OCS Study
MMS 2001-082

Proceedings: Twentieth Annual Gulf of Mexico Information Transfer Meeting

December 2000

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

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ACKNOWLEDGMENTS

The Minerals Management Service thanks all ITM participants. Recognition goes to the speakers whose timely individual and panel presentations stimulated discussions and exchange of information. Authors are listed by name with their articles and again in an index at the back of this publication.

We are grateful to the chairs and co-chairs for the many hours spent in organizing and chairing the sessions and for spending time gathering presentation summaries. They are listed by name in the table of contents as well as at the beginning of each session.

The University of New Orleans, Office of Conference Services, was the contractor responsible for the meeting. The dedicated staff and subcontractors play an integral role in the execution of this meeting and the completion of the proceedings. Their tireless efforts are greatly appreciated.

The staff of the Airport Hilton were personable and accommodating to our countless requests.

INTRODUCTION

Ms. Debra L. Vigil
Environmental Sciences Section
Minerals Management Service

The primary purposes of the ITM are (1) to provide a forum for interchange on topics of current interest relative to environmental assessments in support of offshore oil and gas activities in the Gulf of Mexico OCS Region; (2) to present the accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico and of other research programs or study projects; and (3) to foster an exchange of information of regional interest among scientists, staff members, and decision-makers from MMS, other Federal or State governmental agencies, regionally important industries, and academia and to encourage opportunities for these attendees to meet and nurture professional acquaintances and peer contacts.

The ITM agenda is planned and coordinated by the MMS staff of the Gulf of Mexico OCS Regional Office around the three themes mentioned above—issues of current interest to the Region or MMS oil and gas program; accomplishments of the agency; and regional information exchange. Presentations are by invitation through personal contacts between session chairpersons and speakers who have demonstrated knowledge or expertise on the subject.

The ITM is considered a meeting of regional importance and is one of the Region's primary outreach efforts. Attendance in recent years has been 250-300 people, including scientists, managers, and laypersons from government, academia, industry, environmental groups, and the general public.

Support funding is provided through the MMS Environmental Studies Program. Logistical support for the ITM is provided by a contractor and subcontractors selected through the Federal procurement process. A proceedings volume is prepared for each ITM based on summaries of brief technical papers submitted by each speaker and on each session chair's added comments.

SESSION 1A

MISSISSIPPI-ALABAMA MARINE ECOSYSTEM MONITORING PROGRAM

Co-Chairs: Dr. Gary Brewer, USGA Biological Resources Division
Dr. Robert Rogers, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Study Overview	Dr. Neal W. Phillips Continental Shelf Associates, Inc. Jupiter, Florida
Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring–Physical Oceanography and Hydrography in the Mississippi/Alabama Pinnacle Trend Area During May 1997 Through April 1999	Mr. F. J. Kelly Conrad Blucher Institute for Surveying and Science Texas A&M University-Corpus Christi Dr. Les C. Bender Dr. Norman L. Guinasso, Jr. Geochemical and Environmental Research Group Texas A&M University
Geophysical Detection and Characterization of Chemosynthetic Organism Sites	Dr. William W. Sager Dr. Ian R. MacDonald Texas A&M University
Northeast Gulf of Mexico Pinnacles Study Hard-Bottom Communities	Mr. Dane D. Hardin Applied Marine Sciences, Inc. Mr. Keith D. Spring Mr. Stephen T. Viada Dr. Alan D. Hart Mr. Bruce D. Graham Continental Shelf Associates Mr. Michael B. Peccini Texas A&M University
Fish Assemblages	Mr. David B. Snyder Continental Shelf Associates, Inc.

(continued on next page)

Presentation	Author/Affiliation
Trophic Subsidies in the Twilight Zone: Zooplankton Availability and Food Web Structure of Deep Reef Fishes along the Mississippi-Alabama Outer Continental Shelf	Mr. Douglas C. Weaver Dr. Kenneth J. Sulak USGS Biological Resources Division

STUDY OVERVIEW

Dr. Neal W. Phillips
Continental Shelf Associates, Inc.

INTRODUCTION

This presentation summarizes the synthesis phase of the Northeastern Gulf of Mexico Coastal and Marine Ecosystems Program: Ecosystem Monitoring, Mississippi/Alabama Shelf. The project was sponsored by the U.S. Geological Survey, Biological Resources Division. The project team includes Continental Shelf Associates, Inc. (CSA), the Geochemical and Environmental Research Group of Texas A&M University (GERG), Applied Marine Sciences, Inc., and independent consultants.

PROGRAM GOALS

The overall goal of the program was to characterize and monitor biological communities and environmental conditions at carbonate mounds along the Mississippi-Alabama (Outer Continental Shelf) OCS. Specific objectives were as follows:

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

- To characterize the geological, chemical, and physical environment of the mounds as an aid in understanding their origin, evolution, present-day dynamics, and long-term fate.

STUDY AREA

The study area was located in the pinnacle trend area along the OCS off Mississippi and Alabama (Figure 1A.1). This area has been the subject of two previous MMS-sponsored studies: the Mississippi-Alabama Marine Ecosystems Study and the Mississippi-Alabama Pinnacle Trend Habitat Mapping Study. Based on previous studies, five megasites were selected for detailed geophysical reconnaissance. Within these megasites, nine sites were ultimately selected for monitoring. The sites were stratified into three relief categories (high, medium, and low) and three location categories (western, central, and eastern). Water depths ranged from about 60 to 120 m.

SAMPLING SCHEDULE

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

- Phase 1 included two reconnaissance cruises (Cruise 1A, November 1996; and Cruise 1B, March 1997) followed by final site selection (April 1997) and the initiation of monitoring and companion studies on Cruise 1C (May 1997).

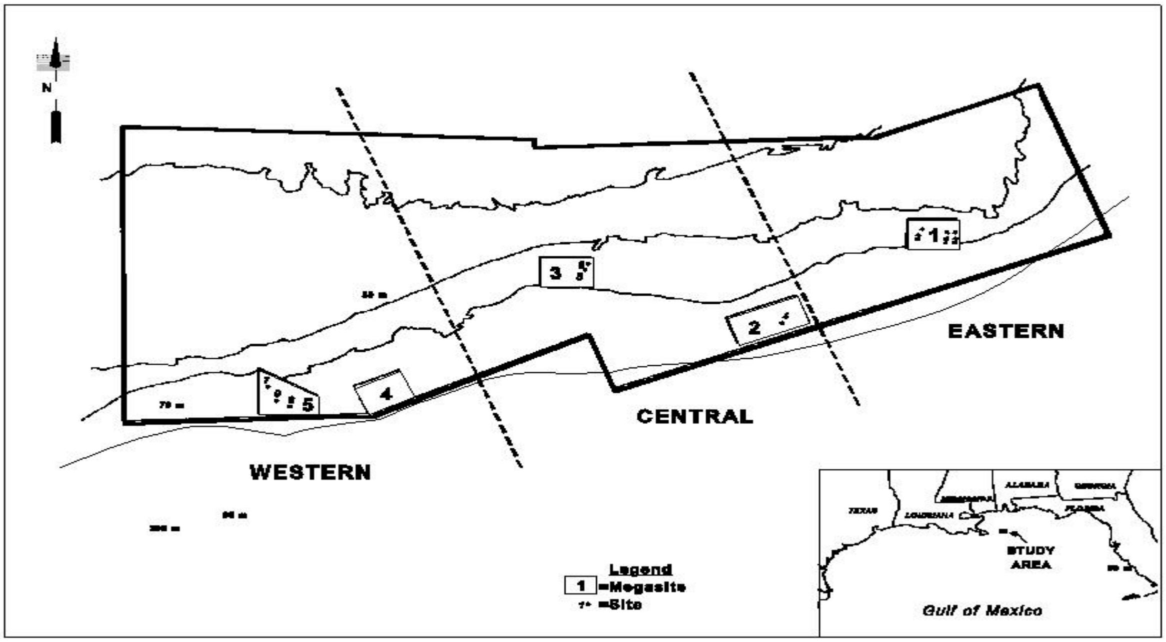


Figure 1A.1. Locations of final monitoring sites.

- Phase 2 included two monitoring cruises, M2 (October 1997) and M3 (April-May and August 1998). In addition, mooring service cruises were conducted in July 1997, January 1998, and July 1998.

- Phase 3 concluded the field sampling program with two additional mooring service cruises (October 1998 and January-February 1999) and one final monitoring cruise (M4, April and July-August 1999).

- Phase 4 did not include any new field work. During this phase, investigators analyzed and synthesized data from the entire program. Preliminary results have been discussed in three previous Annual Interim Reports.

Essentially, after reconnaissance and site selection, there were two full field years of monitoring at the nine sites.

PROGRAM COMPONENTS

Four components formed the core of the program. These are geology, physical oceanography/ hydrography, hard-bottom communities, and fish communities.

Geology

The geology component included three subtasks: geologic characterization, geochemistry, and sediment dynamics. Principal investigators for the geologic characterization were William W. Sager and William Schroeder. This task attempted to derive as detailed a physical picture of the mounds as possible with conventional geophysical and geologic data. Target areas were mapped using high-resolution side-scan sonar images, high-frequency subbottom profiles, grab samples, and video observations. Results are summarized in Dr. Sager's presentation.

The principal investigator for geochemistry was M.C. Kennicutt II. This subtask included a combination of hydrocarbon, metal, grain size, total organic carbon, and total inorganic carbon measurements in sediments and sediment trap materials. Grab samples were collected on all four monitoring cruises and analyzed for total organic carbon and total inorganic carbon. Samples from the first monitoring cruise also analyzed for hydrocarbons and selected metals (barium, cadmium, chromium, iron, lead, mercury, and zinc). Results essentially showed little or no elevation of hydrocarbon or metal concentrations in the study area.

The sediment dynamics subtask, conducted by Ian D. Walsh, included monitoring of nepheloid layer dynamics. Sediment traps were deployed at three heights above bottom (2.5 m, 7 m, 15 m) at four monitoring sites during eight trapping periods. Transmissometer profiles were conducted on all cruises, with data calibrated against measured particle concentrations. Optical backscatter sensors were included on current meter moorings, but did not produce useful data. Both the water column particulate measurements and the sediment trap data indicated high spatial and temporal variability in resuspension and nepheloid layer dynamics among sites. A benthic nepheloid layer was present at all sites during all casts, though with a wide range in concentrations; it was most persistent at Sites 5 and 9. Two hurricanes that passed near the study area in September 1998 caused extreme responses in sedimentation rates at all sites.

Physical Oceanography and Hydrography

Physical oceanographic and hydrographic data were collected to help understand the geological and biological processes of the carbonate mounds. Data from moored instrument arrays, hydrographic profiles conducted on all cruises, and collateral sources provided a basis for characterizing regional and local current dynamics and understanding the dynamics of environmental parameters such as temperature, salinity, dissolved oxygen, and turbidity. Instrument moorings were deployed at four sites (1, 4, 5, and 9) throughout the program, with two additional moorings at Site 1 during the first year, and relocated to Site 5 in the second year. Current meters were located at 4 m and 16 m above bottom. The instruments also recorded temperature, conductivity, and dissolved oxygen. Principal investigators for this component were F.J. Kelly and Norman L. Guinasso, Jr., with Les C. Bender also contributing to the synthesis report. Results are summarized in Dr. Kelly's presentation.

Hard-Bottom Communities

Hard-bottom community monitoring consisted mainly of video and photographic sampling at each site. These included both random photography and video transects, as well as repetitive photography of fixed stations. The nine sites were visited by a remotely operated vehicle (ROV) on each of four monitoring cruises. In general, 100 random photographs were taken per site on each cruise. Random photographs were used to estimate the abundances of sessile and motile epibiota. Video observations (recorded along the ROV's path between random photograph points) were used to quantify larger and more widely dispersed organisms and to broadly characterize substrates and species composition. Fixed video/photoquadrats (five per site) were used to study temporal changes related to growth, recruitment, competition, and mortality. Voucher specimens were also collected. Principal investigators for the hard-bottom community component were Dane D. Hardin, Keith D. Spring, Stephen T. Viada, Alan D. Hart, Bruce D. Graham, and Michael B. Peccini. Results are summarized in Mr. Hardin's presentation.

Fish Communities

There was no dedicated fish sampling during this program. Instead, random photographs and video recorded during the hard-bottom community study were analyzed to evaluate fish distribution. In addition to standard descriptive analysis of the fish communities associated with the mounds, habitat use by 17 common fish species was assessed at three spatial scales ranging from tens of kilometers to a few centimeters. The principal investigator for fish communities was David B. Snyder. Results are summarized in Mr. Snyder's presentation.

Microhabitat Studies

This component focused on octocoral orientation in relation to currents at five sites and octocoral and antipatharian distribution in relation to microhabitat variables (e.g., small and medium scale roughness, sediment veneer) at four sites. The microhabitat studies also included development of a geographic information system (GIS) incorporating much of the data collected during this program (e.g., bathymetry, side-scan sonar mosaics, grab sampling and photo locations, substrate types). Principal investigators were Ian R. MacDonald and Michael B. Peccini.

Epibiont Recruitment

In this component, settlement plates were deployed on moored arrays to document the process of larval settlement, growth, and community development. The study focused on hypotheses about variations with time and space, height above bottom, and orientation of settling surface, as well as effects of disturbance and small-scale turbulence. Biomoorings with settling plates were deployed at four sites throughout the program. A spatial study compared settlement among sites. A temporal study at a single site assessed the effect of duration of exposure. Principal investigators for the recruitment study were Paul A. Montagna and Tara J. Holmberg.

Dr. Neal W. Phillips is a senior scientist with CSA, with 18 years of experience in environmental data analysis, interpretation, and impact assessment. He received a Ph.D. in ecology from the University of Georgia and an M.S. in marine studies from the University of Delaware. His background is in benthic ecology.

NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: ECOSYSTEM MONITORING — PHYSICAL OCEANOGRAPHY AND HYDROGRAPHY IN THE MISSISSIPPI/ALABAMA PINNACLE TREND AREA DURING MAY 1997 THROUGH APRIL 1999

Mr. F. J. Kelly
Conrad Blucher Institute for Surveying and Science
Texas A&M University – Corpus Christi

Dr. Les C. Bender
Dr. Norman L. Guinasso, Jr.
Geochemical and Environmental Research Group
Texas A&M University

INTRODUCTION

This component of the program monitored oceanographic conditions (i.e., currents, temperature, salinity, turbidity, dissolved oxygen, etc.) at topographic features along the Mississippi-Alabama Outer Continental Shelf (OCS) during May 1997 through April 1998. Specific objectives of this component are (1) to characterize the regional and local currents in the study area; (2) to determine the dynamics of important oceanographic parameters; and, (3) in concert with the other project components, to define the relationship of the currents and oceanographic conditions to the geological and biological process. The hard-bottom features of interest are flow obstacles that extend up to 13 m above the 70-120 m bottom depth. The topic of this paper is the variability induced in the near-bottom flow as it passes over and around the mounds, which is an important subject for some of the other project components.

METHODS

One mooring was placed at each of four of the nine study sites. (See Sager *et al.* 2001 (this volume)) for site maps. These four mooring locations were permanent and maintained throughout the two-year field program to provide long-term time-series data. The fifth and sixth moorings were re-locatable. During the first year, they were placed at Site 1 to form, in conjunction with the permanent mooring, a triangular pattern (Figure 1A.2). They were moved to Site 5 in May 1998. The moorings' sensors recorded current velocity, temperature, conductivity and other parameters at 4 meters above bottom (mab) and at 16 mab. A detailed description of the mooring design is given in the Proceedings of the 18th Annual Gulf of Mexico ITM (Kelly *et al.* 2000). CTD casts were taken during the monitoring and servicing cruises to provide details about the vertical structure.

For this discussion, tables of the joint frequency distribution (JFD) of speed and direction (tabular version of the current rose), as well as basic statistics and principal axis analysis are used to provide a compact method of summarizing the large volume of observations. The results for Site 1 at 16 mab are shown in Table 1A.1, as an example. These analysis techniques also provide a method of detecting possible topographic effects on the near-bottom flow. The direction octants of the JFD are

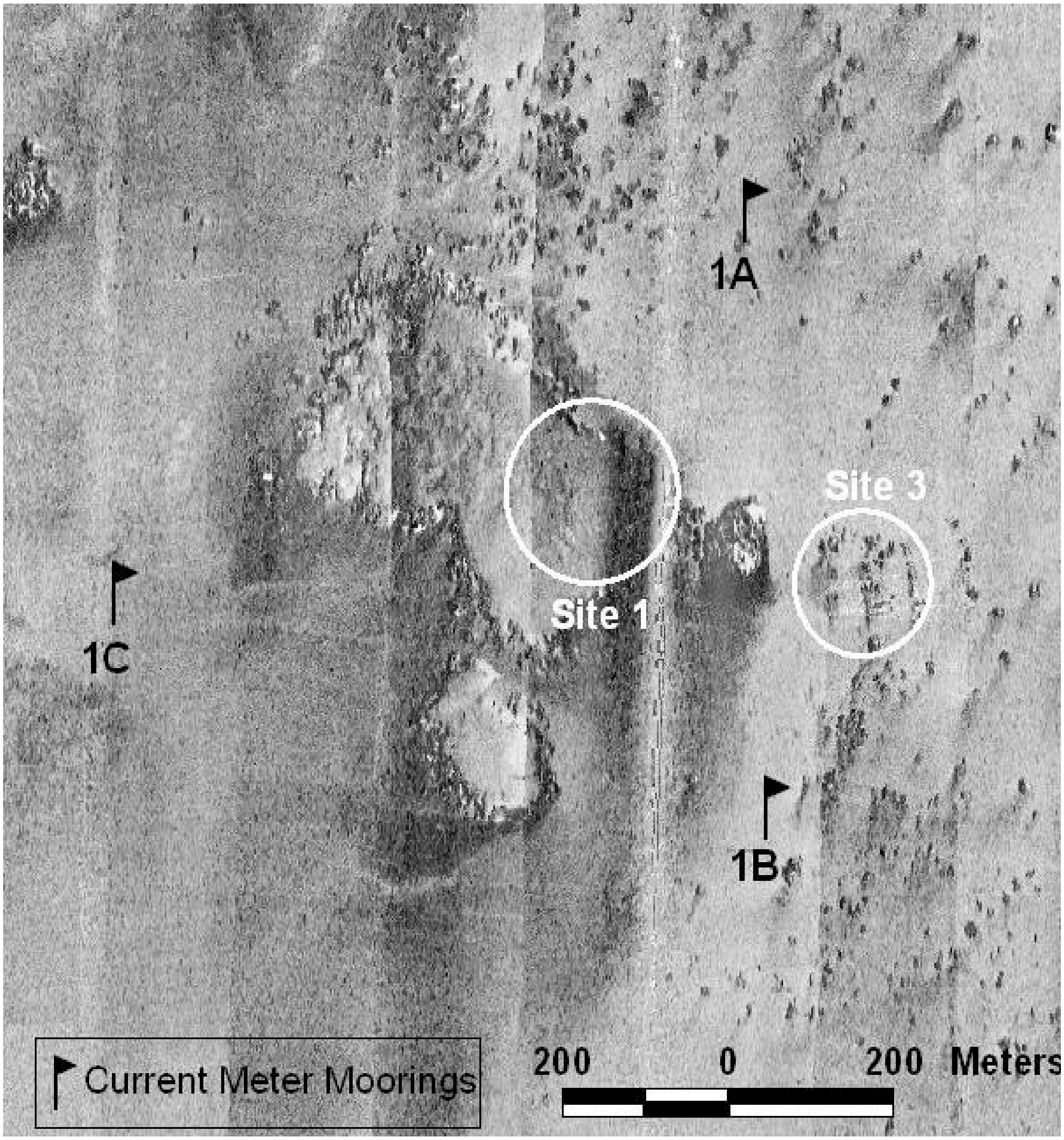


Figure 1A.2. Composite side-scan image of Sites 1 and 3 with locations of current meter moorings noted.

Table 1A.1. Results of statistical analyses for currents observed at 16 mab at Mooring 1A.

a) Table of the Joint Frequency Distribution (JFD) of speed and direction in percent occurrence.

RANGE (CM / S)	N	NE	E	SE	S	SW	W	NW	ROW TOT
<=5	2.56	3.38	3.42	2.12	2.11	3.18	4.46	3.09	**24.32**
>5 <=10	3.14	4.96	5.12	2.69	3.14	4.57	5.52	3.74	**32.87**
>10 <=15	1.51	2.81	3.69	1.40	1.85	2.29	2.59	1.96	**18.10**
>15 <=20	0.52	2.31	3.48	0.70	0.80	1.80	1.34	0.66	**11.59**
>20 <=25	0.20	1.81	3.07	0.36	0.15	1.86	0.88	0.22	**8.55**
>25 <=30	0.04	0.48	0.98	0.04	0.04	0.93	0.39	0.09	**3.01**
>30 <=35	0.00	0.16	0.35	0.00	0.01	0.34	0.11	0.01	**0.99**
>35 <=40	0.00	0.03	0.05	0.00	0.01	0.14	0.01	0.00	**0.25**
>40	0.00	0.00	0.01	0.00	0.00	0.31	0.01	0.00	**0.33**
COL TOTALS	**7.97**	**15.95**	**20.17**	**7.32**	**8.11**	**15.41**	**15.30**	**9.77**	**100.00**

b) Principal Axis Analysis

Mean Current Vector: 0.9 cm/s at 91.8° True
Principal Axis Orientation = 66.2°
Major Axis = 11.5 cm/s **Minor Axis** = 6.5 cm/s

c) Basic statistics

Basic Stats	Min.	Max.	Mean	Std.	No. Obs.
SPEED:	1.1	96.7	**10.6**	7.8	29351
U (East):	-69.1	40.0	**0.9**	10.8	29351
V (North):	-73.5	29.9	**-0.0**	7.5	29351
T (Deg. C):	15.4	27.4	**20.6**	1.6	29351
Salinity:	35.0	37.0	**36.2**	0.3	29351

abbreviated to E for east, NE for northeast, etc. The oceanographic convention for direction is used, i.e., towards which the current flows. Results from the CTD casts are used to compute the stability (buoyancy frequency) of the water column.

RESULTS

Flow at 16 mab

The current meters at 16 mab measure the mesoscale flow just above the pinnacles. At this height, there is substantial similarity across the entire pinnacle study region in the observed flow characteristics. Site 1, a high-relief site, and Site 9, a low-relief site, span the east-west extent of the study region and provide the maximum contrast in mound height. At both sites (e.g., Table 1A.1), the most frequent direction octant is E (20% at Site 1 and 25 % at Site 9). The NE, S and SW octants are the next most frequent at about 15% each. This reflects the generally NE/SW nature of the flow at the 16 mab level, which is above the bottom Ekman layer. The most frequent speed range is 5-10 cm/s, (33% at Site 1 and 28% at Site 9), and the overall scalar mean speeds are similar at 11-12 cm/s. Strong currents, i.e., greater than 40 cm/s, are most frequently directed SW or W, particularly during Hurricane Georges (92 cm/s at Site 1 and 98 cm/s at Site 2). The results at Site 5, located about midway across the study region, are very similar to those at the each end. The depths at all three sites are similar (78-92 m). At Site 4, located farther out on the shelf in deeper water (112 m), the distribution and statistics of speed at 16 mab are similar to the other three sites, with 5-10 cm/s being most frequent (33%). Because of the greater depth at this site, the maximum speed, recorded during Hurricane Georges, is only 66 cm/s. The distribution of direction at Site 4 has a slight southwesterly bias compared to the other three sites, as the most frequent direction octant is SW (26%). It is followed closely by E (24%), which is the most frequent octant at the other sites. The SW bias is a result of speeds greater than 20 cm/s, which are most frequently in the SW octant.

Flow at 4 mab

Compared with the flow at 16 mab, the near-bottom flow is more site-specific. Bottom friction and the local topography influence the flow, particularly at Site 1. A comparison is again made between Sites 1 and 9, the high-relief eastern site versus the low-relief western site. The most frequent speed range at Site 9 is a virtual tie between the 5-10 cm/s range and the 10-15 cm/s range, at 26% each. At Site 1, on the other hand, the most frequent range is 0-5 cm/s (44%). The overall mean speed is also lower at Site 1, i.e., 6.3 cm/s compared to 10.3 cm/s at Site 9. Observations of direction also differ significantly between the two sites. The most frequent direction octant is SW at Site 9 but S at Site 1, and the angles of the principal axes are 60.7˚ (NE/SW) versus 20.3˚ (N/S), respectively. At Sites 4 and 5, the flow statistics at 4 mab are similar to those at Site 9.

Vertical Comparison of Principal Axes

A difference between the two levels is clearly revealed by the principal axis analysis (Table 1A.2). At 16 mab, there is a slight clockwise (CW) rotation, going from east to west, in the orientation of the major axes, i.e., 66.2˚ at Site 1 to 75.5˚ at Site 9. This trend is probably related to the large-scale trend of the bathymetry, rather than the mesoscale-scale topography near each site. At 4 mab at Sites

Table 1A.2. Summary of results of Principal Axis Analysis.

Mooring I.D. and height above bottom of current meter	Major Axis Angle °(CW from N) and dir. octant	Major Axis Amplitude (cm/s)	Minor Axis Amplitude (cm/s)	Rotation (°) 4mab relative to 16mab	Sense of rotation
16mab					
C1A	66.2 (NE)	11.5	6.5	-	-
C4A	70.4 (E)	11.8	4.5	-	-
C5A	74.4 (E)	10.5	5.4	-	-
C9A	75.5 (E)	13.2	6.3	-	-
4mab					
C1A	20.3 (N)	5.8	4.7	45.9	CCW
C4A	50.6 (NE)	9.9	5.9	19.8	CCW
C5A	55.8 (NE)	9.0	5.4	18.6	CCW
C9A	60.7 (NE)	9.7	7.2	14.8	CCW

4, 5, and 9 the axes are rotated 15-20˚ counterclockwise (CCW) from those at 16 mab, i.e., to the left, looking down. This is what one would expect because of friction in the bottom Ekman layer. At Site 1, the vertical difference in angles is 45.9˚, considerably larger that at the other three sites, which may indicate some local influence by the topography of Site 1.

Mooring 1A is located about one “mound” diameter northeast of Site 1. Because this site is the tallest and the topographic surveys found a steep slope on the east and northeast sides of the mound, it is the site most likely to create measurable flow disturbances at 4 mab. Compared to the other three sites, the 4-mab currents at Site 1 have a lower mean speed, greater percentage of near stagnant conditions, and a much larger CCW rotation of the principal axis. We conclude that the extent of the flow disturbance created by the topography of Site 1 extends at least the distance to Mooring 1A.

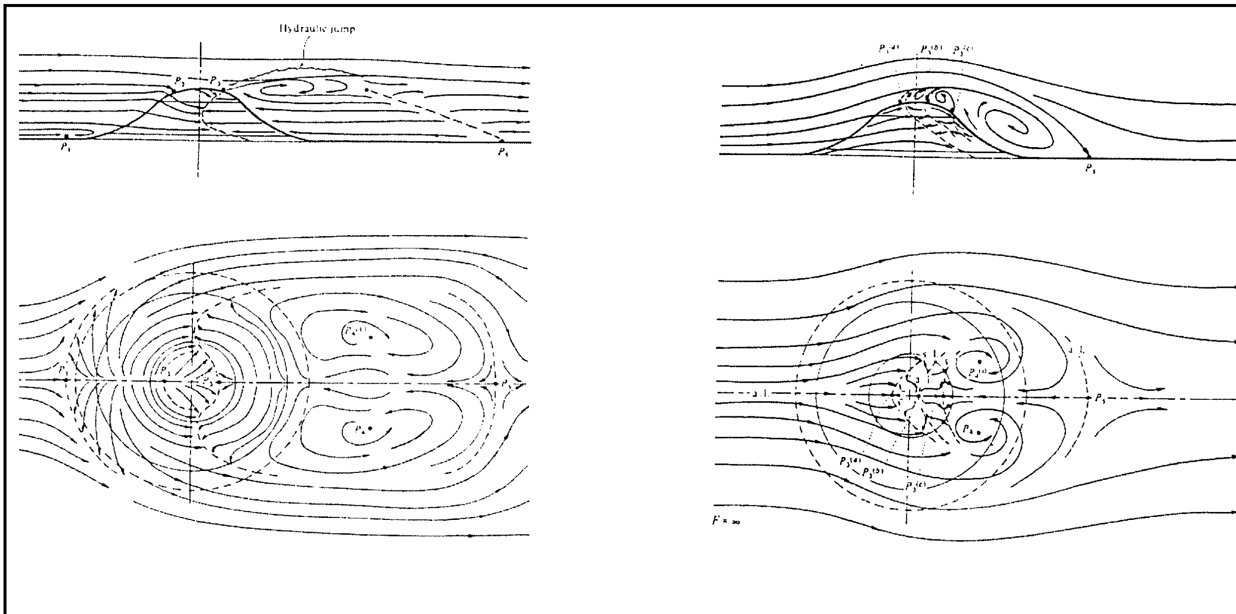
Flow Structure over Generalized Mounds

The observations from the deployed current meters provide a good, quantitative description of the mesoscale flow conditions between the bottom and 16 m above the bottom in the study region. The results also indicate some possible flow perturbation at Site 1 and possibly at Site 5 at distance of one “mound” diameter. A detailed observational study of the flow on the sides and tops of the sites was beyond the scope of the study. However, a qualitative picture of what such flow might look like can be inferred from the results of laboratory studies of three-dimensional, stratified, non-rotating flow over small obstacles. The non-rotational assumption applies because the features of interest in this study have small horizontal extent (L ~ 200 m). Even for very weak flow (U ~ 10 cm/s), the Rossby number (U/fL) at the mounds is greater than one, and a typical time scale is less than one hour. Therefore, the effect of the earth’s rotation, i.e., the Coriolis acceleration on the flow, can be ignored. (Thus, studies and models of flow around larger scale obstacles such as seamounts are not applicable to mounds or pinnacles of this study.)

Baines (1995) reviews the current state of the theoretical and laboratory models of non-rotating, stratified flow over small obstacles. Much of Baines' discussion of three-dimensional flow is based on the experiments of Hunt and Snyder (1980). The most important non-dimensional parameter in this field of study is the internal Froude number, $F = U/Nh$, where h is the height above bottom of the obstacle, U a characteristic upstream speed at the level of h, and N is the buoyancy frequency (also called the Brunt-Väisälä frequency) in radians per second. The value of F indicates, based on experiments and models, whether streamlines from upstream impinge on the hill, go around it, or go over the top. It also indicates, as a function of stratification, where to expect the locations of internal hydraulic jumps and their size, and the region of separated or recirculating flow in the lee of the hill.

Hunt and Snyder (1980) conducted a set of laboratory experiments to observe the flow structure over a bell-shaped hill at values of F from 0.1 to 1.7 and at $F = \infty$. Two examples of their results are reproduced in Figure 1A.3a (for $F = 0.2$) and Figure 1A.3b (for $F = \infty$). To relate their observed laboratory flow patterns to specific sites of this study, one must make assumptions about the frequency of occurrence of various ranges of the value of N. Based on smoothed profiles of N computed from all the CTD casts, a reasonable assumption would seem to be that $N \geq 0.01$ much of the time. Lower values obtain when a very homogeneous bottom water mass advects through a site or when very strong turbulent vertical mixing occurs, such as during a hurricane.

Because of the ranges of the values of h and U used to compute the buoyancy frequency, the 16 mab values of the Froude number cover at least two orders of magnitude. The values of F near 1.0 are of particular interest because near this critical value the flow changes from a hill-hugging lee flow



a) $F = 0.2$ b) $F = \infty$

Figure 1A.3. For Froude number (U/Nh) a) $F = 0.2$ and b) $F = \infty$. Derived center-plane streamline (top) and surface shear-stress patterns (bottom). From Hunt and Snyder (1980).

to a separated lee flow. For a 15-m hill and N = 0.025 rad/s (strong stratification), the Froude number is subcritical (less than 1.0) for speeds up to 37.5 cm/s. At N = 0.001 rad/s (very weak stratification), the flow is subcritical only for the weakest currents, i.e., for speeds less than 1.5 cm/s.

At Site 1, assuming $N \geq 0.01$ rad/s most of the time and h = 13 m, the frequency occurrence of values of F can be estimated from the JFD tables (e.g., Table 1A.1). The flow will be subcritical ($F < 1.0$) for speeds up to 13 cm/s, which occurs almost 75% of the time. In this case, the flow pattern over the site probably looks something like Figure 1A.3a. As $F \rightarrow 1.0$, the flow has more energy to move in the vertical direction; the region where the flow goes over the top of the hill broadens; a plume (dye) emanating from an upstream point near the base would spread thinly to cover a greater portion of the hill; and a strong hydraulic jump develops downstream of the lee separation point. Downstream, a symmetric pair of vertically oriented vortices causes an upstream flow on the centerline. However, they become smaller and move closer to the base of the hill as $F \rightarrow 1.0$.

Near 13 cm/s ($F \sim 1.0$), the flow begins separating from the top of the lee side of the hill. At the maximum observed speed of 96.7 cm/s ($F = 7.4$), the flow in Figure 1A.3b is probably a reasonable depiction, especially because turbulent mixing would decrease the value of N below the assumed value of 0.01, making F even larger. Now the flow separates on or before the top of the hill, and a large recirculating region develops on the leeward slope. The pair of vortices disappears and a horseshoe pattern develops.

Over the much lower relief feature at Site 9, where the height is only a few meters, the Froude number is higher to begin with. Assuming $N \geq 0.01$ rad/s and h = 3 m, the flow will be subcritical only at speeds less than 3 cm/s. More than about 80% of the time, the flow will be supercritical, and Figure 1A.3b would be appropriate flow model. The maximum observed speed of 91.7 cm/s yields a Froude number of 30.6, but the turbulent mixing would probably create near neutral flow ($F = \infty$).

SUMMARY

The current meters at 16 mab measure the mesoscale flow just above the pinnacles, and it is similar across the entire study region (Table 1A.4). There is measurable flow disturbance at 4 mab at Site 1. Compared to the other three sites, the 4-mab currents at Site 1A (northeast side of the mound) have:

A) a lower mean speed,

B) a greater percentage of near stagnant conditions, and

C) a much larger CCW rotation of the principal axis.

Laboratory studies of 3-D, stratified, non-rotating flow over small obstacles may give a qualitative picture of flow over the study mounds, when scaled by the Froude Number. At Site 1 the flow is probably subcritical ($F < 1.0$) up to 13 cm/s, which occurs ~ 75% of the time.

Table 1A.3. Percent occurrence of Froude Number (U/Nh) at 16 mab at each of the four sites with currents meters based on the Joint Frequency Distribution Tables (e.g. Table 1A.1.). The upper limit of the speed bin was used for U; a value of 0.01 rad/s was assumed for N; and the measured mound height was used for h.

	Speed Bin Upper Limit (5 cm/s bins) →	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
Site 1A	**F**	*0.4*	*0.8*	*1.2*	*1.5*	*1.9*	*2.3*	*2.7*	*3.1*
	% Occurrence	**24.3**	**32.9**	**18.1**	**11.6**	**8.6**	**3.0**	**1.0**	**0.3**
Site 4A	**F**	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5*	*4.0*
	% Occurrence	**19.9**	**35.8**	**19.5**	**13.7**	**9.1**	**1.7**	**0.3**	**0.1**
Site 5A	**F**	*0.5*	*1.0*	*1.5*	*2.0*	*2.5*	*3.0*	*3.5*	*4.0*
	% Occurrence	**26.6**	**33.4**	**19.5**	**11.9**	**6.0**	**1.9**	**0.4**	**0.1**
Site 9A	**F**	*1.7*	*3.3*	*5.0*	*6.7*	*8.3*	*10.0*	*11.7*	*13.3*
	% Occurrence	**23.4**	**27.9**	**16.7**	**12.7**	**10.9**	**5.9**	**1.8**	**0.3**

REFERENCES

Baines, P.G. 1995. Topographic Effects in Stratified Flows. New York: Cambridge University Press.

Hunt, J.C.R., and W.H. Snyder. 1980. Experiments on stably and neutrally stratified flow over a model three-dimensional hill. J. Fluid Mech. 96, 671-704.

Kelly, F.J., N.L. Guinasso, Jr. and L.L. Lee III. 2000. Northeastern Gulf of Mexico coastal and marine ecosystem program: Ecosystem monitoring—physical oceanography and hydrography in the Mississippi/Alabama pinnacle trend area during May 1997 through April 1998 and during September 1998. *In* Proceedings: Eighteenth Annual Gulf of Mexico Information Transfer Meeting, December 1998. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, La. OCS Study MMS 2000-030. pp 331-340.

Sager *et al.* This session

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GEOPHYSICAL DETECTION AND CHARACTERIZATION OF CHEMOSYNTHETIC ORGANISM SITES

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OVERVIEW AND RATIONALE

Owing to their small size and the deep ocean depths that they inhabit, chemosynthetic organisms cannot be detected directly by remote sensing methods from the sea surface. This poses a problem for offshore industries and management entities who must determine whether a given site has been colonized by these organisms. Furthermore, much of our knowledge of Gulf of Mexico (GOM) chemosynthetic organisms comes from a few intensely-studied sites, raising the question of whether these sites are representative and whether these organisms are abundant or rare.

Although chemosynthetic organisms themselves are difficult to detect from a distance, they inhabit hydrocarbon seeps, which can be imaged by acoustic techniques. This occurs because seeps alter the physical properties of the seafloor and near surface sediments, thus changing the acoustic reflection character (e.g., Roberts *et al.* 1990; Sager *et al.* 1999). In this study, our goal was to compare and contrast geophysical acoustic methods of detecting and characterizing hydrocarbon seep sites inhabited by chemosynthetic organisms. In general, this is a broad task, far beyond the limited scope of time and resources available to this study, so our approach was to survey the literature, talk with industry geophysicists, and focus on the geophysical signatures of the area surrounding several chemosynthetic organism sites that have been the object of study for a decade or more. Because of this focus, we ran the risk of provincialism, that the small number of sites studied is not entirely representative of all chemosynthetic organism sites. Furthermore, because of the small number of sites, we could not make statistically significant tests of hypotheses concerning relations to particular geophysical signatures. Nevertheless, the results of this study are consistent with what is known about seeps and chemosynthetic organisms. Our overarching conclusion is that there is no one method of detecting chemosynthetic organism sites that is always accurate. Ultimately, confirmation depends on actually seeing the organisms by submersible, deep-camera platform, or recovery of recently live specimens in trawl or core. Defining areas of the seafloor that have been affected by seepage is more straightforward and can limit the area of seafloor that may be considered inhabited by chemosynthetic organisms to a fraction of the deep slope.

DATA AND METHODS

Although three-dimensional multichannel seismic (3D MCS) data are the geophysical data most commonly used to image the seafloor and subsurface by the energy industry, such data are expensive and therefore not readily available to us for study. In contrast, side-scan sonar can make an acoustic image of the seafloor rapidly and at low cost; consequently, we used a long-range side-scan sonar to image the seafloor in three areas of known seeps on the Louisiana continental slope. Side-scan sonar responds to the physical properties of the seafloor, making a high-resolution acoustic image akin to an aerial photograph (e.g., Johnson and Helferty 1990). The three areas that were surveyed totaled about 2400 km^2 and included a 12 x 13 km site centered on an active mud volcano at the border of Garden Banks leaseblocks 424 and 425, a 21 x 41 km rectangle on the upper slope in the Green Canyon leaseblock area, and a 30 x 41 km rectangle on the middle slope, also in the Green Canyon leaseblock area. The upper slope study site includes water depths of 300 to 1050 m. It contains several chemosynthetic organism sites that have been routinely studied (Bush Hill, Brine Pool NR-1, GC234). The deeper site contains depths ranging from 1,000 to 2,250 m; owing to its depth, relatively little is known about its specific geology or biology.

To aid interpretation, we collected several types of ground-truth data and compared the side-scan sonar images to other geophysical data. During the program, we collected 33 piston and gravity cores, mainly from the shallow Green Canyon site. The cores were targeted at anomalous features in the side-scan images that appeared to be seep-related. Stratigraphy and physical properties of the cores were examined for evidence of seepage or chemosynthetic organisms and for an understanding the response of the side-scan sonar. In addition, 3.5 kflz echo-sounder profiles were collected at the sea surface along all sonar tracks, and near-bottom visual observations and chirp sonar (2-12 kHz frequency) were collected using the submarine NR-1 at 17 sonar target features in the shallow Green Canyon survey area. These data were combined with prior submersible dive information from several sites (Bush Hill, Bush Lite, Green Canyon 139-140, Green Canyon 272, Brine Pool NR-1, and Green Canyon 234) to better understand how the geology of seeps is imaged by the side-scan sonar. The sonar images were also compared with maps of seafloor acoustic character constructed from prior 3.5 kHz echo-sounder surveys (Behrens 1988) and with industry 3D MCS data from six leaseblocks.

RESULTS & DISCUSSION

Side-scan sonar images display variations in the amount of acoustic energy scattered back from the seafloor to the sonar ("backscatter"). In general, the muddy seafloor of the Louisiana slope gives low backscatter but is punctuated by areas of high backscatter. In the shallow survey areas, the high backscatter areas correspond mainly to spots where the hydrocarbon seepage has changed the surface and near surface physical properties of the sediments. In the Garden Banks survey area Figure 1A.4), a number of linear features are seen. Correlation to 3.5 kflz echo-sounder profiles shows them to be the surface expressions of faults caused by salt movement in the sedimentary cover. In places, the faults, are visible by either strong backscatter off a fault scarp facing the sonar or shadows caused by a scarp facing away. More often, the faults are visible as curvilinear high-backscatter features, evidently where seepage has occurred and modified the sediments around the fault. Large areas of irregular high backscatter are seen along the faults and cores from these areas typically display some sort of seep-related anomaly: oil, gas, gas expansion cracks and voids, carbonate nodules, crusts, or carbonate mudstone gravels, chemosynthetic bivalve shells, and layers that are anomalously dense or overconsolidated. Because evidence of gas is widespread, we believe that the strong backscatter areas are primarily caused by gas, but potentially in association with other introduced materials or sedimentary changes. Several subcircular and elliptical high-backscatter areas, several hundreds of meters in diameter, correspond to mud mounds likely formed by the expulsion of formation fluids containing mud (i.e., "mud volcanoes"). One circular high-backscatter feature appears to be a crater (as judged by its bathymetric profile) with a floor filled with gas

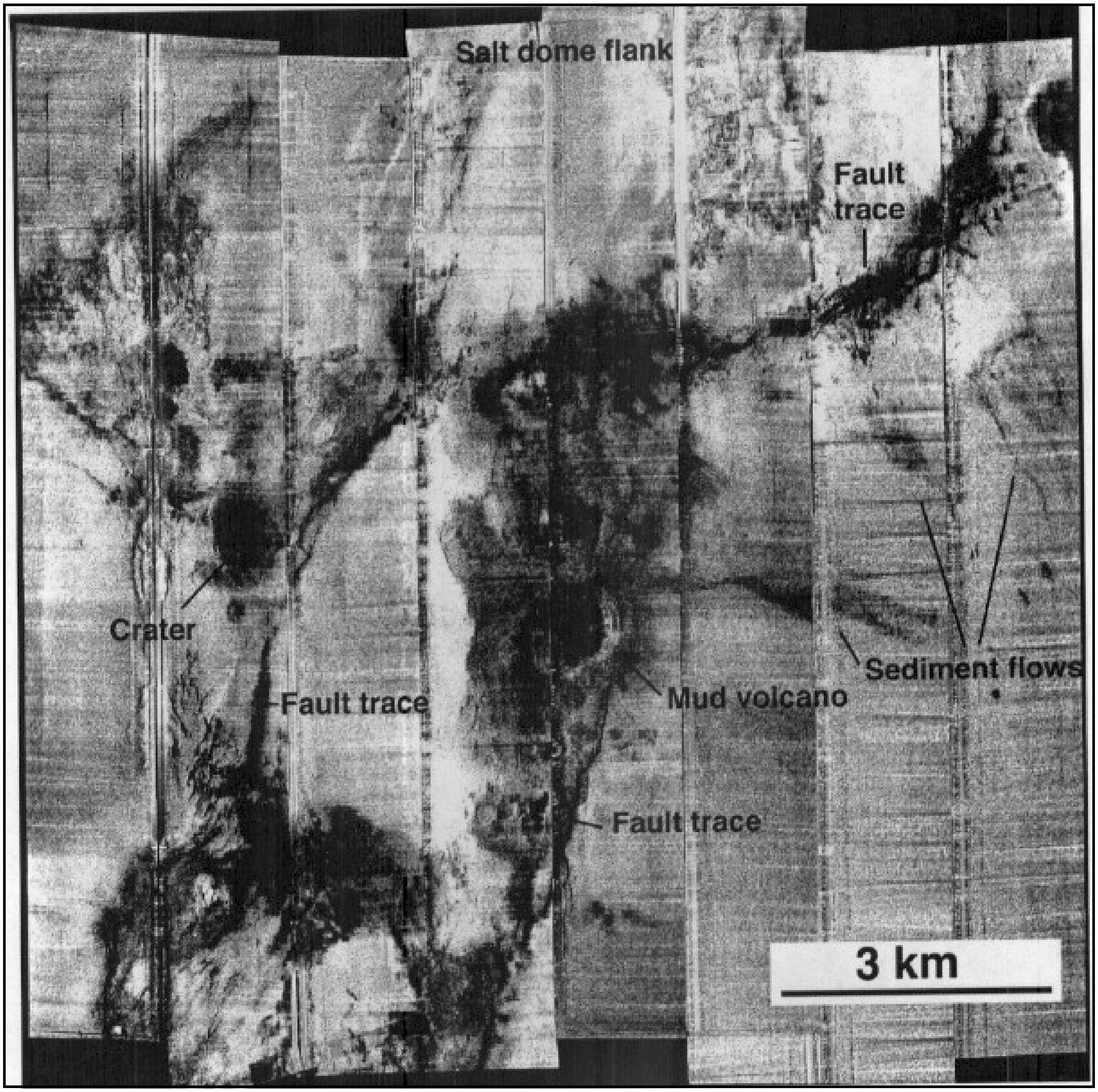

Figure 1A.4. Side-scan sonar mosaic of the Garden Banks survey site. Dark areas represent seafloor with high acoustic backscatter whereas light areas represent low-backscatter seafloor. Most of the dark areas are seep-affected zones along faults. Several subcircular features are mud volcanoes. Linear downslope-trending features are sediment flows. Vertical lines are the ship track locations.

charged sediments. Several linear high-backscatter features that trend downslope appear to be sediment flows as judged by their shape.

In the Shallow Green Canyon survey area Figure 1A.5), similar features are seen, i.e., fault traces, curvilinear high-backscatter features, irregular high-backscatter zones along the fault zones,

Figure 1A.5. Side-scan sonar mosaic of the seafloor in the shallow Green Canyon survey area. Conventions as in Figure 1A.4.

subcircular and elliptical high-backscatter features corresponding to mud mounds, and linear, down-slope trending high-backscatter features probably caused by sediment flows. In addition, many subcircular, rough-looking mound features are observed in Green Canyon 139 and 140, atop a salt dome. These are likely mounds consisting of authigenic carbonate reported in that area (Roberts and Ahron 1994). In addition, two large, fan-shaped high-backscatter features, several square kilometers in area, appear in Green Canyon 272 and 233. Both have the appearance of complex, multiple sediment flows erupted from effusive mud volcanoes.

The deep Green Canyon survey area has a markedly different appearance from the shallow survey areas. This survey covers an area of salt highs and intrasalt basin, in contrast to the gentler, less tectonically-disturbed upper slope survey areas. The sonar mosaic (Figure 1A.6) shows many areas of high-backscatter and an overall more chaotic appearance. Irregular backscatter zones (with both high and low backscatter features) occur on salt flanks where faulting has produced rough zones. In addition, mass wasting has caused slumps and sediment flows, which appear as high backscatter

Figure 1A.6. Side-scan sonar mosaic of the seafloor in the deep Green Canyon survey area. Conventions as in Figure 1A.4.

features on the intrasalt basin floors. High backscatter spots, like those observed in the shallow areas also occur, implying the existence of hydrocarbon seeps and seep alteration, but in this survey area they are harder to define owing to the background of tectonic features.

Comparison of known chemosynthetic organism sites with side-scan sonar and other data types highlights the difficulty in attempting to find a diagnostic geophysical signature that will flag inhabited seep sites. Several sites are characterized by large mud volcanoes. Several are highly active, such as the Garden Banks 425 site, the Bush Lite site, and the TAMU-6 and TAMLJ-17 sites discovered in Green Canyon leaseblocks 191 and 233 during the NR-1 cruise. Bush Hill, in contrast, is continuously active, venting gas, but shows no evidence of recent sediment or fluid expulsion as do the others. In contrast, the GC 234 and Brine Pool NR-1 sites are ones that are not obvious in either the side-scan sonar or MCS data. Both occur in areas of high acoustic backscatter, but the locations of the chemosynthetic communities do not stand out against the complex anomalies located along fault zones in the vicinity.

Interestingly, several different types of mound character were noted in the geophysical data. The side-scan sonar data show three types: (1) nearly homogeneous high backscatter, (2) highbackscatter center with a halo of lesser backscatter (“bulls-eye”), and (3) high backscatter with a “dead spot” from which the sonar receives no return (“dead-eye”). Bush Hill is an example of type 1, and this

Table 1A.4. Chemosynthetic community site indicators.

Indicator	Data type	Likelihood*
Deep rooted fault	Multichannel 2D or 3D seismic data	M
Acoustic wipeout	High-frequency echosounder profiles	M
Strong amplitude anomaly	Multichannel 2D or 3D seismic data	M
Mound along fault	Swath bathymetry; 3D multichannel seismics, geohazard survey	M
Confluence of regional faults	Multichannel 2D or 3D seismic data	H
Sea surface oil slick	Aerial photography; space photography; synthetic-aperature radar	H
Gas stream in water column	High-frequency echosounder profiles	H
High backscatter along fault	Side-scan sonar	H
Chimney-shaped acoustic wipeout	Multichannel 2D or 3D seismic data	H
Strong amplitude anomaly along fault	Multichannel 2D or 3D seismic data coincident with mound	H
High backscatter along fault coincident with mound	Side-scan sonar	VH
Strong amplitude anomaly along fault, negative reflection coefficient, coincident with mound	Multichannel 2D or 3D seismic data	VH
Presence of small mounds	Near bottom high-frequency echosounder profiles	VH
Presence of small mounds	Near bottom side-scan sonar swaths	VH
Oil, gas	Cores	VH
Chemosynthetic shell debris	Cores	C
Images of chemosynthetic organisms	ROY video, camera sled, submersible	C

*Likelihood of chemosynthetic community code: M=moderate; R=high; YR=very high; C=confirmed appears to be a result of a mound charged with gas and gas hydrate but without an obvious fluid expulsion vent. Type 2, the bulls-eye mound, were found in the chirp sonar surveys to have a central hard-bottom surrounded by a region of acoustic wipeout likely caused by gas-charged sediments. These mounds were not inhabited by chemosynthetic organisms and appeared to be senescent or dormant. The dead-eye mounds (type 3) were all highly active mud volcanoes with brine pools or brine vents. We speculate that the dead spots are caused by specular reflection of the sonar signal away from the sonar (i.e., no backscatter) or nearly complete absorption of the sonar signal by an extremely gas-charged, sediment/fluid slurry in the vent region.

Comparison with MCS data shows that the seafloor amplitude anomaly associated with the known chemosynthetic sites and mounds is variable. Bush Hill has a negative reflection coefficient, implying a reduction of seismic velocity within the mound and a reversal of the signal polarity, probably as a result of gas-charged sediments. In contrast, the Garden Banks 425 mound shows a ring of slightly greater reflection around the mound perimeter, with the mound center showing no anomaly. This type of signature was noted on several other mounds. The TAMU-17 mound, a highly active mud volcano with abundant tube worm clusters, displays a positive amplitude anomaly. The Brine Pool NR-1 and GC234 sites are also difficult to detect with MCS amplitude anomaly data.

In all, it appears that there is no one characteristic geophysical signature that will allow an interpreter to find all of the known chemosynthetic organism sites in our study areas. Instead, the geophysical data can be used to define areas affected by seepage, and these generally make up only a small fraction (about 11%) of the total survey area (although the percentage can be much higher within a localized area, such as a single leaseblock). Whether chemosynthetic organisms inhabit a given locality can probably only be determined by direct observations, such as submersible observations, camera sled or ROV photos, or specimens recovered in core or trawl. However, the likelihood of chemosynthetic organism occurrence can be inferred by using a number of geologic and geophysical observations to build a case for their occurrence or absence (Table 1A.4).

REFERENCES

Behrens, E. W. 1988. Geology of a continental slope oil seep, northern Gulf of Mexico. American Association of Petroleum Geologists Bulletin 72:105-114.

Johnson, H.P., and M. Helferty. 1990. The geological interpretation of side-scan sonar. Reviews of Geophysics 28:357-380.

Roberts, H.H., and P. Aharon. 1994. Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations. Geo-Marine Letters 14:135-148.

Roberts, H. H., P. Aharon, R. Carney, J. Larkin, and R. Sassen. 1990. Sea floor responses to hydrocarbon seeps, Louisiana continental slope. Geo-Marine Letters 10:232-243.

Sager, W.W., C.S. Lee, I.R. Macdonald, and W.W. Schroeder. 1999. High-frequency nearbottom acoustic reflection signatures of hydrocarbon seeps on the northern Gulf of Mexico continental slope. Geo-Marine Letters 18: 267-276.

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NORTHEAST GULF OF MEXICO PINNACLES STUDY HARD-BOTTOM COMMUNITIES

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Abstract

Hard-bottom communities were sampled at nine sites in the northeastern Gulf of Mexico during four cruises from May 1997 to August 1999. The sites fell into three categories of vertical relief (i.e., low, medium, and high) and three categories of region (i.e., east, central, and west). Low-relief sites averaged 3 m in vertical relief, medium-relief sites averaged 5-7 m in vertical relief, and high-relief sites averaged 10-12 m in vertical relief. Sites in the east, central, and west regions ranged from 143-147 km, 108-125 km, and 70-71 km from Main Pass in the Mississippi River delta, respectively.

The communities were sampled photographically, with approximately 100 random and five fixed photographic samples being collected at each site in each cruise. Photographs were analyzed with a random-point contact method to estimate percent cover and density of each taxon. Statistical analyses focused on the 40 taxa with the highest average percent cover over all sites and times. These 40 taxa accounted for 90% of the total average biological cover at the sites. Ahermatypic corals, octocorals, and antipatharians dominated the biological cover data, while octocorals and poriferans had the most taxa.

Analysis of variance tests for the effects of habitat relief, region, and time (i.e., cruise) indicated that 90% of the taxa differed among relief categories, 80% varied among regions, and 70% differed among cruises. Interpretation of these main effects was complicated by a high number of significant interactions; all taxa had at least one significant interaction and 57.5% of taxa had significant interactions for all possible two-way and three-way combinations.Using these ANOVA results only as a guide to roughly assign taxa to habitat preferences, 23 taxa preferred medium-relief or high-relief habitat and 12 preferred low-relief habitat, and five had no habitat relief preference.

Construction of linear models using all random samples to test for the effects of 11 environmental variables revealed that distance from the Mississippi River and cruise affected 75-100% of taxa, regardless of habitat preference. Because distance from the Mississippi River was estimated from the center of each site, a single value was associated with all samples from a given site.

Consequently, distance from the Mississippi River functioned as a surrogate for site in this analysis, limiting its value as a descriptor of environmental effects on hard-bottom communities. Moreover, not all sites were sampled in each cruise, which may account for the high numbers of taxa exhibiting significant cruise effects. Among the other nine environmental variables, depth, sediment veneer, and medium-scale habitat roughness affected much higher percentages of taxa that preferred medium-high relief habitat when all sites were included, as compared to analyses that included only medium or high-relief sites. This suggests that these variables are important determinants in the higher abundances of many taxa in medium or high-relief habitat.

Location on feature and fluxes of suspended sediments also affected substantial numbers of taxa that preferred medium to high-relief habitat. Several medium-high relief taxa varied according to the bearing from the center of rock features and were significantly correlated with estimated food flux and kinetic energy in currents. Canonical correspondence analysis also indicated that a strong effect of sediment veneer on many taxa that preferred medium or high-relief habitat, with strong negative correlations. Chi-square analysis of data from fixed photographs indicated observed frequencies of sediment accumulation were significantly higher than expected before two hurricanes passed over the study area, whereas samples from shortly after the hurricanes passed indicated no differences between observed and expected frequencies of sediment accumulation. The effects of depth, sediment veneer, medium-scale habitat roughness, location on feature and flux of suspended sediments on hard-bottom communities can all be related to flux and accumulation of sediment.

We suggest that sedimentological processes are important regulators of hard-bottom communities in the study area and that hurricanes may be important in limiting the effects of sediment accumulation on these communities.

FISH ASSEMBLAGES

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INTRODUCTION

Along the Mississippi-Alabama Outer Continental Shelf (OCS), numerous carbonate mounds ranging from less than a few meters to nearly a kilometer in diameter form a trend in water depths of 60 to 100 m. Although these deep reef features represent complex hard-bottom habitats for fishes and invertebrates, little is known concerning the existing biotic assemblages. In an effort to provide basic information, the U.S. Geological Survey (USGS), Biological Resources Division and the Minerals Management Service sponsored a multidisciplinary program entitled “Northeastern Gulf of Mexico Coastal and Marine Ecosystems Program: Ecosystem Monitoring, Mississippi/Alabama Shelf.” The primary focus of this program (conducted by Continental Shelf Associates, Inc. and Texas A&M University, Geochemical and Environmental Research Group) was to describe and monitor epibiotal communities and gain an understanding of the dominant environmental processes that control or influence the distribution, establishment, and development of these communities. A secondary biological component was to assess the fish assemblages associated with the study sites using video footage and still photographs collected during the epibiotal surveys as a data source. This report provides a preliminary account of the fish assessment component of the program.

STUDY OBJECTIVES

The objectives of this study were

1) to describe the fish assemblage structure and dynamics at nine study sites;

2) to examine the effect of relief (high, medium, and low) and location (east, west, and central) on assemblage composition; and

3) to examine multi-scale habitat associations for common species.

This report provides results from the first two objectives.

MATERIALS AND METHODS

Hard-bottom assemblages were sampled at nine sites using a remotely operated vehicle (ROV). Sampling sites were chosen to fall within three categories of relief (i.e., low, medium, and high) in three regions from east to west (Figure 1A.7). Site selection was based on data from geophysical surveys and ROV reconnaissance surveys. At each site, random photographs were taken and random video transects were surveyed during each monitoring cruise. Video images were used to assess the occurrence and composition of fishes and broadly to characterize substrates. Two videocameras simultaneously recorded the path taken by the ROV during its operations; one was forward-viewing

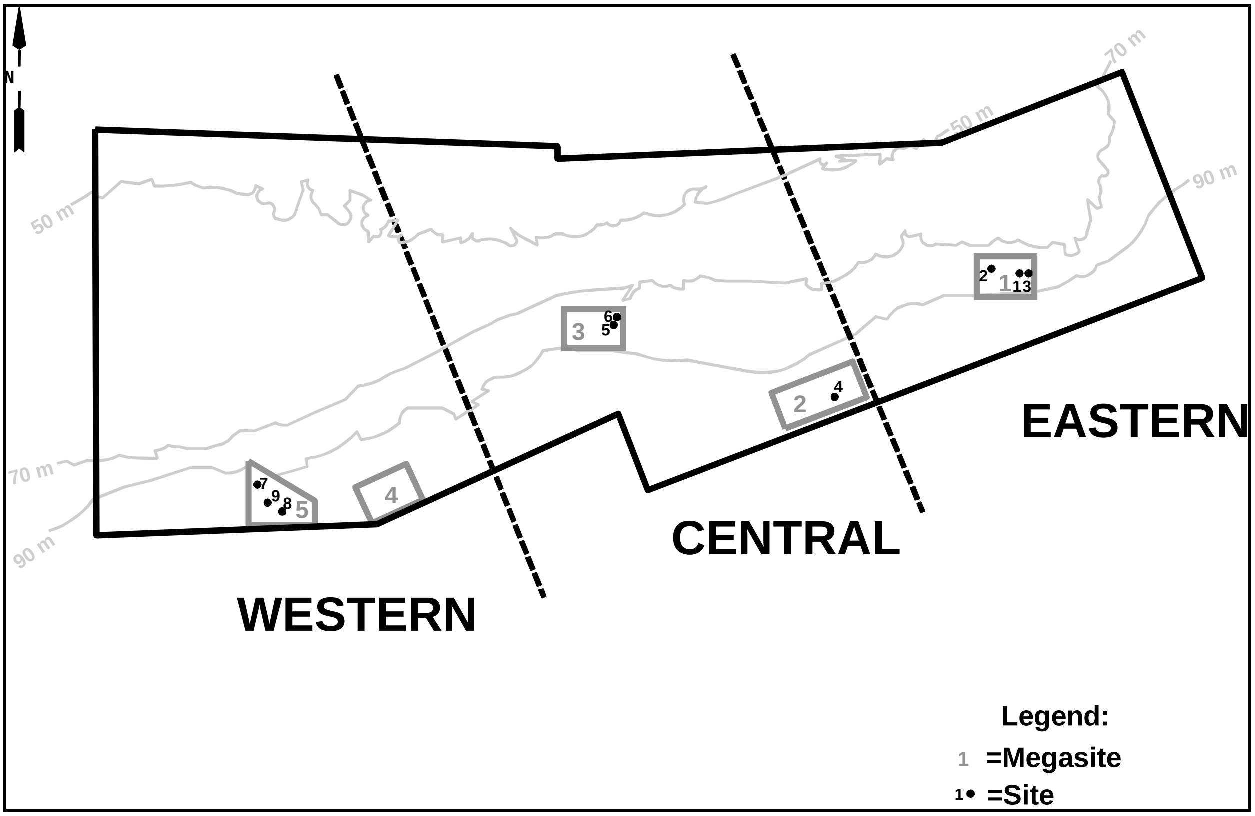

Figure 1A.7. Location of monitoring sites.

for piloting the ROV, while the other was downward-viewing, perpendicular to the substrate, for recording quantitative benthic photographs. Random photographs were collected within eight sectors of a single circular plot located within each site. The paths recorded on video by the ROV as it moved from photograph to photograph provided the best data available for characterizing the fish taxa present at each site. These paths represented random, non-overlapping transects through each of eight sectors at all sites. Fish assemblages associated with the study sites were described from the available video and still photographic data collected during four monitoring surveys, conducted in April 1997 (1C), October 1997 (M2), April 1998 (M3), and August 1998 (M4).

RESULTS AND DISCUSSION

Analysis of 244 video transects from four cruises yielded 73 fish taxa in 32 families. The most speciose families observed were sea basses (Serranidae), squirrelfishes (Holocentridae), lizardfishes (Synodontidae), jacks (Carangidae), wrasses (Labridae), and butterflyfishes (Chaetodontidae). The most frequently occurring taxa in the videotapes were roughtongue bass (*Pronotogrammus martinicensis*), short bigeye (*Pristigenys alta*), bank butterflyfish (*Chaetodon aya*), red barbier (*Hemanthias vivanus*), and tattler (*Serranus phoebe*). Figure 1A.8 illustrates the rank species-frequency relationship for all transects combined.

Although pelagic (e.g., sharks, jacks, bluefish, and king mackerel) and demersal (flounders) fishes also were observed, the ichthyofauna consisted primarily of reef fishes. Commonly seen species

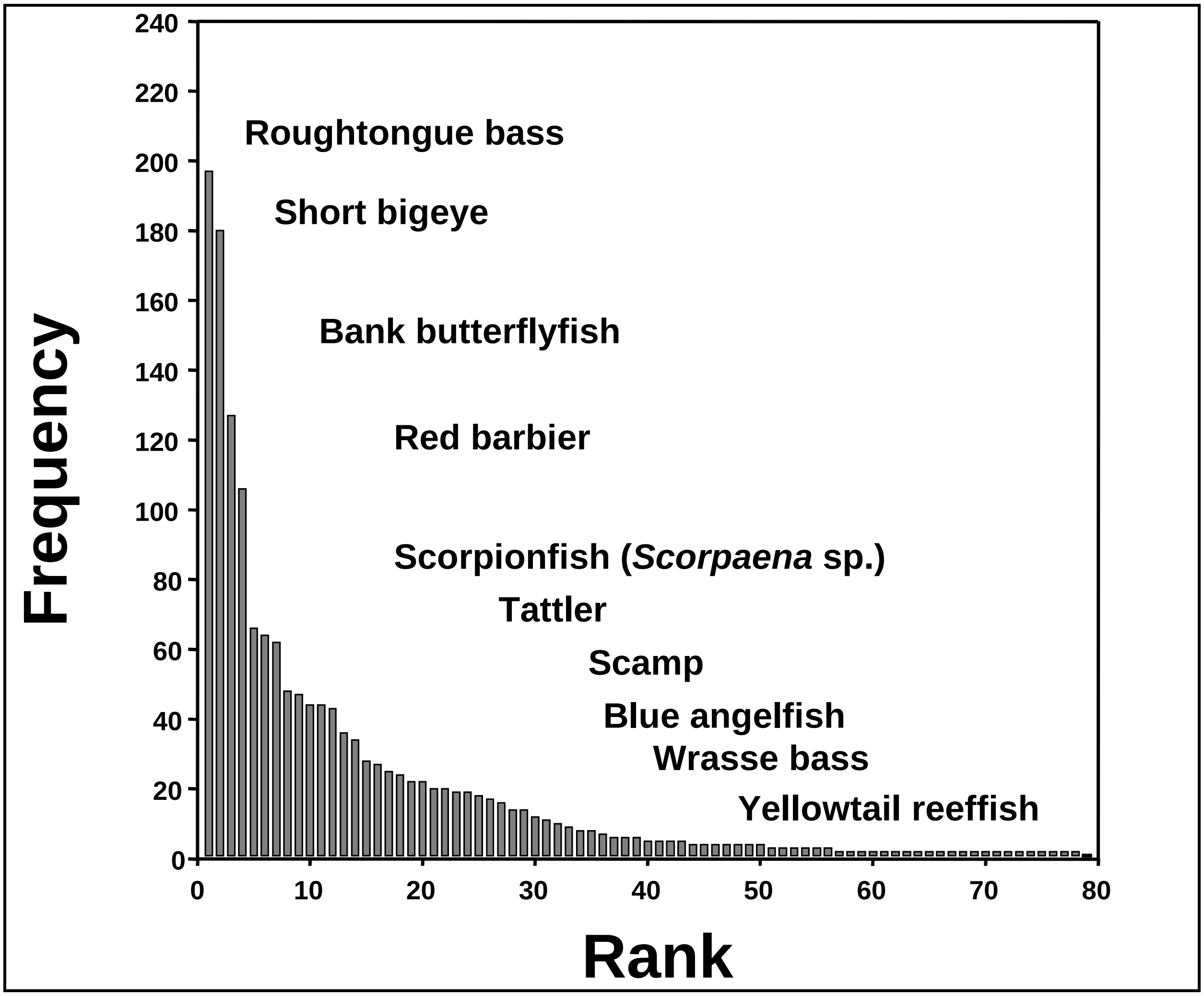

Figure 1A.8. Rank-frequency relationship for all fish taxa observed in video transects across study Sites 1 through 9 for Cruises 1C, M2, M3, and M4.

represent the deep reef fish assemblage reported for water depths of 50 to 300m in the western Atlantic. Similar species have been reported by previous investigations of the pinnacle features, off the southeastern U.S. (Parker and Mays 1998), within the lower portion of the topographic features in the northwestern Gulf of Mexico (GOM) (Dennis and Bright 1988), and near the head of De Soto Canyon (Shipp and Hopkins 1978). The total number of taxa represents about half of the fish fauna known from the hard banks and reefs of the northern GOM.

Taxonomic richness recorded from videotapes for each cruise varied across all sites and cruises (Figure 1A.9). During Cruise 1C, the number of taxa observed ranged from 5 at Site 9 to 22 at Site 7 and averaged 15.3 taxa per site. Cruise M2 yielded an average of 20.7 taxa per site, ranging from 13 taxa at Site 6 to 30 taxa at Site 1. Cruise M3 yielded an average of 28.1 taxa per transect, ranging from 37 taxa at Site 1 to 19 taxa at Site 8. Transects during Cruise M4 averaged 15.2 taxa per transect, ranging from 23 taxa at Site 1 to 9 taxa at Site 3.

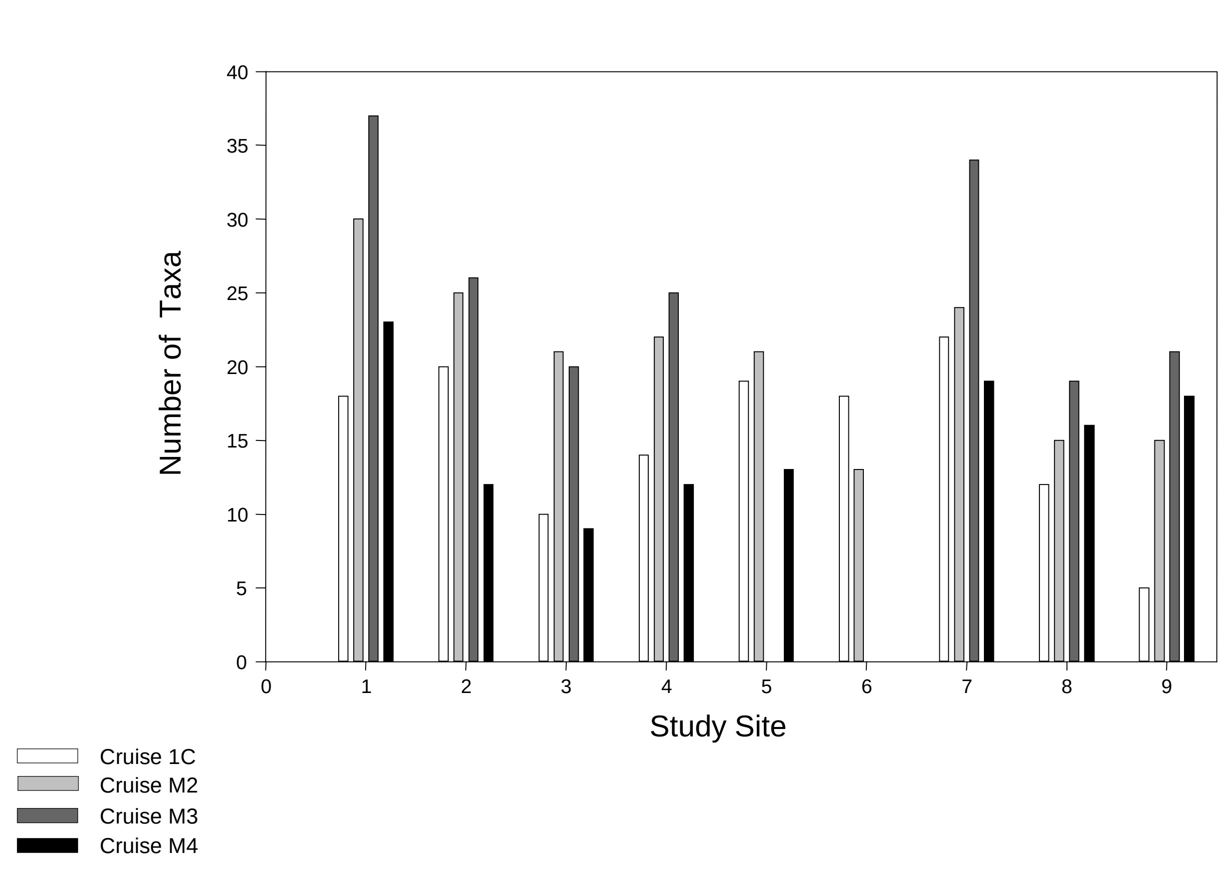

Figure 1A.9. Total fish taxa observed in video transects across study Sites 1 through 9 for Cruises 1C, M2, M3, and M4.

The influence of relief category (high, medium, and low relief), location (east, central, west), water depth, and distance from the Mississippi River mouth on fish assemblage composition was examined by correspondence analysis (Figure 1A.10). Overall, there were no strong, consistent relationships. Site 1 had the most distinct species composition and supported the highest richness of reef species. Site 1 is in the high-relief category, is the farthest from the Mississippi River mouth, and more importantly, is the shallowest of the study sites. Many fishes observed here, but not at other sites, commonly occur in shallow waters. These include sand tilefish (*Malacanthus plumieri*), honeycomb cowfish (*Lactophrys polygonia*), rock beauty (*Holacanthus tricolor*), squirrelfish (*Holocentrus adscensionis*), and sharpnose puffer (*Canthigaster rostrata*). The different species composition and richness at Site 1 may be due simply to shallow water depth or other unmeasured correlates of shallow water depth rather than distance from the Mississippi River mouth or relief category.

REFERENCES

Parker, R.O. and R.W. Mays. 1998. Southeastern United States deepwater reef fish assemblages, habitat characteristics, catches, and life history summaries. NOAA Tech. Rep. 138. 41 pp.

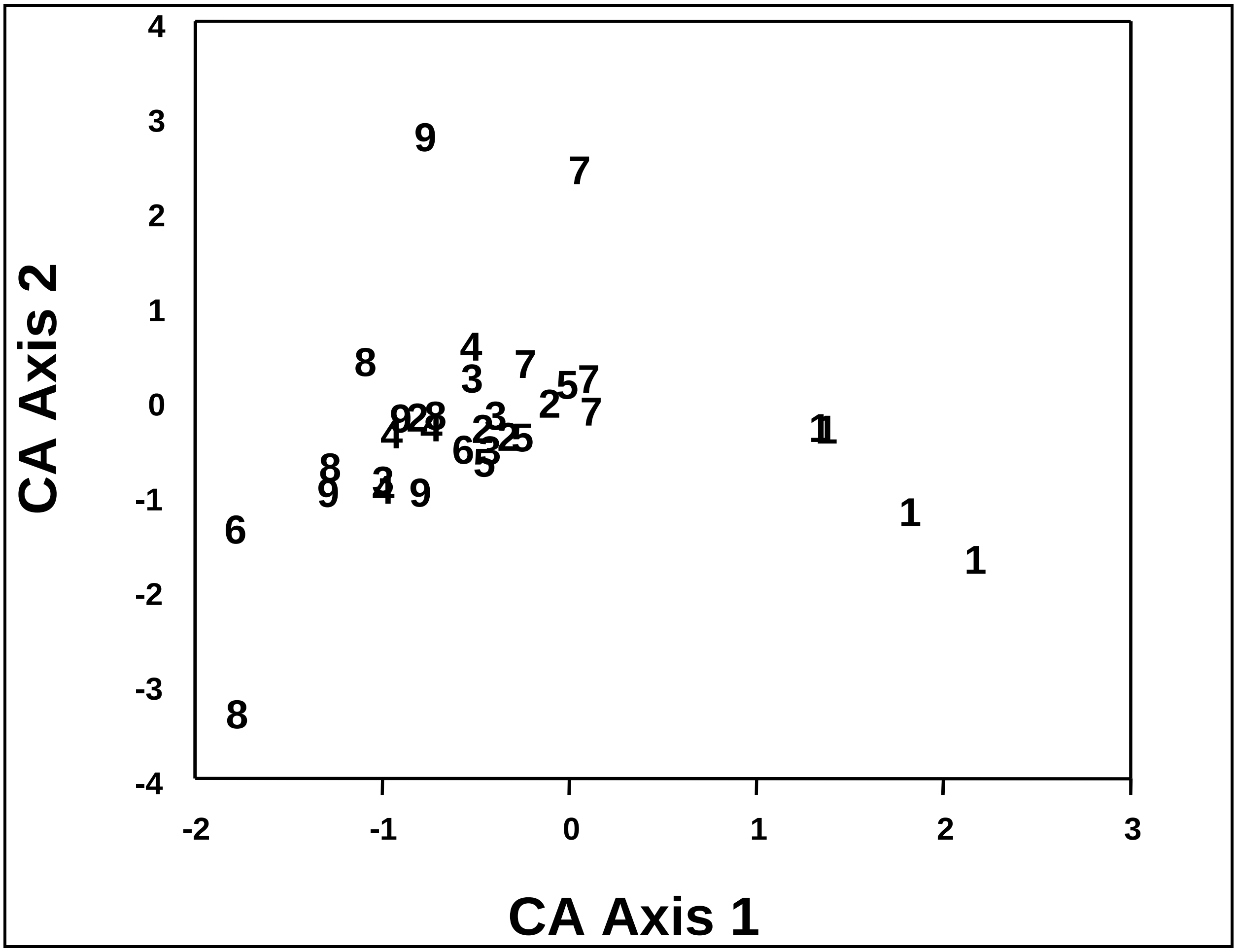

Figure 1A.10. Sample scores from correspondence analysis of a taxa-by-samples matrix based on video transects plotted on Axes 1 and 2. The scores are labeled 1 through 9 to represent the monitoring sites. Sites 1, 5, and 7 are high relief; Sites 2. 4, and 8 are medium relief; and sites 3, 6, and 9 are low relief.

Shipp, R.L. and T.S. Hopkins. 1978. Physical and biological observations of the northern rim of the De Soto Canyon made from a research submersible. Northeast Gulf Sci. 2(2):113-121.

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TROPHIC SUBSIDIES IN THE TWILIGHT ZONE: ZOOPLANKTON AVAILABILITY AND FOOD WEB STRUCTURE OF DEEP REEF FISHES ALONG THE MISSISSIPPI-ALABAMA OUTER CONTINENTAL SHELF

Mr. Douglas C. Weaver
Dr. Kenneth J. Sulak
USGS Biological Resources Division

ABSTRACT

The food web structure and pelagic prey encounter rates of deep (50-110m) reef fishes in the northeastern Gulf of Mexico was examined. Fish communities on high-profile topographic features at the edge of the continental shelf are numerically dominated by two species of streamer basses (Serranidae: Anthiinae): the roughtongue bass, *Pronotogrammus martinicensis*, and the red barbier, *Hemanthias vivanus*. Stomach content analysis revealed that calanoid copepods, pelagic tunicates, pteropods, and invertebrate larvae dominate the diets of both species, and that these small planktivores serve as primary prey for many larger reef predators. To compare diets of reef fishes with pelagic prey availability and encounter rates, stationary plankton tows (0.5m diameter, 335m mesh conical nets) were made in the water column at near-surface (2m), midwater (35m) and near-reef (60-70m) depths. Preliminary results indicate high flow rates (3.7-24.5 cm/sec, mean=15.6cm/sec) and high prey availability (estimated at 1.5 million zooplankters per day per meter) in the vicinity of deep reef features. Estimates of the relative abundance of fishes indicate that 90 to 99% by number are small planktivores, and 65-90% of their diets are calanoid copepods, forming the main link from the benthos to water column productivity and the primary source of prey for the demersal reef fish community.

INTRODUCTION

Feeding habits, food web structure, and prey availability for reef fishes occurring along the Mississippi-Alabama outer continental shelf were surveyed. Trophic pathways are important for understanding the ecological framework in the reef fish community, including the role of resident reef fishes in the diet of large predatory fishes, predator-prey relationships among fishes and invertebrates, and the role of fishes in supplying nutrients to the benthic invertebrate community. Identification of trophic pathways can also identify functional links of organismal abundance to geological/ oceanographic processes and trophic links to off-reef benthic and pelagic communities. From a bioenergetic standpoint, dietary analysis and identification of prey consumption rates also can identify energy availability for growth and reproduction.

