is the corner region of the slope between the wide west Florida shelf and the Mississippi delta. Circulation in the canyon and on the upper slope is expected to be a strong influence on the exchange of properties and biological organisms between the shelf and the deep waters of the eastern Gulf of Mexico. Satellite sea surface temperature (SST) imagery has shown that, on occasion, Loop Current (LC) or Loop Current eddy derived water can be transported north onto the narrow shelves of Alabama and the Florida Panhandle. Similarly, it is known that Mississippi brackish water can be transported east and south of the delta and be entrained into the LC. Transport mechanisms are strongly influenced by the eddy field over the northeastern Gulf of Mexico (NEGOM) slope. SAIC, under MMS funding, has recently completed a two-year (March 1997 to April 1999) intensive field study of the NEGOM slope employing 15 moored current meter arrays and regular hydrographic surveys at four month intervals. The positions of the moorings and CTD stations from a typical survey are given in Figure 12. Preliminary results from ongoing analyses by a team of Principal Investigators are presented below.

Eddy Circulation

The NEGOM slope is dominated by eddies which are similar in character to eddies found on the Louisiana and Texas slopes, west of the delta. Eddy diameters range from about 20 km to about 100 km with the larger diameters more likely to be found on the lower slope. There is evidence from remote sensing that the larger eddies may be related to peripheral or frontal eddies of the LC or major LC anticyclones. These types of eddies are often cyclonic but over the slope both cyclonic and anticyclonic circulation are found. The eddy scales over the slope are such that they are often not very well resolved even with the high resolution of present generation, numerical circulation models of the Gulf. Figure 13 shows the near-surface geostrophic velocity map derived from the April 1998 hydrographic cruise. Two adjacent cyclones are on the lower slope with a number of smaller cyclones and anticyclones over the shelf break and head of the canyon. In this case, the vigorous circulation of the cyclones has transported warm salty water originating from a recently detached LCE towards the slope (Fig. 13b). A more common circulation is for upper layer anticyclones to form an eastward flowing, upper- slope jet with a counter flow below about 200 m. Figure 14 shows the surface circulation in March 1997, and the depth structure of the geostrophic velocity field along transect B (see Figure 12). In this case, the surface eastward flows bypass the head of the canyon and continue southeastward along the west Florida slope. A weak cyclonic-anticyclonic pair of eddies has formed over the head of the canyon. This type of flow easily transports the low salinity water, from near the delta, eastwards over the slope and into deep water. The time series of currents, salinity and temperature from the moored array confirm the validity of the geostrophic calculations and also show an upper-layer eastward mean flow along the upper slope. The mean flows also show a weak cyclonic circulation over the head of the canyon particularly at depths greater than ~ 40 m. The relative isolation of the canyon from the eddy driven flows of the lower slope may be a possible larval retention mechanism.

Variability

There are many different period motions (excluding tides and inertial motions) observed in the time series. They range from relatively rapid fluctuations ~5 to 12 days to long period motions with periods of 20 to 30 days and 60 to 100 days. Moreover, the dominance of the ~ 10 day relative to the 20 to 30 day period fluctuations changes with apparent season. The December 1997 to March 1998 period was characterized by highly energetic ~ 10 day motions whereas in the summers of 1997 and 1998 the 20 to 30 day motions were more prominent. The former winter period was characterized by the formation and detachment of LC eddy F. The following winter of 1998-1999 has similar energy levels to the Summer records and the LC had retracted to the south of 24EN for most of this time. Thus, it is not clear whether the change in energy levels is a seasonal phenomenon or indirectly linked to the northward penetration of the LC and the formation of LC eddies. The type of variability influences the exchange across the shelf-break. Large advective fluxes can occur over a long period (~ weeks) if there is a relatively stationary eddy near the shelf break. The shorter period motions are less effective at transporting large volumes of water on or off the shelf.

Conclusions

The NEGOM slope flows appear to be primarily driven by eddies that are distinct from the LC and LC anticyclones. Slope eddies have much smaller scales but they may be generated by instability mechanisms of the larger scale flows. Thus, slope eddy circulation should not be thought of as being separate from the complex flows found around and to the north of the LC. The LC may also have an indirect effect on the magnitudes and periods of the fluctuating flows as well as on the basic circulation patterns. These topics are being investigated as part of the ongoing analysis of the physical oceanography of the De Soto canyon slope.

Figure 12. Map of mooring positions (solid dots), standard grid hydrographic (CTD) stations (open squares), and meteorological buoys and CMAN stations (solid diamonds).

Figure 13. Geostrophic velocities relative to 1000 dbar calculated from CTD data (a) and near-surface salinity (b) for the March (PE-9830) hydrographic cruise.

Figure 14. Near-surface geostrophic velocities relative to 1000 dbar (a), and the vertical section of geostrophic velocity along transect B (b) for the March 1997 cruise (PE-9722). Positive values are the normal component directed towards the east.

Biographical Sketch

Dr. Peter Hamilton is a Senior Oceanographer with Science Applications International Corporation. He has served as a Principal Investigator on many MMS programs in the Gulf of Mexico and other coastal oceans. He received his Ph.D. from the University of Liverpool (United Kingdom) in 1973.

Some Remarks About Currents on the Continental Shelf in Relation to Their Relevance to Cross-shelf Transport

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For several decades, physical oceanographers have studied the wind-driven flow on continental shelves. The general category of "coastal trapped waves" or continental shelf waves can be handled fairly well. Analytical models such as the one by Clarke and Van Gorder allow calculation of the longshore flow to an accuracy that is probably limited more by our knowledge of the wind field than of the physics involved. Comparison between model calculations and observations from current meter moorings yield very favorable comparisons for the longshore wind-driven component when the bottom topography is not too irregular.

The coastal trapped waves, having periods of roughly 3 days to 3 weeks, are essentially in geostrophic balance. This means that the flow follows the isobaths. For currents at depths of roughly 10 - 50 m, a tide gauge at the coast serves as a good current meter for the longshore flow.

However, most of the questions asked by my biologist friends deal with the cross-shelf flow, not the longshore flow. In order to move particles (such as fish larvae) across the shelf, we can invoke several processes:

1. Catastrophic events, such as the 10-year floods.
2. Eddy fluxes, of the type $\langle v'L' \rangle$ where v means the offshore velocity, L is the concentration of "something" such as larvae or salinity or your favorite variable, the brackets imply a time average, and the primes mean fluctuations about some average value.
3. Small squirt-like things caused by instabilities, with horizontal scales of perhaps 20-30 km.
4. Friction-induced cross-shelf flow.

For this talk I will assume that the last one is the most important. This is called "proof by assumption."

Figure 15 shows a map of several current meter moorings that have been employed since the early 1990s. Figure 16 shows a typical velocity record at "mid depth" at the mooring labeled C56. The higher frequency variability is largely from inertial motions. Figure 17 shows a "progressive vector diagram" of the currents measured at the mooring labeled C30, south of Pensacola/Panama City on the 55 m isobath. This mooring was installed (paid for) by Chevron, using MMS equipment. The data are available on my web page [http://gulf.ocean.fsu.edu] as are the data from most of the other moorings shown in Figure 15.

In Figure 17 we see that the first 3-month setting of the moorings finds flow (at 10 m depth) fairly consistently along the local isobaths, with a mean flow (for just the time of this mooring) to the northwest. If you look closely you will also see a progressive vector plot that is only about 25% as long, and off to the left about 30°. This is the flow observed at an instrument 3 m above the bottom. This flow off to the left is of course the result of friction in the bottom Ekman layer. The main point of this figure is that such cross-isobath flow is reliably present, near the bottom, in all observations, even if the magnitude is small.

For observations at the sea surface, we look to the observations from drifters. During February 1996 - March 1997 MMS sponsored a major drifter program in the north-east Gulf led by P. Niiler. The drifters are 1 m tall, and float in the surface layer, with only a tiny amount of flotation above water. They have been very carefully designed to follow the water, not the wind. Weekly plots of the drifter tracks (courtesy Walter Johnson, MMS and P. Niiler) are on my web page; movies of the drifter motions are available in various forms as well as on the web page mentioned. The primary motions that we *notice* in these movies are the back-and-forth flow induced by the passage of synoptic wind systems, in the “wind band” of 3 days to 3 weeks. These are the coastal trapped waves, and they are largely along the isobaths.

The drifters also show a significant amount of cross-shelf motions. It is difficult (but not impossible) to piece together a good continuous time series from the data. But scatter plots, or correlation diagrams, can easily be made between the wind and the drifter motions. For the onshore component of the drifter velocity, the correlations are most highly significant when the winds are rotated such that the onshore velocity is 30° – 40° to the right of the wind. Ekman wins again. Note that (a) this angle will vary, depending on the strength of the vertical stratification, and (b) we usually think of the Ekman transport as being 90° to the right of the wind. This is true of the total, vertically integrated flow in the Ekman layer. The part we are talking about here, however, is only the first upper meter of that Ekman spiral.

The onshore component of the drifter velocity in this upper meter is found to be (from such scatter plots) approximately 2% of the wind speed. A cross spectrum shows that at frequencies where there is a substantial amount of power in the wind, there is significant coherence with the drifter motion.

The continental shelf off Pensacola is roughly 70 km wide. We can compute the monthly mean winds that are approximately in the correct orientation to drive onshore flow. If the winds (at this orientation) reach values of perhaps 2 m/sec (not a large value, to be sure), this gives an onshore velocity of approximately 4 cm/sec. This speed, for an entire month, suggests an onshore motion of over 100 km quite enough to move a particle, or larvae, from the shelf break to the coast if the particle is in the upper meter of the water column.

Figure 18 shows a plot of the “nearly onshore component of wind” that would drive onshore flow toward Panama City. These data are from the NCEP re-analysis wind data set, available from the NOAA web pages. In this plot we see, first, a large annual signal. The feature to notice is that mean monthly speeds as large as 2 m/sec are found rather often, suggesting that onshore motions, all the way across the shelf, can be expected from such wind-driven flow in the upper Ekman layer.

For a particular situation, such calculations can be made more carefully, or for an extended portion of the coast.

Acknowledgements

During the preparation of this work I have been supported in part by the MMS NEGOM program, for which I am most grateful. I thank Dr. B.G. Hong, Mr. Chris DeHaan and Mr. Jianguo Wang for help with these calculations.

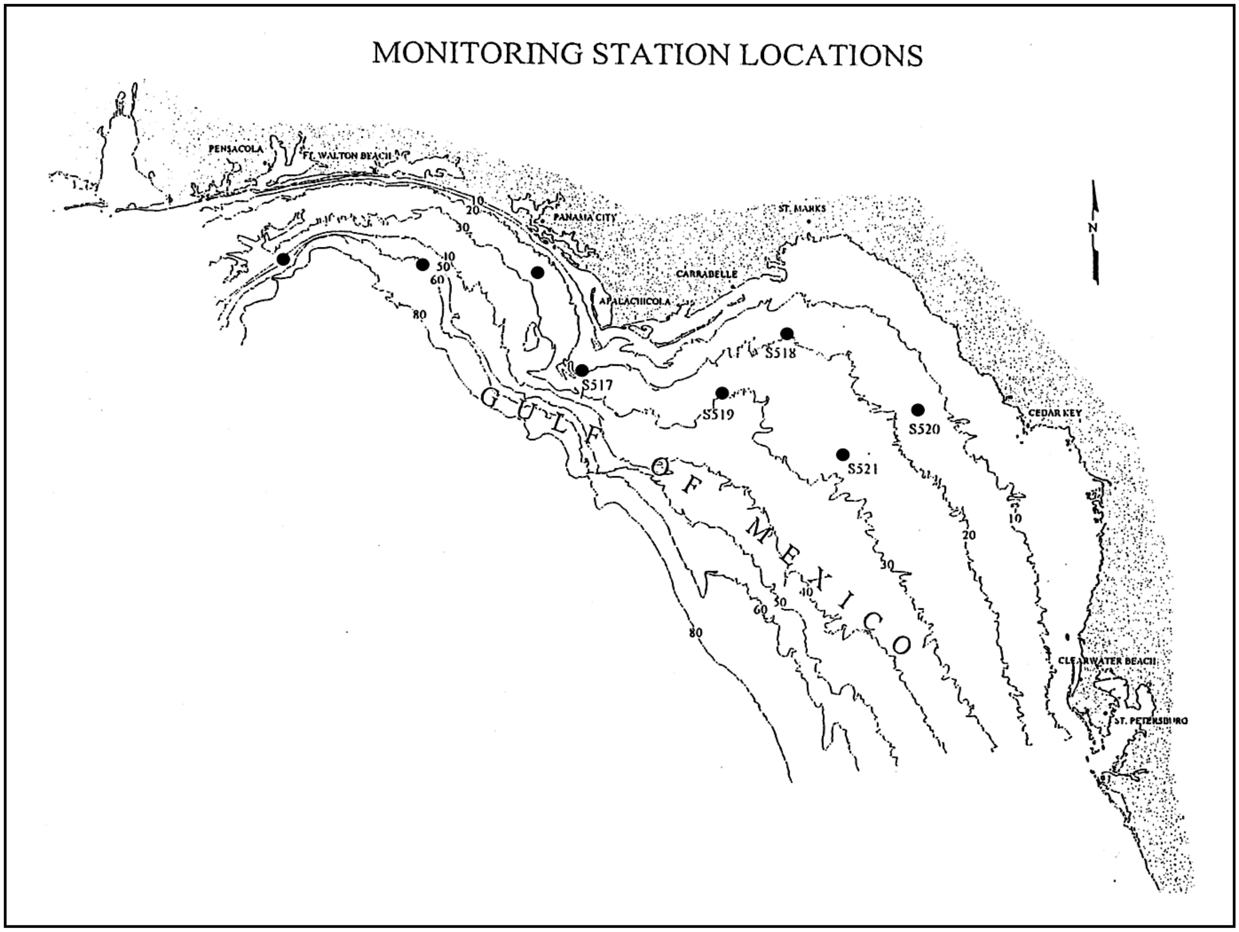

Figure 15. Map of several current meter moorings that have been employed since the early 1990s.

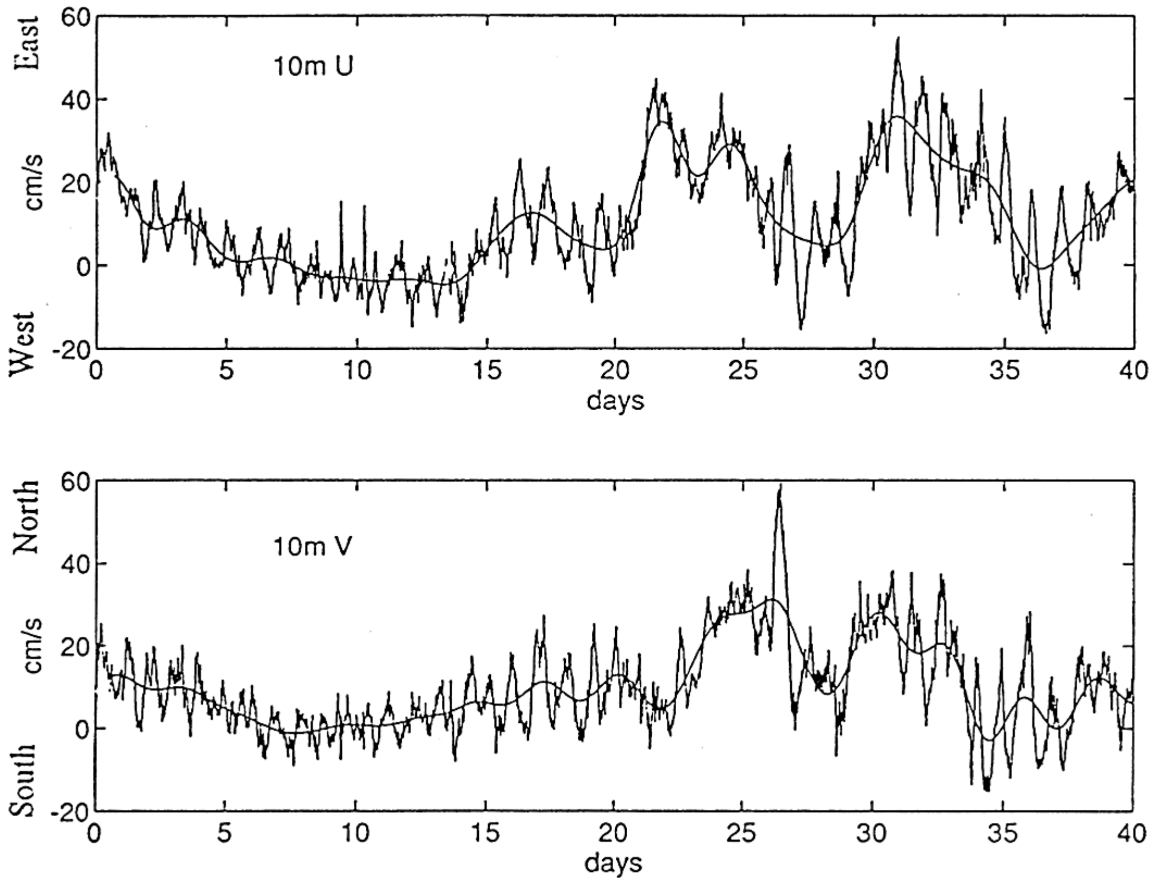

Figure 16. The east-west (u) and north-south (v) components of currents observed at the 13 m instrument during the first 40 days of the first mooring deployment. The record begins on 30 July 1992. The observed values every 10 minutes are shown, together with the smoothed values from a low-pass filter that removes power at periods of 24 hours or less, and passes power at 72 hours.

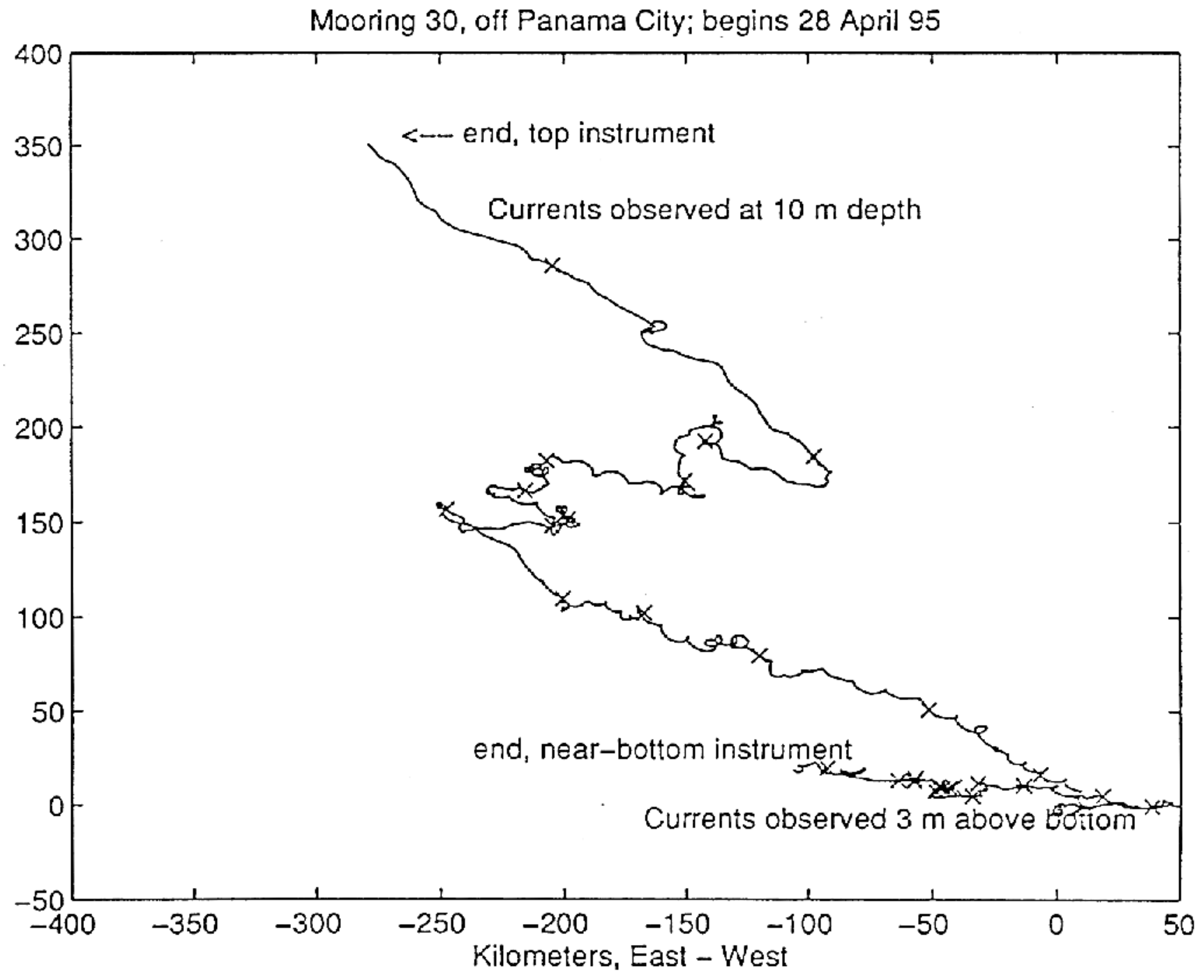

Figure 17. A progressive vector diagram showing the upper (10 m) and near-bottom currents at mooring 30 for the first deployment. The track begins at the lower right, at 0,0. North is up.

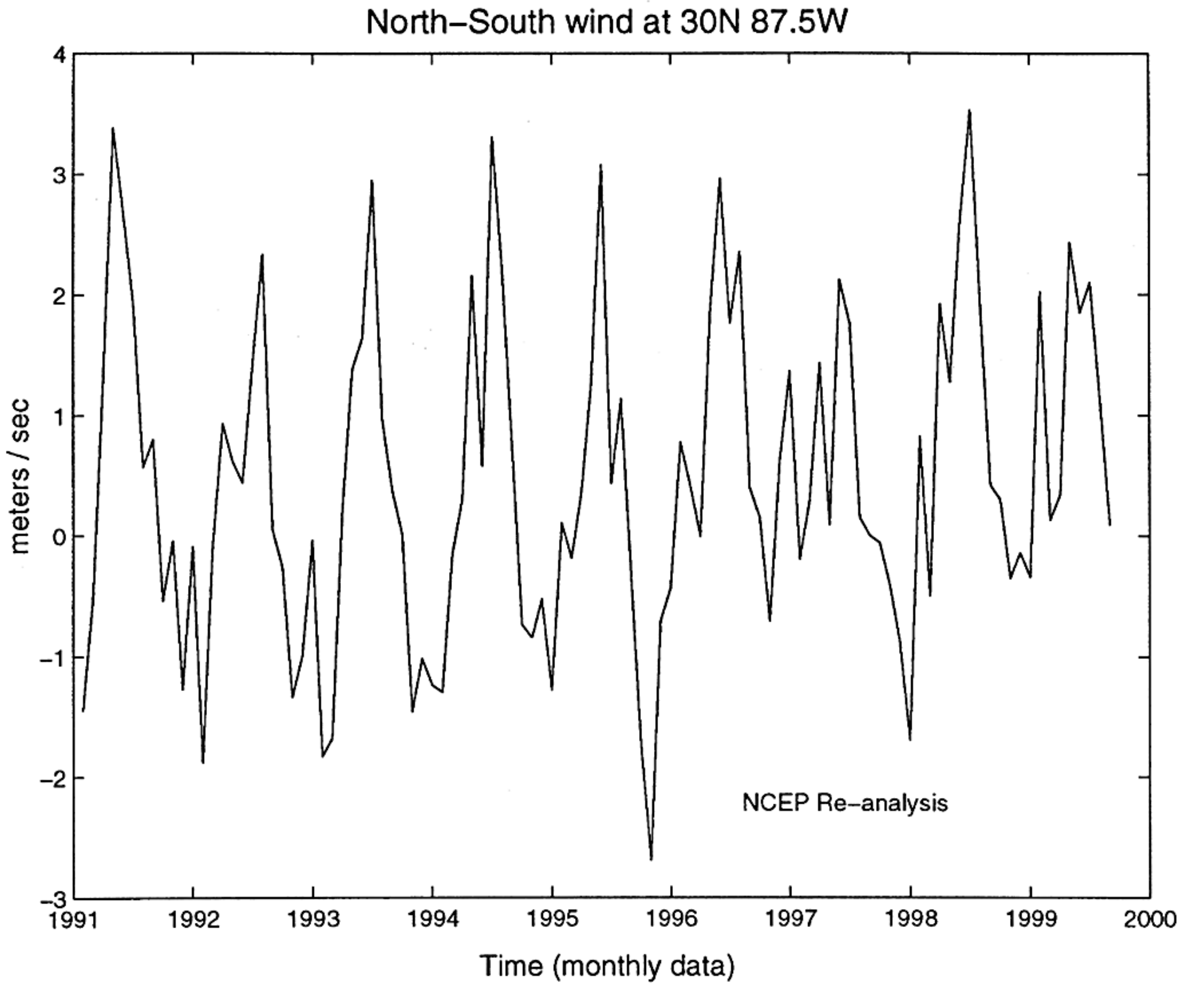

Figure 18. These data are from the NCEP re-analysis wind data set, available from the NOAA web pages. This figure shows a plot of the "nearly onshore component of wind: that would drive onshore flow toward Panama City. In this plot we see, first, a large annual signal. The feature to notice is that mean monthly speeds as large as 2 m/sec are found rather often, suggesting that onshore motions, all the way across the shelf, can be expected from such wind-driven flow in the upper Ekman layer.

Biographical Sketch

Professor Wilton (Tony) Sturges has been in the Department of Oceanography, Florida State University, since 1972. Prior to that he was on the faculty of the University of Rhode Island. He obtained his Ph.D. at The Johns Hopkins University. He is funded by MMS for the project, "Strong Mid-depth currents and a deep cyclonic gyre in the Gulf of Mexico." He has previously been Principal Investigator on the MMS study measuring near-shore flows in the Northeastern Gulf of Mexico. His interests are in understanding coastal flow in the Gulf, large-scale oceanic flows, primarily in the Atlantic, Caribbean and Gulf of Mexico, the slope of sea level along coasts and the long-term rise of sea level. His recent MMS-funded work in the Gulf of Mexico can be found at http://gulf.ocean.fsu.edu.

Surface Sediments of the NW Florida Inner Continental Shelf: A Review of Previous Results, Assessment and Recommendations

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Introduction

Nearshore sediments off northwest Florida are predominantly sands called the West Florida Sand Sheet by Doyle and Sparks (1980). Studies on the origin of these sediments based on clay mineralogy, heavy minerals, and grain size and shape analysis have indicated a fluvial origin dominated by the Apalachicola River and rivers of the southeastern United States, with some reworking by coastal or offshore wave processes (Griffin 1962; Ludwick 1964; Hyne and Goodell 1967; Arthur et al. 1986; Donoghue 1989; Mazzullo and Peterson 1989). Present shelf sedimentary facies and distributions patterns reflect some combination of preexisting control on sediment sources combined with reworking under marine conditions of the past several thousand years.

Herein we summarize findings pertinent to surface sediment facies and distribution patterns in Florida State waters west of Cape San Blas to the Alabama border. Previous discussions of the sediment data were available only in unpublished reports (Locker et al. 1988; Logue 1990), while the subsurface stratigraphic framework in this area was reported on by Locker and Doyle (1992). The western portion of the study area exhibits a finer-grained source reflecting the Mississippi-Alabama shelf apparently influenced by the Mississippi River and other river systems in Alabama and western Florida. East of Pensacola the sand sheet coarsens, reflecting a more relic sand sheet combined with increased biogenic carbonate material indicative of hard bottoms. Just west of Cape San Blas, an increase in mud accumulation reflects modern input. Surface sediment data, combined with side-scan sonar imagery, allow subdivision of the study area into 3 zones: A) the western half of the study area to south of Choctawhatchee Bay, B) the area between Choctawhatchee Bay and St. Andrews Bay containing increased carbonate and hard bottom substrates, and C) an area distinguished by fine-grained mud WNW of St. Joseph Sound.

Methods

A geophysical survey consisting of 3200 trackline kilometers at a 3.2 km (2 mile) spacing was acquired in December 1986 (Fig. 19). Geophysical methods consisted of a high-resolution boomer analog seismic system and an EG&G 100 kHz analog side-scan sonar system. In addition, 681 bottom samples were collected every 2.4 km using an underway bottom sampler (Fig. 20). Sediment analyses included grain size at 1-phi intervals from –1 to <8 phi (see Table 2 for mm equivalents). Statistical parameters of grain size (mean phi and standard deviation) were calculated by the method of moments (Folk 1974). Contour maps for mean phi, standard deviation, % carbonate and % mud were produced using inverse-distance gridding which tends to smooth spatial variability and attenuate minimum and maximum values.

Table 2. Relationship of standard phi units to millimeters for range of data in this study.

Phi size	millimeters	Wentworth Size Class
-1	2	
		very coarse sand
0	1	
		coarse sand
1	0.5	
		medium sand
2	0.25	
		fine sand
3	0.125	
		very fine sand
4	0.0625	
		silt
8	0.0039	
		clay

In this study, "mud" refers to silt+clay, > 4 phi (< .0625 mm).