MATERIALS AND METHODS

Fishes were collected by hook-and-line angling during four research cruises along the Pinnacles Reef Tract of the Mississippi-Alabama Outer Continental Shelf from August 1997 to October 1998. During each cruise, a variety of artificial and natural baits were used to sample fishes over a wide range of body sizes, and specimens were placed on ice and frozen or immediately preserved in 10%

buffered formalin in the field. Fishes were dissected in the laboratory to remove gastrointestinal tracts, and stomach contents were removed for identification. Prey items were examined under a dissecting microscope and identified to the lowest possible taxon. Numerical abundance of prey was calculated to estimate relative importance of individual prey taxa in the diet of each species of reef fish. Diets of the common reef fishes were incorporated into a working food web model following the methods of Winemiller (1990) to identify the dominant trophic pathways in the deep reef fish community.

To identify prey availability for planktivorous reef fishes, stationary plankton samples were made using 0.5m diameter, 335m mesh opening-closing plankton nets equipped with mechanical flowmeters while the vessel was anchored over study reefs. Plankton samples were made at the surface (2m depth), midwater (35m depth), and near-reef (60-70m) to identify patterns in zooplankton densities throughout the water column, and availability of pelagic prey to the demersal fish community. Estimates of zooplankton availability to the deep reef community was estimated based on plankton densities, foraging range of planktivores, and length of day (feeding period).

RESULTS

Reef fishes of the deep reef community occupy a wide range of trophic pathways, and prey on a diverse array of planktonic and benthic organisms (Figure 1A.11). Calanoid copepods, gelatinous

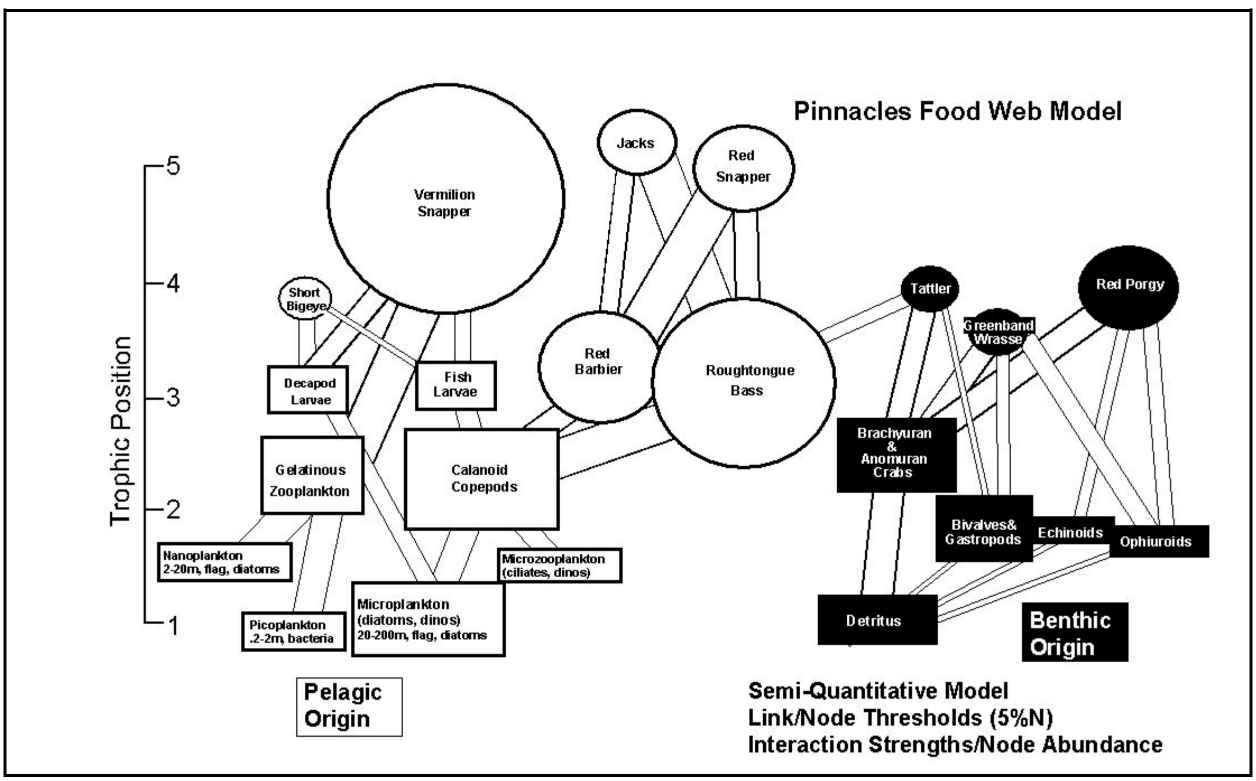

Figure 1A.11. Food Web model of the Pinnacles Reef Fish Community. Lower trophic groups follow Christensen (1995).

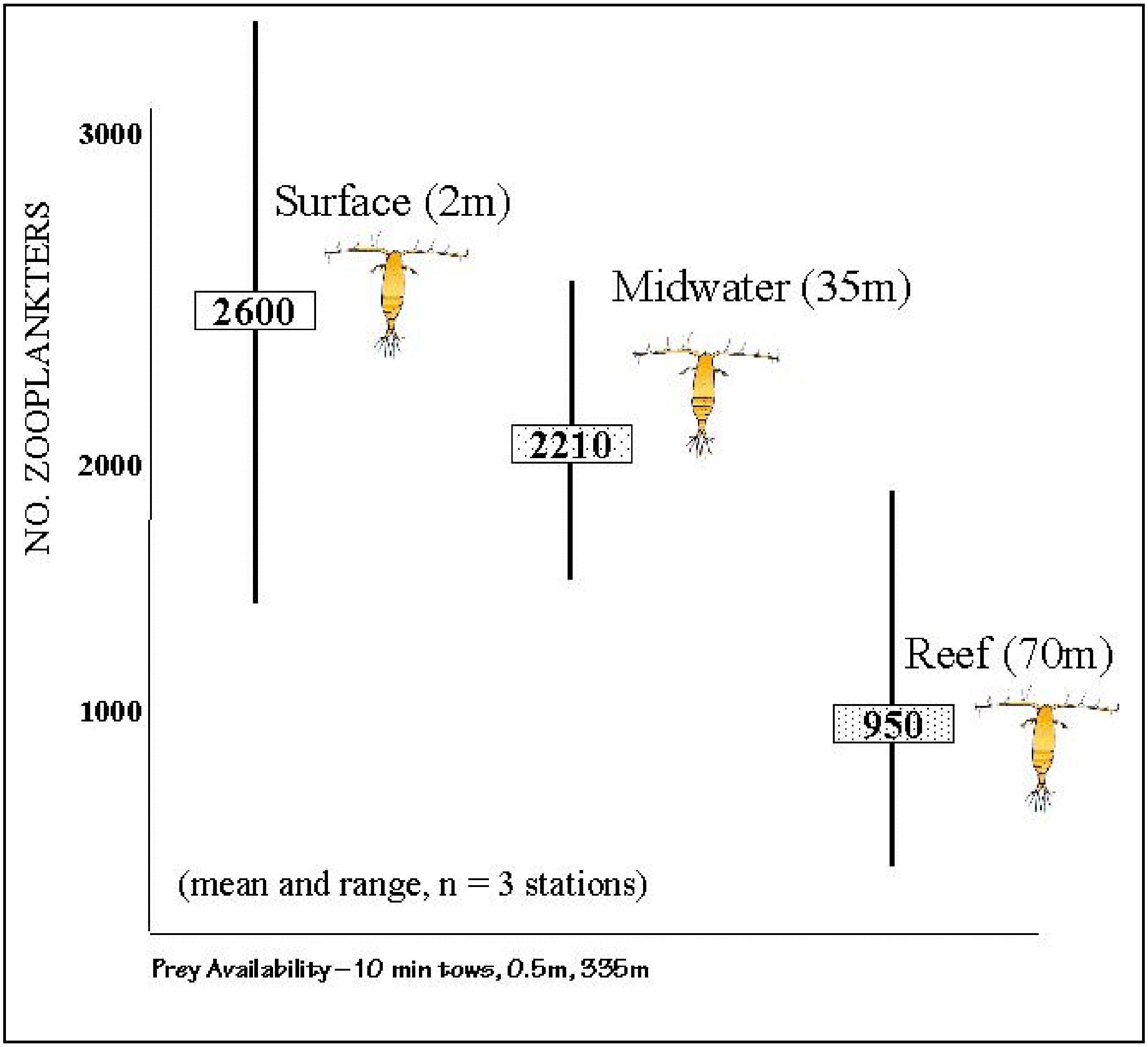

Figure 1A.12. Zooplankton abundance estimated at near surface (2m), midwater, and near-reef water depths during March 2000. Samples were collected using stationary, 0.5m diameter, 335µ mesh opening-closing plankton nets. Values given are number of zooplankters collected per 10-minute sample.

zooplankton and crustacean larvae dominate the diets of streamer basses, vermilion snapper, and short bigeye, respectively. Streamer basses are found in stomach contents of red snapper, jacks, tattler, and other carnivores. Benthic carnivores include red porgy, greenband wrasse, and tattler. These fishes prey on a variety of benthic invertebrates that are associated with soft-bottom sediments.

Estimates of zooplankton abundance and prey availability reveal a decline in zooplankton abundance from surface waters to near reef depths (Figures 1A.12 and 1A.13). Samples taken in March 2000 reveal an average of 2,600 zooplankters per 10-minute tow at 2m, 2,210 at 35m, and approximately

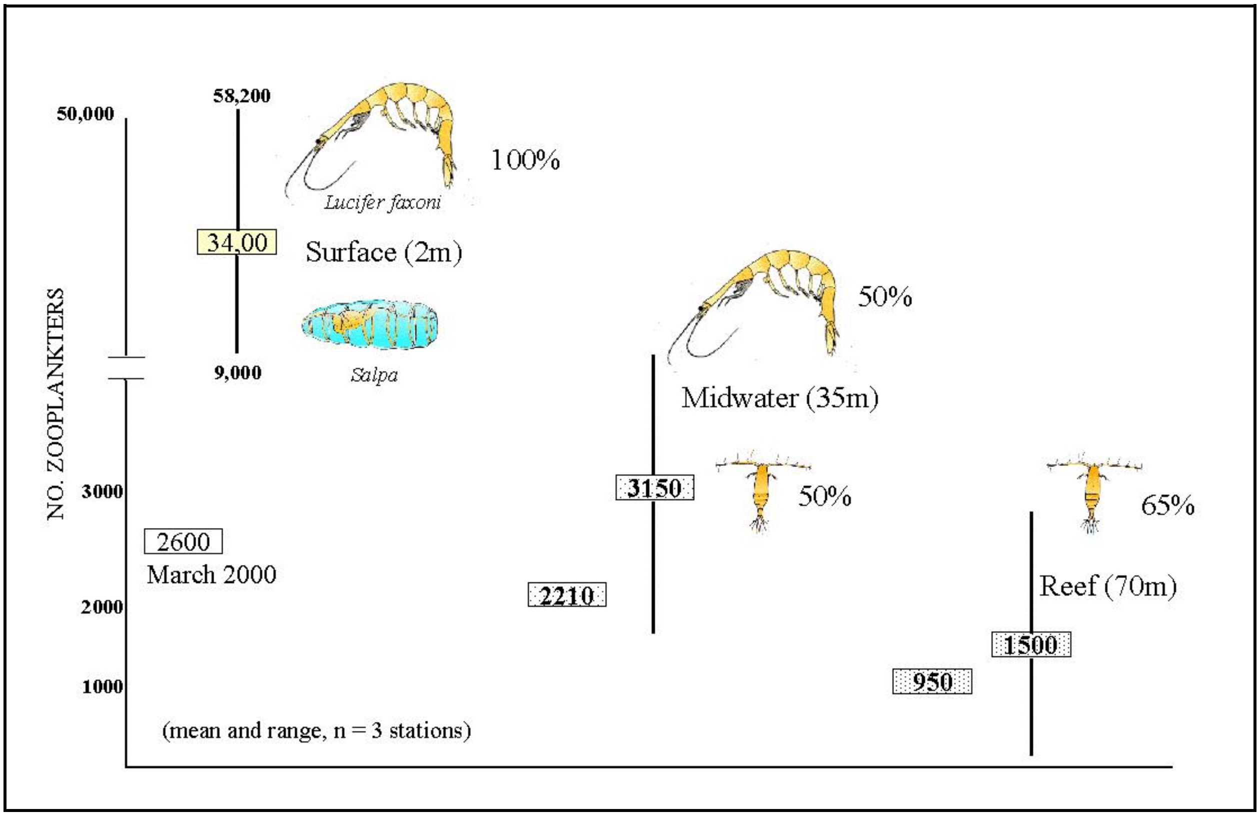

Figure 1A.13. Zooplankton abundance estimated at near surface (2m), midwater, and near-reef water depths during May/June 2000. Samples were collected using stationary, 0.5 m diameter, 335µ mesh opening-closing plankton nets. Values given are number of zooplankters collected per 10 minute sample.

950 zooplankters collected at near-reef water depths. Calanoid copepods dominated zooplankton samples at all depths during the March sampling period. Zooplankton abundance increased dramatically during May/June samples, ranging from 34,000 zooplankters at near surface waters per sample to 1,500 at near-reef water depths. Surface and midwater samples were dominated by the sergestid shrimp, *Acetes faxoni* or the pelagic tunicate *Salpa,* while near-reef samples were dominated by calanoid copepods. Measurements of current speed made during plankton tows ranged from near zero to 54 cm/sec, with a mean speed of 19.5cm/sec at 2m, 13.2 cm/sec at 35m and 15.6 cm/sec at near-reef depths. These values are similar to those reported by Kelly and Bender (2000).

Rough estimates of prey availability to the deep reef community were calculated based upon zooplankton densities present in the March 2000 samples, for conservative predictions of planktivore densities that could be sustained by incoming prey resources (Figure 1A.14). Initial estimates of 1,000 zooplankters per sample, collected during a 10-minute sampling period and with a net opening of .196 m^2 , equals approximately 5,000 zooplankters per meter square per 10 minutes. Using an estimate of a 10-hour feeding/daylight period and a 5m foraging range for demersal planktivores (based on observations made from ROV videotapes, and K. Rademacher, NMFS-Pascagoula pers. comm.), an estimated 1.5 million zooplankters would be available to planktivores along a one-meter wide swath in the water column that passes over the reef community.

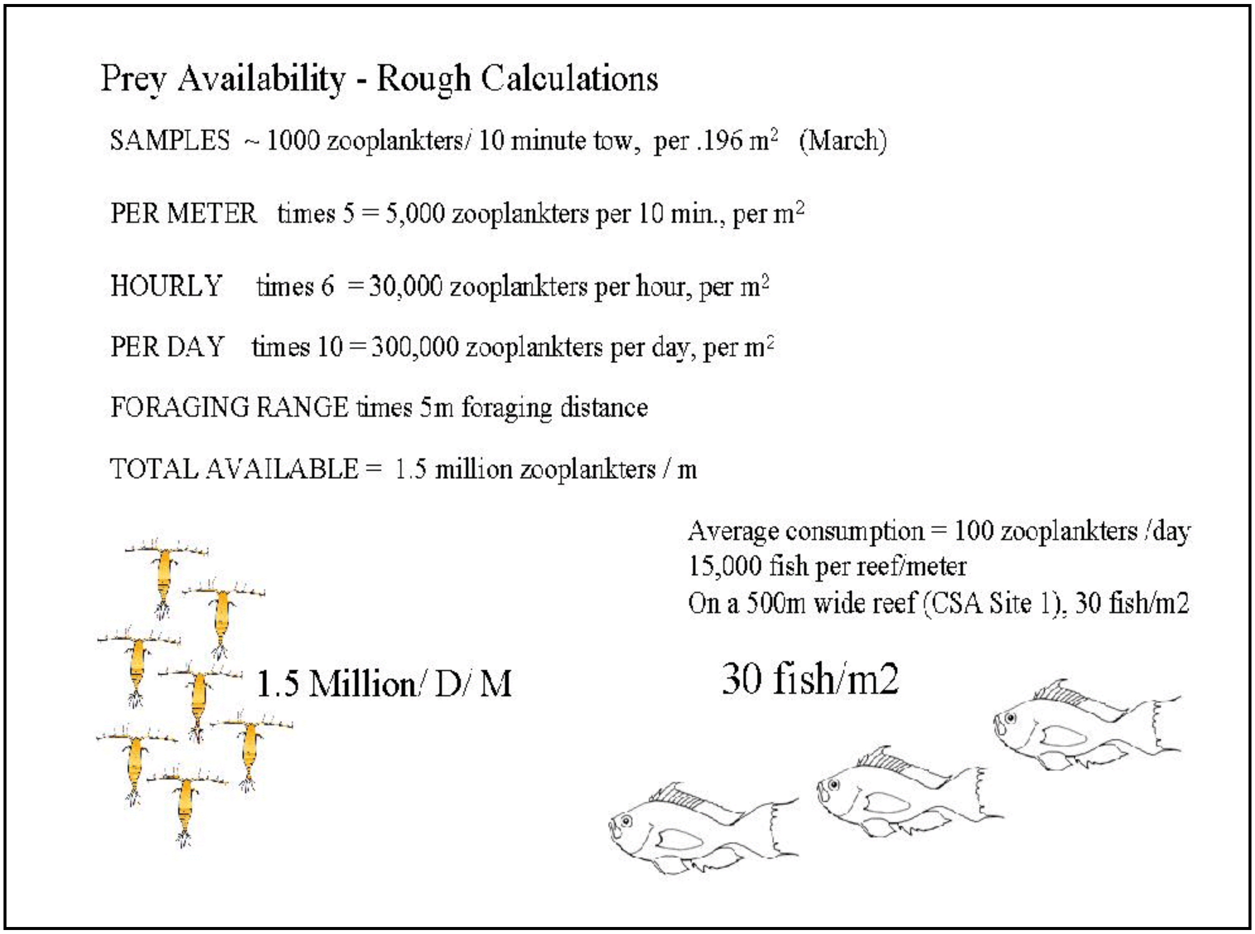

Figure 1A.14. Planktonic prey availability to deep reef zooplanktivores.

If each planktivore consumed an average of 100 zooplankters per day, zooplankton availability would enable approximately 15,000 planktivorous fish to occupy each meter-wide swath of reef habitat, based on water-column prey resources alone. On large flat-topped reefs that may reach a diameter of up to 500m, planktonic prey resources would support up to 30 individual planktivores per square meter, along a meter-wide transect across the reef. Estimates of availability of planktonic prey would be supplemented by emergent zooplankton that occur in sediments within or adjacent to the reef community (Porter and Porter 1977), including nocturnally-active zooplankton that would support nocturnal predators (such as short bigeye).

DISCUSSION

Direct feeding on pelagic plankton dominates the trophic pathways of the deep reef community, and estimates of zooplankton abundance indicate high prey availability for resident planktivorous reef fishes of the shelf-edge community at the Pinnacles Reef Tract. Estimates of number of planktonic prey availability to the deep reef community are higher than values given for shallow reef fishes at Davies Reef on the Great Barrier Reef (Approximately one million over a twelve-hour period, Hamner *et al.* 1988). Local oceanographic conditions in this region, including intrusion of fresh-water input from the Mississippi and other rivers to the outer shelf (Kelly and Bender 2000), may contribute to the high densities of planktonic prey occuring in this study.

ACKNOWLEDGMENTS

This study was funded by the Outer Continental Shelf Ecosystem Program of the U.S. Geological Survey- Biological Resources Division, K. Sulak, Principal Investigator.

REFERENCES

Christensen, V. 1995. A model of trophic interactions in the North Sea in 1981, the Year of the Stomach. Dana 11(1):1-28

Kelley, F. J. and L. C. Bender. 2000. Chapter 6: Physical Oceanography/Hydrography. *In* Continental Shelf Associates and Texas A&M University. Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem monitoring, Mississippi/Alabama shelf; Final Synthesis Report. U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division and Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA.

Hamner, W. M., M. S. Jones, J. H. Carleton, I. R. Hauri and D. McB. Williams. 1988. Zooplankton, planktivorous fish, and water currents on a windward reef face: Great Barrier Reef, Australia. Bulletin of Marine Science 42(3):459-479.

Porter, J. W. and K. G. Porter. 1977. Quantitative sampling of demersal plankton migrating from different coral reef substrates. Limnology and Oceanography 22(3):553-556.

Winemiller, K. O. 1991. Spatial and temporal variation in tropical fish trophic networks. Ecological Monographs 60(3):331-367.

SESSION 1B

AIR QUALITY

Chair: Dr. Chester Huang, Minerals Management Service
Co-Chair: Ms. Terry Scholten, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Observation of the Atmospheric Boundary Layer in the Western and Central Gulf of Mexico	Mr. Gary S. Zeigler URS Corporation (Radian International LLC)
Boundary Layer Study in the Western and Central Gulf of Mexico	Dr. Paul T. Roberts Mr. Clinton P. MacDonald Mr. Timothy S. Dye Sonoma Technology, Inc. Dr. Steven R. Hanna AMS Certified Consulting Meteorologist
IMPROVE: The Visibility Monitoring Network	Ms. Kristi Morris U.S. Fish and Wildlife Service
Development of Gridded Source Emissions Inventories (Mobile and Stationary)for OCS-Related Activities in the Gulf of Mexico in 1977 and 1988	Mr. Lyle Chinkin Ms. Dana Coe Sonoma Technology, Inc. Dr. Mark Yocke ENVIRON International Corp. Mr. David Scalfano Northlake Engineers, Inc.

OBSERVATION OF THE ATMOSPHERIC BOUNDARY LAYER IN THE WESTERN AND CENTRAL GULF OF MEXICO

Mr. Gary S. Zeigler
URS Corporation
(Radian International LLC)

This meteorological measurements project was initiated by MMS in late 1997. A planned three-year data collection period began as of 3 June 1998 and has run continuously since that date. This paper briefly summarizes project implementation actions and provides the status of the data collection effort as of the end of fiscal year 2000.

PROJECT OBJECTIVES

For the Gulf of Mexico (GOM), data sets from automated weather stations and observational satellites poorly represent how temperature, winds, and mixing heights vary vertically over the atmospheric boundary layer and free troposphere. Because data from these sources do not accurately or precisely measure a range of altitudes, empirical constants and relationships are used to approximate vertical variations in boundary layer properties. For instance, MMS applies estimated winds, temperature, and mixing heights in several ways when assessing changes in air quality from oil and gas production. The MMS assessments use conceptual models of pollutant transport through the marine boundary layer and theoretical analysis on the marine boundary layer. The MMS, therefore, has interest in collecting actual field measurement of the vertical structure of the marine boundary layer because such observations would reduce uncertainties in environmental assessments.

To help address the need for meteorological measurements in the GOM, the MMS initiated the "Observation of the Atmospheric Boundary Layer in the Western and Central Gulf of Mexico" project with the following objectives:

- Accurately collect, record, and report meteorological observations for three years.

- Collect surface data measurements, which include air and sea surface temperatures, pressure, wind, and humidity. Collect upper air data to include temperature and wind profiles.

- Perform quality control checks on the data and strive for a data capture rate of 90% or higher.

PROJECT IMPLEMENTATION

Management

The project is carried out by personnel from Radian International LLC ("Radian") and Sonoma Technology Inc ("STI") under the direction of the MMS staff. Radian is responsible for program management and the installation and operation of the equipment. STI is responsible for the data collection, processing and archiving tasks. Radian and STI share the quality assurance and quality control functions.

Measurement Equipment

Upper air wind and virtual temperature profiles are measured by a LAP®-3000 boundary layer wind profiler at each site. Standard surface meteorological sensors are mounted on a small tower at each site: anemometer, wind vane, air pressure sensor, and relative humidity sensor. In addition, an infrared sea surface temperature sensor is installed at each site.

Measurement Sites

Two oil platforms were selected as measurement sites in the GOM, one in relatively shallow water, approximately 30km off-shore, and the other in relatively deep water, approximately 130km off-shore.

- Shallow Water Site: Vermillion 22D at 29.4^{o}N, 92.5^{o}W, owned by ERT.
- Deep Water Site: South Marsh Island 160A at 28.1^{o}N/91.9^{o}W, owned by Newfield Exploration.

Measurement Configurations

All data are reported as hourly averages referenced to central standard time (CST). The radar profiler uses 5 minutes of each hour in the virtual temperature measurement mode and the remaining 55 minutes of each hour in the wind measurement mode. The profiler measures winds from about 130 to 4,900 meters above antenna level, and virtual temperatures to about 1,300 meters above antenna level. The surface meteorological sensors are mounted on the small tower at platform level.

Data Communications

Surface meteorological data are collected at each site on a Campbell Scientific data logger and are transferred hourly from there to the radar profiler's "Gateway" Computer. Also on an hourly basis, the Gateway Computer collects upper air wind and temperature data from the site's Radar Computer, builds a consolidated, compressed data packet, and sends it to the site's Synergetics GOES Data Collection Platform (GOES DCP). At times authorized by NOAA, the GOES DCP transmits the surface and upper air data packet each hour. Each data packet is then relayed by the GOES satellite to the NESDIS facility in Wallops Island, VA, where STI accesses it hourly via an internet connection. After quality checks, the processed data are sent to MMS in monthly increments. Separately, NOAA's Forecast System Laboratory can access the hourly data directly from NESDIS. A telephone modem installed at each site provides a backup means for site status checks and data retrieval.

Data Collection Period

After receipt of GOES transmit time allocations from NOAA, the project's planned three year data collection period began on 3 June 1998.

PROJECT FISCAL YEAR 2000 ACTIVITIES

Data Collection Completed

As of the end of FY00 on 30 September 2000, the project had successfully completed 28 consecutive months of the planned 36-month data collection period, with data collection and reporting operations continuing in progress. Overall data capture rate for the project as of the end of FY00 was 91%. For the FY00 portion of the project, the data capture rate was slightly lower at 87%. Data losses during FY00 were due to a variety of equipment and communications issues that were addressed during site visits and by remote telephone access.

Site Visits

Three site visits were completed during FY00, as summarized below:

- 12-17 January 2000, Unscheduled Visit. On 1 January 2000, the radar profiler at each site ceased collecting data. All other data flow from both sites continued normally via GOES. Trouble-shooting efforts by phone with operator personnel at both platforms failed to identify the cause of the problem or to successfully restore radar operations. However, separate from this project, it was determined that deployed radar profilers on other (non-MMS) projects were experiencing similar interrupts due to a configuration problem causing the installed Global Positioning System (GPS) clock updates to be giving the radar profiler computers the wrong year (i.e., 1900 instead of 2000). Troubleshooting on the other projects identified the specific cause of the GPS problem. Platform visits were subsequently performed in January 2000, during which system configuration changes were implemented that restored normal data collection by both radar profilers and transmission of the data via GOES. Equipment audits were also performed at both sites during these site visits.

- 24-26 March 2000, Unscheduled Visit. On 26 February 2000, the Vermillion 22D site stopped transmitting meteorological data. Attempts to resolve the situation remotely were not successful, thus requiring an unscheduled maintenance visit. During this trip, a failed power supply in the charger for the data logger was discovered to be the cause. The power supply was replaced, after which data transmissions successfully resumed on 24 March 2000. During this visit, a Y2K leap year software fix to the GOES transmission software was also installed at both the Vermillion 22D and the South Marsh Island 160A sites.

- 13-17 June 2000, Scheduled Visit. Semi-annual audits of all upper air and surface meteorological equipment were conducted during this scheduled visit to both sites. A Windows-95 operating system software fix was also installed at both sites to keep the data time stamps at Central Standard Time (CST) all year. At the start of Daylight Savings Time

(DST) in April 2000, the data time stamps changed from CST to DST, even though the Windows-95 software had been set to stay on CST. After some research, a problem fix was obtained from Microsoft and was successfully implemented at both sites.

Potential Site Relocation Problem

On 11 February 2000, Newfield Exploration announced their tentative planning to soon begin drilling operations on their South Marsh Island 160A platform. They specified that the MMS project's measurement equipment would need to be removed before the new drilling could begin. In response, MMS authorized additional site survey work to identify other suitable platforms in the area for siting the measurement equipment in case it had to be moved from South Marsh Island 160A. The additional survey work was successfully completed and contingency relocation plans were formulated. Fortunately, on 20 May 2000, Newfield Exploration further announced that their drilling plans had been placed on hold and that the MMS project's measurement equipment could remain in place until further notice. This status continued throughout the remainder of 2000, and will, it is hoped, hold through the completion of the project's full data collection period.

SUMMARY OF PROJECT STATUS

The MMS project to collect a three-year database of surface and upper air meteorological measurements at two platform sites in the Gulf of Mexico continues in progress. Data collection began as of 3 June 1998. Since that time, all monthly data reports and annual project summary reports have been delivered to MMS on schedule. During FY00 operations, the data capture rate was somewhat below average at 87% due to an assortment of equipment and communications issues that were corrected as they arose. For the project-to-date period through the end of FY00, the data capture rate achieved was 91%, meeting the project's data capture rate objective of 90% or greater.

BOUNDARY LAYER STUDY IN THE WESTERN AND CENTRAL GULF OF MEXICO

Dr. Paul T. Roberts
Mr. Clinton P. MacDonald
Mr. Timothy S. Dye
Sonoma Technology, Inc.

Dr. Steven R. Hanna
AMS Certified Consulting Meteorologist

This four-year project began in late 1998. The Study Plan was approved in 1999 and technical work has begun. This talk presents a summary of the plan for the project, plus several examples of data analysis results. Further updates on the project will occur at future ITM meetings.

PROJECT OBJECTIVES

The purpose of this study is to provide the MMS with a description and analysis of the atmospheric boundary layer and to explain how its structure influences the dispersion and transport of pollutants in the western and central Gulf of Mexico (GOM). The results of this study will be used by the MMS to support techniques for evaluating the effects of oil and gas exploration, development, and production activities in the Outer Continental Shelf (OCS) on air quality over coastal areas. To complete this study, we will conduct a number of technical tasks including the following:

- Produce a data inventory for synthesizing the characteristics of the Atmospheric Boundary Layer (ABL) and its dispersion properties in the western and central GOM, based on 1998 to 2001 observations and modeling results.
- Evaluate annual, seasonal, and diurnal variations in the ABL's structure.
- Describe the processes governing variations in the ABL's structure.
- Evaluate transport and mixing characteristics that govern pollutant dispersion over diurnal and multi-day scales.
- Provide conceptual model summary of processes that influence the ABL's structure and variability and pollutant transport and dispersion.

KEY TECHNICAL ISSUES

There has always been great uncertainty concerning the vertical and horizontal variability of the atmospheric boundary layer in the GOM. For example, the depth of the boundary layer and its vertical stability and wind and turbulence structure can vary greatly in OCS zones due to horizontal variations in sea surface temperature and the overlying air mass. We are fortunate that the MMS now has available the following new boundary layer observations in the GOM–two meteorological stations collecting observations of the atmospheric boundary layer for three years (1998-2001) by using 915 MHz radar wind profilers (RWP), 2 KHz Radio Acoustic Sounding Systems (RASS), and surface meteorology units. The profilers measure winds and virtual temperatures between the surface and heights of a few kilometers, and the surface stations measure sea surface temperature as well as wind speed, wind direction, air temperature, and mixing ratio.

The two most important meteorological parameters for use in transport and dispersion models are wind velocity and vertical stability. These parameters are needed over the full depth of the overwater boundary layer (i.e., up to heights of 1 or 2 kilometers), to better account for variations in transport speed, transport direction, turbulent dispersion, and stability over the depth of the pollutant plume. Over travel times of several hours to a few days, or travel distances of several kilometers to a few hundred kilometers, such pollutant plumes can disperse upwards to the top of the boundary layer, can shear off in several directions, and can be subjected to layering during the transition and nighttime hours. The previous practice of using estimates of stability based on the difference between sea surface and air temperature, and single wind speed observations was often unsatisfactory.

The new data are being analyzed to investigate the following technical issues:

- The overwater surface energy balances are being studied using the near-surface observations for both steady-state horizontally-homogeneous conditions and for conditions variable in time and space. A climatology of latent heat versus sensible heat fluxes are being developed for both situations, and parameterizations will be developed for use in situations when only degraded data are available. Our research on this topic has greatly benefited from the results of the so-called Tropical Ocean-Global Atmosphere Coupled-Ocean Atmosphere Response Experiment (TOGA COARE). Many researchers participated in TOGA-COARE, which made use of the most advanced state-of-the-art instrumentation. A major output of TOGA-COARE is the COARE computer program, which allows surface fluxes over the ocean to be accurately parameterized using routine observations (Fairall *et al.* 1996). The basic structure is an outgrowth of the Liu-Katsaros-Businger (Liu *et al.* 1979) method, sometimes referred to as the LKB method. This program allows fundamental boundary layer scaling parameters such as the surface roughness length, z_o, the friction velocity, u*, the scaling temperature, T*, the scaling water vapor mixing ratio, q*, and the Monin-Obukhov length, L, to be estimated. From these parameters, the mixing depth, h, and the vertical profiles of wind speed, temperature, and water vapor mixing ratio can be estimated.

- Given the surface energy balance components, the vertical profiles of wind and temperature will be studied to develop climatologies and parameterizations. In particular, it is desirable to be able to estimate the full vertical profiles of wind and temperature based only on near-surface measurements of air-water temperature differences and wind speeds.

- The extensive vertical temperature profiles are being studied to estimate the mixing depths and to prepare empirical formulas to parameterize these observations.

- The frequency of occurrence of very stable conditions near the surface and in layers aloft are being investigated due to the importance of these layers for defining worst-case conditions for the dispersion of air pollutants.

- The horizontal spatial variability of wind speed and direction are being studied to identify the fraction of time that wind directions and speeds persist over several hours in the Gulf of Mexico, thus causing direct straight-line transport of pollutants toward receptors on the shoreline.

- Estimates of the scaling velocity (u*) and scaling temperature (T*) derived from the observational data are being made using the COARE algorithm. Since turbulent velocities (important to dispersion) are directly proportional to u*, it should be possible to derive improved parameterizations for the dispersion coefficients s_y and s_z. Perhaps the single most important technical issue for understanding over-water air quality dispersion is the ability to properly assess the mixing depth. Mixing height, z_I, or the height of the surface inversion, h, can be estimated from either the radar profiler refractive index structure parameter (C_n^2); RASS virtual temperature data from MMS profiler stations combined with surface temperature; or other upper-air data sources on land that are augmented by profiles included in observed Eta fields, and buoyancy flux as described in Hsu 1997.

- Radar profiler mixing depth estimates have been demonstrated to relate well to other fundamental mixing depth estimation techniques using rawinsonde temperature profiles and aircraft data. Estimating hourly mixing depths from profiler data is relatively straightforward. Using a technique developed by STI, we will estimate mixing depths from the profiler's reflectivity measurements and RASS's virtual temperature profiles. The refractive index structure parameter (C_n^2) is computed from the profiler's reflectivity measurements. Maximum values of C_n^2 have been theoretically and observationally linked to the top of the mixed layer. RASS virtual temperature profiles coupled with surface virtual temperature measurements can estimate the height of the mixed layer by using stability analysis (Parcel Method).

ESTIMATION OF FLUXES AND OTHER ABL PARAMETERS PRELIMINARY

This section describes the implementation of the TOGA COARE algorithm, which uses observational data to develop boundary layer parameters that characterize the Atmospheric Boundary Layer (ABL). The results of this work will be used to characterize the ABL, evaluate annual, seasonal, and diurnal variations in ABL structure, and describe processes that influence ABL structure and variations. The overall objective of this work is to provide the MMS with a description and analysis of the atmospheric boundary layer in the western and central GOM.

The COARE algorithm is designed to estimate surface fluxes and scaling parameters over the deep ocean in tropical regions. The COARE algorithm requires wind speed, air temperature, and relative humidity (RH) within the surface layer; sea surface skin temperature (T_s) or sea temperature near the surface; and mixing height. We used a mixing height of 600 m. If the near-surface sea temperature is used, then solar and downwelling longwave irradiance data are required to correct this temperature to a skin temperature. Precipitation data is not required, but if available, COARE will estimate the precipitation contribution to the latent heat. Site time and position data are required.

- Data collected at offshore buoys and at the VRM and SMI platforms meet the COARE data requirements.

- CMAN stations monitored all the required data, but these sites are not located in deep water. The COARE algorithm is not tuned to handle the sea-state at shallow-water sites such as CMAN stations. However, based on discussions with Scientific Review Board members and Chris Fairall from NOAA, we concluded that the error produced by inaccurate representation of the sea-state was acceptable for transport and dispersion analysis; therefore, data from CMAN stations were used in the analysis.

- The offshore buoy sites did not have skin temperature measurements or solar and downwelling longwave irradiance data; thus, we were unable accurately to correct the .5 m underwater temperature to skin temperature. Because the temperature corrections from near surface temperature to skin temperature are typically within tenths of a degree Celsius, Chris Fairall, a COARE algorithm author, suggested that in the absence of radiation information, it would probably be safe to assume that the .5 m temperature equals skin temperature. We could estimate radiation fluxes from cloud and sun elevation information but felt that the errors from these estimates could be larger than the errors from assuming that the underwater temperature equals the T_s. By not correcting the underwater temperature for the warm layer effect, we underestimate T_s when the sun is out and the wind is light and, therefore, we underestimate both the sensible and latent heat fluxes. However, under sunny and light wind conditions the evaporative cool skin effect is also greatest and should somewhat offset the warm layer effect. Also note that the T_s measured by the radiometer may be slightly cooler than the skin temperature away from the platforms due to turbulence in the water created by wave and currents moving around the platforms.

Based upon the data requirements, we obtained and processed 1998 and 1999 offshore buoy data from seven sites, CMAN station data from five sites, and data collected on the VRM and SMI platforms. Figure 1B.1 shows the locations of the offshore buoys, the CMAN stations, and the platforms. Of the seven offshore sites and five CMAN sites only Offshore Buoy sites 42035 and 42040 and CMAN site GDIL had complete enough data to estimate the boundary layer parameters that characterize the ABL.

COARE OUTPUT

Using the hourly meteorological data from sites 42035, 42040, GDIL1, SMI, and VRM we calculated hourly sensible heat flux, latent heat flux, surface stress, frictional velocity, temperature, and relative humidity scaling parameters, z_r/L, and roughness length. These data are contained in a working MS Access database. Note that the averages derived from buoy and CMAN stations are for January to December of 1998 and that the averages derived from the platforms are from June of 1998 to June of 1999. Further work will include expanding this data set to include 1999 and 2000 data as the data become available.

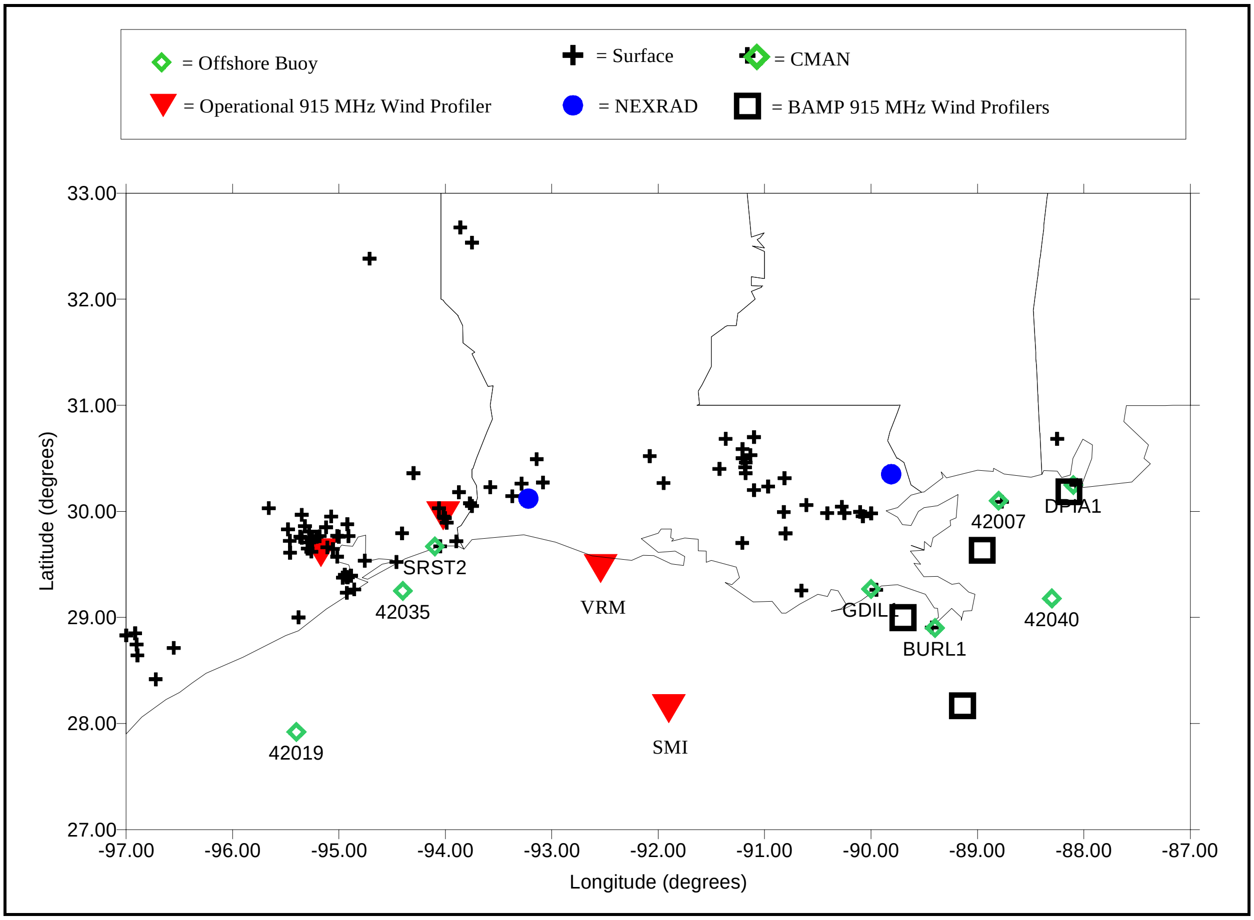

Figure 1B.1. Meteorological Stations in the MMS Gulf of Mexico Study domain.

We calculated monthly and hourly averages by month for selected parameters at each site. For the z_r /L stability parameter we calculated the median instead of the average because L approaches zero under neutral conditions resulting in infinite z_r/L. Case study time series of selected meteorological and derived ABL parameters were also created. Monthly averages were not computed if more than 80% of the data in a given month were missing.

RESULTS FROM MONTHLY PLOTS

- The fluxes and scalar parameters calculated by the COARE algorithm seem physically consistent with our conceptual expectations and were similar to results from TOGA. Sensible heat flux of 10 w/m^2 is typical of other non-Gulf over-water sites. Sensible heat flux at most sites are about 5 to 30 w/m^2. In November and December 1998 the sensible heat fluxes were 40 to 55 w/m^2, respectively. Latent heat fluxes of 50 to 100 w/m^2 is typical of other over-water sites and similar values were calculated for the Gulf sites.

- The sensible heat flux at VRM, SMI, and 42040 were generally within a factor of 2 of one another. In August and September 1998 the sensible heat fluxes at these sites were within 20% of one another. There are slightly higher sensible heat fluxes in winter, possibly due to warm water and cold air, with the reverse in late spring and early summer. This agrees with annual variation of T_s.

- The greatest monthly average sensible heat flux of about 55 w/m^2 occurred at VRM in December 1998, and the flux was nearly double the typical monthly average. The high average sensible heat flux at VRM in December was a result of a skin temperature minus theta difference of 5 degrees Celsius, about double the typical monthly average. It seems as if the air temperature in December is erroneous.

- Discarding GDIL1, there is a factor of 2 or less variability among the three sites. February and March have very good agreement. The magnitudes roughly follow the T_s (and hence q_{sat}) annual trend, with higher values in late summer, and lower values in late winter, although the variation is not strong.

- Sensible heat fluxes were about 1/5 of the latent heat fluxes and were generally greatest in the winter and early spring at all sites with the exception of GDIL1, which had no distinct yearly cycle.

- The monthly average latent heat fluxes are generally greater in the summer and fall months. This is due to higher air temperatures at those times. The latent heat fluxes range from about 40 w/m2 in January at VRM to about 190 W/m^2 at GDIL1 in September. The shallow-water site of GDIL1 generally had the greatest latent heat flux of all the sites during the spring and summer months and it also had the highest water temperature of all the sites during these months.

- The total heat flux is in good agreement (within a factor of 2) between sites. Magnitude generally follows T_s annual variation, since latent heat flux is larger than sensible heat flux.

- Frictional velocity, u*, is in great agreement among sites and well within a factor of 2 and often 20%. This is important because u* is the key scaling velocity for estimating transport speeds and dispersion rates. u* is slightly less from May through August and peaks in September, probably due to hurricanes.

- Temperature scaling, T*, is in good agreement among sites other than GDIL1. T* tends to be smaller in April and May when T_s is still cool and the air is warming up due to changing seasons.

- The humidity scaling parameter, q*, is in good agreement among sites and is within a factor of 2 between sites. It is highest in late summer, when T_s and hence q_{sat} are highest.

- Air temperatures are in good agreement among sites. The temperatures are warmest in July and August and coolest in the winter. The December temperature at VRM appears to be erroneously low by about 5 degrees Celsius. This possible error needs to be investigated.

- Sea surface temperatures are in good agreement among sites. The temperatures are warmest in July and August and coolest in the winter. The December temperature at VRM appears to be erroneously low by about 5 degrees Celsius. This possible error needs to be investigated.

- T_s minus theta temperature differences are on the order of +1 to +3 degrees Celsius at most sites all year. There are larger temperature differences at buoy 42040 and VRM in November and December, respectively. We suspect that there might be a problem with the data during November and December at these two sites and will investigate.

- Surface wind speed, U, shows good agreement among sites. The lowest speeds occur in July and August and the highest in September and October. Review of weather maps indicates that the high wind speeds in September are a result of tropical storms and the high wind speeds in October are a result of strong continental winds or Bermuda Highs.

- RH is in good agreement among sites and is around 80 percent during all months.

RESULTS FOR MIXING HEIGHTS

We derived hourly mixing heights and inversion heights, respectively, using the VRM and SMI RASS virtual temperature data coupled with the platform surface data for May through November 1998. The platform temperature was used instead of the sea surface temperature because the platform temperature likely better represents the temperature of the parcel. The RASS-derived mixing heights and inversion heights are stored in an MS Access database. Review of the data indicates that the mixed layer was convective 98% of the time. From this point forward we use the term “mixing height” to imply both the mixing heights and the inversion height. Mixing heights using C_n^2 data or buoyancy flux methods are not complete.

Preliminary mixing height observations include:

- Ninety-eight percent of the time the surface temperature was warmer than the aloft temperature and, therefore, the height of the mixed layer was estimated using stability analysis. This means that only 2% of the time, the reported mixing height is actually the inversion height capping a stable layer. Under this stable layer condition, the reported inversion height is likely a gross overestimate of the actual mixing height. However, because these conditions occurred infrequently during the study period, they do not strongly influence the monthly average diurnal profiles.

- The average mixing heights at VRM and SRI show similar diurnal profiles, and the profiles for each month were similar at the two sites. The highest mixing heights occur in July and August at both sites and the lowest mixing heights occur in November. In July, the nighttime mixing heights are about 600 m at both sites and increase to about 900 m during the midday hours before decreasing to about 600 m by evening. In November, the mixing heights at VRM are about 200 to 300 m all day. At SMI the mixing heights in November range from 200 m at night to about 400 m during the day. Note that the lowest observable mixing height is 140 m for SMI and 160 m for VRM; the actual mixing heights could, at times, be lower than 140 m or 160 m.

- The standard deviation of hourly mixing heights by month is large, ranging from about 50 m on November nights to about 400 m on August days.

- The standard deviation at SMI has a diurnal profile similar to the mixing heights with high standard deviations during the day and low standard deviations at night. The standard deviation at VRM has no obvious diurnal cycle.

CONCEPTUAL MODEL DEVELOPMENT

We will develop a conceptual model of ABL characteristics and variability (as part of Task 3) and of pollutant transport and dispersion (as part of Task 4) in the offshore and coastal environment of the western and central Gulf of Mexico. The conceptual model will describe and illustrate the major meteorological phenomena that control the ABL structure and variability (Task 3) and that control pollutant transport and dispersion (Task 4). The purpose of developing a conceptual model is to summarize the current state of knowledge, to provide a basis for testing and evaluating specific hypotheses, to focus continuing analysis efforts on the most important issues, and to identify those processes which must be represented in models.

Figure 1B.2 shows a schedule for the project.

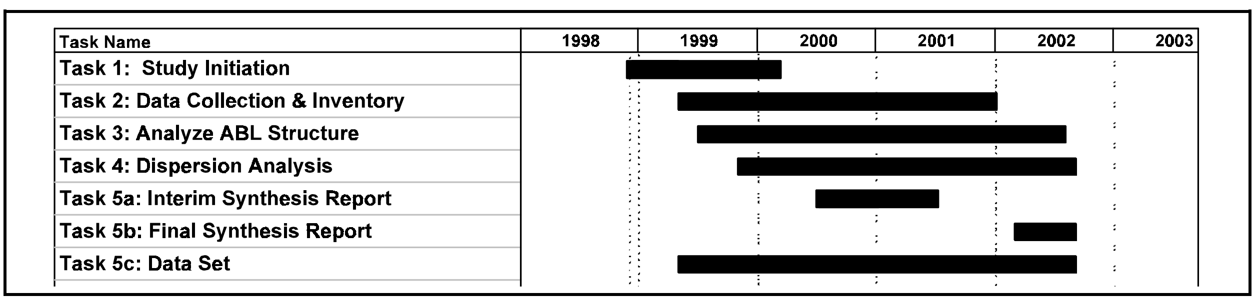

Figure 1B.2. Project schedule, 1998 – 2003.

Dr. Paul T. Roberts, STI Vice President, designs and manages air quality field, data management, and data analysis projects. Most of these projects have involved the use of field data and analysis methods to understand important meteorological and air quality phenomena, and to develop, apply, and evaluate meteorological and photochemical models. Specific projects during which boundary-layer processes over water and shoreline environments were important components include the MMS-sponsored Gulf of Mexico Air Quality Study (southeast Texas and Louisiana and offshore), the Southern California Air Quality Study (SCAQS) and several subsequent data analysis efforts in and around the South Coast Air Basin (SoCAB), the Lake Michigan Ozone Study, and the NARSTO-Northeast Air Quality Study (covering Virginia to Maine, including offshore).

Mr. Clinton P. MacDonald, a Senior Meteorological Analysis at STI, has performed meteorological and air quality data analyses in coastal and inland environments throughout the U.S. He has made extensive use of radar wind profiler and RASS virtual temperature upper-air meteorological data to understand the phenomena occurring in the atmospheric boundary layer. Mr. MacDonald has developed and implemented several computer software tools to process and interpret upper-air and surface meteorological data.

Mr. Timothy S. Dye, STI's Manager of Meteorological Programs, has operated, quality-controlled, and analyzed radar wind profiler wind and temperature data for over 11 years. Mr. Dye has extensively used these upper-air data to conduct analyses of pollutant formation, transport, and dispersion. He developed algorithms to estimate mixing height from radar profiler reflectivity and temperature data and has used this technique to understand marine and overland boundary layer structure and evolution in such programs as the Lake Michigan Ozone Study, the Gulf of Mexico Air Quality Study, and the NARSTO-Northeast Air Quality Study. Mr. Dye is co-author of the new EPA guidelines for collecting, quality controlling, and managing the upper-air data from radar profiler/RASS, sodar, and rawinsonde systems and has designed several methods for conducting Level 2 data validation of upper-air data.

Dr. Steven R. Hanna is a specialist in atmospheric turbulence and dispersion, in the analysis of meteorological and aerometric data, and in the development, evaluation, and application of air quality models. He is an AMS Certified Consulting Meteorologist with over 30 years of experience. He has led several research and development projects involving, for example, the statistical evaluations of hazardous gas dispersion models and regional ozone models; the development of models for the dispersion of emissions from tall power plant stacks and from offshore oil platforms; and the analysis of data from large regional field experiments in the Santa Barbara area, in the Lake Michigan region, in the Gulf of Mexico, and in the northeastern United States. He led the development of the OCD Model. From 1988-1997, Dr. Hanna was Chief Editor of the *Journal of Applied Meteorology*, and has published over 100 articles in peer-reviewed journals, six chapters in books, and four books in which he is the primary author.

IMPROVE: THE VISIBILITY MONITORING NETWORK

Ms. Kristi Morris
U.S. Fish and Wildlife Service

The 1999 Regional Haze Rule requires monitoring representative of each of the 156 visibility protected federal Class I areas (CIAs), beginning in January 2000 to track progress toward the national visibility goal. The deciview index calculated from ambient particle chemical speciation data was selected to track haze levels. This tracking entails particle sampling and analysis of the major aerosol components using methods patterned after those utilized since 1987 by the IMPROVE Network and consistent with the aerosol monitoring portion of the 1999 Visibility Monitoring Guidance document issued by EPA.

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program is a cooperative measurement effort designed

(1) to establish current visibility and aerosol conditions in mandatory CIAs;

(2) to identify chemical species and emission sources responsible for existing man-made visibility impairment;

(3) to document long-term trends for assessing progress towards the national visibility goal; and

(4) with the enactment of the Regional Haze Rule, to provide regional haze monitoring representing all visibility-protected federal CIAs where practical.

The program is managed by the IMPROVE Steering Committee that consists of representatives from the U.S. Environmental Protection Agency (EPA), the four Federal Land Managers (FLMs-National Park Service, Forest Service, Fish and Wildlife Service, and Bureau of Land Management), the National Oceanic and Atmospheric Administration, four organizations representing state air quality organizations (State and Territorial Air Pollution Program Administrators/Association of Local Air Pollution Control Officials, Western States Air Resources Council, Northeast States for Coordinated Air Use Management, and Mid-Atlantic Regional Air Management Association), and an Associate Member, the State of Arizona Department of Environmental Quality.

In 1999, the IMPROVE Network consisted of 30 monitoring sites in CIAs, 20 of which began operation in 1987 with the others starting in the early 1990s. Each monitoring site includes PM2.5 sampling on a twice per week schedule with subsequent analysis for the fine particle mass and major aerosol species as well as PM10 sampling and mass analysis. Many of the sites also include optical monitoring with a nephelometer or a transmissometer, and color photography to document scenic appearance. In addition, approximately 40 sites, most in remote areas, that use the same instrumentation and monitoring and analysis protocols (called IMPROVE Protocol sites) were operated individually by federal or state organizations in recent years.

Beginning in 1998, EPA provided supplemental support to IMPROVE to expand the network to provide representative particle speciation monitoring that would be needed for the then anticipated Regional Haze Rule for all of the visibility-protected CIAs where it was practical. With the exception of ~10 sites, all IMPROVE and Protocol sites have been installed. The remaining sites will be installed in the near future. In making the decision to support the expansion of the IMPROVE Network, EPA also considered the value of the PM2.5 mass and speciation data in remote areas for use by states in their implementation of the PM2.5 regulation. Provisions were made in those regulations so that states could elect to use IMPROVE monitoring data to meet their requirements for regional background and transport monitoring sites.

EPA requested IMPROVE change some aspects of its monitoring protocol to increase the comparability of the monitoring to that required of states at their PM2.5 compliance and speciation monitoring sites. The IMPROVE Steering Committee agreed to change the twice-weekly sampling schedule to the national every third day sampling, to add routinely operated collocated instruments at 10% of the sites to generate quality assurance data, and to provide all of the monitoring data to the Aerometric Information Retrieval System (AIRS) database. To accommodate these changes, a new version of the IMPROVE sampler was developed that provides for more flexible sample schedule control and continuous monitoring of sample flow and temperature, while maintaining the same sample collection characteristics of the original version of the sampler.

The IMPROVE sampler was designed for the IMPROVE Network and has been operated extensively in the network and during field studies since the winter of 1987. The IMPROVE sampler consists of four independent modules. Each module incorporates a separate inlet, filter pack, and pump assembly; however, all modules are controlled by a singular timing mechanism. It is convenient to consider a particular module, its associated filter, and the parameters measured from the filter as a channel of measurement (i.e., module A). Modules A, B, and C are equipped with a 2.5 μm cyclone. The module A Teflon filter is analyzed for fine mass (PM2.5) gravimetrically, nearly all elements with atomic mass number =11 (which is Na) and =82 (which is Pb) by proton induced x-ray emission (PIXE) and by x-ray florescence (XRF), elemental hydrogen by proton elastic scattering analysis (PESA), and for light absorption.

Fine aerosol concentrations are highest in the eastern United States (in the Appalachian Mountains, Mid-South, Mid-Atlantic, and Washington, D.C. regions). Concentrations are also relatively high in the Southern California region. The lowest concentrations occur in the Great Basin in Nevada, the Colorado Plateau in the Four Corners states, Wyoming, and Alaska.

The largest single component of the fine aerosol in the East is sulfate at 60-65% of the mass; in the Pacific Northwest it is organics; and in southern California it is nitrates. In general, the largest mass fractions of the fine aerosol are sulfates, organics and soil/dust. Of the 21 regions in the IMPROVE Network, carbon (organic plus light-absorbing carbon) is the largest single component in ten regions, primarily in the West. Sulfate is the largest single component of fine aerosol in ten regions, primarily in the East, and nitrates are slightly greater than carbon in the Southern California region.

The light-extinction coefficient *(bext)* is calculated from the measured aerosol species' concentrations by multiplying the concentration of a given species by its light-extinction efficiency and summing over all species. Since sulfates and nitrates are assumed to be hygroscopic, their light-extinction efficiencies increase with relative humidity; therefore, extinction efficiencies for soluble species must be adjusted according to average relative humidity at each site.

To show the effect on visibility of aerosol extinction, the deciview (dv) scale is applied to the total (Rayleigh included) reconstructed aerosol extinction. By utilizing the dv scale, the effect of light extinction on visibility is portrayed in a way that is approximately linear with respect to perceived visual air quality. Because higher extinction coefficients lead to higher dv numbers, the geographic trends in visibility follow the trends in reconstructed extinction. Pristine or Rayleigh conditions correspond to a dv of zero.

Deciview and reconstructed light extinction varies throughout the United States in a way analogous to fine aerosol concentrations. The greatest light extinction occurs in the eastern United States and in southern California, while the least light extinction occurs in the relatively nonurban west and in Alaska. However, because relative humidity (and therefore the light-scattering efficiency of sulfate and nitrate) is higher in the East than in the West, the difference between eastern and western light extinction is even more pronounced than the difference in aerosol concentrations.

The smallest dv value or best visibility is reported at Denali National Park with 7 dv. A broad region, which includes the Great Basin, most of the Colorado Plateau, and portions of the Central Rockies, has visibility impairment of less than 10 dv. Moving in any direction from this region generally results in increasing dv values. The highest annual dv values, greater than or equal to 26 dv, occurring in the eastern United States in the general region of the Ohio River and Tennessee Valleys.

The summer months have the highest fine mass loadings at 19 of the 20 monitoring regions. With few exceptions, sulfate, organic carbon, and light-absorbing carbon components of fine mass are highest in summer as well. In the Pacific Coastal Mountains region, fine mass concentrations are nearly the same in the summer and autumn seasons, while the West Texas fine mass loadings are nearly the same in spring and summer. In the Northern Rocky Mountains region, fine mass loadings are greatest during the autumn season primarily because of increased organic mass concentration. East of the Mississippi sulfates make up about 60-70% of the fine mass in all seasons, while in much of the inner-mountain west, fine mass concentrations are somewhat evenly split between sulfates, carbon, and soil/dust mass concentrations.

The goal of the Regional Haze Rule is to remedy existing and prevent any future man-made impairment in the 156 mandatory class I areas. The Rule requires visibility to improve on the 20% haziest days and to ensure that no degradation will occur on the 20% clearest days. Five Regional Planning Organizations (RPOs) have formed across the U.S. to ensure state compliance with the Regional Haze Rule. These organizations will use IMPROVE data to determine current conditions and the slope of the glide path necessary to achieve natural conditions in 60 years. State and Tribal Implementation Plans are due in 2003 or 2008.

For more information on the IMPROVE Network and data analysis, the IMPROVE web site (*http://yampa.cira.colostate.edu/improve*) was made available to the public in January 2001.

DEVELOPMENT OF GRIDDED SOURCE EMISSIONS INVENTORIES (MOBILE AND STATIONARY)FOR OCS-RELATED ACTIVITIES IN THE GULF OF MEXICO IN 1977 AND 1988

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This report summarizes the approach to and results of the development of gridded emissions inventories for mobile and stationary sources operating in the Outer Continental Shelf (OCS) areas of the Gulf of Mexico (GOM). The subjects of this study were only those sources related to oil and gas exploration and production activities in the OCS and included:

- crew and supply boats,
- pipeline laying ships,
- research and exploration vessels,
- crew and supply helicopters,
- drilling ships/rigs, and
- platforms

The data sources and methods for estimating emissions from the source categories were somewhat different. Therefore, we present a section discussing the methodologies and results for each source category. First, we discuss issues common to more than one category.

GENERAL ISSUES

Emissions totals for the entire GOM OCS have been prepared by source category for each pollutant species for 1977 and 1988 (Table 1B.1). In addition, emissions were spatially allocated to a 45 (west to east) by 26 (south to north) grid, as shown in the attached figures. Grid squares are roughly 20 km by 20 km; the grid origin (southwest corner) is located at coordinates 26 degrees North latitude and 97.2 degrees East longitude.

We used ARC/INFO (a common GIS software package) to digitize this grid and then "intersect" the grid cells with the geographical locations of active OCS platforms. This was done to facilitate the allocation of estimated emissions from some source categories where the number of active platforms in each grid served as the spatial surrogate.

Table 1B.1. Total Gulf of Mexico emissions by source.

	1977 Annual Total Emissions (kg)							
	THC	VOC	CO	NOx	SOx	TSP	PM10	PM2.5
Helicopters	541	487	6893	24130	3334	3315	1833	1293
Crew & Supply Boats	128947	128947	1355115	12073949	2185342	300237	300237	276218
Exploration Ships	16603	16603	161539	1240136	572835	30981	30981	28502
Drill Ships	23089	23089	290017	3660733	1643671	90349	90349	83121
Pipe Laying Ships	10303	10303	100238	769528	355455	19224	19224	17686
TOTAL	179483	179429	1913803	17768475	4760638	444107	442625	406821

	1988 Annual Total Emissions (kg)							
	THC	VOC	CO	NOx	SOx	TSP	PM10	PM2.5
Helicopters	966	870	12316	43113	5956	5923	3276	2310
Crew & Supply Boats	230390	230390	2421180	21572492	3904545	536433	536433	493519
Exploration Ships	16603	16603	161539	1240136	572835	30981	30981	28502
Drill Ships	41616	41616	513400	6480364	2909687	159939	159939	147144
Pipe Laying Ships	12522	12522	121837	935343	432047	23366	23366	21497
TOTAL	302098	302001	3230272	30271446	7825072	756643	753996	692973

Because some of the spatial data used provide vessel operations by lease tract, we also needed to identify in which tract(s) each grid cell lies. This was done by manually intersecting the boundaries of the lease tracts in the GOM OCS against grid square boundaries. Thus, each grid cell was assigned wholly or partially to one or more tracts.

The 1993 MMS Offshore Activity Data Bases (MOADS) contains data pertaining to the numbers, activities, fuel consumption, and engine sizes of platforms, crew and supply boats and helicopters. These data provide 1993 emissions totals, which serve as basis for back-casting and gridding of emissions for some of these sources categories. In addition, MMS recently published a series of data CDs entitled “50 Year Anniversary Offshore Oil and Gas CD Collection.” Data from this 4-CD set, and additional data downloaded from MMS Internet Website, were used to estimate the numbers of active platforms, production levels, and drilling and pipe-laying activities and locations in 1977 and 1988. The ship vessel registration and characteristics data maintained by the US Coast Guard (USCG) were accessed and used to characterize the size and propulsion units on research vessels. A private data source (Offshore Data Services [ODS]) provided historical information about pipe-laying and drill ship activities. For each mobile source category, specific emission factors were obtained from the USEPA databases (AP42 and/or NONROAD) for THC, CO, NO_x, SO_x, and TSP.

VOC factors were expressed as fractions of THC emissions, and PM10 and PM2.5 factors were expressed as fractions of TSP emissions.

The inventory for stationary sources is not complete, and no results are available at this time. The following section focuses on the methodology being used in the stationary source emissions while the last section reports the preliminary results of the mobile source categories.

STATIONARY SOURCES

Production Platforms

Activity Data Source: Several methods of activity data sources were explored before the one described below was chosen.

First, MMS historical records were reviewed in the Information Technology Department (ITD) to determine if records of actual platform equipment and/or fuel consumption were available. This included review of inspectors' records and safe charts. Data on actual equipment, etc. from 1977 and 1988 were not available in the MMS records. Archived safe charts were not retained; only current, up-to-date versions were on file. Inspectors' reports from 1977 and 1988 did not include equipment lists.

Second, we contacted some oil companies to determine whether records from 1977 and 1988 were available. Most did not have access to record documents that would describe equipment or activity from 1977 and 1988. A couple of companies did provide a list of equipment from 1988 or schematics from 1977 on three to five platforms, but without certain data—such a horsepower ratings— it was difficult to calculate estimated emissions. Also, such a small representation of those platforms from 1977 and 1988, if extrapolated on the basis of production, could introduce larger discrepancies in the final database.

Finally, it was decided to use the 1993 MOADS database of emissions as related to production rates. Production rates from 1977, 1988, and 1992/3 are readily available from the MMS. Once determined, these emissions/production rates would be applied production rates and platform locations as per records from MMS from 1977 and 1988.

Gas reported vented or flared in 1993 MOADS database will be used to establish a ratio of gas vented / flared vs. production rates. MMS records from 1977 and 1988 for gas vented and/or flared is available from OGAR B reports. These reports do not differentiate between venting and flaring. Once the gas vented/flared rate vs. production from 1977 and 1988 is established, then the appropriate emissions can be adjusted to represent the variation in venting/flaring in 1993 to 1977 and 1988.

For construction activities, i.e. platform installations, the list of platforms installed in 1977 and 1988 is available from the MMS. At these locations, a estimate of installation time, derrick barge spread and fuel consumed and emissions generated will be added to this platform location.

Emissions Factors: By default, i. e. using the 1993 MOADS emissions as related to production rates, the emission factors used in the 1993 MOADS database will be the same used in the 1977 and 1988 emissions. These factors were predominately AP-42 for the following sources:

1. Crude and Diesel Storage Tanks,
2. Natural Gas and Diesel Reciprocating Internal Combustion Engines,
3. Line/Process Heaters,
4 Turbines,
5. Flares and Vents,
6. Fugitives,
7. Gas Sweetening, and
8. Gas Dehydration.

A complete description of the emission factors is available in MMS report 95-0040 Gulf of Mexico Air Quality Study, Final Report.

Emissions Calculations: The emission calculations are going to be a direct reflection of those in the 1993 MOADS database except for a slight modifications for changes in flaring and venting and platform installation activities.

Once the venting and flaring rates vs. production rate from 1993 is determined, then the combined vent/ flare rate vs. production rates for 1977 and 1988 will be determined. The portion of emissions due to venting and flaring in 1993 will then be adjusted up or down depending on the comparison from 1993, 1977, and 1988.

The emissions for each platform installation will be calculated using a kg/hp-hr emission factor and the assumed hp and duration.

PM10 and PM2.5 were estimated from TSP using the fractions 1.0 and 0.92, which were taken from the EPA NONROAD SPECIATE database version 1.5 profile # 32202—Heavy duty diesel. Due to lack of data, it was assumed that VOC emissions are approximately equal to THC. This assumption seems reasonable because heavy-duty diesel engines emit little methane or ethane.

Drill Rigs

Activity Data Source: Drill rigs differ from drill ships (see below) in that drill rigs are allocated to a production platform and not to an exploratory well. Drill rigs could be jack-up, platform, or tender type rigs. We obtained borehole data from the MMS Website. These data contained detailed information about the locations and time of installation of boreholes for both 1977 and 1988. To determine the duration of the drilling for each borehole, the “spud date” was assumed to indicate the start of drilling, and the “total depth date” the final day. Continuous operation was assumed between these two dates. The effective drill period was assumed to be the duration between the spud and total depth dates or 10 days, whichever was longer. Only drilling that occurred within the calendar year for each year was considered (if drilling lasted from December 1988 to January 1989, only December was counted).

Emissions Factors: Drill ship emission factors were obtained from Table 5-1 of *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA, February 2000, (http://www.epa.gov/otaq/models/nonrdmdl/c-marine/r00002.pdf). The equation published therein for calculating PM, NO_x, CO, and HC emissions factors is:

Emissions Rate (g/kW-hr) = a (Fractional Load)^(-x) + b

The equation for SO2 is:

Emissions Rate (g/kW-hr) = a (Fuel Sulfur Flow in g/kW-hr) + b

The equation given for fuel consumption is::

Fuel Consumption (g/kW-hr) = 14.12/(Fractional Load) + 205.717

However, since we didn't have fractional load data, we used an average drill rig fuel usage rate of 2,256 gallons/day, which was published in a April 1995 letter from the Offshore Operators Committee to Chris Oynes of the MMS.

Marine diesel fuel sulfur levels were obtained from Table 4 of *In-Use Marine Diesel Fuel* (for EPA by ICF, August 1999 [*http://www.epa.gov/otaq/regs/nonroad/marine/ci/fr/dfuelrpt.pdf*] as 0.91 % by weight for DMB [the predominant marine fuel for large engine vessels]. The mass of emissions per mass of fuel consumed emission factors were converted to kg emissions/ gal fuel using a fuel density of 2.6kg/gal.

Emission factors were estimated at 100% load.

Emissions Calculations: Emissions were calculated for each drill rig reported in the MMS borehole database for 1977 and 1988. Platform coordinates were used to allocate emissions to the appropriate location. Since only a small fraction of the rig time is spent in transit and most borehole locations in these years were near the coastline, we allocate all emissions to the platforms containing the borehole (i.e., we did not account for emissions associated with travel to-and-from the borehole locations).

MOBILE SOURCES

Crew and Supply Helicopters

Activity Data Source: There are approximately thirteen OCS helicopter operating companies represented in the 1993 MOADS. 1993 helicopter activity levels, areas of operations, as well as emissions estimates were derived from this data base..

Emissions Factors: Helicopter emission factors used are from AP-42, Table II-1-8. We selected emissions factors representative of turbine engines in the helicopter fleet operating in the GOM OCS region.

Emissions were estimated for all phases of operation since these helicopters most often operate within the convective marine mixing layer. Since landings/takeoffs (LTOs) comprise a very small portion of the total hours of operation and no LTO data are available, they are ignored in this analysis. Furthermore, since helicopters utilize a relatively constant amount of power for all phases of operation, a single emission factor was used for all flight modes. Thus, emissions were estimated as the product of the emission factor and the total hours of flight.

The AP-42 emissions factors, which are expressed in kg of emissions per kg of fuel consumed (kg/kg fuel), were converted into kg/gal fuel units by assuming a jet fuel density factor of 2.6 kg/gal.

Emissions Calculations: 1988 and 1977 helicopter emissions were estimated by assuming that OCS-wide emissions were proportional to the number of platforms operating in those years compared to 1993. The total OCS emissions were then spatially allocated by assuming that emissions in each cell were proportional to the number of operating platforms in that cell.

PM2.5 and PM10 were estimated from TSP by applying mass fractions of 0.390 and 0.553 taken from the NONROAD SPECIATE database version 1.5 (profile #34001 - Jet Aircraft). VOC was estimated as 90% of THC. Based upon the SPECIATE database (Version 3.0, profile 1098 - Aircraft Landing/Takeoff (LTO) - Commercial), it was assumed that methane and ethane comprise about 10% of total hydrocarbons.

Crew and Supply Boats

Activity Data Source: The MOADS data contains 1993 annual usage data in hours and rated horsepower for the crew and supply boats by engine type.

Emissions Factors: The crew and supply boat emission factors were derived based on information given in Table 5-1 of *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA, February 2000, *http://www.epa.gov/otaq/models/nonrdmdl/c-marine/r00002.pdf*). This reference presents the following equation for calculating PM, NO_x, CO, and HC emissions factors:

Emissions Rate (g/kW-hr) = a (Fractional Load)^(-x) + b

The equation for SO2 is:

Emissions Rate (g/kW-hr) = a (Fuel Sulfur Flow in g/kW-hr) + b

The equation for fuel consumption is:

Fuel Consumption (g/kW-hr) = 14.12/(Fractional Load) + 205.717

Marine diesel fuel sulfur level was obtained from Table 4 of *In-Use Marine Diesel Fuel* (for EPA by ICF, August 1999, (http://www.epa.gov/otaq/regs/nonroad/marine/ci/fr/dfuelrpt.pdf) as 0.36 % by weight for DMA, the predominant marine fuel for medium- and small-engine vessels.

Emission factors were estimated at 70% load, based upon Table 5-2 in the reference above, and expressed as mass per horsepower-hour (hp-hr).

Emissions Calculations: The 1977 and 1988 total emissions were estimated by scaling the 1993 emissions by the ratio of platforms operating in 1977 and 1988 to those operating in 1993, respectively. The total emissions were increased by a factor of 1.56 to account for the fact that only 64% of the crew and supply boat operators responded to the 1993 MOADS activity survey. The spatial allocation procedures used were the same as for crew and supply helicopters, with each cell receiving the amount of emissions proportional to the number of platforms present.

PM10 and PM2.5 were estimated from TSP using the fractions 1.0 and 0.92, which were obtained from the NONROAD SPECIATE database version 1.5 profile # 32202—Heavy duty diesel. For lack of specific data, it was assumed that VOC emissions are approximately equal to THC. This assumption seems reasonable in the case of heavy-duty diesel engines since they emit little methane or ethane.

Drill Ships

Activity Data Source: We obtained borehole data from the MMS Website. These data contained detailed information about the locations and time of installation of exploratory boreholes for both 1977 and 1988. To determine the duration of the drilling for each borehole, the "spud date" was assumed to indicate the start of drilling, and the "total depth date" the final day. Continuous operation was assumed between these two dates. The effective drill period was assumed to be the duration between the spud and total depth dates or 10 days, whichever was longer. Only drilling that occurred within the calendar year for each year was considered (if drilling lasted from December 1988 to January 1989, only December was counted.

Emissions Factors: Drill ship emission factors were obtained from Table 5-1 of *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data* (EPA, February 2000, (*http://www.epa.gov/otaq/models/nonrdmdl/c-marine/r00002.pdf*). The equation published therein for calculating PM, NO_x, CO, and HC emissions factors is:

Emissions Rate (g/kW-hr) = a (Fractional Load)^(-x) + b

The equation for SO2 is:

Emissions Rate (g/kW-hr) = a (Fuel Sulfur Flow in g/kW-hr) + b

The equation given for fuel consumption is::

Fuel Consumption (g/kW-hr) = 14.12/(Fractional Load) + 205.717

However, since we did not have fractional load data, we used an average drill ship fuel usage rate of 2,256 gallons/day, which was published in a April 1995 letter from the Offshore Operators Committee to Chris Oynes of the MMS.

Marine diesel fuel sulfur levels were obtained from Table 4 of *In-Use Marine Diesel Fuel* (for EPA by ICF, August 1999 [http://www.epa.gov/otaq/regs/nonroad/marine/ci/fr/dfuelrpt.pdf] as 0.91 % by weight for DMB [the predominant marine fuel for large engine vessels]. The mass of emissions per mass of fuel consumed emission factors were converted to kg emissions/ gal fuel using a fuel density of 2.6kg/gal.

Emission factors were estimated at 100% load.

Emissions Calculations: Emissions were calculated for each drill ship voyage reported in the MMS borehole database for 1977 and 1988. Borehole coordinates were used to allocate emissions to the appropriate grid cell. Since only a small fraction of the vessel time is spent in transit and most borehole locations in these years were near the coastline, we allocate all emissions to the cells containing the borehole (i.e., we did not account for emissions associated with travel to-and-from the borehole locations).

Exploration Vessels

Activity Data Source: The activities of exploration vessels were estimated using 1988 MMS exploration and research permit data. 1977 permit data were not available, so we assumed the levels and locations of exploration vessel activities in 1977 to be the same as 1988.

The MMS data were arranged by individual ship voyage with a specified time frame and the area of exploration. We obtained USCG vessel registration data and vessel-specifications for the vessel lists in the MMS permit archives. If the rated horsepower of a ship's engines was not available in this USCG database, horsepower was estimated using a correlation between boat length and horsepower developed from the available data points. If boat length was also unavailable, an average value of 3,000hp was used.

The MMS permit data specified those lease block(s) in which a specific research/exploration vessel was to operate. We assigned emissions from each voyage uniformly to all grid cells contained within the listed lease block(s). The records that did not have a block assigned or had inconsistent data were examined and treated on a case-by-case basis. For example, in the case of voyages that involved a single ship without an assigned block, emissions were spread over the entire OCS. When a voyage date for a specific ship overlapped significantly those of a second voyage of the same ship, the second record was ignored to avoid double-counting. It was also necessary to correct obvious inconsistencies or errors in the ship registry numbers.

The number of operating days was estimated and allocated based upon the permit dates and blocks. Although in some cases the 1988 permits allowed exploration into 1989, the numbers of operating days were estimated using 31 December 1988 as a cutoff. It was determined through discussions with operators that the permit periods are often much longer than the actual voyages. Based on these discussions, the number of operating days per permit was assumed to be two weeks or the total permit period, whichever was smaller.

Emission Factors: Exploration vessel emission factors were calculated in the same manner as for crew and supply boats. However, the load factor used was 60% (based on discussions with operators), and SO_2 emissions were estimated assuming 0.91% fuel sulfur content, which is the average for DMB, the most common distillate fuel for large-engine ocean-going vessels according to *In-Use Marine Diesel Fuel* (EPA, Aug 1999).

Emissions Calculations: Horsepower ratings were determined by matching either the ship's name or registry number to the available USCG vessel information data. Registry number was used first and if that did not produce a match, then the name was used. If these two did not produce a match, then the average of 3,000hp was used -- this occurred in the cases of only four voyage permit records.

PM10 and PM2.5 were estimated from TSP using the fractions 1.0 and 0.92, which were obtained from the EPA NONROAD SPECIATE database version 1.5 profile # 32202—Heavy duty diesel. Due to lack of data, it was assumed that VOC emissions are approximately equal to THC. This assumption seems reasonable because heavy-duty diesel engines emit little methane or ethane.

Estimated exploration vessel emissions for each voyage were uniformly allocated to those grid cells within the lease tracts listed in each permit. If there were multiple tracts in any single permit record, each tract was assumed to have received an equal portion of the emissions, without regard to the size of the tract. Permit records that covered the entire Gulf had their associated emissions spread evenly across the entire OCS grid.

Pipe-Laying Ships

Activity Data Source: We obtained information about pipelines installed in the GOM in 1977 and 1988 from Offshore Data Services (ODS). These data included information about the area (tract) into which the pipe was installed, pipe diameter, and pipeline length. In 1988, a few of the pipelines started and terminated in different tracts. These cases were examined individually. If the dominant length of the pipeline extended in one tract, then that tract was assigned the whole length of the pipe. If the distance in each tract was roughly equal, the pipe length was divided between the tracts.

The ODS database also included some information on "days-to-complete," which was assumed to be equal to the duration of pipe-laying activities in each case. However, this information was missing from many records. Using data from the records that were complete, two statistical regression analyses were performed using Excel, one relating pipe length to installation duration, and the second relating both pipe length and diameter to installation duration. Although the regression using both pipe length and diameter had fewer complete records, it produced a stronger regression coefficient. Thus, the second regression was used to estimate the duration of pipe installations cases with missing completion time records.

All pipeline installations were assumed to have been performed using ships with 3,000 hp engines at 60% load.

Emission Factors: The emission factors for pipe ships were derived in the same manner as for exploration vessels, using 0.91% sulfur content.

Emissions Calculations: The emissions for each installation were calculated using a kg/hp-hr emission factor and the assumed hp and duration.