Surface Sediment Characteristics

Grain Size

The mean grain size of surface sediment is show in Figure 21. Medium-size sand dominates the inner shelf area. However coarser-grained patches are found west of St. Andrews Bay, and then fined-grained mud deposits are located west of St. Joseph Bay (Fig. 22.). The source of the mud was not determined, and could represent natural accumulations (concentration by current or exposed pre-existing back-barrier deposits) or unnatural origins such as dredge material. In either case, mud sized material is dispersed throughout numerous samples in the eastern-most area. The sedimentary facies zones A-C are evident in the mean grain size distribution patterns (Fig. 21). The patches of coarse sand on the shelf between Choctawhatchee Bay and St. Andrew Bay correspond with patches of high carbonate content (Fig. 26).

Sorting

A plot of mean grain size versus standard deviation is in shown in Figure 23. Nearly half of all samples collected are well-sorted medium-size sand. Samples containing mud (lower mean phi values) display poorer sorting values which reflect mixing of mud with the more typical shelf sands. A slight trend of increased grain size with increased standard deviation is associated with increased carbonate grains found in Zone B, however carbonate is mixed somewhat across grain sizes (Fig. 24). A contour map of standard deviation values clearly shows a trend toward poorer sorting toward the east (Fig. 25).

Composition

The sand fraction consists of quartz and quartzite grains reworked during the Holocene sea-level rise. Bottom samples high in carbonate characterize Zone B (Fig. 26). The carbonate fraction contains a mixture of non-living or relic components such as lithoclasts and blackened grains (such as phosphatic coatings or H_2S stained shells) and an assemblage of grains indicating production associated with live bottoms (Fig. 27).

Side-Scan Sonar Imagery – bottom types and bedforms

Figures 28 and 29 present interpretations of side-scan sonar imagery that also support subdivision of the inner shelf into 3 zones. Lineation patterns plotted in Figure 28 show that megaripples and sand waves occur throughout the study area. The largest scale sand waves are found in the eastern Zone A associated with thicker sands mapped by Hyne and Goodell (1967). Line drawing interpretation of the sonar imagery becomes difficult in the middle Zone B area related to much thinner and patchy sediment cover along with the presence of hard bottoms. A smaller-scale suite of megaripples and more linear megaripples in the eastern-most Zone C suggest some control by changes in shelf energy and current patterns. A summary plot of many of these bottom types in Figure 27 correlates well with the sediment facies changes previously discussed.

Assessment

The number and distribution of bottom samples allowed a much more detailed analysis of sediment distribution patterns on the inner shelf. However this information is more highly variable in character than has been presented thus far. The primary limitation is correlation of sample location to bottom type (hard bottoms, various bedforms, etc). Clearly, a better map of bottom types, trends, patchyness, and spatial scale is needed. At the time this side-scan imagery was collected, interpretation techniques were based on scrolling through paper records, digital mosaicing was not available. The 2-mile spacing of survey lines was very good to gain an overall understanding of bottom characteristics, yet we have a poor understanding of the size, distribution and type of hard/live bottom types in the study area. Sediment analyses remain a time consuming technique. However improved seafloor imaging techniques now allow routine acquisition of full-coverage mosaics of the seafloor for assessment of habitat type and patchyness.

Recommendations

Information on the occurrence and distribution of bottom types is essential for understanding benthic environments. Hard bottom environments are distributed throughout the shelf are critical to benthic and pelagic fauna. Current-produced bedforms are widespread, yet little is known about distribution with depth and the implications for rates and timing of sediment transport or resuspension, such as storm events. Additionally, the near surface geologic framework may be important to understand textural and bottom type patterns – such as exposed "bedrock" or location of paleoshorelines or deltaic depocenters. Continuous side-scan coverage of the entire shelf is probably too much effort to consider. However a broad reconnaissance survey approach, followed by a fill-in phase of surveys to collect continuous bottom imagery in areas of interest, is needed to better understand the location and spatial extent of benthic environments.

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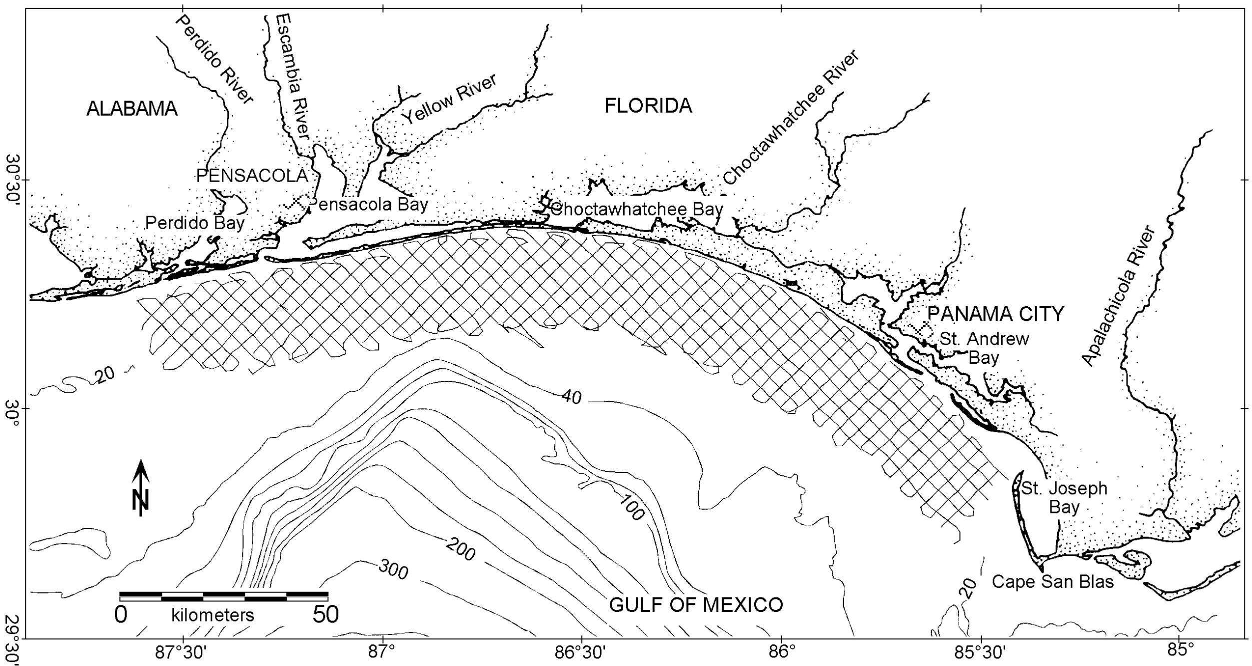
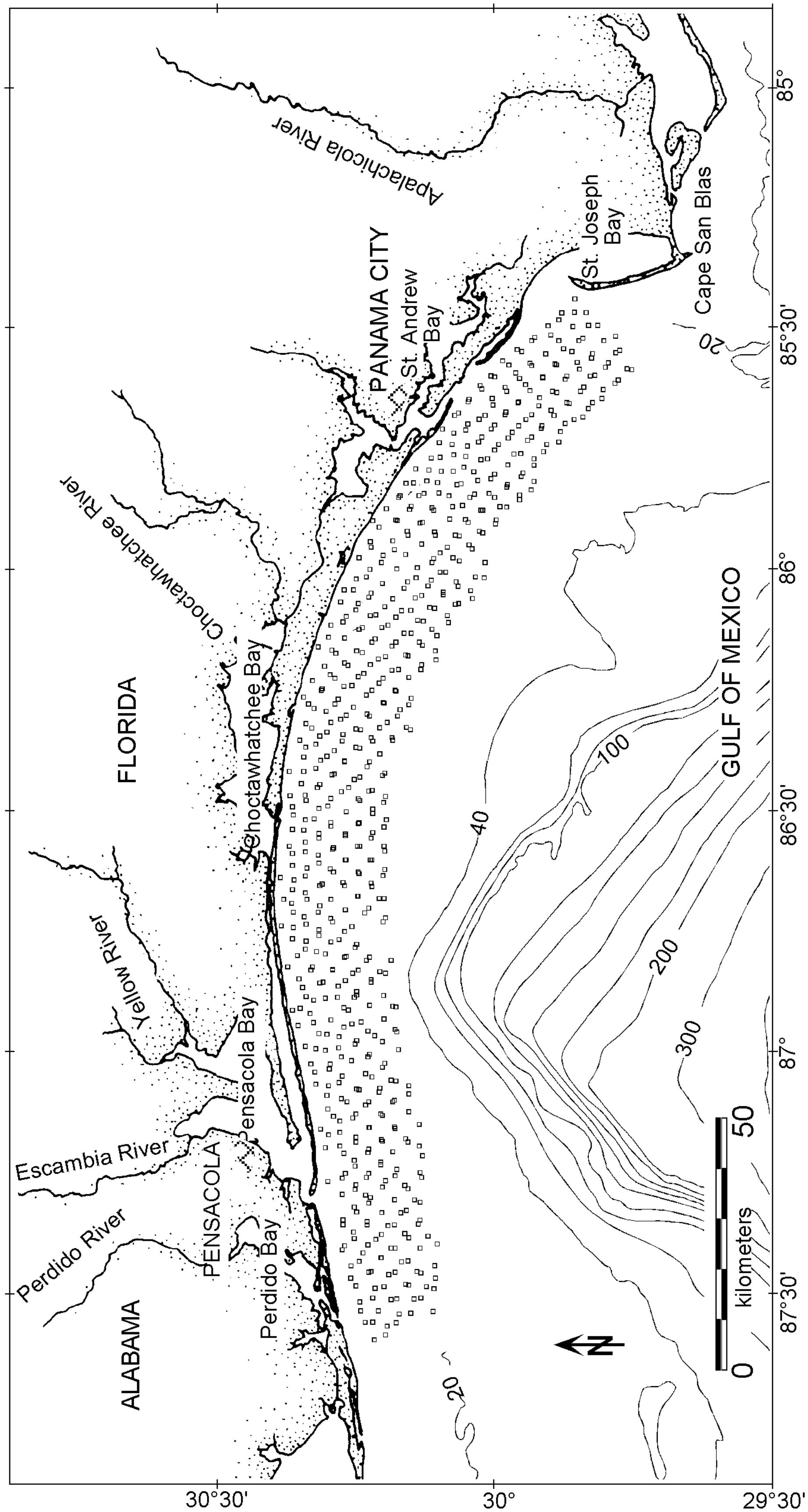


Figure 19. Location of high-resolution seismic and side-scan sonar coverage on the inner shelf.


ALABAMA
FLORIDA
Perdido River
Escambia River
Yellow River
Choctawhatchee River
Apalachicola River
PENSACOLA
Perdido Bay
Pensacola Bay
Choctawhatchee Bay
PANAMA CITY
St. Andrew Bay
St. Joseph Bay
Cape San Blas
GULF OF MEXICO
20
40
100
200
300
20
0
50
kilometers
87°30'
87°
86°30'
86°
85°30'
85°
30°30'
30°
29°30'

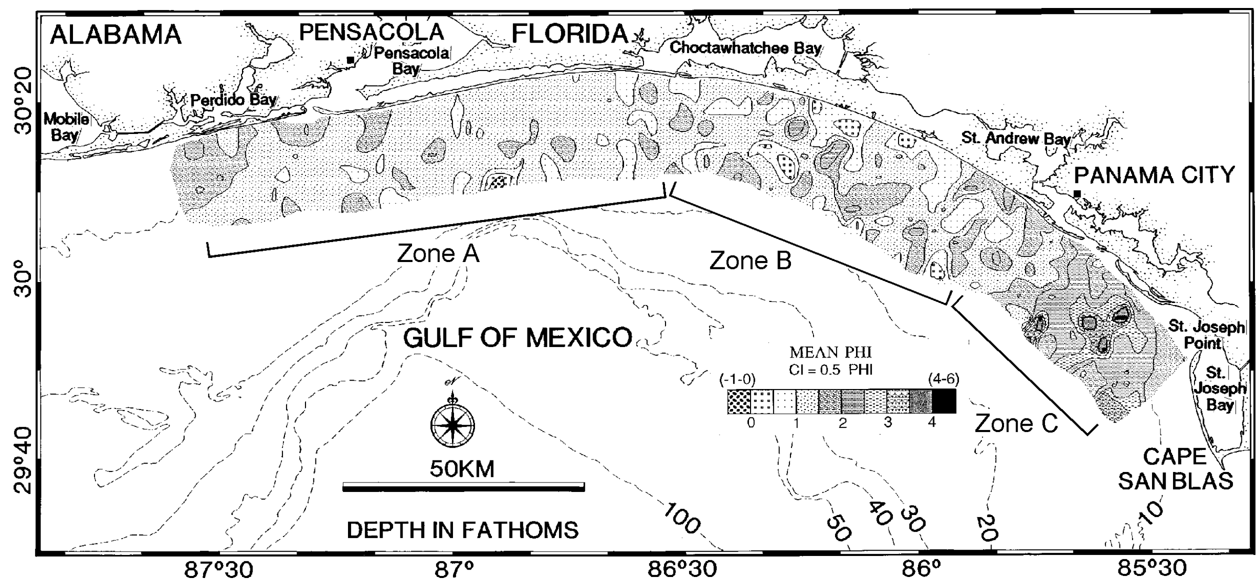


Figure 21. Mean grain size of surface sediments. The dominant texture is 1-2 phi (medium sand). The 3 principal sedimentary facies zones A-C are defined based on grain size and carbonate percentages.

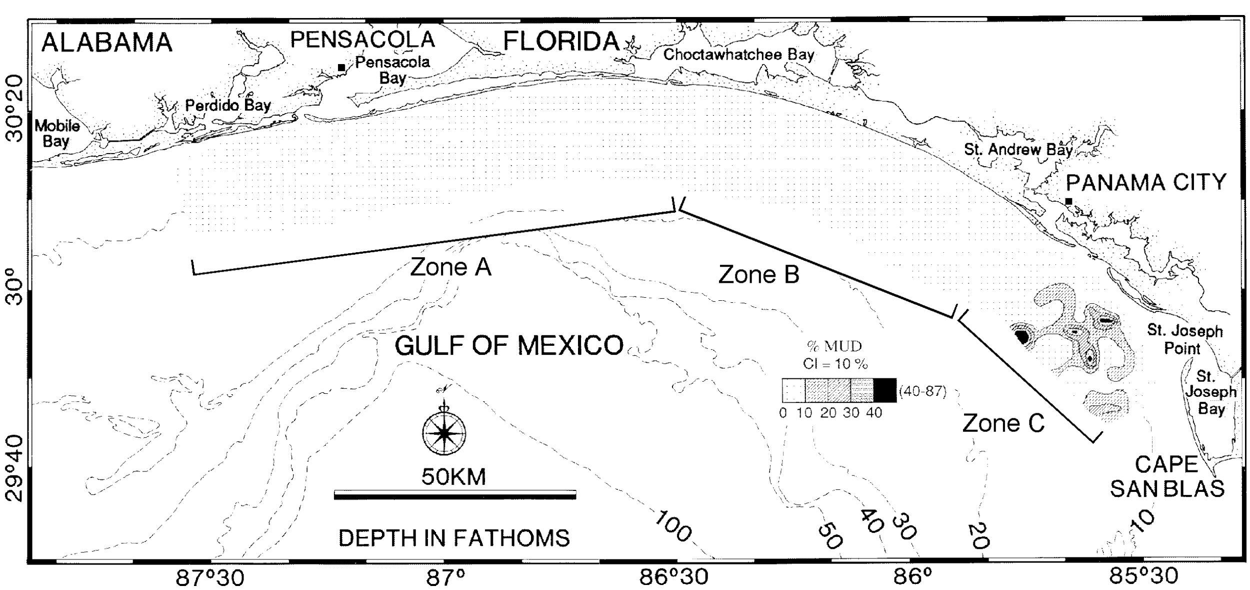


Figure 22. Map of percent mud in surface sediments. Significant mud deposits were found only in the eastern-most portion of the study area and defines Zone C.

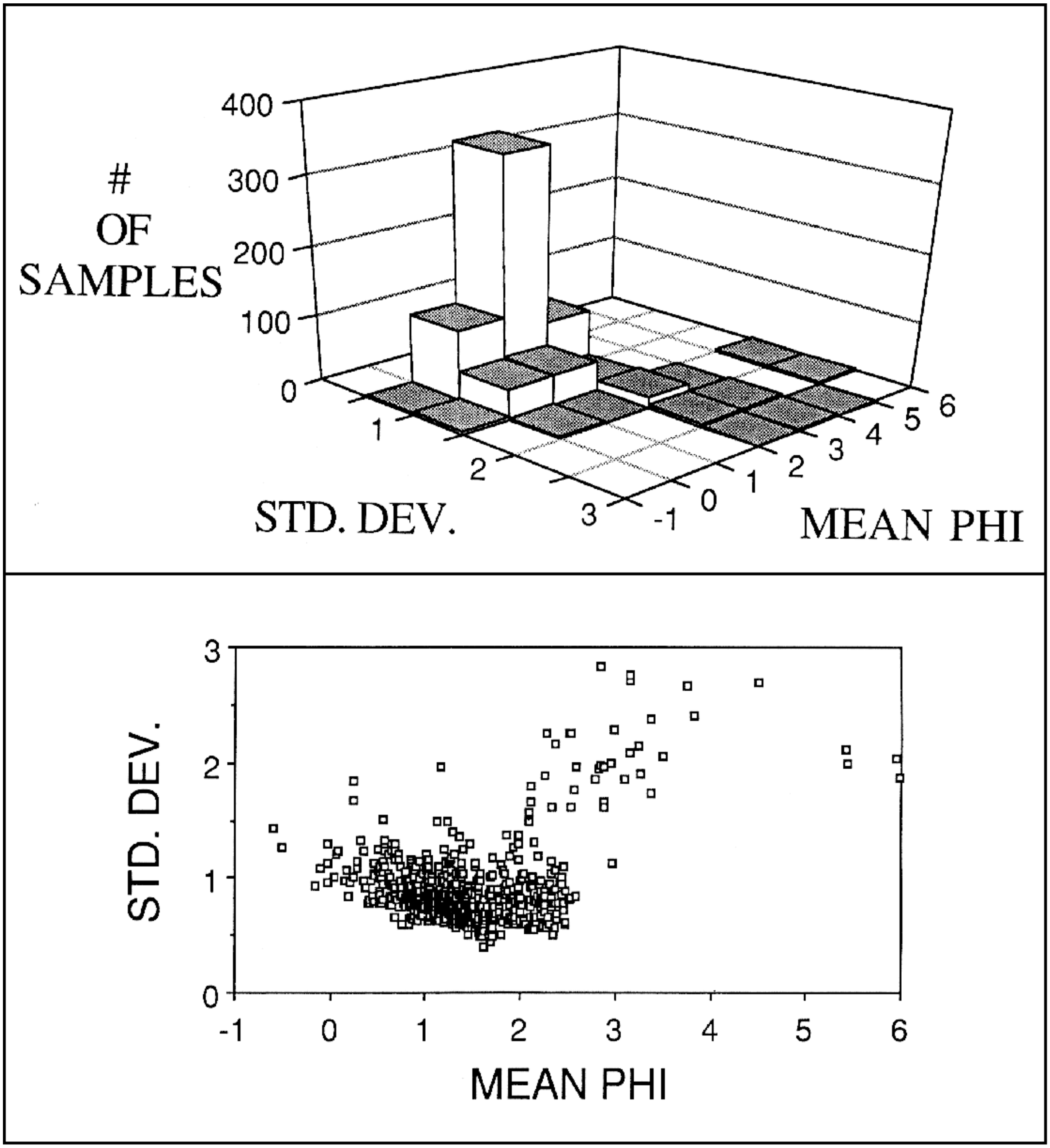


Figure 23. Plot of mean grain size versus standard deviation. Well-sorted medium-size sand predominate. Poorer sorting is related to increases in mud or coarse-grained carbonates.

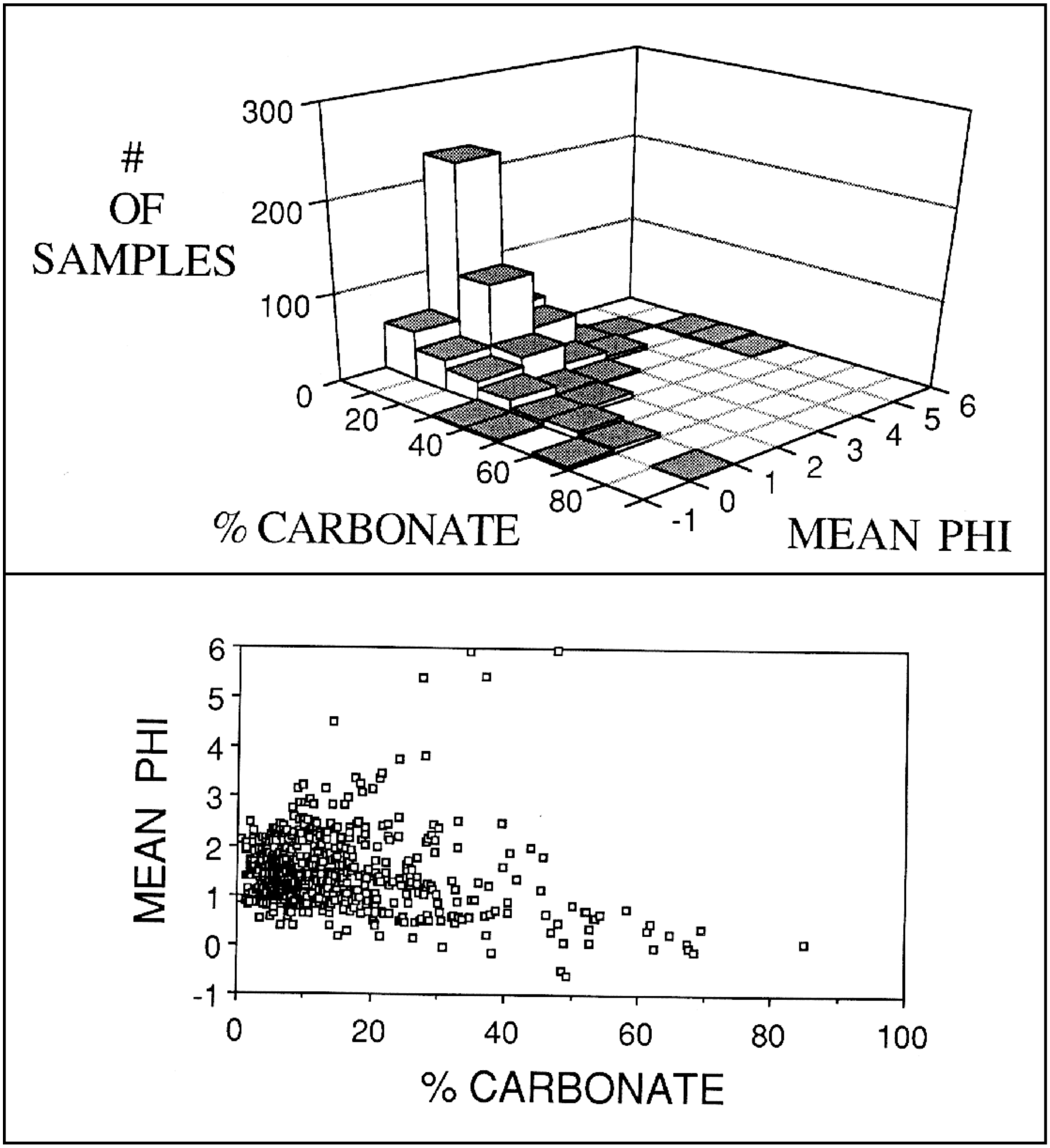


Figure 24. Plot of mean grain size versus % carbonate shows a distribution of carbonate grains somewhat independent of normal shelf sediment textures.

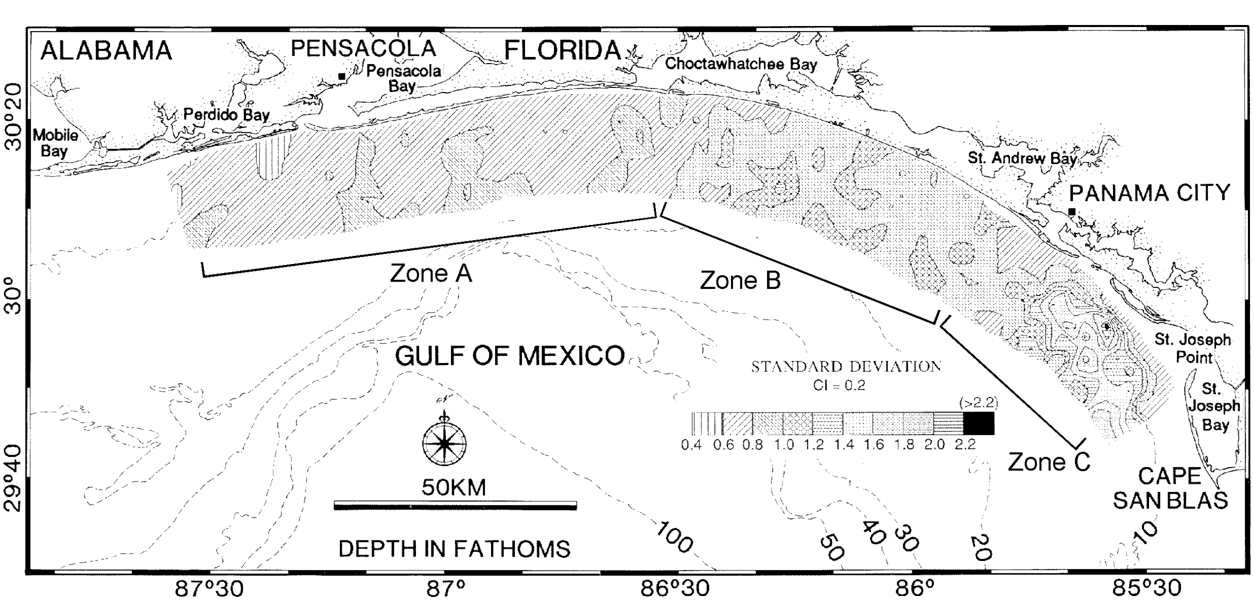


Figure 25. Map of standard deviation values clearly show 3 main zones for sorting in the study area. Well-sorted sands occur to the west. Poorly sorted sediments containing mud occur in the east. Moderately-sorted sands in Zone B correspond to the highest carbonate accumulations.

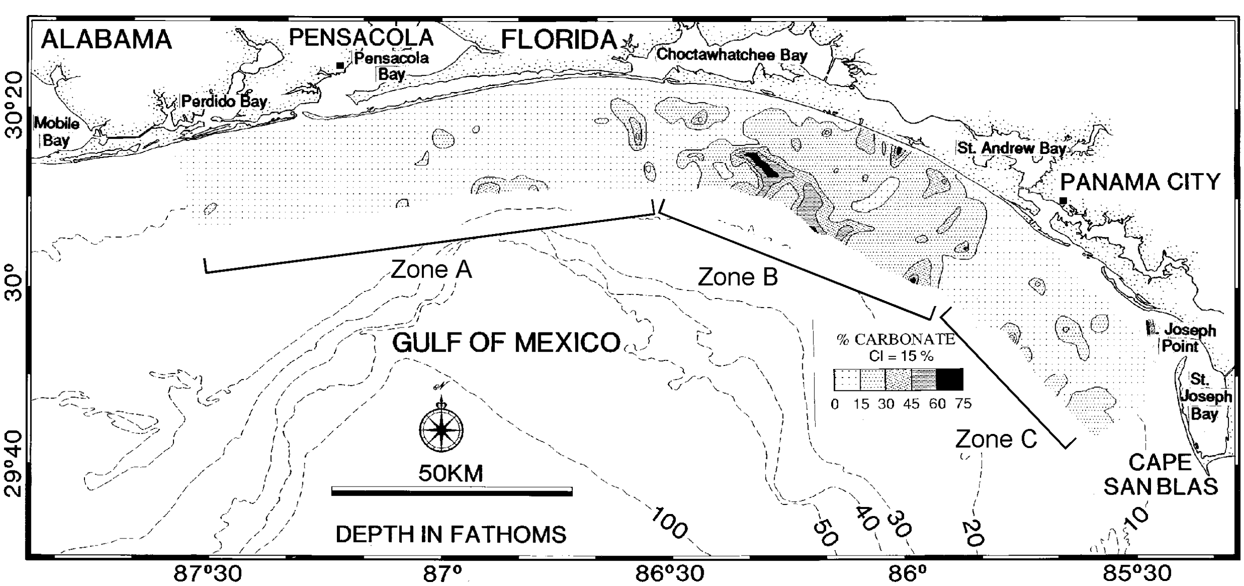


Figure 26. Map of percent carbonate shows highest concentrations occur along the seaward side of Zone B.

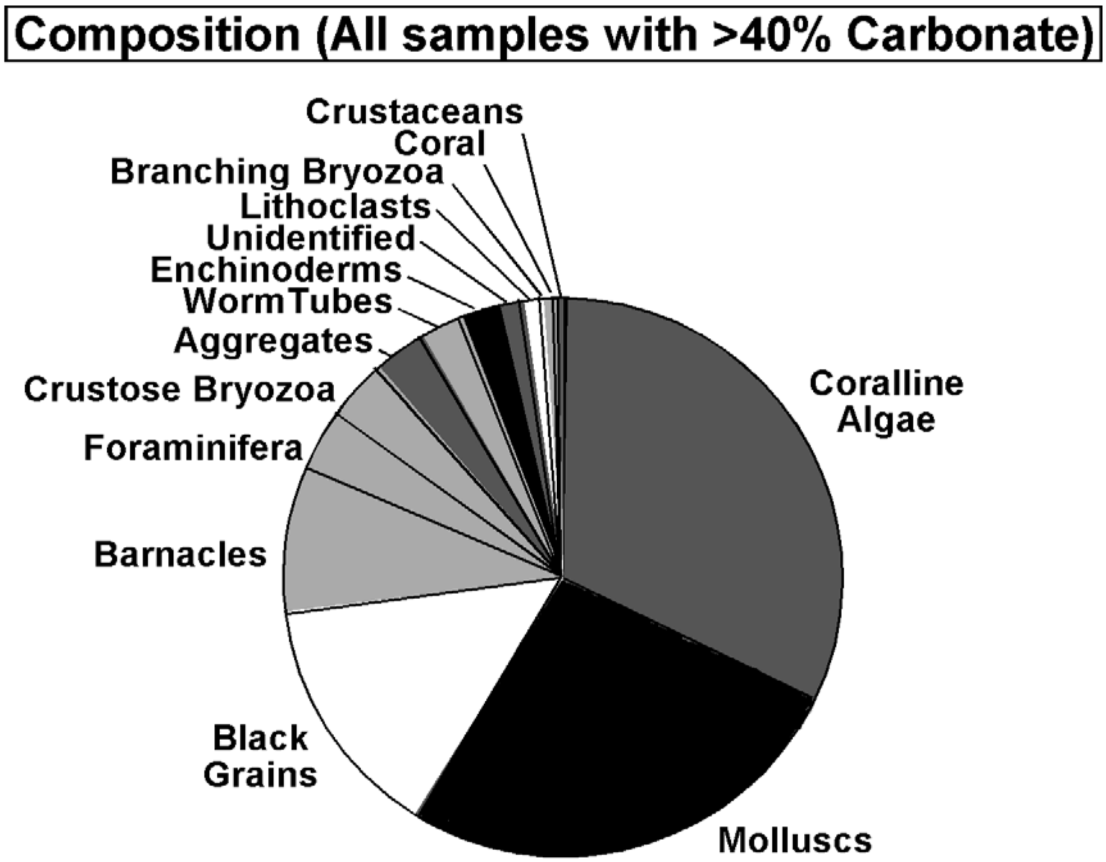


Figure 27. Plot of composition data for all samples with > 40% carbonate shows a mixture of carbonate-producers and non-living grains derived from hard-bottom exposures.

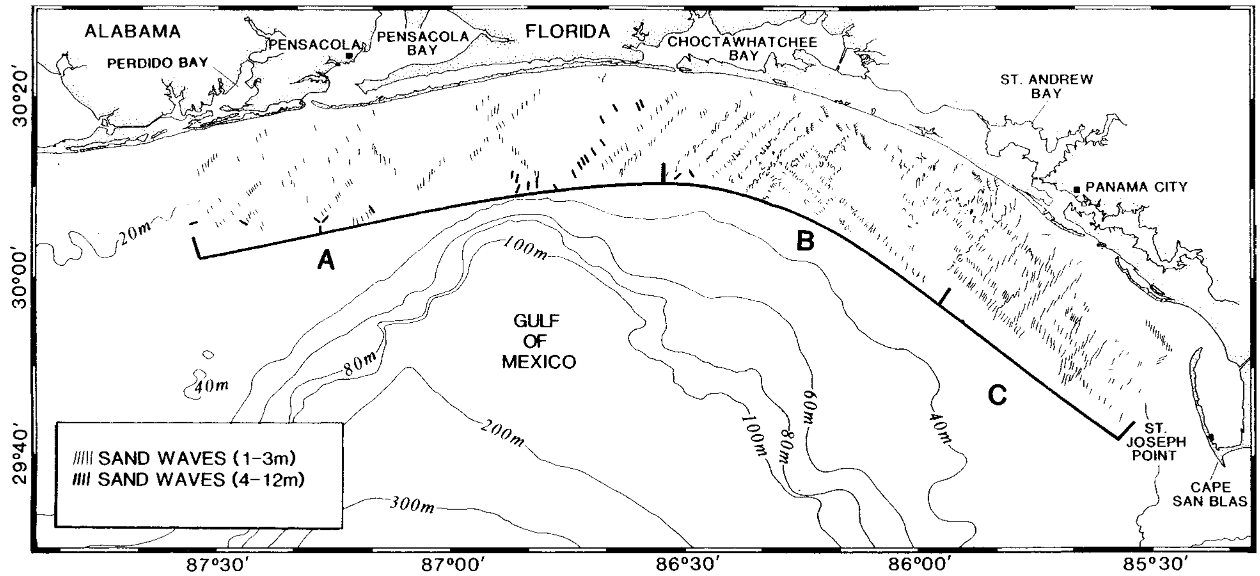


Figure 28. Interpretation of lineation patterns from side-scan sonar imagery (modified from Logue 1990). Bedforms tend to be normal or slightly oblique to the shoreline. Random patterns in Zone B is related to patchy (sediment-starved?) sand bodies and hard bottoms.

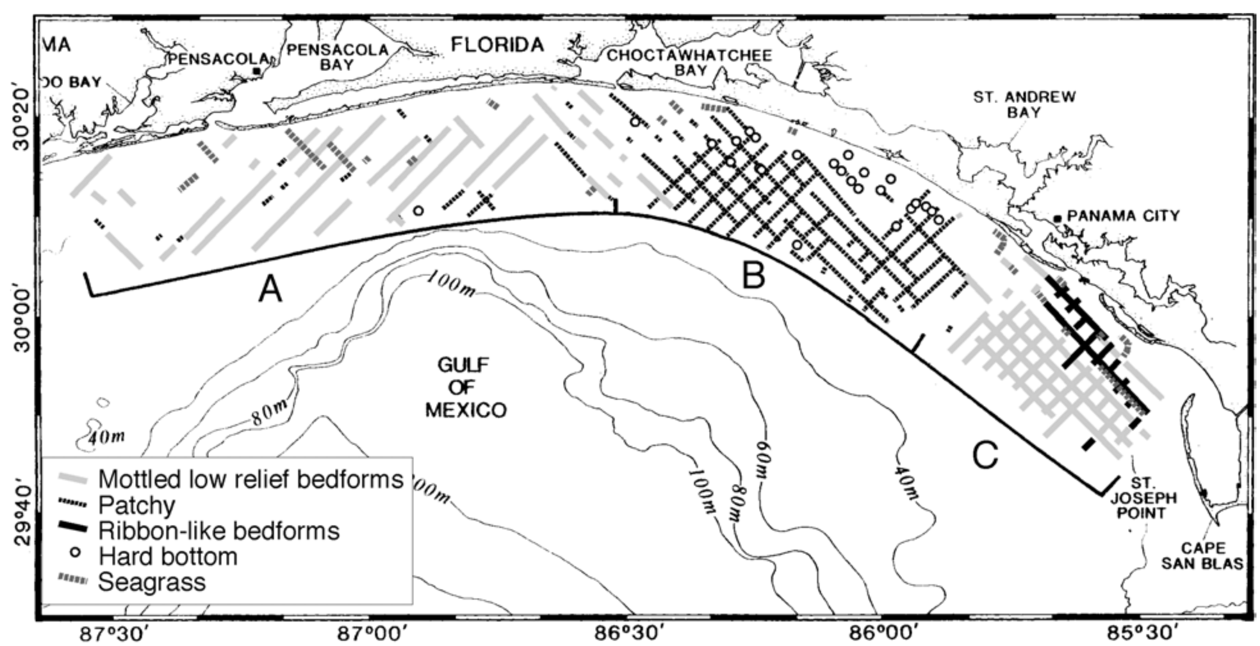


Figure 29. Plot of bottom types based on side-scan imagery (data from Logue 1990). Mottled low relief bedforms correspond to megaripples that are superimposed on some of the larger sand waves located in Figure 26. Patchy sand bodies in Zone B are 10's to 100's of meters in scale but segmentation of these patches suggest they are sediment-starved. Ribbon-like features are more linear megaripples that were found only in Zone C.

Biographical Sketches

Dr. Stanley D. Locker is a Research Scientist in the Department of Marine Science at the University of South Florida. His research interests include the integration of stratigraphic architecture and depositional processes of continental margins, with emphasis on high-resolution applications of seismic reflection and side-scan sonar techniques. He received his Ph.D. degree in Oceanography from the University of Rhode Island.

Dr. Larry J. Doyle is Director of the Center for Nearshore Marine Science located at the University of South Florida, St. Petersburg, FL. He is author of over 100 papers, books, abstracts, etc. in sedimentology and marine geology of continental margins, both recent and ancient, from the shoreline through the continental slopes.

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SHELF NUTRIENT CHEMISTRY - THE GULF OF MEXICO

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It has long been recognized that while the world's ocean basins are filled with water, it is not pure water. This fundamental observation has wide ranging consequences for understanding the dynamics of water masses within basins and sets the stage for a coupling of biological, chemical, geological and physical processes in oceanic environments. The distribution of these "impurities" is not homogeneous throughout the water column nor geographically, reflecting the dynamic interactions of input and removal processes that vary both temporally and spatially within a basin such as the Gulf of Mexico. The constituents of sea water can be dissolved as well as particulate and each type of added material can have profound effects on the fundamental properties of seawater such as density and optical properties. It has also been long recognized that seawater properties are directly effected by the presence of living organisms. The ongoing processes that form the basis of life, such as photosynthesis and metabolism, are reflected in both the dissolved and particulate properties of seawater. Particulate matter can be living or non-living, with non-living material being comprised of both organic and inorganic compounds and materials. The following presentation briefly describes the biogeochemical consequences and important processes that contribute to and control the distribution of nutrients in the Gulf of Mexico. Marine plants and phytoplankton require micronutrient elements such as nitrogen and phosphorous for their growth. The distribution of nutrients is closely coupled with related seawater chemical constituents such as oxygen, carbon dioxide, particulate organic carbon, and dissolved organic carbon. The chemistry of nutrients in the Gulf of Mexico is best understood in the broader context of all of these seawater properties.

Nitrogen is essential for life by providing the elemental building blocks for many organic compounds such as amino acids and proteins. Nitrogen occurs in seawater as dissolved molecular gas (N_2) and inorganic and organic compounds. The principal inorganic forms of nitrogen in seawater are nitrate (NO_3^-), nitrite (NO_2^-), and ammonia. Seawater also contains minute amounts of other inorganic compounds as well as dissolved and particulate organic nitrogen compounds. The distribution of the major inorganic nitrogen species in the ocean are controlled by biological processes. Once incorporated into biomass, nitrogenous materials are redistributed in the water column due to sinking of the detrital remains of dead organisms and upwelling of deeper waters to the nearsurface. These processes operating in unison establish a nitrogen cycle in the sea. While phytoplankton normally synthesize proteins from nitrate, nitrite and ammonia, bacteria preferentially incorporate organic nitrogen. During metabolism nitrogenous material, mainly in the form of urea, is excreted by living organism. The nitrogen cycle in the sea is not a closed system in that nitrogenous material is constantly being deposited in sediments and nitrogen enters the sea from river and rain water. Important processes that control the distribution of nitrogen in the sea include nitrogen fixation, assimilation of fixed nitrogen, and regeneration of nitrogen. Most nitrogen assimilation occurs in the euphotic zone whereas regeneration of nitrate can occur throughout the water column and in the sediments. This offset in the vertical occurrence of these processes leads to the commonly observed vertical heterogeneity observed in water column profiles of inorganic nitrogen. Because the distribution of nitrogenous materials in the sea is primarily influenced by biological processes, there is a strong seasonal variation in the observed concentrations.

Phosphorous is an additional micronutrient required by living organisms, the same input and removal processes control its distribution in the sea. Similar to nitrogen, phosphorous occurs in seawater in a variety of dissolved and particulate forms. Inorganic phosphorous is predominantly in the form of orthophosphate ions (PO_4^{-3}). Dissolved phosphorous in sea water also occurs as organic compounds mostly derived from the decomposition of organismal remains and excretion from living organisms. Phosphorous also occurs in the particulate form in sea water in association with living organisms and detrital remains from dead organisms. A phosphorous cycle has also been proposed. Removal mechanisms include sedimentation and inputs are derived from riverine discharges, rainfall, and regeneration, both in the water column and sediments. Phytoplankton usually satisfy their phosphorous needs by direct assimilation of orthophosphate followed by metabolic transformation to organophosphorus compounds (phospholipids, phosphonuleotides, etc.). In most of the world oceans, phosphorous is available in amounts exceeding the needs of the resident organisms. Bacteria generally satisfy their nutritional needs for phosphorous from detritus and are an active component, in addition to intracellular enzymes, in the regeneration of phosphorous. Similar to nitrogen, the close coupling of phosphorous to biological processes results in strong temporal variations primarily associated with the seasons. Vertical and spatial heterogeneity in phosphorous distributions reflect the dynamic interplay of inputs and removal processes. Differences in the localities where these processes occur establish the often-observed spatial gradients in phosphate concentrations.

Silicon is also present in seawater in both dissolved and particulate forms. The dissolved form is commonly determined as silicate (SiO_4). A major source of silicon to the Gulf of Mexico is weathering of rocks on land followed by riverine transport to the sea. Within the water column, there are many organisms, including diatoms and radiolarians that have skeletons composed of hydrated silica-opal. Upon their demise, the siliceous skeletons slowly dissolve in seawater as they sink to the underlying sediments. High concentrations of silicon are observed in inshore regions and can account for as much as 60% of the water column particulate matter depending on geographic location. Seawater is undersaturated with respect to silicon and therefore dissolution is almost always an ongoing process. The incorporation of silicon into biological structural components is an efficient mechanism of removing silica from seawater. These materials are also efficiently transported and deposited in sediments due to the rapid settling rates. The sea contains several groups of plants (e.g., diatoms) and animals that require silicon to maintain their structural integrity. The concentration of silicon in surface waters is generally low except in regions of upwelling due to the uptake of silicon by organisms in the euphotic zone. As with the other nutrients, close coupling of silicon with biological processes produces spatial and temporal variations in its distribution. The silicon cycle produces a heterogeneous distribution reflecting the balance of inputs, uptake, and remineralization. Each of these processes can be more or less important depending on the local setting thus producing significant regional variations in silicon distributions.

Nutrient concentrations and distribution in the Gulf of Mexico are controlled by a combination of biogeochemical and physical processes described above. The processes that control nutrient concentrations; river discharges, coastal currents and winds, upwelling, biological activity, and rainfall;

are all operative in the Gulf of Mexico. In near-bottom waters, remineralization of organic matter can lead to elevated levels of nutrient concentrations. Excess or enhanced nutrient levels can contribute to oxygen depletion and plankton blooms. On the outer continental shelf differences in nutrient concentrations between surface water and bottom waters are substantial. The concentrations of nitrate and silicate increase from below the detection limit in surface waters to about 30 ΦMXL^{-1} in the deep waters of the outer continental shelf. Waters as deep as 70 m tend to be nutrient-poor, with nutrient concentrations far below those of deep waters. An abrupt increase in nutrient concentration; particularly for phosphate, nitrate and silicate occurs between 70 and 100 m water depth. This vertical structure develops as a result of fixation of nutrients into biomass by phytoplankton in the euphotic zone and remineralization of organic matter in the deeper waters. These features are constant enough to characterize water masses in the Gulf of Mexico (Table 3).

Table 3. Water Masses in the Gulf of Mexico and Associated Property Extrema and Potential Densities (compiled from Morrison and Nowlin 1977; Morrison et al. 1983; Nowlin and McLellan 1967).

	Eastern Gulf of Mexico			Western Gulf of Mexico		
Water Mass	Depth (m)	Feature(s)	Sigma-theta mg cm^{-3}	Depth (m)	Feature(s)	Sigma-theta mg cm^{-3}
SUW-LC	150-250	Sal_{max}	25.40			
SUW	150-250	Sal_{max}	25.40	0-250	Sal_{max}	25.40
181CW	200-400	O_{2max}	26.50			
TACW	400-700	O_{2min}	27.15	250-400	O_{2min}	27.15
AAIW				500-700	NO_{3max}	27.30
AAIW	700-900	PO_{4max}	27.40	600-800	PO_{4max}	27.40
AAIW	800-1000	Sal_{min} SiO_{2max}	27.50	700-800	Sal_{min} SiO_{2max}	27.50
UNADW	900-1200	SiO_{2max}	27.70	1000-1100	SiO_{2max}	27.70

SUW-LC = Subtropical Underwater in Loop Current and new LCEs
SUW = Subtropical Underwater in the Gulf but outside Loop Current
181CW = 181C Sargasso Sea Water
TACW = Tropical Atlantic Central Water
AAIW = Antarctic Intermediate Water
UNADW = Mixture of Upper North Atlantic Deep Water and high silicate Caribbean mid-water

Nutrient rich waters are often apparent in the plumes of the dominant Gulf of Mexico river systems. This dynamic interaction of potential sources and sinks results in seasonal and geographic variations in nutrient distributions across the Gulf of Mexico. For example, in the northwestern Gulf of Mexico phosphorous and silicate distributions are biologically controlled while nitrate distributions are influenced by large riverine inputs. Nutrients concentrations exhibit spatial, seasonal, and interannual variations controlled by water column stability, river discharge, and local wind fields.

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Biograpical Sketch

Dr. Mahlon C. Kennicutt II has more than twenty years of experience in environmental chemistry, organic geochemistry, environmental monitoring and project management. Educational credentials include a B.S. in chemistry (1974, Union College) and a Ph.D. in Oceanography (1980, Texas A&M University). Dr. Kennicutt served as a post-doctoral appointee at the University of Tulsa and has spent the last 19 years in various roles with the Geochemical and Environmental Research Group of Texas A&M University. His present titles at GERG include Director, Senior Research Scientist, member of the Graduate Faculty, and Program Manager. During his career he has served in various roles in large federally-funded environmental projects from field technician to principal investigator to program manager. He has more than 120 peer-reviewed publications and has made more than 120 scientific presentations to national and international forums. Dr. Kennicutt currently manages a staff of 60 and a research budget in excess of $6 million. Dr. Kennicutt serves as an external reviewer to a wide array of scientific journals and federal, state, and private agencies including a current appointment as Associate Editor of Geochimica Cosmochimica Acta.

SHELF HARD BOTTOM HABITATS

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Hard bottom features and sites represent unique locations where important biological habitats develop. These habitats are known to play significant roles in the structure and function of the various ecosystems in which they are found (Parker and Curray 1956; Avent et al. 1977; Reed 1980; Wenner et al. 1983; Messing et al. 1990; Rezak et al. 1990; Hopkinson et al. 1991; Gittings et al. 1992). In particular, they are often essential components for commercial and recreational fisheries (e.g., red snapper, grouper and other reef fishes) associated with continental shelf regions (Grimes et al. 1982; Parker et al. 1983; Chester et al. 1984; Putt et al. 1986; Dennis and Bright 1988). The specific type of community assemblages that form on hard bottoms are governed in large part by: 1) the geomorphic characteristics of the lithified substrates (e.g., rock rubble, isolated outcrops, and reef-like features; areal extent and vertical relief); 2) the composition of adjacent unconsolidated sediments; 3) variability in water quality (e.g., fluctuations in salinity and/or suspended solids resulting from fluvial input); 4) physical environmental factors influencing benthic boundary layer processes (e.g., water depth; wave and current climatology), and the stability of the feature or site under present day conditions (e.g., exposure-burial cycles) (See Thompson et al. 1999).

Over the past 40 years a number of specific studies and general offshore surveys and inventories have been undertaken to identify, describe, and characterize hard bottom features, sites, and habitats on the Mississippi-Alabama continental shelf province (e.g., Ludwick and Walton 1957; Ludwick 1964; Upshaw et al. 1966: Ballard and Uchupi 1970; Martin and Bouma 1978; Shipp and Hopkins 1978; J. E. Chance & Associates, Inc. 1985; Schroeder et al. 1988; Laswell et al. 1990; Brooks 1991; Continental Shelf Associates, Inc. 1992; Mitchell et al. 1992; Parker et al. 1992; Sager et al. 1992; Mitchell et al. 1993; Schroeder et al. 1995). However, to date, no comprehensive attempt has been made to synthesize all of the geologic information contained in the publications and reports generated by these research and survey efforts.

The continental shelf province is triangular shaped from the Mississippi River Delta to the head of the De Soto Canyon and then nearly rectangular on to Cape San Blas and extends from the coastline seaward to the 200 m depth contour. The eastern portion connects directly to the West Florida Shelf while the western portion has only limited access to the Texas-Louisiana Shelf by a 15 to 20 km strip around the birdfoot delta. Off Mississippi and Alabama the shelf has a maximum width of 128 km, and then narrows to within 51 km of the Florida coast where the deep, central axis of the De Soto Canyon extends northward. East of the canyon the shelf broadens out again reaching a maximum width of 96 km. Both regions can be characterized as almost flat plains, sloping gently from the coast to the shelf break zone at between 60 to 100 m. The shelf break marks a change in the slope of the ocean bottom. The area seaward of this break is most often classified as the beginning of the upper slope. Along the western rim of the De Soto Canyon, between the shelf break and the 200 m contour, the ocean floor is narrow and steep while along the eastern rim this zone is wide and has a gradually increasing slope. Most of the shelf province is covered by a fine-grained quartz sand sheet. Some exceptions are the clay and silt deposits associated with the birdfoot delta of the Mississippi River and the shelf bottom seaward of the sandy Chandeleur Islands where the submerged St. Bernard Delta, formed 3000 years ago by the Mississippi River, consists of silty clay. Also, a nearshore sandy mud is presently being deposited just south of the Mississippi Sound barrier islands by silt and clay being flushed from the adjacent estuaries. In the deeper waters near the shelf edge the sand sheet gives way to limy-mud deposits.

Topographic features of a hard bottom nature are relatively common on the shelf province. These features provide substrate for sessile epifauna not ordinarily found on the extensive areas of unconsolidated sediment. The biological assemblages are diverse and include soft and hard corals, sponges, bryozoans and crinoids, as well as numerous fish species (See Thompson et al. 1999). Hard bottom sites in water depths of 18-40 m are common on the inner shelf offshore of Alabama and NW Florida. They range from scattered rock rubble to tabular plates as large as 6 m across and 40 cm thick with little or no vertical relief to isolated outcrops up to 5 m across and with 2 m of relief to long limestone ledges up to 4 m in relief to clusters of small to moderate sized reefs a few meters to 10's of meters across with up to 3 m in relief. These sites are annually subjected to winter storms and periodically to tropical storms which produce waves and currents capable of suspending and transporting sand size particles that can either result in high mortality among the epifaunal community due to the abrasive action from the moving sand or will contribute to a long-term exposure-burial cycle observed at the low relief sites.

The most extensive hard bottom area is built up on the outer shelf region east of the Mississippi Delta and south of Mobile Bay, in 60 to 200 m of water. The features investigated to date occur in five morphologic configurations: pinnacles, flat-top reefs, patch reefs, reef-like mounds, and isobath parallel ridges. Pinnacles are high-relief, spire-like structures 10-50 m wide at their bases and up to 18 m tall. They are found in an elongated, curved cluster in the southwest part of the study area at depths of 105-120 m and scattered in the far west at depths of 77-90 m. Flat-top reefs are broad, steep sided-features up to 1000 m across and 15 m in vertical relief. They are located in the west-central region between 74-82 m. Patch reefs are mostly mushroom shaped with 1-5 m wide pedestal-like bases and bulbous tops up to 10 m across. They occur at depths of 74-84 m in at least two separate fields in the western region. Reef-like mounds are found along the western rim of the De Soto Canyon. They are 10-70 m wide, up to 4 m high and are found at depths of 70-80 m. Isobath parallel ridges are 10's to 100's of meters wide and up to 15 km long with seaward facing escarpments up to 8 m in relief. Most are confined to a depth range of 68-76 m. The carbonate material represents a crust over relict barrier island or longshore bar deposits.

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Biographical Sketch

Dr. Schroeder is a Professor of Marine Science at The University of Alabama and a Senior Marine Scientist at the Dauphin Island Sea Lab. He first became involved in oceanographic endeavors 36 years ago and has conducted research in the Gulf of Mexico since 1967. He has authored or co-authored over 50 refereed publications and many more reports dealing with geological and biological aspects of continental margin and deep-sea habitats, estuarine, shelf and open ocean hydrography and circulation, and paleoceanography. Over the past decade his principal interest has been contributing to integration and synthesis phases of interdisciplinary investigations. He received his B.S. in Zoology from San Diego State College and his Ph.D. in Oceanography from Texas A&M University.

BENTHIC MACROINFAUNA OF THE NORTHEASTERN GULF OF MEXICO OCS, NEAR DE SOTO CANYON

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Introduction

It has been over 25 years since Dr. Sneed Collard and Charles D'Asaro provided the last summary of knowledge about benthic macroinvertebrate ecology in the northeastern Gulf of Mexico (Collard and D'Asaro 1973). Their review was comprehensive and addressed estuarine as well as marine ecosystems, and identified eight principal benthic community types, including "Bays, Channels and Sounds," "High Energy Beaches," "Shallow Shelf Communities: Carolinian Affinities," "Deep Shelf Communities: West Indian Affinities," "Slope Communities," and other estuarine assemblages. The present workshop is intended to describe the interrelationships between physical/biological processes in the outer continental shelf (OCS); this paper describes the ecology of soft-bottom benthic macroinfauna associated with offshore habitats from the east side of Mobile Bay to Cape San Blas.

Since 1973, several benthic investigations have been performed in this region (Fig. 30). Some, like the MAFLA studies from 1974 to 1979 (Alexander et al. 1977; Dames and Moore 1979), and the MAME studies from 1987 to 1989 (Harper 1991), sampled small numbers of sites over wide geographic areas. Other studies involved large numbers of sample points within relatively small study areas, including offshore Alabama surveys in 1980-1981 (Shaw et al. 1982) and ocean dredged material disposal site (ODMDS) surveys off Panama City/Port St. Joe in 1983 and 1986 (Barry A. Vittor & Associates, Inc. 1986) and Pensacola, 1986 to 1990 (Barry A. Vittor & Associates, Inc. 1991). Most recently, benthic communities were studied in the Destin Dome area off Alabama and Florida in 1992-1993 (Continental Shelf Associates, Inc. 1994), and in potential sand borrow areas off Alabama in 1997 (Byrnes et al. 1999). All of these investigations included analyses of sediments as well as macroinfaunal assemblages. The emphasis in these studies was on the OCS west of De Soto Canyon, and in waters shallower than 30 m; the MAFLA and MAME studies included only 13 sites deeper than 60 m, of which only 4 were east of the Canyon (Fig. 30, Table 4).

This presentation synthesizes the results of the above studies, to characterize the composition and distribution of benthic macroinfauna in relation to habitat parameters such as sediment texture and water depth. (Detailed discussions of physical and chemical characteristics of this region have been provided in previous presentations.)

Table 4. Distribution, frequency, and intensity of benthic investigations conducted since 1973, from the eastside of Mobile Bay to Cape San Blas.

Investigation	Location(s)	Water Depths	Survey Frequency	Number of Stations	Replicates?
MAFLA Benchmark Ecology Study (Alexander et al. 1977; and Dames and Moore 1979)	Two transects in the Alabama and NW Florida OCS	30 m to 220 m	Seasonal; 3 years (1974-1978)	18	Yes
Offshore Alabama Benthic Community Study (Shaw et al. 1982)	One zone in the Alabama OCS	11 m to 18 m	Two seasons (1980-1981)	6	Yes
Panama City/Port St. Joe ODMDS Study (Barry A. Vittor & Associates, Inc. 1986)	Three potential ODMDSs and two reference sites off NW Florida	12 m to 17 m	Two seasons (1986)	98	Yes
Pensacola ODMDS Studies (Barry A. Vittor & Associates, Inc. 1991)	Two ODMDSs off NWS Florida	18 m to 30 m	Three seasons (1986-1987, 1990)	20	Yes
MAME Study (Harper 1991)	Two transects off Alabama and NW Florida (De Soto Canyon)	20 m to 200 m	Five seasons (1987-1989)	12	Yes
Chevron Destin Dome Baseline Study (Continental Shelf Associates, Inc. 1994)	Destin Dome Area and potential pipeline corridor off NW Florida and Alabama	20 m to 90 m	Five seasons (1992-1993)	20	Yes
Alabama Sand Borrow Area Study (Byrnes et al. 1999)	Three potential borrow sites in the Alabama OCS	9 m to 18 m	Two seasons (1997)	60	No

Macroinfaunal Assemblage Composition and Distribution

Benthic assemblages in this area are dominated numerically by polychaetous annelids; typically, polychaetes comprise 30 to 40% of taxa and 50 to 60% of individuals. Crustaceans are generally second most abundant with respect to both taxa (20 to 40%) and individuals (15 to 25%), while mollusks represent 15 to 25% of taxa and 15 to 25% of individuals. Other major taxonomic groups found in the northeastern Gulf include echinoderms (especially ophiuroids), sipunculids, cephalochordates, and rhynchocoels. Both crustaceans and mollusks exhibit high variability in distribution, and are more abundant (and diverse) in sandier substrates than in finer substrates. Numerous species are associated with a wide range of habitats, including polychaetes such as *Paraprionospio pinnata, Prionospio cristata, Synelmis albini, Nephtys picta,* and *Sigambra tentaculata*; the crustaceans *Eudevenopus honduranus* and *Ampelisca agassizi*; and the mollusks *Ervilia concentrica, Caecum pulchellum, Caecum cooperi,* and *Nassarius albus*.