PM10 and PM2.5 were estimated from TSP using the fractions 1.0 and 0.92, which were taken from the EPA NONROAD SPECIATE database version 1.5 profile # 32202—Heavy duty diesel. Due to lack of data, it was assumed that VOC emissions are approximately equal to THC. This assumption seems reasonable because heavy-duty diesel engines emit little methane or ethane.

Spatial allocation of estimated emissions from pipe-laying ships began by totaling the emissions in each tract. Then, we assumed that pipelines generally extend from one facility or platform to another. Thus, the emissions total for each tract was allocated to each grid cell in proportion to the number of active platforms in the cell.

RESULTS

Table 1B.1 summarizes the emissions totals by pollutant species and by source type for 1977 and 1988. Crew and supply boats clearly are the largest contributors to emissions totals in both years. Since all of the mobile sources are internal combustion engines, NO_x, CO, and SO_x are the species with the largest emissions. Consistent with the expansion of exploration and production levels, estimated emissions in 1988 were roughly 70% larger that those calculated for 1977.

The figures in Table 1B.1show the gridded distribution of estimated emissions totals by pollutant species in 1977 and 1988. The spatial emissions patterns reflect the geographical distributions of active platforms in those years. Also shown are the distributions of NO_x emissions by mobile source type for 1977 and 1988. [NO_x was selected because it has the largest estimated emission totals of all species.]

SESSION 1C

GAS HYDRATES IN THE GULF OF MEXICO

Chair: Dr. Mary Boatman, Minerals Management Service
Co-Chair: Mr. Jesse Hunt, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Gas Hydrates in a Complex Geologic Province—Northern Gulf of Mexico Continental Slope	Dr. Harry H. Roberts Coastal Studies Institute Louisiana State University
Application of High-Resolution Seismology to Issues Related to Gas Hydrates in the Gulf of Mexico – Document not submitted –	Dr. Joe Gettrust Naval Research Laboratory, Stennis
Monitoring the Physical and Chemical Conditions Affecting the Hydrocarbon System Within the Hydrate Stability Zone of the Northern Gulf of Mexico	Dr. J. Robert Woolsey, Director The Center for Marine Resources and Environmental Technology The University of Mississippi
Gas hydrates in the Gulf of Mexico: A Geochemical Perspective	Dr. Roger Sassen Geochemical and Environmental Research Group Texas A&M University

GAS HYDRATES IN A COMPLEX GEOLOGIC PROVINCE— NORTHERN GULF OF MEXICO CONTINENTAL SLOPE

Dr. Harry H. Roberts
Coastal Studies Institute
Louisiana State University

The northern Gulf of Mexico (GOM) slope province exhibits complex structural relationships resulting from dynamic adjustments between sediments and salt. Numerous faulted pathways exist for deep subsurface fluids and gases to be transported to the modern seafloor. Seafloor response to these hydrocarbon-rich fluids and gases is highly variable and dependent largely on rate and duration of delivery as well as fluid and gas composition. Rapid expulsions of fluids (including fluidized sediment) and gases generally result in buildups of sediment in the form of cones (mud volcanoes) that vary from a few meters to several kilometers in diameter and/or sheet-like flows that may extend tens of kilometers downslope. Slow seepage promotes lithification of the seafloor through precipitation of a variety of mineral species. Microbial utilization of hydrocarbons encourages the precipitation of ^{13}C-depleted Ca-Mg carbonates as by-products. These carbonates have $\delta\ ^{13}C$ values that are light (to –55 % PDB). The ^{13}C-depleted carbonates form mounds and hardgrounds that occur over the full depth range of the slope. Mounds have relief of up to 30 m, but mounds of 5-10 m relief are most common at sites thus far investigated. Carbonates comprising the mounds are mixed mineral phases of aragonite, Mg-calcite, and dolomite with Mg-calcite being the most common. Other products like barite are precipitated from mineral-rich fluids that arrive at the seafloor in low-to-moderate seep rate settings. However, barite precipitation is not as pervasive as that of ^{13}C-depleted carbonates. Intermediate flux settings are best described as areas where gas hydrates occur at the seafloor or in the very shallow subsurface. This environment displays considerable variability with regard to surficial geology and on a local scale have elements of both rapid and slow flux settings. Intermediate flux environments appear to have the unique set of conditions necessary to support and sustain densely populated communities of chemosynthetic organisms. Most of these areas are associated with faulting at the edges of intraslope basins. At these sites, surficial or shallow subsurface gas hydrates (accessible by piston coring) are oriented along these faults and not in broad areas characterized by distinct bottom simulating reflectors (BSRs) as is the case in many simpler geologic settings. Shallow gas hydrates are composed of a complex mixture of biogenic-thermogenic methane and other thermogenic gases. *In situ* experiments have shown that slight variations in near-bottom water temperature resulting from a variety of natural oceanographic processes cause gas hydrate dissociation and out-gassing resulting in the degradation to disappearance of surficial gas hydrate mounds.

INTRODUCTION

Much of what we know about the geology of the northern Gulf continental slope comes from data collected in search of hydrocarbons. The northern Gulf slope is the most mature deep-water oil and gas province in the world. With 3D-seismic and higher resolution acoustic data sets used for geohazards assessment, a new vision of the slope seafloor is being established. Even though these data sets are exceptionally revealing regarding the seafloor and probable processes impacting it, they typically cover small areas. These high resolution data sets are site specific and usually separated by considerable distances. Therefore, the wide variety of bottom features and their links to formative processes have been difficult to determine. However, multibeam bathymetry and 3D-seismic have provided a detailed and yet regional view of the slope surface. These two data types have emphasized the complex surface geology. Mapping surface amplitude anomalies from 3D-seismic data (Roberts *et al.* 1992a; Roberts 1996; Hill 1996) has helped identify fluid and gas expulsion features. Coupled with polarity analysis of the surface reflector, these methodologies can identify hard-bottom from soft-bottom areas as well as areas charged with gas. Calibrated to "ground-truth" data provided by piston cores and direct observation and sampling using manned submersibles, it is now clear that fluid and gas expulsion is an important process affecting both seafloor geology and biology across the entire depth range of the northern and northwestern GOM continental slope. Although most calibration data have been acquired from the upper slope (< 1000 m water depth), 3D-seismic amplitude data, piston cores, and a few ROV and manned submersible observations confirm the importance of fluid and gas expulsion processes to the base of the slope at water depths of about 2500 m.

On the flanks of intraslope basins, complex faulting and associated salt masses focus the flux of subsurface fluids and gases to the modern seafloor resulting in a variety of response features generally superimposed on dome-like regional features supported by underlying salt. Such complex areas are regionally distinct on the multibeam bathymetry image of Figure 1C.1 from smooth-bottom areas representative of the intraslope basins. The small-scale geologic features that mantel salt-supported domes and other salt-associated areas of the seafloor are partly the products of fluid and gas expulsion. These intraslope basins formed within large salt masses that were emplaced during the Oligocene and Miocene (Diegel *et al.* 1995). Later, Cenozoic deposition of large volumes of siliciclastic sediments mobilized allochthonous salt masses out of the shelf minibasin and detachment provinces into the tabular salt and minibasin province (Prather *et al.* 1998). Subsequent loading of the salt has formed the complex array of basins and basin-flanking features that shape today's slope surface (Figure 1C.1).

This paper organizes data on surficial geology, and to a lesser extent biology, related to the flux of fluids and gases to the modern surface of the slope. Even though quantification of flux rate has been an elusive target, the present database qualitatively suggests a strong relationship between flux rate and seafloor response. The objective is to explore a qualitative framework for understanding the links between flux-related processes and geologic-biologic responses at the slope surface. Special emphasis is placed on gas hydrates and authigenic carbonate mounds.

FLUID AND GAS EXPULSION FEATURE SPECTRUM

Although a quantitative relationship between fluid–gas expulsion and geologic-biologic response has yet to be derived, it is clear that qualitatively geologic-biologic response is not only dependent on fluid and gas type but largely on flux rate and frequency of delivery events (Roberts and Carney 1997), Figure 1C.2. Data on the frequency, composition, and impacts of expulsion events are essentially nonexistent for the slope. However, repeated observations of expulsion sites on the upper continental slope of the northern Gulf support the short-term episodic nature of fluid-gas venting and seepage at a scale still not predicted by numerical simulations of the process.

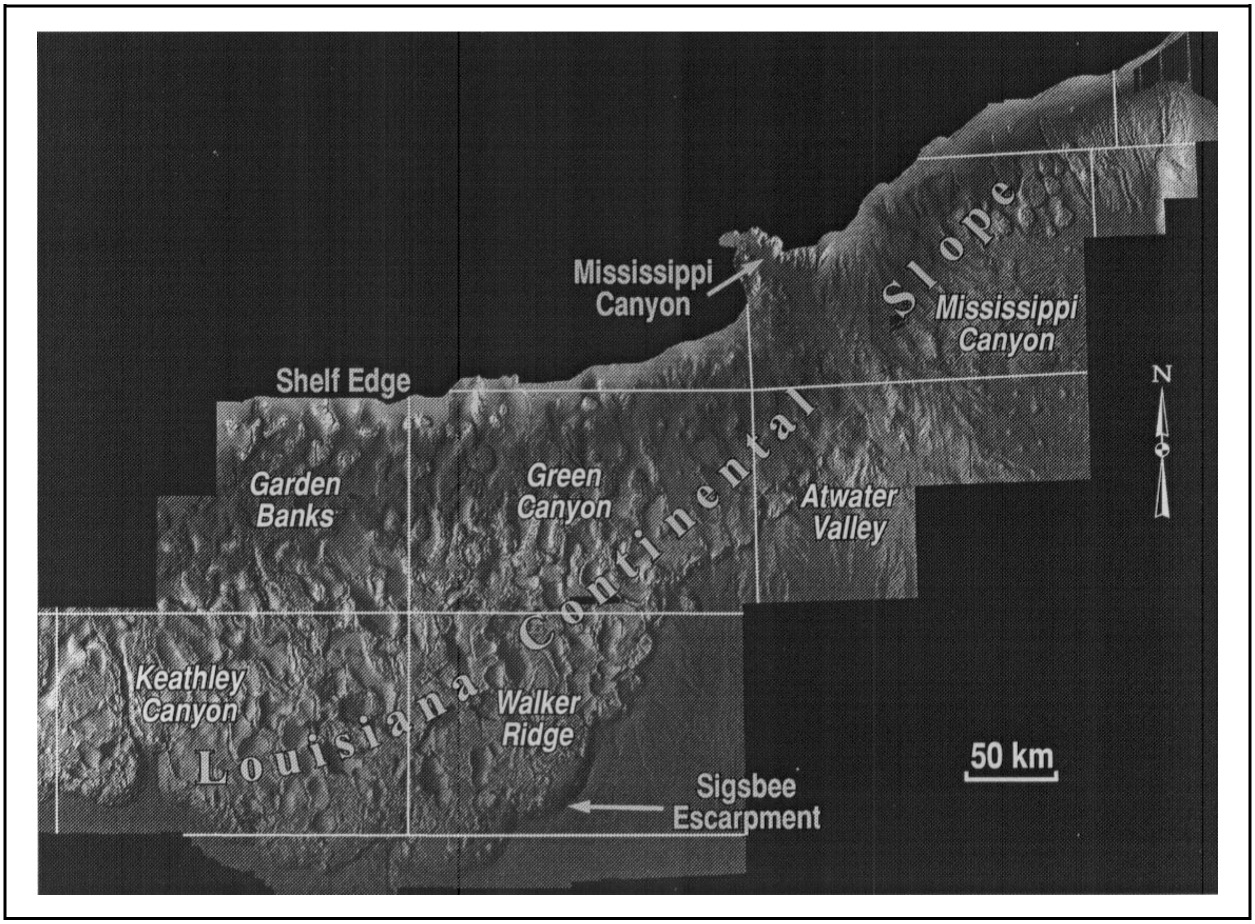

Figure 1C.1. The Gulf of Mexico continental slope off the state of Louisiana as portrayed by computer enhanced multibeam bathymetry.

Figure 1C.2. This figure summarizes the spectrum of seafloor responses associated with rapid fluid and gas venting (mud-prone) to slow seepage (mineral-prone).

Seafloor features that are the consequence of the fluid-gas expulsion process convey information about the types of fluid and gases being delivered, the episodic nature of the delivery process, the duration of expulsion events, and the delivery rate. On both high resolution and lower frequency exploration-scale seismic profiles, most expulsion features are accompanied by an acoustically opaque zone (acoustic wipe-out zone) that extends from the seafloor into the subsurface (Figure 1C.1). The general interpretation for this response is the presence of a free gas phase (bubbles) in surface and near-surface sediments. On seismic records, gas-charged sediments are identified by high amplitude reflecting horizons and/or acoustic wipe-out zones below (Bryant 1981). Although an acoustically opaque response on a seismic record can result from a number of surface and subsurface conditions (Roberts *et al.* 1999a), expulsion features are associated with free gas as well as fluids. In most cases, these features are clearly linked to faulting as determined from seismic records.

Rapid Flux (Mud Prone) Case

The vertical migration of gas and fluids through unconsolidated-to-semiconsolidated sediments may create a slurry-like mixture of sediment, gas, and water that may be extruded on the seafloor to form a variety constructional features (Hedberg 1974). Mud volcanoes and extruded mud sheets have been observed from many different marine geologic settings (Hovland and Judd 1988), ranging from degassing and dewatering of accretionary prisms during subduction to areas of active salt deformation like the Gulf (Neurauter and Bryant 1990) to breached anticlines in the Caspian Sea (Corthay and Aliyev 2000).

Numerous examples of features produced by rapid flux of fluidized sediment can be found on the northern GOM continental slope. Most of these features develop into conical mounds of various dimensions that are collectively referred to as mud volcanoes. Mud volcanoes are generally accompanied by a vertical pathway of acoustic attenuation (acoustic wipe-out zone) that is commonly interpreted as an indicator of free gas as well as sediment remolding in a subsurface feeder system (Figure 1C.3). This interpretation is easy to accept since abundant gas can frequently be observed escaping from the central vent of active mud-extrusion features.

In the rapid flux setting, exemplified by mud volcano formation, considerable heat is transported to the modern seafloor along with fluidized sediment. McDonald *et al.* (2000) have just published measurements from a mud volcano from the Garden Banks area that reached an absolute temperature of 48˚C on a part of the slope with ambient water temperatures that range between 4-7˚C. This heat flux can preclude the formation of gas hydrate or decompose it if it forms during periods of mud vent inactivity. The process of rapid vertical flux of fluids and gases suggests that there is little time for the hydrocarbon fraction of the carrier fluids to be microbially oxidized. Sassen *et al.* (1994) note that oil-stained sediments from an active mud volcano in Green Canyon 143 (27˚50.14'N, 91˚21.93'W) have characteristics (an envelope of n-alkanes and isoprenoids) suggesting that the oil has not been microbially degraded. In this case, bacterial oxidation is unable to keep pace with high rates of hydrocarbon venting typical of the rapid flux and mud prone setting.

Fined-grained expulsions, both as suspended sediment and as flows, create environments that are hostile for benthic fauna. For filter feeders, high suspended sediment loads overwhelm respiratory

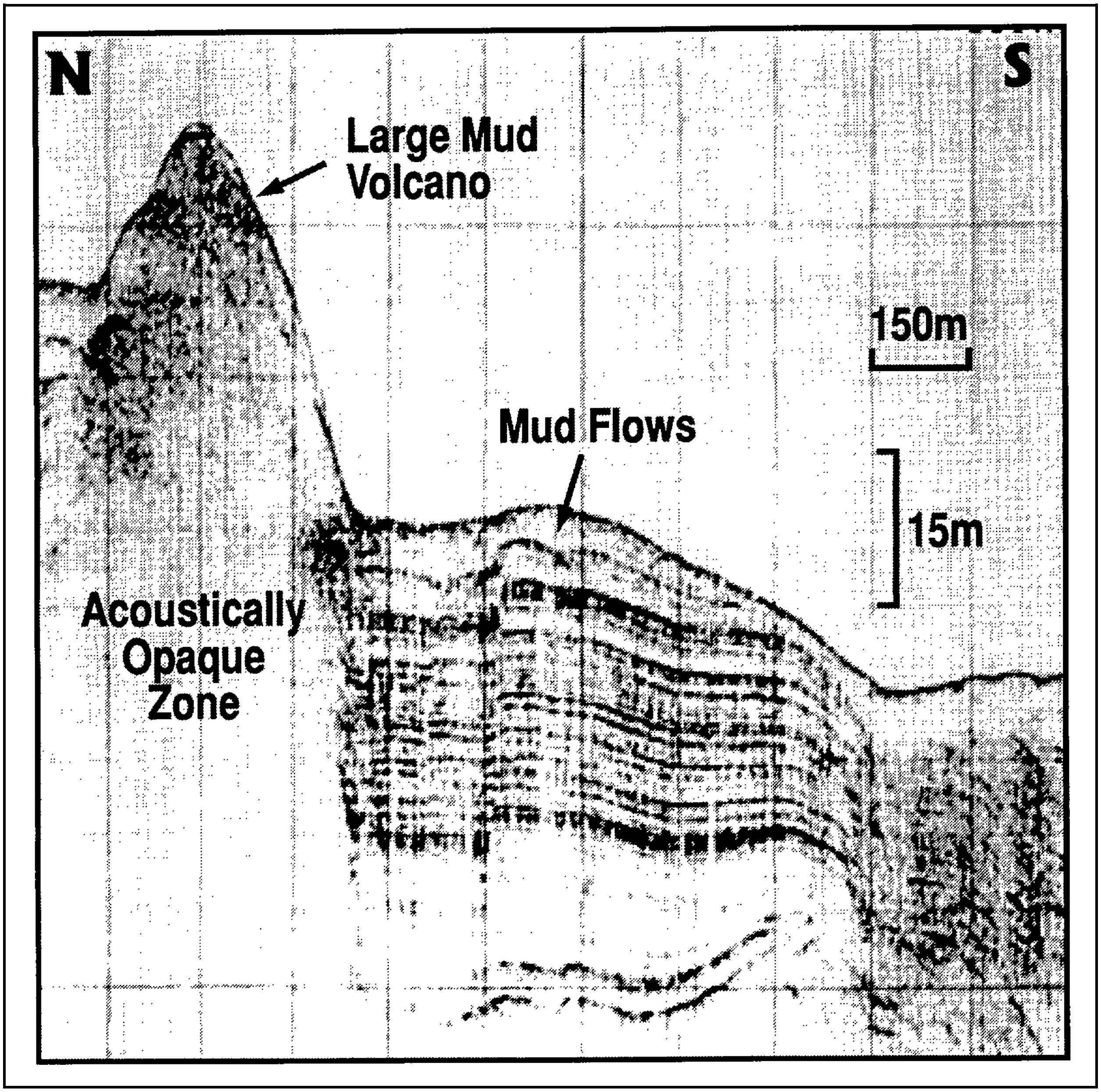

Figure 1C.3. A high resolution subbottom profile across an active mud volcano in Green Canyon 143. Rapid venting of fluidized sediment, other fluids (including crude oil) and gases have created this cone-like buildup and its downslope mudflow deposits.

systems, and flows can bury benthic organisms or make life positioning difficult or impossible. Extruded sediment may derive from sources containing little sulfide. High sediment delivery rates preclude sulfide-producing anaerobic oxidation of hydrocarbons. Mat-forming bacteria *Beggiatoa* may colonize the surface of hydrocarbon-laced fluidized sediments surrounding the venting area or on recently deposited flows. Once the fluidized mud has been deposited, lucinid-vesycomyid clams can colonize as biodegradation of incorporated hydrocarbons produces a sufficient sulfide source. Since expulsion events are episodic, any one flow deposit has a limited hydrocarbon charge and sulfide-producing potential. For this reason infaunal lucinid clam communities establish themselves and then quickly deplete the available sulfide source. Large surficial accumulations of lucinid-vesycomyid clam shells are frequently scattered over the surfaces of extruded muds. Multiple lucinid-vesycomyid shell layers in piston cores through sediments near active expulsion features confirm the episodic nature of mud extrusion events.

Moderate Flux Case

Below water depth of ~ 500 m, sites on the upper continental slope of the northern Gulf that fall within this category commonly display gas hydrate exposures at the seafloor. These sites are characterized by dense and comparatively diverse chemosynthetic communities consisting of bacterial mats, lucinid-vesycomyid clams, pogonophoran tube worms, vestimentiferan tube worms, and bathymodiolid mussels. Only infrequent occurrences of chemosynthetic organisms have been reported shallower than the gas hydrate "water depth window" which is dictated by termperature, pressure, and mixture of hydrocarbon gases (Sloan 1990). Association of gas hydrates and chemosynthetic communities is probably not fortuitous since gas hydrates store the trophic resources necessary to sustain long-term and diverse chemosynthetic communities. Such communities require sustainable sources of hydrocarbon gases and sulfide. As Carney (1994) suggests, "solid-phase gas hydrates of methane and water, which are stable at the pressure and temperature conditions below 400-500 m of water depth in the GOM, may be that unique aspect of deep ocean methane and sulfide chemistry that allows for chemosynthetic community development."

A mound-like feature ("Bush Hill") in Green Canyon 185 (27°46.97'N; 91°30.47'W) is a site where gas hydrates are frequently observed as exposures at the seafloor (Figure 1C.4). At this locality, seismic profiles indicate that vertically oriented acoustically opaque corridors connect with the deep subsurface. An antithetic fault that connects to a major fault system penetrating deep Pliocene sediments connects to the GC185 mound (Cook and D'Onfro 1991). Gas analyses of gas hydrate at the mound crest prove the incorporation of thermogenic hydrocarbons derived from the deep subsurface (Table 1C.1). On 3D-seismic surface amplitude data the mounds shown in stand out as high amplitude features of negative polarity, suggesting free gas in near-surface sediments (Roberts *et al.* 1992a).

Within a few tens of meters at the GC185 mound top one can move from areas of outcropping gas hydrate covered with orange *Beggiatoa* mats (Figure 1C.5) to complex and densely arranged chemosynthetic communities of mussels and tube worms mixed with small outcrops of authigenic carbonate.

It is apparent that in many cases, gas is being vented up faults through the gas hydrate complex and into the overlying water column. Minor faults and fractures are the probable conduits for free gas through the hydrate stability zone. It is also apparent through site specific experiments at GC185 (Roberts *et al.* 1999b) that surficial gas hydrates decompose and out-gas as a product of water column temperature changes. Out-gassing from an exposure of gas hydrate is strongly coherent with the water temperature signal (Roberts *et al.* 1999b). Even though temperature fluctuations are relatively small during the period when out-gassing and water temperature were simultaneously measured (maximum variation ~ 1.5°C), much more energetic out-gassing is expected during the

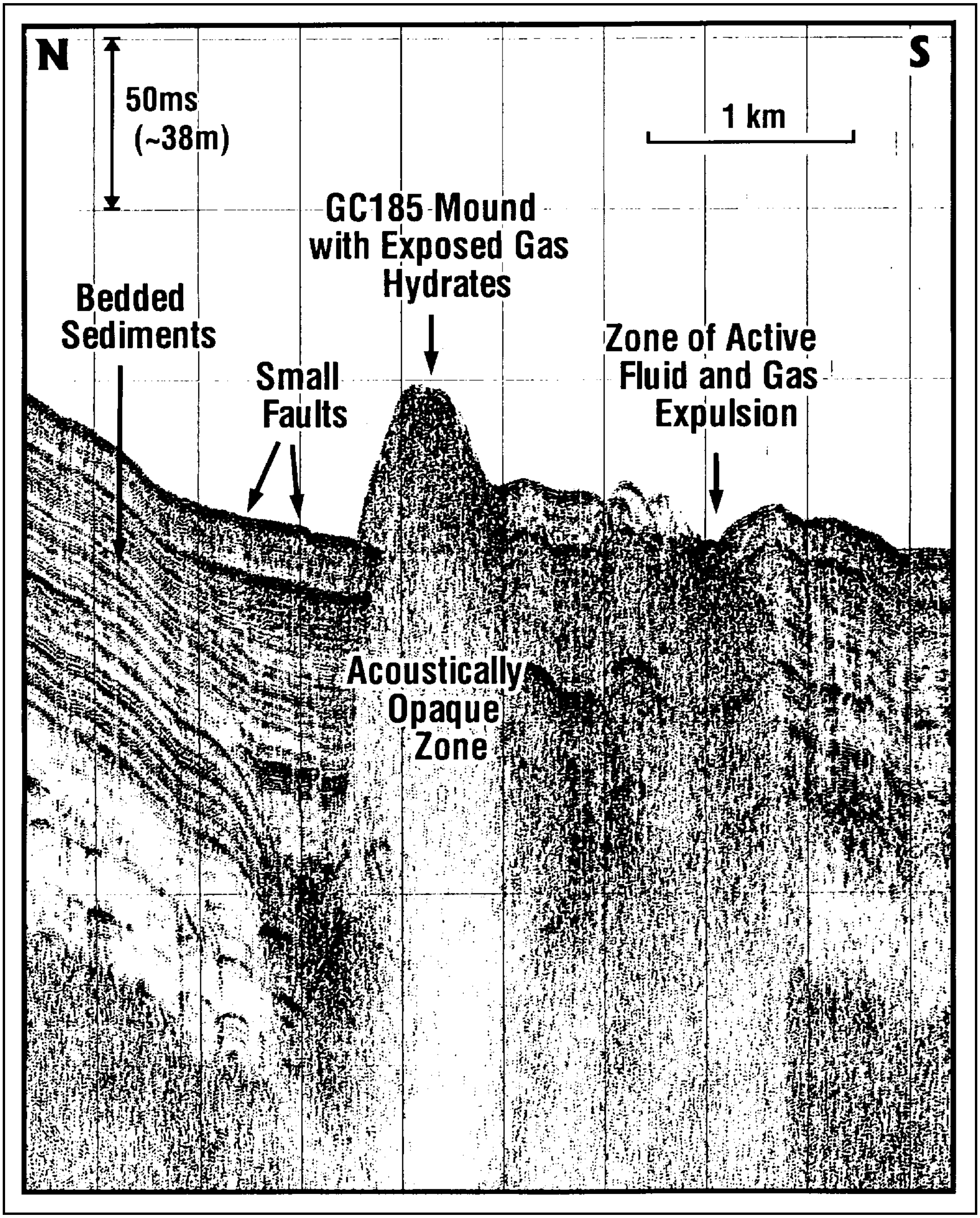

Figure 1C.4. A north-south high resolution seismic profile (15 in^3 water gun) across the mound in Green Canyon 185 (Bush Hill) which contains gas hydrate deposits at the surface and in the shallow subsurface.

Table 1C.1. Green Canyon 185 molecular and isotopic compositions of gas hydrate samples.

Sample	$\delta^{13}C$ C^1	δD C^1	$\%C^1$	$\delta^{13}C$ C^2	$\%C^2$	$\delta^{13}C$ C^3	$\%C^3$	$\delta^{13}C$ i - c^4	% i - c^4	$\delta^{13}C$ n - C^4	% n - C^4	$\delta^{13}C$ i - C^5	% i - C^5	$\delta^{13}C$ n - C^5	% n - C^5	% neo-C^1	$\delta^{13}C$ CO^2
Gas Hydrate	-42.9	-163	83.1	-28.6	7.6	-24.9	8.1	-27.2	0.9	-22.1	0.2						-27.8
Gas Hydrate	-42.2	-190	71.7	-29.0	10.6	-25.5	12.6	-27.6	2.6	-22.8	1.7	-26.2	0.8				-20.0
Gas Hydrate	-43.5	-177	80.2	-29.7	9.4	-25.5	7.3	-27.9	1.6	-23.0	1.2	-24.8	0.3				-23.7
Gas Hydrate	-42.5	-193	72.1	-29.2	12.4	-25.7	11.4	-27.8	2.3	-22.7	1.6	-24.7	0.3				-21.6
Gas Hydrate	-42.9	-115	85.7	-28.6	6.3	-25.6	6.1	-26.8	1.1		0.8						
Gas Hydrate	-43.6	-167	72.1	-29.8	10.5	-26.1	12.4	-28.1	2.5	-24.0	1.7		0.7		<0.1		+17.5

Data from Sassen *et al.* (1999a, 1999b) and Sassen *et al.* (1998).

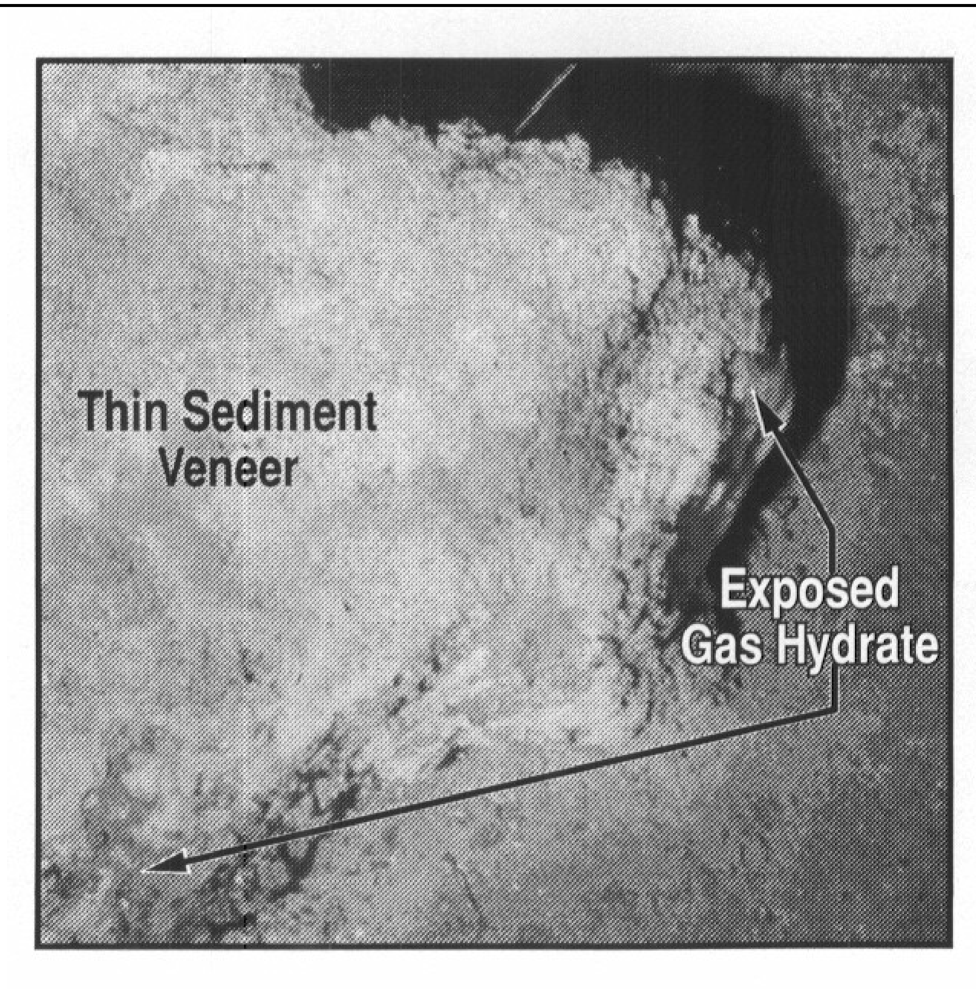

Figure 1C.5. An outcropping of gas hydrate at apex of the Green Canyon 185 mound. This outcrop was orange in color covered with gray mud on which orange *Beggiatoa* mats occurred. The field of view is about 2 m across.

passage of Loop Current eddies that can elevate water temperatures near the bottom on the upper slope by 4-6°C in water depth to ~1000 m (Hamilton 1990). Repeated observations of the same sites over nearly a decade of submersible research suggests that some sites go through cycles of decomposition and formation at an interannual frequency.

Slow Flux (Mineral Prone) Case

GOM slope sites that demonstrate slow vertical fluid and gas flux display abundant forms of sea-floor lithification but have few macro-scale chemosynthetic organisms. Instead, they are inhabited by microbial communities of sulfate-reducing bacteria, methanogenic bacteria, sulfide- and methane-oxidizing bacteria, and bacteria that oxidize thermogenic hydrocarbon gas and crude oil (Jannasch 1984; Sassen *et al.* 1993). Microbial communities are critical to carbon cycling in intermediate-to-slow seepage environments and to producing chemical gradients that result in precipitation of calcium-magnesium carbonates (Ritger *et al.* 1987; Roberts *et al.* 1992a; Paull *et al.* 1992), and mineral phases such as barite (Roberts and Aharon 1994; Fu *et al.* 1994; Torres *et al.* 1996).

Authigenic carbonates produced by these bacterially-mediated processes inherit their $\delta^{13}C$ signatures from a carbon pool comprised of carbon that is converted to dissolved inorganic carbon (DIC) from crude oil to biogenic methane as well as DIC from sea water. Therefore, it is unlikely that the carbon in Ca-Mg carbonates is derived from an individual source. However, authigenic carbonates from areas seeping primarily crude oil have $\delta^{13}C$ values that are close to crude oil value (-24 ‰ to –34 ‰ PDB), while similar carbonates from methane seeps are more ^{13}C-depleted. Therefore, the $\delta^{13}C$ values associated with hydrocarbon seep-vent carbonates appear to be a window into the parent carbon sources and the formative microbial processes that initiated precipitation sources (Aharon *et al.* 1990). Carbonates derived from sites of fermentation are much closer to $\delta^{13}C$ values for normal marine biogenic carbonates. The general range of $\delta^{13}C$ values for seep-vent related authigenic carbonates from the northern GOM slope is from –18 ‰ to –58 ‰ PDB, while the $\delta^{13}C$ range is about 1.8 ‰ to 5.6 ‰ PDB (Roberts and Aharon 1994).

Mineralogical complexity of authigenic carbonates from the northern Gulf is greater than counterparts from the base of the Florida Escarpment (Paull *et al.* 1992), and all three phases-aragonite, Mg-calcite, and dolomite occur (Roberts *et al.* 1992b). Magnesian calcites are the most commonly encountered authigenic carbonate mineral phase.

Authigenic carbonates are found as nodular masses within surficial sediment, hardgrounds, slabs, and mound-like buildups of various dimensions. Nodular masses, hardgrounds, and crusts are most common to the intermediate-to-slow flux rate settings. Mounded carbonates and chimneys are also found primarily in slow flux rate environments. Cement morphologies and mineralogies associated with the various authigenic carbonates found in association with seep-vent sites are highly variable. These morphologies range from microcrystalline dolomites and Mg-calcites to void-filling and circum-granular acicular and botryoidal aragonites (Roberts *et al.* 1992b; Roberts and Aharon 1994).

One of the best examples of mounded authigenic carbonates is in Green Canyon 140 (Figure 1C.6). On the 3D-seismic surface amplitude data, the Green Canyon 140 dome crest provides very high

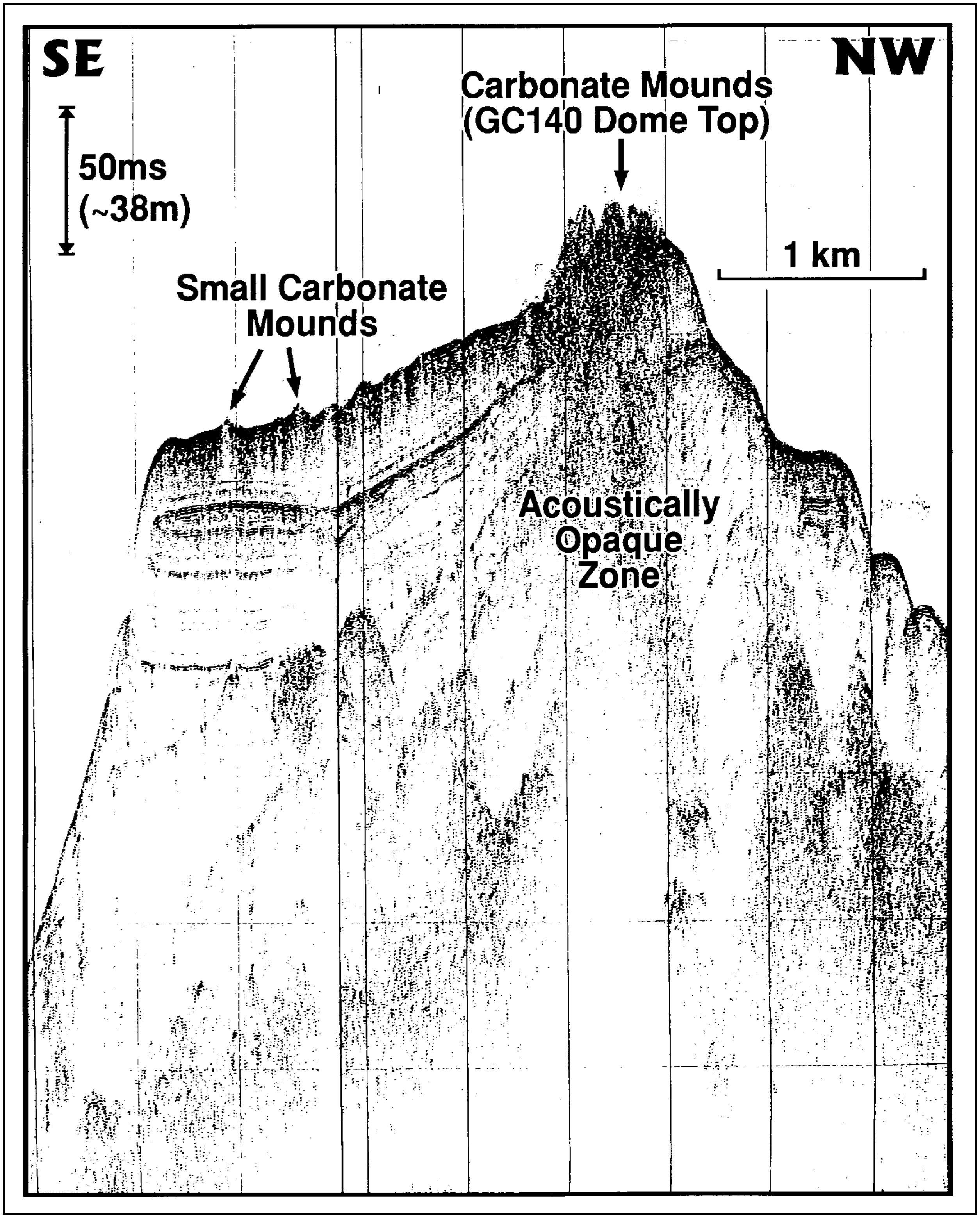

Figure 1C.6. A high resolution seismic profile across a part of the dome in Green Canyon 140. Note the irregular surface made up of authigenic carbonate mounds that appear to have developed in a slow seepage environment.

amplitude response because of the high reflective areas of lithified seafloor. The positive polarity of the 3D-seismic surface reflector suggests a hard-bottom area with limited gas-charge near-surface sediment (Roberts *et al.* 1992a). High resolution seismic profiles and side-scan sonar swaths across the dome crest (water depth ~240-280 m) reveal a mounded seafloor. Individual mounds express themselves as hard targets with sharp boundaries, irregular surfaces, and average relief above the surrounding seafloor ranging between 5-10 m (Figure 7). Direct observations and sampling of these mounds using manned submersibles clearly identify them as hard, rocky structures with very few attached organisms (e.g., gorgonians). Each mound appears as an accumulation of chaotically tilted and fractured blocks separated by well-defined crevasses (joints) that apparently result from flexure of underlying shallow salt. Laboratory analyses on these carbonates (Roberts *et al.* 1992b) indicate that they are extremely ^{13}C-depleted ($\delta^{13}C$ values to –55°/oo PDB) and have a mineralogy that is primarily Mg-calcite 1>mole°/oo Mg, with dolomite frequently lining pores and fractures (Roberts 1992b). The range of $\delta^{13}C$ values for samples from these mounds suggests a variety of hydrocarbon sources. The $\delta^{13}C$ values range from those associated with crude oil that is found trapped in the pores of many samples from these mounds to the extremely ^{13}C-depleted carbonate cements suggesting that methane is the contributor of isotopically light carbon (Roberts and Aharon 1994). The slow flux of fluids and gases to the modern seafloor in this setting is thought to be related to the presence of shallow salt and the limited migration pathways provided by faults that originate from the salt and extend above to the domed ocean floor. These complex fault families do not presently have direct access to petroleum systems deep within the adjacent sedimentary basin.

Transitional Cases

Not all fluid and gas expulsion features conveniently fit into the rapid flux-to-slow spectrum discussed in this paper and in Roberts and Carney (1997). Variations from the simple qualitative relationships illustrated in Figure 1C.2 occur because of (a) differences in the chemistry of fluids and gases being transported to the seafloor; (b) the frequency of expulsion events; (c) duration of expulsion events; (d) the strength of these events; and, (e) the number of expulsion sites within a given area. Through time, sites may shift from one part of the feature spectrum to another, either by a systematic increase or decrease in the rate that fluids and gases are delivered to the seafloor. For example, thin but rapidly deposited mudflows from the crest of a salt-cored diapiric mound in Garden Banks 427 (27˚33.59'N; 92˚25.53'W) display surface lithification, a slow flux characteristic, because of the infrequency of expulsion events. This surface lithification (primarily Mg-calcite) produces a highly reflective seafloor response on 3D-seismic surface amplitude maps. However, the positive-to-negative polarity shift in the surface seismic reflector suggests the presence of gas-charged sediments (Roberts and Doyle 1998). In settings where expulsion events are more frequent than in the Garden Banks 427 case, such as large and active mud volcanoes, seafloor lithification does not generally occur over broad areas, but still may be found at localized sites (Roberts and Doyle 1998).

SUMMARY

Fluid and gas expulsion features of the northern GOM continental slope fall into three general categories that have rather distinct assemblages of geological features and biologic communities.

These categories, originally discussed by Roberts and Carney (1997), have been identified as rapid, moderate, and slow flux settings.

Rapid flux of fluids (including fluidized sediment) and gases create mud-prone topographic features such as mud volcanoes and/or mud flows in the form of broad sheets or stacked sheets. Mud volcanoes range in scale from local features < 1 m across to large forms with diameters of > 1 km. Mud flows display the same wide range of scales. Existing evidence suggests that the delivery of fluidized sediment to create these features is episodic. During rapid flux events, sedimentation rates are so high that diagenetic processes of mineralization and biogenic processes have little opportunity to impact the geologic record. These rapid flux, mud-prone deposits contain hydrocarbons that show little evidence of biodegradation, a conspicuous reduction in hard mineralized surfaces (particularly authigenic carbonates) and few-to-no remains of chemosynthetic organisms. Rapid sedimentation buries sessil organisms and smothers those that are filter feeders and provides only a limited trophic resource for sustaining life for chemotrophic organisms. Bacterial mats (*Beggiatoa*) and lucinid-vesycomyid clams are the only chemosynthetic organisms typical of rapid flux, mud-prone settings.

Moderate flux cases display the most local variability in small-scale geologic features, substrate types, and biologic communities. The rather constant but moderate flux of hydrocarbon gases and to a lesser extent fluids (including moderately biodegraded crude oil) to the seafloor within the hydrate stability zone promotes the formation of gas hydrates at or near the ocean floor (in water depth below ~500 m). Gas hydrates may not be excluded from more rapid and slower flux settings, but in the moderate flux case, the hydrocarbon delivery system causes gas hydrate to form in the subsurface and to the sediment-water interface. In this setting, abundant gas is being fluxed through the sediments and by-passing the zones of gas hydrate formation to the water column. In the upper continental slope setting, plumes of gas are commonly documented on echo-sounders above areas where gas hydrates are exposed on the seafloor. Accompanying surface and shallow subsurface concentrations of gas hydrates are densely populated and the most diverse and widely distributed chemosynthetic communities thus far encountered on the northern GOM continental slope. These communities consist of bacterial mats (*Beggiatoa*), lucinid-vesycomyid clams, pogonophoran and vestimentiferan tube worms, bathymodiolid mussels, and a variety of accessory organisms. In addition to gas hydrates and associated chemosynthetic communities, moderate flux settings can display localized outcroppings of authigenic carbonate, nodular masses of carbonate in near-surface sediments, and a variety of small-scale gas-fluid expulsion features (small mud volcanoes, mud vents, and shallow pockmark-like depressions).

Slow flux environments are mineral-prone. As hydrocarbon-rich fluids and gases are slowly transported to the modern seafloor, microbial communities oxidize the hydrocarbons. Products of this process help induce the precipitation of authigenic carbonates (mainly aragonite, Mg-calcite, and dolomite) as by-products. In some cases, barite is precipitated at the seafloor in a variety of forms (crusts, small mounds, and chimneys). The carbonates occur as nodular masses within the sediment, hardgrounds, and lithified slabs, and mound-like buildups that have a wide range of relief (< 1 m to > 20 m above the surrounding seafloor). The carbonate buildups themselves do not generally support abundant chemosynthetic organisms. However, small communities consisting of bacterial mats, pogonophoran tube worms, and lucinid-vesycomyid clams are sometimes found on the mud bottoms surrounding the buildups, in crevasses within the buildups, and adjacent to hardgrounds and slabs.

Finally, the responses to the rate of fluid and gas flux to the modern seafloor discussed in this paper are end-member types. However, because of the episodic nature of expulsion events and the systematic changes in flux rate at a given sites, the seafloor may shift from one part of the feature spectrum to another given sufficient time.

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REFERENCES

Aharon, J.B., H.H. Roberts, R. Sassen, and J. Larkin. 1990. Stable isotopes and petrology of chimneys and calcarious fauna from hydrocarbon vents on the Gulf of Mexico slope, Geological Society of American Abstracts with Programs 22:A208.

Bryant, W. R. 1981. Gas charged sediments. *In* A.H. Bouma, ed. High resolution seismic profiling and side-scan sonar: United States Geological Survey, Office of Marine Geology.

Carney, R.S. 1994. Consideration of the oasis analogy for chemosynthetic communities at Gulf of Mexico hydrocarbon vents: Geo-Marine Letters, 14:149-159.

Cook, D. and P.D. D'Onfro. 1991. Joliet field thrust fault structure and stratigraphy-Green Canyon block 184, offshore Louisiana: Gulf Coast Association of Geological Societies Transactions, 41:100-121.

Corthay, J.E. and A.A. Aliyev. 2000. Delineation of a mud volcano complex, surficial mudflows, slump blocks, and shallow gas reservoirs, offshore Azerbaijan: Proceedings Offshore Technology Conference, OTC Paper 12066, p. 1-14.

Diegel, F.A., J.F. Karlo, D.C. Schuster, R.C. Shoup, and P.R. Tauvers. 1995. Cenozoic structural evolution and tectono-stratigraphic framework of the northern Gulf Coast continental margin, pp 109-151. *In* M.P.A. Jackson, D.G. Roberts, S. Snelson, eds. Salt Tectonics: A Global Perspective. AAPG Memoir 65:109-151.

Fu, B., P. Aharon, G.R. Byerly, and H.H. Roberts. 1994. Barite chimneys on the Gulf of Mexico slope: Initial report of their petrography and geochemistry: Geo-Marine Letters, 14:81-87.

Hamilton, P. 1990. Deep currents in the Gulf of Mexico: Journal of Geophysical Research 20:1087-1104.

Hedberg, H.H. 1974. Relation of methane generation to under compacted shales, shale diapirs, and mud volcanoes. American Association of Petroleum Geologists Bulletin 58:661-673.

Hill, A.W. 1996. The use of exploration 3D data in geohazard assessment: Where does the future lie? Proceedings Offshore Technology Conference, OTC Paper 7966, p.113-117.

Hovland, M., and A.G. Judd. 1988. Seabed pockmarks and seepages: Impact on geology, biology and the marine environment. Graham and Trotman. London. 293 pp.

McDonald, I.R., D.B. Buthman, W.W. Sager, M.B. Peccini, and N.L. Guinasso, Jr. 2000. Pulsed oil discharge from a mud volcano: Geology, 28:907-210.

Neurauter, T.W. and W.R. Bryant. 1990. Seismic expression of sedimentary volcanism on the continental slope, northern Gulf of Mexico. Geo-marine Letters 10:225-231.

Paull, C.K., J.P. Chanton, A.C. Neumann, J.A. Coston, C.S. Martens, and W. Showers. 1992. Indicators of methane-derived carhonates and chemosynthetic organic carbon deposits: Examples from the Florida Escarpment. Palaios 7:361-375.

Prather, B.E., J.R. Booth, G.S. Steffens, and P.A. Craig. 1998. Classification, lithologic calibration, and stratigraphic succession of seismic facies of intraslope basins, deep-water Gulf of Mexico: American Association of Petroleum Geologists Bulletin, 85:701-728.

Ritger, S., B. Carson, and E. Suess. 1987. Methane-derived authigenic carbonates formed by subduction-induced pore-water expulsion along the Oregon/Washington margin. Geological Society of America Bulletin, 98:147-156.

Roberts, H.H., D.J. Cook, and M.K. Sheedlo. 1992a. Hydrocarbon seeps of the Louisiana continental slope: Seismic amplitude signature and seafloor response. Gulf Coast Association of Geological Societies Transactions 42:349-362.

Roberts, H.H., P. Aharon, and M.M. Walsh. 1992b. Cold-seep carbonates of the Louisiana continental slope-to basin floor, pp.95-104. *In* Rezak, R. and D. Lavoie, eds. Carbonate Microfabrics. Springer-Verlag, Berlin.

Roberts, H.H. and P. Aharon. 1994. Hydrocarbon-derived carbonate buildups of the northern Gulf of Mexico continental slope: A review of submersible investigations: Geo-Marine Letters, 14:135-148.

Roberts, H.H. 1996. Surface amplitude data: 3D-seismic for interpretation of seafloor geology (Louisiana slope). Gulf Coast Association of Geological Societies Transactions, 46:353-366.

Roberts, H.H., and R. Carney. 1997. Evidence of episodic fluid, gas and sediment venting on the northern Gulf of Mexico continental slope. Economic Geology, v.92, p.863-879.

Roberts, H.H. and E. H. Doyle. 1998. Seafloor "calibration" of high resolution acoustic data and amplitude rendering of the "diapiric hill," Garden Banks 427: Proceedings Offshore Technology Conference, OTC Paper 8592.

Roberts, H.H., B. Kohl, D. Menzies, and G.D. Humphrey. 1999a. Acoustic wipe-out zones – A paradox for interpreting seafloor geologic/geotechnical characteristics (An example for Garden Banks 161): Proceedings Offshore Technology Conference, OTC Paper 10921, p. 1-12.

Roberts, H.H., W.J. Wiseman, Jr., J. Hooper, and G.D. Humphrey. 1999b. Surficial gas hydrates of the Louisiana continental slope - Initial results of direct observations and in situ data collection. Offshore Technology Conference, Houston, Texas. OTC 10770, 259-272.

Sassen, R., I.R.MacDonald, A.G. Raquejo, N.L. Guinasso, Jr., M.C. Kennicutt II, S.T. Sweet, and J.M. Brooks. 1994. Organic geochemistry of sediments from chemosynthetic communities, Gulf of Mexico Slope: Geo-Marine Letters, 14:110-119.

Sassen, R., I.R. MacDonald, N.L. Guinasso, S. Joye, A.G. Requejo, S.T. Sweet, J. Alcala-Herrera, D.A. DeFreitas, D.R. Schink. 1998. Bacteria methane oxidation in sea-floor gas hydrate: Significance to life in extreme environments. Geology 26:289-293.

Sassen, R., S.T. Sweet, A.V. Milkov, D.A. DeFreitas, G.G. Salata, E.C. McDade. 1999a. Geology and geochemistry of gas hydrates, central Gulf of Mexico continental slope. Transactions Gulf Coast Association of Geological Societies 49:462-468.

Sassen, R.S. Joye, S.T. Sweet, D.A. DeFreitas, A.V. Milkov, I.R. MacDonald. 1999b. Thermogenic gas hydrates and hydrocarbon gases in complex chemosynthetic communities, Gulf of Mexico continental slope. Organic Geochemistry 30:485-497.

Sloan, E.D., Jr. 1990. Clathrate hydrates of natural gases: Marcel Dekker, Inc., New York and Basel, 641 p.

Torres, M., G. Bohrmann, and E. Suess. 1996. Authigenic barites and fluxes of barium associated with fluid seeps in the Peru subduction zone: Earth and Planetary Science Letters 144:469-481.

MONITORING THE PHYSICAL AND CHEMICAL CONDITIONS AFFECTING THE HYDROCARBON SYSTEM WITHIN THE HYDRATE STABILITY ZONE OF THE NORTHERN GULF OF MEXICO

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INTRODUCTION

A definite need exists to address questions related to the shallow hydrocarbon system within the hydrate stability zone of the Continental Slope, northern Gulf of Mexico (GOM). The possibility of designing and developing a remote, multi-sensor monitoring station for long-term investigation and research of this problematic near-sea floor hydrocarbon system has been discussed for some years. During 22-26 March 1999, a workshop entitled “New Concepts in Ocean, Atmosphere and Sea Floor Sensor Technologies for Gas Hydrate Investigations and Research” was held in Biloxi, Mississippi. It was sponsored primarily by the Center for Marine Resources and Environmental Technology (CMRET) of the University of Mississippi. It was attended by an international group of participants that included a delegation from the Russian Academy of Sciences. One day was devoted to intensive discussion sessions that addressed practical aspects of assembling and deploying such a station. By June 1999, those and subsequent discussions had led to a written document describing a project that would produce a station primarily for studying sea floor stability. That document was well received by government, industry, and academia. The interest it generated led to further discussions and meetings and the project concept has been revised incrementally to include a widening spectrum of interests.

As of December 2000, the intention is to assemble a station to monitor physical and chemical parameters of the sea water and sea floor sediments on a more or less continuous basis over an extended period of time. The project will initiate collection of a data base for assessing and modeling the stability of the sea floor and factors associated with the formation and dissociation of gas hydrates. This data base will also be available for planning hydrate area exploration/delineation and, eventually, for analyzing the impact of producing hydrates from the ocean floor. It is also possible to expand the capabilities of the station to include biological monitoring. This expansion would allow the study of chemosynthetic communities and their potential as a source for natural products/drug discoveries as well as an assessment of their environmental health and interactions with geologic processes.

BACKGROUND INFORMATION

The near-sea floor hydrocarbon system of the northern GOM is manifested by a variety of unusual features. One of the more interesting and perplexing is the occurrence of gas hydrates, an ice-like mineral composed of natural gases and water. Gas hydrates are stable within a hydrate stability zone (HSZ) defined by pressure, temperature and gas composition. If the gas is almost pure methane, the proper conditions typically are found at ocean depths greater than 400m. The vertical extent beneath the sea floor is largely controlled by the geothermal gradient. Gas hydrates commonly form along faults and intersecting fractures near the sea floor where the hydrocarbon gases that migrate up from deep reservoirs interact with sea water. Mounds form on the sea floor containing gas hydrates and various minerals deposited by bacteria feeding on the hydrocarbons. Variations in pore pressure, temperature distribution, chemical composition of the gas, and gas flow rate combine to determine whether hydrates within the mounds accumulate or dissociate. Many geoscientists familiar with recent geologic processes in the GOM think that events that produce changes to the mounds also trigger episodes of sea floor instability.

Hydrates in direct contact with a large volume of sea water are only marginally stable. This instability causes parts of the mounds where hydrates outcrop to be more or less ephemeral, capable of changing greatly within a matter of days. The eddies of warm water that periodically separate from the Loop Current, a major current that runs northward through the Yucatan Strait and eastward through the Straits of Florida, are potentially prominent influences on outcropping hydrates because they can raise bottom temperatures by as much as 2-3 degrees C and thereby impose a quasi-cyclicity of sea floor hydrate formation and dissociation. Changes in pore pressure, gas composition, and flow rate may also be major influences but their causes are not well understood. They may relate to tectonic activity associated with salt movement.

Hydrates contained in sediments are stable when the host sediment is within the HSZ. If hydrocarbon gases migrating up faults encounter sediments of sufficient permeability within the HSZ, hydrates can form within pore spaces, along bedding planes, and within fractures. When hydrates act to cement the sediment grains, the shear modulus, and thereby the bearing capacity, of the sediment increases. When outside influences, such as thermal distortions due to salt movement, fluid migration, or drilling activity, act to dissociate the hydrates; the bearing capacity decreases and the potential for sea floor instability is created.

Common indicators of bearing capacity are the speeds at which compressional (P) and shear (S) waves propagate below the sea floor and the efficiency of P-to-S conversion (PS) at reflecting horizons. A comprehensive monitoring station would be capable of measuring these and many other parameters that are relevant to the formation and dissociation of gas hydrates.

The degree to which biological factors come into play is the subject of increasing amounts of research. For example, over time, bacteria consume the hydrocarbon molecules within the hydrate crystals and precipitate minerals, such as calcium carbonate, which cement sediment particles and increase bearing capacity.

OVERVIEW OF STATION SYSTEMS

Sea Floor Positioning System

The first system to be installed at the monitoring station site will be a sea floor navigation system by which the locations of other systems are referenced. It will be a long baseline system that encompasses an area of about 10 square miles (25 km^2), somewhat larger than that required to deploy all other systems. It will remain in place throughout the lifetime of the station.

Vertical Line Arrays/Sea Floor Probes

The heart of the station will be a net of vertical arrays (VLAs) and sea floor probes (SFPs). The VLAs will occupy the lower portion of the water column while the SFPs will be placed in shallow bore holes (10m) in the sea floor close proximity to the anchor points of the VLAs. VLA and SFP sensors will be selected to monitor dynamic oceanographic and geologic processes acting on the lower water column and the near-sea floor sedimentary section.

The VLAs and SFPs will be designed with the following general architecture and sensor compliment:

- a three component ocean bottom accelerometer will be imbedded at hole bottom of the SFP for measurements of S-waves and seismicity;

- extending upwards, the SFP will consist of a string of interspersed hydrophones for measurements of P-waves and sound speed; pressure sensors for measurement of pore fluid pressure; and thermistors - for measurement of pore fluid /host sediment temperature and heat flow gradients (in the near-sea floor); (in addition to these subbottom sensors, fiber optic sensors for pore fluid chemistry measurements may also be incorporated on the string); and

- the VLA will extend into the water column approximately 200m and will be fitted with interspersed hydrophones for measurement of P-waves and sound speed, and thermistors for measurement of water temperature (in the lower water column).

The signal from each sensor will be digitized and recorded individually.

Hydrophones

The set of acoustic signals provided by the hydrophones will be processed by correlation and matched field processing (MFP) techniques that make use of time and amplitude information to provide estimates of

- temperature variations in the water column (by travel-time tomography);

- speeds of P-wave propagation in sea floor sediment/hydrate (by MFP); and

- 3-D images of geological structure beneath the sea floor (by MFP).

These estimates will be used to detect changes in the sea floor resulting from a triggering event and to provide an image of the subbottom geological structure after an event is detected.

Ocean Bottom Accelerometers (OBAs)

The three components of OBAs will allow the identification of S-waves and measurement of their amplitudes, thereby providing subbottom information not available from P-waves alone. During site calibration, S-wave speeds immediately below the sea floor will be measured by recording signals from an S-wave generator towed on the sea floor; the PS-waves converted at deeper reflecting horizons will be generated by sources deployed on the sea surface. Between calibrations, the three-component instruments will monitor seismic activity and the noise of passing ships. The complete set of accelerometer data will be useful for studying the

- approximate delineation and evolution in time of the gas hydrate stability zone;
- underlying free-gas zone associated with the hydrate edifice; and
- configuration of pathways through which gases and liquids migrate.

After the station has been deployed, the site will be calibrated by determining an acoustic model of the station's environment using controlled sources towed by ships and fired at known precise locations and times. The noise of passing ships, i.e. sources of opportunity, will then be traced and employed to monitor changes to that model on a more or less continuous basis. The site will be recalibrated as necessary using controlled sources.

An issue to be addressed in consideration of appropriate systems for S-wave measurement is whether the 3-component instruments should be seismometers or accelerometers. Seismometers are more traditional but accelerometers can have broader bandwidths and are more shock resistant. When ocean bottom seismometers (OBSs) are deployed on the surface of sea floor sediment, their data can be degraded if the coupling between the instruments and the sediment is poor. That is probable in the GOM where sediments are often very soft. The sea floor earthquake measurement system (SEMS IV) of the Minerals Management Service reports great success using OBAs pushed into soft sediments to monitor earthquakes offshore California. An experiment will be conducted during the site selection phase in which OBSs and OBAs will be pushed into the bottom by a remotely operated vehicle (ROV). Recordings from each will then be compared to determine whether OBAs rather than OBSs should be used at surface locations. Regardless of the outcome, the OBAs will be the only practical sensors for the SFPs.

Thermistors

The thermistors mounted on the sensor string of the SFP will be designed to monitor heat-flow density from which heat flow gradient estimates may be determined. These data will in turn provide estimates for the depth dimensions of the HSZ as well as provide a base for mapping heat flow anomalies relating to localized hydrocarbon fluid flow (primarily gas).

The subbottom thermal measurements will be accompanied by pore-fluid pressure measurements to provide information pertaining to hydrate dissociation and its effects on the physical/mechanical properties of the sediments. The results will be described in terms of both absolute pressure (and how it changes due to a small amount of gas release), and load partitioning between sediment matrix and pore fluid during tidal cycles and meteorological events.

Thermistors mounted on the VLA will add to the thermal study by enabling the monitoring and input of bottom-water temperature variations.

Optical Spectroscopy

Using a technique similar to that employed by the Mars Rover, an optical spectrometer will be used to identify and quantify hydrocarbon gases present in the sea water. Samples will be illuminated by laser light shining through an optic fiber and the backscattered light collected by other optic fibers. Spectral analysis of the backscattered light will provide information concerning the chemical composition of the gas in each sample. Of particular interest is a recent advancement in mid infrared (MIR) spectroscopy, under development, which utilizes a miniature cryogenic cooler at the sensor which has been demonstrated in the laboratory to produce very significant analytical results with mixed hydrocarbon gases. An obvious and very useful application of this technology would be its incorporation in the sea floor mounted tip bucket, a free gas volume measurement device presently in use on small gas vent sites. For instance, a sample might be analyzed after a programmed number of tips of the bucket. A less conventional but equally valuable application would be the installation of optical sensors on the SFP string for measurement of pore fluid chemistry *in situ*.

Current Measurements

An acoustic doppler current profiler (ADCP) will be installed on the sea floor to monitor current flow at several levels within the lower approximate 200m of the water column. These data will also be processed for backscatter intensity to yield an estimate of suspended particulate mass, a parameter affected by both sediment resuspension due to water currents and by sediment mass movements. In addition, a number of three-axis acoustic current meters will be installed near the VLA to assist in the determination of VLA receiver geometry. Each of these meters will record temperature, pressure, and optical backscatter as well as current flow.

Underwater Vehicles

A variety of underwater vehicles will be used at various stages of the project: deep-tow and bottom-tow devices, tethered ROVs, manned and eventually autonomous underwater vehicles (AUVs). The latter will carry sensors that are more effective when moved about, thus improving spatial resolution, while the former group will be vital to reconnaissance and station assembly. The locations of underwater vehicle activities will be determined in relation to the long baseline navigation system.

Towed vehicles and ROVs will be deployed from surface ships during site selection and calibration. Towed vehicles will reconnoiter areas with survey tools such as side scan sonar, seismic/acoustic subbottom profilers, and the electromagnetic profiler. ROVs and manned vehicles will be used to survey smaller areas with greater precision and to deploy and service instruments such as OBSs and OBAs, cameras, conductivity-temperature-density (CTD) probes, pore-water samplers, pH meters, dissolved oxygen (O_2) probes, and the optical spectrometer. Together, they will provide close-up images of the sea floor and measurements to identify hydrate zones, hydrocarbon seeps and chemosynthetic communities.

A future consideration, not presently factored, will be the use of AUVs. It is anticipated that the AUV will carry imaging instruments and measuring probes but will be used primarily during periods when the station is not attended by surface ships. It will be guided by the long baseline navigation system to carry imaging systems along specific transects or to take measurements at specific locations. It will be guided by genetic algorithms and other software to search designated sectors for new targets. Given appropriate development, it will operate from a docking facility near the monitoring station where data can be downloaded, instructions received, and batteries recharged. The dock will be connected by fiber optic to a site, probably an oil platform, where the images and spectral data can be transmitted ashore and instructions received. Electric power for recharging batteries will also be obtained from that site.

INITIAL EXPERIMENTS

A suite of experiments will be carried out in the spring of 2001 that, taken together, will approximate the operation of a monitoring station. The experimental site is expected to be in Mississippi Canyon Block 798 where verbal permission, subject to formal request, has been received from the lease holder. The topography of the bottom is relatively gentle there and the presence of hydrate mounds has been confirmed. Additional investigation was done using OBS deployments and high resolution seismic profiling during a June 1998, cruise funded by CMRET, the U.S.Geological Survey, and the U.S.Department of Energy. The existing data are sufficient to provide a reasonably detailed understanding of the configuration of the subbottom there.

Systems used in the Block 798 will include an autonomous VLA, several OBSs and OBAs, and several resistivity and heat flow conventional gravity probes. The instruments will be deployed for a period of 7-10 days. High resolution seismic profiles will be recorded, using surface-deployed seismic sources of various energy levels. Signals from these sources also will be recorded by the VLA, OBSs, and OBAs. In addition, the sounds of ships will be recorded to test the usefulness of sources of opportunity; probes will be deployed to obtain resistivity and heat flow data; and gas samples will be collected by an ROV.

For a period of some months commencing in 2002, Conoco has offered to provide facilities in the Green Canyon area (Marquette and Joliet fields) for the purpose of performing experiments related to the monitoring station. The offer includes limited access to platforms, electrical power, and satellite communications. It is expected that one of the first experiments to be performed using these facilities will be a test of the feasibility of measuring fluid flow rates (from sea floor vents) using the sound of bubbles and possibly the deployment of a video monitoring system.

VIDEO MONITORING SYSTEM

If the monitoring station has access to sufficient electrical power, several video systems with pan and tilt capability will be installed for scientific, educational, and public outreach purposes. Not only will the live images be useful to scientists for visual evaluation of sea floor conditions as they change in response to either experimental or natural stimuli, but they will be made available to K-12 educators for use in classrooms as well. Students at any facility with access to the Internet will be able, on a predetermined schedule, to pan, tilt, and zoom the cameras, engage different lights, and compare the images with other data and with images from other, similar systems.

SITE SELECTION

A short list of potential monitoring station sites will be identified on the basis of their geologic framework and the applicability of available and appropriate technologies tested during the initial experiments. The final choice will be the responsibility of the project's board of scientific supervisors.

The process of selecting a site for the monitoring station will commence with evaluation of candidate sites for which pertinent information already exists. Many sites have been studied over a period of years, especially by the Coastal Studies Institute of Louisiana State University and the Geochemical and Environmental Research Group of Texas A&M University. These sites will have priority in the selection process. Appropriate physical conditions form only part of the criteria for a suitable site. Much of the sea floor in the GOM is under lease to private parties and sea floor instruments cannot be installed in leased areas without permission of the lease holder(s). Another criterion for site selection is reasonable proximity to a telemetering site and an electrical power source.

The most efficient method for reconnoitering potential sites is reflection seismic profiling. A substantial body of exploration seismic data exists, and some of it is available for review. The resolution of exploration data is generally low, however, and higher resolution data will be required prior to final site selection. The higher resolution data will make it possible to resolve layers a fraction of a meter thick near the sea floor while providing somewhat lower resolution up to a kilometer below the sea floor.

Seismic profiling can provide information concerning reflection coefficients and, to some extent, speeds of seismic propagation, but other types of geophysical data will be required before a final site choice can be made. Optical, side scan and swath-bathymetry images as well as shear-wave, geoelectric and heat-flow measurements will be collected at sites on the short list. Core samples will also be taken as necessary.

STATION DEVELOPMENT, DEPLOYMENT, AND OPERATION

A period of two years will be required to construct, integrate station systems, and deploy the VLAs/SFPs, the end of the second year marking the beginning of operations of the initial station on the sea floor. Probably, a third year will be required to complete the station as presently planned. A few systems require at least some development before they can be constructed. These include certain of the SFP sensors and the optical spectrometer.

As noted previously, the VLAs and SFPs will represent key components of the monitoring station. Considering the architecture and economics involved, the VLAs are retrievable systems while the SFPs, by design and location, must be considered more or less permanent in their placement and expendable.

Deployment

Following assembly and testing of the SFP, it will be deployed using a modified version of existing CMRET remote sea floor drilling technology. The present version is designed remotely to emplace and extract casing of up to 11.4cm (4.5 in.) O.D. by 12m (40 ft.) length to take cores and implant sensor probes. In the case of the latter, the probe, consisting of a string of various sensor elements, which may or may not be incased in a gel-filled plastic tube, is emplaced in the delivery casing. To meet the requirements of the proposed project, a fishtail drill point of greater diameter than the selected casing will be loosely inserted at the lower end of the casing and provided with a slot to permit torquing of the casing during the emplanting procedure. The sensor string or tube is attached to the fishtail drill point such that on extraction of the casing, the sensor string remains in the hole, anchored to the bottom by the detached drill point.

With this program in mind, the CMRET remote sea floor drill (RSD) design modification plans have been completed and await implementation, which will permit system operation to 1,000m. Basically, the modifications involve a battery powered d.c. electric-hydraulic system supplying an existing bottom mounted semi-rotary (reciprocal) casing drive mechanism fitted with hydraulic cylinders for pull-down and pull-up. The existing system is operated via a pressure vessel-encased computer system controlled by a computer on deck. Additional modifications will include the installation of a locator pinger and a video camera and light to assist in site location. Once modified, the RSD may be deployed from offshore vessels of opportunity, suspended from a single coaxial communication/suspension cable.

Operation

Initial operation of the VLAs/SFPs will be in an autonomous mode, utilizing battery power (pressure compensated) and data recording. While recording of thermal, pore pressure, and chemical data can be recorded for extended periods, the high volume typical in acoustic data collection will require down loading at three to five day intervals. Since the acoustic source for both P and S wave studies will be deployed from an appropriate surface vessel, servicing batteries and downloading the recorders can be accomplished by means of ROVs. It is, however, the long term intent to utilize power and communication uplink where available at the sea floor. The station will produce many channels of data on a more or less continuous basis. The total data volume will be large and recovery is not a trivial problem. Present plans are to digitize each channel on site and transmit the digital signals via optic-fiber cable to a structure, such as an oil platform, where they can be telemetered to an onshore processing facility.

CONCLUSIONS

Aspects of installing a station to monitor an area of the sea floor near hydrate mounds on the continental slope of the northern GOM have been discussed in depth by some of the world's foremost experts in appropriate fields. Unanimous agreement that not only is the concept feasible but that most of the necessary components exist and already have been used in deep ocean applications. A few components still require some development, though initial experiments and site selection will commence in the spring of 2001.

The monitoring station will commence initial operation by the end of 2003 and will begin collection on a more or less continuous basis in 2004. Physical and chemical information concerning sea floor stability and the accretion/dissociation of gas hydrates will be the initial primary focus. If that information reveals factors as expected, which elicit responses from chemosynthetic communities residing nearby, the stations's capabilities could be expanded to include biologic monitoring. This expansion should provide an excellent means of exploring the interactions between life forms and physical/chemical stimuli as well as ways of exploring how biologic agents produce or modify geologic materials and processes.

Transfer of technology and science to industry and government agencies will be regarded as a primary responsibility. Also, an effort will be made to make activities and results of the monitoring station available for use in classrooms. The access will be in near-to-real time and, as much as possible, interactive.

A Cooperative Effort with Support/Participation From

DEPARTMENT OF COMMERCE
National Oceanographic and Atmospheric Administration
National Undersea Research Program

DEPARTMENT OF DEFENSE
Naval Research Laboratory
Naval Oceanographic Office

DEPARTMENT OF ENERGY
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Woods Hole Oceanographic Institution

Facilitated by:
The Center for Marine Resources and Environmental Technology
The University of Mississippi

GAS HYDRATES IN THE GULF OF MEXICO: A GEOCHEMICAL PERSPECTIVE

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ABSTRACT

Thermogenic gas hydrate is abundant on the Gulf of Mexico (GOM) continental slope because hydrocarbon gases from a deep, hot subsurface hydrocarbon system vent prolifically to the sea floor where regions of low temperatures and high pressures are within the gas hydrate stability zone (GHSZ). The presence or absence of gas hydrate is controlled by geologic structure, among other factors. Structure II gas hydrate is commonly encountered and contains mainly C_1-C_4 hydrocarbons that crystallize from relatively unaltered vent gases. Structure H hydrate is occasionally found in association with structure II hydrate and contains abundant isopentane. Most structure II gas hydrate at sites studied in the ~540-1930 m water depth range appears to be stable, and gas hydrate is thought to be accumulating to considerable depth in sediment (> 1 km) because of prolific gas venting. A leaky hydrocarbon system is probably the main contributor of thermogenic greenhouse gases to the ocean and atmosphere from the GOM, not gas hydrate decomposition. The geology of gas hydrate in the GOM is particularly favorable for future development as an energy mineral.

INTRODUCTION

The GOM has possible global significance as a large reservoir of hydrate-bound greenhouse gases. Gas hydrates are abundant on the Gulf slope because hydrocarbon gases vent to a sea-floor temperature and pressure regime in which gas hydrates are stable. Larger gas hydrate outcrop sites have been discovered on the sea floor of the GOM Salt Basin than in any other basin (Sassen *et al.* 1999a). Intact gas hydrate samples have been recovered from sediments by piston coring and by research submersibles from >50 localities in the Gulf slope (Figure 1C.7). Gas hydrate localities form a belt that extends laterally across the Gulf from offshore Texas to the central Gulf offshore Louisiana over a distance >500 km; near the center of this range, the maximum width of the belt is >100 km (Figure 1C.7). The minimum observed water depth of occurrence of gas hydrate in the GOM is ~440 m and the maximum water depth is >2,400 m (Sassen *et al.* 1999a). The thickness of the gas hydrate stability zone (GHSZ) increases with water depth, and models suggest that gas-hydrate bearing sediments could be >1 km thick in 2-3 km deep water (Milkov and Sassen 2000).

Gas hydrates are ice-like crystalline minerals in which hydrocarbon gases and non-hydrocarbon gases are held within rigid cages of water molecules. Structure I gas hydrate has a body-centered cubic lattice, structure II gas hydrate has a diamond lattice, and structure H gas hydrate has a hexagonal lattice (Sloan 1998). Structure I gas hydrate, which occurs in the Gulf and many other basins, is usually dominated by bacterial methane (Kvenvolden 1995, 1999). Theoretically, Structure I gas hydrates could contain either thermogenic or bacterial methane, but no examples of thermogenic methane gas hydrate (structure I) are yet known from the GOM. The $\delta^{13}C$ and δD of bacterial methane from seafloor gas vents sampled by research submarine and from deep-water

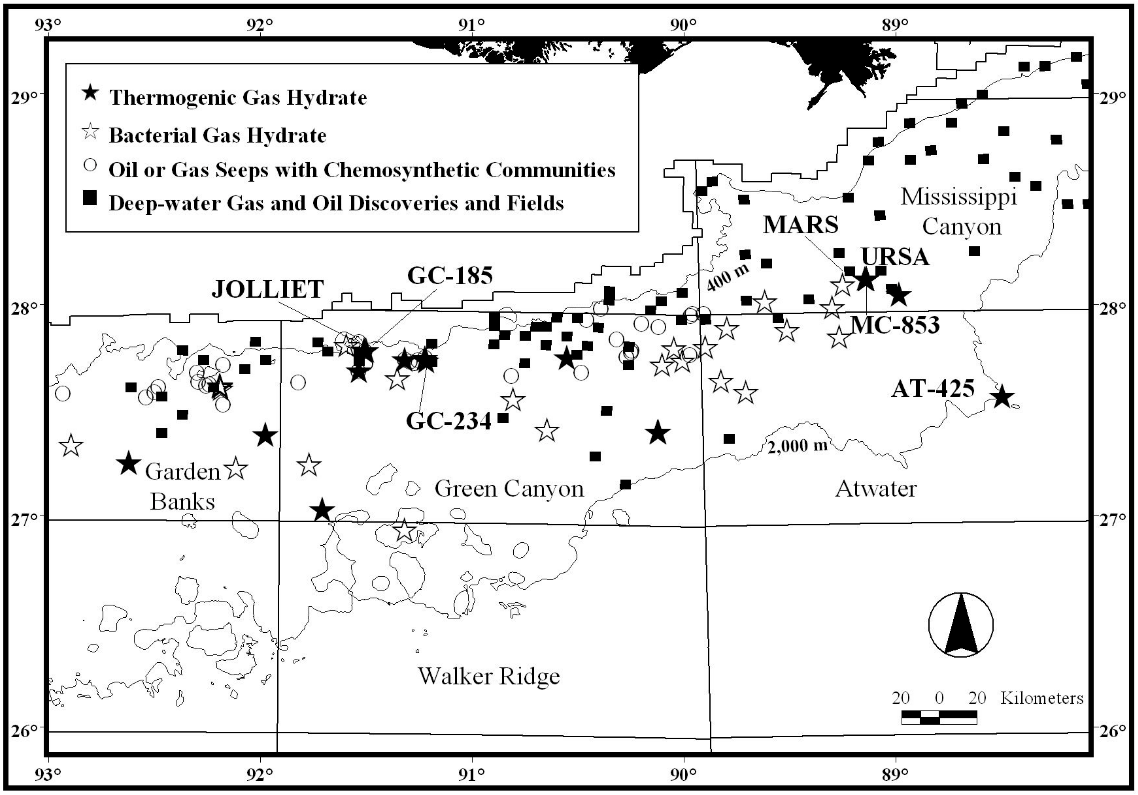

Figure 1C.7. Sketch map showing distribution of known gas hydrate sites, seeps with chemosynthetic communities, and oil and gas fields in the Gulf of Mexico. Note study areas (GC 185, GC 234, MC 853, AT 425) and closely associated oil fields (Jolliet, Mars, Ursa).

structure I gas hydrates are thus far consistent with an origin from methanogenesis via CO_2 reduction (Sassen *et al.* 1999a, b). The origin of bacterial (structure I) gas hydrate, which contains only a single hydrocarbon molecule, thus appears relatively straightforward in the GOM and will not be discussed in this paper.

In contrast to simple bacterial methane hydrate, thermogenic gas hydrates preserve complex information on origin and stability because numerous hydrocarbon molecules of varying properties are held within crystal lattices. Both structure II and structure H gas hydrates are believed to co-exist in the Gulf at water depths as shallow as ~540 m (Sassen and MacDonald 1997). Structure II gas hydrate generally includes C_1-C_4 hydrocarbons (methane through isobutane), whereas structure H gas hydrate generally includes C_1-C_5 hydrocarbons (methane through isopentane) as significant components (Sloan 1998).

Temperature, pressure, and availability of hydrate-forming gas molecules are fundamental factors, among others, that control the stability of gas hydrate (Sloan 1998). Thermogenic gas hydrates (structure II and H) are stable at higher temperatures and lower pressures than structure I gas hydrate (Sloan 1998; Milkov and Sassen 2000). Roberts *et al.* (1999) suggest that outcropping structure II gas hydrates at GC 185 (~540 m) are transiently stable because of natural fluctuations in temperature of seawater. Variable or decreasing rates of free gas flux also impact gas hydrate stability, especially of gas hydrate that outcrops on the sea floor (Egorov *et al.* 1999). Bacterial oxidation of hydrate-bound methane and of free hydrocarbon gases in adjacent sediments also could decrease stability of structure II gas hydrate by removing key hydrate-forming hydrocarbons (particularly propane) necessary to maintain equilibrium (Sassen *et al.* 1998, 1999b). Less is known about the stability and composition of thermogenic gas hydrates buried at depth in sediment and in deep water near the downdip limit of the GOM Salt Basin.

Massive decomposition of gas hydrate and concomitant release of greenhouse gases including methane are suggested as an agent of rapid climate change (e.g. MacDonald 1990; Dickens 1995, 1997; Bains *et al.* 1999; Max *et al.* 1999). Kvenvolden (1999) believes this climate change hypothesis is overstated. The volume of free gas from hydrate decomposition is thought, on the basis of indirect evidence, to be meaningful in some basins, contributing to the formation of sea floor seep features (e.g. Vogt *et al.* 1994; Paull *et al.* 1995), and impacting sediment fabrics (Kennet and Fackler-Adams 2000). Although the line of reasoning is attractive, direct molecular and isotopic evidence of significant gas hydrate decomposition is thus far lacking, and other explanations are possible. Recent piston coring and submersible investigations have given us the opportunity to add to our GOM database and obtain intact sediment-free samples of thermogenic gas hydrate from new and deeper-water sites in the GOM.

The primary objective of the present paper is to review recent work on gas hydrate and associated sediments from shallow to ultra-deep water within the GHSZ. Secondary objectives are to address the basic geologic questions of whether there is stable net accumulation or decomposition of gas hydrate in the GOM. We also consider gas hydrate as a future energy mineral.

GEOLOGIC SETTING

The main structural features of the northern GOM are salt basins including the large GOM Salt Basin and a series of smaller interior salt basins that extend from south Texas to Alabama. The basins formed during Late Triassic rifting and were floored by salt (Louann/Werner formations) during Middle Jurassic marine incursions. During the Tertiary, when the development of large river systems to the north provided abundant sediment to the basin. An important effect of the rapid sediment influx was massive deformation of underlying salt. The GOM continental shelf is now characterized by numerous salt domes, whereas the continental slope is more affected by large sheet-like salt thrusts that extend from the shelf edge across the continental slope to the Sigsbee Escarpment, near the edge of the abyssal plain. The Mississippi Fan Foldbelt is a zone of rapid geologic transition that extends northeast-southwest for ~350 km along the lower continental slope of the GOM (Weimer and Buffler 1992; Wu 1993; Rowan 1997). Some salt pierced through the overlying section to form allochthonous salt bodies at shallow depths, providing localized conduits for migration to the sea floor. The Mississippi Fan Foldbelt represents the downdip limit of the

GOM Salt Basin, and undeformed salt-free sediments of the abyssal plain are thought to occur immediately to the south.

The geology of the GOM slope is conducive to seepage from deeply buried petroleum systems to the sea floor because hydrocarbon generation is geologically recent within deep sediment sections of large salt withdrawal basins (Wenger *et al.* 1994). Fracture zones associated with moving salt sheets, as well as active faults, provide efficient migration conduits for fluid flow to the sea floor including hydrocarbons and brines. The sea floor shows markedly irregular bathymetry from structural deformation, faulting, fracturing, and slumping (Roberts and Carney 1997). Massive hydrocarbon seepage manifests itself at the Gulf sea floor as gas hydrate, oil-stained sediments, authigenic carbonate rock with light $\delta^{13}C$, and unique hydrocarbon-driven chemosynthetic communities (e.g. Aharon *et al.*1997; Roberts and Aharon 1994; MacDonald *et al.* 1989; Roberts and Carney 1997). Because the fluid flow is structurally focused, gas hydrate accumulations are concentrated along the rims of salt-withdrawal basins, over salt ridges, and near the faulted and folded margin of the Sigsbee Escarpment near the downdip limit of the GOM Salt Basin (Sassen *et al.* 1999a). Seep-related features such as gas hydrates are only infrequently observed within salt withdrawal basins themselves because such sediments are less deformed and usually lack major migration conduits to shallow sediments or the sea floor.

MAIN STUDY SITES

The GC 185 and 234 sites are on the upper slope of the GOM in ~540 m water depth (Figure 1C.7), near the upper limit of the GHSZ. The most recent episodes of hydrocarbon venting in this area appear to have commenced during the late Pleistocene (Aharon *et al.* 1997). The GC 185 site (Bush Hill) is a fault-related seep feature (27˚ 45.7' N and 91˚ 30.5' W). An antithetic fault at GC 185 is related to nearby Jolliet Field (GC 184). Oil and gas that vent at GC 185 and which occur in reservoirs at ~2-3 km depth in Jolliet Field correlate (Kennicutt *et al.* 1988). Composition of gas venting to the sea is consistent with an origin from the same hydrocarbon source system or from Jolliet Field itself. Research submersible observation shows that sea-floor gas hydrate mounds are generally associated with active gas vents (Figure 1C.8).

Multiple gas hydrate mounds at GC 185 have persisted for >7 years, but mounds show deformation over a scale of months or years (MacDonald *et al.* 1994). Vent mounds show typical features (Figure 1C.8). Gas hydrate is capped by thin layer of highly deformed hemipelagic mud that contains bacterially oxidized crude oil, free gas, dispersed gas hydrate nodules, authigenic carbonate depleted in ^{13}C, and H_2S (Sassen *et al.* 1993, 1994, 1999a, b). The fabric of the sediment cap is affected by tubular polychaete burrows that extend down to the gas hydrate, and sediment contains abundant calcareous fragments of chemosynthetic mussels as well as various bivalves and gastropods (Sassen *et al.* 1998). The gas hydrate mounds are covered by bacterial mats (*Beggiatoa*, which oxidizes sulfide) and are surrounded by a complex chemosynthetic community including tube worms (Sassen *et al.* 1999a, b).

The GC 234 site (27˚ 44.8' N and 91˚ 13.3' W) at ~543 m water depth is a fault-related seep area over shallow salt. When the site was first identified by a research submarine in 1997, a small gas hydrate vein-filling surface (~1 m) outcropped on the surface of an upthrown fault scarp in

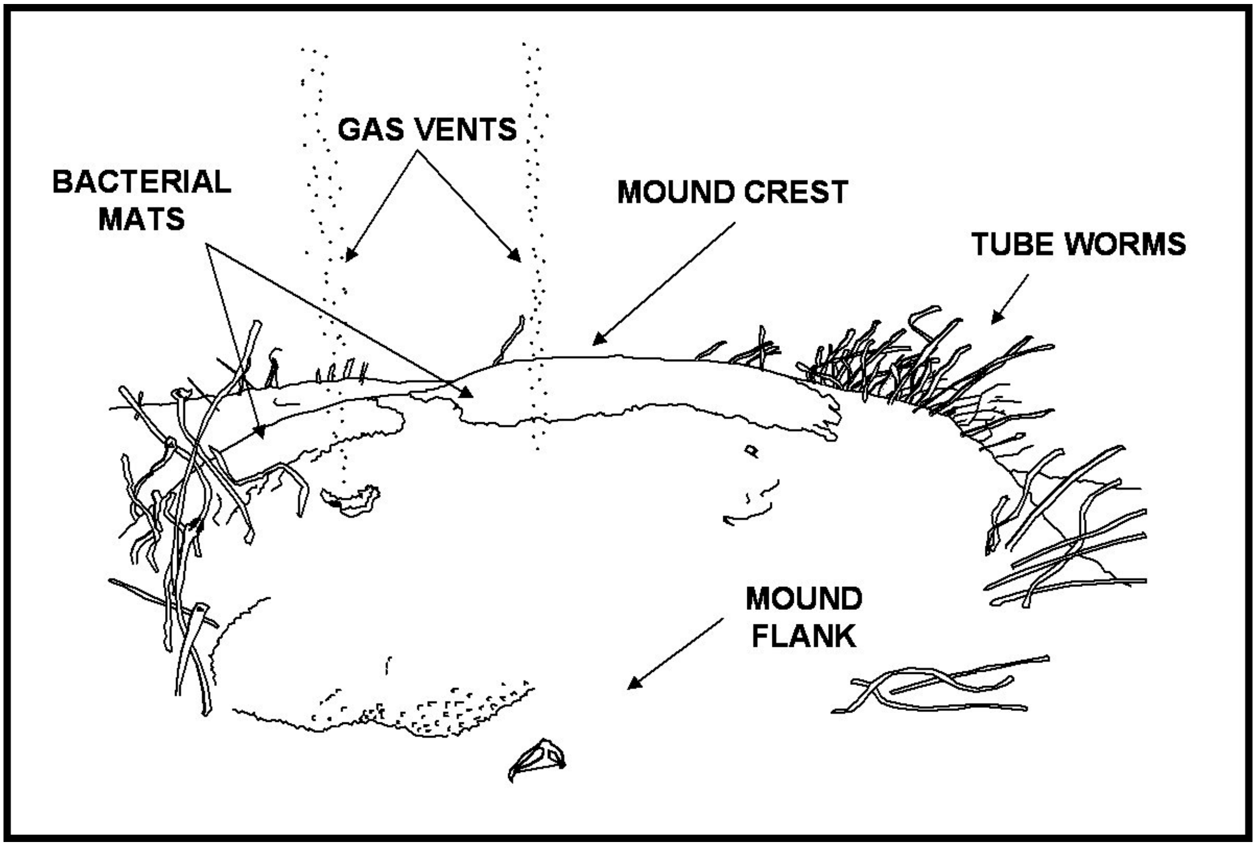

Figure 1C.8. Sketch showing main elements of a typical gas hydrate mound (1-3 m across) formed around thermogenic gas vents in a chemosynthetic community. (From Sassen *et al.* 1999b.)

association with gas vents. The exposure was actively undercut by vent gas expulsion. The gas hydrate was unstable in contact with seawater, and exposed gas hydrate had decomposed by 1998 (Sassen *et al.* 1999b). Bacterial mats (*Beggiatoa*) covered the sediment surface over the exposed gas hydrate. A complex chemosynthetic community including tube worms is present at this site (Sassen *et al.* 1999b). Maximum depth of stability in sediments of structure II hydrate at the GC 234 site is ~650 m, similar to the GC 185 site (Milkov and Sassen 2000).

The Mississippi Canyon 853 site (28° 7.4' N, 89° 8.2' W) at ~1060-1070 m water depth is a large sea-floor mound (~1.5 km across, with ~30-40 m of relief) on the middle Gulf slope (Figure 1C.7). The mound directly overlies shallow salt on the edge of a large salt withdrawal basin near Ursa and Mars fields (Figure 1C.7). The mound is believed to contain large volumes of gas hydrate, free gas, authigenic carbonate, and highly deformed sediments (Sassen *et al.* 1999a). The MC 853 site is in close association with Ursa Field and the giant Mars Field (Figure 1C.7). The GC 185, GC 234, and MC 853 sites show rapid hydrocarbon flux related to maturation and vertical migration from the same or similar Mesozoic source facies (Wenger *et al.* 1994) at ~6-10 km burial depth.

The AT 425 study site is an isolated sea-floor vent feature on the lower GOM slope (27˚ 34.1' N and 88˚ 29.7' W) at ~1920-1930 m water depth (Figure 1C.7). The site is part of the Mississippi Fan

Foldbelt (Weimer and Buffler 1992; Wu 1993; Rowan 1997). The hydrocarbon source system at AT 425 is thought to represent a different Mesozoic source facies than encountered updip in the GOM Salt Basin at our other study areas. The AT 425 site is characterized by sea-floor seep features related to faults overlying an allochthonous salt ridge at shallow depth in sediments (Sager and Kennicutt 2000). Fluids from depth beneath the AT 425 site pierce a thick apron of gently dipping sediment deposited by transport from the Mississippi Fan Channel. The AT 425 vent is assumed to be a major fluid flow release site from depth in the Mississippi Fan Foldbelt because no other vent and gas hydrate sites are known within tens of km (Figure 1C.7).

OVERVIEW

Vent Gases

The molecular and isotopic properties of gases that vent directly to the water column from gas hydrate mounds on the sea floor can determine whether the gases are related to ongoing crystallization of associated gas hydrate or whether they are related to gas hydrate decomposition. Thus, molecular and isotopic data on vent gases from hydrate-bearing sediments are pivotal and should be an objective focus of future research on gas hydrate stability. The change in phase from vent gas to solid structure II gas hydrate involves molecular fractionation that favors gases of appropriate molecular diameter (Sloan 1998). Methane decreases in abundance relative to vent gas and the C_{2+} hydrate-forming gases (especially ethane and propane) increase in abundance in structure II gas hydrate (Sloan 1998). Meaningful carbon isotopic fractionation is not thought to occur during gas hydrate crystallization (Claypool *et al.* 1985, Brooks *et al.* 1986; Kennicutt *et al.* 1988; Sassen and MacDonald 1997; Sassen *et al.* 1999a, b). On this basis, vent gas from decomposition of structure II gas hydrate would be isotopically similar but would display a characteristic molecular distribution with anomalous percentages of hydrate-forming hydrocarbons (such as ethane, propane, and butanes).

Thermogenic gas vents, thus far, have only been sampled overlying hydrate-bearing sediments at the GC 185 and GC 234 sites on the GOM slope at ~540 m water depth. These vents are near the upper limit of the GHSZ (Milkov and Sassen 2000). The molecular distributions of gas venting from gas hydrate mounds show generally decreasing relative abundance of C_1-C_5 hydrocarbons with increasing carbon number, as generally observed in relatively unaltered reservoir gases (e.g. James and Burns 1984). The molecular distributions of vent gas are incompatible with significant flux from gas hydrate decomposition when compared to flux from the deep subsurface (Sassen *et al.* 2001). Instead, the molecular and isotopic properties of vent gases are consistent with direct migration of relatively unaltered hydrocarbon gases from deeply buried source rocks, or with leakage from nearby subsurface oil reservoirs (Kennicutt *et al.* 1988; Sassen *et al.* 1999; Sassen *et al.* 1999a, b). This assessment of vent gas properties over shallow hydrate-bearing sediments in the GOM has important implications. At gas hydrate study sites in the GOM, rapid flux of thermogenic greenhouse gas to the water column appears to be dominated by an unusually leaky subsurface hydrocarbon system that also charges subsurface reservoirs with oil and gas (Sassen *et al.* 2001). Similarly, most other large seep features at the GOM sea floor, as well as chemosynthetic communities, are related to rapid flux from the subsurface hydrocarbon system, and are generally not related to hydrate decomposition.

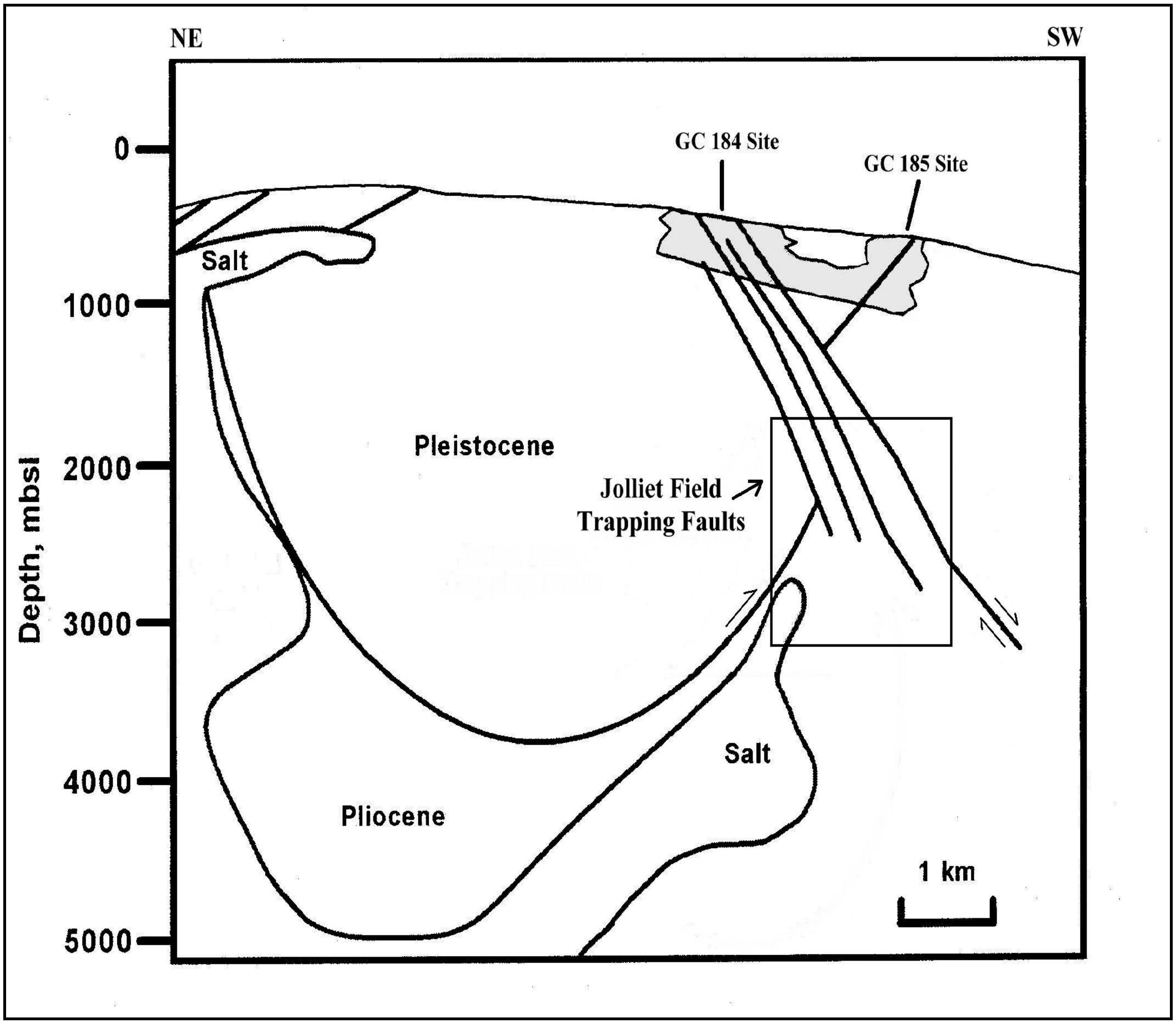

Figure 1C.9. Sketch showing modeled subsurface distribution of gas hydrate at the GC 185 site. Note that much gas hydrate is thought to be deeply buried and stable in sediments where thermogenic hydrocarbon flux from the Jolliet Field faults is continuous for meaningful spans of time.

Measurements of filling rates of plastic tubes of known volume during gas hydrate experiments at the sea floor suggest that the rate of venting from a single bubble stream to the water column at the GC 185 site is about 60 L/minute (STP). In aggregate, venting rates from large numbers of orifices at gas hydrate sites could be considerable. The observation that decomposition does not impact vent gas compositions (Sassen *et al.* 2001) serves as direct evidence that gas hydrate decomposition is not quantitatively significant because most gas hydrate is buried and stable at depth in sediments (Figure 1C.9). It is postulated that the bulk of buried gas hydrate masses at study localities within the GHSZ are stable or are still accreting because of the relatively rapid flux of gases from the subsurface (Sassen *et al.* 2001).

Gas Hydrate and Sediment Fabrics

Interpreting observed gas hydrate fabrics and textures helps to address whether net gas hydrate accumulation or decomposition is occurring in the GOM. Deformed vein-filling gas hydrates and gas hydrate nodules are observed exposed on the flanks of gas hydrate mounds at the GC 185 and GC 234 sites (~540 m) in the GOM (Sassen *et al.* 1998; 1999a). The basic morphology of gas hydrate recovered from piston cores at the deep-water AT 425 and MC 853 sites consists of vein fillings and nodules at sediment depths in the 1.8 to 4.4 m range. The fabrics we observe both in shallow and ultra-deep water are typical of gas hydrate settings with high flux rates of hydrocarbon gases (Ginsburg 1998; Ginsburg and Soloviev 1998).

Based on experimental precipitation of thermogenic gas hydrates at natural gas vents at the Gulf sea floor (Sassen and MacDonald 1997), natural gas hydrate crystallization can occur rapidly (on a scale or seconds or minutes). The vein fillings observed in cores are postulated to result from sudden episodic increases in gas pressure that open up tension fractures along sub-horizontal zones of weakness in hemipelagic muds, mixing gas and water to effect rapid crystallization that holds the fractures open. The gas hydrate vein-fillings probably further expand during subsequent gas injections, and as a consequence of pressure of crystallization (Sassen *et al.* 1999a). Associated sediments are highly deformed by crystallization of the gas hydrates. One could speculate that, in the GOM at present, soft sediment deformation from gas hydrate crystallization is more important than the effects of gas hydrate decomposition.

Structure II and Structure H Gas Hydrates

Structure II gas hydrate has been identified from oily sediments of the GOM (Brooks *et al.* 1986) and from the Caspian Sea (Ginsburg and Soloviev 1998). Gas hydrate samples from the shallow GC 185 and GC 234 sites at ~540 m water depth have C_1-C_5 hydrocarbon molecular distributions that are broadly consistent with structure II gas hydrate, in that methane, ethane, propane, and butanes are significant components (Sloan *et al.* 1998). The structural assignment (structure II) based on molecular distribution is confirmed by solid state nuclear magnetic resonance (NMR) of intact gas hydrate sample from GC 184 (Davidson *et al.* 1986), and from GC 185 (Sassen and MacDonald 1997). C_1-C_5 molecular distributions from the AT 425 and MC 853 sites are consistent with structure II gas hydrates because of their basic molecular similarity to proven structure II gas hydrate at GC 184/185. Structure II gas hydrates from ultra-deep water at AT 425 and MC 853 also appear to have crystallized from relatively unaltered C_1-C_5 hydrocarbon gases at or near natural gas vents with high flux rates.

Rapid crystallization of gas hydrate appears to affect the molecular distribution of gases in associated sediments by exclusion of incompatible molecules. Crystallization of structure II gas hydrate preferentially removes hydrate-forming gases (i.e. methane, ethane, propane) and enriches residual gases in incompatible hydrocarbons (i.e. pentanes) that are too large to fit within structure II hydrate cages. Isopentane is present in anomalous abundance in sediment samples that directly overlie buried structure II gas hydrate at AT 425 (Sassen *et al.* 2000). Similarly, isopentane is present in anomalous abundance (as much as 13.8%) in sediments near active gas hydrate mounds at GC 185 and GC 234 (Sassen *et al.* 1999b). The free isopentane in hydrate-bearing sediments further contributes to explaining the observed association of structure H gas hydrate, rich in isopentane, with structure II gas hydrate in the GOM (Sassen and MacDonald 1994). Other novel crystal structures of gas hydrate are likely to be discovered in the GOM.

CONCLUSIONS AND SYNTHESIS

The major source of thermogenic greenhouse gases in the GOM is a leaky subsurface hydrocarbon system that also charges subsurface reservoirs of oil and gas. GOM gas hydrate accumulations are also a meaningful reservoir of greenhouse gases that may be released from sediments if gas hydrate decomposition occurred. One basic question is assessment of the relative rates of gas hydrate accumulation and decomposition in the GOM. Several lines of reasoning suggest that structure II gas hydrate is forming in the GOM at a significantly greater rate than it is decomposing. Vent gases over hydrate-bearing sediments and gas hydrate mounds do not show evidence that gas hydrate decomposition is quantitatively significant.

All study sites (~540-1930 m water depth) are high-flux settings where hydrocarbon migration conduits intersect the sea floor deep within the GHSZ. Gas hydrate and sediment fabrics are consistent with the rapid crystal growth caused by high flux rates of hydrocarbon gases. The C_{2+} hydrocarbons of gas hydrates are protected from bacterial oxidation when locked within the stable structure II gas hydrate crystal lattice (Sassen *et al.* 1998,1999a, b). The abundance of incompatible isopentane in sediments adjacent to structure II gas hydrate provides additional evidence of recent or ongoing gas hydrate crystallization, and also contributes to explaining the observed association of structure II and isopentane-rich (structure H) gas hydrates in the GOM (Sassen and MacDonald 1994).

The process of generation and migration of oil and gas from source rocks can last as much as millions of years. We conclude that gas hydrate is sometimes unstable in the GOM, particularly when exposed to the water column at shallow water depths near the upper limit of the GHSZ, where water temperatures are most variable. Nevertheless, overall results are consistent with net accumulation of gas hydrates buried in sediment as a consequence of recent and ongoing crystallization. Thermogenic gas hydrate crystallization is driven by hydrocarbons from an active subsurface hydrocarbon system.

The three-dimensional aspect is important. Maximum thickness of the GHSZ increases with increasing water depth. Models of stability suggest that thermogenic gas hydrate could accumulate within sediments at depths >1 km beneath the sea floor of the ultra-deep GOM (Milkov and Sassen 2000). Deeply buried gas hydrates are probably well insulated from the transient effects (such as temperature changes) that impact gas hydrate at or near the sea floor. Large volumes of gas hydrate in the GOM are probably buried as stable accumulations in sediments of ultra-deep water where the maximum thickness of the GHSZ is greatest (Milkov and Sassen 2000).

The molecular distributions of thermogenic gas vents suggest that the flux of hydrocarbon greenhouse gases from a leaky subsurface hydrocarbon system is far more significant than from gas hydrate decomposition in the GOM. Insofar as the GOM is a meaningful analog, it appears prudent to constrain or modify speculation on the relation between gas hydrate decomposition and global climate change. Other factors, such as coincident maturation of prolific hydrocarbon source rocks in leaky basins on global continental margins could be more important. Because gas hydrate crystallization results in net trapping of hydrocarbons before subsurface gases can impact the sea and atmosphere, stable or accumulating gas hydrates appear likely to buffer the atmosphere by sequestering some greenhouse gases (Sassen *et al.* 2001). Thus, massive accumulation of gas hydrate in leaky basins could contribute to global climate stability over meaningful spans of geologic time.

The GOM is probably one of the first areas in which economic production of gas hydrate energy will occur. Instead of being thinly dispersed in pore spaces of sediment, gas hydrate in the GOM often occurs as thick vein-fillings (as much as 40 cm) in fracture porosity and as nodules. Moreover, models suggest that gas hydrate is stable and extends to great depth in sediment, perhaps as thick as a kilometer. Thus, gas hydrate is highly concentrated in the GOM, which is an important factor in economic assessment. The Department of Energy predicts that conventional supplies of gas will begin an era of permanent decline in production within 10-20 years, yet demand is projected to increase at the same time. Alternate sustainable energy resources (e.g. hydrogen-based energy) will take longer than that to bring on line. Energy from gas hydrate could bridge the gap from conventional fossil fuels to a sustainable energy future.

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REFERENCES

Aharon, P. H.P. Schwarcz, H.H. Roberts. 1997. Radiometric dating of hydrocarbon seeps in the Gulf of Mexico. GSA Bulletin 109, 568-579.

Bains, S., R.M. Corfield, R.D. Norris. 1999. Mechanisms of climate warming at the end of the Paleocene. Science 285, 724-727.

Brooks, J.M., H.B. Cox, W.B. Bryant, M.C. Kennicutt II, R.G. Mann, T.J. McDonald. 1986. Association of gas hydrates and oil seepage in the Gulf of Mexico. Organic Geochemistry 10, 221-234.

Claypool, G.W., C.N. Threlkeld, P.N. Mankewizc, M.A. Arthur, T.A. Anderson. 1986. Isotopic composition of interstitial fluids and origin of methane in slope sediment of the Middle America Trench, Deep Sea Drilling Project Leg 84. *In* von Huene, R., Aubouin, J., *et al.*, eds., Initial Reports, Deep Sea Drilling Project 84. Government Printing Office, Washington, D.C., pp. 683-691.

Davidson, D.W., S.K. Garg, S.R. Gough, Y.P. Handa, J.A. Ratcliffe, J.A. Ripmeester, J.S. Tse, W.F. Lawson. 1986. Laboratory analysis of a naturally occurring gas hydrate from sediment of the Gulf of Mexico. Geochimica et Cosmochimica Acta 50, 619-623.

Dickens, G.R., J.R. O'Neil, D.K. Rea, R.M. Owen. 1995. Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Paleocene. Paleoceanography 10, 965-971.

Dickens, G.R., M.M. Castillo, J.C.G. Walker. 1997. A blast of gas in the latest Paleocene: Simulating first-order effects of massive dissociation of oceanic methane hydrate. Geology 25, 259-262.

Egorov, A.V., K. Crane, P.R. Vogt, Rozhkov. 1999. Gas hydrate that outcrops on the sea floor: stability models. Geo-Marine Letters 19, 69-75.

Ginsburg, G.D., V.A. Soloviev. 1998. Submarine gas hydrates. VNIIOkeangeologia, St. Petersburg, p. 216.

Ginsburg, G.D. 1998. Gas hydrates in deep-water sediments. *In* Henreit, J.-P., Meinert, J., eds., Gas hydrates: Relevance to world margins and climate change. Geological Society, London, pp. 51-62, Special Publication 137.

James, A.T., B.J. Burns. 1984. Microbial alteration of subsurface natural gas accumulations. AAPG Bulletin 68, 957-960.

Kennet, J.P., B.N. Fackler-Adams. 2000. Relationship of clathrate instability to sediment deformation in the upper Neogene of California. Geology 28, 215-218.

Kennicutt II, M.C., J.M. Brooks, G.J. Denoux. 1988. Leakage of deep, reservoired petroleum to the near surface of the Gulf of Mexico continental slope. Marine Chemistry 24, 39-59.

Kvenvolden, K.A. 1995. A review of the geochemistry of methane in natural gas hydrate. Organic Geochemistry 23, 997-1008.

Kvenvolden, K.A. 1999. Potential effects of gas hydrate on human welfare. Proceedings National Academy of Sciences, USA 96, 3420-3426.

MacDonald, G.J. 1990. Role of methane clathrates in past and future climates. Climatic Change 16, 247-281.

MacDonald, I.R., G.S. Boland, J.S. Baker, J.M. Brooks, M.C. Kennicutt II, R.R. Bidigare. 1989. Gulf of Mexico hydrocarbon seep communities II. Spatial distribution of seep organisms and hydrocarbons at Bush Hill. Marine Biology 101, 235-247.

MacDonald, I.R., N.L. Guinasso, Jr., R. Sassen, J.M. Brooks, L. Lee, K.T. Scott. 1994. Gas hydrate that breaches the sea-floor on the continental slope of the Gulf of Mexico. Geology 22, 699-702.

Max, M.D., W.P. Dillon, C. Nishimura, W.P. Hurdle. 1999. Sea-floor methane blow-out and global firestorm at the K-T boundary. Geo-Marine Letters 18, 285-291.

Milkov, A.V., and R. Sassen. 2000. Thickness of the gas hydrate stability zone, Gulf of Mexico continental slope: Mar. Petrol. Geology, v. 17, p. 981-991.

Paull, C.K., W. Ussler, III, W.S. Borowski, F.N. Spiess. 1995. Methane-rich plumes on the Carolina continental rise: Association with gas hydrates. Geology, 23, 89-92.

Roberts, H.H., P. Aharon. 1994. Hydrocarbon-derived buildups of the northern Gulf of Mexico: A review of submersible investigations. Geo-Marine Letters 14, 135-148.

Roberts, H.H., R. Carney. 1997. Evidence of episodic fluid, gas, and sediment venting on the northern Gulf of Mexico slope. Economic Geology 92, 863-879.

Roberts, H.H., W.J. Wiseman Jr., J. Hooper, G.D. Humphrey. 1999. Surficial gas hydrates of the Louisiana continental slope – Initial results of direct observations and in situ data collection. Offshore Technology Conference, Houston, Texas. OTC 10770, 259-272.

Rowan, M.G. 1997. Three-dimensional geometry and evolution of a segmented detachment fold, Mississippi Fan Foldbelt. Journal of Structural Geology 19, 463-480.

Sager, W.W., M.C. Kennicutt II. 2000. Proposal for Ocean Drilling Program on gas hydrate in the Gulf of Mexico. Offshore Technology Conference, Houston, Texas. OTC 12111, p. 17.

Sassen, R., H.H. Roberts, A. Aharon, J. Larkin, E.W. Chinn, R. Carney. 1993. Chemosynthetic bacterial mats at cold hydrocarbon seeps, Gulf of Mexico continental slope. Organic Geochemistry 20, 77-89.

Sassen, R., I.R. MacDonald. 1994. Evidence of structure H hydrate, Gulf of Mexico continental slope. Organic Geochemistry 23, 1029-1032.

Sassen, R., I.R. MacDonald. 1997. Hydrocarbons of experimental and natural gas hydrates, Gulf of Mexico continental slope. Organic Geochemistry 26, 289-293.

Sassen, R., I.R. MacDonald, N.L. Guinasso, S. Joye, A.G. Requejo, S.T. Sweet, J. Alcala-Herrera, D.A. DeFreitas, D.R. Schink. 1998. Bacterial methane oxidation in sea-floor gas hydrate: Significance to life in extreme environments. Geology 26, 289-293.

Sassen, R., S.T. Sweet, A.V. Milkov, D.A. DeFreitas, G.G. Salata, E.C. McDade. 1999a. Geology and geochemistry of gas hydrates, central Gulf of Mexico continental slope. Transactions Gulf Coast Association of Geological Societies 49, 462-468.

Sassen, R., S. Joye, S.T. Sweet, D.A. DeFreitas, A.V. Milkov, I.R. MacDonald. 1999b. Thermogenic gas hydrates and hydrocarbon gases in complex chemosynthetic communities, Gulf of Mexico continental slope. Organic Geochemistry 30, 485-497.

Sassen, R., S.T. Sweet, D.A. DeFreitas, and A.V. Milkov. 2000. Exclusion of 2-methylbutane (isopentane) during crystallization of structure II gas hydrate in sea-floor sediment, Gulf of Mexico: Org. Geochem., v. 31, p. 1257-1262.

Sassen, R., S.T. Sweet, A.V. Milkov, D.A. DeFreitas, and M.C. Kennicutt II. 2001. Thermogenic vent gas and gas hydrate in the Gulf of Mexico slope: Is gas hydrate decomposition significant? Geology, v. 29, p. 107-110.

Sloan, E.D. 1998. Clathrate hydrates of Natural Gases, 2nd Ed., Dekker, New York., p. 705.

Vogt, P.R., K. Crane, E. Dundvor, M.D. Max, S.L. Pfirman. 1994. Methane generated (?) pockmarks on young, thickly sedimented oceanic crust in the Arctic: Vestnesa Ridge, Fram Strait. Geology 22, 255-258.

Weimer, P., R.T. Buffler. 1992. Structural geology and evolution of the Mississippi Fan Foldbelt, Deep Gulf of Mexico. AAPG Bulletin 76, 255-251.

Wenger, L.M., L.R. Goodoff, O.P. Gross, S.C. Harrison, K.C. Hood. 1994. Northern Gulf of Mexico: An integrated approach to source, maturation, and migration. *In* Geological Aspects of Petroleum Systems. Proceedings, First Joint American Association of Petroleum Geologists/Asociasion Mexicana de Geologos Petroleos Research Conference, Mexico City, p. 6.

Wu, S. 1993. Salt and Slope Tectonics Offshore Louisiana. Ph.D. Thesis, Rice University, Houston, Texas, p. 251.

SESSION 2A

DEEPWATER SESSION

Co-Chairs: Mr. G. Ed Richardson, Minerals Management Service
Mr. James Regg, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Status on the Floating Production, Storage, and Offloading Environmental Impact Statement	Ms. Deborah Cranswick Minerals Management Service
Status of the Comparative Risk Assessment	Mr. James Regg Minerals Management Service Gulf of Mexico OCS Region
Regulatory Framework for Floating Production, Storage, and Offloading Systems	Ms. Wanda Parker WJP Enterprises
Deepwater Oil Transportation: Future Vision	Mr. C.G. (Chuck) Stuebe Conoco Shipping Company
DeepStar Activities, Accomplishments, and Plans	Mr. Allen J. Verret DeepStar Mr. Steve Brooks ExxonMobil
Update on U.S. Coast Guard OCS Activities	LCDR John Cushing Chief, Outer Continental Shelf Branch Eighth Coast Guard District

STATUS ON THE FLOATING PRODUCTION, STORAGE, AND OFFLOADING ENVIRONMENTAL IMPACT STATEMENT

Ms. Deborah Cranswick
Minerals Management Service

BACKGROUND

Several projects are underway in the Gulf of Mexico OCS Region to determine the applicability of placing a floating production, storage, and offloading (FPSO) system in the Gulf of Mexico (GOM). These include (1) an "outsourced" environmental impact statement (EIS) for FPSO systems, (2) a comparative risk assessment that compares potential risks associated with FPSOs, tension-leg platforms, spars, and fixed platforms that serve as "hubs" for other developments, and (3) a regulatory model to identify potential gaps in regulations regarding FPSOs.

Why was an EIS required for the proposed use of FPSOs in the GOM? FPSO usage in the GOM is considered to be new and unusual technology. Specifically, FPSO systems involve the on-site storage of oil, offloading procedures, and transport of OCS-produced oil by surface vessels (shuttle tankers or barges).

THE ENVIRONMENTAL IMPACT STATEMENT

Map of Study Area

Figure 2A.1 depicts the study area for the FPSO EIS.

Issues in the EIS

The following are issues to be addressed in the FPSO EIS:

- Operational Issues, including
    - Oil spill risks and spill response
    - Offloading and tankering operations
    - Emissions
    - Associated gas
- Regulatory Issues (involving jurisdiction and applicable regulations), including

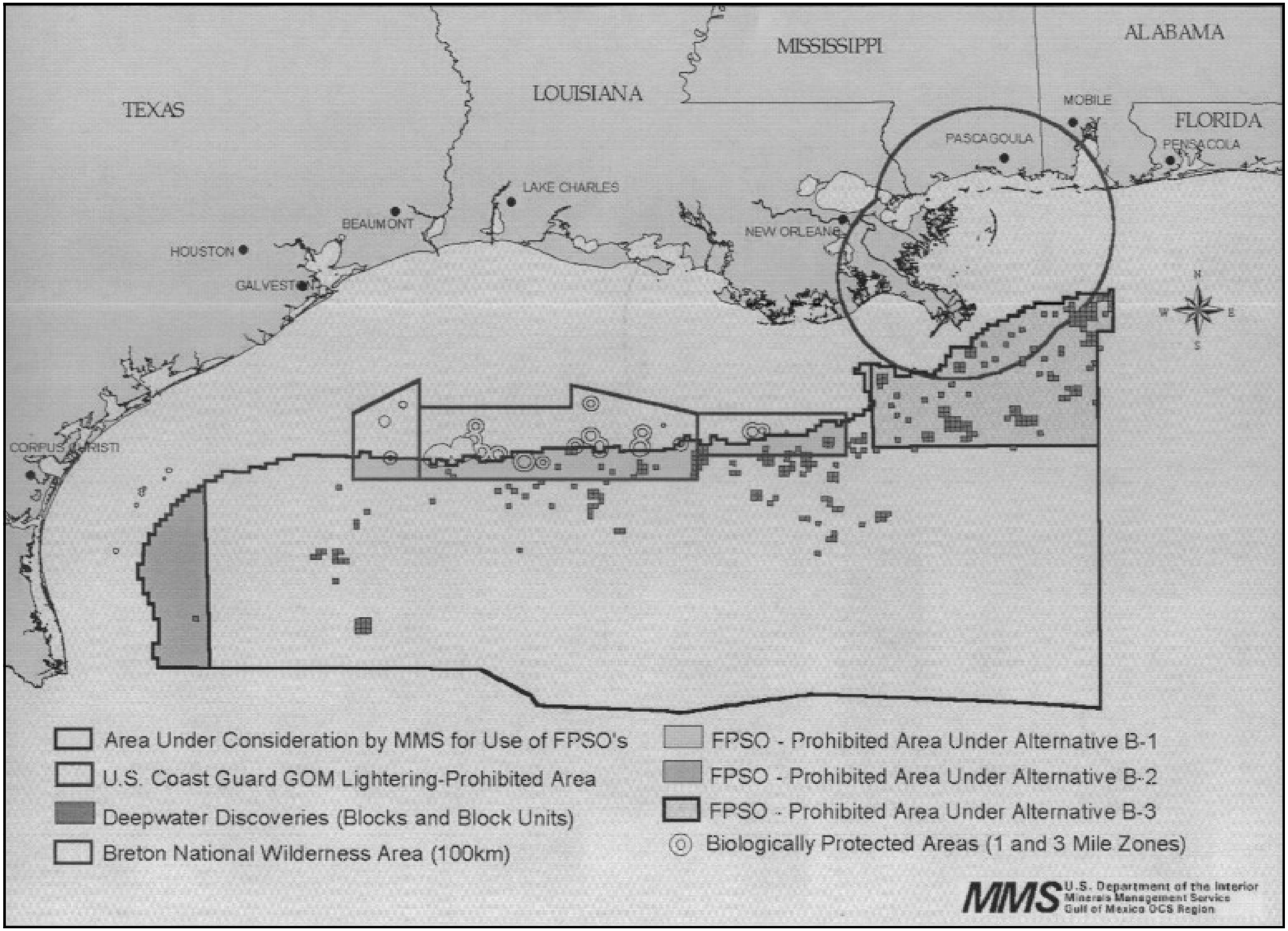


Figure 2A.1. Alternatives in FPSO EIS.

- Technical issues
- Unusual technologies verses spill risks
- Mooring

• Socioeconomic Issues.

Alternatives Considered in the Draft EIS

The FPSO EIS contains three alternatives for evaluation. These include

- Alternative A: approval of the general concept of using FPSOs in deepwater areas of the Western and Central Planning Areas of the GOM
- Alternative B: approval of the general concept of using FPSOs in deepwater areas of the Western and Central Planning Areas of the GOM with geographic restrictions and operational conditions
- Alternative C (No Action): the general concept of using FPSOs in the deepwater GOM is neither approved nor disapproved at this time.

FPSO Configuration

The following is a description of the generic FPSO configuration analyzed in the EIS:

- 1 MM bbls of oil storage
- Processing capabilities of up to 300,000 BOPD and up to 300 MM CFGPD
- Multi-well subsea clusters
- Transport of OCS-produced oil by 500,000 bbl shuttle tankers and
- Transport of OCS-produced gas by pipeline.

EIS Timelime

Table 2A.1 depicts the timeline for the remaining portions of the FPSO EIS process.

Draft EIS Distribution

The Draft EIS was a popular publication among the MMS external customers. Five hundred copies of the Draft EIS were printed. The public consumed all of these copies in less than two weeks. An additional 250 copies were printed. Most of these copies are gone. Customers also used the MMS

Table 2A.1. FPSO EIS process timeline.

DATES	EVENTS
17 August 2000	Draft EIS is issued
18-21 September 2000	Public Hearings on the Draft EIS
10 October 2000	Public Comment Period on the Draft EIS Ends
19 January 2001	Final EIS is issued
February 2001	Record of Decision is issued

website to gain information about the Draft EIS. During the interval of 13 August to 16 September 2000, the MMS website was visited 1,177 times by 429 visitors who downloaded 1,879 section of the Draft EIS.

Findings of the Draft EIS

The following is a listing of the finding contained within the Draft EIS document:

- Potential site-specific impacts are essentially the same as for other production systems

- Potential emission impacts to the Breton Wilderness Area occur from potential FPSO locations in the Viosca Knoll and northern Mississippi Canyon areas

- Comparable oil spill risks – "FPSO and shuttle tanker risk are comparable to the existing deepwater production structures and oil pipeline risks…the net gain in risk would be negligible"

- Potential FPSO-unique spills are 5% of the total spill risk.

Public Hearings

Public hearings on the Draft EIS were held in September 2000 at various locations in the Gulf States. Table 2A.2 characterizes these public hearings.

The public hearings developed the following comments and issues regarding the Draft EIS:

- Industry supports the use of FPSOs and Alternative A in the EIS

- Transportation issues include

  - Piloting of shuttle tankers

Table 2A.2. Locations of public hearing on the Draft EIS held in September 2000.

LOCATION	NO. OF ATTENDEES	NO. OF SPEAKERS
Mobile, AL	28	4
New Orleans, LA	40	2
Houston, TX	79	10
Lake Charles, LA	7	2

  - Safe movement from FPSO to ports
  - Tankers verses ocean-going articulated tug barges
- Single bottom/double sided verses double hull FPSOs
- FPSOs will create jobs
- The OCS spill record has improved
- Environmental Justice (benefits to minorities)

In addition, the MMS received 37 comment letters or cards regarding the Draft EIS. These documents raised the following issues.

- Hurricane survivability
- Pilotage of the shuttle tankers in ports
- Reliability and maneuverability of ocean going articulated tub barges
- Oil spills and spill response
- Attendant vessel requirements
- MMS verses U.S. Coast Guard jurisdiction

EIS Decision Model

Figure 2A.2 describes the FPSO EIS Decision Model.

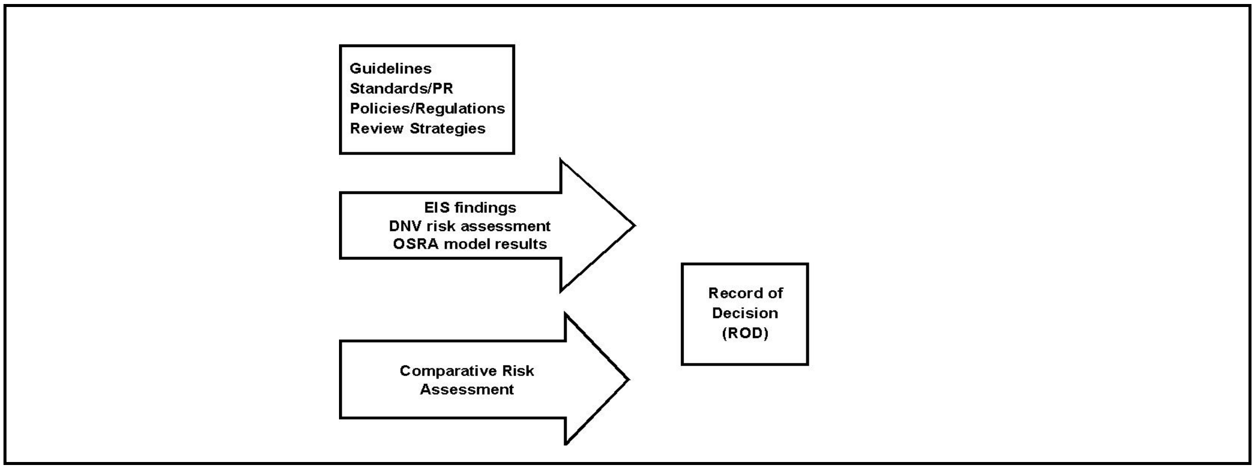


Figure 2A.2. The FPSO EIS Decision Model.

What Happens after the EIS and CRA

Figure 2A.3 depicts what is expected to happen after the EIS process and the comparative risk assessment is completed.

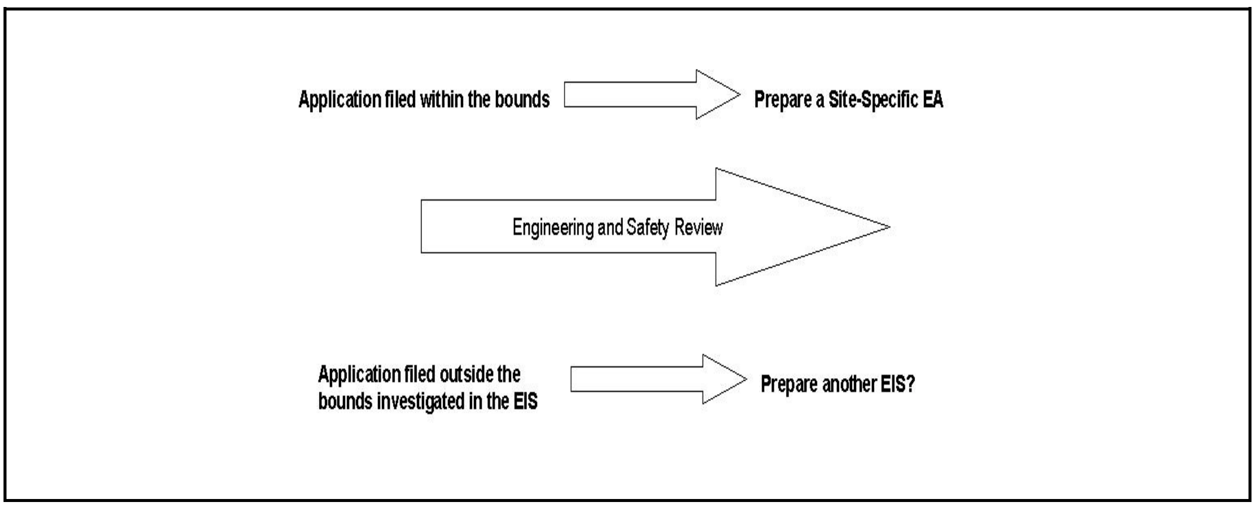


Figure 2A.3. What is expected to happen after the EIS process and the comparative risk assessment is completed.

Ms. Deborah Cranswick is a Senior Environmental Scientist in the Environmental Assessment Section in the MMS Gulf of Mexico Region. She is the Contracting Officer's Technical Representative on the contract for the FPSO Environmental Impact Statement and is also the EIS Coordinator.

STATUS OF THE COMPARATIVE RISK ASSESSMENT

Mr. James Regg
Minerals Management Service
Gulf of Mexico OCS Region

BACKGROUND

The purpose of the comparative risk assessment (CRA) is to determine the relative risks of floating production, storage, and offloading (FPSO) systems compared to the existing deepwater Gulf of Mexico (GOM) production facilities. Specifically, the CRA would examine the risks associated with tension-leg platforms (TLPs), spars, and fixed platform "hubs" or "hosts" compared to FPSO systems.

Table 2A.3 depicts the phases of the CRA and the status of each phase.

Table 2A.3. Phases and status of the CRA.

PHASE	PHASE DEFINITION	STATUS
I	System Definition	Completed
II	Events and Outcomes	Completed
III	Preliminary QRA	Completed
IV	Final Report Review and Presentation	Project Completion Projected for January 2001

WHY DO A COMPARATIVE RISK ASSESSMENT

In 1999, Bechtel Corporation conducted a risk assessment of an FPSO in the GOM. However, no risk acceptance criteria had been established for the GOM. Existing deepwater systems provide known risks. They comply with existing regulations. They are designed and operated under existing standards. The current production systems exhibit satisfactory operating experience.

COMPARATIVE RISK ASSESSMENT STUDY LIMITS

Study limits had to be established for the CRA. A "field life" definition was established. The interval starts when oil flows from the first well and ends when all wells are shut in. This definition excludes pre-drilling, site preparation, and installation of facilities. These events may be common to all systems under evaluation and therefore provides no differential. The study would include oil and gas production, drilling and well workovers during production, offshore processing of oil and gas, and transportation of oil and gas to the shore.

A study scenario and boundaries had to also be established. Table 2A.4 depicts CRA risk measures.

Table 2A.4. Risk measures of the CRA.

RISKS	MEASURE	UNIT
Human Safety	Total Fatalities	Number of Fatalities
Environment (Chronic)	Total Volume of Oil Release	BBLs of Oil
Environment (Acute)	Max. Volume of Oil Release in a Single Event	BBLs of Oil

A table of events and outcomes had to be developed. Table 2A.5 is an example of the type of events and outcomes considered in the CRA study.

Table 2A.5. Event types and outcomes considered in the CRA.

SYSTEM	SUBSYSTEM	PHASE	EVENT	POSSIBLE OUTCOME	COMMENTS
TLP	Riser	Production, Workover	Dropped Object	Damage to wells or riser	SCSSV should prevent major consequences

Figure 2A.4 represents an example of the result format expected from the CRA study. Note the A, B, C, and D representing each bar in the chart would be the production systems; e.g., TLP, spar, etc.

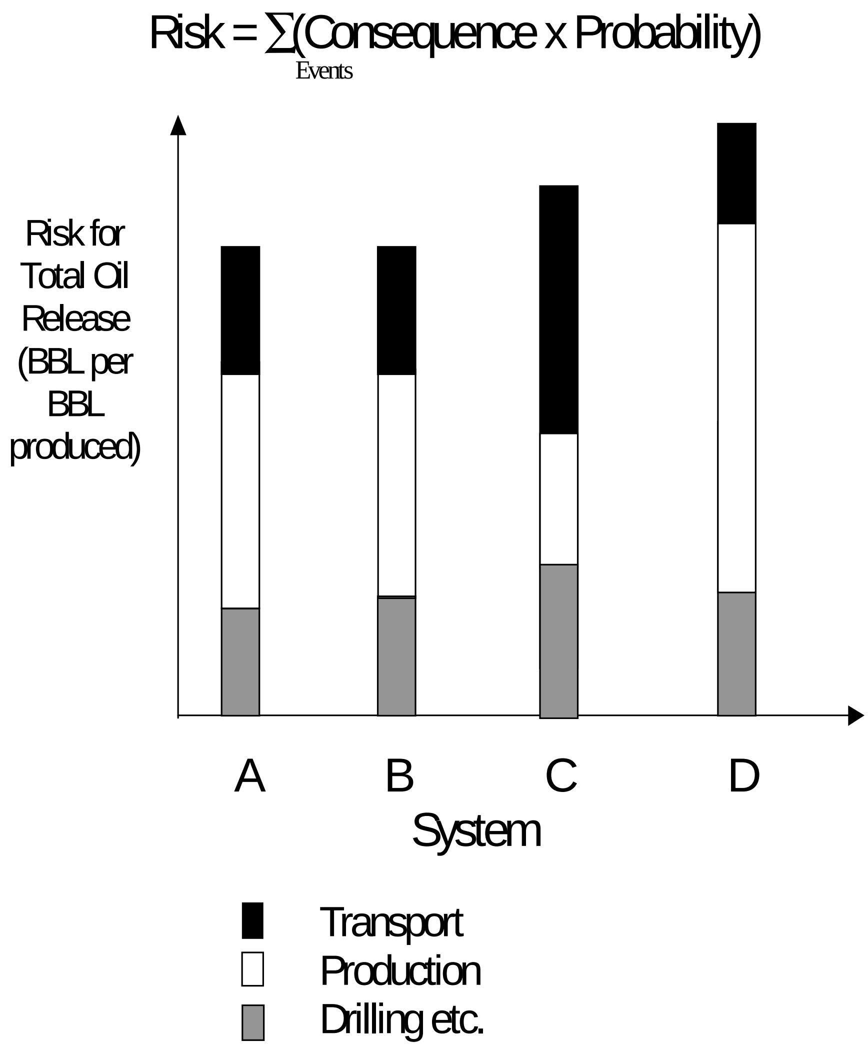


Figure 2A.4. An example of the result format expected from the CRA study.

The following steps remain in the study's timeline:

1. Draft Final Report is prepared
2. MMS review is needed

3. Presentation of results to the MMS and the USCG

4. Publication to put information in the public domain

5. Integrate information into the Record of Decision for the FPSO EIS

Mr. Jim Regg is the Chief of the Technical Assessment and Operations Support Section with the MMS Gulf of Mexico Region, located in New Orleans. His office is responsible for technical, safety, research, and regulatory issues relating to drilling and production activities in the GOM Outer Continental Shelf. Jim has offshore experience in drilling and production operations in Alaska and the Gulf of Mexico, and also experience with the MMS's offshore inspection program. He has had numerous papers published, conducted several workshops, and serves on several joint MMS-industry initiatives, including DeepStar. Jim received a B.S. degree in petroleum and natural gas engineering from the Pennsylvania State University in 1983.

REGULATORY FRAMEWORK FOR FLOATING PRODUCTION, STORAGE, AND OFFLOADING SYSTEMS

Ms. Wanda Parker
WJP Enterprises

BACKGROUND

The FPSO regulatory framework investigation was initiated on 22 March 2000 by the MMS. A work group was formed under the Offshore Operators Committee (OOC). This work group was composed of 16 industry members, seven MMS representatives, three members from the U.S. Coast Guard (USCG), 11 participants from the class societies, and one API representative. The goals of the work group were to (1) review the existing regulations and industry standards covering the design, construction, and operations of FPSOs in the Gulf of Mexico (GOM) and (2) identify gaps in the regulations and standards.

THE FPSO REGULATORY FRAMEWORK

To form the basis of the study, several FPSO characteristics were considered. These include the following:

- U.S. flag or undocumented FPSO
- Ship-shaped configuration
- Permanently moored FPSO
- Focus discussions on systems that are unique to the FPSOs

Several work products were established for the study. These include:

- A table of jurisdictional issues based on the MOU between the MMS and the USCG,
- A table of unique FPSO systems, and
- A summary of conclusions, gaps, and recommendations.

CONCLUSIONS

The study made several conclusions. The following is a listing of these conclusions:

- The USCG’s MSC and Headquarters groups need to be fully engaged in determining regulations for FPSOs in the GOM.

- The existing regulatory framework is adequate with some modifications.

- A large number of class society guides and rules as well as API documents exist that cover FPSO systems designs and operations. Some review and updating of these documents is needed.

- Regulations for non-ship-shaped FPSOs will need additional consideration.

- Many of the recommendations are applicable to other types of floating facilities.

RECOMMENDATIONS

Recommendations were made for each of the major stakeholders regarding FPSO activities. The following lists depicts these recommendations on and individual entity basis.

Recommendations to the MMS:

- The MMS's CVA regulations should be updated for floating systems.

- The MMS should review and adopt API RP 2FPS, RP 2SM, 2SK, 2RD and 17J.

Recommendations to the USCG:

- Specific floating facility regulations should be adopted in Subpart N.

- Marine crew manning and qualification regulations should be codified.

- The API's RP 500/505 for area classification should be adopted.

- Regulations for fire-fighting systems for production systems should be codified.

- The API's RP 75 should be recognized as the basis for an acceptable safety management system.

Joint recommendations were offered for the USCG and the MMS:

- The CVA process should be acceptable to both agencies to review and certify the design of the turret and mooring systems.

- The jurisdiction of integral hull tanks used as process vessels should belong to the MMS.

The study had recommendations to the industry as well:

- Representatives from the industry should review the overboard discharge regulations of the U.S. Environmental Protection Agency and the USCG for adequacy for FPSO operations.

- The industry should develop a strategy for obtaining a formal determination from the U.S. Department of Customs regarding the acceptability of foreign-flag FPSOs.

- The industry should review the various API documents on mooring and riser design, composite materials, and RP 14C, RP 14E for adequacy for floating systems.

- Industry representatives need to review and update (as needed) API's RP 75 for FPSO operations.

- The industry should confirm appropriate standards for cargo tank cleaning for FPSOs.

The workgroup also had some recommendations to continue its investigation of certain related matters:

- Operational standards for offloading from FPSOs in the Gulf of Mexico should be developed.

- A LOC checklist for foreign flagged FPSOs should be developed.

- The integration of the monitoring and safety systems should be addressed.

- It should be determined where specifications break between the MMS and the USCG regulations should occur.

Ms. Wanda Parker is a private consultant for offshore regulatory issues, specializing in deepwater. Prior to her consulting, Ms. Parker worked 22 years for Sun and Oryx Energy in various engineering positions, including 10 years focusing on regulatory and environmental work. Ms. Parker is a member of the NOSAC Committee and an active participant in various OOC committees as well as the DeepStar Regulatory Issues Committee. She received a Bachelor of Science in Petroleum Engineering from Texas A&M University.

DEEPWATER OIL TRANSPORTATION: FUTURE VISION

Mr. C.G. (Chuck) Stuebe
Conoco Shipping Company

The Gulf of Mexico (GOM) has extensive pipeline infrastructure that supports production on the continental shelf. Pipelines have begun to reach into deepwater areas of the Gulf; however, resources have been discovered beyond the reach of these pipeline assets. For future deepwater development, several alternatives may be viable. Figure 2A.5 depicts cost verses concept for an offshore-based approach compared to a shipping-based approach.

DEEPWATER FIELD DEVELOPMENT SOLUTIONS

Several options for deepwater field development are available to operators. These include

- FPSOs – provide low-cost "real estate" for processing equipment, but require a rig for well interventions

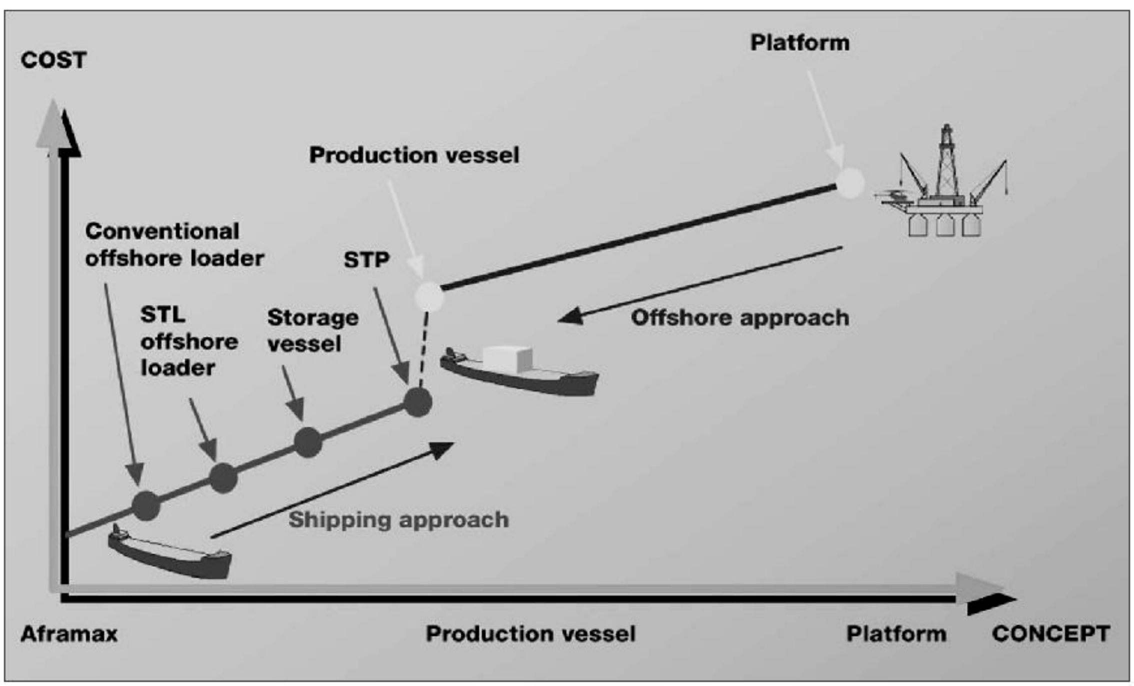


Figure 2A.5. Cost verses concept for an offshore-based approach compared to a shipping-based approach.

- TLPs – favored when direct vertical access is needed and many wells are required for optimal recovery of hydrocarbon resources

- Spars and TLPs – lack storage, but minimal storage can be designed into the structures

SHIPPING-APPROACH ALTERNATIVES

Two of the most viable shipping-approach alternatives for deepwater developments are floating production, storage, and offloading systems (FPSOs) and direct shuttle loading (DSL). The following is a brief characterization of the two shuttle offtake solutions.

- Floating Production, Storage, and Offloading Systems
  - Offtake configuration is usually in tandem
  - Offtake occurs from a spread-moored or weather vaning FPSO or FSO
  - Field storage of liquid hydrocarbons is an integral part of the system

- Direct Shuttle Loading
  - DSL offers a variety of offtake configurations
  - Offtake can occur from fixed platform, spar, or TLP
  - DSL has minimal or no storage of liquid hydrocarbons in the field
  - DSL can accommodate a wide range of production rates

Floating storage works. There are 66 FPSO vessels operating worldwide today. There are 62 floating storage and offloading (FSO) vessels also operating worldwide. Both of these systems are adaptable to worldwide sea conditions—from the North Sea to South America. These systems are independent of infrastructure. There has not been a significant spill in the 20-year operating history of these systems.

Conoco's Heidrun direct shuttle loading is an example of the DSL systems available to offshore operator today. The Heidrun oil offloading system operates off the coast of Norway in the North Sea. Since its inception in 1995, the Heidrun system has been able to maintain 100 % uptime. It has had production rates of up to 250,000 barrels of oil per day (BOPD).

There are some DSL concepts for a GOM application. The design would accommodate expected Gulf sea conditions. It would be capable of operating in four-meter significant wave heights. The system would be water-depth independent. The Figures 2A.6 through 2A.10 depict a possible DSL system for the Gulf.

Chuck Steube's has been Director of Floating Systems Operations for Conoco Shipping Company since 1997. He has more than 25 years of operations experience with Conoco ranging from onshore, arctic, offshore field operations, and field developments. He was part of the Project Team that installed Conoco's first FPSO in Nigeria and was the Offshore Superintendent for that installation. Chuck holds a B.A. degree from Texas Tech University and an MBA from Tulane University.

Figure 2A.6. A 40m by 20m L&B. It has 4x2 MW horizontal thrusters and 4x1 MW vertical thrusters. The system is powered by a high-voltage cable/umbilical.

Figure 2A.7. A shuttle tanker, one example of a GOM crude oil shuttle vessel alternative.

Figure 2A.8. A sea-going articulated barge, another example of a GOM crude oil shuttle vessel alternative.

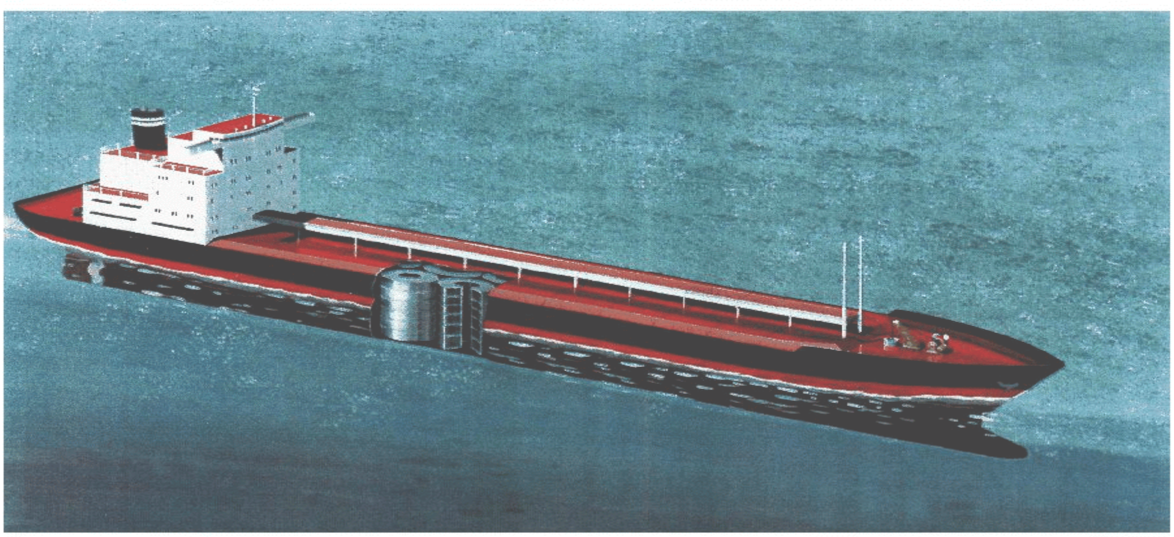
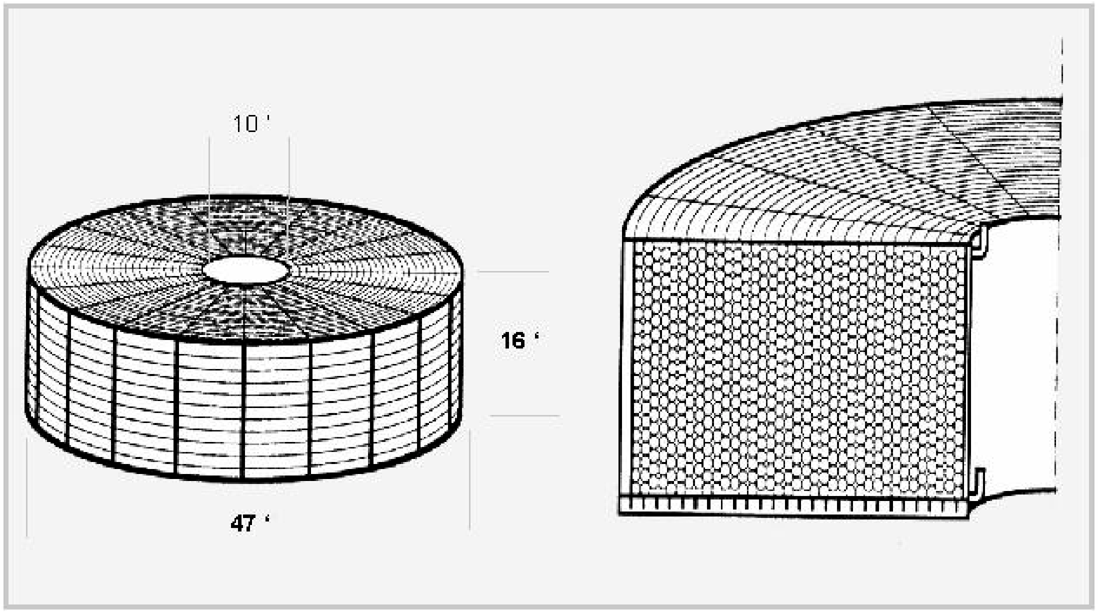


Figure 2A.9. A depiction of a coselle CNG carrier from Cran and Tenning Technology, Inc., of Calgary, Canada. The carrier is a 60,000 DWT ship with 108 coselles capable of transporting 300 mmscf of natural gas.



Pipe Dimensions		
O.D.	6.625	in.
Wall	0.25	in.
Length	10.6	mi.
Total Vol.	11,500	cf
Pipe Wt.	435	t.
Container Wt.	40	t.

Capacity per Coselle		
GHV	1,150	Btu/scf
Stored gas wt.	61	t.
Stored gas Temp	50	°F
Stored gas Pressure	3,000	psig
Sales gas stored	3.2	mmscf
	3,700	mmBtu

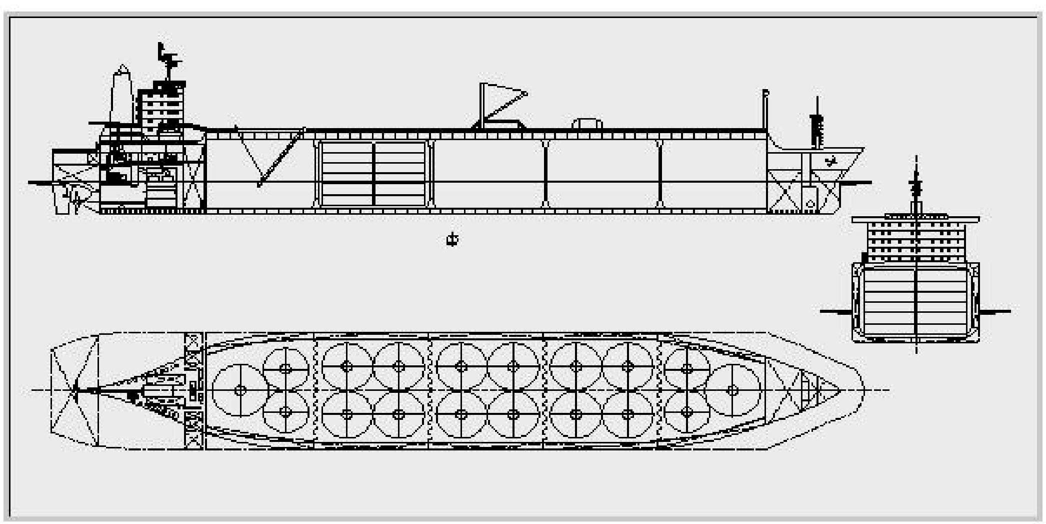


Figure 2A.10. A depiction of natural gas storage in coselles on a CNG carrier.

DEEPSTAR ACTIVITIES, ACCOMPLISHMENTS, AND PLANS

Mr. Allen J. Verret
DeepStar

Mr. Steve Brooks
ExxonMobil

BACKGROUND

DeepStar is an industry-led cooperative effort to develop economically viable, fit-for-purpose deepwater production technology with global applicability and to support the regulatory acceptance of this technology. Its initial focus is on the Gulf of Mexico (GOM). DeepStar's original focus was on "extended reach subsea tieback concepts." Over time, its focus evolved and broadened to "how to develop deepwater technology." With this change in focus, participation contracts broadened. Figure 2A.11 depicts the various components of DeepStar's Phase V cooperative.

The DeepStar cooperative has eight working Technical Committees. Table 2A.6 depicts the technical groups and the persons (and their company affiliation) that serve as chairs for the committees.

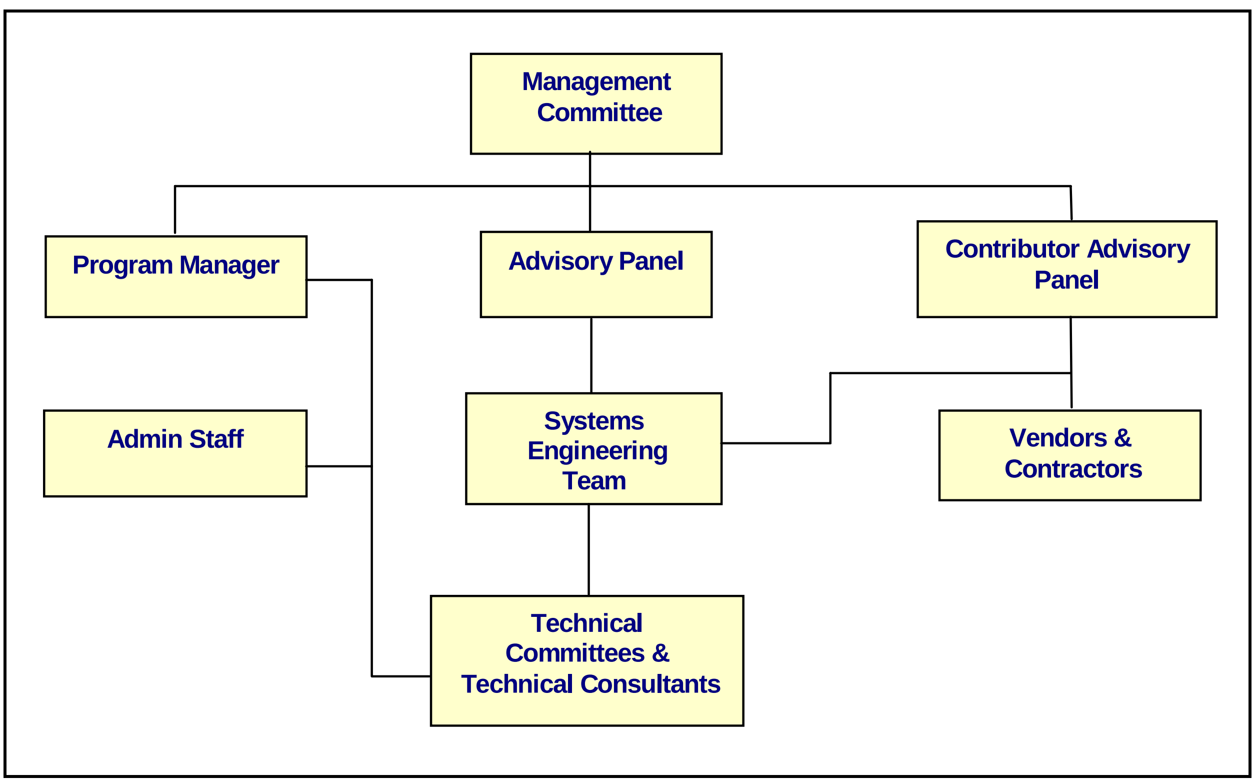


Figure 2A.11. Components of DeepStar's Phase V cooperative.

Table 2A.6. DeepStar technical committees.

GROUP	PERSONS – COMPANY
5100 Regulatory Group	Steve Brooks – ExxonMobile Debra Beaubien – BP-Amoco Allen Verret – Mark A. Stair & Assoc.
5200 Flow Assurance	Harvey Hensley – Phillips Jim Chitwood – Chitwood Engineers
5300 Controls, Pipelines, & Subsea	Otto Granhaug – Oxy USA Ray Seid – Paragon Steve Stockman – Texaco
5400 Vessels, Mooring & Risers	Paul Devlin – Texaco
5500 Drilling Completions	Rod Roberts – Marathon George Medley – Signa
5600 Project Management	Paul R. Hays – Texaco
5700 Reservoir Engineering	Walt Bozeman – Vastar
5800 Met-Ocean	Tom Mitchell – Texaco
5900 Systems Engineering	Denby Morrison – Shell Jim Chitwood – Chitwood Engineers

The monetary expenditures for the various phases of the DeepStar cooperative are shown in Table 2A.7.

Table 2A.7. DeepStar phase expenditures.

PHASE	DOLLARS (U.S.)
I	550,000
II	4,800,000
IIA	9,500,000
III	7,800,000
IV	15,300,000
V	8,000,000
TOTAL VALUE	**45,950,000**

DEEPSTAR PHASE V

Phase V of DeepStar was begun in January 2000. It is an $8,000,000, two-year program with 16 paying participants. DeepStar is pursuing other prospective participants to join this phase of the program. The budget is segmented into specific areas of concentration. They are the following:

- Systems Engineering
- Enhancing existing technology in water depths of up to 6,000 feet
- Enabling new technology in water depths from 6,000 feet to 10,000 feet
- Implementation through standards and regulations, and
- Administration of the program

DeepStar has two primary goals for Phase V. They are to

- Optimize existing tools and processes and
- Deploy technology

The following are examples of deployed technology under DeepStar's projects:

- For the Gemini Project:
  - Multiplexed control system architecture and functional requirements
  - Combination metal tube umbilical in lieu of thermo-plastic hose to reduce costs and risks offering better resistance to collapse and spill prevention
  - Fluid compatibility matrix—work done ahead of time that expedited project execution
- For the Arnold and Oyster Projects:
  - Pipe-in-pipe insulated flowlines—first 6-inch in 10-inch reeled pipeline (Arnold)
  - Round trip piggable flowline system
  - Full-life transit analysis of multiphase flow in deepwater pipeline systems
  - Designated, retrievable flow cut devices with quick acting control systems
- Other technology deployed by industry:
  - Agip and Unocal have already used extended reach blockage hardware in GOM field applications—more than 10 other deployments have occurred off of GOM platforms
  - Feedback has been provided and the Ambar System is continuing to undergo modifications to be a more effective tool for blockages

REGULATORY COMMITTEE

The DeepStar's Regulatory Committee has focused its attention primarily on OCS activities and the federal agencies that have that jurisdiction. DeepStar was most supportive of the Memorandum of Understanding (MOU) between the MMS and the U.S. Coast Guard that detailed regulatory responsibilities on the OCS. The MOU was revised and executed in late 1999.

DeepStar also undertook a major effort in funding an "outsourced" environmental impact statement (EIS) regarding floating production, storage, and offloading systems (FPSOs). DeepStar's intent was to provide accurate technical and environmental information about FPSOs so that the MMS could determine their applicability in the GOM. The outsourced EIS would help to expedite the MMS's decision on FPSOs. The EIS is projected to cost the industry approximately $1.3 million. In addition, the industry has expended about $750,000 in assistance to the EIS. Possible outcomes from the EIS include:

- Use of FPSOs with no conditions
- Use of FPSOs with special conditions, or
- No decision on a general basis with reviews done on a case-by-case basis

DeepStar is also involved in a comparative risk assessment (CRA) regarding offshore production systems. The CRA is an MMS funded and DeepStar-supported effort to compare the risks of operating tension-leg platforms (TLPs), spars, fixed platforms as "hubs" and FPSOs in the GOM. The industry has several roles and methods of participation in the CRA. The industry's input, experience, and expertise in all the systems are important to the success of the CRA study. The CRA Study process includes

- Interactive workshops for industry to provide input and share its experiences and expertise
- Interim reports with an opportunity for industry review and comments, and
- A final report with an opportunity for review and comments

Workshop participation was offered both online and offline. Online industry had topical inputs and discussions. Consistency from workshop to workshop was sought. The workshops also helped develop a consensus of views. Offline, participants reviewed pre-workshop materials and prepared for the meeting. Post-workshop actions involved reviewing reports and providing feedback. Participants also worked with others in the industry to ensure appropriate information was provided in the workshop. Everyone strove to provide useful information and data. The CRA Study was programmed to be completed at the same time that the FPSO EIS would be available.