Macroinfaunal assemblages in the northeastern Gulf have been classified variously on the basis of depth (*e.g.*, inner shelf, outer shelf), sediment texture (*e.g.*, coarse sand/shell hash, sandy silt, sand), or a combination of these parameters. Based on the several studies that have been cited, sediment texture is more important in determining macroinfaunal assemblage composition than water depth, location, or season. However, there clearly are linkages between sediment texture and those other variables, through patterns of sediment deposition, transport, or resuspension. Salinity has not been found to play a significant role in macroinfaunal distributions, due to the absence of major riverine discharges. The assemblages described here reflect substrate type, with water depth variations. Figure 31 depicts a generalized distribution of these assemblages, which are described below. Representative species are listed in each case, in alphabetical order.

Sand Assemblage, Shelf-Wide

Assemblage I is distributed broadly throughout the OCS, typically in sand sediments that contain negligible (< 5%) amounts of silt/clay or gravel (shell hash). Although there are some changes in species composition with depth, the numerically dominant taxa in Assemblage I are found from nearshore shallow waters to the edge of the shelf. Most species in these habitats are filter feeders, epibenthic deposit feeders, or carnivores. The mollusks *Astarte nana*, *Chione intapurpurea*, *Ervilia concentrica*, and *Tellina aequistriata* are filter feeders, while *Caecum cooperi*, *C. imbricatum*, and *Cadulus tetrodon* are epibenthic deposit feeders. Carnivorous species include several polychaetes (*Nephtys picta*, *Sigambra tentaculata*, *Synelmis albini*, most syllids) and some mollusks (*Nassarius albus*, *Tectonatica pusilla*). Most of the crustaceans in Assemblage I are surface deposit feeders (e.g., *Rutiderma darbyi*) or filter feeders (*Ampelisca agassizi*).

Abra lioica (M)
Alpheopsis harperi (C)
Alpheus floridana (C)
Ampelisca agassizi (C)
Aricidea wassi (P)
Astarte nana (M)
Cadulus tetrodon (M)
Isolda pulchella (P)
Laonice cirrata (P)
Mooreonuphis pallidula (P)
Nassarius albus (M)
Nephtys picta (P)
Nucula ageensis (M)
Notomastus americanus (P)

Caecum cooperi (M)
Caecum imbricatum (M)
Chione intapurpurea (M)
Cyclaspis pustulata (C)
Diopatra tridentata (P)
Ervilia concentrica (M)
Eudevenopus honduranus (C)
Eusarsiella disparalis (C)
Exogene lourei (P)
Rictaxis punctostriatus (M)
Rutiderma darbyi (C)
Rutiderma mollitum (C)
Sigambra tentaculata (P)
Synelmis albini (P)
Sphaerosyllis piriferopsis (P)
Tectonatica pusilla (M)
Tellina aequistriata (M)
Typosyllis amica (P)

Silty Sand Assemblage, Inner Shelf (< 100 m)

Assemblage II comprises taxa associated with silty sand and sandy silt sediments in shallower areas of the shelf. Sediments in these habitats generally contain more than 5 to 10% silt and occur in areas affected by sediment transport from estuarine systems such as Mobile Bay and Escambia Bay, or by disposal of dredged material from navigation channels in the embayments in the area. Assemblage II species are primarily detritivores, including burrowing and surface deposit feeders. Polychaetes predominate, represented by species such as *Armandia maculata, Dispio uncinata, Magelona pettiboneae, Paraprionospio pinnata,* and *Spiophanes bombyx.* However, suspension and filter feeding taxa are also abundant in these habitats, including the crustacean *Ampelisca agassizi, Branchiostoma* sp., and the polychaetes *Diopatra cuprea* and *Owenia fusiformis*. This assemblage contains few species associated with organic fine sediments (*e.g.*, capitellid polychaetes).

Abra aequalis (M)
Aglaophamus verrilli (P)
Ampharete americana (P)
Ampelisca agassizi (C)
Aricidea wassi (P)
Armandia maculata (P)
Aspidosiphon albus (S)
Branchiostoma sp. (Ce)
Caecum pulchellum (M)
Diopatra cuprea (P)
Dispio uncinata (P)
Galathowenia oculata (P)
Golfingia trichocephala (S)
Goniada littorea (P)
Goniadides carolinae (P)
Lumbrineris verrilli (P)
Magelona pettiboneae (P)
Mediomastus sp. (P)
Montecellina dorsobranchialis (P)
Nereis micromma (P)
Owenia fusiformis (P)
Paraprionospio pinnata (P)
Phoronis sp. (Ph)
Prionospio cristata (P)
Scoletoma verrilli (P)
Sigambra tentaculata (P)
Spiophanes bombyx (P)
Syllis hyalina (P)
Synelmis albini (P)
Tellina versicolor (M)
Tharyx annulosus (P)
Turbonilla conradi (M)
Xenanthura brevitelson (C)

Coarse Sand/Gravel Assemblage

Assemblage III has a limited distribution, based on patchy occurrences of coarse sand with shell hash or rubble. These habitats are found in shallow to deep water and contain surface-dwelling, motile species, as well as filter feeders and burrowers. Assemblage III species include epibenthic deposit or suspension feeders (*e.g.*, *Caecum cooperi,* the crustaceans *Metharpinia floridana* and *Apseudes* sp., and the polychaetes *Aonides paucibranchiata, Chone duneri,* and *Filograna implexa*). Carnivores are also abundant, including the polychaetes *Chloeia viridis, Eunice vittata, Nephtys picta,* and *Bhawania heteroseta.*

Abra lioica (M)
Ampelisca agassizi (C)
Ampharete acutifrons (P)
Amphiodia pulchella (E)
Aonides paucibranchiata (P)
Apseudes sp. (C)
Aricidea taylori (P)
Armandia maculata (P)
Bhawania heteroseta (P)
Branchiostoma sp. (Ce)
Caecum cooperi (M)
Ceratonereis mirabilis (P)
Chione sp. (M)
Chloeia viridis (P)
Chone duneri (P)
Ervilia concentrica (M)
Eunice vittata (P)
Exogene dispar (P)
Filograna implexa (P)
Metharpinia floridana (C)
Nephtys picta (P)
Parapionosyllis longicirrata (P)
Polygordius sp. (P)
Prionospio cristata (P)
Protodorvillea kefersteini (P)
Scoletoma verrilli (P)
Sphaerosyllis piriferopsis (P)
Synelmis albini (P)

Silty Sand Assemblage, Outer Shelf (> 100 m)

Assemblage IV is associated with fine sand and silty sand habitats in waters over 100 m deep. These sediments occur on both sides of the De Soto Canyon, and in side channels that lead into the Canyon. The organic content of these sediments is similar to that of the shallower silty sand habitat (i.e., 0.5-1.0 percent TOC), and similar feeding habits are exhibited by the Assemblage IV species. Burrowing and surface deposit feeders predominate, including the polychaetes *Ampharete acutifrons, Aricidea neosuecica, Armandia maculata, Laonice cirrata, Poecilochaetus johnsoni*, and *Prionospio steenstrupi*; and the mollusks *Nuculana acuta* and *Yoldia liorhina*. Carnivores/omnivores are also abundant, and include the polychaetes *Goniada maculata, Paralacydonia paradoxa,* and *Synelmis albini.*

Aglaophamus verrilli (P)
Ampelisca verrilli (C)
Ampharete acutifrons (P)
Aricidea neosuecica (P)
Armandia maculata (P)
Goniada maculata (P)
Laonice cirrata (P)
Micropanope nuttingi (C)
Nephtys incisa (P)
Nuculana acuta (M)
Paralacydonia paradoxa (P)
Paraprionospio pinnata (P)
Poecilochaetous johnsoni (P)
Prionospio steenstrupi (P)
Synelmis albini (P)
Yoldia liorhina (M)

Benthic Community Summary Statistics

Basic benthic community parameters such as individual density and species diversity vary significantly between habitat types and between surveys. Differences between surveys relate to seasonal as well as annual influences. Species and individual abundances are generally higher in medium sand substrates shallower than 60 m, and lower in deeper waters and in finer sediments. Species diversities are highest in medium to coarse sand habitats, and are lower in finer sediments and at water depths over 60 m. Ranges of values of these parameters are summarized in Table 5, and should be viewed primarily as reflecting general trends only. The wider ranges of values in Assemblages I and II are most likely artifacts of the more numerous data for those habitats, as opposed to Assemblages III or IV.

Table 5. Ranges of macroinfaunal species and individual abundances in the northeastern Gulf of Mexico.

Assemblage	Number of Taxa	Individuals per M^2	Diversity as H′*
I Sand Assemblage, Shelf-Wide	59-271	948-17,881	2.04-4.71
II Silty Sand Assemblage, Inner Shelf (< 100 m)	61-213	411-10,290	2.56-3.61
III Coarse Sand/ Shell Hash Assemblage	82-327	506-2,252	3.50-4.64
IV Silty Sand Assemblage, Outer Shelf (> 100 m)	50-132	277-994	3.25-3.67

*H′ is based on log base e

Relationships Between Shelf Processes and Benthos

Most of the sedimentary habitats in the northeastern Gulf of Mexico region described in this paper comprise medium to coarse sand; areas characterized by fine sand or silt are found in deeper waters in the De Soto Canyon, and in some shallower waters. Sediment distribution in the upper MAFLA study area is shown in Figure 32 (from Feldhausen et al. 1979), and conforms generally to the macroinfaunal assemblage classification described here. These patterns indicate that little of this region is a depositional area for fine sediments; rather, most sediments are re-worked and transported by wind-driven currents and turbulence, and are carried by littoral drift from east to west. Disposal of fine material has been monitored at several ocean dredged material disposal sites (ODMDSs). Dredged material from Pensacola Harbor, Panama City, and Port St. Joe was found to cause shifts in sediment texture, from less than 1% silt/clay to over 8% silt/clay. These habitat changes resulted in macroinfaunal shifts from Assemblage I, Sand to Assemblage II, Silty Sand/Inner Shelf (Barry A. Vittor & Associates, Inc. 1986, 1991).

Natural events also have the ability to alter macroinfaunal communities; Alexander et al. (1977) reported significant changes in sediment composition in the De Soto Canyon area, after Hurricane Eloise crossed the West Florida Shelf in Fall, 1975. Similar sediment changes were observed by Barry A. Vittor & Associates, Inc. (1996) after Hurricane Opal passed over the Destin Dome area in Fall, 1995.

Macroinfaunal assemblage structure in sand habitats off Alabama was found to change between Spring and Fall seasons, while changes in sandy silt habitats were masked by the greater variability associated with the finer sediments (Byrnes et al. 1999). Harper (1991) reported that macroinfaunal species and individual abundances decreased during Winter, while very little seasonal variation in assemblage structure or abundance was observed in the Destin Dome Area by Continental Shelf Associates, Inc. (1994). Recent reports of upwelling and hypoxia along the northwest Florida coast suggest that dissolved oxygen depletion is an unusual occurrence in the northeastern Gulf; there are no reports of regular benthic defaunation due to hypoxia in this region.

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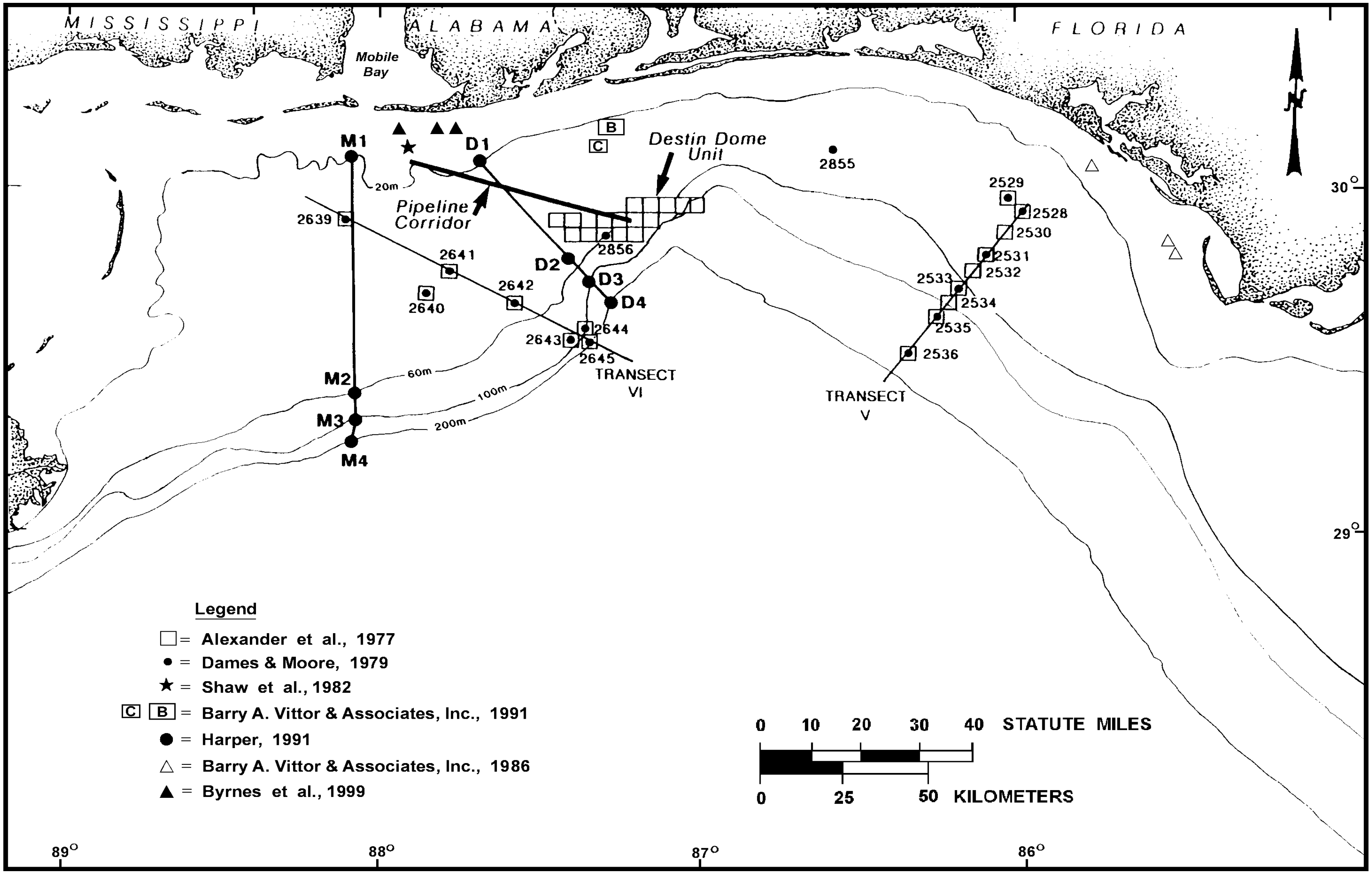

Figure 30. Locations of benthic investigations in the northeastern Gulf of Mexico, 1973-1999.

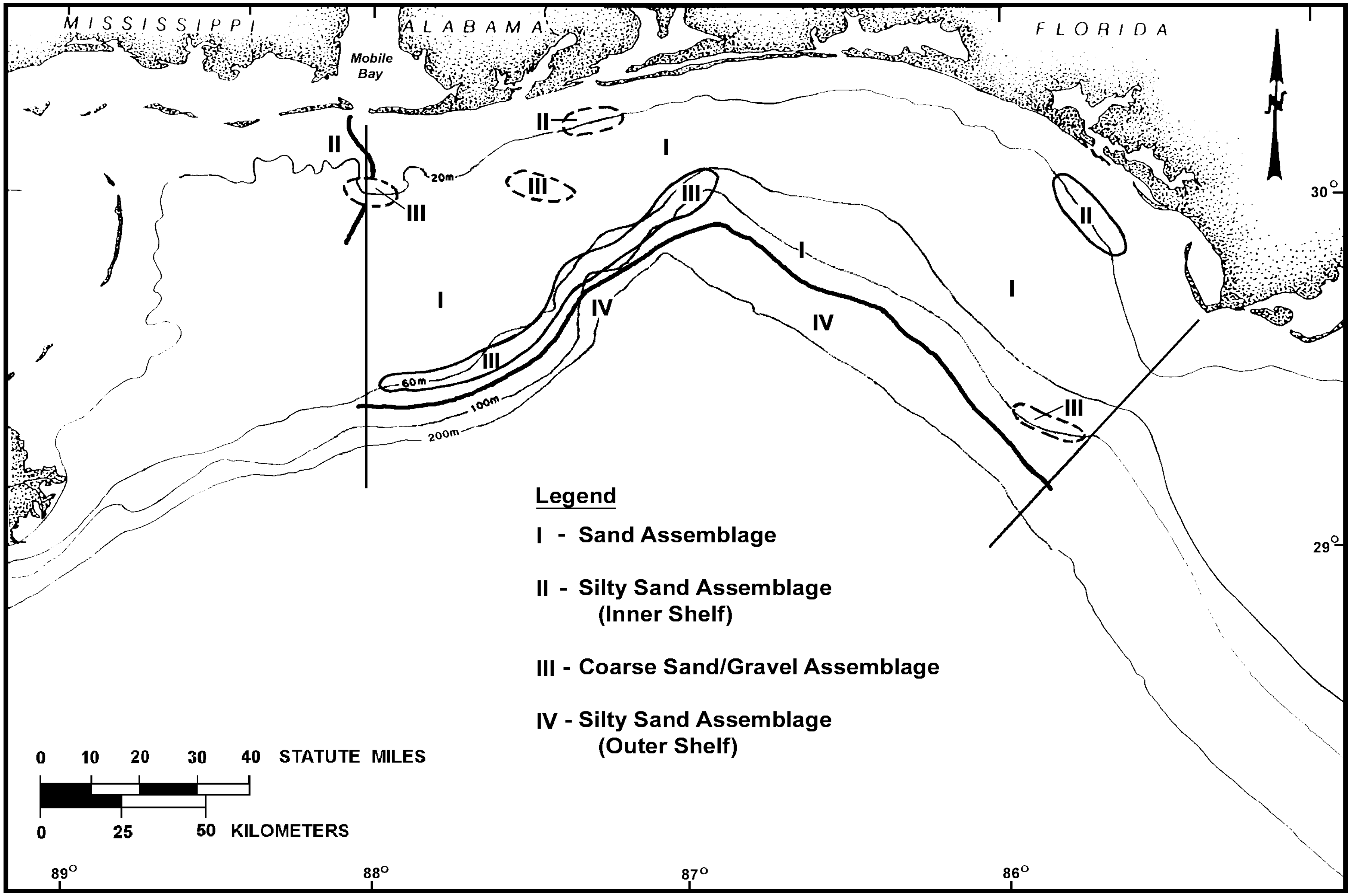

Figure 31. Generalized distribution of benthic macroinfaunal assemblages in the northeastern Gulf of Mexico.

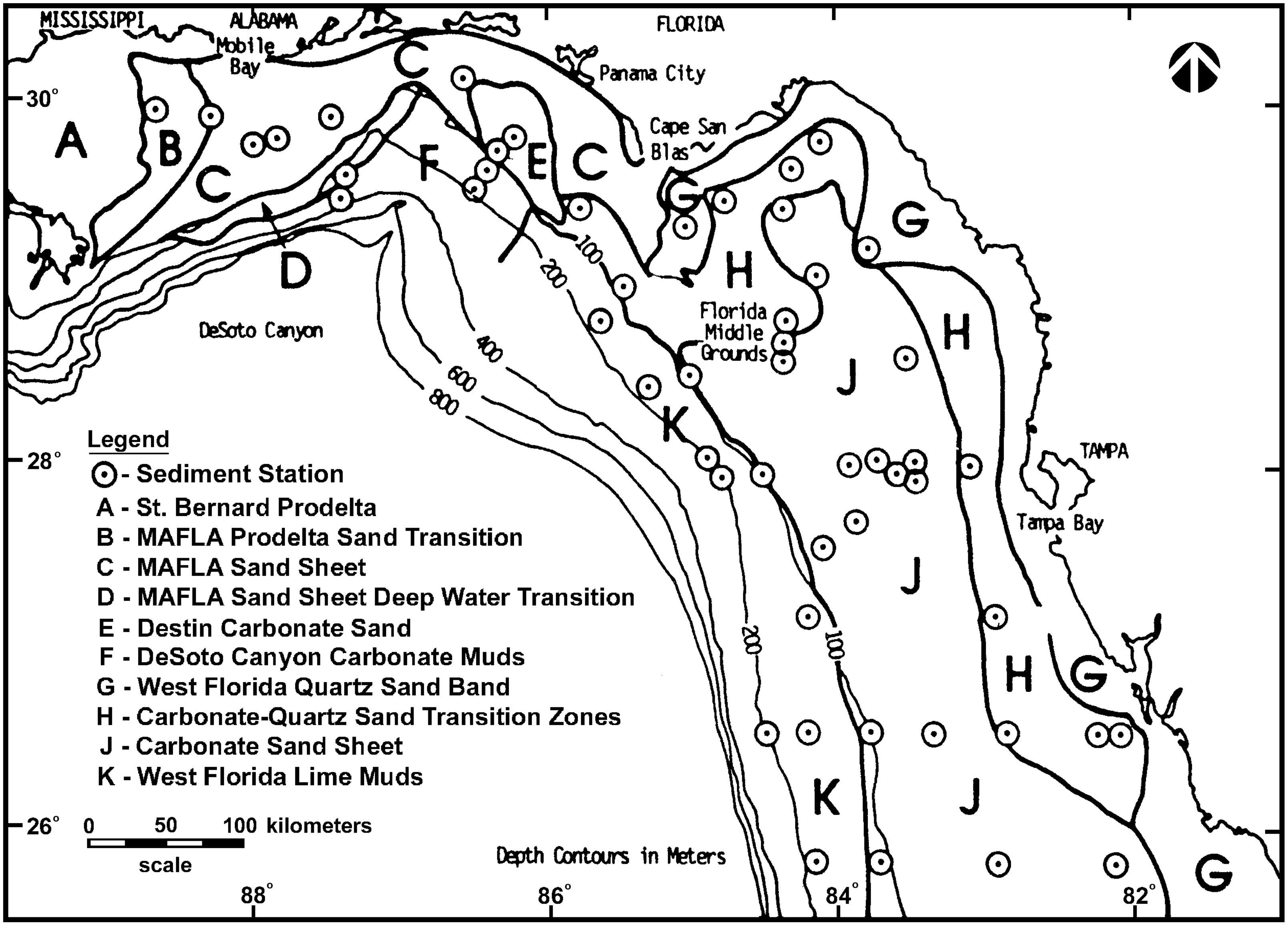

Figure 32. Map of bottom sediment facies from the MAFLA study area (modified from Feldhausen et al. 1979).

Biographical Sketch

Dr. Barry A. Vittor is President of Barry A. Vittor & Associates, Inc., an environmental consulting firm based in Mobile, Alabama. He has performed several benthic ecology studies for the Minerals Management Service in the northeastern Gulf of Mexico and has conducted numerous other benthic macroinfaunal communities studies in the Gulf for other agencies and private clients. Dr. Vittor's areas of interest include estuarine and marine benthic ecology; sediment toxicity and bioaccumulation; and impacts of dredging, petroleum resource development, and coastal development. He received his Ph.D. in Ecology from the University of Oregon.

NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: ECOSYSTEM MONITORING, MISSISSIPPI/ALABAMA SHELF; INTRODUCTION AND OVERVIEW

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Introduction

Continental Shelf Associates, Inc. (CSA) was awarded a contract by the U.S. Geological Survey, Biological Resources Division to conduct an ecological study of an area offshore Mississippi/Alabama. The project team consists of CSA, the Geochemical & Environmental Research Group of Texas A&M University, University of Texas, Applied Marine Sciences, and independent consultants.

Geographic Area of Study

The geographic area of study is the Mississippi-Alabama pinnacle trend area in approximately 50 to 150 m water depths (Fig. 33). Several studies have been conducted in the area, which was first described by Ludwick and Walton (1957). There have been four Minerals Management Service-funded studies (Woodward-Clyde Consultants 1979; Brooks 1991; Continental Shelf Associates, Inc. 1992; Shinn et al. 1993) and an oil and gas lease block clearance survey (Continental Shelf Associates, Inc. 1985) conducted in the area.

Study Objective

The objective of this study is to describe and monitor biological communities and environmental conditions at hard bottom features located within the geographic area of study. A number of oil and gas lease blocks are encompassed by the study area with at least one oil and gas production platform present. Information gained from this study will be used to review existing lease stipulations to determine their adequacy in protecting the biological communities present on the hard bottom features. This study also meets several objectives of the National Research Council (1992) regarding the assessment of environmental impacts from oil and gas operations. These objectives include (1) identifying representative species; (2) describing seasonal patterns; (3) acquiring basic ecological information for key or representative species; and (4) obtaining information on factors that determine sensitivity of biota to outer continental shelf activities and their recovery potential.

Study Components

The 4-year study is divided into four phases of 1 year duration each with annual reports planned at the end of each phase. The phases are as follows:

- Phase 1 - Reconnaissance, Baseline, and Monitoring;

- Phase 2 - Monitoring;
- Phase 3 - Monitoring; and
- Phase 4 - Data Interpretation and Information Synthesis

All of the 11 cruises planned for the study have been completed. These encompassed reconnaissance (two cruises), baseline (one cruise), monitoring (three cruises), and mooring servicing (five cruises).

Reconnaissance

During the reconnaissance portion of Phase 1, five "megasites" (Fig. 33) (approximately 25 to 35 km^2 areas) were selected for detailed study. These sites were selected as being representative of the hard bottom features previously identified in the area (Brooks 1991; Continental Shelf Associates, Inc. 1992). The megasites were surveyed in November 1996 using swath bathymetry, high resolution side-scan sonar (11 and 72 kHz), and a subbottom profiler (2 to 8 kHz). Nine areas of approximately 0.2 to 1.5 km^2 size were selected during the cruise and surveyed in more detail. Previously collected video and still photographic data from these nine sites were reviewed and additional visual data collected during a second reconnaissance survey using a remotely operated vehicle (ROV) to aid in the selection of nine study sites. The study sites were selected to provide representative hard bottom features of high, medium, and low relief in the eastern, central, and western portions of the study area (Fig. 33).

Baseline and Monitoring

The focus of the baseline and monitoring portions of the study is to understand the geological and oceanographic processes as factors in controlling/influencing the hard bottom communities at the nine study sites. Data were gathered during the reconnaissance survey on substrate characteristics; hard bottom orientation, size, and morphology; and depth of surrounding soft sediments. One baseline and three monitoring cruises have been completed (April 1997, October 1997, August 1998, and August 1999). Data on microtopography are being obtained from the collection and analysis of rock samples and video and photographic data during these cruises. Grab samples collected during the monitoring cruises are being analyzed for grain size (four cruises) and concentrations of hydrocarbons and metals (first cruise only). Six instrument arrays comprised of current meters; sediment traps; and temperature, salinity, dissolved oxygen, and turbidity (optical backscattering) sensors were deployed during the first cruise in the vicinity of the hard bottom features. The arrays were recovered and redeployed at 3-month intervals and recovered on the final monitoring cruise. Sediment trap contents are being analyzed for grain size, total inorganic and organic carbon, and metals. During each of the four cruises, water column profiles were made for conductivity, temperature, dissolved oxygen, transmissivity, and optical backscatter, and samples were collected for analysis of particle sizes, dissolved oxygen, and salinity. Water column profiles also were made during the five mooring servicing cruises.

Biological Data

Hard bottom communities were sampled at the nine sites by ROV. At each site, random photographs were taken and random video transects were surveyed using an ROV during the baseline and monitoring cruises. Random photographs are used to estimate the abundances of sessile and motile epibiota, whereas video images are used to quantify larger and more widely dispersed organisms including fishes and to broadly characterize substrates and species composition. In addition, fixed video/photoquadrats were established and resampled on subsequent cruises; the data will be used to describe temporal changes related to growth, recruitment, competition, and mortality. Voucher specimens also were 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, variation within and among sites, and relationships between the biota and physical variables.