Mr. Allen Verret entered service with Texaco after receiving his B.S. in civil engineering at the University of Louisiana at Lafayette in 1970. He was assigned to the then-new Offshore District Office in Morgan City. During his career with Texaco, Allen held engineering, management and advisor positions in field, district, and division offices and worked in engineering, construction, field operations, production, drilling, and workover operations as well as being active in the marine technology development needs. Mr. Verret has been active in the DeepStar Project since its inception and has served as Texaco's Senior Advisor on the Management Panel as well as being the Chairman of the Regulatory Committee for Phase I through Phase IV. Allen retired from Texaco in 1999 after 29 years of service in their offshore Gulf of Mexico operations. He is currently the Technical Advisor to the Regulatory Issues Committee and serves as the Executive Director of the Offshore Operators Committee in New Orleans, LA.

Mr. Steve Brooks graduated from the University of Tennessee. He has been with Exxon almost 33 years, including time in the U.S. Army. Steve started his career in marketing, but the last 19 years have been in various engineering and management positions associated with offshore production operations. Steve is currently responsible for ExxonMobil's offshore regulatory compliance activities. He serves as the co-chair for the DeepStar Regulatory Issues Committee, and Chairman of OOC Technical Subcommittee. Additionally, he is involved with several other industry committees, most recently chairing the API Recommended Practice 2D - 3rd Edition - committee and the API RP 14C - 7th edition - committee.

UPDATE ON U.S. COAST GUARD OCS ACTIVITIES

LCDR John Cushing
Chief, Outer Continental Shelf Branch
Eighth Coast Guard District

INTRODUCTION

The U.S. Coast Guard (USCG) has three major areas of regulatory activities concerning the Outer Continental Shelf that may be of interest to you. They are

- Revision of Subchapter N (33 CFR 140-147),
- The current USCG position on floating production, storage, and offloading (FPSO) facilities and applicable regulations, and
- The memorandum of understanding (MOU) between the USCG and the Minerals Management Service (MMS).

SUBCHAPTER N (33 CFR 140-147)

Subchapter N is being written in “plain English.” The notice of proposed rule making (NPRM) was published on 7 December 1999. Comments from the public were due on 5 April 2000. The USCG extended the comment period until 30 November 2000. Major changes were proposed for certain subparts of Subchapter N.

33 CFR 142, Workplace Safety and Health

Subpart B (Personal Protection Equipment) includes these new requirements (note subsections are in parentheses to facilitate identification):

- Hearing protection (142.135),
- Electrical safety training (142.145),
- Personal transfer net certification and inspections (142.165),
- Radiation monitoring (142.175 to 142.179),
- Airborne substance exposure limits (142.180 to 142.183), and
- Infectious material exposure training (142.185)

Subpart C (General Workplace Conditions) also received modifications that contained new requirements. These are

- Preventing deck obstructions near survival craft (142.207),
- Noise surveys and required singage (142.235 to 142.240),
- Guards for rotating and reciprocating machines (142.245 to 142.250)
- Proper use and maintenance of equipment (142.255)
- Use and maintenance of slings (142.260),
- Use and maintenance of personnel transfer nets (142.265 to 142.280), and
- Warning sign requirements (142.285).

Subpart D (Confined Space Entry) is a new part of the regulations. The following are requirements contained in this subpart:

- A comprehensive confined space entry program,
- Testing of confined spaces prior to entry,
- Testing be conducted by a
  - Certified marine chemist
  - Certified industrial hygienist
  - Offshore competent person, and
- Presence of “rescue team” during entry.

The subpart also identifies training requirements for an “offshore competent person.”

33 CFR 143, Fixed Facilities

Significant changes were made to the lifesaving equipment requirements of the regulations. These include

- Lifeboats on all manned OCS facilities (100 % capacity)
- Two lifeboats for facilities with more than 31 persons
- Rescue boat required on facilities with more than 8 persons

- Lifefloats (vice liferafts) permitted for additional 100 % lifesaving capacity if facility is within three (3) nautical miles of a “safe haven”

- “New” equipment is required within two years of the effective date of the Final Rule.

Substantial changes were made to the fire-fighting equipment requirements as well. These changes include

- Comprehensive requirements for portable and semi-portable fire extinguishers
- Manned facilities must have fire main systems (water) for
  - Accommodation spaces
  - Helicopter decks
- Two fireman’s outfits are required if a facility has more than 8 persons
- The fire-fighting equipment detailed under 33 CFR 143, Subpart K, is required within two years of the effect date of the Final Rule.

Structural fire protection (SFP) for manned facilities is addressed under Subpart L. These requirements only apply to new manned facilities.

- Requires accommodation spaces meet SFP requirements of NFPA 101

- Have independent “A-60" fire wall if within 30 meters of platform hydrocarbon source, or

- Meet SFP requirements of 46 CFR 108 (MODU regulations)

Maximum noise limits have been set for new facilities are shown in Table 2A.8.

Table 2A.8. Maximum noise limits for new facilities.

AREAS	MAX. NOISE LEVEL (in dbA)
Sleeping rooms	60
Mess rooms	65
Offices	65
Recreation rooms	65
Open recreation areas	75
Galleys	75

33 CFR 144, Floating OCS Facilities

Comprehensive requirements are proposed for floating units (TLPs, Spars, FPSs, FPSOs, etc.) These new regulations include:

- Meeting 33 CFR 142, Workplace Safety & Health standards,
- Lifesaving requirements for MODUs (generally)
- Firefighting and structural fire protection for MODUs (generally)
- Design and equipment requirements for MODUs and possibly API RP 2FPS (draft)

Overall Status of Subchapter N

- Significant comments from the industry are on the docket
- Comments are likely to delay the Final Rule
- The USCG has the MMS's comments, and the USCG is committed to a close partnership with the MMS

FLOATING PRODUCTION, STORAGE AND OFFLOADING (FPSO) FACILITIES

The current USCG position on FPSO in part is as follows:

- FPSOs are vessels regardless of their shapes
- Oil stored within a FPSO is considered to be “cargo”
- The OPA-90 hull requirements apply

Applicable USCG regulations that apply to FPSOs are

- 33 CFR 144 (being developed): Floating OCS facilities
- 33 CFR 157 (OPA –90): Double hull
- 46 CFR Subchapter D: Tank vessels

MEMORANDUM OF UNDERSTANDING (MOU) BETWEEN THE USCG AND THE MMS

The following is a brief update on the MOU between the two agencies.

- The MMS is to do annual “CG inspection” on fixed platforms

- Implementation:
    - Short term: Training, forms (address in MOU?)
    - Long term: MOU, eventually Subchapter N

- The MMS/USCG transition team is working on short- and long-term implementation

- USCG legal department is reviewing authority for MMS to enforce USCG regulations

- Target for short-term implementation is 1 July 2001

Lieutenant Commander John Cushing is the Chief of the Offshore Compliance Branch, Eighth Coast Guard District, located in New Orleans. Prior to his current assignment, he worked two separate tours of duty in the Marine Safety Office Portland, Oregon (1986-1990 and 1996-2000), serving as Marine Inspector, Resident Shipyard Inspector, and Assistant Chief in the Inspections Department. Between his assignments in Portland, he served four years in the Marine Safety Center in Washington, DC. His duties in the MSC were Staff Engineer, performing structural & stability plan reviews, and Chief of the MODU Branch. LCDR Cushing has served on the USCG Cutter *Sherman* in 1985-1986 as an Assistant Engineer Officer, and the Cutter *Mellon* from 1984-1985 as a Student Engineer. LCDR Cushing graduated from the Coast Guard Academy (Class of 1984) with a B.S. in civil engineering. He received M.S. degrees in mechanical engineering, and naval architecture and marine engineering from the Massachusetts Institute of Technology in 1992.

SESSION 2B

AIR QUALITY (continued)

Chair: Dr. Chester Huang, Minerals Management Service
Co-Chair: Ms. Terry Scholten, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Assessment of Air Pollutant Emissions in the Gulf of Mexico	Ms. Darcy Wilson Eastern Research Group Research Triangle Park, NC Mr. Brian Boyer COMM Engineering Lafayette, LA
Recent Advances in Air-Sea Interaction Studies Applied to Overwater Air Quality Modelling	Dr. S. A. Hsu Professor of Marine Meteorology Louisiana State University

ASSESSMENT OF AIR POLLUTANT EMISSIONS IN THE GULF OF MEXICO

Ms. Darcy Wilson
Eastern Research Group
Research Triangle Park, NC

Mr. Brian Boyer
COMM Engineering
Lafayette, LA

ABSTRACT

The Minerals Management Service (MMS) is responsible for determining if air pollutant emissions from platform and other sources in the Gulf of Mexico (GOM) influence the ozone attainment (and nonattainment) status of onshore areas. To this end, MMS implemented the *Gulfwide Emission Inventory Study* to develop a base year 2000 inventory of criteria pollutant emissions for all oil and gas production-related sources in the Gulf. MMS will ultimately provide the inventory data to state agencies for their use in regional modeling.

MMS conducted an initial study of emission sources in the GOM whose results are summarized in the 1995 report: "Gulf of Mexico Air Quality Study" (MMS 1995). The 1995 study covered many types of offshore emission sources, focusing on oil and gas production platform emissions. MMS is working on a project that affects only platforms near the Breton National Wilderness Area in the Gulf. As a part of this program, MMS developed a Visual Basic program for platform operators to use to submit activity data on a monthly basis. The Breton Offshore Activities Data System (BOADS) is being used by affected operators to submit activity data for a number of production platform emission sources.

The *Gulfwide Emission Inventory Study* builds upon these MMS studies with the goal of developing criteria pollutant and greenhouse gas emission inventories for all oil and gas production-related sources in the entire GOM. The Gulfwide Offshore Activities Data System (GOADS) is being developed from the BOADS Visual Basic program, modified to request activity data for additional emission sources. The 1995 "Gulf of Mexico Air Quality Study" will be used as the starting point for non-platform sources covered in the Gulfwide Study.

This paper focuses on the (1) the form emission sources that will be covered in the *Gulfwide Emission Inventory Study* that are not covered in the Breton Island study and (2) the methods that will be used to estimate emissions from these sources. It will also briefly discuss the non-platform sources covered, and how emissions estimates for these sources will be developed. Lastly, we will present the proposed schedule for the *Gulfwide Emission Inventory Study*.

INTRODUCTION

MMS published Notice to Lessees and Operators (NTL) 99-G15 to introduce the "Production Activities Information Collection and Reporting" requirements for lessees and operators of federal oil, gas, and sulphur leases in the Outer Continental Shelf, Gulf of Mexico OCS Region. A workshop was held in New Orleans 15 November 1999 to discuss and explain the GOADS information collection and reporting procedures, the pollutants to be covered in the study, and why the GOADS study was being undertaken. In addition, information was provided to assist in submitting activity data needed for GOADS. Much of the information provided is available on the GOADS website: *http://www.gomr.mms.gov/homepg/regulate/environ/airquality/goad.html*

Information posted on this website by MMS includes:

- NTL 99-G15
- Frequently Asked Questions (FAQs) and other updates on data collection and reporting
- The BOADS Users Guide (for use until GOADS is available)
- The BOADS Activity Database (for use until GOADS is available)
- Slides and other helpful activity data collection tips from 15 November 1999 workshop

When it is available, the GOADS data collection software will also be posted here. A training course is planned for 15 March 2001.

In addition to collecting activity data from platform operators, we are modifying an existing Oracle® program to house the GOADS platform activity data and develop emission estimates. This Oracle® program will also house activity data and other data needed to calculate emissions for non-platform sources in the Gulf. Non-platform sources that will be included in GOADS include:

- Drilling vessels
- Pipe laying vessels
- Survey vessels
- Construction barges
- Off-shore tugs
- Crew boats
- Supply boats

- Lightering vessels
- Helicopters
- The Louisiana Offshore Oil Port (LOOP)
- Oceangoing barges
- Commercial fishing
- Recreational fishing
- Commercial marine vessels
- Military activities
- Biogenic sources

ACTIVITY DATA NEEDED AND ESTIMATION METHODS FOR NEW PLATFORM SOURCES

The goal of the *Gulfwide Emission Inventory Study* is to develop an emission inventory for all criteria pollutants and greenhouse gases. To this end, activity data are needed for sources that are not covered in BOADS, particularly sources of volatile organic compounds (VOCs). Listed below are the new equipment in GOADS (but not in BOADS), and the data needed and methods that will be used to estimate emissions. Operators will also be asked to provide a sales gas analysis for each platform.

Pressure/Level Controllers

For pressure and level controllers, we need to estimate emissions associated with the bleed-rate of each controller. Information needs for pressure and level controllers were discussed at the 15 November 1999 GOADS workshop. Operators will be asked to provide the following information, but <u>only for controllers that are in natural gas service</u>. Operators should not include units in compressed air service.

- Service type (pressure control vs. level control)
- Manufacturer and model (with pre-populated lookup tables, or can be added)
- Amount of natural gas consumed in SCF/hr (optional)
- Hours of operation in the reporting period
- Average elevation above mean sea level

Hydrocarbon emissions for pressure and level controllers will be developed using the following equation (EIIP 1999):

Lbs/hr = (SCFH) (mole weight of gas, lbs/lb-mole) (1 lb-mole/379 SCF)

Where SCFH = standard cubic feet per hour of natural gas used.

Pneumatic Pumps

For pneumatic pumps, we need to estimate emissions associated with each pump (i.e., chemical injection, Wilden diaphragm, Texstream chemical and diaphragm, etc.). Information needs for pneumatic pumps were also discussed at the 15 November 1999 GOADS workshop. Operators will be asked to provide the following information, but again, only for pumps that are in natural gas service. Operators should not include pumps in compressed air service.

- Manufacturer and model (with limited pre-populated lookup tables)
- Amount of natural gas consumed in SCF/hr (optional)
- Hours of operation in the reporting period
- Average elevation above mean sea level
- Whether it is vented to a manifold, a flare, or the atmosphere

Hydrocarbon emissions for pneumatic pumps will be developed using the following equation (EIIP 1999):

Lbs/hr = (SCFH) (mole weight of gas, lbs/lb-mole) (1 lb-mole/379 SCF)

Where SCFH = standard cubic feet per hour of natural gas used.

Losses from Flashing

Flash gas is natural gas that is liberated when an oil stream undergoes a pressure drop. BOADS requests data for flash gas associated with storage tanks. For GOADS, we also need to collect data associated with separators, heater treaters, and surge tanks. We only need to account for flash gas that is vented to the atmosphere or burned in a flare. Flash gas that is routed back into the system (e.g., sales pipeline) should not be reported in GOADS.

Each point of separation/treatment must be examined as a potential source of flash gas. For example, oil from a low-pressure separator may be sent to a heater treater, then on to a storage tank. Flash gas that is vented or flared from each vessel must be accounted for.

Flash gas can be vented to the atmosphere or burned in flares from the following equipment: high, intermediate and low pressure separators; heater treaters; surge tanks; accumulators; and fixed roof atmospheric storage tanks.

Operators will be asked to report the following parameters for each part of the process:

- API gravity of stored oil
- Operating pressure (psig) of each vessel (i.e., separator, heater treater, surge tank, storage tank)
- Operating temperature (°F) of each vessel
- Actual throughput of oil for each vessel
- Disposition of flash gas from each vessel – routed to system (e.g., sales pipeline, gas-lift), vented to atmosphere, or burned in flare
- SCF of flash gas per bbl of oil throughput specific to your source (optional)

Emissions for losses from flashing will be developed using the Vasquez and Beggs Correlation Equations to estimate tank vapors in standard cubic feet per barrel of oil produced.

Fugitive Emissions

Fugitive emissions are included in the BOADS software, but operators are not required to report the information for BOADS. However, fugitives must be reported in the annual report for the GOADS effort. To report fugitive emissions in GOADS, operators will be required to supply the information requested for fugitives in the BOADS software. This information includes delineating the stream type (gas, heavy oil, light oil, or water/oil) and average VOC weight percent of fugitives, and an equipment inventory (number of components). To facilitate this process, MMS will only require a one-time submittal of this information—operators will not be required to cut and paste the equipment inventory data every month.

Operators are encouraged to prepare an equipment inventory by making direct counts of components by service type. It may be beneficial to use of the information presented in Table 2B.1 as a starting point, however. This information was compiled for MMS by the Offshore Operators Committee and can be adjusted by service type for each component for each part of the production train (i.e., for each skid type).

Also note that because there is a large variation in emissions for compressor seals, operators will also be asked to specify the compressor and seal type as:

- Centrifugal-wet seal

Table 2B.1. Summary of Equipment Inventory Data (Number of Components) by Skid Type[a]

Skid Type	Valves	Pump Seals	Threaded	Flanges	Open Ended Lines	Compressor Seals	Diaphragms	Drains	Dump Arms	Hatches	Instruments	Meters	Pressure Relief Valves	Polished Rods	Other Relief Valves	Vents
Separator Skid	34	0	13	73	0	0	0	2	0	0	15	1	1	0	0	0
Heater Treater Skid	98	0	70	114	0	0	0	3	0	0	25	0	3	0	0	0
LACT Charge Pump Skid	21	3	6	47	0	0	0	1	0	0	9	0	0	0	0	0
LACT Skid	62	1	75	69	0	0	0	1	0	0	34	4	6	0	0	0
Pipeline Pumps Skid	39	3	12	78	0	0	0	2	0	0	70	0	3	0	0	0
Pig Launcher/Receiver Skid	13	0	14	16	0	0	0	0	0	0	9	0	1	0	0	0
Compressor Skid	119	0	113	138	0	4	0	1	0	0	69	0	9	4	0	0
Filter/Separator Skid	30	0	25	37	0	0	0	1	0	0	9	0	1	0	0	0
Gas Dehydration Skid	23	0	14	40	0	0	0	1	0	0	12	0	1	0	0	0
Glycol Regeneration Skid	134	0	110	194	0	0	0	4	0	0	45	1	7	6	1	0
Gas Meter	10	0	11	26	0	0	0	1	0	0	21	2	0	0	0	0
Fuel Gas Skid	62	0	47	85	0	0	0	1	0	0	32	1	4	0	0	0
Flotation Cell Skid	41	1	34	70	0	0	1	1	0	15	8	0	2	0	2	0
Scrubber	13	0	13	18	0	0	0	1	0	0	9	0	1	0	0	0
Amine Unit	226	8	166	391	0	0	1	5	0	0	121	2	12	0	1	0
Line Heater	30	0	46	18	0	0	0	1	0	0	10	0	0	0	1	0
Production Manifold	108	0	31	148	0	0	0	1	0	0	43	0	0	7	0	0
Wellhead	15	0	6	19	0	0	0	0	0	0	11	0	0	0	0	0
Import or Export Pipeline	3	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0

[a] Provided to MMS by the Offshore Operators Committee, August 2000.

- Centrifugal- dry seal
- Reciprocating- shaft packing, or
- Other (specify)

The information in Table 2A.2 may also be useful for completing the GOADS fugitive emissions general information tab.

Table 2B.2. Speciation weight fractions for total hydrocarbon (THC) emissions by stream type[a].

THC Fraction	Gas	Light Oil (³ 20 API Gravity)	Heavy Oil (<20 API Gravity)	Water/Oil[b]
Methane	0.687	0.612	0.942	0.612
Non-methane	0.313	0.388	0.058	0.388
VOC	0.171	0.296	0.030	0.296

[a] Source: API. 1996. Calculation Workbook for Oil and Gas Production Equipment Fugitive Emissions.

[b] Water/oil refers to water streams in oil service with a water content greater than 50% from the point of origin to the point where the water content reaches 99%. For water streams with a water content greater than 99%, the emission rate is considered negligible.

Emission estimates for fugitives will be developed using the emission factors shown in Table 2B.3.

Table 2B.3. EPA Average Emission Factors for Total Hydrocarbon Emissions from Oil and Gas Production Operations (lb/component-day)[a]

	Gas	**Heavy Oil (<20 API Gravity)**	**Light Oil (³ 20 API Gravity)**	**Water/Oil**
Connector	1.1E-02	4.0E-04	1.1E-02	5.8E-03
Flange	2.1E-02	2.1E-05	5.8E-03	1.5E-04
Open-end	1.1E-01	7.4E-03	7.4E-02	1.3E-02
Other[b]	4.7E-01	1.7E-03	4.0E-01	7.4E-01
Pump	1.3E-01	Not Avail	6.9E-01	1.3E-03
Valve	2.4E-01	4.4E-04	1.3E-01	5.2E-03

[a] Source: API, 1996. Calculation Workbook for Oil and Gas Production Equipment Fugitive Emissions.

[b] Includes compressors, diaphragms, drains, dump arms, hatches, instruments, meters, pressure relief valves, polished rods, and vents.

Mud Degassing

Mud degassing emissions occur when gas that has seeped into the well bore and dissolved or become entrained in the drilling mud is separated from the mud and vented to the atmosphere (EIIP 1999). In GOADS, operators only need to include information on platform drilling rigs or from jack-up rigs adjacent to platforms. For required drilling activity, operators should keep a record of:

- Number of days that drilling operations occurred
- Number of wells drilled
- Depth of each well
- Type of drilling mud used (water-based, synthetic, oil-based)

Hydrocarbon emissions will be estimated using emission factors provided in the 1977 EPA report: *Atmospheric Emissions from Offshore Oil and Gas Development and Production* (0.4 Mg/day for water-based and 0.09 Mg/rig for oil-based muds).

ACTIVITY DATA NEEDED AND ESTIMATION METHODS FOR NON-PLATFORM SOURCES

For the non-platform emission sources in the Gulf, we will use the 1995 GOM inventory as the starting point. For all of the vessels and barges included in this study, emissions will be calculated using the following information:

- Number of vessels by engine type, horsepower and typical load factors
- Duration and route of travel
- Duration of ship hotelling (LOOP)
- Hours of operation
- Fuel consumption by vessel

The appropriate activity data will be combined with the most up-to-date emission factors. Most of the marine sources are diesel powered, and we will use recently published emission factors from the EPA’s Marine Diesel Engine Regulatory Program, with spatial, seasonal, and diurnal adjustments to reflect monthly activity (EPA 2000). For helicopters, emissions will be estimated based on landing-takeoffs (LTOs) and hours of operation. These data will be combined with the emission factors used in the 1995 study.

In addition to emissions associated with fuel combustion, loading and ballasting emissions will be developed for lightering vessels and the LOOP based on throughput. Mud degassing emissions will be generated using data from the MMS Platform Inspection System. Volatile organic compound emissions from sub-surface oil and natural gas seeps will be estimated using from the 1995 MMS report “Northern Gulf of Mexico Chemosynthetic Ecosystems Study” (McDonald *et al.* 1995).

SCHEDULE

Operators are encouraged to use the BOADS software until the GOADS software is finalized. It is important that the operators maintain a copy of every monthly BOADS survey with a unique file name. The files should be named so that the month can be conveniently identified later from the filename. These data can then be directly uploaded into the GOADS software when it becomes available. Operators will then have to enter only data for the new data elements and equipment discussed in this paper.

Training on the GOADS software is currently scheduled to take place 15 March 2001 in New Orleans. Operators will be given the GOADS software and GOADS User’s Guide, and will receive training on uploading their BOADS files, and entering new data elements and equipment information unique to GOADS.

An important new feature of GOADS is the QA Summary Form, which operators will be required to print out and submit along with their electronic files. The QA Summary Form identifies key missing or inconsistent data that would prevent calculation of emissions. This form is designed to identify missing data so they can be corrected before the files are sent to MMS. Otherwise, the missing data would be identified during MMS’s review of the files, and the operators would be contacted and asked to submit the missing data. The goal of the QA Summary Form is to make the GOADS data collection process more efficient and to reduce the burden on both MMS and the operators.

Following the release of the GOADS software and User’s Guide, and training on its use, the current schedule proposes that operators submit their GOADS files (with the QA Summary Form printout) by 15 June 2001.

MMS will complete the QA/QC of the submitted activity data files and take the necessary corrective actions by 1 December 2001. Draft emission calculations will be prepared by February 2002; final by July 2002.

REFERENCES

API, 1996. Calculation Workbook for Oil and Gas Production Equipment Fugitive Emissions.

Emission Inventory Improvement Program (EIIP). 1999. Preferred and Alternative Methods for Estimating Air Emissions from Oil and Gas Field Production and Processing Operations (EIIP Volume II – Chapter 10).

Minerals Management Service (MMS). 1995. Gulf of Mexico Air Quality Study. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region. MMS 95-0040.

McDonald *et al.* 1995. Northern Gulf of Mexico Chemosynthetic Ecosystems Study. Prepared by the Geochemical and Environmental Research Group. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region. MMS 95-0023.

Offshore Operators Committee. August 2000. Summary of Equipment Inventory Data (Number of Components) by Skid Type.

U.S. Environmental Protection Agency (EPA). 1977. Atmospheric Emissions from Offshore Oil and Gas Development and Production. EPA-450/3-77-026.

U.S. Environmental Protection Agency (EPA). 2000. Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data. Office of Transportation and Air Quality, Ann Arbor, MI. EPA-420/R-00-002.

RECENT ADVANCES IN AIR-SEA INTERACTION STUDIES APPLIED TO OVERWATER AIR QUALITY MODELLING

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INTRODUCTION

Air pollution meteorology is concerned with the fate of pollutants once they are emitted into the atmosphere and addresses natural releases, deliberate industrial emissions, and accidental spills. According to Zannetti (1990), air quality modeling is an essential tool for most air pollution studies. For more detail about air pollution meteorology and air quality modeling, see, e.g. Hanna *et al.* (1982), Zannetti (1990), and Arya (1999).

Overwater dispersion characteristics required in air quality modeling include stability classification, turbulence intensity, eddy diffusion, and mixing height. The purpose of this review is to synthesize recent advances in these parameterizations. The most important difference between sea and land is that the sea surface is in motion while the land surface is fixed. Sea waves and currents will affect the aerodynamic roughness so that rapid changes in both space and time depend upon the wind-generated wave characteristics. Hence the drag coefficient, which is fixed on land, cannot be treated as a constant. This in turn affects a host of other overwater characteristics.

DETERMINING THE STABILITY CHARACTERISTICS

For overwater air quality modelling, the Offshore and Coastal Dispersion Model (OCD) (see Hanna *et al*. 1985) has recommended for regulatory use by both the U.S. Environmental Protection Agency (EPA) and the U.S. Minerals Management Service (MMS) for emissions located on the outer continental shelf (see Zannetti 1990). In this EPA preferred model, the stability parameter z/L is required, where z is the height above the surface and L is the Monin-Obukhov stability length, which is defined as (see, e.g., Garratt 1992, p. 38)

$$L = -\frac{u_*^3\,\theta_v}{g\,\kappa\,\overline{w'\theta_v'}} \tag{1a}$$

or as (e.g., Panofsky and Dutton 1984, p. 132)

$$L = -\frac{u_*^3\ \rho\ C_{ph}\ T_{air}}{g\ \kappa\ H\left(1+\dfrac{0.07}{B}\right)} \tag{1b}$$

where u_* is the friction velocity, θ_v is the virtual potential temperature, g is the gravitational acceleration, κ is the von Karman constant, is the surface buoyancy flux, ρ is the air density, C_{ph} is the specific heat of air at constant pressure, T_{air} is the air temperature, H is the surface layer sensible heat flux, and B is the Bowen ratio (the ratio of sensible to latent heat flux). Note that T_{air} should be T_v, the virtual temperature. However, since $T_v = T_{air}$ (1 + 0.68q) and q is at most 5% (see, e.g., Komen *et al.* 1994, p. 59), we use $T_v – T_{air}$.

Since direct measurements of u_* and H are not available routinely, the following parameterization is employed.

From Eq. 1b and Smith (1980, Eqs. 3 and 4)

$$\frac{H}{\rho\, C_{ph}} = C_T\, U_{10}\left(T_{sea} - T_{air}\right) \tag{2}$$

and

$$C_d = \left(\frac{u_*}{U_{10}}\right)^2 \tag{3}$$

or $u_*^3 = U_{10}^3 C_d^{3/2}$, we have for unstable condition ($T_{sea} > T_{air}$)

$$L = -\frac{T_{air}\; C_d^{3/2}\; U_{10}^2}{g\,\kappa\, C_T\left(T_{sea} - T_{air}\right)\left(1 + \dfrac{0.07}{B}\right)} \tag{4a}$$

and for stable condition ($T_{sea} < T_{air}$)

$$L = -\frac{T_{air}\; C_d^{3/2}\; U_{10}^2}{g\,\kappa\, C_T\left(T_{sea} - T_{air}\right)} \tag{4b}$$

where C_T is the heat flux coefficient (= 1.1 x 10^{-3} for unstable, 1.0 x 10^{-3} for neutral and 0.83 x 10^{-3} for stable conditions (see Smith 1980 and 1988)), C_d is the drag coefficient, U_{10} is the wind speed at 10 m above the sea surface, and T_{sea} is the sea surface temperature.

On the basis of thermodynamic conditions, a relationship between B and ($T_{sea} - T_{air}$) under unstable conditions (i.e., $T_{sea} > T_{air}$) has been proposed by Hsu (1998) that

$$B = a\left(T_{sea} - T_{air}\right)^b \tag{5a}$$

where a and b are to be determined by field experiments. Based on the availability of additional data sets from tropical oceans and coastal seas, Hsu (1999) found

$$B = 0.146\left(T_{sea} - T_{air}\right)^{0.49} \tag{5b}$$

with a high correlation coefficient of 0.94 between B and (T_{sea} - T_{air}). This paper will attempt to verify Eq. (4) by employing this B parameterization along with a proven C_d formulation used successfully in the third generation wave model (see WAMDI 1988, p. 1784) that

$$C_d = \begin{cases} 1.2875\, x\, 10^{-3}, & U_{10} < 7.5\, m\, s^{-1} \\ \left(0.8 + 0.065 U_{10}\right) x\, 10^{-3}, & U_{10} \geq 7.5\, m\, s^{-1} \end{cases} \tag{6}$$

In order to verify Eq. (4), simultaneous measurements of T_{air}, T_{sea}, U_{10}, and L are necessary. The data sets provided in Donelan *et al.* (1997) supply all of these parameters. We classify z/L # -0.03 as unstable, |z/L| < 0.03 as near-neutral, and z/L $ 0.03 as stable. In this verification, we set z = 10 m to correspond to U_{10} and the C_d formulation used in Eq. (6). Our results are shown in Figures 2B.1 and 2B.2 for unstable and stable conditions, respectively. If one accepts the small RMSE values (.8 to 11 m) for the range of L between zero and approximately 350 m, Eq. (4) is verified. Note that the term of B, i.e., (1 + 0.07/B) in the denominator of Eq. (4a) was dropped for stable conditions in Eq. (4b) when T_{air} is larger than T_{sea} and therefore no sensible heat is directed from the sea to the air.

DETERMINING OVERWATER FRICTION VELOCITY, u_*

The friction (or shear) velocity, u_*, can be computed by Eqs. (3) and (6). On the other hand, from the Wind-Wave Interaction method (Hsu 1995)

$$u_* = \frac{0.4\, U_{10}}{11.0 - \ln\left(\dfrac{H_s}{\left(C_p / U_{10}\right)^{2.6}}\right)} \tag{7}$$

where $C_p = gT_p / 2\pi$, is the phase speed of the waves at the spectral peak. Note that the parameter C_p / U_{10} is defined as the wave age.

Figure 2B.3 shows the results of our comparison between Eqs. (3), (6), and (7) for the Gulf of Mexico. Since the root mean square error is only 0.9 cm s^{-1} for the data range between 20 and 70 cm s^{-1}, either Eq. (6) or (7) can be used. Since Eq. (6) is easier to use, it is recommended for operational computations, although Eq. (7) can be used to explain Eq. (6) based on wind-wave interaction characteristics. For more detailed discussion, see Hsu *et al.* 2000.

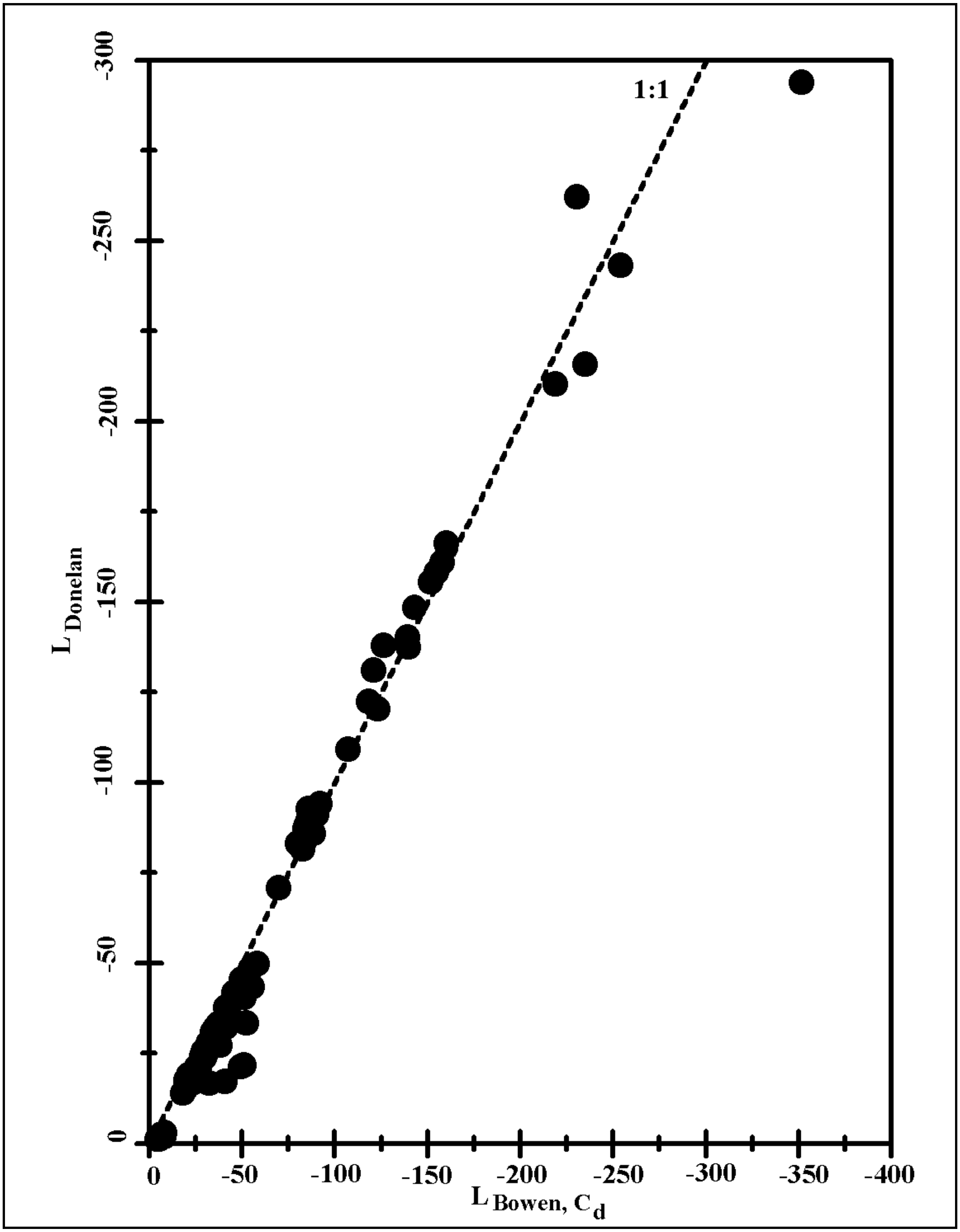

Figure 2B.1. A verification of Eq. (4a) for unstable conditions.

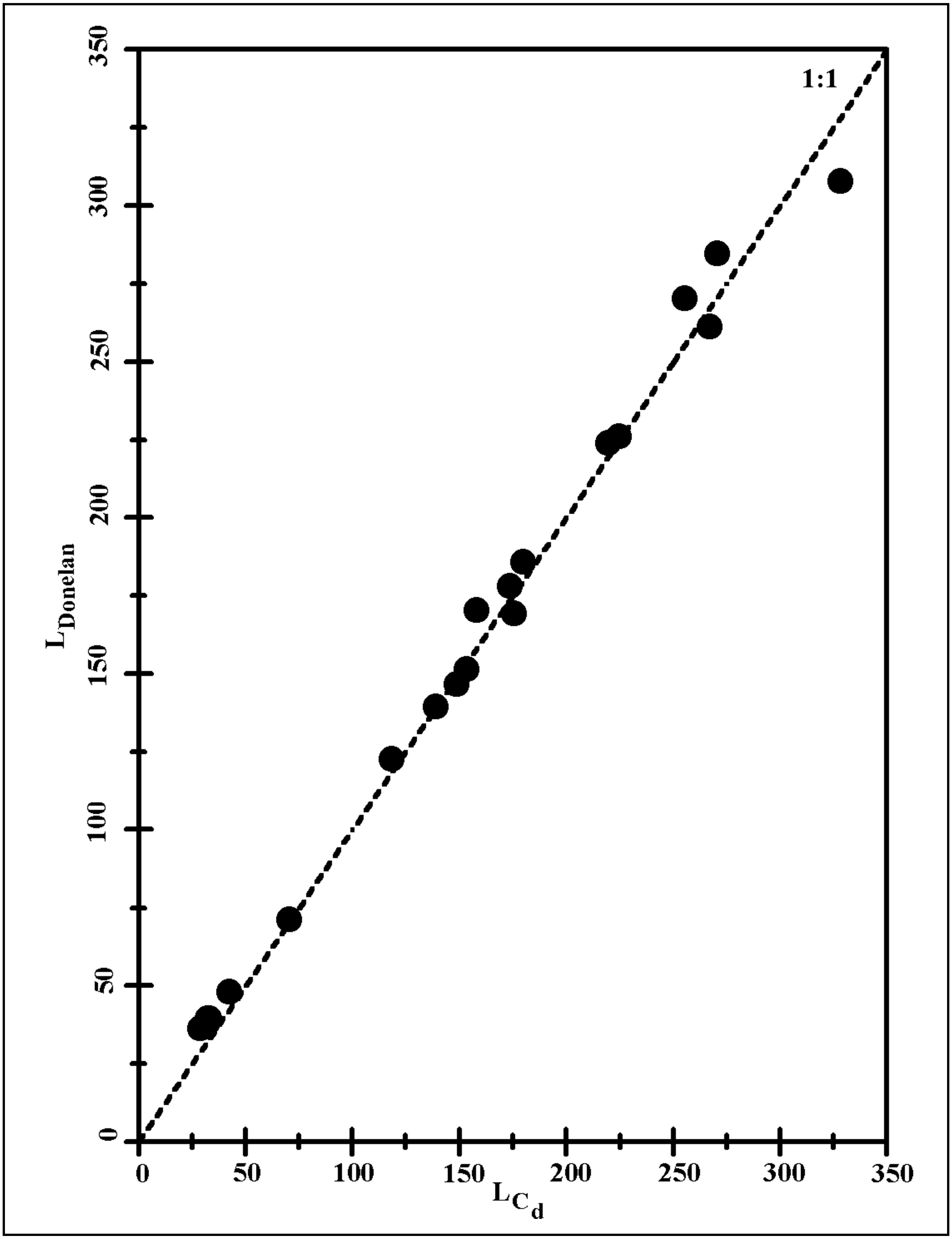

Figure 2B.2. A verification of Eq. (4b) for stable conditions.

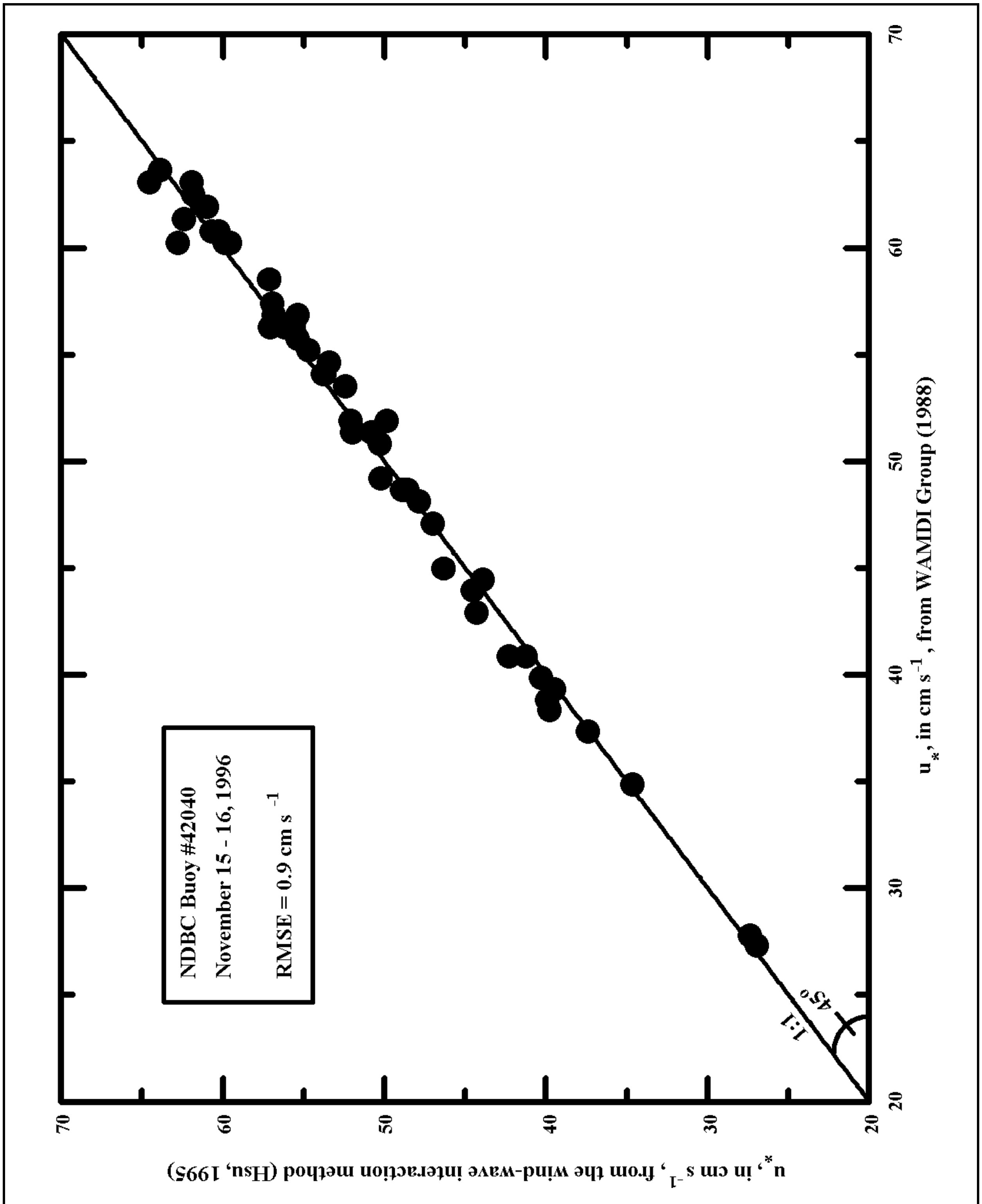

Figure 2B.3. A comparison of the shear velocity u* based on Eqs. (3), (6), and (7) using buoy #42040 during 15 and 16 November 1996 in the northeast Gulf of Mexico (Hsu *et al.* 2000).

Due to potential evaporation, the air over the water is usually moister than that over land, and the top of the marine boundary layer is oftentimes capped by clouds (see, e.g., Garratt 1992). On the basis of analysis of vertical soundings by research aircraft, rawinsondings, and radar wind profilers and Radio Acoustic Sounding Systems (RASS), it has been shown by Garratt (1992) that the mixing height h = LCL, the lifting condensation level under cumulus cloud conditions (where LCL = cloud base). The height of the LCL may be estimated by (see Hsu 1998)

$$H_{LCL} = 125\left(T_{air} - T_{dew}\right) \tag{8}$$

where H_{LCL} is in meters and the dewpoint depression at the sea surface in degrees Celsius.

On the eastern and Gulf coasts of the U.S., as well as over the East China Sea, cold air outbreaks are common in the winter season. Under these conditions, according to Hsu (1997), the mixing height, Z_i, is convectively unstable that

$$Z_i = A + B\left(\overline{w'\theta_v'}\right)_o \tag{9}$$

and from experiments conducted off the U.S. east coast and over the East China Sea, Z_i is found to be

$$Z_i = 369 + 6004\left(\overline{w'\theta_v'}\right)_0 \tag{10}$$

where Z_i is in meters and is the buoyancy flux in meters per second Kelvin.

For operational applications, the buoyancy flux at the sea surface is found to be

$$\left(\overline{w'\theta_v'}\right)_0 = C_T\, U_{10}\, \left(T_{sea} - T_{air}\right)\left(1 + \frac{0.07}{B}\right) \tag{11}$$

where $C_T = 1.10 \times 10^{-3}$ under unstable conditions (Smith 1980) and B is the Bowen ratio which has been provided in Eq. (5b).

Alternately, if we know the mixing height on land, H_{land} (in meters), and a barotropic boundary layer across the coastal zone exists, we may estimate the mixing height over the water, H_{sea} (in meters) by applying (Hsu 1988, p. 183)

$$H_{sea} = H_{land}\left(\frac{C_{d\ sea}}{C_{d\ land}}\right)\left(\frac{U_{sea}}{U_{land}}\right)^2 \tag{12}$$

where $C_{d\,land}$ is the drag coefficient on land, $C_{d\,sea}$ is based on Eq. (6), U_{sea} and U_{land} (both in m s^{-1}) are the wind speeds at sea and over land, respectively.

If the planetary boundary layer is baroclinic across the coastal zone, i.e., under the land and sea breeze effects, according to Hsu (1988, p. 204)

$$H_{sea} = H_{land} - 123\left(T_{land} - T_{sea}\right) \tag{13}$$

where T_{land} and T_{sea} (both in °C) are the air temperatures over land and sea, respectively.

In certain geographic regions and occasionally elsewhere, the sea surface temperature is less than the air temperature. Therefore, the boundary layer is said to be stable. The mixing height under stable conditions, h_{stable}, is (see Garratt 1992)

$$h_{stable} = c^{*}\sqrt{\frac{u_{*}\,L}{f}} \tag{14}$$

where f is the Coriolis parameter. From limited measurements under stable conditions, the coefficient c^{*} is found to be 0.11. Certainly, more field experiments are needed to further substantiate Eq. (14) and the value of c^{*}.

STANDARD DEVIATIONS OF THE CROSSWIND (σ_y)
AND VERTICAL (σ_z) DIRECTIONS

Some dispersion models require σ_y and σ_z in which Pasquill (1971) suggested that

$$\sigma_y = \sigma_v\ t\ S_y\left(\frac{t}{T_L}\right) \tag{15}$$

$$\sigma_z = \sigma_w\ t\ S_z\left(\frac{t}{T_L}\right) \tag{16}$$

or

$$\sigma_y = \left(\frac{\sigma_v}{U_{10}}\right) x\ S_y\left(\frac{t}{T_L}\right) \tag{17}$$

$$\sigma_z = \left(\frac{\sigma_w}{U_{10}}\right) x\ S_z \left(\frac{t}{T_L}\right) \tag{18}$$

For overwater applications, the turbulence intensities are found to be (Geernaert *et al.* 1987)

$$\frac{\sigma_v}{U_{10}} = 0.0586 + 0.0012 U_{10} \pm 0.015 \tag{19}$$

and

$$\frac{\sigma_w}{U_{10}} = 0.0369 + 0.0010 U_{10} \pm 0.005 \tag{20}$$

All symbols are conventional in air-pollution meteorology (see, e.g., Zannetti 1990).

THE VERTICAL EDDY DIFFUSIVITY

In some K-diffusion models, the vertical eddy diffusivity, K_z, is required, e.g. (Hanna 1984)

$$K_z = c\, u_*\, Z\left(1 - \frac{Z}{h}\right) \tag{21}$$

where u_* is the friction velocity and h is the mixing height. For example, the Urban Airshed Model (UAM), the preferred model of the U.S. Environmental Protection Agency for ozone studies, has a meteorological preprocessing subroutine which employs the gradient transport (K) modeling (Zannetti 1990, p. 234). Since in the K-theory, u_* is required for the computation of vertical diffusivity, K_z, and concentration, χ, it is recommended that proper formulas to reflect the overwater variations in aerodynamic roughness length, Z_0, and drag coefficient, C_d, be made in light of recent advances in the air-sea interaction field as discussed previously.

SUMMARY

In air quality modeling, many parameters are required. Therefore, parameterization is needed. Because the sea surface is mobile due to various wind waves and ocean currents, this review attempts to synthesize those parameterizations specifically applied to the marine environment for the determination of stability length, overwater friction velocity, the mixing height, turbulence intensity, and vertical eddy diffusivity. Many more field experiments are needed in order to further substantiate these results. The review provided here offers a guide for practical applications since many *in situ* air-sea interaction parameters may not be available over vast regions of the ocean.

ACKNOWLEDGMENTS

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REFERENCES

Arya, S.P. 1999. Air Pollution Meteorology and Dispersion. Oxford: Oxford University Press.

Donelan, M.A., W.M. Drennan, and K.B. Katsaros. 1997. The Air-Sea Momentum Flux in Conditions of Wind Sea and Swell, J. Phys. Oceanogr. 27, 2087 - 2099.

Garratt, J.R. 1992. The Atmospheric Boundary Layer. Cambridge: Cambridge University Press.

Geernaert, G.L., S.E. Larsen, and F. Hansen. 1987. Measurements of the Wind Stress, Heat Flux, and Turbulence Intensity During Storm Conditions Over the North Sea, J. Geophys. Res. 92(C12), 13127 -13139.

Hanna, S.R., G.A. Briggs, and R.P. Hosker, Jr. 1982. Handbook on Atmospheric Diffusion. Technical Information Center, U.S. Dept. of Energy, DOE/TIC-11223.

Hanna, S.R. 1984. Applications in air pollution modeling. *In* F.T.M. Nieuwstadt and H. Van Dop, eds., Atmospheric Turbulence and Air Pollution Modeling. D. Reidel Pub. Co. pp. 275 - 310.

Hanna, S.R., L.L. Schulman, R.J. Paine, J.E. Pleim, and M. Baer. 1985. Development and Evaluation of the Offshore and Coastal Dispersion Model, J. Air Poll. Contr. Assoc. 35, 1039 - 1047.

Hsu, S.A. 1988. Coastal Meteorology. San Diego, CA : Academic Press.

Hsu, S.A. 1995. A proper wind-stress drag coefficient formulation for computer modelling of seas and coastal regions. *I*n C.A. Brebbia, L. Traversoni, and L.C. Wrobel, eds., Computer Modelling of Seas and Coastal Regions II, Computational Mechanics Publications, Boston, pp. 413 - 420.

Hsu, S.A. 1997. Estimating Overwater Convective Boundary Layer Height From Routine Meteorological Measurements For Diffusion Applications At Sea, J. Appl. Meteor. 36, 1245 - 1248.

Hsu, S.A. 1998. A Relationship Between the Bowen Ratio and Sea-Air Temperature Difference Under Unstable Conditions at Sea, J. Phys. Oceanogr. 28, 2222 - 2226.

Hsu, S.A. 1999. On the Estimation of Overwater Bowen Ratio from Sea-Air Temperature Difference, J. Phys. Oceanogr. 29, 1372 - 1373.

Hsu, S.A., X. Zhang, and B.W. Blanchard. 2000. An evaluation of nine dimensionless fetch-limited wind-wave interaction formulas for the northeast Gulf of Mexico. Journal of Coastal Research, 16(4), 1063 -1067. West Palm Beach, Florida. ISSN 0749-0208.

Komen, G.J., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann, and P.A.E.M. Janssen. 1994. Dynamics and Modelling of Ocean Waves. Cambridge: Cambridge University Press.

Pasquill, F. 1971. Atmospheric Dispersion of Pollution, Quart. J. Roy. Meteor. Soc. 97, 369 - 395.

Panofsky, H.A. and J.A. Dutton. 1984. Atmospheric Turbulence. New York: Wiley.

Smith, S.D. 1980. Wind Stress and Heat Flux Over the Ocean in Gale Force Winds, J. Phys. Oceanogr. 10, 709 - 726.

Smith, S.D. 1988. Coefficients for Sea Surface Wind Stress, Heat Flux, and Wind Profiles as a Function of Wind Speed and Temperature, J. Geophys. Res. 93, 15467 - 15474.

The WAMDI Group. 1988. The WAM Model - A Third Generation Ocean Wave Prediction Model, J. Phys. Oceanogr. 18, 1775 - 1810.

Zannetti, P. 1990. Air Pollution Modeling. New York: Van Nostrand Reinhold.

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SESSION 2C

ARCHAEOLOGY

Chair: Dr. Richard Anuskiewicz, Minerals Management Service
Co-Chair: Mr. David Bull, Minerals Management Service

Date: December 5, 2000

Presentation	Author/Affiliation
Introduction	Dr. Richard J. Anuskiewicz Mr. David A. Ball Minerals Management Service
Rational for Refining and Revising the Gulf of Mexico OCS Region High Probability Model for Historic Shipwrecks	Dr. Richard J. Anuskiewicz Minerals Management Service
Results of Seafloor Monitoring for Historic Shipwreck Management	Mr. David A. Ball Minerals Management Service
Archaeology Under Pressure: Surveying for Shipwrecks Is a Challenge in Deep Water	Dr. Jack B. Irion Minerals Management Service

INTRODUCTION

Dr. Richard J. Anuskiewicz
Mr. David A. Ball
Minerals Management Service

This session focuses on the mission of the Gulf of Mexico Region's archaeological resource management program,"to manage archaeological resources through the pursuit of quality science while applying a fair, reasonable and consistent management strategy." To meet the goals articulated in our mission statement and to manage the workload and technology challenges of the 21st century, the Gulf of Mexico Region's archaeology program has had to evolve. Once a program involving primarily office work, it has expanded to combine office work, fieldwork, and research in the pursuit of quality science to manage submerged archaeological resources. The three presentations in this session provide a brief history of the region's involvement in developing archaeological management strategies, provide a management work-in-progress report, and suggest future possibilities for management of deepwater submerged archaeological resources for the 21st century.

RATIONALE FOR REFINING AND REVISING THE GULF OF MEXICO OCS REGION HIGH-PROBABILITY MODEL FOR HISTORIC SHIPWRECKS

Dr. Richard J. Anuskiewicz
Minerals Management Service

ABSTRACT

After using the present archaeological historic shipwreck model for the past 11 years, the Minerals Management Service (MMS) Gulf of Mexico (GOM) Region archaeological resource management program has concluded that model is not effective in finding shipwrecks and is thus flawed. This paper provides a brief history of the evolution of shipwreck modeling in the MMS GOM Region from 1977 and then discusses the 1989 shipwreck model and its shortcomings. The paper also provides insight on a new shipwreck model study presently under way that is expected to be completed by summer of 2002.

BACKGROUND: THE 1977 SHIPWRECK MODEL

For the past 16 years, the MMS has relied on a shipwreck model as justification to require the oil and gas industry to conduct remote-sensing surveys on lease blocks before exploration and development to look for historic shipwrecks. The first shipwreck model to require remote-sensing surveys was initiated and funded jointly by the National Park Service and the Bureau of Land Management in 1977 by Coastal Environments, Inc. (CEI). The CEI study recommended conducting 150-m (500 ft) remote-sensing shipwreck survey linespacing for all lease blocks shoreward of a line that roughly followed the 60 m (200 ft) bathemetric contour line, which encompassed about 2,395 lease blocks in the Western and Central GOM Region. This was called the “yes” or “no” conceptual model (meaning if a lease block fell shoreward of the model line a remote-sensing survey was required and if the block fell seaward of the line “no” survey was required) (Figure 2C.1). These initial surveys cost the lessee about $25,000 to $30,000 per lease block.

THE 1989 SHIPWRECK MODEL

In 1987 The Gulf of Mexico OCS Region contracted with Texas A & M University to conduct a study to reevaluate the Region’s 1977 historic shipwreck model and make recommendations, if necessary, to refine and revise the existing historic shipwreck model (Garrison *et al.* 1989). The study was to also determine whether there was a relationship between survey linespacing of magnetometer readings and side-scan sonar targets and the detection of objects below the sea floor. Another study task was to investigate whether remote-sensing data gathered during required archaeological shipwreck surveys in the Gulf could be analyzed to discriminate between historic shipwrecks and modern marine debris. Still another study goal was to develop, with a high confidence level, a shipwreck model that would provided the best available information the location of wrecks in the GOM based on their last known location. The Texas A&M study was completed in 1989 and provided a totally different shipwreck high-probability model both technically and

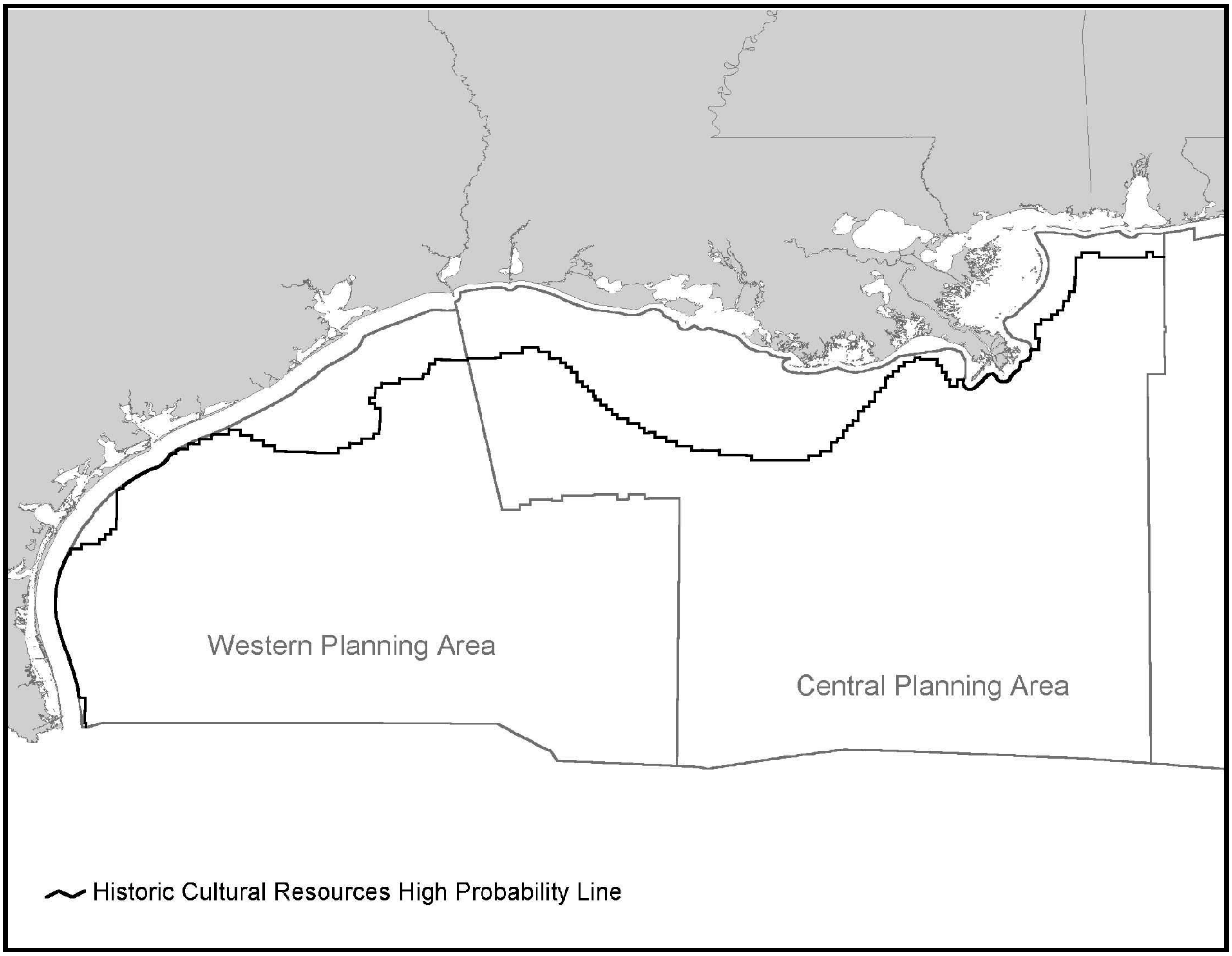

Figure 2C.1. The 1977 High-Probability Shipwreck "Yes/No" Line.

visually from the 1977 CEI model. The literature search for this study inventoried more than 4,000 shipwrecks throughout the GOM. Over 75% of shipwrecks inventoried occurred near shore and in state waters with the remainder in the open sea or federal waters. Of the over 4,000 shipwrecks inventoried less than one-half of one percent have known or verified locations. Therefore, approximately 99.5 % of the shipwreck locations inventoried during this study are only location estimates of where they sank. Based on these data and information, the contractor developed and recommended the following model and remote-sensing instrumentation shipwreck search strategy. One important factor that led to the development of the1989 shipwreck model was researching the evolution of navigation technology. Archival shipwreck research indicated the older the wreck, the less reliable was the wreck location information because of error factors in early navigation maps and instruments.

The 1989 study attempted to narrow the search location where wrecks might have sunk by developing the following remote-sensing search guidelines. The remote-sensing search guidelines were based on using the last known or reported location of a shipwreck and placing that location, if it fell within federal waters, in federal lease block. Since these locations are only estimates, the contractor theorized that the wreck would fall within 4.5-mile radial circle of the wreck's last known position. For federal lease blocks, the study recommended using a lease block as the center of a radial point and then swinging a 4.5-mile radial arc around that point forming a 9-mile circle which encompassed a nine-lease block square or shipwreck *centroid*. The nine-block centroid represents a high-probability area for the occurrence of historic shipwrecks and is the basis for requiring the oil and gas industry to conduct 50-m remote-sensing surveys for a particular lease block. There are approximately 1,440 lease blocks within the 1989 high-probability shipwreck model areas requiring surveys within the Western and Central GOM Region. Of these blocks, 251 (e.g. 28 wrecks/centroids) are in water depths greater than 60-m (200 ft) and only require 300-m survey linespacing. The remaining 1,189 blocks (e.g. 152 wrecks/centroids) require 50-m survey (Figure 2C.2). These 50-m surveys can cost the lessee upwards of $60,000 per block surveyed; deepwater surveys cost over $100,000 to $300,000 for a block survey.

PROBLEMS WITH THE 1989 SHIPWRECK MODEL

We simply do not know the precise locations of the nearly 300 historic shipwrecks thought to exist on the OCS. We have relied on the 1989-shipwreck model to reduce the area where these more expensive surveys must be conducted by designating certain leases as falling into a "high-probability" area for wrecks. Since the GOM OCS Region first instituted archaeological research into the lease block review process, over 70 shipwrecks have been discovered on the OCS. Very few of these shipwrecks have been determined to be historic. Most significantly, almost none of the historic wrecks were discovered within the "high-probability" zone designated by the 1989 model.

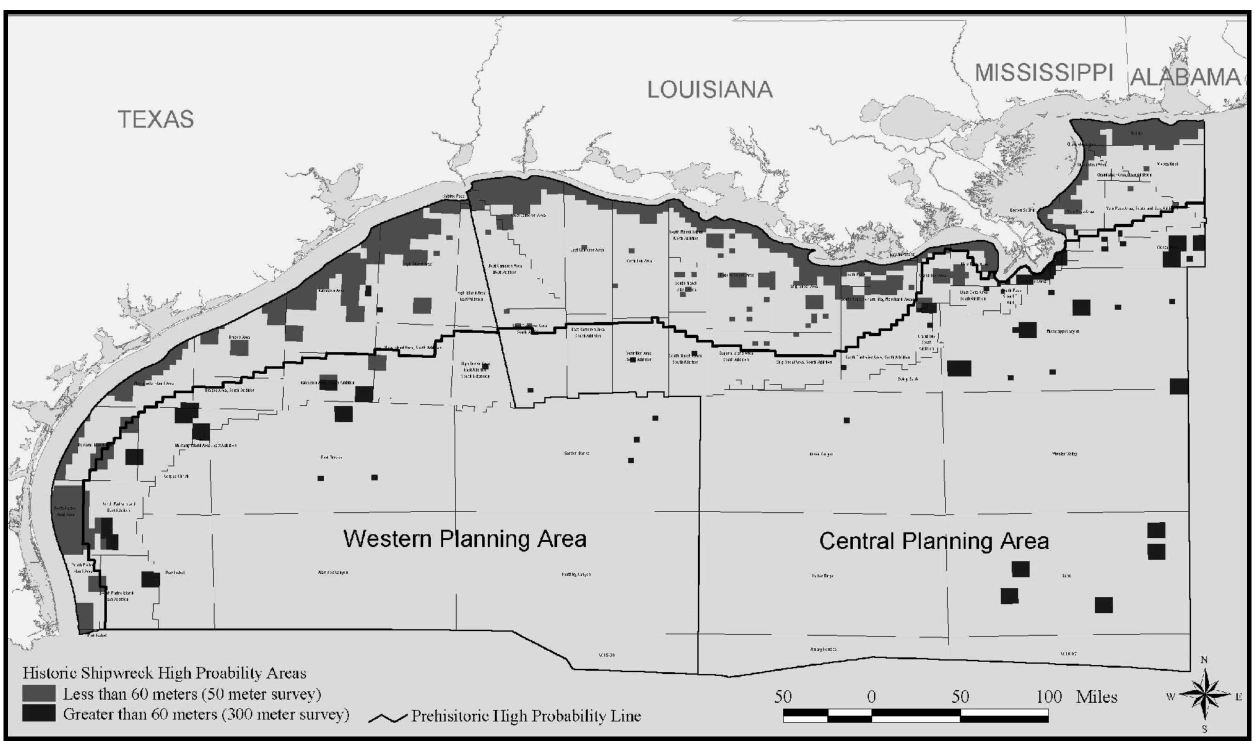

Figure 2C.2. The 1989 High-Probability Shipwreck Model.

How is the 1989 Shipwreck Model Flawed? After eleven years of using this model, the Region's archaeologists have determined the model must be updated. A new study must incorporate primary as well as secondary literature sources, and also sources not considered during the original study (e.g. hang sites). The new study must also correct errors in the data used to develop the 1989 model. In addition, many new developments have occurred in marine survey instrument technology in the last 11 years. Using this new technology would significantly improve our ability to detect potential shipwrecks if these instruments and methodologies were required by the MMS. At present, our experience with these older instruments limits our ability to design appropriate survey methodologies to find shipwrecks. Some of these new instruments promise the ability to conduct surveys, and gather and interpret data at a much faster rate, which would reduce survey costs while producing better-quality remote-sensing data.

STUDY OBJECTIVES OF THE NEW SHIPWRECK MODEL

The objectives of this study are to review the existing MMS shipwreck model, to examine new shipwreck databases, to review old shipwreck data sources to determine specifically where the 1989 study is flawed, and to determine how this model can be improved. This study will also examine the correlation between existing shipwrecks and hang sites associated with the MMS/NOAA sponsored "Fisherman's Contingency Fund" hang site database. Another objective will be to ground-truth, by archaeological divers, a limited number of "hangs" and develop a new, more refined, shipwreck model for the GOM OCS Region. This task will serve to verify the presumed correlation between sea floor hangs and shipwreck sites and establish the validity of the new model. All of this information will be synthesized and these data then used to develop a new high-probability shipwreck model. This study will also review, compare, and contrast the state-of-technology transfer of marine remote-sensing instrumentation that could be used to better fulfill requirements in the Region's archaeology NTL.

STUDY METHODS

A three-pronged research approach is being used to refine and revise the Region's high-probability shipwreck model. Ongoing now is a primary and secondary source archival search for historic period shipwrecks that sank within the GOM OCS Region's jurisdiction. This information is being compared with the 1989 shipwreck data base and the existing Fisherman's Contingency Fund along with other sea floor hang records, as well as existing lease block surveys. This research is being done to determine whether there are common shipwreck and hang site locations. This information will be synthesized to select a limited number of shipwrecks and/or underwater hang sites that will be surveyed by marine remote-sensing instrumentation and then ground-truthed by archaeological divers. Wrecks discovered during this task and/or two known historic wrecks will be then surveyed using both the "industry standard" proton precession magnetometer in concert with a 100 kHz side-scan sonar system and using a 50 m survey line spacing. The same wreck sites will be resurveyed using new cesium magnetometer and a high resolution 500 kHz side-scan sonar system at varying line space intervals and survey speeds. Next, the contract calls for comparing and contrasting results of these surveys over the selected shipwrecks sites to determine if present survey requirements are adequate to detect wrecks or if different survey standards should be required to encourage the use of more modern technology.

ANTICIPATED DELIVERABLES

Based on the results from the study objectives, the contractor will prepare a new revised predictive model for historic shipwrecks in the GOM and recommend survey instrumentation and strategies that would be the most effective in locating historic shipwrecks.

BENEFIT TO THE MMS AND OIL AND GAS INDUSTRY OF THE NEW SHIPWRECK MODEL AND STUDY

We anticipate the new archival study results will provide more accurate shipwreck locations and reduce the actual number of wrecks that will require the lease block holders to conduct 50-m linespacing surveys. Ground-truthing hang sites will locate additional shipwreck sites and help to reduce the number of 50-m survey blocks. We also believe that using the scientific methods to compare and contrast magnetometer and sonar technologies and strategies will provide significant technical data and strong justification for considering recommendations to use new instrument packages and survey strategies to conduct archaeological surveys on the OCS.

REFERENCES

Coastal Environments, Inc. 1977. Cultural Resource Evaluation of the Northern Gulf of Mexico Continental Shelf. Prepared for Interagency Archaeological Services, Office of Historic Preservation, National Park Service, Washington D.C. and Bureau of Land Management, New Orleans. 5 Volumes.

Garrison, Ervan G., C. P. Giammona, F. J. Kelly, Anthony R. Tripp, and Gary A. Wolf. Historic Shipwrecks and Magnetic Anomalies of the Northern Gulf of Mexico: Reevaluation of Archaeological Resource Management Zone 1. Prepared for U. S. Department of the Interior, Minerals Management Service, OCS Study 89-0023-25. 3 Volumes.

Richard (Rik) J. Anuskiewicz was awarded his B.A. in 1972 and his M.A. in 1974 in Anthropology, with specialization in archaeology from California State University at Hayward. Rik was employed with the U.S. Army Corps of Engineer Districts of San Francisco, Savannah, and New England Division from 1974 to 1984 as a terrestrial and underwater archaeologist. In 1980 he began work on his doctorate. In 1984 he accepted his present position with Department of the Interior, Minerals Management Service, Gulf of Mexico Region as a marine archaeologist. Rik received his Ph.D. in 1989 in Anthropology, with specialization in marine remote-sensing and archaeology from the University of Tennessee at Knoxville. Rik's current research interest is focused on using remote-sensing instrumentation as a tool for middle-range theory building through the correlation of instrumental signatures to specific observable archaeological indices.

RESULTS OF SEAFLOOR MONITORING FOR HISTORIC SHIPWRECK MANAGEMENT

Mr. David A. Ball
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INTRODUCTION

The Minerals Management Service's Seafloor Monitoring Team was instituted to verify industry compliance with environmental mitigation measures and to ensure the protection of significant seafloor habitats and archaeological properties. It was established in 1997 and receives its authority from the National Environmental Policy Act; MMS legislation 30 CFR 250, which requires operators to conduct various monitoring programs; and the Government Performance Results Act. Additionally, the National Historic Preservation Act requires federal agencies to inventory and protect historic sites and to evaluate these sites for eligibility to the National Register of Historic Places (Irion and Anuskiewicz 1999).

Currently, the Seafloor Monitoring Team consists of seven divers, including three archaeologists, two biologists, an engineer, and a geophysicist. Over the last four years, the team has carried out almost twenty projects; these include assessing industry compliance of resource mitigation, evaluations of natural reefs and hard-bottom areas, and investigation of almost twenty shipwreck sites. Of the almost twenty wreck sites that we have examined, five have been identified as historic shipwrecks, and one of these, the 19th century sidewheel steamship *Josephine*, has been listed with the National Register of Historic Places.

As Dr. Anuskiewicz discussed in his paper, the MMS has developed, and is currently revising, the predictive model for where we expect to find historic shipwrecks in the Gulf of Mexico (Anuskiewicz 2001). One of the ways that we manage these shipwrecks is with the Seafloor Monitoring Team. By investigating and ground-truthing reported shipwrecks we are sometimes able to free up several lease blocks from the more costly 50-meter survey requirements. We are also able to create an inventory of these wrecks and evaluate their conditions, thus fulfilling our requirements under the National Historic Preservation Act.

This paper examines the outcomes from a couple of historic wrecks that the Seafloor Monitoring Team has inspected over the last four years, the *Josephine* and the *Tulsa*. Both of these wrecks are located in the Mobile Area. The *Josephine* was originally reported in Mobile Block 810 but was actually found in Block 766, and two separate reports identified the *Tulsa* in Block 1000 and 1001. As a result of the 1989 High Probability Shipwreck study, a nine-block centroid area was set aside for each of these wrecks requiring 50-meter survey line spacing for each block (Garrison, *et al.* 1989).

THE *TULSA*

Historical research has identified the *Tulsa* as a 607-ton barge schooner that was built in 1909 and sunk on 11 March. The vessel was owned by the Texas Company at the time of its sinking (U.S. Treasury Department Bureau of Customs 1944).

Though the 1989 historic shipwrecks predictive model placed the location of the *Tulsa* in Mobile Area, Block 1000, a 1985 survey had identified a cluster of magnetic anomalies and sidescan sonar targets in Block 1001 as the *Tulsa* (Thornton *et al*. 1985). In 1999 a new survey was conducted in the Mobile 1000/1001 area for a right-of-way pipeline. The report from this survey identified a cluster of magnetic anomalies and sidescan targets in Block 1000 as the remains of the *Tulsa* (George *et al.* 1999).

With the information from these two surveys, the MMS Seafloor Monitoring Team developed a research design to conduct its own investigation to determine which of the two reported locations was correct and to evaluate both sites for potential eligibility to the National Register of Historic Places.

In July 2000, the MMS Seafloor Monitoring Team conducted a survey in Mobile Area, Blocks 1000 and 1001. Using our 600 kHz sidescan sonar, we identified a large debris scatter in block 1000, near the 1999 reported location of the *Tulsa*. The debris field extended over 500 feet long by approximately 100 feet wide and was oriented in a northwest by southeast direction. Once the debris scatter was identified, divers were sent down to make observations of the wreck.

During our investigation of the wreck site we located and identified several artifacts specifically associated with a sailing vessel. Divers were able to identify rigging components such as chain plate and eyebolts (where the lower standing rigging or “shrouds” were attached to the side of the ship) and the remains of a deadeye (used for adjusting tension on the lines supporting the mast). We also observed the remains of a winch, part of a small auxiliary steam engine, and metal trusses for attaching the yardarms to the masts. However, no remains of the hull of the vessel were observed during the investigation. The most prominent feature of the site was a large pile of chain surrounding a Danforth-type stockless anchor. Based on the discovery of component parts of the rigging of an early twentieth-century sailing ship, we have determined that the shipwreck located in Mobile Area, Block 1000 is the *Tulsa* (Anuskiewicz 2000).

The second day of our investigation in the Mobile area focused on the reported wreck in Block 1001. Divers observed a very large steel vessel several hundred feet long, sheered off below the deck level. The vessel was determined to be the remains of the lower hold of a “Liberty” ship. Further investigation of available records for this area of the Gulf indicated that the Liberty Ship *Anderson* had been positioned in this area by the Alabama Marine Resources Division in 1973 as part of their artificial reef program.

THE *JOSEPHINE*

The sidewheel steamship Josephine was originally reported to be in Mobile Block 810, but was actually found a couple of miles away in Block 766. The vessel was first brought to the attention of the MMS as a result of a survey performed by Klein and Associates about a decade ago. Though the ship's identity had been long forgotten, the location of the wreck had been well known to locals as a great fishing spot.

With the acquisition of a high-resolution sidescan sonar in 1997, the Seafloor Monitoring Team developed a research design to test its new sidescan unit on this wreck site. The MMS archaeologists running the survey were astonished by the excellent state of preservation of what was clearly a sidewheel steamship with a walking beam engine. Subsequent research, which included the discovery that the wreck was labeled on an 1883 navigation chart, identified the vessel as the *Josephine* (Figure 2C.3), an iron-hulled steamer built in 1867 for the Morgan Line (Irion 2000).

After initial diver investigations of the shipwreck in 1997, historical research was conducted to learn more about the history of the *Josephine* and also to determine its potential significance for nomination to the National Register of Historic Places. Research has found that this vessel was owned by New York businessman Charles Morgan, one of the foremost figures in the development of the steamship trade along the Gulf Coast of the United States.[1]

Construction of the *Josephine* was completed in 1868 by the Harlan and Hollingsworth Company of Wilmington, Delaware, which was one of the premier companies to manufacture merchant steamers in the 19th century. The ship was built specifically for use by Charles Morgan and his

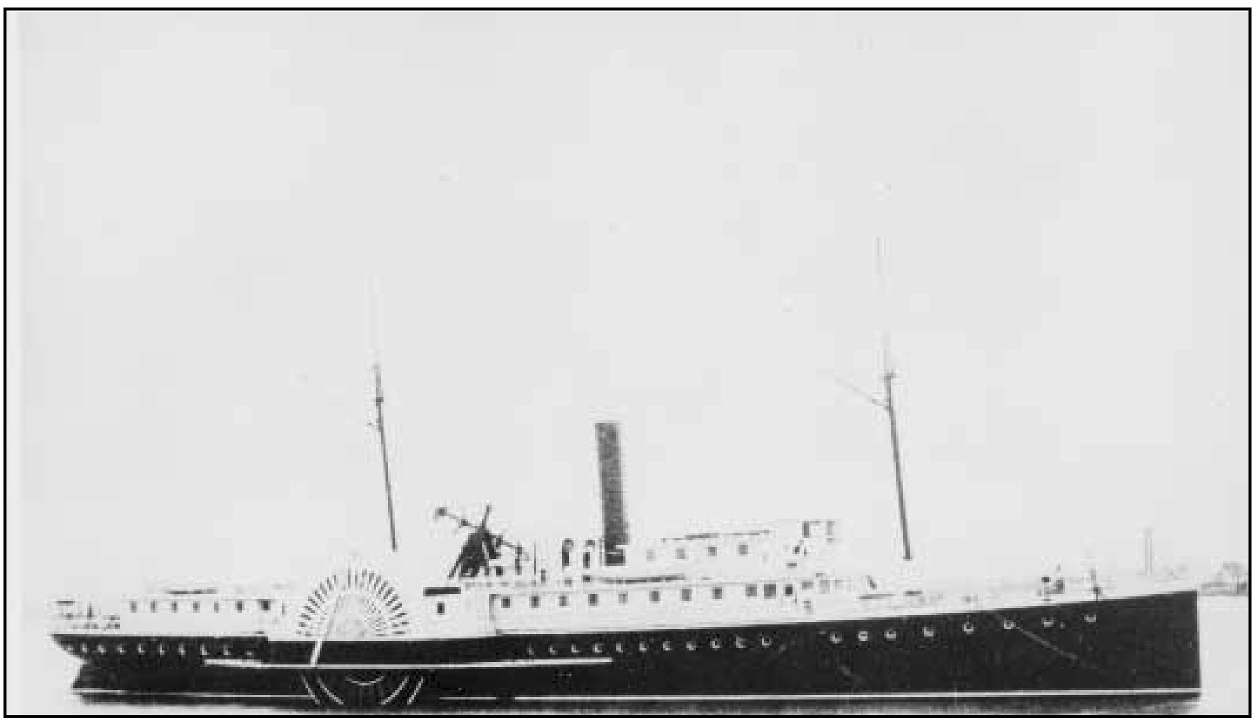

Figure 2C.3. The Josephine (Photo courtesy of the Mariner's Museum, Newport News, VA.)

[1] Charles Morgan's influences are still seen through the south today. For example, Brashear City, LA, was renamed Morgan City in his honor, and one of his sons-in-law, Charles Whitney, who worked in the Morgan steamship business for many years, went on to found Whitney Bank.

Louisiana and Texas Railroad and Steamship Company. Upon her arrival at New Orleans in 1868, she was immediately assigned to regular weekly service between New Orleans and Galveston.

Early in 1881, the *Josephine* was transferred to the New Orleans to Havana route. This was to be her last voyage. On 27 January, the *Josephine* left New Orleans, and arrived in Havana a few days later. On 2 February she departed Havana with several passengers and a cargo of tobacco and cigars.

According to one passenger's account of the foundering, the steamer began her return trip to New Orleans at 5 p.m. on 2 February. She arrived in Key West the following afternoon and departed for Cedar Key that evening, arriving on the morning of Friday, 4 February. At Cedar Key the *Josephine* picked up several more passengers. Included among the new passengers were 14 members of an Italian crew that had recently survived the sinking of their lumber ship, originally bound for London from Pensacola.

The *Josephine* left Cedar Key around 4 p.m. Friday enroute to New Orleans, evidently sailing without incident until sometime Sunday, when it was noticed that the vessel was leaking. Passengers and crew worked to bail water, but could not control the leak. The captain made arrangements to abandon ship; however, before the captain gave the order, the leak began to subside. Yet not long after, the seas picked up and the vessel began to take on water once more. On Monday evening the captain again had the crew prepare to abandon ship. By 3 a.m. Tuesday morning all had escaped, and the vessel began to heel to one side (*Daily Picayune* 1881).

The Seafloor Monitoring Team returned to the wreck site in 1999 and made several dives. Measurements of significant features of the vessel, as well as photo and video documentation and sidescan sonar images were obtained (Figure 2C.4). Researchers observed that much of the hull of the wreck remains buried, while the upper hull above the waterline is gone. This observation is based, in part, on the position of the attachment points for the paddlewheels, which are still intact, and the iron spokes of the paddlewheels, some of which survived. The bow of the vessel is completely buried, but the line of the hull may be followed with only short interruptions to the vessel's rudder. By measuring the paddlewheel eccentrics, MMS divers were able to derive the stroke of the engine at 11 feet, the same dimension published for the *Josephine*'s engine. One of the most dramatic features of the wreck is the walking beam, the diamond-shaped feature that connected the engine piston to the eccentric of the paddlewheels, which lies collapsed against the starboard side. Based on observations made by the MMS seafloor monitoring team, we are confident in identifying the wreck, which has been assigned Mississippi State Historic site number 22HR843, as Morgan's *Josephine* (Irion and Ball 2000).

NATIONAL REGISTER NOMINATION OF THE *JOSEPHINE*

With two separate visits by MMS divers to the *Josephine*, and a good idea of the history of the vessel, MMS archaeologists next began to evaluate the acquired information to determine if the vessel were eligible to be listed on the National Register of Historic Places.

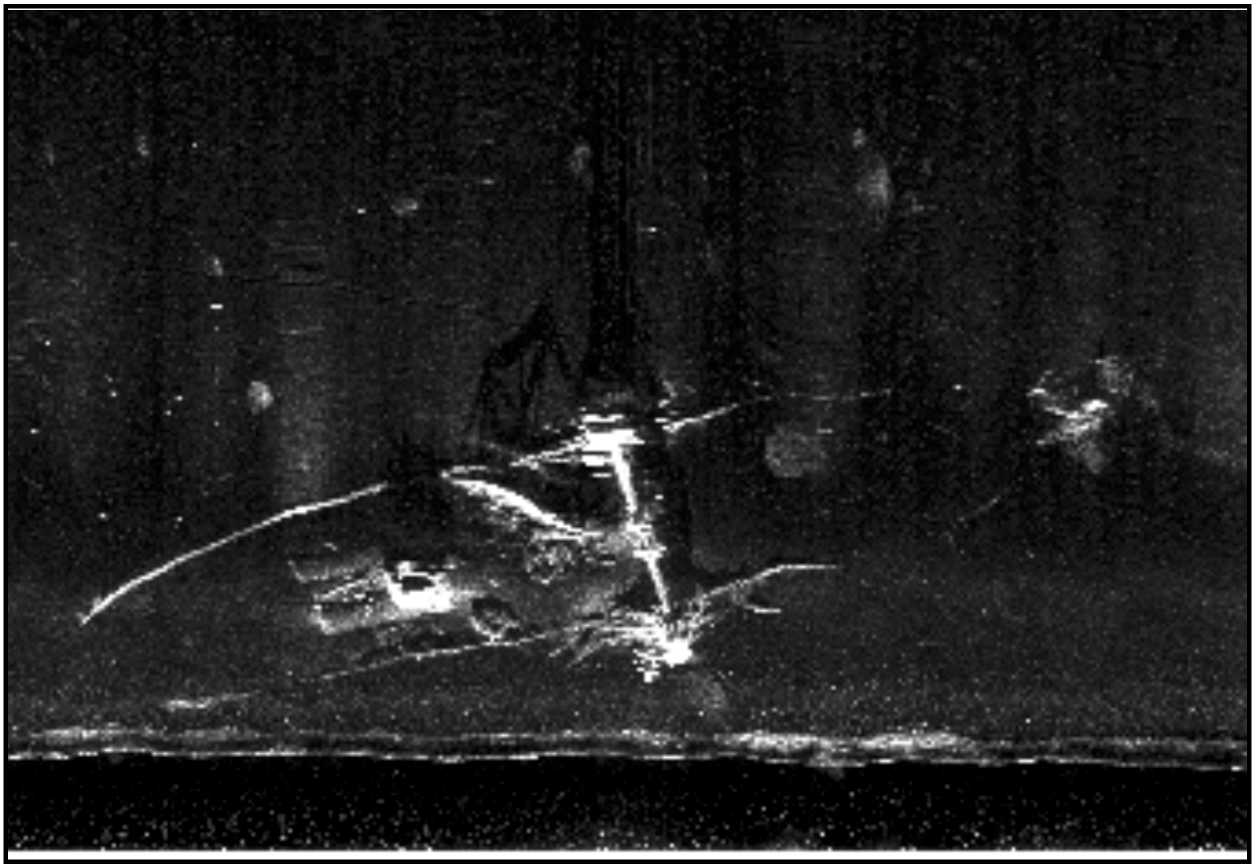

Figure 2C.4. Sidescan image of the Josephine.

In order for an archaeological site to be listed with the National Register, the site must meet at least one of four criteria for eligibility. Criterion A evaluates a site based on its association with events that have made a significant contribution to the broad patterns of our history. Criterion B states that a site must be associated with the lives of persons significant in our past. Criterion C requires an assessment based on unique design or construction methods. The final criterion, D, considers a site's information potential. In other words, properties may be eligible if they have yielded, or may be likely to yield, information important in history or prehistory (NRHP website 2000).

Though an argument could be made that the *Josephine* qualifies for listing under each of the four criteria, the vessel was officially nominated, and accepted, under criteria C and D. On 21 September 2000 the Mississippi Department of Archives and History's National Register Review Board accepted the steamship *Josephine* to the National Register of Historic Places. It was posted in the Federal Register on 6 November 2000.

CONCLUSION

The investigation and evaluation of the reported locations of the shipwrecks *Tulsa* and *Josephine*, located on the Federal OCS, provided valuable information for the MMS Archaeological Resource Management Program. Based on divers' observations, video, and photographic documentation, the

MMS was able to identify two historic shipwrecks. And through additional historical research and evaluation of these wrecks, the MMS has fulfilled its obligation under the National Historic Preservation Act to "assess and inventory" archaeological sites under its control.

We were able to determine that because of the *Tulsa's* rapid rate of deterioration since its loss in 1943, and its lack of structural and physical integrity, the vessel most likely does *not* meet the necessary eligibility criteria for listing in the National Register of Historic Places. Because of the excellent preservation of a large portion of the *Josephine*, this vessel has now been listed, and therefore will receive protection under the National Register of Historic Places. Additionally, identification of these vessels will enable the MMS to release several lease blocks from 50-meter survey requirements, thereby providing significant survey cost savings to the oil and gas industry.

REFERENCES

Anuskiewicz, Richard A. 2000. Trip Report for National Register Evaluation of the Schooner Tulsa, Mobile Area, July 18-20, 2000. U.S. Government Memorandum, Minerals Management Service, New Orleans, LA.

Anuskiewicz, Richard A. 2001. This session.

Daily Picayune. 10 February 1881. Microfilm collections, Jefferson Parish Public Library, Metairie, LA.

Garrision, Ervan G., Charles P. Giammona, Frank J. Kelly, Anthony R. Tripp, and Gary A. Wolff. 1989. Historic shipwrecks and magnetic anomalies of the northern Gulf of Mexico. U.S. Department of the Interior Minerals Management Service, Gulf of Mexico Region, OCS Study No. MMS 89-0024.

George, Tony, Robert A. Church, Stephen Fournet, Paul K. Monier, and Daniel J. Warren. 1999. Archaeological, Engineering and Hazard Report "Buccaneer" Pipeline Project Proposed 36-inch Pipeline Route. Prepared by C & C Technologies Survey Services, Lafayette, LA.

Irion, Jack. 2000. "MMS Divers Identify Historic Shipwreck." *In* The Gulf of Mexico Alligator. US Department of the Interior Minerals Management Service, Gulf of Mexico Region, New Orleans, LA.

Irion, Jack B. and Richard J. Anuskiewicz. 1999. MMS Seafloor Monitoring Project: First Annual Technical Report, 1997 Field Season. U.S. Department of the Interior Minerals Management Service, Gulf of Mexico Region, OCS Report No. MMS 99-0014.

Irion, Jack B. and David A. Ball. 2000. The *New York* and the *Josephine*: two steamships of the Charles Morgan line. U.S. Department of the Interior Minerals Management Service, Gulf of Mexico Region. *http://www.gomr.mms.gov/homepg/whatsnew/publicat/gomr/Irion_and_Ball.pdf*

National Register of Historic Places, Listing a Property. *http://www.cr.npw.gov/nr/listing.htm* . May 2000. (Accessed 13 Dec. 2000).

Thornton, K., I. Preece, D. Price, and D. Stier. 1985. Geohazard, Archaeological and Live-bottom Survey Report for Viosca Knoll Block 32. Prepared by Comap Geosurveys, Inc., Houston, TX.

U.S. Treasury Department Bureau of Customs. 1944. Merchant Vessels of the U.S. U.S. Government Printing Office, Washington, DC.

Dave Ball received his Bachelor of Arts degree in anthropology from Sonoma State University in 1992 and his Master of Arts degree, which focused on marine archaeology, from Florida State University in 1998. He has conducted fieldwork in archaeology for over eight years and has directed field research on both land and underwater archaeological sites from Florida to Washington State. Some of the more notable sites that Dave has worked on include an inundated prehistoric site at Little Salt Spring, Florida, dating back about 10,000 years; a 1533 Spanish shipwreck in the Dry Tortugas; a Confederate Ironclad in Mobile Bay, Alabama; and the 1686 French shipwreck *la Belle*, which wrecked in Matagorda Bay, Texas. Dave has been employed with the MMS as a Marine Archaeologist since October 1999.

ARCHAEOLOGY UNDER PRESSURE: SURVEYING FOR SHIPWRECKS IS A CHALLENGE IN DEEP WATER

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ABSTRACT

This paper addresses one of the major challenges facing historic preservation in the 21st century. As the oil and gas industry moves into the deep water environment, balancing the need to extract resources with the mandate to protect natural and cultural resources tests the limits of our resourcefulness. This presentation explores some of these challenges, examines some of the technology that is now being applied to deepwater surveying, and offers practical solutions for dealing with these issues

As the oil and gas industry moves its operations farther and farther from shore and into ever-deeper water, the Minerals Management Service faces new challenges in fulfilling its role as environmental steward. Not the least of these challenges comes as a result of our responsibility to protect significant archaeological resources on the seabed. MMS, as a federal agency, is obligated under Section 106 of the National Historic Preservation Act to consider the effect of its actions, which includes the granting of exploration and development permits, on properties deemed important enough to be eligible for the National Register of Historic Places. The MMS estimates that there are well over 4,000 historic shipwrecks in the Gulf of Mexico (GOM), which, if discovered, could potentially meet these criteria (Garrison *et al*. 1989: I-1). The phrase “if discovered” is key. At present, we have only a vague idea of where most of these shipwrecks lie based on historical research using old maps, wreck reports, and other primary and secondary sources. As a result, the only way to locate these properties is to conduct remote sensing surveys of lease blocks before operations commence.

In an attempt to target these surveys in a way that would optimize the discovery of potential shipwrecks, the MMS funded a study in 1989 to designate certain “high-probability” blocks for more intensive survey using instruments that have proven successful for the purpose: the proton precession magnetometer and the side-scan sonar. The magnetometer measures localized fluctuations in the earth’s magnetic field caused by the presence of anomalous deposits of ferrous metal. Anchors, cannon, or the iron hulls of 19th century steamships all cause detectable anomalies. The side-scan sonar, on the other hand, paints a picture of the surface of the seafloor using reflected sound. The outline of a ship’s hull, if it protrudes above the seabed, can easily be distinguished from the surrounding bottom. Over a hundred shipwrecks have been located to date in the Gulf using these methods, 14 of which are in water depths greater than 1,000 feet (Table 2C.1). Discovered shipwrecks include such historically important vessels as the *New York*, the *Hatteras*, the Josephine, and nearly a dozen casualties from World War II.

The process on the relatively shallow waters of the shelf has been as follows. In blocks designated as having a high potential for shipwrecks, the leasee is required to conduct a high-resolution survey

Table 2C.1. Discovered vessels in deep water.

Vessel Name	Area	Wreck Date	Min Depth (meters)	Max Depth (meters)
Unknown	GC	?	802	965
Unknown	MC	?	315	519
Unknown	MC	?	572	784
Unknown	GB	?	441	592
Unknown	GB	?	622	900
Gulf Oil?	MC	1942?	1209	1359
Unknown	MC	?	1163	1231
Unknown	VK	?	1250	1427
Unknown	EB	?	1109	1144
Unknown	EB	?	967	1224
Unknown	GB	?	1062	1146
Gulf Penn?	MC	1942?	455	578
Alcoa Puritan	MC	1942	1399	1642
Robert E. Lee	MC	1942	1399	1642

using a boat-towed magnetometer, a side-scan sonar, a subbottom profiler, and a fathometer. These surveys differ from normal shallow hazard surveys only in that they are conducted along tracklines spaced 50 meters (165) apart instead of 300 meters (990 ft) apart. The reduced line spacing is important because shipwrecks occupy relatively small, defined areas, and 50 meters is determined to be the widest interval to allow the sensor to detect a wreck on at least three passes. This clustering of anomalies helps the archaeologist distinguish a possible shipwreck from casually discarded small debris. At wider line spacing, virtually any detected magnetic anomaly could be a shipwreck. Worse, at the 300-meter line spacing, something like a 400-year-old Spanish galleon could go completely undetected by the magnetometer between the survey lines.

The high-probability block model was based on the idea that historic shipwrecks would likely be found within 10 miles of their historically reported positions. Unfortunately, this has not proven to be entirely accurate. Over the past ten years, a number of important wrecks have been found many miles away from their reported position and outside of the 9-block grid designated for their search. This is due to a number of factors, mostly relating to the general vagueness of historic wreck reporting, which increases exponentially as one goes farther back in time, and the inherent inaccuracy in pre-GPS navigation. Many historic wrecks were recorded simply as “lost between Galveston and New Orleans” or “sunk 35 miles south [of] the Sabine River.” Even the recorded positions of relatively recent World War II wrecks are woefully inaccurate. The problems associated with the current shipwreck model and steps that we are taking to correct this problem is the subject of a paper in this session by Dr. Rik Anuskiewicz.

Many of the wrecks discovered in oil and gas industry surveys were located by side-scan sonar using standard shallow hazard survey methods despite being outside the archaeological high-probability survey grid. In fact, the routine use of side-scan for shallow hazard surveys outside of any lease area designated for archaeological survey has given us something of a comfort factor for those areas beyond the 60 meter depth contour where archaeological survey was not required. As a result of industry's use of the deep-tow sonar, for example, two World War II era wrecks—the *Robert E. Lee* and the *Alcoa Puritan*—were discovered in over 5,000 feet of water in the Mississippi Canyon Area. Again, these ships lay outside of the two 9-block grids designated for their search from our historical research.

The difficulties associated with locating shipwrecks become exacerbated as industry moves farther offshore and into deeper water. Historical estimates of location based on dead reckoning become exaggerated and the likelihood of survivors to report the wreck decreases. In very deep water, the drift of the vessel through the water column for a mile or more can result in a large discrepancy between the reported position when the vessel began sinking on the surface to its final resting place on the ocean floor. The great uncertainty associated with historic shipwreck positions coupled with the current trend in the industry to eschew traditional "hi-res" survey instruments in favor of 3-D seismic imaging is forcing MMS to re-think its approach to Section 106 compliance in the face of the steady advance into deepwater areas.

At present, MMS estimates that there are some 35 historic shipwrecks in the GOM in water depths greater than 1,000 feet (Table 2C.2). These vessels range in date from 1752 to 1942, and include several merchant ships lost to U-boat attacks such as the *Ontario*, the *Torny*, the *Ampala*, the *Carabelle*, the *Gulf Penn*, and the *Gulf Oil*. The majority of the reported losses, however, are schooners ranging from 300 to just over a thousand tons that foundered in the late nineteenth and early twentieth century.

If industry were routinely conducting high resolution sonar surveys of their lease blocks, we would have a fair degree of confidence that many of these wrecks would be discovered even if they fell outside of an "official" archaeological survey area. Sadly, that is no longer the case. Because of the high cost of conducting high-resolution surveys in deep water, the current trend is to utilize 3-D seismic data in hazards analyses in areas without complex bottom topography. Unlike high-resolution survey instruments, whose sensors must be towed close to the seafloor, 3-D seismic instrumentation consists of streamers and airgun arrays that are towed just below the surface. A typical survey boat tows 9 streamers that can be up to 12 km in length. 3-D seismic technology has proven to be a real boon to the oil and gas in the Gulf, primarily because it permits, for the first time, accurate definition of reserves beneath salt domes, which act as a barrier to traditional 2-D imaging. With proper post-processing, 3-D data also have proven useful in mapping surface faults, vents, and other "geological hazards." As a result, MMS biologists currently are using these data to predict the location of chemosynthetic organisms (Roberts *et al*. 2000).

It would be fortunate if 3-D seismic data could also be used to locate shipwrecks, since these data are routinely acquired in deepwater lease blocks. Unfortunately, though, this does not appear likely based upon analysis of two test cases. As discussed earlier, two important wrecks have already been discovered in Mississippi Canyon Area in over 5,000 feet of water using the deep-tow sonar. Both

Table 2C.2. Reported shipwrecks in deep water.

Vessel Name	Centroid	Wreck Date	Min Depth of Search Area (meters)	Max Depth of Search Area (meters)
Rhoda B. Taylor	DC 347	1878	368	439
Marion N. Cobb	DC 141	1925	1421	2321
Walter L. Plummer	DC 347	1894	282	335
B-1	DC 412	1942	889	1061
James C. Clifford	DD 504	1909	258	525
Villa y Hermano	DD 984	1905	669	810
Springfield	DC 543	1918	1083	1398
Ontario	DC 800	1942	2495	2743
C.W. Wells	DT 853	1921	770	1006
Northern Eagle	EB 199	1908	246	483
Helena E. Russel	EL 451	1899	799	1195
William J. Keyser	EL 459	1898	296	487
Emma L. Cottingham	EL 984	1906	1046	3230
Allegheny	HE 287	1921	2985	3051
Torny	HE 334	1942	3032	3118
Biscayne	HE 345	1913	3159	3219
Rosetta McNeil	HE 480	1882	3180	3219
Fred P. Litchfield	HE 970	1906	3008	3082
Horace M. Bickford	HH 598	1925	3292	3322
Speedwell	LL 449	1920	2888	2926
Providencia	LL 451	1936	2906	2999
Isaac T. Campbell	LL 503	1909	2995	3072
Three Marys	LL 755	1920	2792	2890
J.W. Clise	LU 168	1940	2637	2762
W.H. Marston	LU 344	1927	2601	2787
Ampala	LU 453	1942	2825	2918
Carabelle	LU 671	1942	2966	3033
Carrie Strong	LU 775	1916	2773	2883
Nokomis	MC 1008	1905	2220	2579
Western Empire	MC 332	1875	978	2171
Gulf Penn (see Table 2C.1)	MC 499	1942	426	720
Gulf Oil (see Table 2C.1)	MC 795	1942	381	757
Elmer E. Randall	VK 826	1906	250	1042
Anona	VK 830	1944	378	1321
Bradford C. French	VK 957	1916	709	1497
Gulf Oil (see Table 2C.1)	MC 795	1942	381	757

of these wrecks, believed to be the *Robert E. Lee* and the *Alcoa Puritan*, are quite large with substantial remains showing above the seafloor. The German submarine U-166 torpedoed the passenger ship SS *Robert E. Lee* on 30 July 1942, while it was in route from Trinidad to New Orleans (Figure 2C.5). At the time of her loss, her compliment consisted of 131 crewmembers, 6 Naval Armed Guard, and 270 passengers, most of whom were survivors of other torpedoed American ships. Ten crewmembers and 15 passengers were lost. The *Robert E. Lee* was built in 1924 and was 375 ft long with a 54-ft beam and a gross tonnage of 5,184. The side-scan image of the wreck shows it to be largely intact and upright on the seafloor with a relief off the seabed of over 30 ft.

The vessel *Alcoa Puritan*, located a short distance away in the same lease block, was in route from Trinidad to Mobile when it came under fire from the German submarine U-507 on 6 May 1942. After losing steerage, her crew of 40 abandoned her and the U-507 sunk her with a torpedo amidships. The side-scan image obtained by industry of this wreck shows a large vessel broken into at least two pieces. The 6,759-ton *Alcoa Puritan*'s recorded dimensions were 397 ft long with a beam of 60 ft.

Both of these steel-hulled wrecks are quite large with substantial remains above the seafloor. The *Robert E. Lee*, in particular, appears largely intact in the sonar record. Moreover, accurate coordinates of both of these wrecks were obtained in 1986. This permitted a line-by-line analysis of available 3-D data by MMS geophysicists for several hundred feet around both coordinates. Absolutely nothing was observed in these data that could distinguish either of these two large vessels from the surrounding seafloor. As a result, we are forced to conclude that 3-D seismic surveys are completely ineffective for the purpose of locating shipwrecks on the seafloor.

What then are the alternatives? At present, we are forced to continue to rely on boat-towed side-scan sonars as a search tool. The MMS has, at times, waived this requirement when seafloor impacts were minimal and the impact areas could be inspected visually by an ROV. Hopefully, continued advances in technology will make survey using Autonomous Underwater Vehicles (AUVs) practical. AUVs are currently in use that can conduct high-resolution survey along pre-programmed routes and store the data on a hard drive until it can be downloaded on the mother ship after the vehicle is recovered (Chance *et al*. 2000). Since they are not towed by a boat, but operate independently, survey time is greatly reduced. In the meantime, more intensive historical research may help us to refine and improve our model of where shipwrecks are likely to occur in deep water and which of these wrecks might truly be of National Register significance.

Why does the MMS require industry to go to such effort to locate shipwrecks in deep water? The National Historic Preservation Act of 1966 was enacted to recognize that the nation is "founded upon and reflected in its historic heritage" (16 U.S.C. ss. 470 *et seq*., 470[b][1]). By passing this Act into law, Congress proclaimed that

> The preservation of this irreplaceable heritage is in the public interest so that its vital legacy of cultural, aesthetic, inspirational, economic, and energy benefits will be maintained and enriched for future generations. (16 U.S.C. s. 470[b][4]).

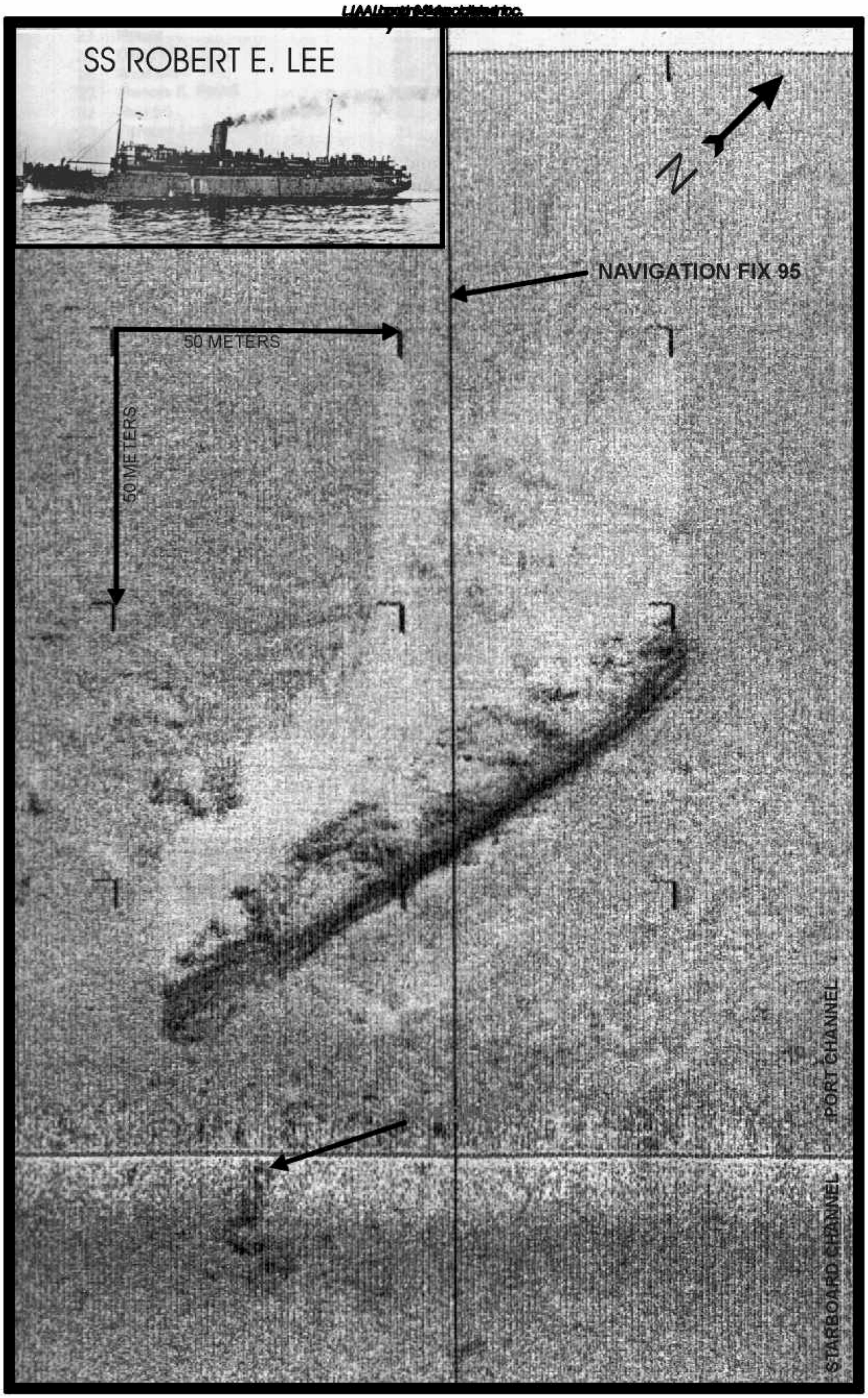

Figure 2C.5.Side-scan image of the SS Robert E. Lee.

Section 106 of the National Historic Preservation Act (NHPA) requires that federal agencies take into account the effect of any proposed federal, federally assisted, or federally licensed undertaking on any historic property that is included in, or eligible for inclusion in, the National Register of Historic Places. The other main provision of the NHPA is section 110(a)(2), which requires federal agencies to manage historical resources under their jurisdiction and control. Such management includes the obligation to survey, inventory, and determine the eligibility of historic properties for nomination to the National Register.

At present, no other historic preservation legislation applies to shipwrecks on the Outer Continental Shelf (Varmer and Blanco 1999). The Abandoned Shipwreck Act (43 U.S.C. ss. 2101-2106 [effective 28 April 1988]) is applied only to state waters, the National Marine Sanctuary Act (16 U.S.C. s. 1431, *et seq*.), only protects shipwrecks in National Marine Sanctuaries, and the Antiquities Act (16 U.S.C. s. 431, *et seq*.) is limited to marine protected areas, such as national seashores. This legislative "gap," however, may soon change. On 12 November 1997, the UNESCO general conference adopted resolution 29C/6.3 to the effect that "the protection of the underwater cultural heritage should be regulated at the international level and that the method adopted should be an international convention." A Draft Convention on the Protection of the Underwater Cultural Heritage was circulated to Member States of UNESCO (the U.S. is only an observer to UNESCO) in April 1998. The UNESCO draft permits nations to regulate and authorize all activities affecting historic shipwrecks or drowned prehistoric sites in the Exclusive Economic Zone and continental shelf (Strati 1999). Once the Draft Convention is finalized and becomes an international treaty, and should the US agree to become a party to the treaty, implementing regulations would have to be passed by Congress. At present, no one knows what effect this could have, if any, on MMS policy with respect to archaeological resources. It would seem likely, though, to bring MMS policies under close scrutiny and to increase pressure on expanding surveys in the deep Gulf.

REFERENCES

Chance, Thomas S., Art A. Kleiner & Jay G. Northcutt. The Autonomous Underwater Vehicle (AUV): A Cost-Effective Alternative to Deep-Towed Technology, Integrated Coastal Zone Mgmt., Vol.I, pp. 65-71.

Garrison, E. G., C.P. Giamona, F.J. Kelly, A.R. Tripp, and G.A. Wolf. 1989. Historic Shipwrecks and Magnetic Anomalies of the Northern Gulf of Mexico. 3 vols. Prepared for the U.S. Department of the Interior, Minerals Management Service, OCS Study MMS 89-0023.

Roberts, H., J. Coleman, J. Hunt, Jr. and W.W. Shedd. 2000. Improving interpretation of seafloor geology, biology from remote sensing, Offshore Vol. 60, No. 9, pp. 126-128, 181.

Strati, Anastasia. 1999. Draft Convention on the Protection of Underwater Cultural Heritage: A Commentary. UNESCO Publication CLT.99/WS/8, 97 p.

Varmer, Ole and Caroline M. Blanco. 1999. United States of America, in Legal Protection of the Underwater Cultural Heritage: National and International Perspectives, Sarah Dromgoole, ed.

Dr. Jack B. Irion is supervisor of the Social Sciences Unit within MMS's Leasing and Environment Section. Before joining the MMS in 1995, he worked as a marine archaeologist in private consulting firms and specialized in conducting remote sensing surveys and diving investigations of historic shipwrecks. He has directed archaeological investigations at a number of significant sites, including the C.S.S. *Louisiana* (1862), the steamships *Columbus* (1850) and *New York* (1846), and, most recently, the S.S. *Josephine* (1881). Dr. Irion received his Ph.D. from the University of Texas in 1990 and has published over 40 reports and articles on topics dealing with underwater archaeology.

SESSION 1D

NORTHERN GULF OF MEXICO CONTINENTAL SLOPE HABITATS AND BENTHIC ECOLOGY STUDY, “DGoMB”

Co-Chairs: Dr. Robert Avent, Minerals Management Service
Mr. Greg Boland, Minerals Management Service

Date: December 6, 2000

Presentation	Author/Affiliation
Deep Gulf of Mexico Benthos	Dr. Gilbert T. Rowe Texas A&M University
Abyssal Macrobenthic Infaunal Biomass in the Southwestern Gulf of Mexico	Dr. Elva Escobar Briones Universidad Nacional Autónoma de México
Biological Findings from DSV *Alvin* Dives in the Deep Gulf of Mexico	Dr. Ian R. MacDonald Geochemical and Environmental Research Group Texas A&M University
Mega-Furrows of the Continental Rises Seaward of the Sigsbee Escarpment, Northwest, Gulf of Mexico	Dr. William Bryant Mr. Dan Bean Dr. Niall Slowey Dr. Tim Dellapenna Department Of Oceanography Texas A&M University Mr. Erik Scott BHP Petroleum (Americas)

DEEP GULF OF MEXICO BENTHOS

Dr. Gilbert T. Rowe
Texas A&M University

INTRODUCTION

A new investigation has been initiated of the benthos of the deep Gulf of Mexico (GOM). Increasing exploitation by industry of fossil hydrocarbon resources offshore has prompted the Minerals Management Service of the U.S. Department of the Interior to support an investigation of the structure and function of the communities of organisms that live in association with the sea floor. Community structure is being used to test hypotheses about what controls the distribution of animal communities in the deep sea. Community function is being investigated by measuring critical fluxes in a food-web carbon model that portrays the relationships between carbon input and carbon flow through the near-bottom biota. The field work covers the entire northern GOM continental slope from depths of 300 meters on the upper slope out to greater than 3,000 meters seaward of the base of the Sigsbee and Florida escarpments. Sampling during three separate years will allow the hypotheses and the models to be revised and re-tested in an iterative fashion in years two and three. Previous data from the Sigsbee Abyssal Plain based on a joint project with UNAM has been put into a dynamic time-dependent model to illustrate the approach to be used (Figures 1D.1 through 1D.3).

The study was designed to improve predictions of variations in the structure of animal assemblages in relation to depth, geographic location, time, and water mass. This predictive capability was adopted because it was not feasible to investigate every physiographic feature of the gulf. Eight hypotheses are being tested on the basis of community structure. These hypotheses propose that community structure will vary as a function of

1) water depth,

2) east vs. west geographic extremes,

3) association with canyons,

4) association with mid-slope basins,

5) surface productivity,

6) proximity to hydrocarbon seeps,

7) variations in time (seasonal scale), and

8) association with the base of escarpments.

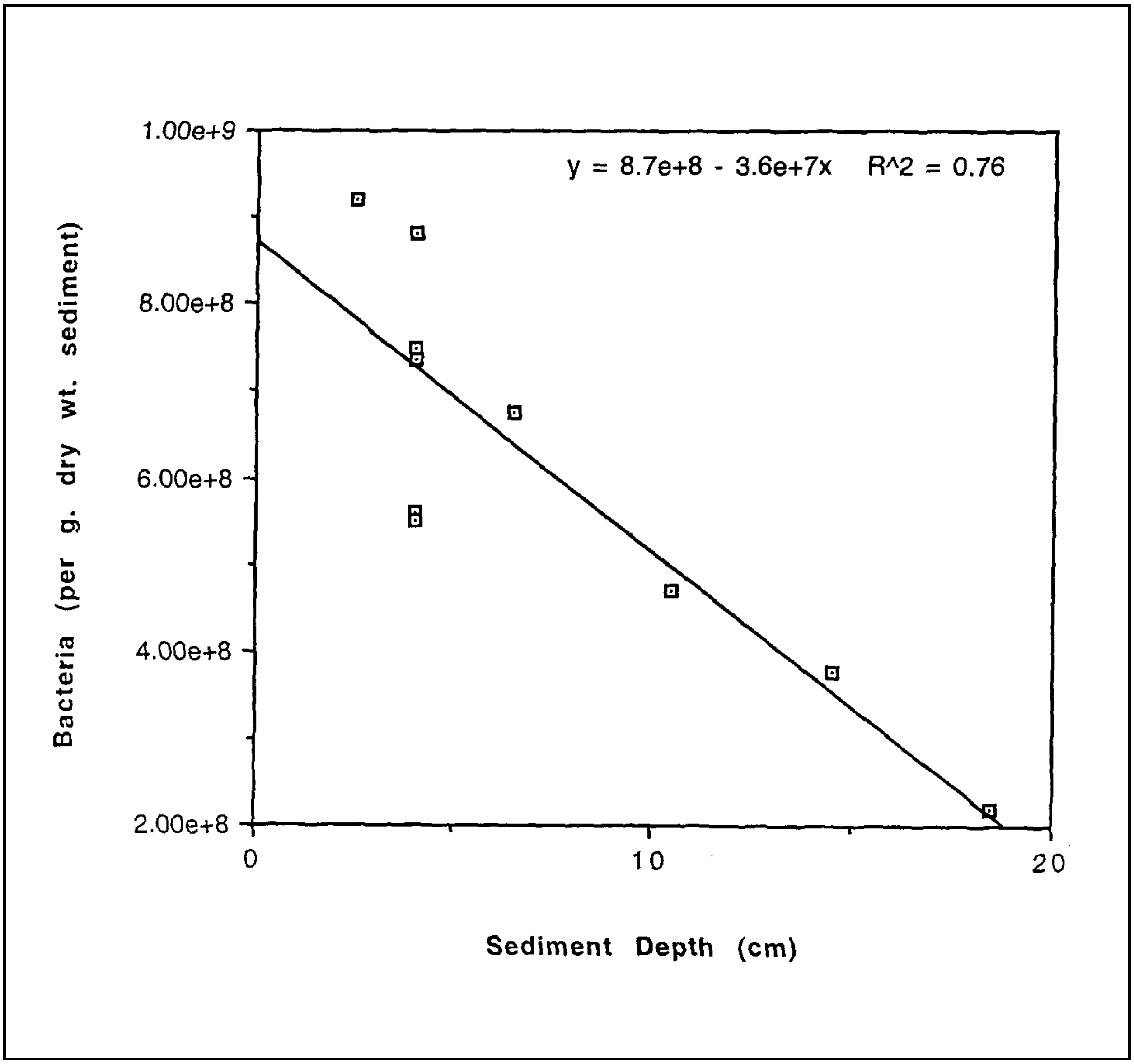

Figure 1D.1. Part 1 of a dynamic time-dependent model.

The structural characteristics of the communities used in the tests are variations in diversity, similarities in taxonomic composition between geographic locations (zonation, for example, with depth), variations in biomass and abundances, and mean size of indivduals within functional size categories.

An underlying premise of the eight hypotheses is that deep-sea communities are all food-limited. This premise leads to the assumption that variations in community structure in time and space, therefore, are a function of food input to the sea floor. The hypotheses thus test the possibility that each of the eight variables is related to how and in what quantities organic matter is provided to the communities. A second assumption is that community dynamics and community structure are interdependent. It follows that community structure, if it can be used to infer relative flows of

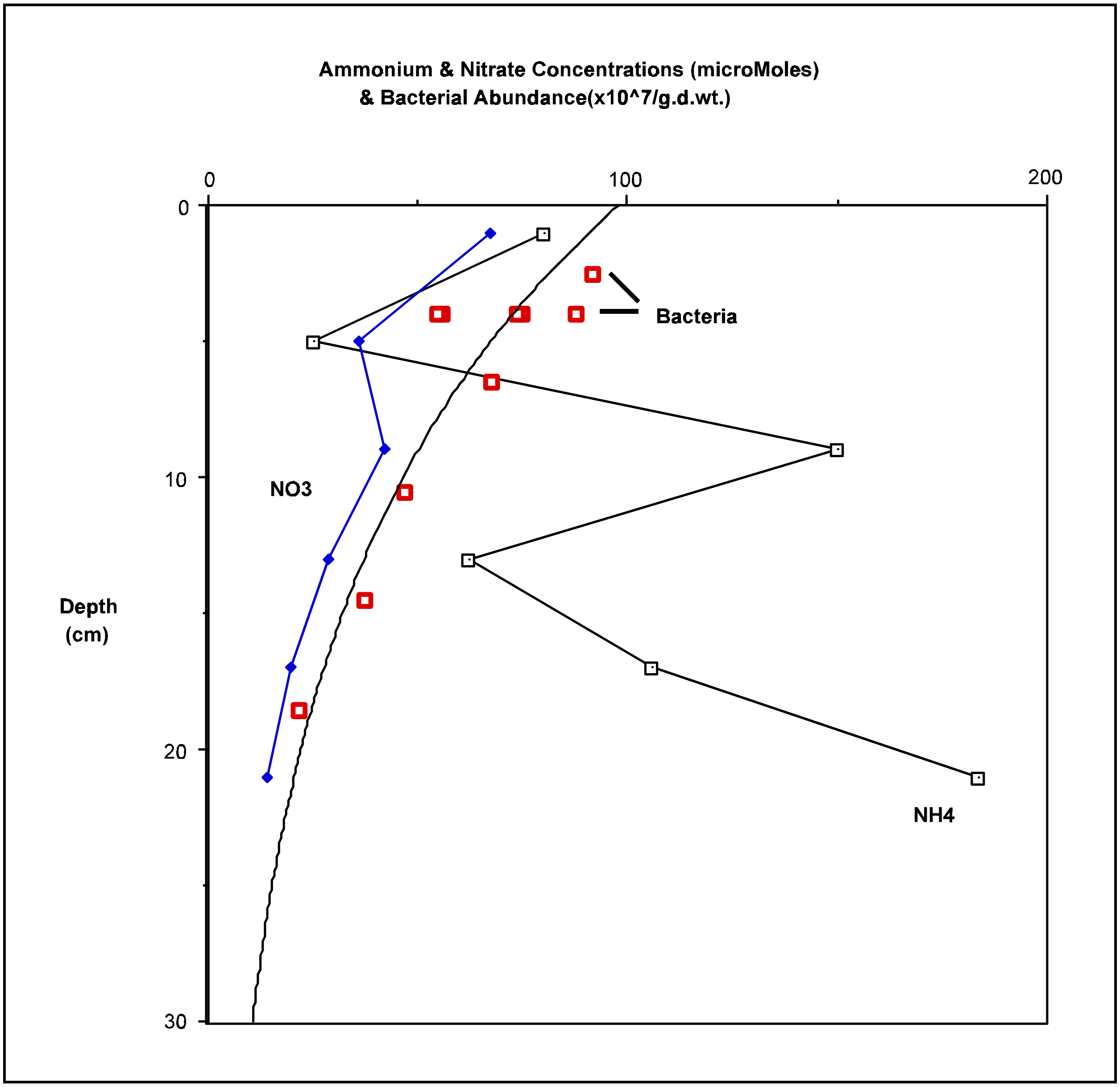

Figure 1D.2. Part 2 of a dynamic time-dependent model.

organic matter into the deep ocean ecosystem, can also be used as a qualitative predictor of community dynamics. This conclusion assumes that community structure and community function are tightly coupled. While few would doubt this generalization, the evidence for it in the deep sea is fragmentary at best.

A conceptual model is being used to represent each of the principal components of the food chain measured in the survey of standing stocks. The model includes demersal fishes, megafauna, scavengers, macrofauna, meiofauna and heterotrophic bacteria. This can be linked, as appropriate, with a simplified model of the seepage of fossil hydrocarbons utilized by chemotrophic organisms, including large invertebrates that contain symbiotic chemotrophs. The boxes represent standing

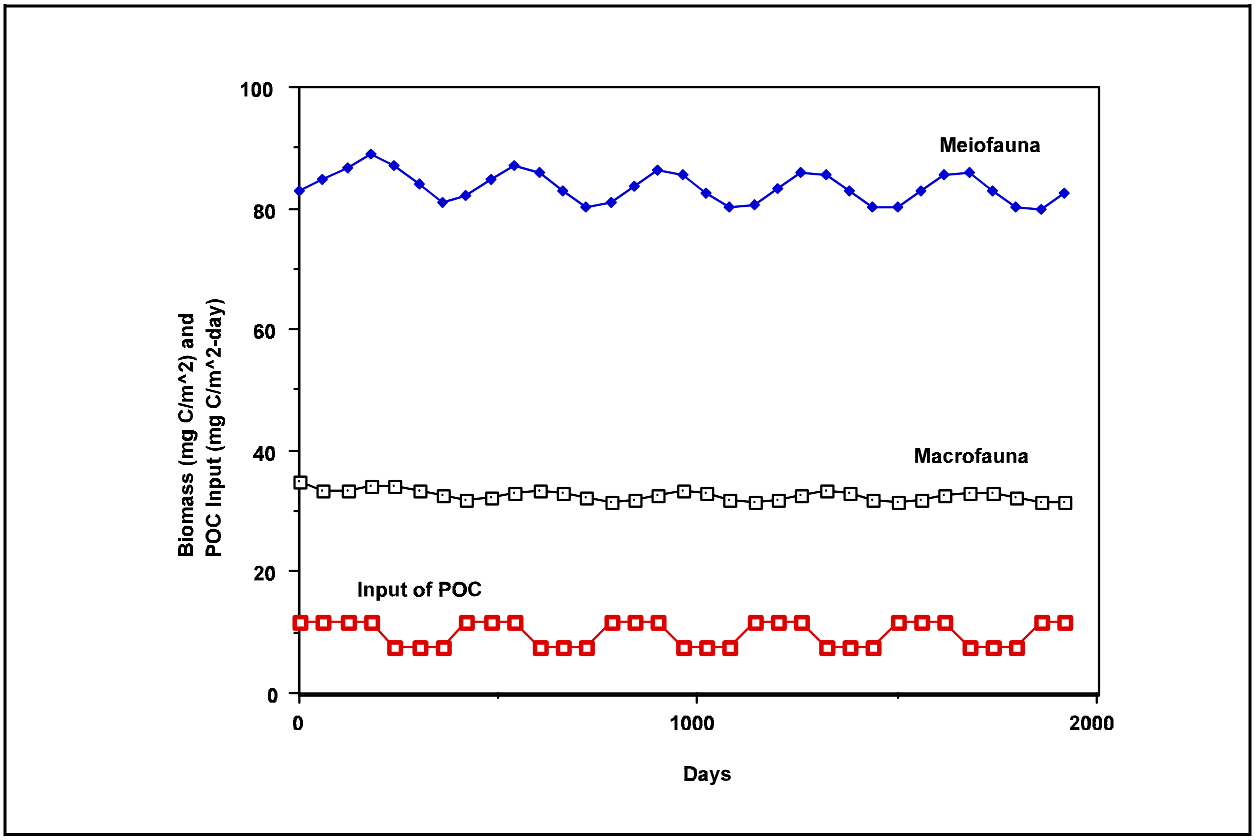

Figure 1D.3. Part 3 of a dynamic time-dependent model.

stocks which have units of biomass in terms of carbon whereas the arrows represent flows of carbon between boxes and hence have units of l/time. For consistency the units are mg C m^{-2} and mg C $m^{-2}day^{-1}$.

Data are used to quantify standing stocks in terms of carbon across the entire survey area. Respiration rates are estimated as a function of size and temperature from previous studies in the literature. The flows representing transfers between components are calculated by difference to balance respiratory losses at steady state. Burial loss is sediment organic carbon concentration times sediment accumulation rate. Input to the bottom is solved by assuming it is equal to the sum of the respiration and burial losses.

The second field phase of the project is designed to test the model. Measurements of fluxes will be made that initially had been estimated based on size and temperature. This measurement will be done on two sequential trips in June of 2001 and 2002. Total community respiration will be determined using a benthic lander. Total respiration will be partitioned by measuring bacterial activity aboard ship in pressure chamber incubations at *in situ* temperatures. Uptake and respiration will be determined using mixed amino acids labeled with radiocarbon. Sulfate reduction will be measured using radiolabeled sulfate incubation aboard ship of samples from cores. Lander fluxes to be measured are oxygen, DIC, inorganic nitrogen compounds, phosphate and silicate. Scavenger domains of occupation will be estimated using baited traps, time-lapse cameras and a current meter array. Stable isotopes of C and N will be used to confirm food chain linkages. Data from the second field year will be used to adjust the model parameters. Experiments during the third field year will be designed to further validate the revised model rates and parameters.

STATUS OF PHASE 2: PROCESSING SURVEY CRUISE DATA

Four kinds of information were collected at each observational site during the survey cruise on GYRE, 4 May to 23 June 2000: physical and chemical properties of the water column, geological characteristics of the sediments, geochemistry of the sediments, and kinds and numbers of organisms present. The present status of these individual data sets will be described separately in interim reports as the data emerge, along with some preliminary interpretation of their significance and how they will affect future directions of continuing research.Through our rather elaborate process of hypothesis testing and model development, followed by hypothesis revision and model validation and adjustment, the DGoMB program anticipates significant improvement in our ability to predict and understand what controls variations in life in the deep sea.

Gilbert T. Rowe has a B.S. in zoology and an M.S. in oceanography from Texas A&M. He obtained a Ph.D. from Duke in 1968. Following a summer at Florida State, he spent 10 years at the Woods Hole Oceanographic Institution, followed by 8 years at the Brookhaven National Laboratory, before returning to Texas A&M in 1987. Last year he was able to work for two months as a Fulbright Scholar at the University of Concepcion in Chile.

ABYSSAL MACROBENTHIC INFAUNAL BIOMASS IN THE SOUTHWESTERN GULF OF MEXICO

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Universidad Nacional Autónoma de México

INTRODUCTION

The central Gulf of Mexico (GOM) is known among the most oligotrophic basins of the world's oceans. Studies in similar impoverished tropical areas have revealed significant correlation between deep-sea infaunal abundances and those factors indicating food availability (Tselepides & Eleftheriou 1992; Boetius *et al.* 1996). These correlations are very low compared to those in temperate regions (Cosson *et al.* 1998), which suggests that low densities of macrofauna reflect the oligotrophic status of tropical seas (Pasternak *et al.* 1975). The extreme oligotrophy in the GOM is related to the persistent stratification of the euphotic layer and low production rates related to the limited availability of nutrients (Escobar-Briones *et al.* 1999). Long-term records of organic matter flux in open-ocean areas of the southern GOM are lacking, but several characteristics of the region probably restrict the organic matter supply to the deep-benthos (max. depth 3,780 m). One example would be the warmth of the upper and intermediate waters which allow for higher decomposition rates. The limited food supply to the deep may be expressed in terms of the benthic community structure, with higher species richness attributed to trophic specialization to the limited organic matter content in sediment (Thiel 1978) and standing stocks determined by alternate energy sources and energy fluxes related to regional events (Tselepides & Eleftheriou 1992).

To investigate the distribution of the macrobenthic infauna in the southern GOM, a series of cruises (R/V Justo Sierra) were conducted from 1993 to 2000. The main objective was to improve the knowledge of the distribution of benthic invertebrates (micro-, meio-, macro and megafauna) and its relation to food availability, and to quantify the contribution of the macroinfauna to total benthic biomass. This short paper presents data on the distribution of macrobenthic infauna in the deep-sea of the southern GOM and discusses the distribution of biomass.

STUDY SITES AND SAMPLING PROCEDURES

Figure 1D.4 shows the position of 193 stations through the southern GOM. Table 1D.1 illustrates the sampling effort that occurred from 1993 to 2000. and shows that sampling of benthic communities in the mesoabyssal (2,275 to 3,200 m) and lower abyssal (>3,225 m) zones started with a joint UNAM-TAMU cruise to the Sigsbee abyssal plain in 1997. The sediments and benthic samples were recovered with a 0.25 US-NEL box corer deployed by replicate at each station to detect the variability in the range of millimeters to centimeters at the sea-floor; the size of the sampled area was 0.0625 per replicate. The sediments samples included the top 10 cm layer. Macrofauna (125 µm to 1 mm) were sieved onboard, fixed in ethanol 95%, sorted by each boxcore replicate and identified to the lowest taxonomic level possible in the laboratory. Every sorted taxon has been stored in the formal collections in separate vials and fixed in ethanol 70%. Biomass expressed as organic carbon was determined by weighing each taxonomic group by replicate by

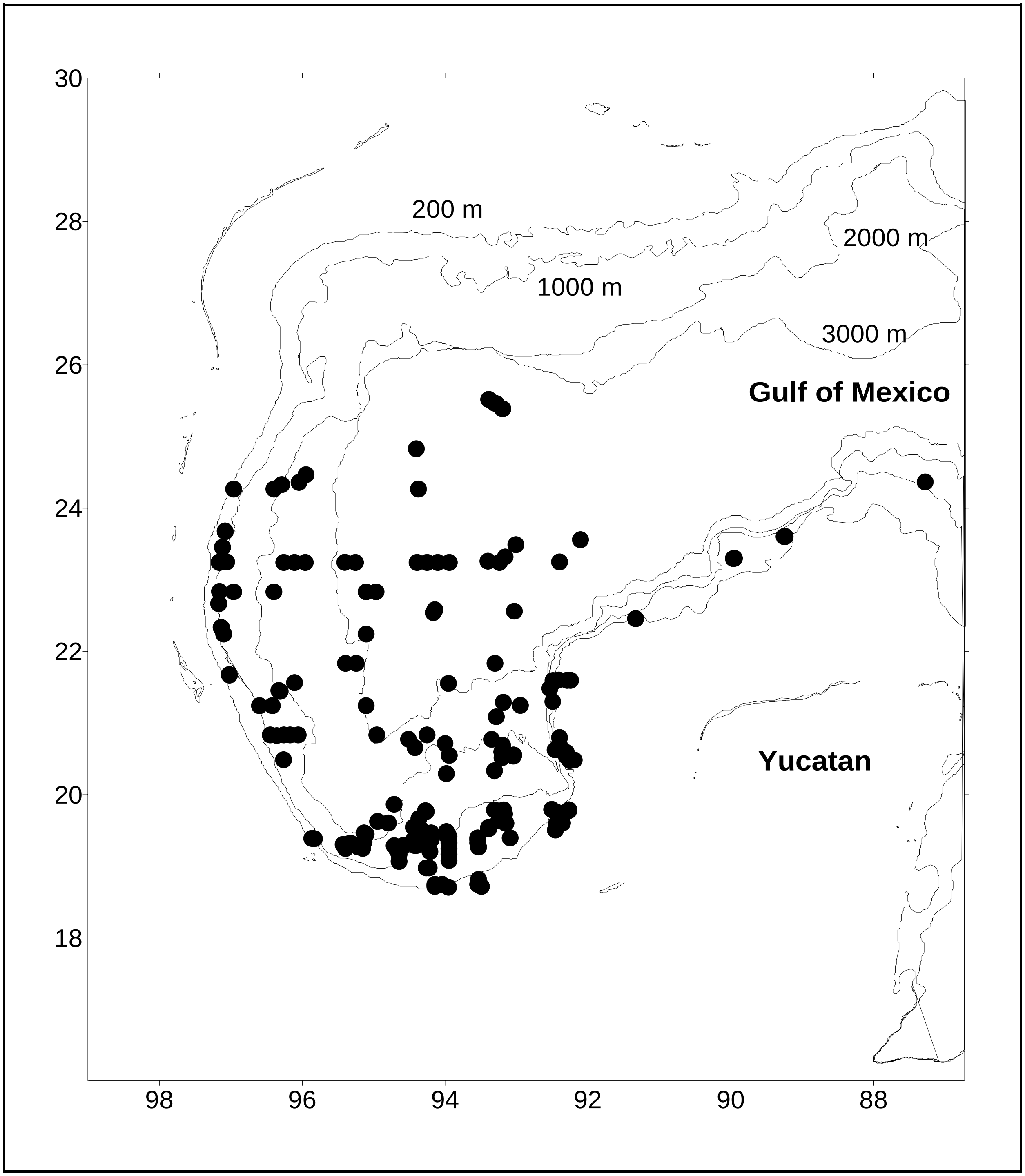

Figure 1D.4.   Positions of 193 stations throughout the southern Gulf of Mexico.

station at each cruise. Grain sizes, organic carbon and nitrogen contents, chloroplastic pigments and temperature were measured on sediments subsamples from the same cores. Faunal composition , density and biomass data were analyzed in a comparative format with the existing data from the northern GOM according to the depth zones described by Pequegnat (1983): transition zone (300

Table 1D.1. Infauna sampling effort in the SW Gulf of Mexico. Zonation according to Pequegnat (1983).

Cruise/Zone			Transition	Arquibenthic	Upper Abyssal	Mesoabyssal	Lower Abyssal	Total
	Month	Year	300 to 450 m	460 to 950 m	975 to 2250 m	2275 to 3200 m	3225 to 3850 m	
OGMEX.11	Abr/May	93	10	11				21
OGMEX.12	Jul	94	1	3	7			11
OGMEX.13	Jun	95	1	8	13			22
OGMEX.14	Jan	96		1				1
OGMEX.15	Jan/Feb	97	4	7	4			15
SIGSBEE	Jun	97		1	3	1	8	13
OGMEX.16	Sep	97	4	6	9			19
ENOS.1	Mar	98		2	9	1		12
ENOS.2	Jun	98		1	4	2	1	8
SIGSBEE.2	Jun	99	1	1	6	4	9	21
PROMEBIO.1	Aug	99	1	3	3	14		21
PROMEBIO.2	Nov	99		1	2			3
PROMEBIO.3	Apr	00	1	4	1	1		7
SIGSBEE.3	May	00		2	4	4	9	19
Sum by zone			**23**	**51**	**65**	**27**	**27**	**193**

to 450 m), archibenthic (460 to 950 m), upper abyssal (975 to 2,250 m), mesoabyssal (2,275 to 3,200 m and lower abyssal (3,225 to 3,850 m) (see Table 1D.1). The analyses were carried out using SAS General Linear Models nested ANOVA procedure, where the model included terms for depth zones, stations within zones, and the year/season (starified vs. mixed conditions) for the time at which each cruise was carried out. Comparisons of depth zones were made against the error terms representing stations, seasons and years within variances, where stations were samples collected given by the means of replicated cores. Interaction between depth zones was analyzed for seasons and years using a replicated measures analysis.

RESULTS

Average macrofaunal biomass values ranged from 0.002 to 0.37 gC.m^2 and were surprisingly more than ten times higher on the lower abyssal plain (average 0.21 gC.m^2, n=106) than on the mesoabyssal zone (average 0.019 gC.m^2, n= 78) and to three times higher than other zones (transition zone 0.060 gC.m^2, n= 73; archibenthic zone 0.078 gC.m^2, n=150), upper abyssal zone 0.019 gC.m^2, n=194). Regionally the largest average biomass values were recorded in the Campeche Bay, followed by lower values in the Campeche Scarpment; the lowest values were consistently recorded off the Mexican Ridges. Seasonal differences were recorded between cruises carried out in the years 1993, 1995 and 1997: ANOVA F 3,15; p= 0.02 with highest values recorded during the mixed conditions in contrast to the stratified condition (Figure 1D.5).

Average macrofaunal biomass during the stratified condition showed significant differences from one year to another on the upper abyssal , mesoabyssal, and lower abyssal zones (Figure 1D.6). The three abyssal zones showed similar biomass values in the years 1997 and 1998. Aa significant decrease in biomass values was observed for the two zones in 1999 that remained equally low in the year 2000 (Figure 1D.6). In general, the biomass values recorded in 1994 were higher than in 1995 and in 1997, in contrast to 1998 and 1999.

Differences in macrofaunal taxonomic composition were observed among depth zones. The polychaetes comprised between 10 and 57 % of the total macrofauna, followed by the crustacea

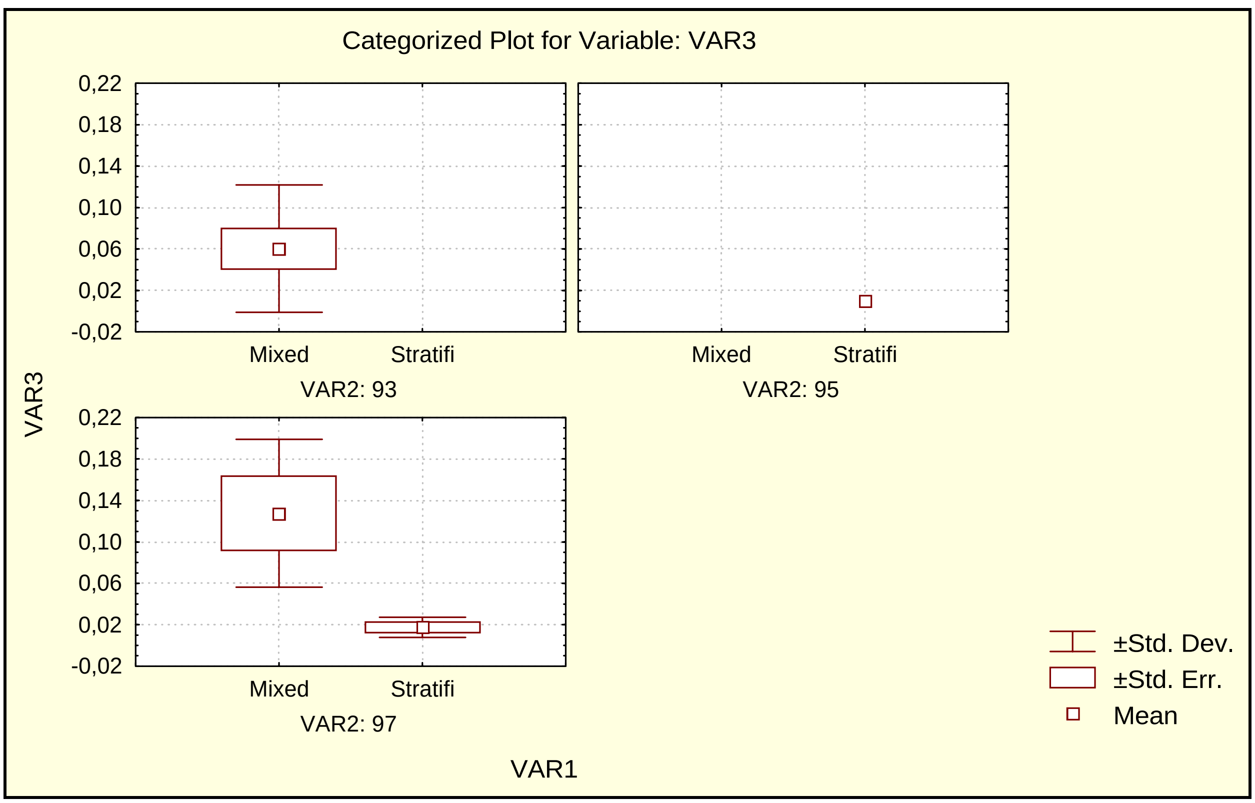

Figure 1D.5. Macrofaunal biomass seasonal (mixed vs. stratified year 1997: ANOVA F 3,15; p= 0.02) variability in the transition zone).

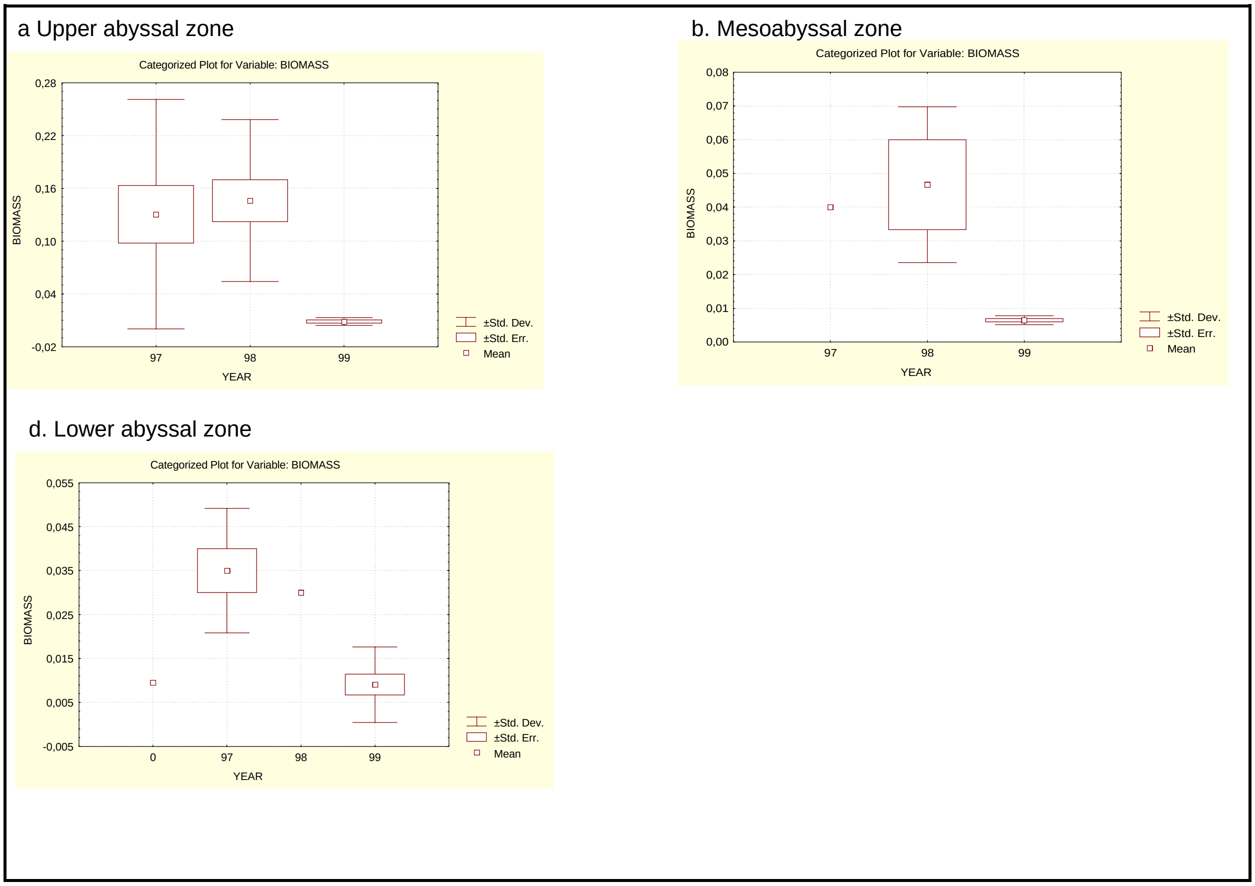

Figure 1D.6. Yearly macrofaunal biomass by depth zones.

from 16 to 50% of the total abundance. At the shallowest sites sampled (<450 m), nematodes, polychaetes and crustacea were mostly present. Taxa present in the deeper zone sediments included mainly peracarid crustaceans. Molluscs other than aplacophorans were rare and echinoderms were conspicuously absent from the abyssal zone sediments.

Macrofaunal taxonomic richness was lowest on the upper abyssal zone (four phyla among 880 ind.m^2), over twice as high on the archibenthic and the abyssal zones (eight phyla among 2,700 ind.m^2). A cumulative percent curve by taxon rank shows strong dominance by a few taxa on the northern abyssal and archibenthal zones and considerably less dominance and higher species richness at the southern abyssal sites.

DISCUSSION

The shallower and deeper zones had different biological assemblages, which we hypothesize is partly a response to food supply. This variation is attributed on the slope, upper abyssal zone, to the presence of a minimum oxygen depth and a differential tolerance to low oxygen, with greater sensitivity to hipoxia of macrofaunal components as has been reported previously at similar depths at the same latitude (Levin *et al.* 1991). Labile organic matter on the sediment and oxygen concentration appear to be good predictors of macrofaunal biomass in the GOM. Patterns of macrofaunal community structure on the deeper sites were characteristic of many other deep-sea regions. Macrofaunal zonation patterns associated with oxygen gradients were reported by Sanders (1969) for Walvis Bay, by Rhoads and Morse (1971) for the Black Sea, Gulf of California, and southern California Basins, by Thompson *et al.* 1985) for the central California slope and are summarized by Thiel (1978) for regions off Chile and Peru. El Niño, which lead to elevated oxygen concentrations in Peruvian waters, produced increases in macrobenthic density, biomass and diversity (Tarazona *et al.* 1988 a, b).

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REFERENCES

Boetius, A., S. Scheibe, A. Tselepides & H. Thiel. 1996. Microbial biomass and activities in deep-sea sediments of the eastern Mediterranean: trenches are benthic hotspots. Deep-sea Research. 43(9):1439-1460.

Cosson, N., M. Sibuet, G.L.J. Paterson, A. Vangriesheim. 1998. Polychaete diversity at tropical Atlantic deep-sea sites: environmental effects. Marine Ecology Progress Series 165: 173-185.

Escobar, E., M. Signoret & D. Hernandez. 1999. Variation of the macrobenthic infaunal density in a bathymetric gradient: Western Gulf of Mexico. Ciencias Marinas 25(2): 193-212.

Levin, L.A., C.L. Huggett & K.F. Wishner. 1991. Control of deep-sea benthic community structure by oxygen and organic matter gradients in the eastern Pacific Ocean. Journal of Marine Research 49:763-800.

Pasternak, F.A., L.I. Moskalev, and N.F. Fedikov. 1975. Some characteristics of the distribution of the deep-sea benthic fauna of the Caribbean and the Gulf of Mexico. Trudy Instituta Okeanologii Akademii Nauk SSSR, Vol. 101:52-64.

Sanders, H.L. 1969. Benthic marine diversity and the stability time hypothesis. Brookhaven symposium in Biology 12:71-81.

Rhoads, D.C. & J.W. Morse. 1971. Evolutionary and ecologica significance of oxygen-deficient marine basins. Lethaia 4:413-428.

Tarazona, J., H. Salzwedel & W. Arntz. 1988 a. Positive effects of El Niño on macrobenthos inhabiting hipoxic areas of the Peruvian upwelling system. Oecologia 76:184-190.

Tarazona , J., H. Salzwedel & W. Arntz. 1988 b. Oscillations of macrobenthos in shallow waters of the Pruvian central coast induced by El Niño 1982-1983. Journal of Marine Research 46:593-611.

Thiel, H. 1978. Benthos in upwelling regions. pp. 124-138. *In* Boje, R. & M. Tomczak, eds. Upwelling Ecosystems. Springer Verlag.

Thompson, J.B., H.T. Mullins, C.R. Newton & T.L. Vercoutere.1985. Alternative biofacies model for dysaerobic communities. Lethaia 18:167-179.

Tselepides, A. & A. Eleftheriou.1992. South Aegean (eastern Mediterranean) continental slope benthos: macroinfaunal-environmental relationships. pp. 139-156. *In* Rowe, G.T. & V. Pariente, eds. Deep-sea food chains and the global carbon cycle. Kluwer Academic Publishers.

BIOLOGICAL FINDINGS FROM DSV *ALVIN* DIVES IN THE DEEP GULF OF MEXICO

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INTRODUCTION

The RV *Atlantis* (Cruise 3, Leg 58) completed DSV *Alvin* Dives 3624-3637 at eight sites across the northern Gulf of Mexico (GOM) (Figure 1D.7) during 16-31 October 2000. The cruise embarked in Galveston, Texas and demobilized in Key West, Florida. There was an at-sea exchange of 13 scientific personnel on 25 October. In all, thirty-six scientists and observers participated in the cruise.

The cruise was jointly funded by National Oceanographic and Atmospheric Administration (National Undersea Research Program), Minerals Management Service (Gulf of Mexico Office), and Dept. of Energy (National Energy Technology Laboratory). The overall objectives of the cruise were to provide submersible and ship support for research being conducted by four separate projects. Fourteen dives at eight separate sites were completed. None of the planned dives were cancelled due to weather or other problems. The *Atlantis/Alvin* group elected not to dive at one scheduled site, Bush Hill, because it was situated less than one mile from an energy production platform. Sites, divers, and localities are summarized in Table 1D.2.

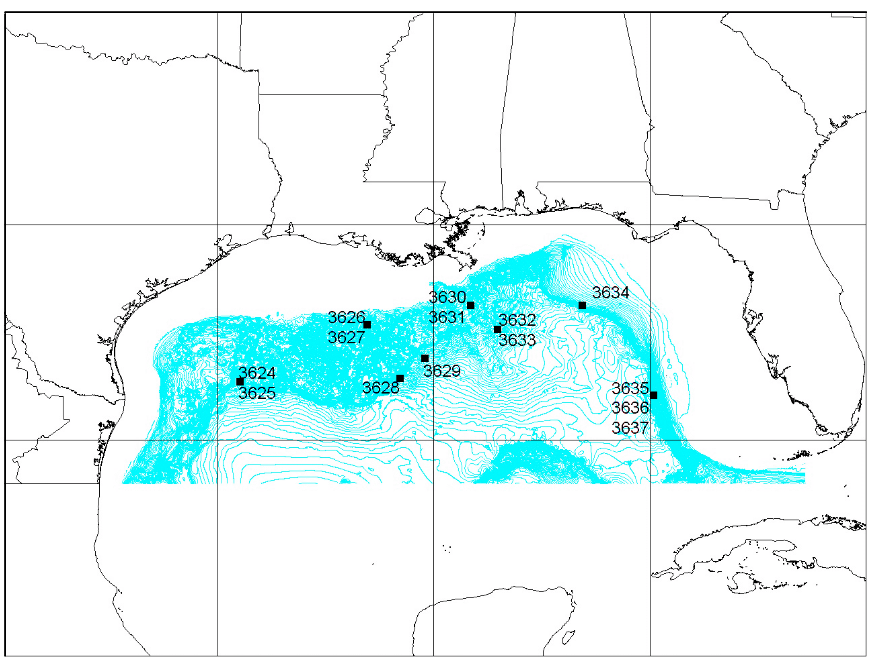

Figure 1D.7. Dive sites and dive numbers for the 14 dives completed during 16-31 October 2000, northern Gulf of Mexico.

Table 1D.2. Summary of dives, sites visited, and scientific divers during cruise.

Dive #	Site	Depth	Sci-1	Sci-2	Latitude	Longitude
3624	Alaminos Canyon	2230	Paul Aharon	Sam Bowser	26.35667	-94.50267
3625	Alaminos Canyon	2230	Barun Sen Gupta	Joan Bernhard	26.35709	-94.48397
3626	Green Canyon 272	687	Paul Aharon	Lorene Smith	27.68644	-91.53670
3627	Green Canyon 272	687	Joan Bernhard	Matt Hackworth	27.68401	-91.53703
3628	Farnella Canyon	2930	Ian MacDonald	Tom Cole	26.44713	-90.77330
3629	Green Knoll	2457	Bill Bryant	Erik Scott	26.92353	-90.21502
3630	Miss. Canyon 853	1079	Ian MacDonald	Anthony Tarantino (PIT)	28.12663	-89.14367
3631	Miss. Canyon 853	1079	Dan Bean	Tim Dellapenna	28.12640	-89.14172
3632	Atwater 425	1955	Ian MacDonald	Andy Shepard	27.57516	-88.48793
3633	Atwater 425	1955	Joan Bernhard	Will Sager	27.57898	-88.51056
3634	N. FL. Escarpment	2873	Ian MacDonald	Sarah Fangman	28.03697	-86.55668
3635	S. Fl. Escarpment	3288	Cindy Van Dover	Karen Jacobsen	26.03069	-84.91954
3636	S. Fl. Escarpment	3288	Mary Turnipseed	Joshua Osterberg	26.03069	-84.91954
3637	S. Fl. Escarpment	3288	Cheryll Jenkins	Anthony Tarantino (PIT)	26.03069	-84.91954

Images taken with video and digital still cameras comprised an important part of the cruise records. Two high resolution systems were added to *Alvin's* standard suite of cameras for selected dives during the cruise. These were a high definition television (HDTV) camera provided by the Visual Data Systems and Development group at Woods Hole Oceanographic Institution and a digital macro camera (Seapix) developed by the Geochemical and Environmental Research Group at Texas A&M University. The standard video records and the Seapix images were copied to principal investigators at the conclusion of the cruise. Although the right to further reproduce and distribute these images resides with the responsible investigators, the cruise participants agreed to freely share the images among themselves for educational purposes. HDTV images will be made available on a best-effort basis in the months following the cruise.

Two instruments for physical oceanography were mounted on *Alvin* throughout the cruise. These were a 300 kHz acoustic doppler current profiler (ADCP) manufactured by RD Instruments, Inc. and a SBE11 conductivity, temperature, and depth recorder (CTD) manufactured by Sea Bird, Inc. Additional data recorded throughout the cruise included multibeam bathymetry and navigation records for the ship and submarine. Additional over-the-side sampling was conducted at most sites.

PROJECT DESCRIPTION

This program element collected otherwise unobtainable samples from the base and flanks of the Sigsbee and Florida Escarpments. Together, the Sigsbee and Florida Escarpments extend for ~1,000km and span a depth gradient of >1,000m in most regions. This topographic regime is a significant component of the benthic environment in the northern GOM and may comprise a significant zoogeographic boundary between the lower continental slope and the abyss. With use of *Alvin*, however, it was possible to collect sediment samples for infaunal and geochemical analysis. It also provided detailed photographic documentation and verbal description of the benthic ecology and geology of the sites.

The Sigsbee Escarpment forms the southern margin of the central sampling area. Like the Florida Escarpment, its precipitous slope poses considerable challenges to sampling from surface ships. Little is known regarding the benthic ecology of the site. A major type of the benthic environment has recently been documented that required reconnaissance by submersible for basic characterization. The features have been designated furrows (W. Bryant, personal communication) and comprise deep, steep-sided gullies, which are often 10m deep and 30m wide. Furrows tend to run parallel to the base of the escarpment and have been identified as contiguous features that extend 100km or more. The sediment cover, and presumably the benthic communities, is entirely different between the bottom of furrows and their upper rims. It was anticipated that in the bottom, the fine Holocene sediments will have been eroded away, exposing coarser sediment. On the rims, the Holocene drape is still present. The origin of furrows is unknown, but they are thought to be formed as a result of intense current events. Because of their small cross section, furrows can only be accurately sampled with use of submersibles.

The investigators also used *Alvin* and the sampling capabilities of *Atlantis* to extend sampling and observation at two sites where deposits of gas hydrate occur near the seafloor. Gas hydrate generates a dynamic seafloor response, including complex biological and geological interactions. This phenomenon is fairly well-known in the GOM and has been investigated with sampling from submarines in depths of about 500 m. This is a setting where it is possible to directly observe and sample the *in-situ* characteristics of the material. The two sites where these dives were conducted are MC853 and AT425, located at depths of 1,040 m and 1,900 m, respectively. These sites are being considered for an Ocean Drilling Program leg to investigate hydrate deposits in 2003.

SUMMARY OF RESULTS

Seven dives were completed as to support this project (Table 1D.2, dive numbers 3628 through 3634). Sample collection during the dives included push cores, and two small box cores. Additional sediment samples were collected with the *Atlantis* deck winch and large box cores. Continual acoustic Doppler current profile (ADCP) data were collected from *Atlantis* along the ship's track throughout the cruise. A second ADCP was mounted on *Alvin* along with a conductivity, depth, and temperature (CTD) instrument. These instruments collected data at the seafloor during each of the dives. Bottle cast and CTD casts were also collected with the *Atlantis* rosette. Swath bathymetry data were recorded with the Sea Beam system mounted on *Atlantis*. These data provided detailed bathymetric maps at each of the dive sites.

A preliminary review of dive results indicates that most of the project objectives were met. The dives at Farnella Canyon and Green Knoll (dives 3628 and 3629, respectively) confirmed that the interpretation of geophysical data from the furrows region was essentially correct. Furrows were found to be distinct, steep-sided features arrayed in parallel bands along the base of the escarpment. The steep angle of furrow edges and the accumulation of sorted, coarse sediment along the bottom of furrow indicated that strong currents continue to shape furrows in the present day. At the Green Knoll site, *Alvin* encountered a strong bottom current sweeping the base of the escarpment along the length of the furrow zone. Concentrations of suspended sediments, including coarse sediments were high. Additional sculpting and erosion of bottom sediments was evident on the slope of the escarpment above the furrow zone.

Four of the dives targeted two potential sites for an Ocean Drilling Program leg (MC853 and At425, Table 1D.2). These dives performed an extensive reconnaissance of possible bore-hole locations, collected sediment samples, and provided the first inspection of active hydrocarbon seeps in water depths of 1,000 m or greater. The preliminary results confirm that oil saturated sediments and shallow hydrate deposits occur at the MC853. Macro oil seepage was also confirmed at AT425 and shallow hydrates were probably sighted as well. Both sites supported seep-related biological communities comprising seep mussels, vesicomyid clams, and extensive bacterial mats. Strikingly, vestimentiferan tube worms, which are the ecosystem forming species at seeps in 500-600m, appeared to be completely absent at these deeper sites. Extensive brine seepage was also noted, mostly on the flanks of topographic highs associated with shallow hydrates.