A total of 1,675 random photoquadrats have been analyzed from the baseline and first monitoring cruises. A total of 42 taxa comprise the 10 taxa with the highest mean density at each site. Cnidaria was the most-represented phylum with 10 taxa of octocorals, five taxa of ahermatypic corals, four taxa of antipatharians, and single taxa of hermatypic corals and actinarians (anemones). Porifera was the next most-represented phylum with seven taxa, followed by Ectoprocta with five taxa. The phylum Echinodermata was represented by three taxa (two crinoids and one echinoid). Algae were represented by two taxa of rhodophyta. The phyla Urochordata and Arthropoda were represented by single taxa of ascidians and galatheids, respectively. Hard bottom community composition revealed by the percent cover data from the random photoquadrats was only slightly different from that revealed by the density data. Although octocorals were represented by the most taxa in both density and percent cover data, ahermatypic corals had the highest mean abundances with 279.3 organisms per m^2 and 5.62 percent cover over all sites, due to the dominance of *Rhizopsammia manuelensis*. Octocorals had the second highest mean density and percent cover over all sites with 13.60 per m^2 and 3.00 percent cover. The relative ranking of antipatharians, poriferans, and ectoprocts varied between density and percent cover data. The aggregate percent cover data for major groups represented by the 40 most abundant taxa suggest substantial variation among sites. Mean percent cover for ahermatypic corals ranged from 0.03 at Site 1 to 10.96 at Site 7. Mean percent cover for antipatharians also was quite variable among sites, ranging from 0.04 at Site 1 to 16.18 at Site 4. Octocorals, poriferans, and ectoprocts displayed relatively less variation among sites. Despite the high variation among sites, there was little difference between sampling times. Abundances at high relief sites (Sites 1, 5, and 7) were neither obviously greater nor more diverse than at sites with lower relief. Little of the biological variation among sites is apparently due to consistent effects of habitat relief. Some taxa occurred in high abundances in all relief categories and others varied inconsistently among relief categories.

Fish assemblages associated with the study sites also are being described from the available visual data collected during the surveys. There are also two additional biological "companion" studies. The first is a geographic information system (GIS) and microhabitats study that focuses on relationships between the physical environment and the hard bottom communities. The microhabitats study is being conducted at Sites 7 (medium relief) and 9 (low relief). The second involves the deployment of settling plates on fixed arrays to study epibiota recruitment, growth, and community development. Settling plate arrays include enclosed and non-enclosed plates plus controls to study predation/disturbance effects. Plates were placed near bottom and above any identified nepheloid layer.

Data Interpretation/Synthesis

The data interpretation and synthesis efforts will involve understanding the relationship of the measured geological and physical factors to the hard bottom communities through statistical analyses. A series of questions determined by the study objective with clearly stated null hypotheses also will be identified and statistically tested.

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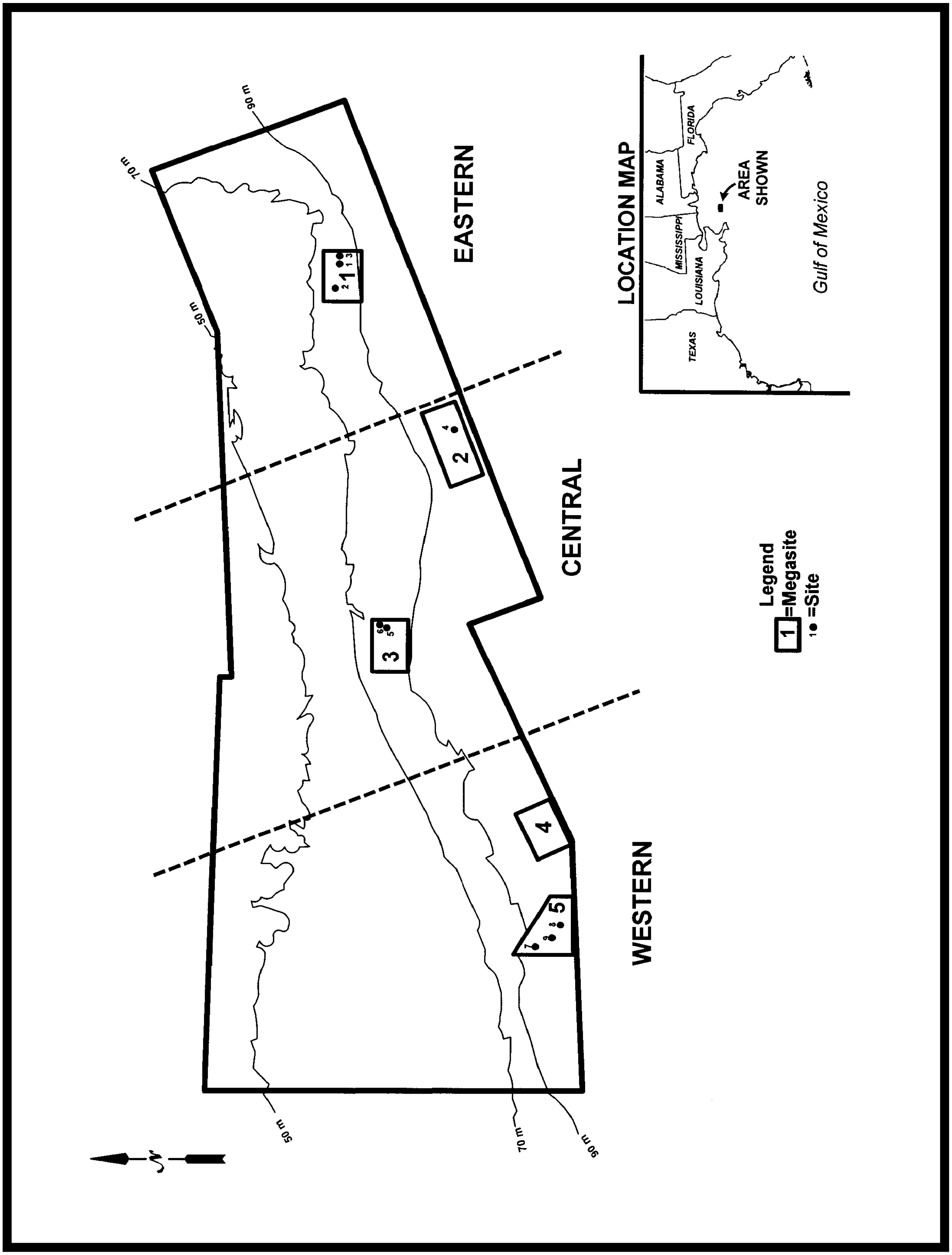
EASTERN
CENTRAL
WESTERN
LOCATION MAP
ALABAMA
FLORIDA
MISSISSIPPI
LOUISIANA
TEXAS
AREA SHOWN
Gulf of Mexico
Legend
1 =Megasite
1● =Site
50 m
70 m
90 m
N

Biographical Sketch

Dr. David A. Gettleson is President and Scientific Director of Continental Shelf Associates, Inc. (CSA), located in Jupiter, Florida. He has 20 years of scientific management experience with major research programs for Federal, State, and industrial clients. He has been involved in the preparation of numerous environmental assessment documents covering a wide range of human activities in the marine environment, including oil and gas operations, dredging and dredged material disposal, beach restoration, artificial reef siting, power plant effluents, sewage outfalls, and waste incineration. Dr. Gettleson received a B.A. degree in Biology from Rollins College in 1971 and earned his Ph.D. degree in Biological Oceanography from Texas A&M University in 1976.

REGIONAL FISHERIES

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Introduction

The Regional Fisheries of the Gulf of Mexico are simultaneously enigmatic as well as paradoxical: Enigmatic because the database upon which our understanding of them is not yet refined (but it is becoming so) and therefore can be misleading; Paradoxical because the fisheries are each simultaneously global, regional and local. The various scales (temporal and spatial) as well as the various levels of community interaction and management jurisdiction make understanding these fisheries particularly difficult and few reliable patterns have emerged. Below are presented some of the highlights of the fisheries in the northern and eastern portions of the Gulf with indications of their peculiarities, especially relative to environmental factors, which complicate our ability to effectively manage their multiple facets.

Species composition

The fauna that compose the fisheries of the northern Gulf region are generally considered part of the larger Carolinian zoogeographic province fauna, which actually has an even broader resemblance to the warm temperate, shelf fauna of the Western Atlantic in both northern and southern hemispheres. Few of the species are limited in distribution; in fact most are rather broadly distributed within the warm temperate region of the Gulf. Most species also have limited populations in subtropical and tropical areas of the western Atlantic. Additionally, many species have geminate species, subspecies, or forms that help compose the respective faunas in this rather broad region.

While the potential number of species that could be part of a fishery is rather large, the actual number of species, which are regularly fished, is quite small. For example, Hoese and Moore (1998) list 552 species of fishes from the region (this list does not include a number of deep sea, off the continental shelf forms). Of these approximately 150 have been, or are being fished as part of either or both recreational and commercial fishing sectors. Normally, however, only about 50 species are fished with enough frequency to have fisheries data ascribed to them. This exaggeration is even more noticeable with regard the macroinvertebrates that compose these fisheries. This includes a least four shrimp species, blue and stone crabs, mollusks (including oysters, clams and squid), and jellyfish. Even adding the few macroinvertebrate species that are normally fished, it is clear that fishers actively seek only a small percentage of the total faunal diversity.

Factors affecting fishes

Temperature and salinity are the factors chiefly responsible for the current distribution of most organisms that compose northern Gulf fisheries. There are physical limits or preferences within which most species thrive. Oppositely, exceeding the limits or preferences can and often does lead to decreases in local abundance. Some of this is due to direct physiological stress while some decreases are due to increases in competition from species more able to adapt to the changed local conditions.

Specific to the northern Gulf of Mexico is the recent discovery of the large, seasonally variable anoxic zone in the mid water areas off the north central Gulf. While most fish and macroinvertebrate species are intolerant of low oxygen levels, the specific limitations that this phenomenon imposes are currently unknown. If it persists or enlarges, however, it is likely that the anoxic zone could have an extreme impact on northern Gulf fisheries.

The Gulf region is dominated by seasonally derived patterns of upwelling, runoff, and currents that have long-term effects on the adaptive state of larval, juvenile and adult stages of fisheries associated species. Most fishes that compose the largest biomass of fisheries are often associated with inshore, lower salinity areas for at least some portion of their life cycle. Thus terrestrial activities can have a profound influence of fisheries with subsequent time and distance translations within the food web.

Interestingly, Gulf fisheries have not been appreciably influenced by the invasion of exotic species. It is also important to note that mariculture has had little impact as yet on the fisheries economy with the possible exception of growing clam mariculture industry.

Habitat

Appropriate habitat is apparently a limiting feature for many species, especially those that associate with seagrass beds during some portion of their life history. Recent surveys indicate a Gulf-wide decline in seagrasses. Many species associate with hard bottom, reef-like features. This habitat is rather limited in the northern Gulf. While the amount of hard bottom may in fact be increasing due to the recent addition of materials to serve as artificial reefs, the total amount of reef material having been added thus far to the Gulf shelf is infinitesimally small. The overall impact of artificial reefs on some of these fisheries cannot be reliably measured.

Zoogeographic features of fish fauna

The distribution of fishes and other aquatic organisms along the nearshore, coastal, and near shelf areas of the Gulf of Mexico display a pattern indicative of the presence of a significant zoogeographic barrier. Many species, for example, have a zoogeographic limit along the northern Gulf of Mexico between Mobile, Alabama and Apalachicola, Florida. Interestingly this zone is quite broad for a zoogeographic limit and does not seem to present any obvious, present day physical limitations to the distribution of many of these species. This is in deference to the intuitive notion that a natural zoogeographic barrier should occur at the Mississippi Delta region where profound and dynamic changes take place in salinity and turbidity. Marine and estuarine organisms that show this northern Gulf distribution anomaly are from a variety of groups including: sparids, stone crabs, seabasses, puffers, and blennies. Examination of geological formations and current geophysical features hint at features that may have been responsible for a historical zoogeographic barrier that is no longer functioning. Subsequently, however, the modern distribution of organisms serves as a reminder of its effectiveness and invites explanation. Combining a knowledge base from Geology and Biology may provide the answer to this perplexing situation. Other features of the distribution of organisms in the northern Gulf indicate strong links to the northern coast of South America.

Fisheries trends

Historical fishery profiles on long-lived, slow growth species such as the red snapper indicate that these fisheries are limited in their spatial scope and easily become overfished. Similar fishery/life history profiles have been observed for other species such as groupers, sharks, and larger pelagic fishes.

Identifying causal relationships among the fisheries landings statistics that are currently available does not permit a clear and meaningful understanding of the trends in the fisheries. Increases in recreational landings are, in many cases, more easily explained by an exponential increase in fishing effort and efficiency. Oppositely, declines among commercial fisheries landings may be more closely aligned with imposed reductions in fishing effort rather than changes in the CPUE (i.e., Catch per Unit Effort) or stock size. Changes in sampling and reporting strategies add significant variability to the database and further retard reliable analysis. Many fisheries, however, show clear evidence of overfishing in that size at maturity is decreasing, average adult size is smaller, and landings are reduced. There is also evidence that the trophic structure of many Gulf fish communities have been considerably altered as a response to overfishing.

Development of additional fisheries

Fish stocks at the shelf edge may be tapped for further expansion of bottom fisheries with several provisions and admonishments. These species are generally slow growing and long lived. Therefore, exploitation (i.e., fishing mortality) must be carefully monitored so as not to exceed their respective abilities to withstand fishing pressure. Providing sanctuaries with sufficient expanse might enable the recovery of some bottom fisheries as well. Also with careful management and assessment, it may be possible to further exploit some previously untapped pelagic resources.

Maintaining fisheries

Below is a list of the “top” things which should be done to help maintain fisheries in the northern Gulf of Mexico.

1. The multi-jurisdictional nature of these fisheries demands total cooperation in management strategies.

2. The development of a standardized, compatible and accurate database is essential. Concomitantly, there must be a sharing of databases and information among agencies.

3. Every effort must be made to fully explain the fisheries management strategy in a meaningful

way to the public.

4. More biological, stock specific information is needed.

5. Management strategies must be community directed rather than species directed. Thus we should develop management plans aimed at managing all species subjected to a specific fishing method.

6. More information on stock limits (i.e., spatial temporal, and genetic) is needed to fully understand the impacts of fishing activities and the imposed management strategy.

7. Essential habitat must be identified. Once identified it must be maintained or, in some cases, improved as part of an overall objective to increase or maintain the fisheries resources.

8. Water quality should be maintained or improved.

9. Fishing effort must be reduced on some stocks, especially on long-lived species in both pelagic and demersal zones.

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Biographical Sketch

Dr. Stephen Bortone is Director of Environmental Science at the Conservancy of Southwest Florida. He has an appointment as Research Professor at Florida Atlantic University and a Courtesy Faculty appointment at Florida Gulf Coast University. He has served as visiting scientist with the Florida Center for Environmental Studies, Director of the Institute for Coastal and Estuarine Research and was Professor of Biology for over 25 years at the University of West Florida. Dr. Bortone has conducted research on fisheries and the life history of fishes chiefly in the southeastern United States and in the Gulf of Mexico for the past 30 years. He has published over 112 scientific articles on the broadest aspects of Biology, including such diverse fields as Anatomy, Physiology, Endocrinology, Systematics and Taxonomy, Evolution, Reproductive Biology, Biogeography, Behavior, Histology, Ecology, Oceanography and Sociobiology.

SHIP AND SATELLITE STUDIES OF MESOSCALE CIRCULATION AND OF ZOOPLANKTON AND MICRONEKTON STOCK IN SPERM WHALE HABITATS IN THE NE GULF OF MEXICO DURING GULFCET II

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Four cruises of R/V *Oregon II* and R/V *Gyre* were combined with tandem remote sensing of sea surface height using the TOPEX/POSEIDON and ERS-2 satellite altimeters to characterize the hydrographic regime of the northeastern Gulf of Mexico for the GulfCet II program. In May-June (early summer) 1996, October (late summer) 1996, May-June (early summer) 1997, and August (mid-summer) 1997, the two ships dropped 560 expendable bathythermographs (XBTs) that profiled the temperature structure of the upper 760 m of the water column. These XBT stations were supplemented with 32 conductivity-temperature-depth (CTD) stations. The early summer cruises focused on the continental slope of the MMS Eastern Planning Area (EPA). The late and mid-summer cruises also surveyed this region of the slope, but these surveyed farther seaward as well, within a deepwater "focal area" where near real-time altimetry maps of sea surface height anomaly provided by the University of Colorado Center for Astrodynamics Research indicated that there was a mesoscale cyclone (cold-core eddy) and anticyclone (warm-core eddy) pair.

The sea surface height anomaly data showed that a broad area of cyclonic circulation was located in the northeastern Gulf throughout 1996. This is evident in monthly or weekly animations of the near-real time data as a temporally persistent although spatially variable region of negative height anomaly. This cyclonic feature was seen from January to September in the region of 27-29^{o}N latitude and 89-84^{o}W longitude. In late summer 1996 (Fig. 34A), altimetry indicated that the cyclone was centered between 27-28^{o}N latitude and 87-89^{o}W longitude, roughly halfway between the mouth of the Mississippi River (MOM) and the northwest edge of Loop Current Eddy C (LCE-C). The R/V *Gyre* documented a 62 dyn cm difference in height between the interior of the cyclone and LCE-C (Fig. 35A). This created a flow confluence between the two features in which upper layer geostrophic velocity exceeded 75 $cm \cdot s^{-1}$ (Fig. 35C) and volume transport was 24 x 10^6 $m^3 \cdot s^{-1}$ (24 Sverdrups).

In mid-summer 1997, the R/V *Gyre* again surveyed a deepwater cyclone-anticyclone pair. This time, the altimetry indicated that the cyclone was centered on the northeast side of the anticyclone and was over the De Soto Canyon (Fig. 34B). The R/V *Gyre* documented a 84 dyn cm difference in height between the interior of the cyclone and LCE-E (Fig. 35B). This created a flow confluence between the two features in which upper layer geostrophic velocity exceeded 100 $cm \cdot s^{-1}$ (Fig. 35D) and volume transport was 31 x 10^6 $m^3 \cdot s^{-1}$ (31 Sverdrups). Continuous shipboard measurements of sea surface temperature, salinity and chlorophyll concentration showed that low salinity, high chlorophyll river water was entrained from off the shelf and transported around the periphery of the cyclone.

Bottle sampling at CTD stations showed that there was a significant relationship between water temperatures less than 22^{o}C and nitrate concentration. As a result, the depth of the 19^{o}C isotherm provided a good estimation of the depth of the 10 µM nitrate concentration. Within the cyclone, the nitracline domed 40-60 m shallower than in the anticyclone. This doming increased the flux of new nitrogen into surface waters so that the deep chlorophyll maximum (DCM) was locally shallower and chlorophyll reached higher maximum concentration in the cyclone. The higher standing stocks of chlorophyll in the upper 100 m of the water column in the cyclones meant that these were biological "oases" of locally high productivity, while the interiors of the anticyclones were more oligotrophic. We hypothesized that the higher secondary productivity of the cyclones supported local aggregations of squid and mid-water fishes that are preyed on by cetaceans.

Net tows and bioacoustic surveys were done to test whether the cyclones also had locally higher standing stocks of potential cetacean prey (zooplankton and micronekton). A 1 m^2 Multiple Opening/Closing Net and Environmental Sampling System (MOCNESS) towed at speeds of 1.5 to 2 knots was used to sample zooplankton and a 14.7 m^2 Isaacs Kidd Midwater Trawl (IKMT) towed at 4 to 5 knots was used to sample micronekton. Continuous measurements of zooplankton and micronekton biomass were made using the ship's 153 kHz Acoustic Doppler Current Profiler (ADCP). Regression analysis was used to relate the net tow biomass to ADCP measurements of acoustic volume backscattering strength (S_v) which could then be integrated for the upper 10-50 m.

Zooplankton biomass from the nets and trawls showed higher values in the cyclone and confluence areas than in the anticyclone. Predicted Mean Biomass (PMB) estimates, derived from the significant positive relationship between integrated zooplankton biomass (as determined by direct net sampling and underway measurements of S_v using the ADCP), also showed that the cyclone and confluence areas were enriched in integrated zooplankton and micronekton biomass relative to the anticyclone. Squid paralarvae and lanternfish (myctophids) are being enumerated from the MOCNESS and IKMT collections by TAMU graduate students Robert Cady and Elizabeth Harris, respectively, as part of their MS thesis work. Cady has found a statistically significant relationship between integrated zooplankton biomass and integrated cephalopod paralarvae numbers, indicating that higher zooplankton and micronekton biomass may correlate with higher concentrations of cetacean prey. Harris is finding that the abundance and diversity of myctophids, another important cetacean prey group, appears to be greater in the cyclones and confluence regions than in the anticyclones. Together, these measurements suggest that the amount of prey for cetaceans may be consistently greater in the cyclone and confluence areas (as opposed to anticyclone), making these mesoscale features preferential habitats for cetacean foraging.

Figure 36 gives the location of sperm whale visual sightings plus acoustic contacts, superimposed on bathymetry, dynamic height anomaly, and nighttime PMB in summer 1996 and summer 1997. Although there was a pronounced diel fluctuation in the vertical migration of sound-scattering organisms during this study, integrated PMB was always greater in cyclones than in anticyclones. Comparing the two plots shows clearly that while most sperm whales were seen in the MOM area in late summer 1996, in mid-summer 1997 more of them were observed some 100-200 miles due east, over deep water of the De Soto Canyon. Whereas the MOM area was strongly cyclonic in 1996, in 1997 the cyclonic circulation was no longer in the MOM area but was centered instead in the De Soto Canyon and sperm whale occurrence shifted similarly. We recognize that since cyclones in the northern Gulf are highly dynamic features, sperm whale distribution is not static. However, with near real-time satellite remote sensing of SSH anomaly, these features can be tracked and used to predict where sperm whales may be concentrated.

For the final report of the GulfCet II program, marine mammal sightings from GulfCet I (1992-1994) and GulfCet II (1996-1997) fieldwork were combined and cetacean-habitat associations then were statistically analyzed for six physical and biological oceanographic variables (Davis et al. 2000). Cetaceans in general were concentrated along the continental slope in areas of cyclonic circulation where chlorophyll was elevated. They were less likely to occur over water deeper than 2,000 m and in anticyclones. Squid-eaters (dwarf and pygmy sperm whales, false killer whales, sperm whales, melon-headed whales, pilot whales, pygmy killer whales, Risso's dolphins, rough-toothed dolphins and all the members of the Family Ziphiidae) occurred more frequently along the upper slope in areas outside of anticyclones. Oceanic stenellids (oceanic dolphins from the genus *Stenella* including clymene dolphins, pantropical spotted dolphins, spinner dolphins and striped dolphins) occurred more often over the lower slope and abyssal regions in areas of cyclonic or confluence circulation. Finally, bottlenose dolphins and Atlantic spotted dolphins were seen most frequently on the continental shelf or along the upper slope, but outside of deepwater hydrographic features such as cyclones and anticyclones.

In summary, most cetaceans in the deepwater northern Gulf of Mexico were concentrated along the continental slope in or near cyclones. These eddies are mesoscale features with locally concentrated zooplankton and micronekton stocks that appear to develop in response to increased nutrient-rich water and primary production in the mixed layer. The exceptions were bottlenose dolphins, Atlantic spotted dolphins and possibly Bryde's whale, that typically occur on the continental shelf or along the shelf break, shoreward of most eddy influence. Low salinity, nutrient-rich water from the Mississippi River, which may also contribute to enhanced primary and secondary productivity in the north-central Gulf, may explain the presence of a resident population of endangered sperm whales south of the delta. However, since cyclones in the northern Gulf are dynamic, cetacean distribution will undoubtedly change in response to the movement of prey associated with these hydrographic features.

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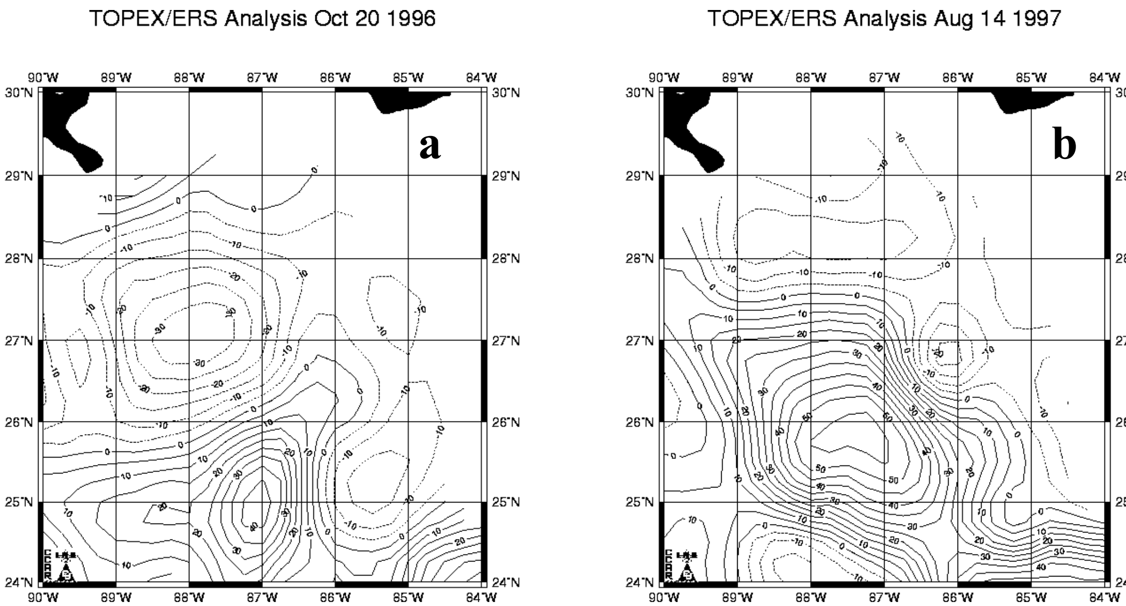

Figure 34. Sea surface height anomaly for water depths > 200 m from satellite altimeter data gridded for the midpoint dates of GulfCet cruises (a) 96G06 (12-29 Oct 96) and (b) 97G08 (6-21 Aug 97). The maps are produced from TOPEX and ERS-2 altimeter data processed using Geophysical Data Records (GDRs) and they are interactively available at: http://www-ccar.Colorado.EDU/~realtime/gom_historical_ssh/. This historical product is designed to retain the mesoscale sea surface height anomalies associated with fronts and eddies.

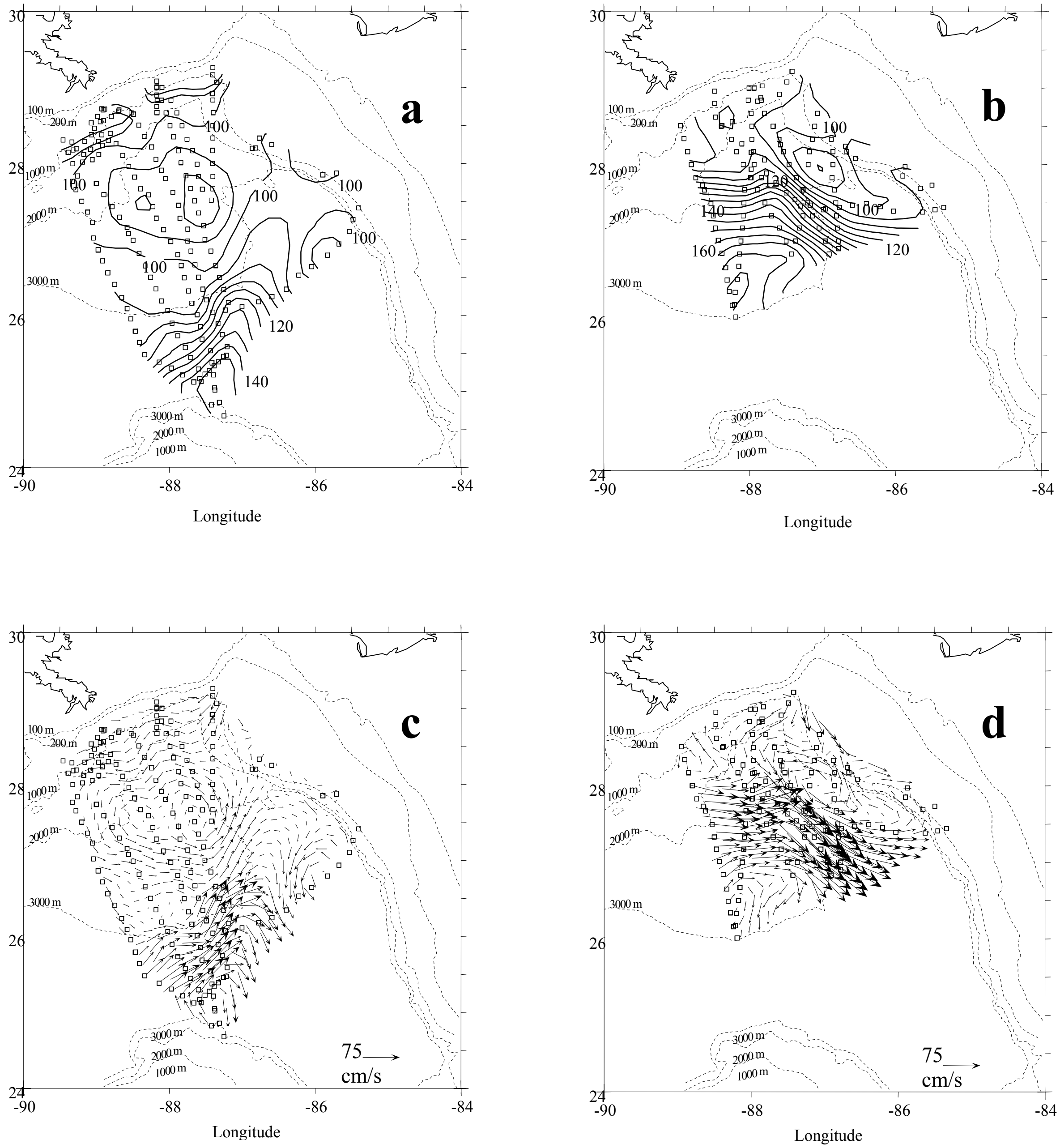

Figure 35. Dynamic topography (cm, 0 m relative to 800 m) of the deepwater focal area in (a) October 1996, as determined from 152 hydrographic stations made on R/V *Gyre* cruise 96G06; (b) August 1997, as determined from 107 stations made on R/V *Gyre* cruise 97G08; and gridded upper layer geostrophic velocity (cm/sec, 0 m relative to 800 m) of the deepwater focal area; (c) as computed from the October 1996 dynamic topography; and (d) as computed from the August 1997 dynamic topography. All from Chapter 2 in Davis et al. (1999).

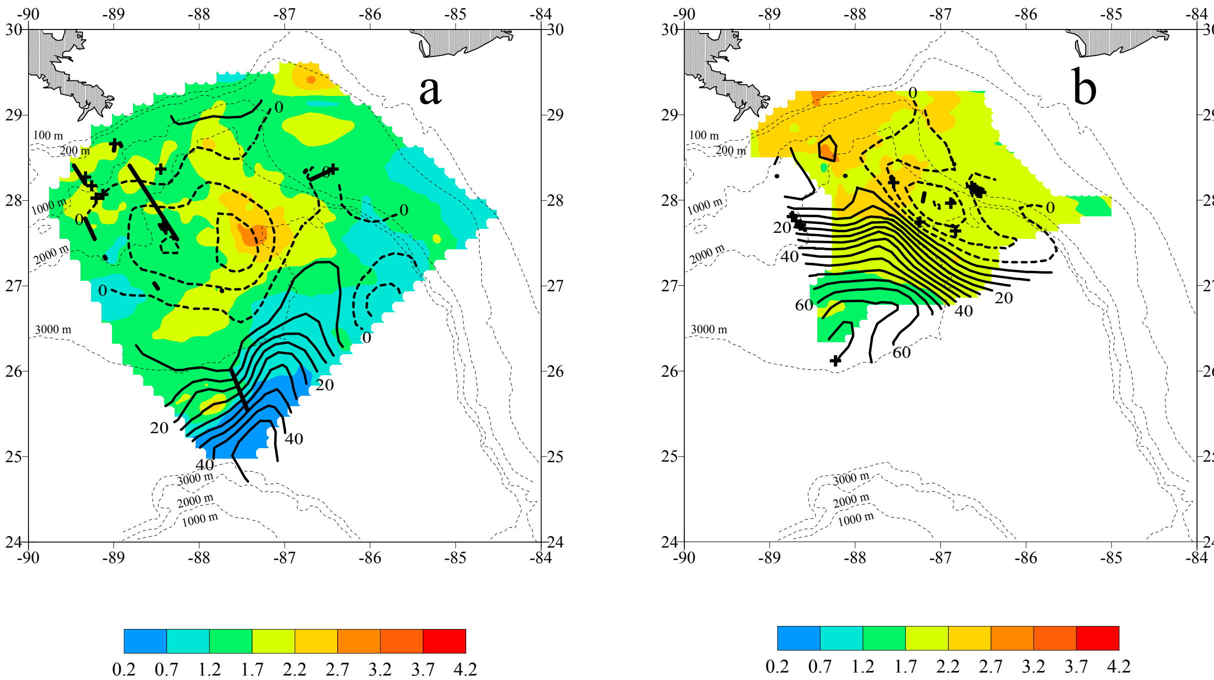

Figure 36. Sperm whale sightings (+) and acoustic contacts (very bold lines and dots) during GulfCet II cruises (a) 96G06 and (b) 97G08. Thin dashed lines denote bathymetry; bold solid (positive) and bold dashed (negative) lines are sea surface dynamic height anomaly (cm) relative to the seasonal mean (100 cm for October; 105 cm for August). Contour intervals are 5 cm. The cyclone is < 0 cm, the confluence between 0 and +25 cm, and the anticyclone > 25 cm dynamic height anomaly. Color contours indicate nighttime predicted mean biomass (PMB, cc m^{-2}) near surface, from 10-50 m. Both from Chapter 6 in Davis et al. (1999).

Biographical Sketches

Professor D. C. Biggs and Professor J. H. Wormuth are both at the Department of Oceanography on main campus of Texas A&M University. With help from TAMU graduate students and marine technicians, their role in the GulfCet II program was to define the environmental patterns and oceanographic processes in the field areas surveyed by R/V *Gyre* in summers 1996 and 1997.

P. H. Ressler, who is one of those TAMU graduate students, is making acoustic estimates of zooplankton and micronekton stocks in the Gulf of Mexico with an ADCP as part of his Ph.D. dissertation research. He received the BA *summa cum laude* in Biology from Bucknell University in 1996.

R. R. Leben is an Research Associate Professor at the University of Colorado Center for Astrodynamics Research. He and his students utilize tandem altimetry to study the mesoscale circulation of the Gulf of Mexico (and other regions of the global ocean) and he has pioneered and continues to host a series of websites that allow near realtime tandem altimetry data to be viewed (see http://ccar.colorado.edu/~realtime/gom-real-time_ssh/).

NORTHEASTERN GULF OF MEXICO PHYSICAL/BIOLOGICAL OCEANOGRAPHIC INTEGRATION WORKSHOP: ESTUARIES AND COASTAL HABITATS

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Introduction

Some of the major features of nearshore ecosystems in the central portion of the NEGOM, from Mobile Bay to Apalachicola Bay, are reviewed to stimulate discussion of nearshore and offshore environmental interactions at various time and spatial scales. In general, connections between coastal ecosystems and those of the shelf, slope and ocean basin are not understood. An integrated, multidisciplinary investigation of coastal-shelf ecosystem coupling is clearly needed in this biologically important region of the Gulf of Mexico.

NEGOM Ecoregions

Three ecoregions with fuzzy, dynamic boundaries can be recognized in the nearshore and shallow shelf waters of the NEGOM: Mississippi Sound; the Barrier Island Coast (Mobile Bay to Apalachicola Bay, including a transitional subregion between Cape San Blas and Alligator Harbor); and the Florida Big Bend (Fig. 37). Mobile Bay receives water from the sixth largest river system in the U.S. (fourth largest in terms of total river input), and the reach of its influence on nearshore marine habitats includes both the Mississippi Sound and Barrier Island Coastal ecoregions.

Barrier Island Region

A series of barrier islands, sand spits and shoals front the estuaries, lagoons and sounds of the nearshore environment from Mobile Bay to Apalachicola Bay. From west to east, these features include Dauphin Island, Fort Morgan Peninsula, Perdido Key, Santa Rosa Island, Shell Island, Crooked AIsland≅ (two sand spits connected to the mainland shore), St. Joseph Spit, Cape San Blas, offshore shoals from Cape San Blas to Cape St. George, St. Vincent Island, Little St. George Island, St. George Island, Dog Island and Alligator Harbor Spit (Fig. 38). The degree of protection to mainland salt marsh, estuaries and lagoon habitats provided by these barrier features has recently decreased owing to the partial or complete destruction of sand dunes during strong storms and human development activities.

Estuaries and Lagoons

Estuaries in the central NEGOM are complex bar-built-coastal plains systems. With the exception of Mobile Bay, water from the impounded portions of these estuaries flows into coastal trending sounds before discharging into the Gulf through passes between barrier islands (Figs. 37 and 38). The Mobile, Perdido, Pensacola, Choctawhatchee and Apalachicola-St. George Estuaries systems receive water from fluvial rivers draining extensive watersheds, while St. Andrew Bay receives fresh water from relatively small, non-fluvial streams and land runoff. St. Andrew Sound and St. Joseph Bay are partially impounded marine lagoons with salinities near those of coastal waters.

Physical, chemical and biological features within and between the six major estuaries and three lagoons of the region are highly variable, and will not be discussed here (see Loyacano and Smith 1979; Collard and Way 1997; Wallace et al. 1998). The objective of the paper is to identify, in a general way, commonalities among regional ecosystems and the potential influence of their discharges on habitats seaward of the immediate coastal zone.

Limited data suggest that similar, chronic, stress-related changes in the chemical and biological features of many of the region=s estuaries and lagoons began 40-50 years ago and continue at the present time. Losses of salt marsh habitats resulting from dredge and fill and other construction activities have in some areas, such as Pensacola Bay and Santa Rosa Sound, reduced the filtration, soil stabilization, filtering and nursery functions of these habitats. Seagrass meadows have been stressed or eliminated because of a region-wide deterioration in water and sediment quality (Collard and Way 1997; Wallace et al. 1998). Since the 1960s, these visible indicators of ecosystem quality have gradually disappeared from Mobile Bay proper and all of the Pensacola Bay system; they have declined in abundance in Bon Secour Bay, Weeks Bay, Perdido Bay, Santa Rosa Sound, Choctawhatchee Bay and portions of St. Andrew Bay; and they have been moderately or severely damaged in St. Joseph Bay and St. Andrew Sound.

Benthic macroinvertebrate assemblages in the region from Mobile Bay to Choctawhatchee Bay are characteristic of stressed ecosystems and, while data on commercially and ecologically important estuaries fish and fisheries are scanty, these animals also appear to have declined in the area.

As human populations upstream and in the coastal zones of Alabama and the Florida Panhandle continue to increase, the water and sediment quality of coastal ecosystems will continue to decrease. The question of whether technological fixes are possible is moot, because resources sufficient to support their implementation are unlikely to be forthcoming.

Data Gaps

Knowledge of nearshore-offshore interactions is either minimal or altogether wanting (summarized in Collard and Way 1997). For example, the impacts of large fresh water discharges on shelf communities are not known. Information on the magnitude and ecological importance of estuaries-shelf water exchanges of dissolved and suspended materials, including toxic substances and inorganic and organic nutrients is very limited, as are the influences of shelf currents on the fate and transport of microorganisms and developmental stages of invertebrates and vertebrates into and out of estuaries, and the impact on shelf communities of within-estuary mass mortalities caused by hypoxia and toxic algae.

Recommendation

Assess and monitor the quantity and Aquality≅ of estuaries discharges as point-source inputs into the Gulf of Mexico. These data will provide valuable, new information on the relationship between major coastal ecosystems and those of the offshore domain.

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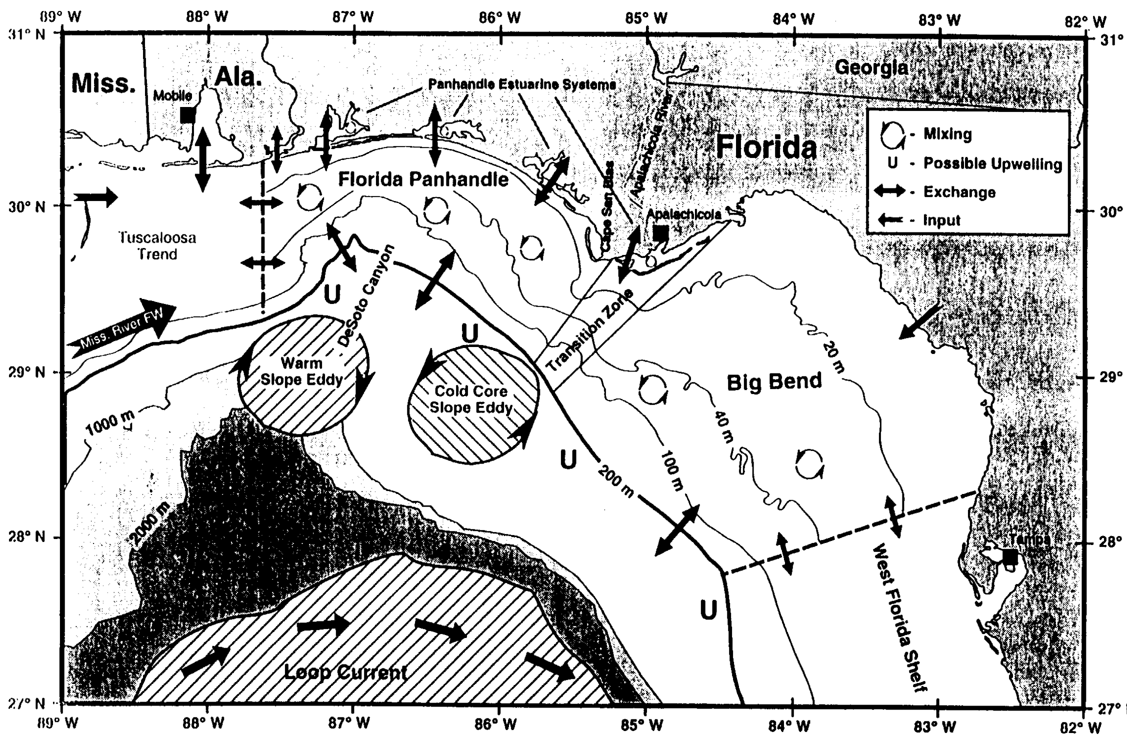

Figure 37. NEGOM core regions and major exchange paths (from SAIC 1997).

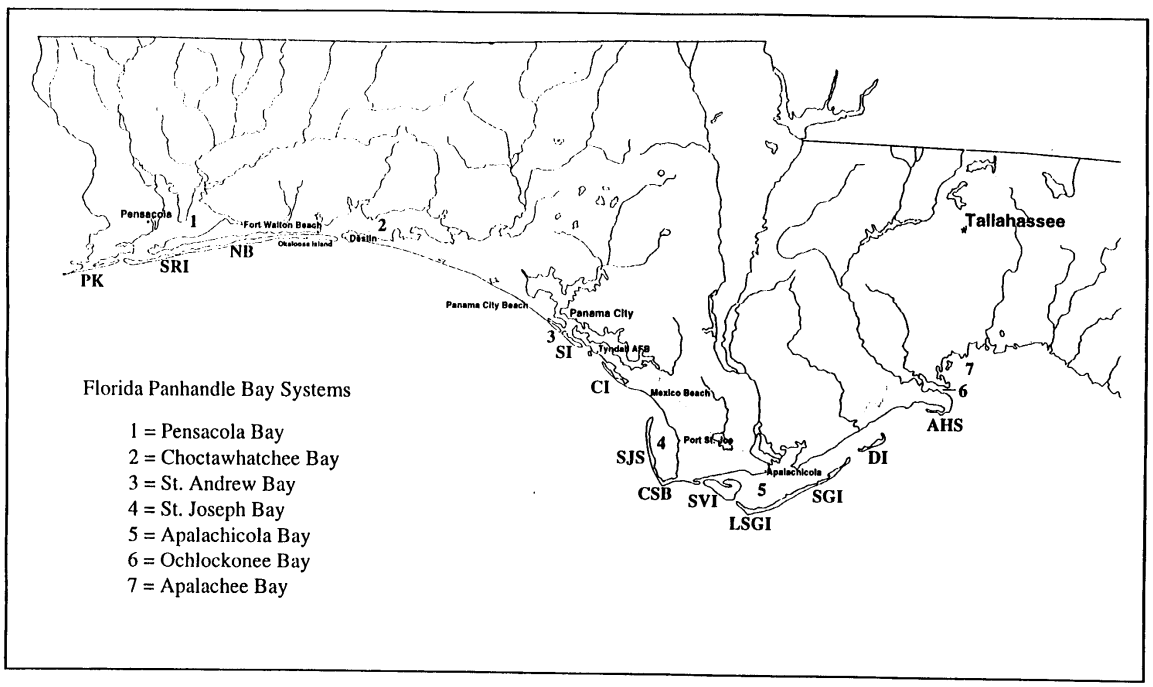

Figure 38. Bay systems and barrier islands. PK=Perdido Key; SRI=Santa Rosa Island; SI=Shell Island; CI=Crooked Island; SJS=St. Joseph Spit; CSB=Cape San Blas; SVI=St. Vincent Island; LSGI=Little St. George Island; SGI=St. George Island; DI=Dog Island; AHS=Alligator Harbor Spit (from SAIC 1997).

Biographical Sketch

The author is a marine biologist with current interests in Gulf of Mexico ecological processes, and the use of suspension feeding invertebrates as biological monitors in the fate and transport of rare earth and other heavy metals in the ocean.

LINKAGES

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Introduction

The continental shelf off the Florida Panhandle has unique fisheries and environmental characteristics that need to be studied in order to understand potential effects of OCS operations. There is a general lack of historical information on the oceanography of the region, which limits inferences that we may make on the linkages between physical and biological phenomena. For example, it is still unclear how features that operate over large scales, such as ocean circulation features like the Loop Current and its associated eddies, and meteorological phenomena, affect the oceanography of this shelf. Indeed, to build a solid infrastructure for designing OCS operations, the following questions need to be addressed:

Are there connections between the NEGOM and the rest of the basin?
What are the patterns of biological production?
What are the processes controlling these patterns?
What are the relevant space and time scales?

This presentation reviewed historical and concurrent Infrared, Radar-Altimetry, and Ocean Color satellite data, as well as selected *in situ* information like drifting buoy trajectories, in an attempt to highlight linkages between various phenomena that affect the Northeastern Gulf of Mexico. A report describing preliminary results and processing techniques is available from the Minerals Management Service's Public Information Office (Report title: Northeastern Gulf of Mexico Physical Oceanography Program: Eddy Monitoring and Remote Sensing. By Muller-Karger, F. E., F. Vukovich, R. Leben, B. Nababan and D. Myhre. 1998.)

Methods

We collect and process satellite time series data to identify and track major circulation features in the Gulf of Mexico. Specifically, we generate daily Advanced Very High Resolution Radiometer (AVHRR) Sea Surface Temperature (SST) distribution fields, Topography Experiment (TOPEX) and European Remote Sensing satellite (ERS-1 and 2) radar altimetry Sea Surface Height (SSH) fields, and Coastal Zone Color Scanner (CZCS) and Sea-Viewing Wide-Field-of-View (SeaWiFS) ocean color-derived pigment concentrations. We hold the historical (1978-1986) CZCS data in archive. We collect and process the AVHRR and SeaWiFS data in real-time mode with an antenna installed in St. Petersburg, FL. The TOPEX and ERS data have been merged and interpolated at the University of Colorado to render one image per day for the study period. We merged AVHRR, altimetry and buoy drifter data by overlaying contours of the sea surface dynamic height in the Gulf of Mexico and NEGOM regions onto time-averaged sea surface temperature fields (day, week, month), and then overlaying individual or monthly-averaged drifter tracks or velocity vectors derived from these tracks. To obtain ground truth for the ocean color data, we participate in the MMS-sponsored NEGOM cruises conducted by Texas A&M University (TAMU).

Much of these data are accessible through our web site (http://paria.marine.usf.edu) or by contacting FMK (carib@marine.usf.edu).

Discussion

Gulf of Mexico-wide connections

1) Seasonal Gulf-wide changes

Figure 39 (a) shows two boxes within the Gulf of Mexico from which we derived phytoplankton concentration and SST cycles using historical satellite data. We also derived SST cycles from the Comprehensive Ocean-Air Data Set (COADS) for comparison, and computed the mixed layer depth based on aggregation of all the hydrographic profile data available for the deep Gulf of Mexico from NOAA's National Oceanographic Data Center (NODC). Figure 39 (b) shows the monthly means computed across years from these data (monthly "climatologies").

The pigment and SST climatologies show cycles that are slightly out of phase. Pigment concentrations peak in December and January, and reach minima in June-August in the interior of the Gulf of Mexico. SST reaches minima in February-May, and maxima in August-September. Since there is sufficient light throughout the year to support growth of phytoplankton in the Gulf of Mexico throughout the year, the process that controls growth in the region is the depth of the mixed layer depth. Seasonal changes in the MLD lead to nutrient supply to surface, sun-lit waters in the winter time through convection driven by cooling and increased mixing action by frontal passages and strong winds. There are several phenomena that modify and extend the growth season in the GOM, specifically the outer front of the Loop Current and upwelling in the NEGOM.

2) The Loop Current

The AVHRR data provides substantial information on circulation patterns during the winter (October-May), when temperature gradients are strong. During summer (June-September), AVHRR data for the most part show uniform sea surface temperature patterns over the NEGOM. Summer AVHRR data can provide some information on the position of the Loop Current after images are contrast-stretched. The ocean color data (CZCS and SeaWiFS) are an effective tool for tracing small scale as well as large scale circulation patterns in the GOM. These patterns are very clearly outlined during summer months by regional phytoplankton blooms and river plumes, and therefore the combination of AVHRR and CZCS/SeaWiFS is very robust for outlining the position of the Loop Current, eddies, and various instability waves visible along fronts in the region. Upon merging the high resolution AVHRR sea surface temperature data (order 1 km pixels), or the high resolution ocean color data (order 1 km pixels), with the coarse resolution (order 100-200 km grid resolution) altimeter fields, we found extremely good correlation between warm areas and elevated dynamic heights, and cool areas and low dynamic heights. Both the individual drifter tracks and the monthly-mean velocities derived from these MMS-deployed drifters help in interpreting the direction of flow within specific features observed in the images.

The Loop Current provides several important linkages to the rest of the Gulf of Mexico. From a physical point of view, the important linkages revolve around the moderating effect that the Loop Current and its eddies have on temperatures far into the northern Gulf, on modification of water masses, and in the adjustment of the thermocline/nutricline depth by geostrophy. From a biological point of view, the Loop Current and its eddies are transport mechanisms for organisms originating in the Caribbean Sea or near Campeche Banks on the Yucatan Peninsula. While there has been much speculation about this transport mechanism, little is actually known about the types of organisms transported, rates, or impacts.

An interesting hypothesis posed by John Walsh (University of South Florida) links red tides along the Florida coasts to nitrogen-fixing blue-green algae (*Trichodesmium*) transported by the Loop Current and delivered into the NEGOM. Specifically, Florida coastal waters are enriched in dissolved phosphorus relative to nitrogen. *Trichodesmium* blooms seem to occur near the Florida coasts where rivers provide a source of dissolved iron, a necessary nutrient for these blue-green algae to grow. The hypothesis proposes that as these blooms decay, the dinoflagellates responsible for red tides off Florida (*Gymnodinium breve*) obtain the necessary nitrogen to grow and bloom, reaching red-tide proportions.

As the Loop Current flows by the Bank of Campeche on the Yucatan Peninsula, substantial upwelling is generated by interaction of the flow with the topography. This upwelling generates a strong cold front, which is maintained as the Loop Current separates from the continental mass off Yucatan. Ocean color satellite data show that this front contains elevated phytoplankton concentrations relative to adjacent waters, and that these plants are transported along the entire periphery of the Loop Current. Indeed, these blooms are carried toward the NEGOM and the West Florida Shelf, and as such can be delivered to these regions if surface waters are moved toward the coast by action of the wind. Eventually, these algae exit the Gulf of Mexico through Florida Strait.

The Loop Current and its eddies have important physical-oceanographic implications on circulation in the NEGOM. As the Loop Current extends far into the Northern Gulf, it periodically sheds an anticyclonic (clockwise-spinning) eddy. If the Loop Current or such an eddy move into the NEGOM, they generate substantial currents and upwelling along the shelf break in the NEGOM and off the West Florida Shelf.

3) The Northeastern Gulf of Mexico (NEGOM) and the West Florida Shelf

There are several important physical phenomena that make the NEGOM a unique location within the Gulf of Mexico. One is that this region receives most of the river discharge that is input to the Gulf of Mexico. It also has the widest shelf, which includes the De Soto Canyon off the Florida Panhandle. This is a deep canyon that serves as a conduit for deep Gulf of Mexico waters to the coastal zone of Florida and Alabama.

Ocean color satellite imagery shows that the bulk of the Mississippi plume flows to the west of the delta, but both in spring (February-May) and in fall (August-October), substantial amounts of Mississippi water flow toward the east and southeast along the edge of the West Florida Shelf.

Significant upwelling events are observed every spring along the periphery of the NEGOM, specifically along the Florida Panhandle and Cape San Blas. This upwelling renders the NEGOM as the coldest and most biologically productive region within the northern Gulf of Mexico for 3-5 months every spring.

The NEGOM upwelling plume is massive. It grows in February-March to the southeast, carrying substantial amounts of Gulf water, river water, and phytoplankton. The plume flows to the southeast following bathymetry and may reach as far south as the keys and wrap around the keys, delivering NEGOM water and materials to the Florida Strait. This plume was originally described by Gilbes et al. (1996).

In January-March 1996, flow immediately to the east of the Mississippi delta seemed to be erratic or turbulent. Flow vectors derived from drifters showed either northward or southward components. However, flow in the eastern portion of the NEGOM and over the west Florida shelf was distinctly and strongly (> 10 cm/s) southward. Waters here are much colder (>5^0C) than Loop Current waters. The Loop Current was extended about half-way north into the GOM from the Yucatan Channel, and a cyclonic eddy sat between the northern extension of the Loop Current and the NEGOM shelf. In April 1996, drifter vectors over the shelf reversed, showing a slow (< 10 cm/s) drift to the north. However, along the shelf break of the West Florida shelf proper, current vectors remained strongly southward. The cyclone north of the LC drifted somewhat to the West in May but drifted back East over the summer. By August, currents over the shelf aligned themselves to flow northward at speeds exceeding 10 cm/s. In September, currents over the shelf were to the south again (~10 cm/s), and an eddy was shed from the Loop Current. The southward flow over the shelf intensified in October. In November, while southward flow was observed over the shelf, northward flow was observed along the shelf break. In December 1996, southward flow prevailed over the West Florida shelf.

Unusual upwelling in May-July 1998 along the coasts of the Florida Panhandle in the northeastern Gulf of Mexico led to 3°C lower sea surface temperatures (SST) than is normal for these waters at this time of the year. Concurrently with the anomalous SST, substantial volumes of turbid Mississippi River water spread along the coast in the region. The upwelling and eastward dispersal of Mississippi water was associated with periodic eastward winds and a large anticyclone that migrated into the northeastern Gulf of Mexico. Wind reversals trapped the Mississippi water against the coast, which led to water column stability and submergence of coastal waters in which phytoplankton had been blooming vigorously during the bloom. This stability probably led to the anomalous hypoxia observed in bottom waters in this region during that time. As upwelling-favorable winds were re-established, and particularly during July 1998, the Mississippi plume was advected offshore and to the southeast along the West Florida Shelf.

The satellite data show that upwelling in the NEGOM is not at all unusual, but that interaction between shelf waters and a large anticyclone, combined with upwelling-favorable winds, can enhance and prolong this phenomenon into the summer months.

Other, more intermittent upwelling can be observed off Pinellas and Manatee Counties (near the mouth of Tampa Bay).

Conclusions and Recommendations

It would be impossible to interpret flow and linkages within the NEGOM and the rest of the Gulf of Mexico without the aid of remotely-sensed data. Satellite data complement hydrographic and drifter-track studies and provide a synoptic view within which these other data can be properly understood.

SST and Altimeter data are now widely available over the internet, including our web site at the University of South Florida (http://paria.marine.usf.edu). However, "fused" data (for example, new products generated by merging various satellite and/or field data) are not yet freely available. Also, the images need to be interpreted for identification of features, compositing (averaging) to minimize the obscuring effect of clouds, and ensuring accurate identification and quantification of phytoplankton blooms versus river plumes, since these latter ones are misclassified as blooms when using standard ocean color satellite-data processing algorithms. Such value-added products are not available except through investigations such as these outlined here. Further, SeaWiFS data remain proprietary.

However, NASA is about to launch the MODIS (Moderate Resolution Imaging Spectrometer) on EOS Terra in 2000, and the University of South Florida has implemented a unique real-time data capture system (an X-band antenna) with NASA support to collect the MODIS data.

With this infrastructure in place, the MMS needs to design and implement a circulation / linkages experiment. This experiment should focus on the following questions:

- What forces surface flow near the shelf break? (What drives spring-time upwelling?)
- What is relative contribution to production of river vs. upwelling?
- What water masses are established by the passage of Hurricanes in the NEGOM?