A single dive was completed to conduct a video survey of the Florida Escarpment off the northern part of the state. The scientists encountered intense sedimentation which had produced a large accumulation of flocculent material at the base of the escarpment. They transited approximate 700m up the vertical face of the escarpment. The effects of ongoing sedimentation were evident in the relative paucity of sessile fauna. Corals, sponges, crinoids, and other forms were found in abundance only where rocky overhangs protected animals from the settling material. The escarpment appears to be a stressed habitat over much of its surface.

These investigations are expected to produce a number of presentations and peer-reviewed publications. Proposals for follow-on work are also anticipated. The public response and media interest in the cruise has been very high. The logistic arrangements offer a model for inter-agency cooperation in deep-sea science.

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MEGA-FURROWS OF THE CONTINENTAL RISES SEAWARD OF THE SIGSBEE ESCARPMENT, NORTHWEST, GULF OF MEXICO

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An extensive field of mega-furrows has been recently discovered on the seafloor at the base of the Sigsbee Escarpment in the northwestern Gulf of Mexico (GOM) (Bryant 1999). Texas A&M deep-tow data and 3-D seismic data supplied by WesternGeco Inc. show that the scale of these fields far exceeds anything previously observed in the world's oceans. These data allow the furrows to be resolved in unprecedented detail. The size of the furrows, variations in their morphology, and their orientation relative to large topographic features all suggest that the furrows are produced by strong deepwater flow. Data from near-bottom current meters confirms that strong, previously unknown, currents do exist at the base of the Sigsbee Escarpment. The furrows and associated environmental processes are dominant features of the northwestern GOM, and similar features will probably be found to exist in many other areas of the world's oceans.

A field of sedimentary furrows, large longitudinal erosional bed forms, was discovered on the continental rise at the base of the Sigsbee Escarpment (approximately 3,000 m water depth) during a 1999 deep-tow survey of the continental slope and rise in the Bryant Canyon area of the northwestern GOM. The furrows are long, relatively narrow depressions in the seafloor that are generally oriented parallel to (along strike) the escarpment. These deep-tow data indicate that individual furrows are ~1 to 10 m deep and ~5 to 50 m wide. The spacing between individual furrows (edge to edge) is ~20 to 200 m and the whole field of furrows extends ~10 to 30 km seaward from the base of the escarpment.

Data show that the field of furrows in the Bryant Canyon area runs along ~100 km at the base of the escarpment. Deep-tow data and seafloor surface renderings derived from 3-D seismic data also show that furrows are present along ~150 km of the continental rise at the base of the Sigsbee Escarpment in the Green Canyon, Green Knoll and Farnella Canyon areas (approximately 2,200 to 3,100 m water depth) in the Western Mississippi Fan Fold Belt—a frontier area for deep water oil and gas exploration. We suspect, but have not verified, that the field of furrows is continuous between the Farnella Canyon/Green Knoll area and Bryant Canyon (300 km) and may extend along the Continental Rise to and may be beyond the Alaminos Canyon area.

Submarine furrows have been previously observed along the base of the continental slope and along the continental rise in other areas of the world (e.g., Brazilian Margin—Flood 1978; Bermuda and

Saharan Rises—Lonsdale 1978a,b; Blake Bahama Outer Ridge—Flood and Hollister 1980). These observations have generally been based on chance encounters and localized observations in small survey areas. The massive extent of the furrows recently observed in the northwestern GOM is unprecedented. In this area they are a dominant morphologic feature of the lower slope/rise, and their existence indicates that the surficial processes which form the furrows and related bedforms are quite significant. The detail with which these furrows have been resolved is also unprecedented. Shipboard multibeam seismic systems are incapable of imaging furrows in water depths of several thousand meters. We are able to investigate deep-sea furrows over much larger areas and at much higher resolution than was possible before because we have access to a deep-towed seismic system and industry collected 3-D seismic data that was not available for previous studies. We suspect that when such data is collected outside the GOM it will be found that sedimentary mega-furrows are present on the lower slopes/rises of many other continental margins.

Sedimentary furrows are one of a series of longitudinal mega-bed forms which can form aligned with the net direction of flowing water and are typically attributed to the development of secondary helical circulation cells that occur above the sediment/water interface (Allen 1969; Flood 1981; Viekman *et al.* 1989). The massive size of the furrows in the northwestern GOM, variations in their morphology, and their orientation relative to large topographic features all suggest that the furrows are produced by strong deepwater flow. A range of furrow morphologies is observed in the deep-tow data—comparison with Allen's (1969) laboratory results suggests that these morphologies reflect different velocities (sediment texture, consolidation history, and other factors undoubtedly play roles also). A fascinating aspect of the northwestern GOM furrows is their long extent and their orientation relative to topographic features on the seafloor. An individual furrow can be traced continuously for at least 50 km on the 3-D surface renderings (it is the longest continuous individual sedimentary marine bed form on the surface of the Earth). The orientation of furrows about the Green Knoll (an ~14 km diameter plug of sediment pushed several hundred meters above the surrounding seafloor by underlying salt) suggests that the knoll formed an obstacle to the flow of water, resulting in increased velocities (closer, more prominent furrows) as the flow from the northeast is deflected around and over the knoll. An area of few furrows on the southwestern side of the knoll suggests drag related turbulence and, perhaps lower velocity, on the western, down-current side of the knoll. Near-bottom current meters deployed by the Minerals Management Service (MMS) and industry show that the high velocity flow implied by the furrows does occur; several current meters have recorded flow events with velocities of more than100 cm/sec.

It appears that the processes responsible for these furrows are active at present. Based on the variation in character of these features from offshore toward the escarpment, and on the rather good agreement of that variation with the pattern of changes observed in published laboratory studies of submarine erosion (e.g., Allen 1969; Dzulynski 1965), the tentative conclusion is that bottom currents responsible for these features have along-isobath components and increase in strength toward the escarpment. Such work attributes the furrows to rows of counter-rotating helical currents generally directed along the furrows with rising parts of the helixes over the furrows. No direct measurements have been reported to test this concept. Laboratory experiments indicate that furrows of different separation, wavelengths, and fundamental character occur for different flow rates. However, it is difficult to scale these model results to field conditions. Speculation is that near-bottom speeds of currents responsible for the inshore furrows might be 50 cm/s or even in excess of 100 cm/s and may be sporadic or quasi-permanent. The furrows and the currents responsible for them may also exist over a considerable part of the yet unexplored base of the continental slope in the GOM and may represent a distinctly different phenomenon than the other classes of currents observed to date and presently under consideration.

Direct observations of the nature of the furrows adjacent to Green Knoll and the furrows near Farnella Canyon by the use of the Deep Submergence Vehicle *Alvin* were undertaken in October 2000. Dives of 2400 m into the furrows adjacent to the southeastern portion of Green Knoll indicated that the slope of the furrow walls ranged from almost vertical to 45 degrees. Active transport of sediment and shells could be observed along a furrow wall. Bottom water currents were estimated to be from 30 to 50 cm/sec from ADCP measurements. A Dive in 3,000m of water in the Farnella Canyon area revealed extensive erosion of the seabed, Large flute-like structures exposing bedded sediment layers were common. as were large sediment ripples composed entirely of large foraminifera.

Analysis of 3-D seismic data in the Green Knoll area indicates the presence of fossil furrows in the subbottom. Surface renderings of 3-D data cube revealed a field of fossil furrows at a depth of 200 ms below the seafloor. Other subsurface expressions have been noted and are now being investigated. It is suggested that the formation of furrows is a high-sea stand event and the filling and burying of furrows a low-stand event.

The presence of mega-furrows and their association with high-bottom water currents in the deep water GOM in and adjacent to areas of potential large oil production presents a definite engineering constraint relative to the stability of seafloor production facilities and pipelines. An exact knowledge of the seabed and the adjacent water column will go a long way in helping to overcome, in an economical fashion, the engineering constraints in operating in such a complex environment.

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REFERENCES

Allen, J.R.L. 1969. Erosional current marks of weakly cohesive mud beds. J. Sedimentary Petrology, 39, 607–623.

Bryant, W.R., T. Dellapenna, A. Silva, W. Dunlap and D. Bean. 2000. Mega-Furrows on the Continental Rise South of the Sigsbee Escarpment, Northwest Gulf of Mexico. AAPG Annual Meeting, New Orleans La.

Dzulynski, S. 1965. New data on experimental production of sedimentary structures. J. Sedimentary Petrology, 35, 196–212.

Flood, R.D. 1983. Classification of sedimentary furrows and a model for furrow initiation and evolution. Geol. Soc. Amer. Bull., 94, 630–639.

Inoue. M. and S.E. Welsh. 1997. Numerical simulation of Gulf of Mexico circulation under present and glacial climatic conditions. OCS Study MMS 96-0067, U.S. Department of the Interior, Minerals Mgmt. Service, 147 pp.

Hamilton, P. 1990. Deep currents in the Gulf of Mexico. J. Phys. Oceangr., 20, 1087-1104.

Sturges, W., J. Evans, S. Welsh, and W. Holland. 1993. Separation of warm-core rings in the Gulf of Mexico. J. Phys. Oceanogr., 23, 250-268.

SESSION 1E

IMPROVEMENTS IN MODELING OF OIL SPILLS

Chair: Ms. Gail Rainey, Minerals Management Service
Co-Chair: Dr. Walter Johnson, Minerals Management Service

Date: December 6, 2000

Presentation	Author/Affiliation
NOAA's Updated Weathering Model (ADIOS 2)	Ms. Debbie Payton National Oceanic and Atmospheric Administration
SINTEF's Weathering Model (Version 1.8)	Dr. Mark Reed SINTEF Applied Chemistry, Norway
MMS Trajectory Model, OSRA: Oil-Spill Risk Analysis	Dr. Walter R. Johnson Dr. James M. Price Mr. Charles F. Marshall Dr. Zhen-Gang Ji Ms. Gail B. Rainey Minerals Management Service
SINTIF's OSCAR Model 2000	Dr. Mark Reed SINTEF Applied Chemistry, Norway

NOAA'S UPDATED WEATHERING MODEL (ADIOS 2)

Ms. Debbie Payton
National Oceanic and Atmospheric Administration

The Automated Data Inquiry for Oil Spills (ADIOS 2) model was developed to provide guidance to responders in estimating fate of oil in the marine environment. The model allows responders to scale the problem (hours or days?), provides guidance to examine possible clean-up alternatives and gives quantitative estimates for the Unified Command. The most recent version, ADIOS 2 was released in December 2000. This 2000 ITM presentation focuses on the changes made to this model. For additional information on the ADIOS 2 model, please refer to Lehr *et al.* 2000, or use the extensive help documentation provided with the model. The model can be downloaded from *http://response.restoration.noaa.gov/software/adios/adios.html*.

The upgrade to ADIOS 2 was undertaken by NOAA's Office of Response and Restoration to provide for changes requested through the broad ADIOS user community as well as changes to reflect improvements in algorithmic approaches. In particular, this upgrade provided better user interface, capability for custom oil libraries, more flexibility in defining release scenarios, incorporation of uncertainty estimates where possible, ability to account for removal, better algorithms for evaporation, spreading, dispersion and emulsification and two new submodels to calculate benzene threat and in-situ burn plume estimates. Given the range of research activities presently underway, ADIOS 2 was engineered as modularly as possible to incorporate additional advances or opportunities as they become available.

User interface was designed to provide multiple options for entering and displaying information. Details of the input information are given on the left-hand side of the screen at all times. Output options are shown along the top bar. Options for changing viewing preferences (i.e., tabular, graphical, preferred units, etc.) are available. The expanded capabilities for user interface reflect work done as part of "usability testing" (Evans *et al.* 1999).

Progressive helps have been developed for ADIOS 2 in standard HTML format. Using these helps, the user can find out basic help information (what range of values can I use for wind speed?) to more detailed technical information (how does the wind speed affect evaporation?). The HTML information serves as both user and technical documentation.

ADIOS 2 contains a library of over 1,000 oils and refined products. This database is a compilation of data from a number of different sources, including Environment Canada, the U.S. Department of Energy, the International Oil Companies' European Organization for Environmental Health Protection (CONCAWE) and contributions from industry. Data critical to determining the physical/chemical changes of the oil over time are part of this database (density, viscosity, flash point, pour point, distillation data, etc.). In addition to the standard database, this version of the model allows for users to maintain a custom oil library to reflect properties of additional oils.

The flexibility of release scenarios that can be described gives the user the capability of having a simple catastrophic release, a continuous release, or a combination of a large release followed by a continuing flow of oil for a number of hours or days. In addition, a new algorithm has been developed to describe the expected loss of oil over time from a damaged tank. The leaking tank portion of ADIOS 2 is one of the algorithms that we expect to improve as results from laboratory studies become available (Simecek-Beatty *et al.* 2001).

Any "model" of a physical process has some inherent uncertainty. Uncertainty in results can be particularly important for operational spill response. Defining and presenting that uncertainty becomes more complex as the model becomes more complex. The ADIOS 2 model provides a mechanism for users to define some uncertainty in the input (i.e., amount of spilled oil, wind speed). Based on input uncertainty, ADIOS 2 provides a graphical representation of uncertainty in the output. This is a substantial change from output provided in previous versions of ADIOS.

A summary of the algorithmic improvements in ADIOS 2 is provided here; more complete detail is provided in Lehr *et al.* 2000:

- Evaporation: uses a multi-component method (Jones 1997)

- Spreading: uses a combination of Fay gravity-viscous, diffusion, wind effects and currents, now allows for variable thickness within the slick.

- Emulsification: new methods were developed to estimate emulsification onset and account for droplet size distributions.

- Dispersion: a new method for estimated breaking waves and new calculations for fetch-limited cases were incorporated and sedimentation was considered as a contributor to dispersion.

- Sedimentation: this process is now included following Payne *et al.* 1987

The ADIOS model has been used for the past number of years during spill response as part of the effort to address requirements under the Field Operations Guide for mass balance estimates to be incorporated into the Incident Action Plan (IAP). Removal mechanisms were included in the model to reflect these needs. In particular, the user may provide information on oil removal from beach cleanup, skimming or dispersant operations. ADIOS 2 will consider this information in subsequent calculations and mass balance estimates. As a removal mechanism, in-situ burning not only accounts for the removal of oil—but estimates plume dispersion from the burn for both neutral and stable atmospheres for the determination of potential threat from particulates less than 10 microns in diameter. In addition, ADIOS 2 provides an option to display the information as ICS Form 209.

Beta-testing of ADIOS 2 has been completed by a broad range of users (industry, government, researchers, and anticipated end-users). The release date of the final version is set for December 2000.

REFERENCES

Evans, M., B. Lehr, D. Wesley and D. Simecek-Beatty. 1999. Why Spill Response Should Emulate a Fire Extinguisher. Proceedings of the 1999 International Oil Spill Conference, American Petroleum Institute, Washington DC, pp 63-67.

Jones, R.K. 1997. A Simplified Pseudo-Component Oil Evaporation Model. Proceedings of the Twentieth Arctic and Marine Oil Spill Program (AMOP), Environment Canada, Ottawa, Canada, pp. 43-61.

Lehr, William, Dave Wesley, Debra Simecek-Beatty, Robert Jones, Gennady Kachook and Jeff Lankford. June 2000. Algorithm and Interface Modifications of the NOAA Oil Spill Behavior Model. Proceedings of the Twenty-Third Arctic and Marine Oilspill Program (AMOP). Environment Canada, Vancouver, Canada. pp 525-527.

Payne, J. R., B.E. Kirstein, J.R. Clayton, C. Clary, R. Redding, D. McNabb and G. Farmer. 1987. Integration of Suspended Particulate Mater and Oil Transportation Study. Final Report. Report to Minerals Mgmt. Service, MMS 87-0083, 1987.

Simecek-Beatty, Debra, William J. Lehr and Jeffrey Lankford. 2001. Leaking Tank Experiments for Heavy Oils. Presented at International Oil Spill Conference, Tampa, Florida, March, 2001. American Petroleum Institute CD.

SINTEF'S WEATHERING MODEL (VERSION 1.8)

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OSCAR2000 is specifically designed to support oil spill contingency and response decision-making. Environmental consequences are important components of such decisions. The model therefore needs to address potential effects in the water column with verisimilitude at least equal to that achieved on the water surface and along shorelines. This paper focuses on the model's capabilities for quantifying the evolution of dispersed oil concentrations in the water column, allowing relatively realistic analyses of dissolution, transformations through degradation, and toxicology, in addition to the usual surface processes. Key components of the system are a data-based oil weathering model, a three-dimensional oil trajectory and chemical fates model, and an oil spill combat model. The system also includes tools for exposure assessment within GIS polygons (delineating, for example, sensitive environmental resource areas).

Potential effects of oil spills in the water column have long been the focus of scientific debate. McAuliffe (1986, 1987) has argued that spilled oil, with or without chemical dispersion, is unlikely to have measurable effects on larvae, juvenile, or adult marine organisms in the water column. In many situations, especially surface releases in open water, this may be the case. The *North Cape* spill, on the other hand, exemplifies a case resulting in very high water column and benthic mortalities, due to the easily dispersed oil type, the shallow water and high-energy environment in which it occurred (Michel *et al.* 1999).

Researchers at SINTEF in Trondheim, Norway, have been studying the weathering of surface oil for many years, as summarized by Daling *et al.* (1999). More recent focus has been on development of a relatively realistic model representation of the formation and composition of the water-accommodated fraction (WAF) of oil for both treated and untreated slicks. This work has been carried out over the past three years under the Advanced Management for Oil Spills (AMOS) Program in the Department of Environmental Engineering (Singsaas *et al*. 1999).

The OSCAR2000 oil spill contingency and response analysis model is one of the primary products of this program. Both surface and sub-surface calculations by OSCAR have been verified in considerable detail (Reed *et al*. 1996). OSCAR2000 differs from its predecessors (Reed *et al*. 1995a,b, 1998, 1999a; Aamo *et al*. 1995) in that the user can specify a relatively large number (30 in the present version) of individual components, pseudo-components, or metabolites to represent the oil and its degradation products. Each component is associated with an array of parameters that govern process rates: solubility, vapor pressure, transformation (first-step degradation) rates, density, adsorption-desorption partition coefficient, and toxicological parameters.

Existing three-dimensional oil spill models accounting for multiple components in processes other than evaporation are few. The U.S. Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME; French *et al*. 1996; Reed *et al*. 1989, 1992) is one example, representing oil composition using four components. More accurate assessments of water column effects of releases of hydrocarbons to the environment require a more detailed representation of oil composition, since volatility, solubility, degradation, and toxicity are not well correlated (Reed *et al*. 2000). The model by Rye (1995) represents oil with 100 pseudo-components, focusing on the processes of evaporation, dissolution and physical transport. OSCAR2000 extends the multiple-component concept into all environmental areas, including recovered oil.

Dr. Mark Reed is Senior Scientist at SINTEF Applied Chemistry, Division of Environmental Engineering in Trondheim, Norway, where he has been since 1992. Prior to that, he worked at ASA in Rhode Island. His area of specialization is marine environmental modeling. Dr. Reed received his Ph.D. from the University of Rhode Island in 1980 in oil spill-fishery interactions and did post-doctoral work in Trondheim, Norway in fish migration modeling.

MMS TRAJECTORY MODEL, OSRA: OIL-SPILL RISK ANALYSIS

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BACKGROUND

As an agency within the Department of the Interior (DOI), the Minerals Management Service (MMS) conducts a competitive leasing program for commercial oil and gas development on the Outer Continental Shelf (OCS). The MMS conducts the development of mineral resources in an environmentally safe manner by analyzing environmental consequences of the program prior to lease sales or approval of industry's action plans and by publishing either an environmental impact statement or an environmental assessment. The Oil-Spill Risk Analysis (OSRA) model was developed in 1975 by the DOI for the analysis of possible oil-spill impact from offshore oil and gas operations (Smith *et al.* 1982).

The OSRA model produces probabilistic estimates of oil-spill occurrence and contact to biological and economic resources using historical records of oil spills, winds, and ocean currents. The model is an analysis tool for use with "historical" data and was not designed for use in "real time" or forecast mode.

The rates of spill occurrence were determined from records of past spills and constructed as a function of volume of oil produced or transported. Different kinds of facilities (platforms, pipelines, tankers) demonstrated different rates of spills, and different sized spills occurred at different rates. The spill occurrence rates have been updated with additional data and analysis (Anderson and LaBelle, 1994).

MODEL FORMULATION

The OSRA model produces statistical estimates of hypothetical oil-spill occurrence and contact from operations projected to occur broadly on the OCS. The model initiates thousands of oil-spill simulations at hundreds to thousands of hypothetical spill locations to generate an ensemble of oil-spill trajectories, which can statistically characterize oil-spill risk over a large area. The spill locations are in areas of prospective drilling and production and along projected pipeline and tanker routes.

The hypothetical spills are initiated every one to four days and move at the velocity of the vector sum of the surface ocean currents plus an empirical wind-induced drift of speed equal to 3.5% of the local wind speed, with a wind-speed-dependent direction according to Samuels *et al.* (1982). The model generates oil-spill trajectories by time-stepping interpolated values of the wind and ocean current fields at intervals short enough to use the full spatial resolution of the ocean current and wind fields.

In addition to the mean advection of the hypothetical spills, the model can simulate dispersion of the individual spills by small-scale processes. Each oil spill can be represented as a collection of hundreds of “spillettes,” which start at the same initial spill location and time. At every subsequent time step, each of the spillettes is advected as described above and additionally by a randomized horizontal dispersion term of a magnitude comparable to observed small-scale processes.

The model uses a geographic grid of mesh size 1 to 4 km to define the locations of land and offshore environmental resources and to compare them at every time-step against the locations of the hypothetical oil spills. Contacts to land and environmental resources are tabulated for specified intervals after spill initiation—typically 3, 10, and 30 days. A contact to shoreline will stop a simulated spill, but contact to an offshore resource will not. For a specific oil-spill source, the number of contacts to a resource divided by the total number of spills initiated from that source is the estimate of the contact probability.

Additionally, the model estimates the joint probabilities of oil spills occurring and contacting resources. The joint probabilities are computed by multiplying the contact probability matrices by the spill rates of the oil-spill sources (platforms, pipelines, tankers) weighted by the estimated volume of oil to be produced or transported over the period of the analysis.

ENVIRONMENTAL DATA

The MMS’s Environmental Studies Program has invested millions of dollars to develop supporting environmental data sets for the OSRA model. These data sets include the best available wind fields from national and international sources such as the National Center for Environmental Prediction, European Center for Medium-Range Weather Forecasting (ECMWF), and the Navy’s Fleet Numerical Ocean Weather Center. Additionally, high-resolution ocean current fields were developed through extensive, agency-funded observational and numerical ocean modeling studies, such as coupled sea-ice-ocean modeling studies of the Beaufort Sea.

For example, the model applied to the GOM uses three-hourly ocean current fields over nine years (1986-1994) generated by the Princeton-Dynalysis Ocean Model (PDOM) (Herring *et al.* 1999). The PDOM is driven by synoptic winds, heat flux, and river flows. The wind field is the analyzed ECMWF surface winds enhanced by observations from meteorological buoys deployed during MMS’s LATEX (Louisiana-Texas Experiment) project. This wind field is also used in the OSRA model for the oil drift. Figure 1E.1 shows the stretched, curvilinear computational grid of the PDOM.

In addition to the driving wind and ocean current fields, the model uses the geographical extents of biological and commercial resources, such as the Florida sea grass beds, Alaska native subsistence areas, coastal habitats, and recreational beaches. The MMS works closely with state and other federal agencies to obtain the best available geographic information on natural resources and the

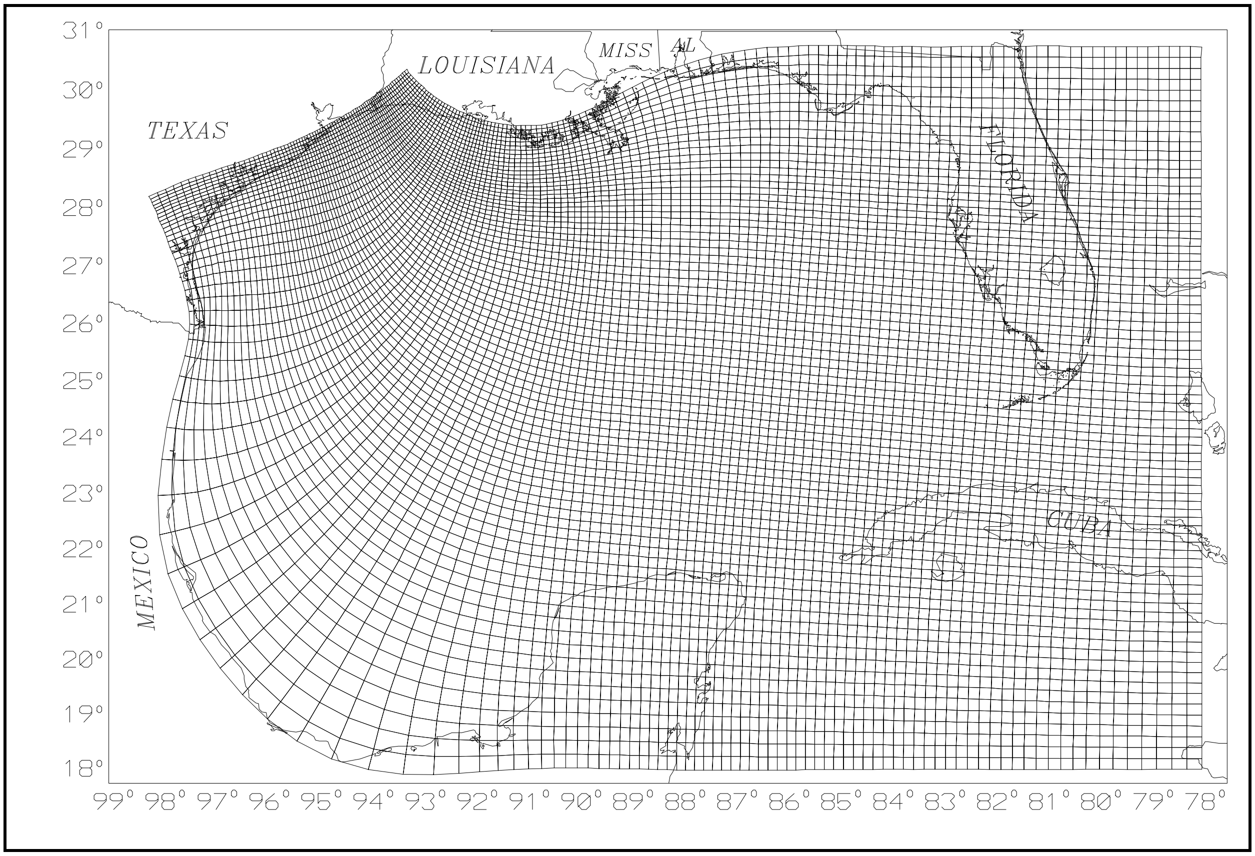


Figure 1E.1. The surface current output grid of the PDOM applied to the Gulf of Mexico. A current map was generated every 3 hours over the 9 years, 1986-1994. This grid is also the OSRA model input grid for both ocean currents and winds.

shoreline, which is represented by one or more equal-distant partitions called land segments. Figure 1E.2 shows an example of offshore environmental resources in a portion of the GOM.

The model inputs are fields of ocean currents, wind velocities, ice concentration and motion, if required, coastline specifications, geographical boundaries of environmental resources, and locations of oil production and transportation.

The model outputs are tables of probabilities of contact to environmental resources from the spill source locations and tables of probabilities of joint spill occurrence and contact. In addition, MMS has begun developing GIS-based tools to graphically display the output probabilities.

The OSRA model's supporting environmental data are among the most comprehensive of all oil-spill trajectory models. The MMS is conducting studies to obtain better ocean current and wind fields through observational and numerical modeling projects.

The MMS uses statistical estimates of oil-spill risk prior to conducting lease sales and approving industry operations. The MMS also uses model results in planning documents to prevent oil-spill impact. The oil industry is another significant user of the OSRA model results. They are required

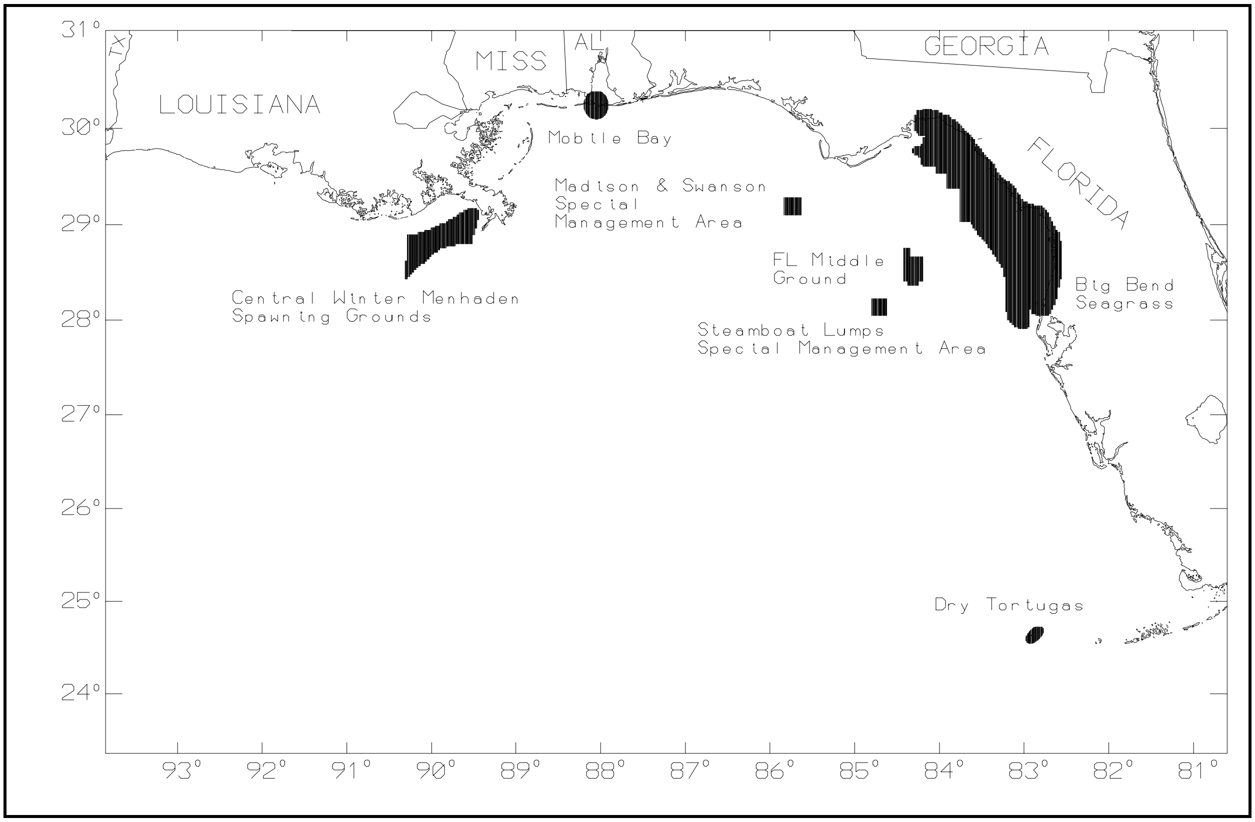


Figure 1E.2. The boundaries of a few of the offshore natural resources analyzed by the OSRA model in oil-spill contact simulations.

to develop oil-spill contingency plans approved by the MMS prior to beginning operations. These plans must predict the likely spill transport and the likelihood of oil-spill occurrence. Industry is required to obtain this prediction from MMS.

Other federal and state governmental agencies, such as the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, examine the OSRA model results contained in MMS's environmental documents to make their coastal zone management consistency determinations, endangered species consultations, and independent judgments about proposed offshore oil and gas operations. Finally, the U.S. Coast Guard has used model results to design safe tanker routes along the coast.

PLANS FOR FUTURE MODEL DEVELOPMENT

Improving the modeling and observations of ocean currents and winds and modeling their action on oil spills with time-varying physical properties are difficult tasks. The MMS is committed to improving of the OSRA model through studies of ocean circulation and numerical modeling of oceanic and spill transport phenomena. The MMS has been working and will continue to work closely with the Hazardous Materials Response Division (HAZMAT), National Oceanic and Atmospheric Administration, U.S. Department of Commerce. MMS has collaborated with HAZMAT on oil weathering methodology, oil weathering properties, Langmuir circulation, coastal circulation modeling, and display of statistical results.

The MMS has several specific objectives for improving the OSRA model over the next fivfe years. They are as follows:

1. Obtain a realistic hindcast of ocean currents wherever possible, including the tides and inertial currents, when important.

2. Increase the length of wind fields with the best available surface wind field products.

3. Introduce subsurface currents and models of oil-spill buoyancy and three-dimensional spreading and dispersion to simulate subsurface oil spills.

4. Improve the modeling of the displacement and dispersion of oil spills by small-scale oceanic processes. This might include the incorporation of Langmuir circulation and other mixed layer processes.

5. Improve Geographical Information System tools for the display and analysis of the model results.

6. Improve the numerical integration scheme with a higher order numerical scheme or some other numerical method for faster integration of the velocity fields.

ACKNOWLEDGMENTS

The authors thank technical editor Eileen M. Lear of MMS's Environmental Division and Robert P. LaBelle, chief of the division, for their many constructive comments.

REFERENCES

Anderson, C.M., & R.P. LaBelle. 1994. Comparative Occurrence Rates for Offshore Oil Spills. Spill Science and Technology Bulletin. 1: 2, pp.131-141.

Herring, H.J., M. Inoue, G.L. Mellor, C.N.K. Mooers, P.P. Niiler, L.-Y. Oey, R.C. Patchen, F.M. Vukovich, & W.J. Wiseman Jr. 1999. Coastal Ocean Modelling Program for the Gulf of Mexico. Technical Report, Dynalysis of Princeton, Princeton, NJ.

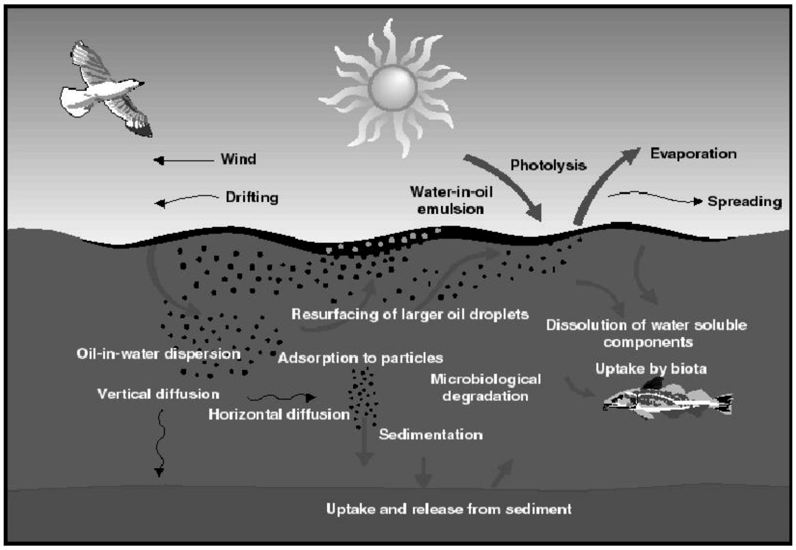
Samuels, W. B., N.E. Huang, D.E. Amstutz. 1982. An oil spill trajectory analysis model with a variable wind deflection angle. Ocean Engineering, 9, pp. 347-360.

Smith, R. A., J.R. Slack, T. Wyant, K.J. Lanfear. 1982. The oilspill risk analysis model of the U.S. Geological Survey. Geological Survey Professional Paper 1227, U.S. Geological Survey, Reston, VA.

SINTIF'S OSCAR MODEL 2000

Dr. Mark Reed
SINTEF Applied Chemistry, Norway

Oil Spill Weathering Processes



Primary Challenge in Modeling Oil Weathering:

Except for evaporation and density, we're unable to predict reliably the weathering behavior of a new (untested) crude oil.

Worst offenders: viscosity and stability of emulsions

Key variables in determining slick lifetime, advective transport, and spill response options.

SINTEF strategy for characterization and prediction of oil weathering properties at sea:

Bench-scale weathering

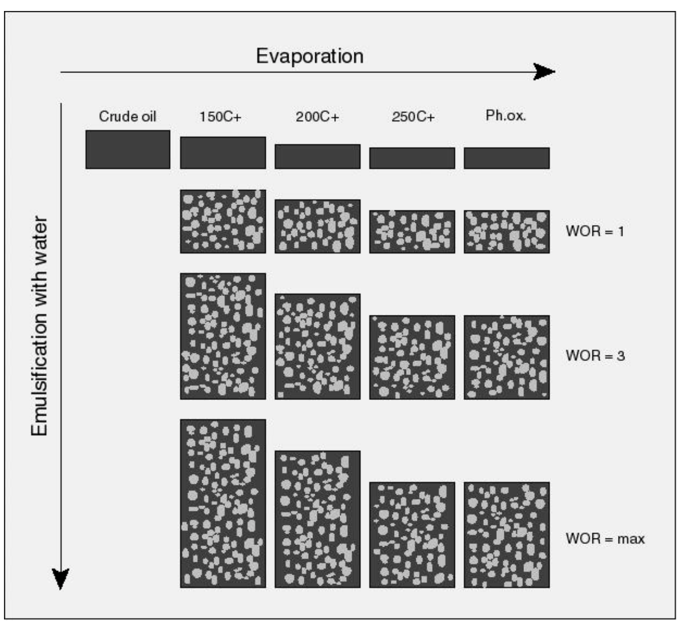
↓

Verification against meso-scale flume and full scale field trials

↓

Oil Weathering Model

Bench-scale weathering of a crude oil



12-16 different weathering samples from 1 crude oil or petroleum product

Norne Crude Oil Test Basin in Horten

Testing of Transrec overflow skimmer

Transrec skimmers are not suitable for collection of solidified oils

Framo Shovel Skimmer

SINTEF Oil Weathering Procedures

- Produce reliable results. (Comparisons with field trials and actual spills have confirmed this.)
- Have been carried out for about 50 crude oils and refined products
- Prediction of weathering behavior for other oils remains extremely uncertain
- Can't expect to perform weathering studies on every oil in the world

Question: How can we use the existing data to improve our weathering predictions for other oils?

Idea:

Apply multivariate analysis to the oil weathering database,

produce predictive equations for the variables of interest (e.g. water uptake, viscosity, stability),

use crude assay data to produce the input data for the equations.

(i.e. synthesize the laboratory data from the crude assay data)

Example correlation equation:

<u>Viscosity of 50% max. water emulsion</u> =

a_0 + a_1 Evap% + a_2 Wt% Residue +
a_3 Density + a_4 Pourp + a_5 Oil Visc +
a_6 FlashP + a_7 Asfh + a_8 Wax + a_9 Ni + a_{10} V

Variables for the multivariate calibration of emulsification properties

Variable	Abbreviation	Units
Evaporative loss	*Evap*	*Vol.%*
Residue	*Res*	*Weight.%*
Density	*Dens*	*g/ml*
Pour point	*Pourp*	*℃*
Flash point	*Flashp*	*℃*
Viscosity (water free oil)	*Visc*	*cP, shear 100* s^{-1}
Wax	*Wax*	*Vol.%*
Asphaltene	*Asph*	*Vol.%*
Nikkel	*Ni*	*Ppm*
Vanadium	*V*	*Ppm*

Problem:

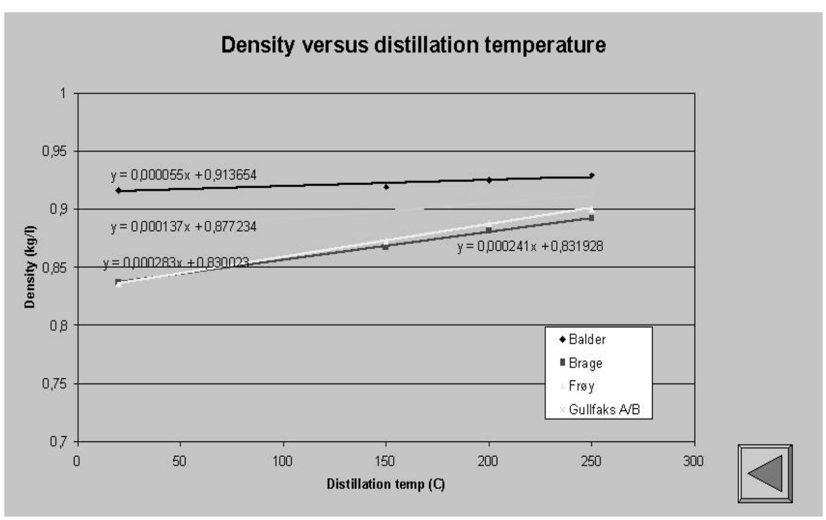
Crude assay data typically does not include all the data required.

Pour point and flash point are examples.

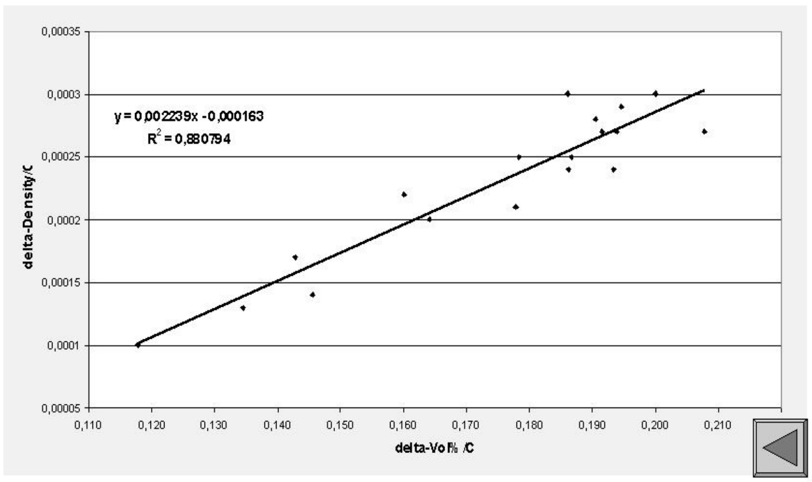
Strategy for Creating Synthetic Weathering Data from Crude Assay Data

- Use TBP curve to predict % evaporated and % residue by weight
- Density, pour point, flash point and viscosity of water free oil vary nearly linearly with temperature
- Use gradient vs gradient to estimate the above values
- Get the asphaltene and metals content from the crude assay data

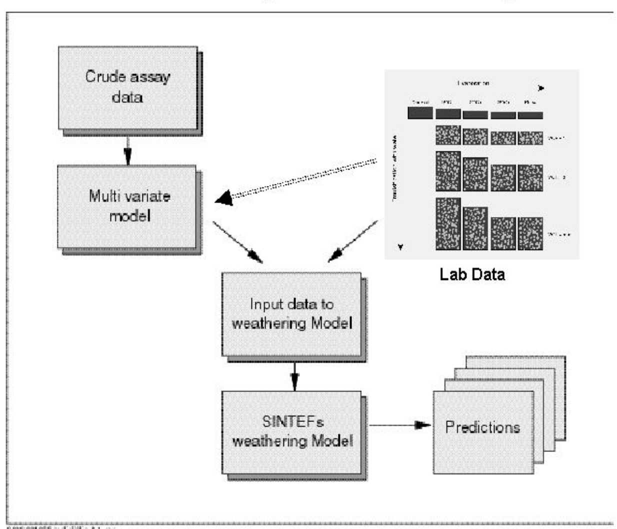
Density for Different Oils As a Function of Vapour Temperature of the Residue



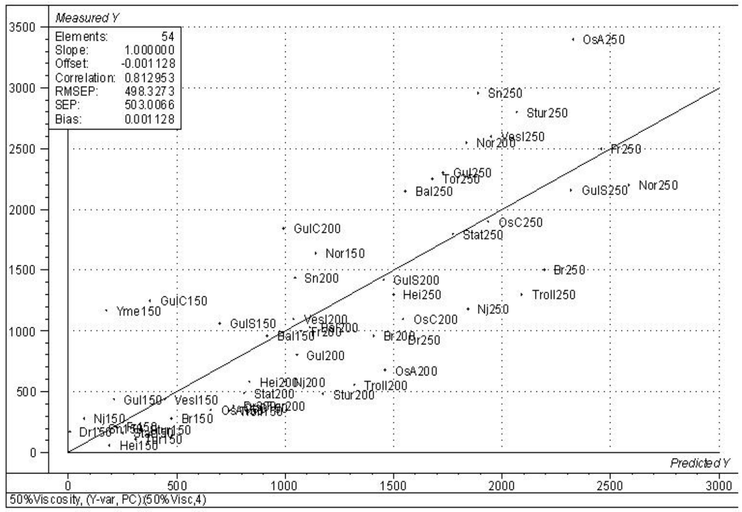
Density gradient vs evaporative loss gradient



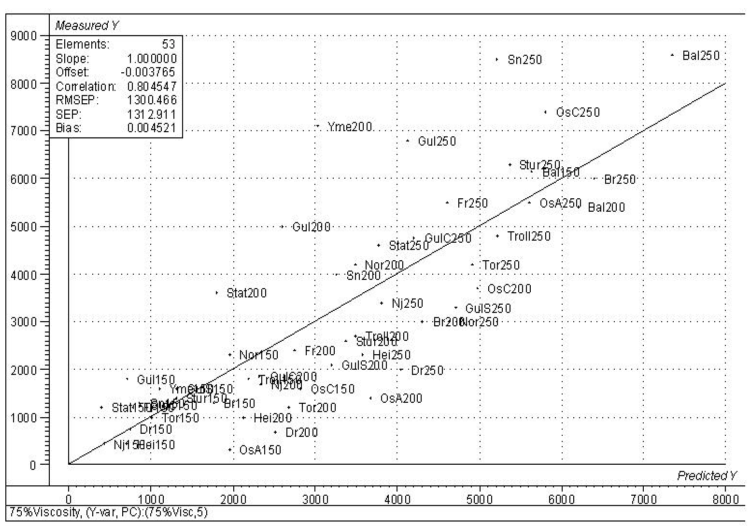
Produce "synthetic" laboratory data, redicted from crude assay data, as input to OWM



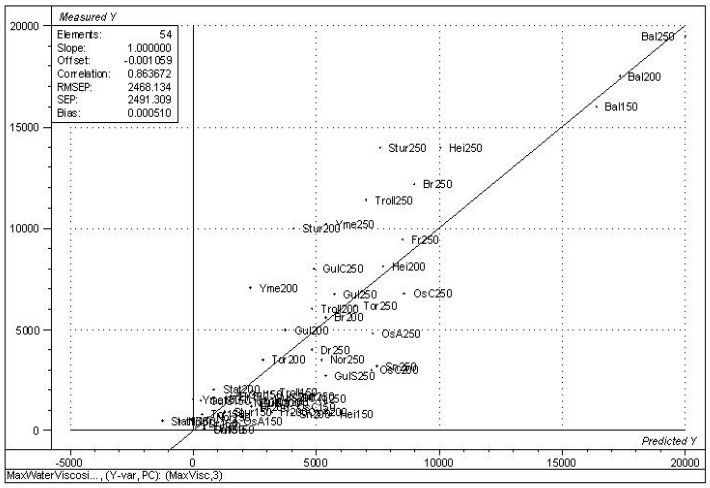
Predicted versus measured viscosity (50% emulsions)



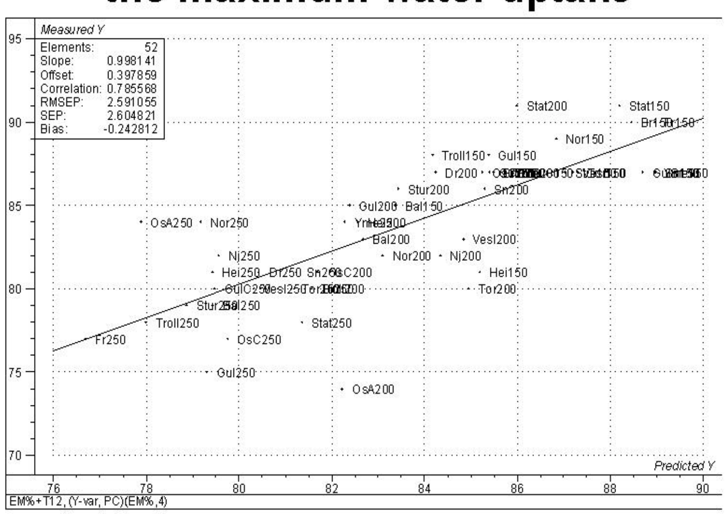
Predicted versus measured viscosity (75% emulsions)



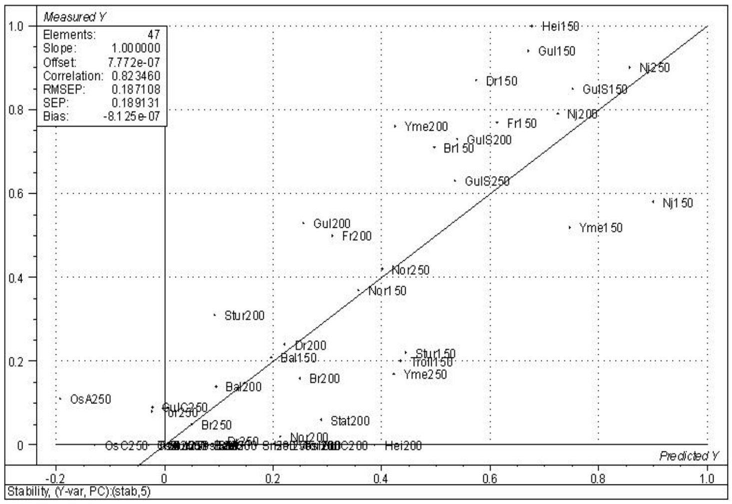
Predicted versus measured viscosity (maximum water content emulsions)



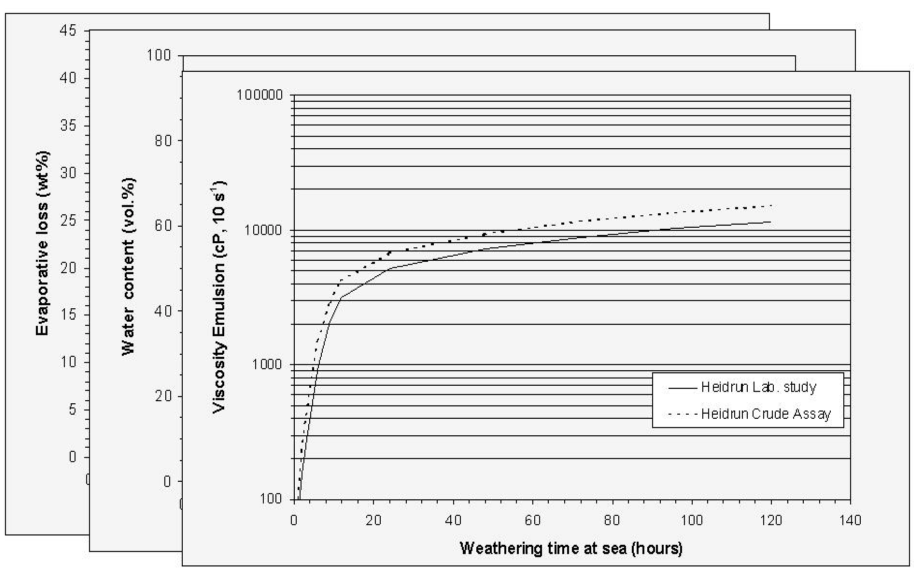
Measured versus predicted values for the maximum water uptake

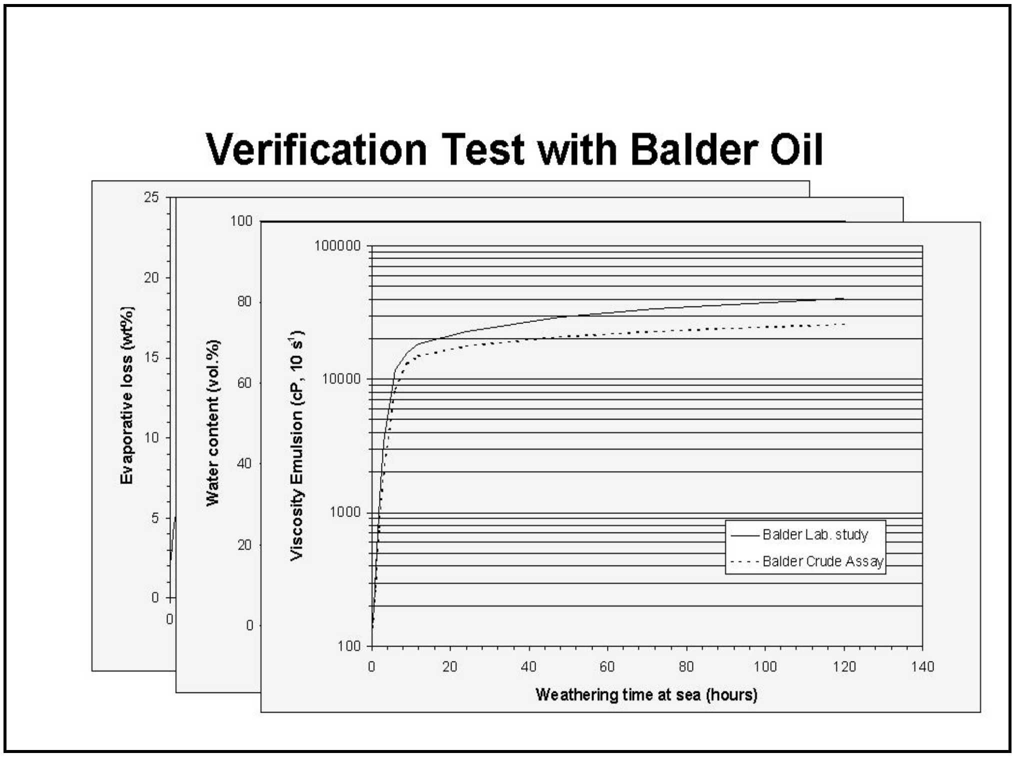


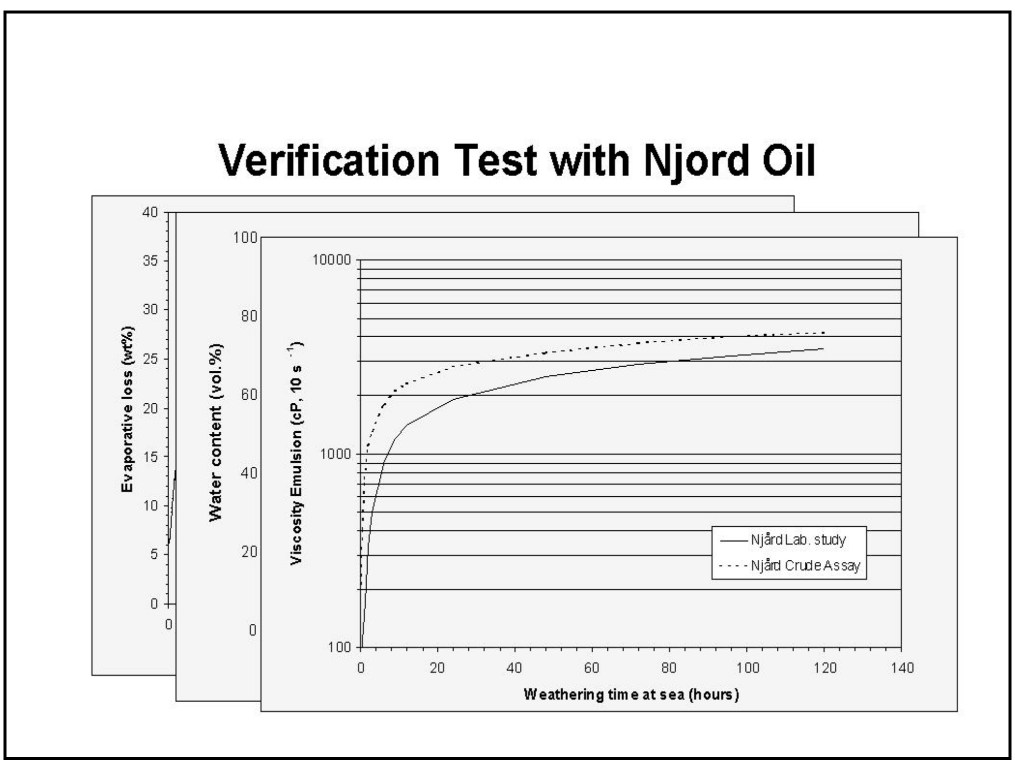
Measured versus predicted values for emulsion stability



Verification Test with Heidrun Oil




Verification Test with Balder Oil
Evaporative loss (wt%)
Water content (vol.%)
Viscosity Emulsion (cP, 10 s-1)
Weathering time at sea (hours)
Balder Lab. study
Balder Crude Assay


Verification Test with Njord Oil
Evaporative loss (wt%)
Water content (vol.%)
Viscosity Emulsion (cP, 10 s-1)
Weathering time at sea (hours)
Njård Lab. study
Njård Crude Assay

Oil types used in this study:

- .Balder
- .Gullfaks A/B
- .Heidrun
- .Oseberg C
- .Oseberg A
- .Snorre
- .Statfjord
- .Oseberg blend
- .Veslefrikk
- .Draugen
- .Brage
- .Troll-95
- .Frøy
- .Gullfaks C
- .Gullfaks Sør
- .Tordis
- .Norne-95
- .Njord
- Yme

Plans for 2001: *Begin version 3.0*

- Add other oils to the analyses
  - Gulf of Mexico
  - Alaska
- Pursue alternate strategies for improving weathering predictions based only on crude assay data

Alternate Idea for Improving Reliability of Weathering Predictions without Laboratory Weathering Data

Database search for "nearest" laboratory-tested oil.

"Nearest" defined as weighted least squares error to:

- TBP curve
- fresh oil viscosity
- segregate on wax content ?
- asphaltenes ?
- heavy metals

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SESSION 1F

BEYOND OIL AND GAS: THE HUMAN EXPERIENCE—SOCIAL SCIENCE IN THE GULF OF MEXICO REGION

Co- Chairs:	Dr. Claudia Rogers, Minerals Management Service Dr. Harry Luton, Minerals Management Service
Date:	December 6, 2000

Presentation	Author/Affiliation
No Single Story	Ms. Barbara Wallace TechLaw, Inc.
Oil, Gas, and Sustainable Development in a Rural Community	Dr. Charles M. Tolbert Department of Sociology and Anthropology Baylor University Dr. John J. Beggs Department of Sociology Louisiana State University Dr. Deborah M. Tootle Louisiana Cooperative Extension Service Louisiana State University
Benefits and Burdens of OCS Activities on Selected Communities and Public Institutions	Dr. John S. Petterson Dr. Karl Eschbach Impact Assessment, Inc.
Deepwater Program: OCS-Related Infrastructure in the Gulf of Mexico	Dr. Jeffrey A. Reidenauer Mr. Jim Burd The Louis Berger Group, Inc. Mr. Steve Mobley Dr. Ron Luke Dr. David Dismukes Research & Planning Consultants, Inc. Dr. Dmitry Mesyanzhinov Econ One Reserach, Inc. Dr. Anatoly Hochstein LSU Ports & Waterways Institute Louisiana State University

(continued on next page)

Presentation	Author/Affiliation
Onshore Effects of Offshore Employment	Mr. Mark Shrimpton Dr. Keith Storey Community Resource Services Ltd. St. John’s, Newfoundland, Canada
Place-Based Community Research and Resource Management	Dr. Domenico Parisi Dr. Duane A. Gill Unit for Community and Environmental Studies Social Science Research Center Mississippi State University

NO SINGLE STORY

Ms. Barbara Wallace
TechLaw, Inc.

In 1996, a team of economists, anthropologists, and a social historian embarked on a three-year study to increase the understanding of and document the relationship between Outer Continental Shelf (OCS) development and the economies, communities, and households of the Gulf of Mexico (GOM) region. The study examines historical, social, and economic changes in selected coastal communities since 1930 and the roles of the offshore oil and gas industry in those changes. This is the second part of a two-phased project to provide a baseline of the social and economic consequences of OCS development on Gulf Coast communities. The title of the study is *Assessment of Historical, Social, and Economic Impacts of OCS Development on Gulf Coast Communities*; it is also referred to as the Baseline 2 study. A secondary objective of the project was to enhance the understanding of methodologies for studying offshore oil and gas impacts through the use and integration of analytical approaches from history, anthropology, and economics.

ISSUE AND STUDY AREAS

The study focused on three issue areas and their relationship to offshore oil and gas in three study areas. The issue areas were changes in economic and social structure; community and land use histories (called community landscapes); and occupation and education. The study areas were South Louisiana, Coastal Bend, Texas, and Mobile Bay, Alabama. The study areas included five counties or parishes and six communities within the counties and parishes as follows:

South Louisiana	Coastal Bend, Texas	Mobile Bay, Alabama
– Lafourche Parish	– San Patricio County	– Baldwin County
• Galliano	• Ingleside	•Gulf Shores
	• Mathis	
– Terrebonne Parish		– Mobile County
• Schriever		•Theodore

Changes in economic and social structure were examined at the county and parish level using time series data. Community landscapes and occupation and education were examined at the community level using rapid ethnographic techniques. Field work for the study was completed in June 1998.

FINDINGS

OCS oil and gas activities have been important to the social and economic characteristics of the study areas. The level of importance has varied over time and with respect to each of the study areas. Federal interventions, other than offshore oil and gas development, and global forces have shaped GOM communities. Extensive and rapid industrialization occurred following World War II which affected, among other things, educational institutions. OCS activity played a role in that industrialization.

Overarching findings from the three issue areas examined include the following:

- *There are similarities among the study areas, but no single story.* While there are similarities across political boundaries in the GOM region, there is no one story as differences occur between and among the counties. The impacts of OCS oil and gas activities have varied among the study areas. Direct impacts have been felt most keenly in the South Louisiana study area, particularly in south Lafourche Parish, an area with strong ties to marine resources, both fish and oil. In the other study areas, the impacts from oil and gas are seen in different ways. Coastal Bend Texas is a fabrication center, an oil refining region, and the home port for the U.S. Navy's minesweepers, whose primary task is to keep the world's harbors and shipping lanes clear. The oil and gas industry is relatively new to the Mobile Bay study area. Impacts from OCS development are less evident in Baldwin and Mobile counties than in the other three study area counties.

  Oil and gas impacts differ within the study areas as well as among them. For example, oil economics affect the agricultural communities in the study areas. Good times for the offshore oil industry can be difficult times for farmers, who are squeezed financially when oil prices rise. (In terms of impacts from OCS, it should be remembered that oil prices are set outside the region.)

- *Federal, but non-MMS, policies affected the study areas.* OCS-related activities were only one source of change of interest and were not the driver for all that occurred. Despite its history and rhetoric of separatism, the Gulf Coast, like the South, is tied to the federal government in a number of ways. Federal policies have driven much of the change in the study areas. The similarities across the study areas often relate to national, although non-MMS related, policies, such as the GI bill and access to education; civil rights movement and school desegregation; development of the Interstate highway system; rise in environmental protection issues; and strategic decisions on military bases and personnel.

- *The mid-1980s decline resulted in changes.* The decline, referred to as the "bust," in oil and gas activity in the mid 1980's brought change to the economies and to individuals most directly affected by the offshore oil and gas industry — Lafourche and Terrebonne Parishes and, to a lesser extent, San Patricio County. The changes are seen in the county-level statistics and in the personal stories told by individuals who lived through the decline years and are still living in the study areas. The changes can also be seen within the industry itself.

- *Leisure/tourism/retirees economics is incompatible with OCS oil and gas activity.* The transition to new economies, as seen in leisure/tourism/retirees, may be fundamentally incompatible with OCS oil and gas activity. Areas with leisure/tourism/retirees and oil and gas economies are dependent on natural resources, but in different ways. The expansion of leisure time and the rise of leisure/tourism/retiree economies is an example of societal changes that occurred during the study's period of interest.

- *The oil and gas industry is complex.* The statistical analysis and the personal stories told revealed many characteristics of the oil and gas industry. The industry is international in scope. It has been transformed by technology multiple times. It operates within the larger context of business and industry and, therefore, is not immune to trends seen in the larger business world. The industry brings uncertainty and can be an agent of change. Neither the industry nor its impacts are monolithic.

- *The three disciplines contribute to identifying and understanding OCS impacts.* The study demonstrated that the analytical approaches of history, anthropology, and economics are useful in identifying and explaining impacts of offshore oil and gas on coastal counties, parishes, and communities. The analytical approaches of each of the disciplines resulted in new insights about the impacts of offshore oil and gas activities. The integration of the findings of the three disciplines provided an added dimension to understanding offshore oil and gas impacts on counties, communities, households, families, and individuals. Yet, in the end there is still much to be learned about the timing, magnitude, and location of OCS impacts on coastal communities and the households, families, and individuals who reside there.

OIL, GAS, AND SUSTAINABLE DEVELOPMENT IN A RURAL COMMUNITY

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Louisiana Cooperative Extension Service
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INTRODUCTION

This research continues a project that began with a focus on a small community in Southwestern Louisiana. With funding from the U.S. Minerals Management Service, we are expanding the scope of our initial work to test hypotheses derived from the community study. Abbeville, a small town in rural Vermilion Parish, appears to be particularly resistant to the income volatility generally associated with periods of increasing and decreasing oil and gas development activities. Previous research on census places in coastal Louisiana indicates that Abbeville experienced relatively less of the economic upheavals often associated with the downturn of the oil and gas industry in the early 1980s (Tolbert and Shihadeh 1995). Research we are now concluding on Abbeville suggests that its resiliency during the 1980s reflects a historical and cultural legacy that fosters rich social resources, facilitates economic development, and yields a local industrial structure that enables it to weather economic disruptions. Our findings suggest that, unlike most oil and gas dependent locations, Abbeville has a diverse industrial base. This industrial diversity is reflected in part by relatively large routine manufacturing, extractive (agriculture), and producer services sectors. This producer services sector is largely oil and gas related as Abbeville is a center for operations and logistics.

In this study conducted partly at the Center for Economic Studies, we employ confidential longitudinal establishment data to analyze the distribution of coastal industrial labor over time and space. We are interested in the extent to which spatial and temporal divisions of labor within the oil and gas sectors similar to those of Abbeville exist elsewhere along the Gulf Coast. We are also interested in the socioeconomic implications of these industrial patterns for coastal communities. We hope to improve on our measures of income volatility in coastal areas which have employed summary information from decennial census long-form data. These findings will contribute to a better understanding of the role of oil and gas activity vis a vis other industrial activity in local coastal communities.

FRAMEWORK

Socioeconomic conditions are primarily dependent upon patterns of industrial organization. Local economies are based on the allocation of employment across distinct industrial sectors. Each sector is associated with different working conditions, opportunities and job outcomes (Lobao 1990). Industrial organization theory generally divides industries into extractive, manufacturing, and service categories. The manufacturing and service sectors can be further divided into four more discrete sectors, defined on the basis of the magnitude of the complexity of their operations and earnings/benefits of workers: complex and routine manufacturing, and producer and consumer services (McGranahan 1988). In general, complex manufacturing and producer services are associated with higher wages and stable employment while routine manufacturing and consumer services are associated with lower wages and unstable employment.

In rural areas (where much of the oil and gas activity is staged), sound economic performance is often a function of a diversified economy. This diversification tends to produce more consistent economic growth. Specialized economies, on the other hand, can expand rapidly but are particularly vulnerable to local- and national-level swings in the economy. Because of a division of labor across space, most rural areas tend to specialize in low wage routine production and consumer service sector jobs. Typically dominated by a single industrial sector, these communities are vulnerable to business cycles and foreign competition which encourage capital flight (Bluestone and Harrison 1982; McGranahan 1988).

Because diversified local economies are not dependent on any single sector source of employment and earnings, they are better prepared than more specialized economies to weather the economic downturns associated with specific industries (Killian and Hady 1988), such as the impending shutdown of such large-scale production facilities throughout southwestern Louisiana (Acadiana). Abbeville, unlike many of the communities in Acadiana, is not solely dependent upon such large-scale production facilities. Oil and gas activity is an integral part of its industrial structure and may help counter the economic downturns associated with the flight of routine production facilities offshore by either absorbing some surplus labor or increasing local household earnings.

Because of the tendency for rural areas to specialize in routine manufacturing and consumer services, the industrial organizational and rural research literatures pay very little attention to producer services in rural areas. It is readily apparent that producer services in rural areas are closely associated with a dominant industrial base, such as mining (Glasmeier and Howland 1995). However, it is not at all clear how these linkages develop across time and space. The Abbeville area differs from other oil activity centers because it appears to be more of a center for oil field logistics and operations than it is for oil field fabrication. We think that the concentration of oil-related producer services in Abbeville is a major factor in Abbeville's resiliency to the decline in oil and gas activity. For the most part, these oil-related producer services firms remained active, albeit at a diminished rate, throughout the 1980s. However, we currently do not have the necessary spatial and temporal data to examine and compare the distribution and differential impact of oil and gas activity across time and space.

The foregoing discussion begs a number of questions: How many specialized service firms are there in Abbeville? How long have they been there? Have these oil and gas service establishments agglomerated in identifiable clusters or is there considerable regionalization or spatial dispersion among them? Are these firms sufficiently embedded in the Abbeville economy to assist in cushioning the impact of a major plant closure or some other episode of economic volatility? Are the same industrial patterns exhibited in coastal communities elsewhere? Do those communities also have a history of less volatile responses to boom and bust episodes? Answering questions of this sort requires a combination of qualitative and quantitative data and methods that we outline in the following section.

METHODOLOGY

With CMI funding, we are conducting research that will help us develop a better understanding of how oil and gas activity contributes to local economic diversity. Our proposed work entails:

1. examining the potential for oil and gas employment to compensate for the loss of employment with Fruit of the Loom, and

2. determining whether a spatial and temporal division of labor exists within the coastal oil and gas sector, and the socioeconomic implications for coastal communities.

This is an in-depth, multi-method study that encompasses community field study and procedures and comparative techniques that permit analysis of enterprise-level data over time and space.

Field Study

We have used field study techniques to determine whether expanding oil and gas employment opportunities might counter some of the economic challenges facing the community with the loss of employment at the Fruit of the Loom plant. This type of analysis will require more in-depth analysis than we can conduct with existing place or establishment level data. We reported on some initial results of the field study at the 17th ITM (Tootle, Tolbert, and Shihadeh 1999). We are developing an in-depth report on the field study, but can summarize the findings as follows:

- The closure of the Fruit of the Loom plant was a protracted event, lasting almost nine months after the initial announcements. This permitted employees to explore options, including job training and other avenues of interim support.

- While the transition period dampened the impact of the closure, there were still clear effects:

  1. ethnicity—displaced workers used community, social, and family support sources in ways that varied by ethnicity. The least likely individuals to avail themselves of governmental and official services were Vietnamese.

  2. oil and gas industry—FOL workers who had family members in oil and gas industry employment were among the first to opt out of plant employment. The oil and gas industry

served as buffer which permitted the displaced workers in those households to leave and begin job searches.

3. the well-organized state job training program worked well that also buffered the impact of the plant closure on the community.

- The diversity of the Abbeville economy—including a large sector of business services oriented to the oil and gas industry—continues to be a primary basis for economic resilience in the community. But, our longitudinal approach suggests that a dynamic view of industrial diversity best explains the sustainability of this rural community:

    1. a key source of sustainability in one year turns out to be problematic in a subsequent year;

    2. a seemingly problematic aspect of the local economy at one point can contribute to sustainability at a later point;

    3. this suggests we should be wary of cross-sectional assessments of the sources of socioeconomic vitality.

Analysis of Enterprise Data over Time and Space

We believe our findings in the Abbeville case study are sufficiently robust to recommend a hypothesis for testing on other communities. The hypothesis is based on our observation of a thriving producer services sector in the Abbeville economy. Are similar service sectors evident in other coastal communities? Can such sectors be shown to be statistically related to the desirable outcomes we have observed in our Abbeville research?

To adequately assess the development of a producer services sector in Abbeville and other coastal communities, we plan to develop models of the coastal division of industrial labor, comparing socioeconomic outcomes for coastal areas with varying industrial and service sector compositions over time. We are especially interested in the extent to which industrial divisions of labor similar to that of Abbeville exist in other coastal communities. Assuming we can identify areas with similar industrial profiles, we will analyze socioeconomic outcomes and compare those to the results we have in hand for Abbeville.

To accomplish this modeling task, we need data on the location and age of establishments, as well as very detailed industry classifications. These data requirements surpass readily available data sources such as *County Business Patterns* or published versions of data from the Economic Censuses. While these data compendia are generally very useful, they frequently do not report data for small areas and small numbers of establishments to ensure confidentiality. Such establishment-level microdata are not in the public domain, but can be accessed through an agreement with the Center for Economic Studies (CES), U.S. Bureau of the Census.

CES has assembled establishment responses to various economic censuses. These data in conjunction with an age proxy available from the Census Bureau's SSEL (essentially a national business register), allow us to study the "embeddedness" of establishments. A major, related--and exploratory--interest of this project is the study of establishment formation/dissolution/survival and identifying how measures of churning in these establishment populations relate to measures of well-being. The economic census data also provide detailed industrial classification (four- and five-digit SIC codes) and establishment type (single-unit vs. multiple location) information. Access to these data represents a significant step forward for socioeconomic analysis. All previous socioeconomic work under the auspices of MMS has necessarily been based on public domain-data, which are often suppressed for reasons of confidentiality *and* which do not contain information on establishment age or type. By contrast, the economic census data contain no suppression and constitute the universe of U.S. establishments. We will use these data to develop a longitudinal database on coastal oil and gas producer services. We have budgeted for database coverage of all states adjacent to the Gulf of Mexico (GOM), and this has been approved by MMS.

Working at CES, we are developing models of the coastal division of industrial labor, comparing socioeconomic outcomes for coastal areas with varying industrial and service sector compositions over time. For MMS resource management purposes, it would be very useful for us to explore the extent to which the Abbeville case is unique or whether there are other, similar areas whose industrial mix appears to buffer them from episodes of increasing and decreasing oil and gas industry activity.

OUTLINE OF CES ANALYSIS

Objectives

1. Employ confidential, longitudinal establishment data to analyze the Gulf Coast industry mix over time and space and its relationship to income levels and income volatility.

2. Identify target industries with emphasis on producer services sector. Search for areas with industrial compositions similar to that of Abbeville, Louisiana (i.e., substantial involvement in oil and gas activity through service industries as opposed to fabrication and extraction).

3. Explore variations in formation/dissolution (churning) of establishments coinciding with episodes of increased and decreased oil and gas industry activity. Compare rates of change for producer services vs. other industries.

4. Explore use of 1990 long-form microdata to compute selected socioeconomic outcome measures and to estimate hierarchical linear models.

UNITS OF ANALYSIS

This analysis employs data for roughly 80,000 persons who work in approximately 900 incorporated places in the states of Texas, Louisiana, Mississippi, Alabama, Florida, and Georgia. All the incorporated places have populations of at least 2,500 persons. This permits us to match the place geography on the 1990 decennial information with the place geography found in the economic census of 1987 and 1992.

Developing a Community Typology

To group the communities into meaningful classifications, we employed factor analytic and cluster analytic procedures to arrive at a typology. From the 1987 and 1992 economic censuses, we developed measures of employment, wages, receipts/sales, and growth in these factors for the set of Gulf Coast places. From 1990 census of population and housing long-form records, we selected measures of employment shares by industry and occupation. The detailed occupational and industrial information permitted us to identify specific occupations and industries likely to be oil and gas related. We also developed measures of labor force factors such as working in place of residence, low-hours workers, and low wages. Lastly, we employed the decennial information to develop a set of demographic measures, including population size, percentage of African American, and population density. In all, approximately 90 measures were taken from the economic census and decennial population census to describe each of the 900 or so Gulf Coast incorporated places.

In a factor analysis of the descriptive measures, we derived a seven-factor solution that accounted for about one-third of the variance among the indicators. In order of magnitude of eigenvalues, we labeled these factors: 1) suburban high-skill, high-wage services, 2) high-wage, high-growth, 3) growth in receipts and wages, 4) high productivity-refining, 5) oil and gas dependent, 6) legal, insurance, and accounting, and 7) retail, especially eating and drinking places. Factor scores for each incorporated place were then employed in a cluster analysis to derive groupings of the communities along these dimensions (or combinations of the dimensions). A satisfactory solution was obtained that indicated six clusters of communities:

1. Non-metro service and manufacturing communities
2. Low-wage, high-growth communities
3. Suburban services, high-wage, high-growth
4. Non-metro high-wage, high-growth
5. Oil and gas dependent communities
6. Large metro, suburban services, high-wage, high productivity communities

These six community types permit us to contrast oil and gas dependent communities with other types of communities.

MEASURES OF EMPLOYMENT VOLATILITY

A primary concern about the social impacts of oil and gas industry ties to communities focuses on potential employment volatility that fluctuations in oil and gas activity may cause. To evaluate the differences between oil and gas dependent and other communities, we developed several measures of employment volatility. We first constructed a measure of *net employment change*: total employment at some time 2 (T2) minus total employment at a time 1 (TI) divided by total employment TI. Data to construct this measure are readily available from public sources (i.e. economic censuses or county business patterns). Economists like David Birch and John Haltiwanger have pointed out the a tremendous amount of job reallocation that is not captured by a gross net change measure like this one. Net job change is composed of jobs that existed at both time points, jobs created between TI and T2, and jobs lost between TI and T2. Job creation and job destruction each have two sources: establishments that existed at both points in time and either expanded or contracted and establishments that were created or dissolved.

To correctly evaluate employment volatility, we need to consider all the sources of employment change. To build such measures, we need establishment-level data for employment at two points in time. These “microdata” are not available from public sources. They are available to us, however, at the Center for Economic Studies at the Bureau of the Census. We use microdata from the economic censuses of 1987 and 1992 to construct our employment volatility measures. We are limited to those sectors of the economy where data are available at both points in time. We used data from the manufacturing, wholesale, retail, and service sectors to construct our measures. We wanted to use the minerals census data also because of our interest in oil and gas employment, but there are problems with local (substate) geography (discussed below). In all other respects, the economic census microdata are ideal because we want to gauge employment volatility in local communities. The establishment microdata include a suite of geography items, including information on the name of the incorporated place where the establishment is located. This permits us to organize the data by locality or community. In all, we use data on 907 incorporated places of 2,500 persons or more from the five states that border the GOM.

We report information on three measures of employment volatility in coastal communities in this presentation. Our first measure evaluates *overall volatility*. It is constructed by summing the jobs which were created either in existing or new establishments plus the jobs that lost either from existing or dissolved establishments. This is then divided by this total plus the jobs that existed at both time 1 and time 2. Our other two measures focus on *job creation* and *job destruction* separately. The first measure is constructed by dividing the jobs created either in existing or new establishments by employment at time 2. The latter measure, job loss volatility, was constructed by dividing the jobs lost either from existing or dissolved establishments by employment at time 1. Our focus in this analysis is on the association of type of community and employment volatility. We do this analysis through the use of OLS regressions in which we contrast five types of communities with oil and gas dependent communities. We use a number of controls in these preliminary models so that we can consider community type net of other potentially relevant constructs.

Table 1F.1 presents the information on means, standard deviations, and zero order correlations information that we were able to get through the disclosure process. Table 1F.2 presents the information on correlations among dependent measures. Table 1F.3 presents the regression results. The first two columns present the results for our gross net change measure. Four of the five types of communities have greater net growth than the oil and gas dependent communities. Since the time period is 1987 to 1992—a period of relative contraction in the oil and gas industry—this result is not surprising. The model does not fit well at all; 9.15% of variance in this measure is explained. The second two columns present the results for our measure of overall volatility. While our model fit is considerably better (r-square is .38) none of the community types is differentiated from the oil

Table 1F.1. Means and standard deviations.