The study needs to incorporates synoptic (space, time) remote sensing tools, a set of moorings for continuous *in situ* time series, a ship-based program, concurrent surface and subsurface drifter deployments, and a numerical modeling component. The remote sensing program needs to incorporate the new MODIS data and develop a series of "fused" and interpreted products. The ship-based program needs to incorporate biological production, hydrography, and optical observations. The mooring program needs to incorporate a minimum of three mooring arrays arranged around De Soto Canyon and along the Panhandle coast in order to properly characterize upwelling, and modeling components. This study should focus the ship-based studies around "transition" periods, namely spring and fall. On top of this infrastructure, which provides a robust basis of environmental information, specific biological oceanographic process studies can be designed that address critical issues on bottom and pelagic fish resources.

Acknowledgements

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(a) **(b)**

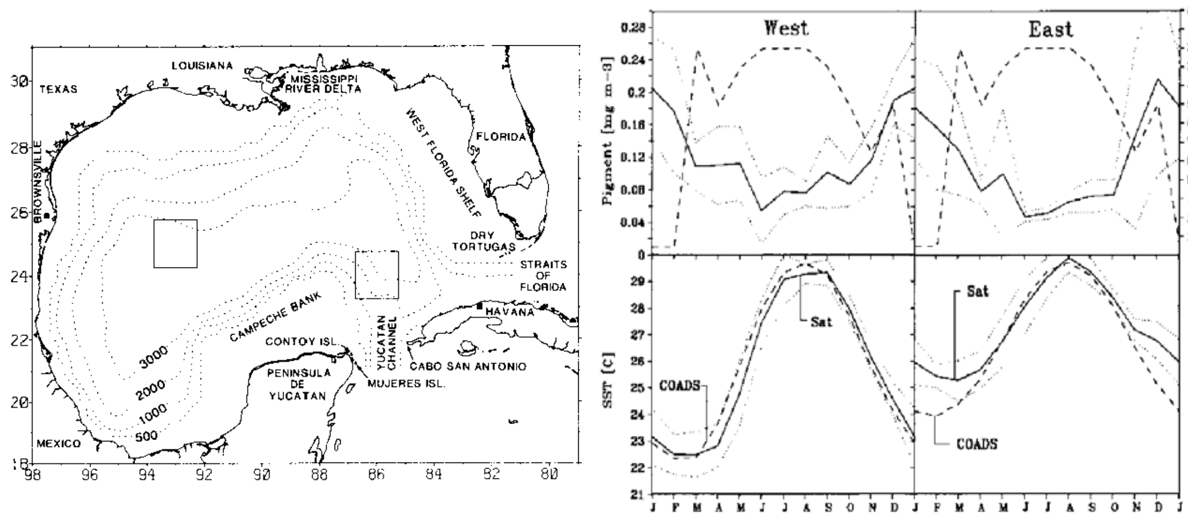

Figure 39. (a) Schematic of the Gulf of Mexico showing two boxes of 200x200 km^2 each for which series of pigment concentration and SST were derived. (b) Time series of pigment concentration (top, left axis), mixed layer depth (top, right axis), and sea surface concentration (bottom) for the two boxes shown in Figure 39 (a).

Biographical Sketches

Dr. Frank Muller-Karger is an Associate professor at the Department of Marine Science, University of South Florida. He is a member of the MMS Northeastern Gulf of Mexico Physical Oceanography team and is Principal Investigator for the Eddy Monitoring and Remote Sensing study. His research interests include the productivity of the ocean and ocean margins, environmental controls on production and nutrient cycles, ocean circulation, and carbon fluxes to the ocean's bottom and their impact on climate change and vice-versa. Muller-Karger uses satellites to measure changes in the color and temperature of ocean basins over time. He received his B.S., M.S. and Ph.D. in Biological Oceanography from the Florida Institute of Technology, the University of Alaska at Fairbanks and the University of Maryland, respectively.

III. WORKING GROUP SUMMARIES

WORKING GROUP I

Chair: Dr. Stephen A. Bortone
University of West Florida
MMS Chair: Dr. Walter Johnson

The consensus of the Group was that there has only been a limited amount of study and OCS activity in the Eastern Gulf. To detail more fully the problem at hand, Group 1 addressed three major questions. These questions had a direct relationship to the specific study area and the overall goal of the MMS effort in the area.

1. What is unique about the study area?
2. What are the major information or data gaps?
3. What physical and biological processes or structure might be disrupted by OCS activities in the area?

All questions served as a guide to identify and direct research activities. The last question was a predominant theme that served as the focal point for hypotheses generated. The first and second questions are addressed below, as the Group believed it was important to have a background on the features that distinguish this area from all others before specific research questions or activities could be developed.

Question 1. - Unique Features

The De Soto Canyon is a massive geographical/geological feature that makes this area unique. The Canyon dominates the impressions one has about the area and serves as the focal point for anticipated OCS associated research activities. In addition to the Canyon itself serving as structurally dominant feature of the region, a second level characteristic is that the Canyon has structural dichotomy between its two sides (i.e., there are differences in the profile of the terrace/escarpment on either side of the Canyon). The structural configuration dictates that deepwater is close to the shelf break on the eastern side. Due to both its physical structure and its position relative to water masses, upwelling apparently dominates the circulation patterns in the region. This has probably led to another feature of the region in that there are recurring cold-water masses associated with the Canyon that are unusual for its latitude.

Concomitantly, but also uniquely, there is a distinct difference in the bottom features in the area with regard to both the Canyon position and distance from east to west and north to south along the shelf and slope. The Canyon structure probably has a significant effect on biological and sedimentological processes. Clearly, these processes are not limited to the Canyon boundary and most certainly they can have impacts far beyond the immediate area. For example, OCS activities may have the potential to impact the Big Bend area and beyond. This is potentially observable by the avenue of flow southward by way of the so-called Green River that moves southerly along the west Florida Shelf from the area just east of the apparent Canyon influence. However, the Green River water, and drifting buoys deployed outside the Big Bend, does not move into the Big Bend, *per se*.

Scientifically interesting and distinctive meteorological patterns in the area have an apparent effect on circulation through the air/sea interface. These unique atmospheric characteristics may be due to the meteorological features associated with the dome/cold-air advection over the shelf (air quality/ozone exceed). There is a unique circulation pattern associated with the Canyon. In conjunction with the distinctive circulation patterns and the structural uniqueness, there is a need to understand small-scale circulation around hard-bottom sites (e.g., pinnacles) and how flow/currents affect biology. The V-shape of De Soto Canyon most probably causes, or is associated with, unique atmospheric phenomena and may enhance eddy interactions with shelf margins. Again, in accordance with its distinctive shape and geographical position, there is an apparent topographic wave interaction within the De Soto Canyon that may interact with the normal upwelling phenomenon of the region. All these structural features have probably influenced the amplitude of the seasonal cycles in some of the physical and biological features of the region. The most obvious and dominating example is a feature described as the Loop Current that invokes large, mesoscale responses and interactions among the physical and biological features.

Due to past geological conditions and geographical position, numerous distinctive but disjunct zoogeographic distributions of biota occur from east to west in the vicinity of the Canyon. This suggests a persistent zoogeographic barrier that most probably once had specific limits. In modern times; however, the barrier is less selective in its effectiveness among species relative to their specific habitat preferences and life history features. Faunal affinities are Carolinian but the fauna has significant and important affinities with warm temperate, Southern Hemisphere biota.

Question 2. - Data/Information Gaps

Proceeding further, Group 1 discussed and identified the data gaps that exist with regard to our general or specific understanding of the study area and oceanic processes. Information regarding an understanding of the uniqueness of the region, when coupled with an evaluation of the data that are essential but lacking, is instrumental in delineating the recommended future research effort.

Group 1 readily recognized that data are lacking from the eastern side of De Soto Canyon, especially with regard to geological features. This is evidenced by the fact that there are no extensive biofacies maps of the area. The lack of biofacies maps is almost certainly due to the lack of information on total amount of hard-bottom in the overall area and lack of specific information on species limits and population sizes in the region. Group 1 acknowledged that small areas have received detailed study, especially on limited areas of hard-bottom habitats. Overall, however, there is a lack of detailed information for the general area.

To develop a clear understanding of the relationship between biological and physical processes, it is normally essential to answer some very important questions. These questions include: Are there seasonal changes in benthos? and; Do these seasonal changes have inter-annual variation? These types of questions are largely unanswerable at our current level of understanding. Specific life history information for fishes and invertebrates is lacking. Similarly, essential fish habitat (EFH) has not been identified for most species found in the region. Some investigations have identified these features for some species but there have been few attempts, to date, to identify the essential fish habitat specifically within this potential OCS region. Similarly, there has been almost no effort to integrate species life history with environmental data using more sophisticated multi-layer, GIS analytical techniques.

There is an obvious need to couple temporal variability on both long- and short-term scales with variability in both physical and biological processes. Presently these relationships are unknown. Similarly, but just as significantly, there is little known about mass balance (i.e., terrestrial, aquatic, atmospheric) in the area, especially relative to the inputs from rivers and estuaries. For example, there are few circulation data on the shelf shoreward of the 100-m isobath. Additional information is needed on offshore water quality to provide a basis for the understanding of mass balance in the area if we are to ever achieve an acceptable level of prediction on the biological conditions of the area.

Tools Needed to Enhance Knowledge

An effort was also made by Group 1 to identify the research tools or techniques that need further development to better enable an understanding of the processes surrounding the linkage between physical and biological features of the region. "Tools" were defined in their broadest sense to include methods, materials, approaches, and data handling methods and protocols. The lively discussion indicated that this was an important area of consideration for support. A consensus was that to address the research topics in a considerate, thoughtful, and productive manner required methods, protocols, and techniques that were "right" for the situation. The didactic nature of the group discussion also ferreted out new and innovative ways of approaching problems. Thus, borrowing techniques and adopting technology from more disparate fields of environmental research might more easily obtain better insight into a problem.

There was a general consensus that there needed to be an improvement in the survey tools. As a specific example, the application of the multi-beam sidescan sonar would be advantageous but its use in the area has been limited and more practical applications may have to be done and specific protocols developed before it could be directly used to obtain data to address program questions. Similarly there have been recent advances in the use of multiple frequency acoustics to assess high seas fish stocks. This technology, while fully developed, has not yet been widely applied to stocks in the northern Gulf of Mexico. The relatively unique circumstance in the Gulf of having warm, clear waters favors the application of visual assessment tools. This could be done on several scales of data gathering: on the larger, population scale of assessment; and on the smaller scale of physiological and behavioral responses to specific conditions or test treatments. It also may be useful in clarifying the relationship between stock and population assessments. Further, there was extensive discussion and consideration of how methods and sampling schedules should allow the collection of biological information from moored sites, simultaneously (and synchronously) with physical measurements. Above all, methods and protocols need to be developed that are time and resource efficient.

Database management was an area of concern. Group 1 agreed that there was an absolute need to put all information resources into an easily accessible database. An example of this is the GWIS database. Through this mechanism it will be possible to integrate historical data with contemporary data. This database would also serve as a resource upon which to test ideas or protocols before the more expensive, *in situ*, experiments were tried.

Potential Studies

After the above discussions occurred, Group 1 entered into a "free running" dialogue of potential studies. The approach was all-inclusive and unrestrictive. Below is a brief indication of potential studies that could be performed. Later many of these "random" ideas were consolidated and combined to identify general themes of research.

The studies are listed below in an order that does not indicate priority level. After each study, a statement of application, intention, or purpose was added to clarify the direction it will give research activities in the area.

- *Assimilate/integrate existing physical and biological data (especially fisheries data) using GIS analytical techniques.* With the advent and wide use of GIS, it is now practical to integrate the entire array of available data. Thus, it is anticipated that previously unrecognized data relationships will become much clearer using the integrative and filtering features available using GIS as a data synthesizer.

- *Determine what factors (e.g., isotherms) affect fish recruitment on both large and small time and space scales.* Once patterns of interrelationships among variables are established it will be important to design studies to determine the nature, degree, and significance of the relationships. This is significant as previous attempts at predicting adult stock size from juvenile stock size, or recruitment success from any number of juvenile indices were not particularly productive or reliable. With the availability of larger data sets and better, more sophisticated data management tools (such as those available with GIS); it may at last be possible to discern patterns of association to the extent that some degree of prediction is gained.

- *Integrate existing circulation data with biological information to determine linkages and patterns.* Lacking in most other studies in the area is direct and predictive evidence of the relationship between the biotic and abiotic variables in the ecosystem. Circulation data are now of sufficiently high quality and quantity that a more integrative approach to their application is not only possible but essential.

- *Study climatological changes relative to biological features such as fisheries, etc.* Currently unknown are the long-term, natural cyclical features of the biological portions of the ecosystem. It is important to determine the degree and scale of these natural cycles to correctly determine the significance of short-term changes. Similarly, long-term monitoring should be performed to establish long period cycles as well as obtain a larger scale understanding of processes.

- *Investigate the significance of cross-shelf transport of materials, including larvae, etc.* Similar to the above study, linking the information base of water mass movement to biological distributions should yield a high level of prediction within the area.

- *Study recruitment patterns and pulses among the biota on hard-bottom areas.* Essential to the understanding of how any system functions is understanding the cyclic, time-dependent relationships among the variables being measured. Establishing the time-dependent, biological response variable relationship allows to the system to be modeled in a meaningful way.

- *Study recruitment/recovery of invertebrates/fishes, especially with regard to the pinnacles and other hard bottom regions.* Despite previous studies that indicate little effect of the pinnacles on the surrounding communities, these pinnacles represent unique features of the sea bottom in the region, and obtaining an understanding of their potential role in the overall scheme of community dynamics is certainly in order. The extent and exact nature of the importance of pinnacles is currently unknown.

- *Study burial/exhumation processes and sediment transport.* An investigation into the relationship of the substrate to the water column is a significant and often overlooked aspect of research in deep oceanic areas. An opportunity should not be missed at being able to discern the significance of this relationship.

- *Map shallow geological habitat to determine the relationship of geological features and structure with overall ecosystem processes.* Superimposing simultaneous distributions of abiotic features and biological processes is an intuitive step toward understanding the linkages within a large ecosystem. Linking the nature of these relationships will go far in predicting the impact that extraneous activities may have on the ecosystem. There is a special need to emphasize the eastern margin of the De Soto Canyon with these studies.

- *Opportunistically take advantage of unique environmental events (hurricanes, eddies, gyres, etc.), especially with regard to the interrelationship between physical and biological processes.* Large, severe and dynamic storms apparently dominate much of the physiography of the Gulf of Mexico. The unpredictable nature of these storm events, however, does not lend to careful, controlled and directed study. Ancillary to other investigations, it was determined that the study design should be robust enough to respond to the occurrence of short-term phenomena within the study area. This may require innovative approaches.

- *Meteorological/climatological data should be an integral part of the overall database.* Essential to the understanding of any system are the conditions in which the system operates. Meteorological information provides the forcing, particularly in water depths less than 100 m.

Questions to be Asked and Answered

After discussions identifying the uniqueness of the area, the data gaps, and some potential studies that might be conducted, we listed a series of questions about the area with regard to the potential relationship of physical and biological processes relative to the potential impacts that OCS activities might have in the area. It is anticipated that to answer these questions a series of specific, testable hypotheses would be generated.

1) Physical processes create or enhance biological "hot spots" (i.e., extreme conditions such as high productivity, low oxygen, etc.). Can understanding these processes be used to help identify or forecast "hot spots"? Are the surface and bottom Ekman layers responsible for across-shelf transport of fish larvae? What is the importance of deepwater upwelling drive sources of nutrients relative to riverine sources of nutrients?

2) Are there spatial differences in the trophodynamic (energy/food transfer) processes in the area of interest?

3) Are benthic habitats stable over space and time? If they are not stable then at what scale (in space and time) do they vary? Are these variations significant? Can the variations be predicted?

4) Are there specific areas that are consistently important for spawning and recruitment? Additionally, is there a relationship between the distribution of certain species and spawning?

5) What is the essential fish habitat within the area of study? To which species and life stage are specific essential habitat ascribed? Is their dependence on essential habitat temporal (i.e., life stage dependent)? Is essential habitat in the area limiting?

6) Are commercially and recreationally important fish species distributed on the west Florida shelf with regard to seasonal spawning activity?

7) Does a change in sediments or current flow result in a change in habitats/recruitment?

8) What is the impact that catastrophic phenomena (e.g., hurricanes) have on fishes and benthic organism?

9) Are there geo-temporal differences in the area relative to the primary/secondary production relationship?

10) Is the water chemistry of the shelf different than the water chemistry in deepwater?

11) Can marine reserves serve to evaluate changes in fish communities in the area?

12) What are the present and future effects of synthetic drilling fluids on the biocommunities throughout the year? Are the effects seasonal?

13) Do OCS activities have the potential to affect natural processes in the study area?

Revised Questions

After the initial hypotheses/questions were listed, our group subsequently reevaluated each and modified, condensed, or combined them to reflect a more meaningful approach to their investigation and evaluation.

1) Physical processes create or enhance biological anomalies. Can they be used to help find or forecast them?

2) Are the surface and bottom Ekman layers responsible for across-shelf transport of substances and/or larvae?

3) What is the relative importance of nutrients derived from terrigenous/riverine versus deepwater upwelling sources? Is the water chemistry of the shelf different than in deepwater?

4) Are there spatial and temporal differences in the trophodynamic (energy/food transfer) processes in the area of interest?

5) Are benthic habitats stable over space and time?

6) Are there specific areas that are consistently important for fish spawning and recruitment? Is there a relationship between the distribution of certain species and spawning? Can current patterns and water mass movement predict the distribution and abundance of fish larvae?

7) Is there a relationship between sediments or current flow and fish species life history requirements such as essential fish habitat and recruitment?

8) Does primary and/or secondary production vary spatially and/or temporally?

9) What catastrophic phenomena occur in the area? Do these catastrophic phenomena (e.g., hurricanes) have the potential to impact fishes and benthic organisms? How important are these effects?

10) Can marine reserves serve as a useful tool in evaluating the impacts of activities in the area such as fishing and potential OCS activities? Do OCS activities significantly affect natural processes in the study area over some space and time scales? Are these effects localized, positive or negative?

Following their reevaluation, the questions were used to organize a response or study outline. Below is an outline of a study profile to be used in whole or in part to direct a research effort aimed at elucidating the potential effects that OCS activities may have in the region.

1. Biological
    a. Primary Productivity / Secondary Productivity
        i) Evaluate using remote sensing of color
        ii) Use acoustic surveys to evaluate secondary production
    b. Community Structure (e.g., Surveys of Benthos, water column, epi-pelagic)
    c. Life History

        i) Essential habitat
        ii) Reproductive Strategies
        iii) Limiting factors
            (1) Water Quality
            (2) Sediments
            (3) Current patterns
    d. Recruitment (community or species)
        i) Stable Isotope Ratios in tissues
        ii) Behavior (seabirds, marine mammal, turtles etc.)

2. Physical
    a. Water Chemistry (Surveys to measure Nutrients, Chl *a*, DOC, CDOM, "Water Quality")
    b. Sediments (mapping description, Sidescan Sonar for distributions, sediment transport, bedforms, nepheloid phenomena).
    c. Circulation
        i) Moored arrays
        ii) Boundary layers, surface, bottom
        iii) Shipboard ADCP
        iv) Drifters
        v) Remote Sensing, SST, Color, and Altimetry

Methods and Evaluation Considerations

Below are some general items that should be considered as part of the overall project development of the area. These should be conditional explanations of the previous information. Much of what was offered above can be conducted with our present abilities and state of knowledge but does require some assumptions.

1. All new data collected and older data sets should be made available in GIS format, compatible with MMS-CORIS.

2. Time facilitation
    a. The ship should be made ready to accommodate processes instead of a "grid" of stations.

    b. Cruise timing should be coincidental with spring events to optimize biological and seasonal variability.
    c. Current meter moorings and benthic sampling should be at the same place but may be on a different schedule.

3. Space
    a. Sampling scale should be small enough to resolve processes of interest.
    b. Scale should include aspects that are large enough to cover domain.
    c. Resolve distinction between east and west side of De Soto Canyon.
    d. Comparative results from Fishery Sanctuary (Marine Reserve) can serve as an appropriate baseline.

Appendix

Additional Input

Below are specific comments made individually by members of the group. These comments can be considered as an Appendix to this report. These comments have received only limited editing to more exactly reflect the opinions of the author.

Doug Biggs

Primary Production: Estimate from remote sensing (Sea WIFS, MODIS) with sea truth during process cruises.

These process cruises would serve to measure pigments as well as colored dissolved organic matter (CDOM), in order to interpret color data.

Collect underway as well as on station data, to give fine scale horizontal (x, y), as well as coarse scale depth (z) variability.

Bob Weisberg

Moored Arrays – 2 moored arrays – inner shelf and across the shelf break

1) shore-normal line beginning at Panama City
2) shore-normal line beginning at Mobile Bay

Both with ADCP moorings at the 10-m, 20-m, 30-m, 45-m, 60-m, 100-m, and 200-m isobaths.

These arrays will link with the Florida COMPS array with moorings (surface) on the 45 m isobath offshore from Charlotte Harbor, Tampa Bay, Apalachicola Bay, and maybe Panama City and Pensacola. These arrays will also line with FSU moorings in the Big Bend. The COMPS mooring also have surface met.

Kathy Scanlon

Low-budget option

- Sediments – especially outer shelf (50 m – 200 m)
  - Sampling (grab)
    - Texture analyses
    - Composition analyses

  - Hi-res seismic profiling

Sediment thickness
Structures (reefs, paleoshorelines)

Sidescan Sonar
Areal extents of sediments types
% variance benthic habitats

Current data at sediment-water interface
Mobility of sediments
Delta's in habitats

Hi-budget options
Sediments and habitats

Multibeam bathymetry w/ backscatter
+ Hi-res seismic profiles
+ Sediment sampling

Gary Fitzhugh

Process – directed studies need to be supported by baseline survey work West Florida Shelf.

Mapping – outer shelf and slope relief <1, >1 to <10, >10-m sediment mapping. Community descriptions / Habitat descriptions / characterizations. Also there is a need for biofacies mapping. Studies should facilitate comparison to inshore (Middle Ground) as well as comparisons to west side of the De Soto Canyon.

WORKING GROUP II

Chair: Dr. Susan Welsh
Louisiana State University
MMS Chair: Dr. Ken Deslarzes

Table of Contents

1. Critical Information Needs

The members of Working Group 2 had very diverse scientific backgrounds (physical oceanography, numerical modeling, fisheries biology, benthic ecology, and water column biology) and were working for a variety of government agencies, colleges and universities, and private companies. The objective of our discussions was to design an integrated biological/physical oceanographic program for the De Soto Canyon region. The members of Group 2 were asked to reflect on the presentation of the previous day and make suggestions as to what were the most important research topics in the De Soto region. These suggestions were merged into the following nine categories:

Nutrients - fluxes, pulses, sources, carbon cycling, x-shelf/long-shore transport

Productivity (biomass) - upwelling areas, river and estuarine inputs, benthic-driven, eddy-driven, spawning sites

Natural and Human Impacts - Oil spills, discharges from rivers and catchments, storms, hypoxia, red-tides

Biological Transports - eggs/larvae, pelagic/oceanic fish, icthyoplankton

Physical Transports - cross-shelf / long-shore, to / from deep basin (eddy & wind driven), time scales, space scales

Physical Processes- upwelling, eddies

Benthos - hard bottom, biotopes, soft substrate, bottom boundary layer, nepheloid layer, benthic communities - meiofauna, primary/secondary productivity

Linkages/Coupling - surface to substrate, surface →midwater → benthic, estuarine → shelf, invertebrate / fish / meiofauna to local topography

Marine Mammals - toothed whales, cetaceans

There are strong associations between the biological and physical processes (as well as geographical and geological setting) in the study area. For example, eddy circulation is associated with nutrients, productivity, carbon fluxes, fisheries, and climate. The majority of biological and physical processes that were presented and the potential relationship of each process to another are presented in Table 6.

Table 6. The relationship of physical processes and geological/geographical setting (row headings) to biological processes (column headings). An "X" indicates that a relationship exist between these factors.

	Nutrients/ Water Quality	Primary and Secondary Productivity	Fisheries	Macrofauna	Meiofauna / Benthic Communities	Red Tide
x-shelf transport	X	X	X	X	X	X
longshore transport	X		X			X
coastal upwelling	X	X	X	X	X	X
eddy circulation	X	X	X			X
discharge from rivers and estuaries	X	X	X	X	X	X
storms	X			X	X	
biotopes / substrate			X	X	X	
hypoxia	X	X	X	X	X	
bottom boundary layer				X	X	

2. Data Gaps and Preliminary Recommendations

Group 2 was next asked to consider what data are missing from the historical data and currently funded research that would be useful to address the topics within the 9 categories listed above. To identify such data gaps, the group sought to identify the most significant biological processes and related physical processes in the proposed study area. The coupling of physical and biological studies should provide broader perspectives of biological processes and ecosystem function. The following information needs were identified:

(a) Information is needed on the coupling of the regional primary/secondary productivity and physical features. The PROBES project in the Bering Sea could be used as a model study to couple biological productivity with physical processes.

(b) Information is needed on the functioning of the shelf of the western region of the DeSoto Canyon as well as the area below the 2000 m isobath. Little or no physical data are available for these areas. Furthermore, there is little data of any kind for the region east of DeSoto Canyon. The results of a Texas A&M University study in this region should produce data on the import of carbon and energy from the shelf into deeper waters.

(c) Information is needed on macrofauna (down to 300 m) and meiofauna (indicators of biomass) in soft and hard bottom areas, and the processes that affect these fauna (hypoxia, freshwater cap, water mass movement).

(d) Information is needed to assess the uniqueness and sensitivity of hard bottoms (benthic habitats).

Members of Group 2 suggested that the following elements be included in a comprehensive study of the De Soto Canyon:

1. Overview of the region with consideration of range of variation
2. Process studies at boundary areas
3. Link water column to benthos for primary productivity (as seen in hypoxia)
4. Which of these event driven productivity pulses are more / most important?
5. Vertical movement
6. Horizontal movement
7. Semi-permanent seasonal features
8. Episodic events such as upwelling.

3. Standard Sampling Methods

The working group reviewed biological and physical sampling methods applicable to integrated physical-biological studies. One motivation for compiling a list of sampling methods was to compare the time and space scales that are typical with each of the sampling methods. ‘Scale’ was a critical component of the discussions, because it is a key element in the design of an integrated study. The sampling methods common to each of the research areas considered in Group 2 are summarized below. Methods for physical oceanography are presented in Table 7 including time and space scales of the observations as well as an estimate of the length of time needed to complete each type of sampling. Methods for biological and chemical oceanography are presented in Table 8.

Table 7. Sampling methods for physical oceanography.

Method	Spatial Scales	Time Scales	Duration
moored array	10 km to 100 km horizontal; 2m to 100 m vertical	~1 hour to 3 years (Loop Current cycle is ~ 9-11 months)	months to years
shipboard surveys “quasi-synoptic” - hydrocast, CTD, ADCP - turbidity profile - dissolved O_2 - nutrient data, flourometer - towed fish	5 km to 100 km horizontal; .5 m to 1 m vertical		1 to 2 weeks to complete
aircraft surveys “truly synoptic” - CTD, XCP, Drifters	5 km to 100 km horizontal; 1 m vertical		2 to 3 days to complete
drifters	whole region horizontal; each drifter stays in a single range from surface to 300 m	months	unlimited
remote sensing			
- SST	1.1 km horizontal —>	~ 6 hours	unlimited
- Ocean Color —>	1.1 km horizontal —>	~ 2 days	
- altimetry —>	~ 100 km horizontal —>	9.9 days	
- GOES —>	4 km horizontal —>	30 min	

Scale Considerations

The scales of physical and biological oceanographic processes need to be defined for successful design and implementation of a research program. The time and space scales of biological and physical studies in the marine environment differ significantly. Where do the scales overlap? Time scales for physical events include the following: tidal, cyclical (spring tides), intermittent (shelf waves - 10 days), seasonal (winter fronts, loop currents interactions), inter-annual, exceptional (hurricanes), and long-term cyclical (El NiZo, La NiZa). An approach to reconciling multiple scales questions may be to embed smaller scale studies within larger scale studies.

Table 8. Sampling methods for biological oceanography.

Water Column	Benthos	Other
nets hydrocast ADCP hook and line cameras stable isotope studies	box core; bottom grabs; dredge fouling plates; re-colonization trawls; spears; hook and line incubation chambers; respirometers semi-permeable membrane device benthic cameras: ROV, AUV, and LLS vertical sediment cameras and traps isotope incubation; stable isotope studies hydro / acoustic surveys	visual and acoustic data for mammals databases from catch / landing information

4. Questions and Research Ideas

After synthesizing the information gathered during the presentations and the group discussions, Group 2 proposed the following specific questions and research ideas:

What role do physical oceanography events (river input, upwelling) controls (benthic and/or water column) productivity on the northern shelf?

What is the frequency and magnitude of cross-shelf transport of materials (food, nutrients)?

Investigate the periphery of Loop Current (LC) rings and deeper periphery eddies near the 2000 m isobath at approximately 27°N. Consider the transport of LC water onto shelf/slope by peripheral eddies.

Investigate sediment transport and sediment re-suspension due to wave/current interactions

Emphasize Eastern De Soto Canyon upwelling and eddies.

Design a seasonal East De Soto Canyon upwelling ecosystem study.

Plan "specific stations" for biology within mooring arrays.

Maximize instrumentation on physical moorings for biology information.

What is the horizontal and vertical extent of nepheloid layers on pinnacles?

What are the locations of hard bottom benthic habitats?

5. Recommendations

Group 2 developed four recommendations for addressing the questions and suggestions presented in Sections 1, 2, and 4. Each of these recommendations requires a true physical-biological integration of the research effort and aims to address the critical processes that have been described in this report.

(1) Biological-Physical Processes East of De Soto Canyon Out to 500m

This recommendation takes into consideration the benthic hard and soft bottom sites along the eastern edge of De Soto Canyon in an area (marked as "1" on Figure 40) characterized by both coastal upwelling and eddy activity. Note that the eastern boundary of the proposed area intentionally extends outside of the map to include Apalachicola Bay as an upstream point source of fresh water.

The first element of this proposed study is a comprehensive topographical survey of the sea floor to locate hard bottom sites using acoustic mapping techniques. The study would feature several cross-shelf transects of fixed moorings creating a mooring array, as well as oceanographic stations to gather biological and physical data. Seasonal changes in water quality and nutrients; variation in the megafauna of the hard bottom areas; and variation of the infauna at the soft bottom areas are key issues. The processes which need to be described are: local circulation, carbon fluxes, import/export of carbon, transport of nutrients between the shelf and deeper waters, fluxes of nutrients in response to upwelling and eddies, and impacts of storms on benthic- and water column-dwelling organisms.

(2) Trophic Dynamics of a "Small" Site West of De Soto Canyon

The purpose of this study would be to couple biological and physical processes on a local scale. A small study site would be located between the 40 m isobath and the 100 m isobath on the western flank of the De Soto Canyon (marked as "2" on Figure 40). The area would include both a pinnacle and other low relief features along with the surrounding sand bottom. The site would be in a region previously studied and for which there are historical data. The research plan would require 2 current meters on a mooring to measure the circulation around a pinnacle. Stable isotope measurements would be made to assess trophic linkages between the water column and benthic organisms.

(3) Biological-Physical Processes West of De Soto Canyon Down to 1000 m

This study site (marked as "3" on Figure 40) was chosen to incorporate the effects of river water on the ecosystem of the De Soto Canyon. Note that the western boundary extends westward toward the Mississippi River Delta to include monitoring the flux of fresh water from the Mississippi Delta.

This study plan is very similar to that of Recommendation 1 and would feature several cross-shelf transects of fixed moorings, that create a mooring array. Also oceanographic stations would gather biological and physical data such as seasonal changes in water quality and nutrients, variation in the megafauna of the hard bottom areas, and variation of the infauna at the soft bottom areas. These measurements would provide information on the local circulation, import/export of carbon, transport of nutrients between the shelf and deeper waters, and the fluxes of nutrients in response to the presence of upwelling, eddies, and Loop Current rings. Information on the impacts of storms on organisms within the water column and benthos could also be measured by means of the oceanographic stations.

This study site would also examine the potential for hypoxia east of the Mississippi River.

(4) Biological-Physical Processes in Eddy-Pairs

The region of interest for Recommendation d is illustrated as a box surrounding the warm and cold core slope eddies in Figure 40. This purpose of this study is to sample the periphery of eddy-pairs and observe the edge effects such as productivity, fish/larval transport, plankton, and recruit of marine mammals. This study is designed as a response team effort that would go into action by the occurrence of an eddy pair over the slope as revealed by remote sensing. If an eddy pair is detected then shipboard measurements would be made to locate the edges of the eddies. No moorings would be used for this study. Rather, shipboard sampling would be conducted as well as collection of visual and acoustic data for marine mammals. Aircraft would be used for physical measurement of the water column.

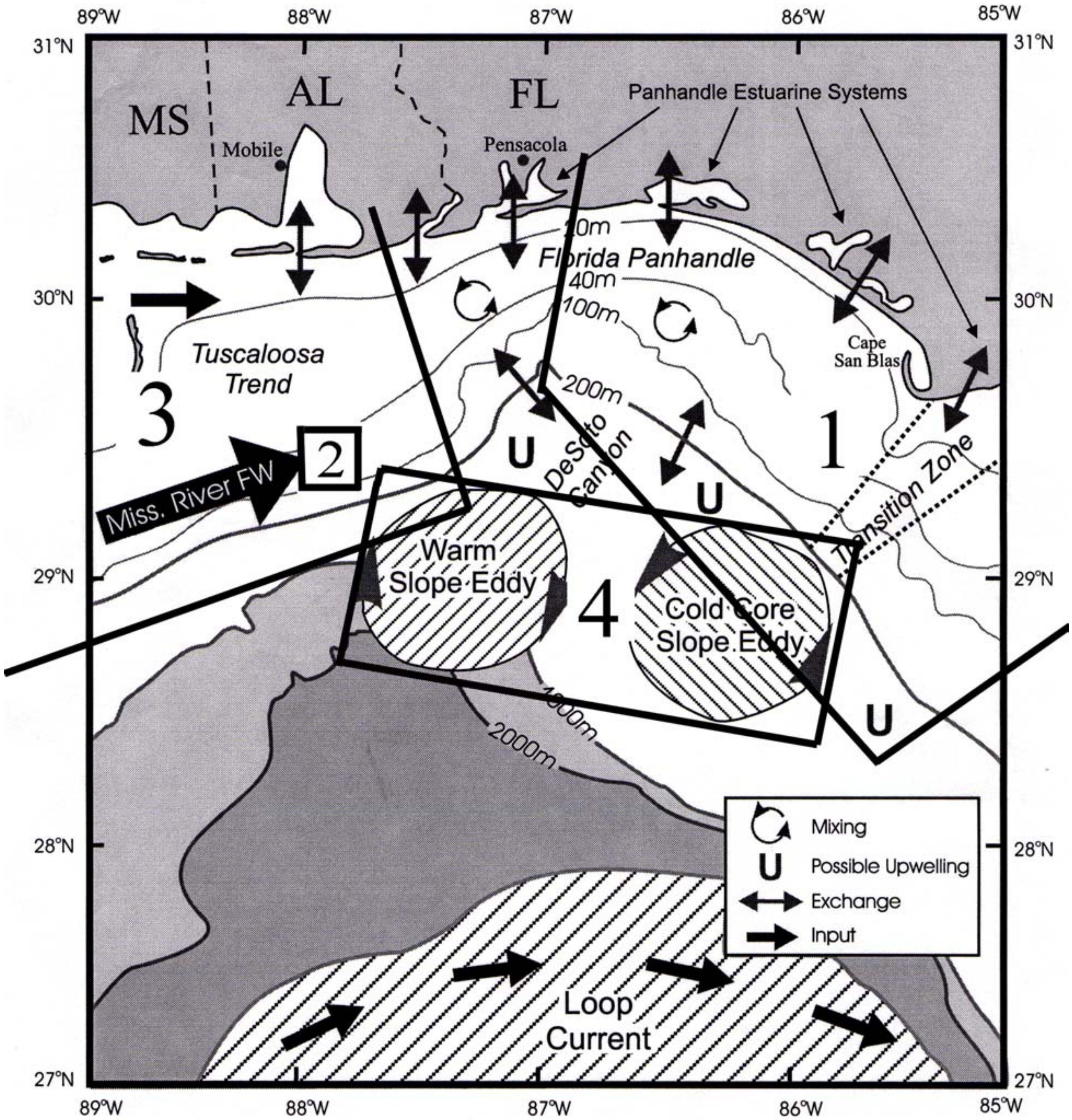

Figure 40. Locations of recommended study locations.

WORKING GROUP III

Chair: Dr. Georges Weatherly
Florida State University
MMS Chair: Mr. Gregory Boland

Introduction

Working Group 3 began by listing the important processes which needed to be identified, measured, and modeled to understand the important biological and physical processes occurring in the De Soto Canyon and Shoreward Region. This list was then considered with the objective of determining another list of what still needed to be done based on the formal, oral presentations given during the first day of the meeting. This second list is reproduced below in Section 1. The reader should bear in mind that our group was aware that the formal, oral presentation given at the beginning of the Workshop could not be expected to fully present all of what had been studied in the region of interest, and that not all of the ongoing or planned studies for the region of interest could be expected to be identified during the first day of the Workshop.

Our group then came up with recommendations intended to suggest (1) what needed to be measured, (2) when it should be measured, and (3) the experimental design to accomplish this. These recommendations are listed in Section 2. It should be noted that the third item, the experimental design, played a large role in our deliberations. Thus our recommendations are primarily formulated as scientific experiments designed to address the items listed in Section 1.

Two experiments are recommended. Group 3 recognized that there were still some important scientific concerns which would not be addressed in the framework of the proposed studies. These items of further consideration are listed at the end of Section 2.

Section 1. Research Needs. The list of topics identified by Group 3 as needing to be further studied in the De Soto Canyon and Shoreward Region is given here. These are grouped in the following eight categories:

1) Current and Circulation

Upwelling on the shelf.
Interaction of eddies with the shelf and slope circulation.
Currents on the eastern shelf and slope region.
Deep currents in the southern 181 Sale Area.
Surface and bottom boundary layer transports on the shelf and slope.
Cross-slope transport at the shelf break.

2) Nutrient Cycles and Circulation

Rivers, estuaries, and deep water as nutrient sources for the shelf.
Micronutrients on the shelf and slope.

3) Biota

Association of fish with upwelling and the De Soto Canyon.
Trophodynamic coupling.
Association of whales with rings, eddies, and the shelf break.
Distribution of phytoplankton, zooplankton, sargassum.
Baseline studies of the shelf and slope benthos.
Analysis of existing ichthyoplankton data.

4) **Estuaries**

Monitoring fresh water, sediment, and chemical input to the shelf.

5) **Storms**

Effects of fresh water input from land sources.
Effects on hydrography of the shelf and slope.
Role in sediment transport.

6) **Benthos and Water-Column Productivity**

Bottom type, benthos assemblage, and sediment distributions on the shelf and slope.
Correlation of hydrography and benthos.

7) **Sediment Dynamics**

Gravity flows in the De Soto Canyon and on the slope.
Nepheloid layer in the De Soto Canyon and on the shelf and slope.
Relative roles of currents and waves.

8) **Models: Physical and Biological Integration**

Existing physical models testing biological conceptual models.
Role of freshwater inflows.
Communication with other groups modeling the same region.

Section 2. Recommended Studies. Two observational programs are recommended.

The reader should be aware that the recommendations are rather specific in that mooring arrays are sketched; this was done to illustrate concepts (e.g., where to measure currents) rather than to suggest specifics (e.g., how to measure currents).

Recommendations

Our group suggested two studies. It was our conclusion that these studies would address some of the "scientific holes" identified earlier as well as some relevant science questions.

Recommendation 1. A study of the deep biology and its correlation with deep currents in the 181-Sale Area.

Description and Objectives. In the deep, southern portion of the 181-Sale Area (approximately the regions deeper than 1000 m in Figure 41) it is known that the Loop Current and the Rings it sheds exist there for many months of the year and for comparably long-duration periods they are absent. (On average once every 9-13 months the Loop Current extends in to the area and sheds a ring there.) Do the Loop Current and its rings extend to the bottom? If so, how do the near-bottom biota respond to extended periods of a strong flow followed by comparable periods of quiescent flow? The intent of this study would be to make long (order two-year) period measurements of the deep flow accompanied by surveys of the near-bottom biota during times of suspected strong and weak bottom flows. The objective would be to see if the Loop Current and its rings extend to the bottom, and if they affect the biota when (if) they do.

Four current meter moorings, one at each of the four deep corners of the lower 181 Sale-Area (nominally at 27.4°N, 87.6°W; 27.4°N, 86.4°W; 28.3°N, 86.5°W; and 28.8°N, 87.7°W) are recommended. The first two sites have nominal depths of about 3000 m, and current meters 100 m above the bottom and at 1000 m and 2000 m depth with upward/ downward looking acoustic Doppler current profilers (ADCPs) at 200 m depth are recommended. The third and fourth sites are, respectively, about 2000 m and 800 m deep, and current meters at 100 m above the bottom, at each site plus upward/downward looking ADCPs at 200 m depth are recommended. The ADCPs at 200 m depth are non critical components to this study; the deep current meters are critical. It is recommended that the deepest current meter on each mooring be equipped with transmissometers or nephelometers. Two consecutive one-year deployments are recommended. The moorings are sketched in Figure 42.

During times of suspected strong and quiescent deep flows – to be determined by examining satellite altimeter and AVHRR products to see when the Loop Current and Loop Current Rings are over or not over the moorings – box coring and bottom trawling are recommended to sample the near-bottom biota. Mid-water trawling could also be considered for collection of mid-water fishes and zooplankton. The sampling regime should be designed to include statistically valid numbers of samples at stations in proximity to each of the fixed mooring locations. Box core samples would be utilized for determinations of sediment community composition and biomass (macrofauna/meiofauna/ microfauna), sediment chemistry, and physical characteristics. Bottom trawling would sample larger benthic megafauna and bentho-pelagic forms that might also be responding to Loop Current and Ring dynamics. Optimally, biological sampling would occur with respect to the behavior of the Loop Current and Loop Current Rings as determined by remote sensing methods, but could be scheduled on a regular basis, e.g., every three months, in conjunction with servicing of mooring array instruments. A shorter elapsed time between sampling efforts would insure that major Loop Current and Ring events would not be missed. Historical satellite and other available data should be utilized to reconstruct past events that may have influenced the biological condition existing prior to the study. Also, during mooring servicing cruises and some biological cruises, CTD/nutrient casts are recommended together with bottom photographs at each mooring site.

Recommendation 2: A continental shelf – upper slope upwelling study.

Description and Objectives: It is evident from several presentations that upwelling occurs frequently in the northern region of the study area. It is also evident from studies of upwelling in other regions of the world's oceans that high levels of biological activity are associated with upwelling events. The objectives of the study would be (1) to better understand the wind-induced upwelling in the region, and (2) to assess the effect the De Soto Canyon has on enhancing upwelling and the associated increased biological activity. It is recommended that three cross-slope mooring arrays be set which span the shelf and extend seaward past the shelf break to about the 200 m depth. One array is to be west of the De Soto Canyon axis but to the east of the Mobile Bay estuary entrance; one is to be in the De Soto Canyon axis; and the third is to be to the east of the De Soto Canyon. Four to six moorings are to be set along each section with current meters on each which span the full water depth (Fig. 43). The current meters are to be outfitted with temperature and salinity sensors, and whenever possible with transmissometers, fluorometers, and oxygen and nutrient sensors. ADCPs, when used, are to be supplemented with moorings having micro-SeaCat-type instruments to profile temperature, salinity, oxygen, and whenever feasible with transmissometers, fluorometers, and nutrient sensors.

Biological sampling is to occur during mooring cruises for pelagic (tows and water bottle casts) and benthos (box cores) and meiofauna (box cores) data. In addition, special biological cruises targeted to sample during intense upwelling and non-upwelling events are recommended. CTDs with oxygen, nutrient, transmissometer, fluorometer full water-column-sections are essential. Satellite color and AVHRR products would be used to detect upwelling events. Primary productivity measurements would be valuable in combination with water nutrient chemistry and other hydrographic measurements. Integration of physical measurements and biological sampling would be important. Initial results from mooring data could influence the location and sampling regime for additional biological collections. In addition to sampling activities established around moorings, a stratified approach could be useful if data coming from mooring instruments early in the study together with models predicted important upwelling events in other areas away from the moorings. In other words, sampling effort would be directed in part, by the upwelling events and physical data from moorings or remote sensing. (The same philosophy should also be applied to the study proposed in Recommendation 1.)

A two-year field program with mooring rotations every three months to minimize fouling effects is recommended. Some real-time monitoring by telemetry is recommended; however, this should not be done at the expense of adequate sampling in space and time on the moorings.

Sampling in the vertical is to be adequate to assess the contributions of the surface and bottom Ekman layers as well as the mid-water column to upwelling transports.

Other Recommendations

The following were thought worthy of further consideration:

- Analyze existing icthyoplankton data from the study area.
- Complete mapping of bottom types – sediments and hard bottom – for the study area.
- Study the effects of natural perturbations – hurricanes, winter cyclones, and cold fronts – and use pre-existing stations (e.g., pinnacles) as study sites.

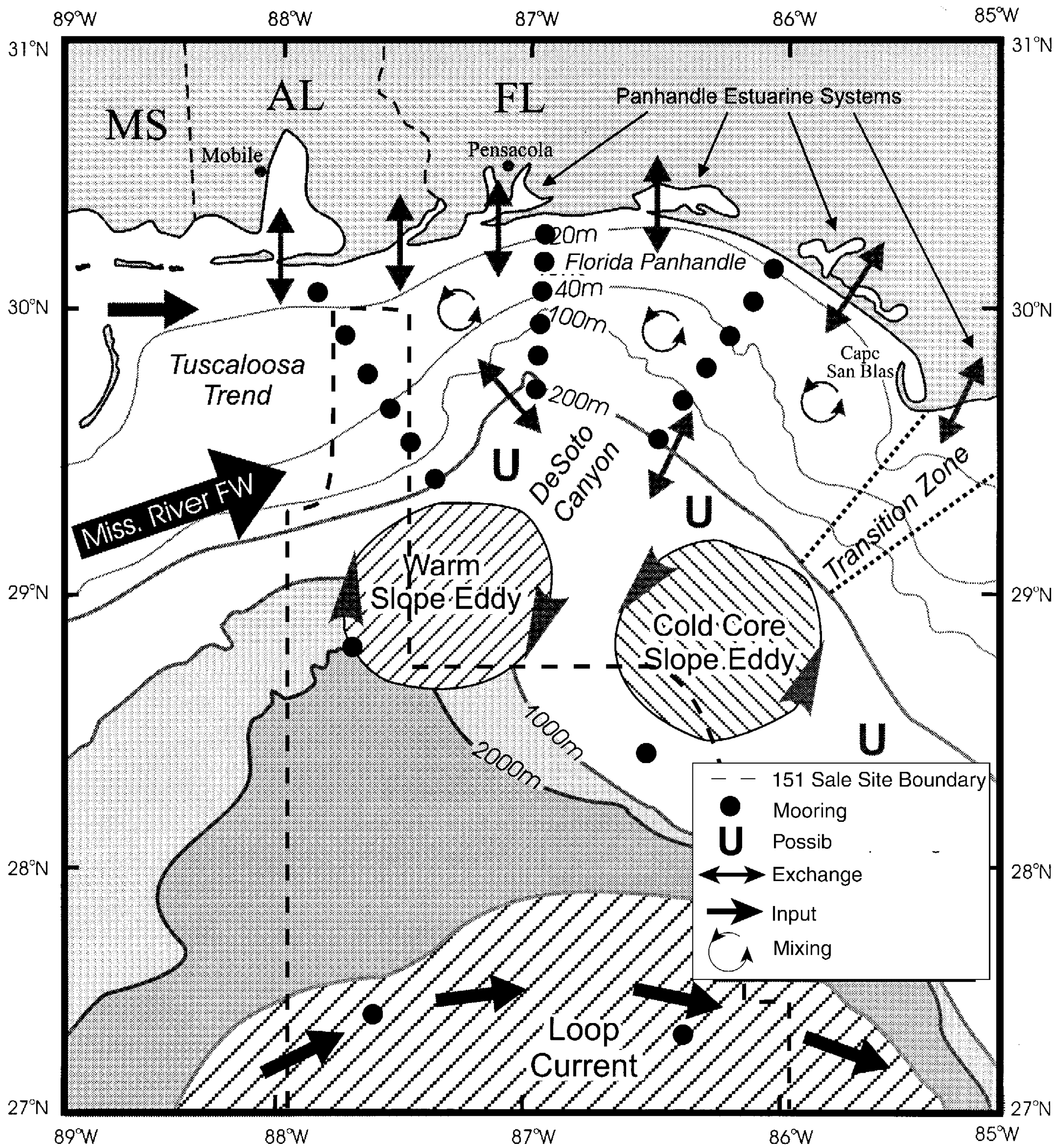

Figure 41. Map of the Northeastern Gulf of Mexico showing the workshop boundaries, major physical exchange paths, forcing mechanisms, and the recommended mooring

sites.

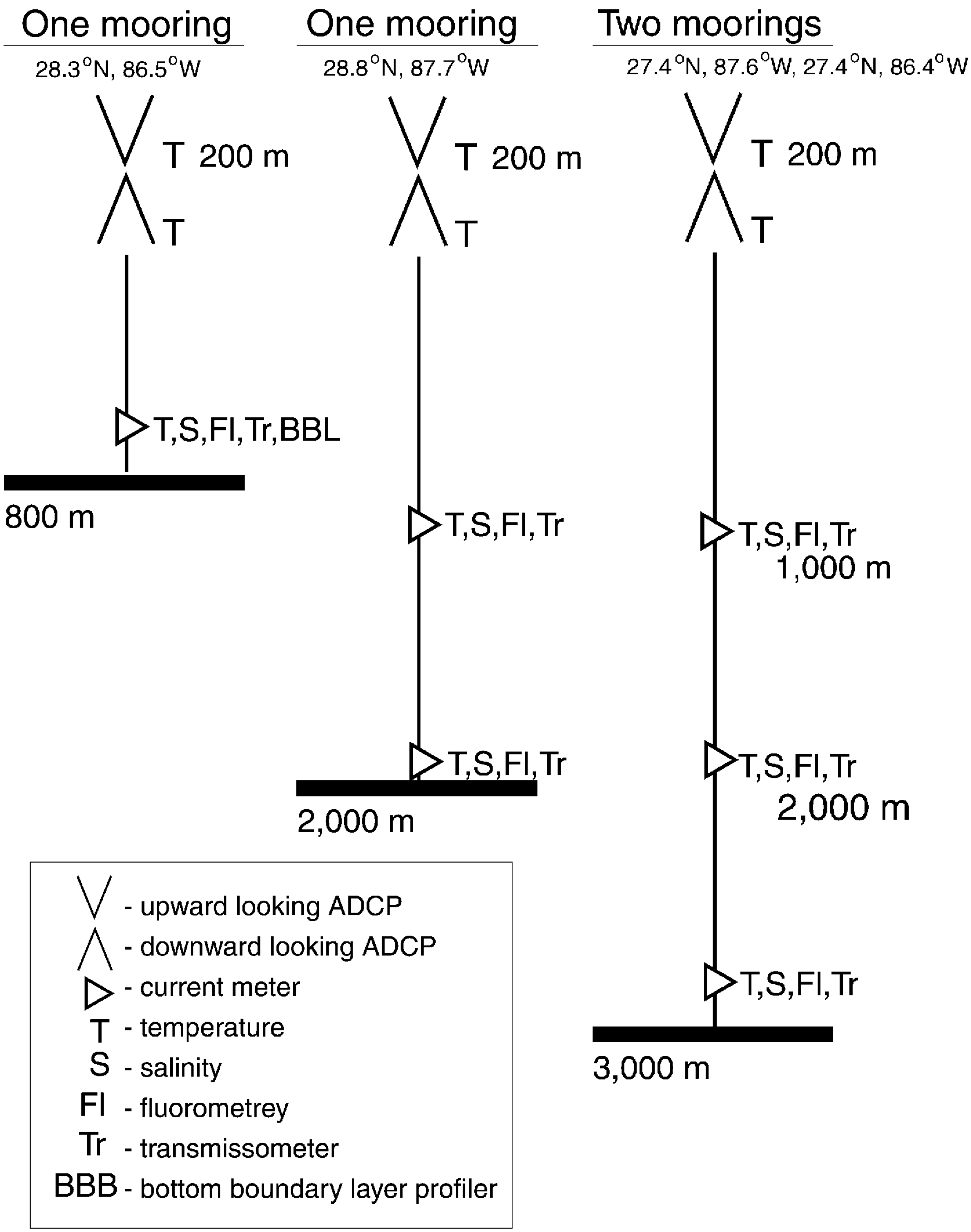

Figure 42. Current Meter Mooring for the Deep, 141 Sale Area.

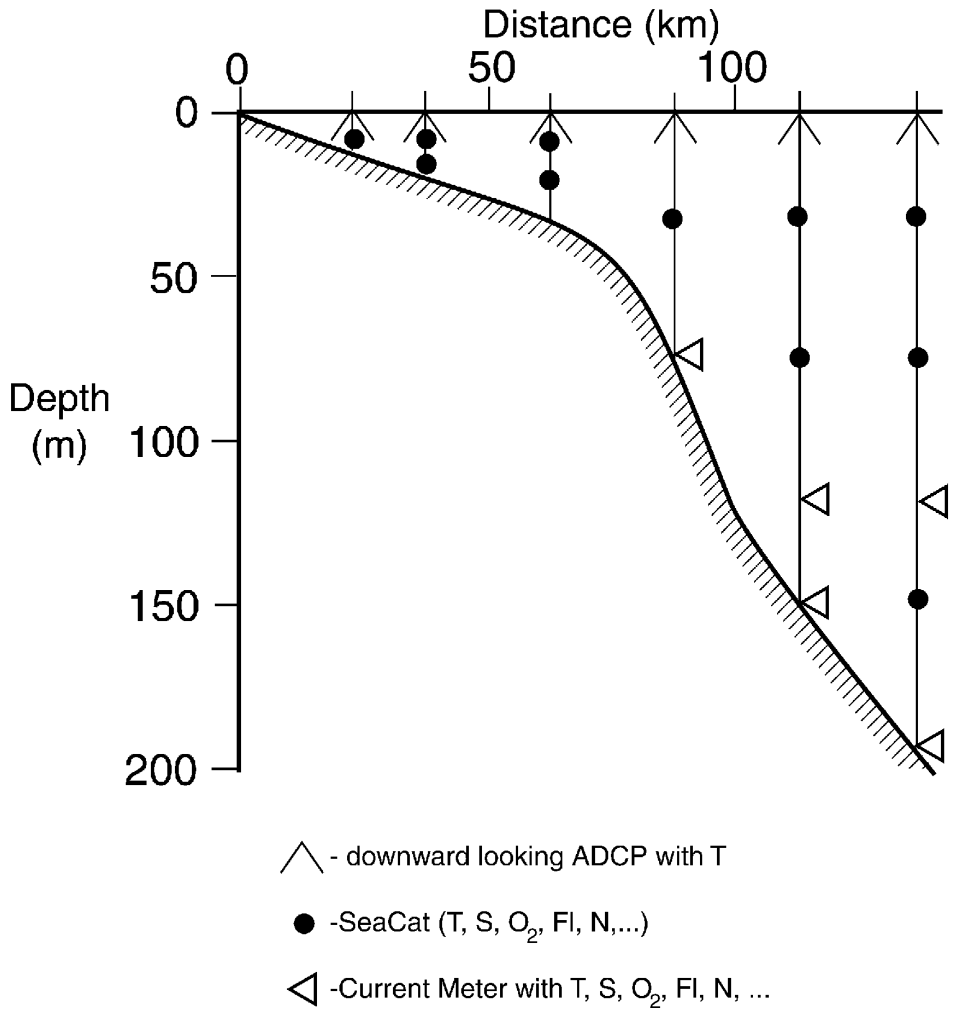

Figure 43. Current Meter Line for the Continental Shelf Upper Slope Upwelling Study.

APPENDICES

Appendix A - Schedule of Invited Presentations
Physical/Biological Oceanographic Integration Workshop

Tuesday, October 19, 1999

8:30 - 8:40	Welcome and Introduction: Dr. James Kendall, Minerals Management Service and Dr. George Crozier, Dauphin Island Sea Lab
8:40 - 9:10	Objectives of the Workshop and Major Features of the Shelf: Dr. William Schroeder, University of Alabama/Dauphin Island Sea Lab
9:10 - 9:35	Regional Meteorology: Dr. S. A. Hsu, Louisiana State University
9:35 - 10:00	Shelf Hydrography: Dr. Ann Jochens, Texas A&M University
10:20 - 10:45	De Soto Canyon Circulation and Exchange: Dr. Peter Hamilton, SAIC
10:45 - 11:10	Shelf Circulation Patterns: Dr. Wilton Sturges, Florida State University
11:10 - 11:35	Shelf Sediments: Dr. Stanley Locker, University of South Florida
1:00 - 1:25	Shelf Nutrient Chemistry: Dr. Mahlon Kennicutt, Texas A&M University
1:25 - 1:45	Shelf Hard Bottom Habitats: Dr. William Schroeder, University of Alabama/Dauphin Island Sea Lab
1:45 - 2:10	Shelf Benthos/De Soto Rim: Dr. Barry Vittor, Barry A. Vittor and Associates
2:30 - 2:55	Regional Fisheries: Dr. Stephen Bortone, The Conservancy of Southwest Florida
3:15 - 3:40	GulfCetII: Dr. Doug Biggs, Texas A&M University
3:40 - 4:00	Estuarine and Coastal Habitats: Dr. Sneed Collard, University of West Florida
4:00 - 4:30	Biological Linkages: Dr. Frank Muller-Karger, University of South Florida

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Thomas Ahlfeld, Minerals Management Service
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The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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