Variable	Mean	S.D.
Clusters		
Cluster 1, Non-metro Service and Manufacturing Communities	–*	–
Cluster 2, Low Wage, High Growth Communities	–*	–
Cluster 3, Suburban Services, High Wage, High Growth	–*	–
Cluster 4, Non-metro High Wage, High Growth	–*	–
Cluster 5, Oil and Gas Dependent Communities	–*	–
Cluster 6, Large Metro, Suburban Services, High Wage, High Productivity Communities	–*	–
Control Measures		
% Employed in Multi-Establishment Enterprise Pieces	–*	–
% Multi-Establishment Enterprise Pieces	23.89	8.06
Average Establishment Size	12.21	6.26
Receipts Per Employee	–*	–
% Less Than HS Education	28.74	11.56
% Labor Force Participation	59.28	9.19
% Lived in Household 10 or More Years	37.62	10.27
Median Household Income	24820.85	11579.89
Non-metro Status of Largest County Piece	.39	.49
Dependency Ratio	.67	.17
Log of Population Size	9.26	1.09
Dependent Measures		
Overall Employment Volatility	–*	–
Net Employment Growth-1987-1992	–*	–
Employment Losses-1987-1992	–*	–
Employment Gains-1987-1992	–*	–

* indicates that statistic was not disclosable

Table 1F.2. Correlations among dependent measures.*

	1	2	3	4
Overall Employment Volatility (1)	1.000	+	+	+
Net Employment Growth-1987-1992 (2)	+	1.000	-	+
Employment Losses-1987-1992 (3)	+	-	1.000	+
Employment Gains-1987-1992 (4)	+	+	+	1.000

* correlation coefficients not disclosable

Table 1F.3. Unstandardized OLS regression coefficients predicting measures of employment volatility.

	Employment Growth		Overall Employment Volatility		Employment Losses		Employment Gains	
	b	s.e.	b	s.e.	b	s.e.	b	s.e.
Cluster 1	4.35	5.20	-1.71	1.34	-3.32*	1.65	-.69	1.62
Cluster 2	15.90*	6.20	1.31	1.60	-1.00	1.96	4.00*	1.94
Cluster 3	12.35*	6.11	1.20	1.57	-.96	1.93	3.37+	1.91
Cluster 4	9.87+	5.91	-1.33	1.52	-3.74*	1.87	-.10	1.85
Cluster 5 (Reference category)	–	–	–	–	–	–	–	–
Cluster 6	28.10***	6.77	3.01+	1.74	-.17	2.14	5.12*	2.11
% Employed in Multi-Establishment Enterprise Pieces	.09	.10	-.14***	.02	-.21***	.03	-.06*	.03
% Multi-Establishment Enterprise Pieces	.04	.19	.15**	.05	.20***	.06	.10+	.06
Average Establishment Size	-1.25***	.24	-.65***	.06	-.41***	.07	-.80***	.07
Receipts Per Employee	.01	.02	-.01*	.00	-.02***	.00	-.00	.00
% Less Than HS Education	.14	.19	-.02	.00	-.08	.06	.01	.06
% Labor Force Participation	.20	.20	.04	.05	.06	.06	.04	.06
% Lived in Household 10 or More Years	-.38*	.16	-.17***	.04	-.06	.05	-.26***	.05
Median Household Income	-.00	.00	.00	.00	.00	.00	.00	.00
Nonmetro Status of Largest County Piece	-1.36	3.09	-2.59**	.75	-2.54**	.98	-2.51**	.97
Dependency Ratio	-10.10	9.85	-2.94*	2.54	-1.54	3.12	-4.61	3.08
Log of Population Size	-2.97*	1.30	-.79	.33	-1.05*	.41	-.87*	.41
Intercept	51.78	24.48	88.09	6.30	67.44	7.75	75.60	7.66
R^2	.09		.38		.27		.33	

+ p<.10, *p<.05, **p<.01, ***p<.001

and gas dependent communities. However, when we look at columns five through eight, we start to see some of the dynamics at the root of the results for our gross net change measure. The results for employment gain volatility indicate that community types 2, 3, and 6 have greater net change than oil and gas dependent communities because they added jobs to their employment base between 1987 and 1992. Conversely, community types 1 and 4 had greater net employment between 1987 and 1992 because they lost jobs a lower rate.

Access to the confidential microdata from the decennial and economic censuses allowed us to address a research issue we had not been able to address with existing publicly available data. We are interested in impact of a small sector of the economy (oil and gas) at a low level of geography (places). The data at CES permit us to develop useful information about the relationship between oil and gas employment in local communities along the GOM. A number of these communities are small non-metro places for which limited, if any, information is available. We obtained a greater understanding of the dynamics of the labor market for these areas through our analysis of the components of employment change.

CENSUS OF MINERALS' GEOGRAPHY

This section consists of a cautionary note about public data sources based on economic census data collection procedures such as the widely used *County Business Patterns*. In our work with the Census of Minerals we have discovered that substate geographies (e.g., metropolitan area, county, place) are not available, either in public data or in the confidential establishment microdata that we employ at Census. Upon further investigation, we have learned that there are circumstances for which the Bureau does not collect or retain information other than state of operation, such as in the case of large enterprises that may have establishments in multiple locations. This lack of data has led us to omit minerals industries (SIC code 13) from our employment volatility analyses at the place level (at least for the time being).

This problem regarding information on minerals industries from *County Business Patterns* is further compounded by the Bureau's suppression of certain data in published reports. This suppression is used to avoid identifying data for specific establishments, most often, to avoid disclosing data on a single dominant firm in an area, but there are other reasons that data are suppressed. Suppression flags appear in data fields of the *County Business Patterns* for establishment employment and payroll. More often than not, the flag references a range of possible data values (say, 500-1,000 employees). Experienced users know to observe the suppression flags in public versions of the data and will typically derive an estimate of employment or payroll by using the midpoint of the interval.

Table 1F.4 illustrates how these two data problems interact to limit substantially the inferences that can be made from the published data sources like *County Business Patterns*. Each of the columns represents one of the Gulf Coast states that are the focus of our ongoing work. The data for Alabama indicate that 23 Alabama counties are identified as having one or more minerals industries establishments. In 20 of those 23 counties, however, employment and/or payroll data are suppressed. There are minerals establishments in other counties of Alabama, but the counties are not identified (the balance of the data are grouped into a single residual geographic category). Establishment counts are not suppressed, so we can report 90 minerals industry establishments for which counties are identified and 41 establishments in the non-identified geographic unit. This sums to the 131 found in the state total section. Payroll and total employment are suppressed for the generic geographic category in Alabama. What do we miss because of this suppression? Since the state total payroll (in $1,000s) is $67,792 and the identified county payroll is $10,357, we do not have substate geography for $57,435 which is 85% of Alabama's minerals industries' payroll. Similarly, we cannot identify a location within the state for 84% of the employment in the industry. We know only

Table 1F.4. Limitations of county business patterns data on mining (SIC = 13).

	Alabama	Florida	Louisiana	Mississippi	Texas
State Totals					
Number of Identified Counties (Valid FIPS) With Mining Establishments	23	27	54	34	205
Number of Identified Counties (Valid FIPS) With Mining With Suppressed Data	20	22	28	26	119
State Total Payroll in Mining	67792	16229	1551169	95173	3913068
State Total Employment in Mining	2016	501	42696	3539	104151
State Total Establishments	131	101	1451	345	6714
Identified Counties (Valid FIPS Code)					
Total Payroll in Mining	10357	1280	409970	21151	2113276
Total Employment in Mining	322	58	13828	743	56021
Number of Establishments	90	85	1284	284	6487
Non-Identified Counties (999)					
Total Payroll in Mining	X	6898	902555	36233	X
Total Employment in Mining	X	191	20776	1132	X
Number of Establishments	41	16	167	61	227
Total Information in Unidentifiable Geographic Unit (State Total-Identified)					
Payroll (% of State Total in Unidentifiable Geographic Units)	57435 (85%)	14949 (92%)	1141199 (73%)	74022 (78%)	1799792 (46%)
Employment (% of State Total in Unidentifiable Geographic Units)	1694 (84%)	443 (88%)	28868 (68%)	2796 (79%)	1664 (47%)
Total Unaccounted Information (State Total-(Identified+Non-Identified))					
Payroll (% of State Total Unaccounted for by County Data)	57435 (85%)	8051 (50%)	238644 (15%)	37789 (40%)	1799792 (46%)
Employment (% of State Total Unaccounted for by County Data)	1694 (84%)	252 (50%)	8092 (19%)	1664 (47%)	1664 (47%)

X=Total Data Suppressed in CBP

that the place of work is somewhere in Alabama. While Alabama may be the extreme case, there is substantial unaccounted information for all states in Table 1F.4.

Among the datasets available to us at Census is the underlying establishment microdata for *County Business Patterns*. There is no suppression in these data, and we are able to work with precise figures rather than estimates. This enables us to resolve the suppression problem, but, we have yet to resolve the geography problem in the minerals data. We have attempted to use several related datasets including the Standard Statistical Establishment List (SSEL), which is the Bureau's national establishment register. None of the business data sets has provided a solution for the geography problem. We are now beginning to use the 1990 population census long-form data from which we can determine place of work. By careful selection of occupation and industry categories, we hope to derive a reliable estimate of location of minerals industry employment activities. In a new project, we will also investigate other solutions, including ES-202 data and proprietary data sources.

REFERENCES

Bluestone, Barry and Bennett Harrison. 1982. The Deindustrialization of America: Plant Closings, Community Abandonment and the Dismantling of Basic Industry. New York: Basic Books.

Glasmeier, Amy K. and Marie Howland. 1995. From Combines to Computers: Rural Services and Development in the Age of Information Technology. Albany: State University of New York Press.

Killian, Molly Sizer and Thomas F. Hady. The economic performance of rural labor markets. pp.181-200. *In* David L. Brown, J. Norman Reid, Herman Bluestone, David A. McGranahan, and Sara M. Mazie, eds. Rural Development for the 1980's: Prospects for the Future. Agriculture and Rural Economy Division, Economic Research Service, U.S. Department of Agriculture, Rural Development Research Report No. 69.

Lobao, Linda M. 1990. Locality and Inequality: Farm and Industry Structure and Socioeconomic Conditions. Albany, NY: The State University of New York Press.

McGranahan, David. 1988. Rural workers in the national economy. pp. 29-40 *In* David L. Brown, J. Norman Reid, Herman Bluestone, David A. McGranahan, and Sara M. Mazie, eds. Rural Development for the 1980's: Prospects for the Future. Agriculture and Rural Economy Division, Economic Research Service, U.S. Department of Agriculture, Rural Development Research Report No. 69.

Tolbert, Charles M. and Edward Shihadeh. 1995. Oil and gas development and coastal income inequality: case studies at the place level. Presentation at the 15th Annual Information Transfer Meeting, U.S. Minerals Mgmt. Service, New Orleans, LA.

Tootle, Deborah, Charles Tolbert, and Edward Shihadeh 1999. Sustainable development in oil and gas country: a case study of Abbeville, Louisiana. pp. 228-36. *In* U.S. Department of the Interior, Minerals Management Service. Proceedings: seventeenth annual Gulf of Mexico information transfer meeting, December 1997.U.S. Department of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, La. OCS Study MMS 99-0042. 710 pp.

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BENEFITS AND BURDENS OF OCS ACTIVITIES ON SELECTED COMMUNITIES AND PUBLIC INSTITUTIONS

Dr. John S. Petterson
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The MMS study entitled “Benefits and Burdens of OCS Activities on Selected Communities and Public Institutions” is organized to achieve five objectives:

1. analyze the benefits and burdens of OCS oil and gas activities at the county/parish and labor market area (LMA) levels of analysis;

2. develop a baseline description of coastal counties/parishes;

3. analyze recent significant changes in the study areas associated with the deepwater program;

4. analyze seven coastal labor commuting areas; and

5. develop recommendations to mitigate potential negative effects of deepwater development.

The geographic scope of the project incorporates all Gulf of Mexico (GOM) coastal counties/ parishes stretching from Alabama to Mexican border, including all LMAs with coastal counties or parishes (and all counties within them). The 40-month project was initiated in September 1998 and funded at $640,000. The study team is composed of: (1) John S. Petterson, Ph.D., PI/Project Manager; (2) Karl Eschbach, Ph.D., PI/Senior Scientist; (3) Jeanne Hurlburt, Ph.D., PI/Team Leader; (4) Carson Mencken, Ph.D., PI/Demographer; and (5) Nicole Flynn, Ph.D., PI/Team Leader.

The study effort is designed to overcome a number of significant theoretical and empirical impediments. Perhaps the most obvious is the problem posed by geography. The study area is composed of over 70 counties and parishes, each with its own unique geographic advantages and disadvantages with respect to OCS development. They include counties adjacent to the coast, interior counties, counties with and without ports, rivers, and access to major transportation corridors. Geographic advantages predetermined, in important ways, where and how offshore oil development would be concentrated, and how those effects would be distributed. To gain an understanding of the distribution of impacts, it is first necessary to understand how and why certain areas became the center of activities while others were ignored.

A second issue is the timing and duration of the impacts. Near shore, offshore, and deepwater oil development have occurred at different points in the histories of these coastal counties and LMAs. As OCS-related activities changed over time, in terms of scale, technology, and geographic location, the distribution of impacts has also changed over time. Similarly, the sensitivity of each coastal community and county to impacts associated with OCS activities has changed over time. Fishing communities of the 1940s and 1950s have, over time, become predominantly OCS offshore oil support communities. If we evaluated the impact of oil activities on Morgan City over the period 1950-1960, it would bear little resemblance to the same analysis over the period 1980-1990. Over what period, and on what population, are we to evaluate the benefits and burdens of OCS?

A third issue is that the natural and social histories (size, economic adaptation, occupational orientation, seasonality, etc.) of individual communities creates a differential sensitivity to the effects of activities carried out in support of OCS development. Where a community of 10,000 residents might not experience 100 new OCS-related employees as a significant impact on social relationships or the local economy, a similar impact on a community of 400 residents could be profound. Similarly, 100 new OCS-related employees in an established oil-oriented community would be very different in a community where no prior oil-related industry existed. These existing differences influence the threshold at which a particular effect may be perceived as an adverse impact.

A fourth issue is that the effects of changes brought about by OCS activities are associated with the specific support function provided by the affected community or county. This results in an industry- or function-based distribution of benefits and burdens. Some coastal areas are oriented, predominantly, to the fabrication of offshore platforms, others to providing transportation to and from the platforms, others to the fabrication of offshore oil supply vessels, others to the manufacture of pumps, pipes, and other materials required to build and maintain the rigs, and still others to accounting and administrative requirements. It is, in turn, the characteristics of these support operations that determine how the benefits and burdens of the underlying OCS activities are distributed among the counties and parishes of the GOM. This underscores the importance small changes in the specific causal agent (e.g., scale, technology, work patterns, location) can have on the resulting benefits and burdens of OCS activity.

To address these, and many other, theoretical and empirical impediments, the “Benefits and Burdens of OCS Activities on Selected Communities and Public Institutions” study has sought to structure county and parish profiles, and to design replicable economic and demographic monitoring methods (at State, LMA, and county/parish levels) in a manner that would allow future researchers to track the distribution of the burdens and benefits of OCS activities.

At the present point in the study effort, we have just submitted our Third Interim Report for MMS review. This report is designed to provide MMS with a complete LMA analysis of changes occurring in the Lafayette LMA and its component parishes over the period 1920 to 1990. The following ITM presentation highlights some of the preliminary findings of that analysis.

Offshore oil and gas extraction activities’ impact on Gulf Coast counties and parishes occur in the context of on-going changes in the economies and demographics of these counties. The period of the emergence of offshore activities after 1947 is one of profound change in these communities. As important as changes in the oil and gas industry are, changes that are occasioned by cycles in the industry are not quantitatively the most important changes that occur, even in areas that we ordinarily think of as being heavily affected by changes in the oil and gas industry. Specifically, these areas were also affected by broader processes of economic and demographic restructuring implicit in the transformation from an agricultural to an industrial and then to a service base.

A second, complementary, point is that there is not a single characteristic effect of oil and gas on local communities across time and space. Discussion of oil industry effects have frequently assimilated the oil and gas extraction industry to other extractive industries and emphasized the supposedly special risks that extractive industries pose to communities that depend on them. The wrenching dislocations associated with the frenetic roller coaster ride from 1973 to 1987 in industry-dependent areas gave credence to this viewpoint, which achieved the status of an axiom as a description of effects on oil-dependent metropolitan areas such as Houston and Lafayette. Yet it is not clear what larger lesson is to be learned from the truly remarkable events of this period, because it is not clear that the period typifies the industry.

The run up in exploration, extraction and supporting activities between 1973 and 1982, followed by the precipitous decline in the next five-year period dominates the analysis of time series detailing economic changes in this period. The effects on demographic changes are somewhat less striking, because they occur in the context of other structural changes that are equally dramatic in their impacts. It is especially unclear that the events of this 15 year period strongly characterize what happened in the industry either in the preceding 25 years, or the subsequent 13 years, or that they provide much clue to what will happen in the future, given the dramatic restructuring in the industry.

SHIFT FROM AGRICULTURAL TO INDUSTRIAL/MINING BASE

In the southern Louisiana portion of the Benefits and Burden study area, economic restructuring throughout the mid-twentieth century is dominated by the decline of agriculture as much as it is by the rise of oil and gas and manufacturing activities. Between 1940 and 1990, census employment in agriculture declines in study area parishes by 69,000 workers. These losses to the region's economic base are offset by the addition of 34,000 jobs in the oil and gas mining sector, and 72,000 jobs in manufacturing. Net changes in economic base in Louisiana are on the whole not sufficient to retain the natural increase in the state's population through this period. Louisiana as a whole is a net out-migration state for each decade between 1950 to 1999, with the exception of the 1970s. This is also true of specific subareas in southwest Louisiana where offshore extraction and service activities were concentrated.

Economic restructuring redistributes economic and population growth within the study area. Among parishes in the study area, 11 experience losses in agricultural employment that are greater than offsetting increases in mining and manufacturing combined, and 16 see mining and industrial job growth that exceed absolute losses of agricultural employment. The Lafayette labor market area in particular is an area where relatively rapid growth in the oil and gas extraction and supporting activities did not offset declines in agriculture. Within this labor market, only Lafayette and Iberia parish see employment growth in mining and manufacturing that exceeds declines in agriculture. Thus, in spite of the relatively rapid growth in the oil and gas activities in Lafayette Parish in the 1950s and 1960s, the labor market as a whole is a net out-migration area in these decades. Net-migration to the LMA is positive in the 1970s, but virtually all of the growth in concentrated in Lafayette LMA itself, with balancing declines in the remainder of the LMA.

HISTORICAL ABSENCE OF REALIZED DEVELOPMENT ALTERNATIVES IN SOUTHERN LOUISIANA

One important perspective on the role of the emergence of offshore oil activities in Southwestern Louisiana is that some parishes may have had few alternatives for the development of a base industry. Apparel manufacture was one industry that emerged alongside oil and gas activities, but on a much smaller scale and with instabilities of its own. St. Landry Parish is a partial example of a parish in which declines in agriculture were not fully offset by the emergence of a manufacturing base, though even St. Landry benefited to some extent from employment opportunities in oil and gas extraction activities in neighboring parishes within the Lafayette labor market. In general, however, the parish continued to experience relative economic decline and high out-migration characteristic of rural parishes whose location was not conducive to full participation in oil and gas activities.

LMA AND METROPOLITAN SPATIAL PATTERNS

]The spatial re-organization of metropolitan and labor market areas is another factor that helps to drive patterns of county/parish change in the study area. These are most dramatic in the case of the New Orleans metropolitan area, where patterns of population redistribution led to rapid growth of Orleans Parish, followed by growth in Jefferson Parish, and then followed by growth in St. Tammany Parish and other outlying parishes. Because of these changes, the picture of change at the labor market level can be quite different from the changes at the county/parish level.

Patterns are more subtle in other LMAs and metropolitan areas in the Benefits and Burdern study area, because spatial reorganization of settlement and commuting occurs in less densely settled space and is not so neatly captured by parish boundaries. One implication of the importance of spatial reorganization is that patterns of economic and demographic change may appear quite different if viewed at the county/parish or labor market level.

MIGRATION TURN-AROUNDS

In Louisiana in particular, the industry boom and bust cycle of the 1970s/1980s was associated with a pattern of migration turn around. Oil and gas involved labor markets that had been net out-migration areas in the decades before 1970 became in-migration areas in the 1970s, and then out-migration areas in the 1980s. However, to put the 1980s experience in perspective, the net out-flows in this decade were generally at the same or a lower order of magnitude of out-flows in all previous decades. Preliminary evidence from the 1990s based on Census Bureau estimates shows the end of these patterns in the 1990s, with many southwest Louisiana labor markets and parishes experiencing net migration near zero, or, for the first time in the 20th century, small positive migration balances.

Texas, by contrast to Louisiana, is a substantial net in-migration state in every decade since 1950. Agricultural declines are proportionately less important than they are in Louisiana, and increases in manufacturing employment far outstrip increases in mining employment as a source of growth.

Interpretation of net-migration pattern must be situated within the broader context of demographic and economic change. The 1970s net in-migration to oil and gas involved parishes occurs in part in the context of reduced out-migration pressure in a formerly agriculture-dependent area, because employment declines in agriculture had slowed and now ceased to have much quantitative importance. Similarly, migration patterns become increasingly “footloose” because of the aging of the population. This implies an increasing component of migration is driven not by the need to equilibrate labor markets, but rather to take advantage of amenities such as warm weather or proximity to family. Such shifts become possible because of compositional shifts in the population from large cohorts of new labor market entrants to a more mature population with resources that are not tied to participation in spatially anchored labor markets. These shifts are one reason why the out-migration that had occurred in the 1980s does not appear particularly dramatic compared to prior decades.

A second corollary of changing population and economic structure is that to some extent the provision of attractive amenities and quality services becomes a part of a region’s base industry. In the 1990s, the service industry frequently becomes a leader in employment growth. Within the service sector, health services is a leading growth industry.

SPATIAL DISTRIBUTION OF 1980S BOOM/BUST EFFECTS ON EARNINGS

Both Texas and Louisiana experienced sharp increases in per capita earnings relative to national norms in the 1970s, followed by sharp declines in the 1980s. Within these states, per capita earnings changes were differentially distributed by sub-region, with abrupt and offsetting changes against state medians in counties and parishes that had a large percentage of employment in oil and gas mining and supporting activities. Oil-dependent counties and parishes have tended by and large to fare relatively well in the 1990s, and on the whole were relatively advantaged in 1998 compared to 1970.

SHARP DIFFERENCES IN DECLINE AND RECOVERY

Different Gulf Coast areas have fared differently in the post-1987 “recovery” of the industry. Employment in the mining sector continued to decline in both Texas and Louisiana, with a net loss of 2,700 jobs in Louisiana in mining over this period, to 66,000, and a loss of 62,000 jobs in Texas, to about 250,000. In Louisiana, the Lafayette labor market area posted relatively substantial increases in oil and gas mining employment (5,100 jobs) . The Houston-Galveston labor market area fared relatively well, with a net increase in 2,800 jobs in Harris County. The Shreveport and New Orleans areas experienced relatively large declines in Louisiana, as did Dallas and Corpus Christi in Texas.

DEEPWATER PROGRAM: OCS-RELATED INFRASTRUCTURE INTHE GULF OF MEXICO

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ABSTRACT

We are approximately 14 months into a two-year study designed to collect pertinent data on existing OCS infrastructure in the Gulf coastal states. The data will be compliant with the MMS Technical Information System (TIMS) and integrated into MMS's CORIS database. In addition, we are preparing a Fact Book that describes the typical facility for each infrastructure type and provides analysis of past and possible future trends in the construction, use, and retirement of OCS-related infrastructure. This information will support MMS NEPA responsibilities and long-range planning and development of OCS activities.

INTRODUCTION

Oil and gas exploration and production has occurred in portions of the Gulf rim states for over 100 years. Activity in coastal waters and on the Outer Continental Shelf (OCS) has occurred for the last 50 years. During this period, numerous OCS-related facilities have been built, such as refineries, gas processing plants, port facilities, pipe-coating facilities, pipelines, waste management facilities, and platform fabrication yards. Because of its statutory responsibilities, MMS must

1. produce lease sale EISs that depict existing, OCS-related infrastructure and its future growth and trends;

2. make a large number of permitting decisions that consider existing, future, and past infrastructure;

3. annually update Visual 1, a map of the Gulf Region depicting existing OCS-related infrastructure; and,

4. guide and monitor long-range planning and development of OCS activities.

Coordinated information and improved trend analyses would help in more reliably projecting OCS development needs, impacts, and opportunities.

Our two-year study began approximately 14 months ago. The objectives of the project are

- To collect pertinent data on existing OCS-related infrastructure in the coastal states of Texas, Louisiana, Mississippi, Alabama, and Florida;

- To develop a database of historical information since 1950 on the infrastructure in the study area and to identify any potential National Register-eligible properties;

- To make the collected data compliant with the MMS Technical Information Management System (TIMS) and to assist in integrating the data into MMS's Geographic Information System (GIS);

- To describe the existing infrastructure;

- To analyze historical data to identify past trends and to identify possible future trends in the construction, use and retirement of OCS-related infrastructure; and

- To provide MMS staff with an analysis of current Texas, Louisiana, Mississippi, Alabama, and Florida infrastructure to be used for Lease Sale 181.

DATA COLLECTION

We are collecting data for the following infrastructure types:

- Refineries

- Natural gas processing plants

- Petrochemical plants

- Pipelines

- Pipe coating yards

- Platform fabrication yards
- Crew supply bases
- Ports
- Ship building yards
- Waste management facilities
- Repair and maintenance yards

Examples of data being collected for each facility:

- Name, location (lat/long), street address, contact information
- Date constructed/operation date
- Size/land area occupied
- Production/capacity/throughput data
- Transportation linkages

Our data collection sources are primarily federal and state agency reports and databases (e.g., USEPA, USACE, DOE, FERC), trade journals, industry directories, as well as information from industry contacts. In addition, we received input from other MMS-funded studies such as the "Benefits and Burdens of OCS Development" project.

Some of the datafields we initially developed for some of the facilities have been difficult to collect. These include, for example, the percentage of petroleum-industry waste that comes from the OCS and for petrochemical plants how much of their material originates from the OCS. We are in the process of re-evaluating the use of these data fields.

We are in varying stages of data collection for each of the facility types. We have collected a significant amount of information for waste management facilities, refineries, natural gas processing facilities, platform fabrication yards, and are at intermediate stages of data collection for the remaining facility types.

GIS OVERVIEW

As noted previously, the databases that are being developed will be compliant with the MMS Technical Information Management System (TIMS) and will be integrated into the MMS's CORIS database. Below, we describe various components of the project's GIS development.

Project Website

A website was created to support the project and provide a means for database development. The three major existing components for the website are general information, database development, and internet mapping. The website address is *http://gis.louisberger.com/mms_ocs*

Database Development

Because the project team was composed of multiple subcontractors, we developed a web-based approach to the initial database development. Together with MMS, we selected data fields for each facility type. A handful of data fields are consistent throughout all facility types. Two such fields, latitude and longitude, describe the spatial location of the facilities and permit database conversion to Geographic Information Systems (GIS) layers.

Access database tables and internet forms were created to reflect the defined data fields. We used Microsoft's Internet Database Connector (IDC) technology to connect the internet forms to the database using Microsoft's Internet Information Server. Internet-based viewing and editing pages have also been created and are in various forms of completion. These pages were created using Cold Fusion Server technology.

Once the Access database has been satisfactorily completed, the tables will first be converted to ArcView shapefiles. The shapefiles will then be converted to Oracle tables using ArcInfo's Spatial Database Engine (ArcSDE). The Oracle tables will be delivered to MMS with appropriate metadata (data about data).

Internet Mapping Site

The project includes the development of an internet mapping site. Internet mapping gives real-time GIS capabilities to anyone with internet access. The current site uses Map Objects Internet Map Server (MOIMS) to serve maps the internet. The OCS facilities on the site are based on the old infrastructure database. Because of time-consuming programming required to access the new database (which has different data fields), we are currently looking at developing a new IMS site switching from MOIMS to ArcIMS, a new internet mapping server. ArcIMS provides much more functionality than MOIMS and requires minimal programming.

FACT BOOK

In addition, to database development, we are preparing a Fact Book which describes OCS-related infrastructure within the project area. It is organized into chapters by facility type and provides a general description of the infrastructure, description of a typical facility, range of attributes, and analysis of past trends. It will discuss future short- and long-term trends in construction, use and retirement. In addition, it will include a discussion of the types and characteristics of infrastructure that would likely develop in "frontier" areas such as western Florida or an Atlantic coast state should exploration occur and should exploration lead to development and production.

PRELIMINARY FINDINGS

Waste Management Facilities

We have identified 42 waste management facilities within the study area: 26 in Louisiana, 11 in Texas, 3 in Mississippi, and 2 in Alabama. The facility types include; subsurface injection, salt cavern disposal, land application, landfilling, separation and reclamation of drilling and completion fluids, and separation and recycling of industrial wastes.

We have collected information on the capacity of waste management facilities including throughput capacity and life-of-site capacity. In addition, there are a number of categories of infrastructure network for wastes returned to land—(1) transfer facilities at ports, (2) special-purpose oilfield waste management facilities, (3) generic waste management facilities.

Differences in laws among states lead to differences in waste management methods as well as industry preferences in siting waste facilities in certain states. For example,

- Texas allows and regulates salt dome disposal of waste, while no other state does.
- Louisiana, Alabama, and Mississippi allow the landfilling of used oil filters and oil-based drilling muds, while Texas does not.
- Texas has regulations allowing oil-based drilling mud to be recycled, through bioremediation, into road-building material.

Summary of findings to date:

- Capacity to manage waste generated by OCS drilling and production activities is adequate for present and for hypothetical future that includes a doubling of current waste volumes.
- OCS activity does not generate a large part of the waste stream into generic waste management facilities and is not expected to be a significant to the overall capacity of the industry.

Platform Fabrication Yards

Production operations at fabrication yards include cutting and welding of steel components, construction of living quarters and other structures, as well as assembling platform components. Fixed platform fabrication can be subdivided into two major tasks: jacket fabrication and deck fabrication.

Location of platform fabrication yards is tied to the availability of a navigable channel sufficiently large to allow towing of bulky and long structures such as offshore drilling and production platforms. Thus, platform fabrication yards are located either directly on the coast of the GOM or inland, along large navigable channels, such as the Intracoastal Waterway. Average bulkhead depth for water access for fabrication yards in the Gulf is 15-20 feet.

Due to both the size of the fabricated product and the need to store a large quantity of materials such as metal pipes and beams, fabrication yards typically occupy large areas, ranging from a just few to several hundred acres. Typical fabrication yard equipment includes lifts and cranes, various types of welding equipment, rolling mills, and sandblasting machinery. Besides large open spaces required for jacket assembly, fabrication yards also have covered warehouses and shops.

Platform fabrication yards vary in the size of the employed workforce, which ranges between less than a hundred to several thousands. Due to the project-oriented type of work, temporary workers account for a significant portion of the workforce.

Platform fabrication is not a mass production industry; every platform is custom built to meet the requirements of a specific project. This feature has given rise to the great degree of specialization in the platform fabrication. There are no two identical fabrication yards; most yards specialize in the fabrication of particular type of platform or platform component. Examples of specialization include construction of living quarters, provision of hook-up services, and fabrication of jackets and decks. According to the published survey of fabrication yards in the Gulf, out of 50 yards 23 fabricated jackets, 15 fabricated decks, 29 fabricated modules, 22 fabricated living quarters, and 20 fabricated control buildings (Gary & Nutter 2000).

Despite a large number of platform fabrication facilities in the Gulf, only a few facilities can handle large-scale fabrication. According to the survey of fabrication yards, nine yards have single piece fabrication capacity over 100,000 tons and twelve have capacity to fabricate structures for water depth over 1,000 feet. Only a few yards fabricate structures other that fixed platforms: only one yard (J. Ray McDermott, Inc. in Amelia, Louisiana) fabricates compliant towers, and only two yards (Gulf Island Fabrication Inc., in Houma, Louisiana and Friede Goldman Offshore in Pascagoula, Mississippi) fabricate tension leg platforms.

Another important characteristic of the industry is a high degree of interdependency and cooperation among the fabrication yards. Because offshore platforms, particularly the ones destined for the deep water, are such complex engineering projects, most facilities do not have technical capabilities to complete the entire projects “in-house,” without the subcontractors and the specialized yards.

Over the whole history of its existence, the ups and downs of the platform fabrication industry have been closely tied to the fortunes of the oil and gas industry. Drilling and production activities are sensitive to the changing prices for oil and gas. This sensitivity, in turn, is translated into “boom and bust” cycles for the fabrication industry, when a period of no work follows a period of more fabrication orders than a yard can complete. To shield themselves from the volatility inherent in the oil and gas industry, platform fabrication yards in the U.S. GOM have started to implement various diversification strategies. These diversification strategies, coupled with the new challenges brought about by the deepwater oil and gas exploration and development, are significantly changing the industry.

To utilize the existing equipment and to keep the highly-skilled workforce in the periods with no fabrication orders, many fabrication yards are expanding their operations into such areas as, for example, maintenance and renovations of drilling rigs, fabrication of barges and other marine vessels, dry-docking, and survey of equipment. These projects, although much smaller in scale and scope than platform fabrication, nevertheless allow the yards to survive the recessions.

Another interesting avenue of diversification is pursuit of international work in platform fabrication. The U.S. GOM fabrication yards have a double advantage of great experience in fabrication work and good climatic conditions, allowing for the year-round operations.

With respect to deepwater development, the challenges for the fabrication industry stem from the greater technical sophistication and the increased project complexity of the deepwater structures, such as compliant towers and floating structures. These needs of the deepwater projects will likely result in two important trends for the fabrication industry. First is the increasing concentration in the industry, at least with respect to the deepwater projects: as technical and organizational challenges continue to mount up, it is expected that not every fabrication yard will find adequate resources to keep pace with the demands of the oil and gas industry. The second trend is the closer integration, through alliances, amalgamations, or mergers, among the fabrication yards and engineering firms.

The platform fabrication industry is undergoing a period of restructuring, which is characterized by transformation from privately to publicly held companies on the one hand, and by the consolidation of the industry through mergers and acquisitions. While implications of these changes are yet to be understood, it is clear that their impact will be significant.

Given the platform fabrication industry characteristics and trends therein, it is not likely that this type of infrastructure would emerge in the frontier areas. There are two main arguments to support that thesis. Firstly, the costs associated with towing a platform to its offshore location are insignificant relative to the overall costs of fabrication. Therefore, physical proximity of an onshore fabrication yard to an offshore location where a platform is to be installed cannot be considered a determining factor in the development of new fabrication yards.

Secondly, the existing fabrication yards do not operate as “stand-alone” businesses; rather, they rely heavily on a dense network of suppliers of products and services. Therefore, a successful operation of a new platform fabrication yard in a geographic area where such a network is not developed seems unrealistic. Further, since such a network has been historically evolving in Louisiana and Texas for over fifty years, the existing fabrication yards possess a compelling force of economic concentration to prevent the emergence of new fabrication yards in the frontier areas.

Ports

A U.S. Army Corps of Engineers database that identifies facilities in the GOM region used as service base ports for the offshore industry shows an astounding number of private port facilities. This database lists 210 in Louisiana alone. Although none are identified in the Port Fourchon area, a survey of that area revealed another 27 facilities. Texas shows 84 landside support operations, and there are others identified in Florida, Alabama, and Mississippi. Even though these are private facilities, they operate within the jurisdiction of a public port authority. And, to attract these operations, the public port must offer certain infrastructural improvements to adequately accommodate these operations.

All supplies must be transported from land-based facilities to marine vessels or helicopters to reach offshore destinations. Thus, both water and air transportation are utilized. The intermodal nature of the entire operation gives ports (which traditionally have water, rail and highway access) a natural advantage as an ideal location for onshore activities and intermodal transfer points. Therefore, ports will continue to be a vital factor in the total process and must incorporate the needs of the offshore oil and gas industry into their planning and development efforts, particularly with regard to determining their future investment needs. In this manner, both technical and economic determinants must influence the dynamics of port development.

This extensive network of supply ports includes a wide variety of shore-side operations from intermodal transfer to manufacturing. Their distinguishing features show great variation in size, ownership, and functional characteristics. Basically, two types of ports provide this supply base. Private ports operate as dedicated terminals to support the operation of an individual company. They often integrate both fabrication and offshore transport into their activities. Public ports lease space to individual business ventures and derive benefit through leases, fees charged, and jobs created. These benefits spread throughout the entire area and are viewed as economic development impacts. Thus, the public ports play a dual role by functioning as offshore supply points and as industrial or economic development districts. An efficient network of ports will both lower costs associated with oil and gas production and significantly boost the well-being of citizens of the adjacent communities.

We have collected data on the physical/operational features of several of the ports within the project area including:

- Port Fourchon (see example below)
- Port of Morgan City
- Port of West St. Mary
- Port of Iberia
- Port of New Orleans
- Port of Panama City
- Port of Mobile
- Port of Houston

An example of the data we have collected for Port Fourchon is shown in Table 1F.5.

Table 1F.5. Sample of data collected for Port Fourchon.

Facility Type	Physical/Operational Parameters
Location	On the Gulf of Mexico, at the mouth of Bayou Lafourche-about 60 miles south of New Orleans
Channel Access	Channel entrance: 300' wide by 24' deep; Interior Channel 300' wide by 23' deep; E-slip 400' wide by 23' deep; Turning Basin 800' wide by 20' deep
Land Access	Highway: LA 3090 2 miles to LA 1, 40 miles to U.S. 90
Docking	No public dock suitable for handling general cargo, numerous privately leased facilities
Intermodal transfer (on dock)	A large number of privately leased docks with crane service and loading/unloading equipment
Warehouse Storage	A large number of privately leased warehouses. One 8,000 sq. ft. refrigerated warehouse
Yard Storage	Numerous storage yards on individual leases. Improved and unimproved property available
Inland Transport	Connection to the Intracoastal Waterway via Bayou Lafourche, Houma Navigation Canal, and Barataria Waterway
Cargo Throughput (per hour)	Cargo throughput varies among docks. Compatibility of heavy lifts up to 200 tons. Numerous 150-ton options
	Planned Expansions/Dates
	The Northern Expansion Project is a 700-acre development consisting of 600' wide slips and over one mile of waterfront. Phase I of the expansion is to be complete in 2001.
	Constraints/Impediments
	Two-lane highway access and lack of rail access are major impediments. Location on the Gulf of Mexico is an advantage but has limited water access to major metropolitan centers.
	Potential Vessel Service
	Ocean/River vessel service, Shortsea Coastal service, Container Port services.

ONSHORE EFFECTS OF OFFSHORE EMPLOYMENT

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INTRODUCTION

Most offshore oil workers spend extended periods, one or more weeks, at their workplace— usually a production platform or a mobile drilling rig. They then leave the workplace and live at home with their families, if any, for a non-work period that is also commonly one or more weeks. The offshore accommodations, recreational facilities and food are provided by their employer, who also provides transportation between the workplace and some onshore "pick-up point," commonly a heliport.

This work system is variously called "commute," "fly-in," "fly-in/fly-out" or "long-distance commute" employment; the first of these terms is used in the rest of this presentation. It was originally developed to meet the needs of the offshore oil industry because daily commuting was not feasible and no "local" workforce or permanent, full-time accommodations were available. It is now also used by the mining industry and by other land-based and marine activities in remote and/or hazardous environments, in situations where the local labor force cannot meet industry needs and where the work schedule makes a daily commute impractical.

The oil industry also uses this system for some onshore operations. For example, about 1,000 production workers commute to gas fields in the Cooper Basin in Southeastern Australia. Commute systems have been used for major oil industry construction projects. In one example, most of the labor force building the Hibernia production platform at a green-field coastal site in Newfoundland, Canada, alternated between living in a well-equipped 3,500-person construction camp and in their home communities. Commute employment is also used to provide labor to remote mines, and in a small number of specialist settings.

This presentation provides a summary of some of the findings of a study of commute employment that is being undertaken under contract to the Minerals Management Service (MMS). This research was designed to complement other MMS studies by providing detailed information on the effects of offshore employment and the options for managing them. It saw the initial preparation of an annotated bibliography on commute employment, its effects and their management. This material was used in the developing a discussion paper, which draws on approximately 80 papers and reports about offshore oil employment in, primarily, the United States, Atlantic Canada, the United Kingdom and Norway. This study will be subject to rigorous peer review, including an international workshop, with the final report, "The Effects Of Offshore Employment In The Petroleum Industry: A Cross-National Perspective," being available in the second quarter of 2001.

OFFSHORE EMPLOYMENT ISSUES

The commute system used at most offshore operations differs from traditional work systems principally because of the distinctive pattern of presence in, and absences from, the place-of-work and place-of-residence. Other characteristics, such as the extended workday and shift arrangements, while important, are not unique to commute employment. Other work arrangements may have some, but not all, of these characteristics. As such, the commute system gives rise to some issues that are unique and others that are shared with other systems.

Offshore employment should not be seen as inherently problematic—like all other work systems, it offers both advantages and disadvantages for workers, as well as for others with responsibility for health and safety, training and other employment-related concerns. It also has implications, which can again be positive or negative, for employees' families and the communities and regions in which they live. Some of the more important of these issues are discussed in two interrelated categories: human resources and family issues and community and regional issues. The focus throughout is the social effects of commuting, with the economic effects (for instance, in terms of the purchasing patterns of commute operations) and management concerns (for example, productivity) only discussed in connection with the effects on workers, families, and the communities in which they live.

It is important to note that there are some important lacunae and biases in the literature on which the study is based. For example, past research has focused on large operations and companies, fixed work schedules and married male workers. The data used are often limited and commonly qualitative or anecdotal. Where quantitative research has been undertaken, different variables often confound each other and make it impossible to separate cause and effect. Furthermore, some important studies are old and particular to specific operations and temporal and geographic contexts. It is not clear to what degree their findings and conclusions are still relevant or can be generalized to other settings. This problem may be exacerbated by the rapid pace of change in both the oil industry and the attitudes and expectations of workers and their spouses.

Offshore work has implications for a wide variety of interrelated work and family life issues. These include the effects on health and safety; the employment of women, minorities, and older workers; family life; and retention and productivity. It also has a number of related effects on the communities and regions where the workers live and employers do business. These include the effects on: residential patterns, expenditures, non-commute employment, local investment, community life, and social and recreational services. These are all discussed in detail in the report.

RESPONSES

This, however, focuses on responses to these issues. It is clear that employer initiatives in such areas as work schedules, accommodations, transportation, communications, hiring, orientation, counseling, and family policies and services can optimize the effects of the offshore employment in respect to all of the above issues. Regulatory authorities, trade unions, local government agencies, community groups and others, including the workers and families themselves, may also have an important role to play. Such optimization can have benefits for employers, workers, their families, their communities and, more generally, local society. A short discussion of these responses is provided below, based on more detailed review that will be available in the research report.

Work Schedules

Offshore work schedules commonly bring together a roster arrangement, whereby employees work one or more weeks and then have a similar period at home, with shift work likely involving the use of extended work days. Where regular rosters are used, they vary for different types of workers, different employers, and in different parts of the world and change over time. The stay offshore is commonly a multiple of seven days, with 7, 14, and 21 being most common. However, increasing number services, contract, and other personnel have very irregular schedules, or are "on-call," depending on operational requirements.

Twelve-hour shifts are the norm, although some specialized employees may be on other schedules or on-call 24 hours a day. Some positions normally only require work during a day shift, but most involve day and night shifts; in the case of fourteen-day and longer work patterns, there is commonly a mid-rotation split shift when employees change from night to day shifts, or vice versa.

This discussion can only provide a short summary of the large literature on offshore work schedules and their effects. The report will include a much longer discussion of this topic, much of it drawing on Dr. Kathy Parkes' review of the literature on the effects on stress, health, and safety on North Sea offshore petroleum installations (Parkes 1998). This review includes an examination of the evidence of the effects of long work hours in conventional work settings. Parkes concludes that the long hours worked by most employees raise serious questions about cumulative fatigue, reduced performance, and impaired well-being among offshore management personnel.

Parkes also discusses the health effects of shift work and notes that onshore research indicates that prolonged shift work over a period of years appears to have cumulative adverse effects on sleep patterns and health, not accounted for solely by increasing age. However, the pattern at commute operations can be more complicated, with workers involved in round-the-clock activities (e.g production, maintenance, and drilling) being exposed not only to extended shifts and demanding work, but also to the need for adjustment to day/night shift changes. The scheduling of shifts poses particular difficulties offshore as rotation patterns are constrained by the helicopter schedules and limited availability of accommodations.

While the information on work schedules is often unclear or inconsistent, there is evidence that mid-rotation shift changes have a variety of negative effects. From a health and safety viewpoint, a strong argument can be made for implementing "fixed-shift" rotation patterns; however, offshore personnel strongly prefer the 7 nights/7 days pattern, which allows them to go on leave adjusted to a normal circadian cycle at the end of each tour.

Accommodations

Parkes also finds evidence that location, size, and type of rigs and platforms are associated with psychosocial outcomes among offshore personnel. However, she concludes that, while these findings can be attributed in part to the fact that newer platforms have improved design standards, recreational facilities, accommodations, emergency alarm systems, and escape equipment (the last two of which may reduce anxiety), they do not allow causal interpretation because new installations can attract highly motivated and adaptable personnel. This latter fact may contribute to the favorable responses by employees on these newer platforms.

Parkes also notes that offshore workers are exposed to physical stressors such as noise, vibration, poor lighting and/or ventilation, confined living accommodation and workspace, and adverse weather conditions. Ratings of noise and other environmental stressors correlate with measures of psychological well-being and that the perceived workload may mediate these relationships. However, the extent of exposure to adverse physical conditions offshore differs across occupational groups, with construction and drilling crew reporting the highest exposure levels.

The physical and social environment of the accommodations seems to make an important contribution to the quality of life and stress-levels of workers. Two factors appeared to be particularly important: privacy and recreational facilities. In the former case, privacy is seen as a key element in coping with the extended work schedule and isolated setting, with shared accommodation placing a strain on workers in this regard. Offshore cabins are normally small, and sharing is not uncommon; on older rigs and platforms, one may see four-berth cabins and, in times of peak labor requirements, “hot-bunking.”

The increased privacy provided by having one’s own room can, however, reduce off-duty social interaction between workers. This isolation can be exacerbated when employees are able to have televisions in their cabins. One Norwegian Offshore Installation Manager countered this, and improved the social atmosphere on the Statfjord A platform, by installing a bar which served only non-alcoholic drinks (Flin 1996). However, space constraints mean that the provision of active and passive facilities offshore is usually limited, especially on rigs and older platforms.

While the design of accommodations, together with policies respecting room allocations and the like are important, there is evidence that the overall social environment is of particular significance when it comes to worker stress. This encompasses aspects of all of the above but is also an independent reflection of the management approach to the accommodations and related arrangements. This includes the need, especially given longer rosters, for the workers to create a “home” offshore. Separating work and non-work life at the workplace, in so far as it is possible, is also important. A clear separation of work from accommodations areas, and interior decoration that differentiates the latter from the functionality of the former, encourages this separation. However, the social environment is also a function of the overall work culture and the full range of management approaches and personnel policies.

Transportation

Transportation arrangements have two major effects on employees and their families. First, safety concerns related to helicopter travel are a major cause of employee stress, with implications for both the worker and his or her family. Second, transportation schedules can be inconvenient from a family perspective, and disruptions can delay the worker’s arrival home and departure to the workplace, creating stress for all family members. In both cases, there is a range of measures that can help optimize the effects on workers and their families.

Communications

Difficulties communicating between the workplace and home can cause offshore workers and their families considerable stress. Policies with respect to vary by company, location, and type of activity. However, there have been major improvements in communications in the last few years. For example, North Sea production workers commonly have unlimited use of links with their homes, using e-mail or a telephone located in their cabin. The increased capabilities and reduced cost of mobile phones provide another option for some workers, although mobile phone use is limited in some settings by fire safety concerns related to battery-powered devices. Workers and families value such high-quality, low-cost, and confidential links whether or not they are used with any frequency; their availability reduces tensions because family members know the links can be used if circumstances warrant.

Hiring and Orientation

There is obvious merit in screening out job applicants who would find offshore work highly problematic and providing an effective orientation program to newly-hired employees. Some companies think these factors are important in selecting employees. For example, some prefer to hire people with previous experience of unconventional work schedules or young unmarried or recently married workers. However, overall, Slaven (1996) concludes that “it is difficult to screen personnel for the possession of qualities which would suggest a propensity for adaptability to (the offshore work pattern and environment).”

Researchers have noted the advantages of having women in the commute workforce. For Heen (1988): “the positive effect on the social environment of having women on platforms is considerable… (it) ‘normalizes’ the atmosphere and this also lessens the differences between onshore and offshore life, which in turn makes the transitions between these two periods easier, lessening the degree of psychological change and making commuting somewhat less of a burden… . Women have also (through their influence) had an impact on the material quality of the work environment.” Many oil companies now seek to facilitate the hiring and retention of women, both onshore and offshore.

Counseling

Offshore work challenges employees and their families in various ways and leads some to experience psychosocial problems. Most deal with these problems themselves or use informal coping strategies. However, North Sea research indicates that offshore workers derive only limited social support from other workers, and while their spouses and friends may also serve as onshore confidantes, the spatial dispersal of workers may limit this option.

Further assistance may be provided by offshore and industrial chaplains. However, a more comprehensive approach, used by increasing numbers of employers, is provided by employee assistance programs (EAPs). These were first developed in North America to provide employees and their families confidential access to a range of emotional, marital, financial and alcohol and drug related counseling services. Most UK sector operators now have such programs. Chevron and Coneco not only use their EAPs for routine counseling, but also for critical incident debriefing following an emergency. Such programs can also have the incidental merit of providing a measure of fluctuations in the psychological well-being of the labor force.

Family Policies and Services

There is clear evidence that home-life problems of many commute workers are in reality work problems and that domestic problems have reciprocal effects in the workplace. The worker brings home work-related concerns and stress, and the commute system generates its own tensions in domestic and personal life. These tensions are in turn brought back to the workplace, where they may affect productivity, safety, retention, and other management concerns. Furthermore, married commute workers see effects on the family life as the primary determinant of satisfaction with the system.

The research on commute employment indicates the types of responses and interventions that may be appropriate in addressing the challenges for family life. Drawing on many of the responses and interventions already described above, they may broadly be placed in four categories:

- Those that improve the compatibility of the work organization and family life. This category includes such things as improved telecommunication links and transportation arrangements between work and home, and optimized the rotation pattern from a family life perspective.

- Those that improve the compatibility of the work culture and home life. This category involves making the workplace and accommodations more familial and less alienating, thereby decreasing the contrast between the two, and includes changes to both the physical and social environment.

- Those that improve self-selection during hiring and help new hires and their families get used to a new work pattern.

- Those that provide assistance, perhaps through an EAP, other counseling program, or support group, to employees and family members requiring them. This category includes self-help groups, such as the UK Offshore Women’s Link Support.

McKee, Mauthner and McLean (2000) report a heightened industry awareness of family issues in the UK, reflected in initiatives in such areas as day care, workplace nurseries, enhanced maternity and parental leaves, and concentrated work weeks. Industry and corporate image concerns, new EU and UK legislation, increased numbers of female managers, and examples from international parent companies are seen as drivers of this interest.

CONCLUSION

As was noted above, offshore employment should not be seen as inherently problematic. It offers both advantages and disadvantages for workers, their families and their communities, as well as for others with responsibility for health, safety, training, and other employment-related concerns. The challenge is to recognize these effects and implement policies and practices that effect them. From an industry perspective, there is evidence that the benefits—in terms of such things as employee retention, accident rates and productivity—can be considerable and the costs modest.

The literature reviewed for this project contains little systematic information about response initiatives and their success. As a result, it was not possible to identify or allocate responsibilities about best practices. Instead, the research report will conclude with a preliminary assessment of research requirements needed to elucidate fully and identify related best practices.

REFERENCES

Flin, R. 1996. Occupational Stress: Identification and Maintenance. *In* Flin, R. and G. Slaven, eds. Managing the Offshore Installation Workforce. Tulsa, OK: PennWell Books.

Heen, H.1988. Making Out in a Man’s World: Norwegian Women Workers Offshore. *In* Lewis, J., M. Porter and M. Shrimpton, eds. Women, Work and Family in the British, Canadian and Norwegian Offshore Oilfields. London: Macmillan.

McKee, L., N. Mauthner and C. Maclean. 2000. “Family Friendly” Policies and Practices in the Oil and Gas Industry: Employers’ Perspectives. Work, Employment and Society, 14: 3.

Parkes, K.R. 1998. Psychosocial Aspects of Stress, Health and Safety on North Sea Installations. Scandinavian Journal of Work, Environment and Health, 24: 5, 321-333.

Slaven, G. 1996. Selection and Training of the Offshore Workforce. *In* Flin, R. and G. Slaven, eds. Managing the Offshore Installation Workforce. Tulsa, OK: PennWell Books.

PLACE-BASED COMMUNITY RESEARCH AND RESOURCE MANAGEMENT

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Sustainable integrated resource management implies a comparative place-based community approach. Unfortunately, at the present time, there is not a well-defined methodology to identify place-based communities and link data to them. To overcome this shortcoming, a GIS-based methodology has been developed to identify, measure, and compare place-based communities. Compared to traditional county-based research, this methodology provides the following advantages: (1) it captures the geographical area so that people can be placed in more clearly defined communities; (2) it allows for a better visualization of the distribution of resources within a community area; (3) it helps to identify processes of interaction and social infrastructures as they relate to place-based actions to address local issues; (4) it allows for an analysis of inter-jurisdictional relationships across administrative boundaries; (5) it captures the area where macro-social and political processes are more likely to impact peoples' lives; and, (6) it allows for the generation of place-based statistics so that community areas can be compared between and within the rural and urban landscapes. These contributions can open new avenues of research for community comparative studies in sustainable integrated resource management.

Empirically, the county is generally used to proxy the concept of community. Some, however, have indicated that the county is not usually coterminous with the geographic dimension of a community (Beckley 1998; Farmer *et al.* 1992; Kemmis 1990; Moon and Farmer 2000; Parisi *et al.* 2000a; Wilkinson 2000). Consequently, the county might be an inappropriate unit of analysis for addressing community-based issues. In addition, county-level data are not generally collected to produce information on community agency (Krannich and Humphrey 1986). Because of the conceptual and empirical limitations related to the use of counties as a unit of analysis, Parisi *et al.* (2000a; 2000b; 2000c) developed a methodology to define geographic units that reflect the concept of community with flexibility to address specific community issues (e.g., welfare reform, economic development, and natural resource management). To date, this methodology has been applied primarily to issues of welfare reform and environmental justice related to industrial hog farm location (Taquino *et al.* Forthcoming) although applications to other issues are readily apparent.

Conceptually, community boundaries should be established by virtue of social and economic relationships among people living in geographic proximity to one another, as well as by the relationships between people and the physical environment where their daily needs can be met (Parisi *et al.* 2000a; 2000b; 2000c). In the case of the welfare-reform act, the primary focus is to transfer responsibility to the clients and the community. Here, community boundaries should be delineated to identify economic and social resources relevant to move clients off public assistance and toward achieving economic independence.

In general, community sociologists have identified boundaries within which social and political action takes place by aggregating a five-to ten-mile radius of outlying areas of diffuse settlement around a compact place (Bohon and Humphrey 2000; Galpin 1915; Goode 1985; Hawley 1950; Kassab 1992; Krannich and Humphrey 1983; Lloyd and Wilkinson 1985; Parisi 1998; Wilkinson 1979; Wilkinson 2000). Areas delineated following this rationale are the locus of social and political action, depicting where people can meet most of their daily needs. However, these same areas may not provide employment opportunities, particularly in rural areas (Beaulieu *et al.* 2000; Wilkinson 2000). People in rural areas are often required to travel to larger places to find employment (Young 1999). This suggests that there are two distances with the same point of origin that people might cover on a daily basis. The first would be a short distance from A to B to meet daily needs, and the second a long distance from A to C to gain employment (see Figure 1F.1). As illustrated in Figure 1F.1, people can travel the short distance within 360 degrees because A-B may fall at any point within the small area, and the long distance (A-C) only in the direction of the larger place. It follows that for a community to be inclusive in terms of meeting the requirements of welfare reform, its area should be identified based on the A-C distance, as shown in the shadowed area of Figure 1F.1.

Distance per se has little socioeconomic value unless it is expressed in units of time spent to reach a final destination (Stephan 1979). It follows, then, that to identify a meaningful community, both short and long distances need to be transformed into an average daily travel time. Given that the estimated average velocity on an existing road system can be approximated to be 45 miles per hour, five and ten miles in distance translates into 6.7 and 13.3 minutes travel time, respectively. In

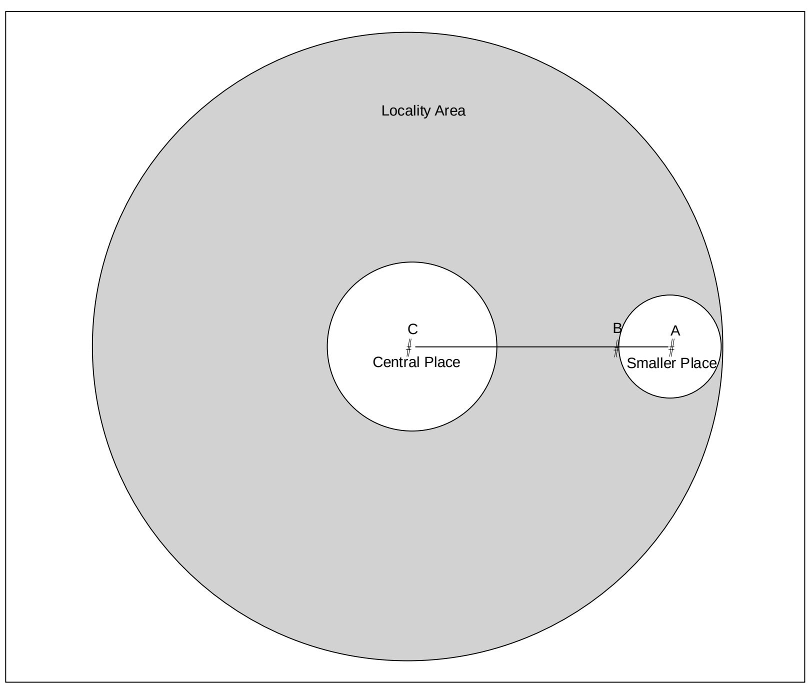

Figure 1F.1. Two distances with the same point of origin that people might cover on a daily basis. The first would be a short distance from A to B to meet daily needs, and the second a long distance from A to C to gain employment.

contrast, if the distance to seek employment outside the ten-minute travel area is considered, then one can use the average travel time to work as reported for each state by the U.S. Census Bureau. In Mississippi, the average travel time to work across rural and urban counties is approximately 20 minutes, with a standard deviation of approximately four minutes. Here, counties whose percentage of people classified as rural was above the overall average for the state were classified as rural. Within rural counties, the average travel time to work is approximately 22 minutes, while for counties classified as urban, it is 18 minutes. Consequently, 20 minutes of travel time to a work destination allows for an identification of a geographic area that is tailored to issues raised by present welfare policy requirements.

In seeking the delineation of geographic boundaries for communities based on ten- and 20- minute travel times, one should be aware of the issue of potential overlapping boundaries. One way to address this problem is to follow the logic of central place theory[1]. This logic maintains that larger places provide job opportunities that are not available in surrounding smaller places. Thus, the largest place within a state is assumed to attract residents from its surrounding places within a given travel distance, making up the first community. By keeping the travel distance to work constant, smaller places included in the first community are excluded when identifying other communities, which are based on the next largest central place not included in the previous community.

Translating the two distances into travel times and establishing an approach to avoid overlapping community boundaries provides a procedure to identify communities' boundaries using a Geographic Information System (GIS)-based methodology. The methodology to identify our communities used the GIS program ArcView. Using GIS technology, place-based communities were identified in a multistage process based on road travel time. Ten-minute travel time was used to identify areas where major social and political actions are more likely to take place. The road network was composed of roads, highways, and interstates with an average speed set at 30, 45, and 60 miles per hour, respectively using 1998 Mississippi street files.

Incorporated Census Defined Places (CDPs) were used as the starting points for the aggregation. These areas are recognized political units with both social and governmental infrastructures central to addressing any place-based policy. Incorporated CDPs have the means for developing interjurisdictional relationships among themselves and with the state. Mississippi has 324 CDPs. Following the logic of the central place theory, the CDPs were first ranked by population size. Aggregation started with the highest populated CDP (in this case, Jackson). Using the latitude and longitude coordinates of the geographic center of the CDP (provided by the U.S. Census Department) as the center of the road network, the aggregation included the census block groups whose centers fell within the ten-minute travel time network of the CDP center, creating the first ten-minute place (see Figure 1F.2). This process continued until no CDPs remained. Of the original 324 CDPs, 296 were identified as incorporated, ten-minute places (see Figure 1F.3). These compact areas can be viewed as geographic places that can make up the larger community based on a given travel distance (A-C).

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[1] In general, the Central Place Theory has been criticized for not being a valuable means of analysis for regional development in terms of consumption of services and goods. However, it is still valid when it is used in terms of job opportunities. According to Young (1983, 1999), and Young and Kmaid (1999), larger communities offer greater job opportunities than smaller communities by creating an hierarchical structural relationship across places.

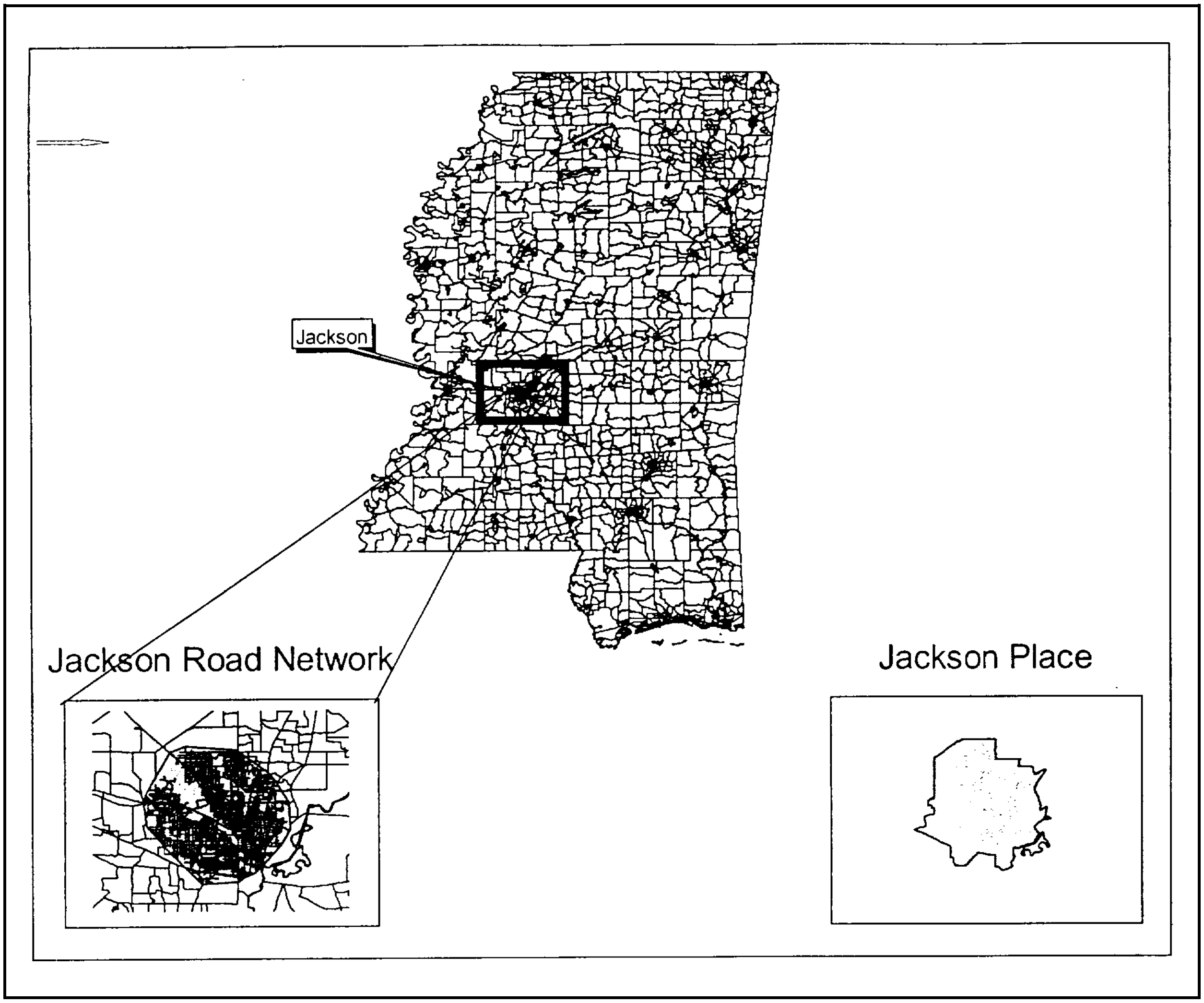

Figure 1F.2. Using the latitude and longitude coordinates of the geographic center of the CDP (provided by the U.S. Census Department) as the center of the road network, the aggregation included the census block groups whose centers fell within the ten-minute travel time network of the CDP center, creating the first ten-minute place.

After identifying place-based community boundaries, a method for extrapolating decennial census data was developed. Community-level census data were generated in three steps. First, a database of census data at the block group level was created using Pro/Filer for Windows, a program developed by Wessex that allows automated extraction of census data. The second step merged the census block group database created in step one to the block groups that make up locality areas. This was based on the block group identification code as a common field to link the data. Third, block groups were aggregated to the locality level by using a unique identifier developed for each locality. As a result, demographic and economic data can be measured and compared across places. Identification of place-based communities can provide a base from which to collect information on locally-oriented collective action (Parisi *et al.* 2000a). This is generally accomplished through the use of community key informants; individuals familiar with local activities through their experiences. Key informants provide information about the place in which they live, about others

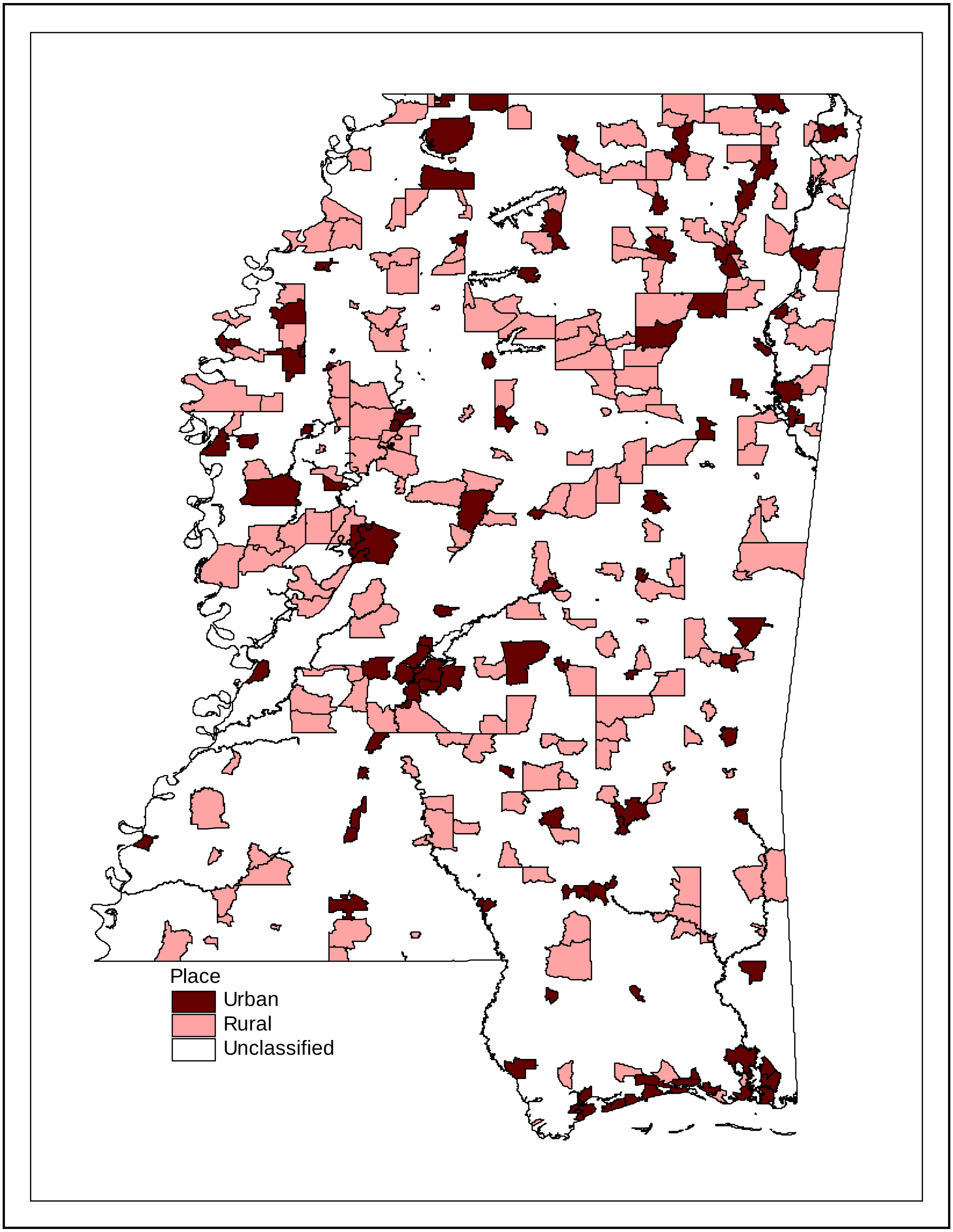

Figure 1F.3. Of the original 324 CDPs, 296 were identified as incorporated, ten-minute places.

in that place, and about themselves. Thus, they should be selected based on their knowledge with the issue at hand, be it welfare reform, economic development, or natural resource management. Key informants are generally privy to important events and are able to provide the researcher with information about them. By using several key informants from each community, the researcher can compare and pool this information and create indicators that proxy locally-oriented collective action. Further, by collecting key informant information from all communities in the study area, comparisons of locally-oriented collective actions can be made across communities.

Using GIS to identify localities has other advantages as well. Data with information, such as addresses or other indicators that identify specific geographic locations, can be mapped and associated with these localities. Community boundaries can also be overlapped with other geographical boundaries such as watersheds, soil conservation districts, and other land use patterns. A primary advantage, however, is that researchers no longer have to rely the county/parish as a proxy for community. The place-based approach to community provides an opportunity to develop data collection strategies that will give more precise information to decision makers.

REFERENCES

Beaulieu, Lionel J., Frank M. Howell, Domenico Parisi, and Lynn Reinschmeidt. 2000. Access to Opportunities: Welfare to Work Challenges in a Rural Mississippi County. Mississippi State University: Southern Rural Development Center.

Beckley, Thomas. 1998. The nestedness of forest dependence: a conceptual framework and empirical exploration. Society and Natural Resources 11:101-120.

Bohon, Stephanie A. and Craig R. Humphrey. 2000. Courting LULUs: Characteristics of Suitor and Objector Communities. Rural Sociology 65(3):376-395.

Farmer, Frank L., A.E. Luloff, T.W. Ilvento, and B.L. Dixon. 1992. Rural Community studies and secondary data: aggregation revisited. Journal of the Community Development Society 23:57-70.

Galpin, C.J. 1915. The social anatomy of an agricultural village. Agricultural experiment station of the University of Wisconsin. Madison, WI: Research Bulletin 34.

Goode, F.M. 1985. The use of microdata to measure employment in small communities. Journal of Economic and Social Measurement 13:187-89.

Hawley, Amos. 1950. Human Ecology: A Theory of Community Structure. New York, NY: The Ronald Press Company.

Kassab, C. 1992. Income and Inequality: The Role of the Service Sector in the Changing Distribution of Income. Westport, CT: Greenwood.

Kemmis, Daniel. 1990. Community and the Politics of Place. Normon, OK: University of Oklahoma Press.

Krannich, R.S. and C.R. Humphrey. 1983. Local Mobilization and community growth: toward an assessment of the “growth machine” hypothesis. Rural Sociology 48:60-81.

Krannich, R.S. and C.R. Humphrey. 1986. Using key informant data in comparative community research. Sociological Methods and Research 14:473-493.

Loyd, Robert C. and Kenneth P. Wilkinson. 1985. Community factors in rural manufacturing development. Rural Sociology 50:27-37.

Moon, Zula and Frank L. Farmer. 2000. Population density surface: a new approach to an old problem. Society and Natural Resources.

Parisi, Domenico. 1998. Community Action and the Development of Community From a Time Perspective. Ph.D. Dissertation.

Parisi, Domenico, Duane A. Gill, and Michael Taquino. 2000a. Building community step by step to shoulder more responsibility: a procedure to identify and measure community. Social Science Research Center, Mississippi State University.

Parisi, Domenico, Duane A. Gill, and Michael Taquino. 2000b. Identifying and Measuring Rural Community: A Necessary Step in Promoting Rural Development in Mississippi and the Nation at Large. Social Science Research Center, Mississippi State University forthcoming.

Parisi, Domenico, Steven Michael Grice, Louis H. Bluhm, Michael Taquino, Duane A. Gill, Terri Canaday, and Jarryl B. Ritchie. Under review. The political paradigmatic shift toward local responsibility: the quest for identifying, measuring, and comparing communities. Rural Sociology.

Stephan, Edward G. 1979. Derivation of some social-demographic regularities from the theory of time-minimization. Social Forces 57:812-823.

Taquino, Michael, Domenico Parisi, and Duane A. Gill. *In press*. Units of analysis and the environmental justice hypothesis: the case of industrial hog farms. Social Science Quarterly.

Wilkinson, Kenneth P. 1979. Social well-being and community. Journal of the Community Development Society 10:5-16.

Wilkinson, Kenneth P. 2000. The Community in Rural America. Middleton, WI: Social Ecology Press.

Young, Frank. 1983. Interdisciplinary Theories of Rural Development. London: JAI Press.

Young, Frank. 1999. Small Towns in Multilevel Society. Lanham: University Press of America.

Young, Frank and Gonzalo Kmaid. 1999. The Communities of New York State. *In* New York State in the 21st Century. Thomas A. Hirschl and Tim B. Heaton, eds. Westport, CT: Praeger.

SESSION 2D

STABILITY AND CHANGE IN GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES: "CHEMO II"

Co-Chairs: Dr. Robert Avent, Minerals Management Service
Dr. Mary Boatman, Minerals Management Service

Date: December 6, 2000

Presentation	Author/Affiliation
Geological and Geophysical Characterization of Carbonate Mounds on the Mississippi-Alabama Outer Continental Shelf	Dr. William W. Sager Department of Oceanography Texas A&M University Dr. William W. Schroeder Marine Science Program University of Alabama
Long Lives and Deep Roots: Tubeworms in Gulf of Mexico Chemosynthetic Communities	Dr. C. R. Fisher Dr. D. C. Bergquist Dr. J. K. Freytag Dr. R. T. Ward Dr. J. P. Andras Dr. B. Begly Dr. S. Schaeffer Dr. K. Nelson Ms. E. McMullin Ms. S. Carney S. MacAvoy Dr. S. Macko Mr. R. Carey Dr. I. MacDonald Dr. M. Van Horn Department of Biology Pennsylvania State University

(continued on next page)

Presentation	Author/Affiliation
Inorganic Biogeochemistry of Cold Seep Sediments	Dr. John Morse Dr. Rolf Arvidson Dr. Samantha Joye Ms. Susie Escoricia Dr. Craig Cooper Mr. Jeffrey Morin Dr. Luis Cifuentes Dr. Ethan Grossman Dr. Steve Macko Texas A&M University
Program Synthesis and Recommendations for Future Work	Dr. Ian R. MacDonald Geochemical and Environmental Research Group Texas A&M University

GEOLOGICAL AND GEOPHYSICAL CHARACTERIZATION OF CARBONATE MOUNDS ON THE MISSISSIPPI-ALABAMA OUTER CONTINENTAL SHELF

Dr. William W. Sager
Department of Oceanography
Texas A&M University

Dr. William W. Schroeder
Marine Science Program
University of Alabama

OVERVIEW AND RATIONALE

This study was built on previous MMS-funded reconnaissance mapping of carbonate "pinnacle" mounds on the Mississippi-Alabama outer continental shelf. Prior studies showed that hundreds of carbonate mounds exist on the outer shelf in this region, with diameters ranging from a few meters to nearly a kilometer (Ludwick and Walton 1957; Schroeder *et al.* 1988; 1989; Brooks *et al.* 1991; Continental Shelf Associates 1992; Sager *et al.* 1992). Additionally, sediments in the region were deposited by late Pleistocene fluvial deltas (Sager *et al.* 1999) and consist mainly of reworked relic sands and biogenic debris. In this study we focused on five "megasites," several kilometers on a side, and mapped the carbonate mounds and upper sedimentary layers in detail using high-resolution acoustic mapping methods (side-scan sonar and chirp sonar). The objectives were to characterize the carbonate mound substrate and sediments in support of biologic studies focusing on the ecosystems developed on and around the mounds.

DATA AND METHODS

Approximately *145* km^2 of the outer shelf was surveyed using a digital, side-scan sonar with a frequency of 72 kHz. Data were collected on 180 track-lines spaced 175 m apart using a 200 m sonar swath width to achieve 228% coverage of the seafloor. The original sonar swaths have pixel resolutions of about 1 m. The survey ship was navigated with differential OPS satellite navigation and the sonar tow-fish was positioned using an ultrashort baseline (USBL) acoustic ranging system. Chirp sonar records (frequency 2-12 kflz) were collected simultaneously to image the upper sedimentary layers. The side-scan sonar data were processed to make mosaics of each megasite, which were in turn studied using GIS methods.

A total of 229 grab samples were collected at 94 stations evenly divided between megasites 1-3 and 5. Of these, 45 stations were repeated four times to examine small-scale variability. Sediments from the grabs were measured using standard grain size analysis techniques.

RESULTS & DISCUSSION

Mounds in the mosaics appear as irregular features with high acoustic returns ("backscatter") and high variability owing to geomorphologic and surface roughness. In contrast, the regional seafloor, characterized by sandy sediments, appears mainly as a low backscatter background. However, seafloor directly adjacent to the mounds, especially on the southwest sides of the mounds in megasites 1, 3, and 5, also display high backscatter resulting from coarsening of the sediments.

Megasite 1 contains two clusters of large mounds, several with flat tops, in addition to hundreds of small- and medium-size mounds. Most of the mounds are circular to subcircular in plan view. Notable features on the mosaics are areas of moderate to strong backscatter surrounding the mounds, with strongest backscatter directly adjacent to the southwest sides of the mounds. In addition, many small and medium mounds are seen to have high backscatter "tails," typically a few meters or tens of meters wide and tens to several hundred meters in length. Comparison with chirp sonar profiles shows that the high-backscatter areas on the southwest sides of the mounds are often erosional depressions where fine sediments have been removed. Furthermore, the high backscatter tails are seen to be erosional troughs, typically only a meter or two in depth.

Like Megasite 1, seafloor with high backscatter is also seen around the mounds in Megasite 2; however, the strong return areas tend to be more symmetrically disposed around the mounds. The sonar shows many mounds that appear to be low, generally flat carbonate hard-grounds, typically a few hundred meters in diameter but not more than a few meters in height. Also in this area, many steep, irregularly shaped mounds are imaged. This is the region of the original "pinnacle" mounds of Ludwick and Walton (1957). Subbottom profiles show that variability in the thickness of the upper sedimentary layer, a relict sand deposited during the transgression since the last ice age, is highest at this megasite near the shelf edge. In many instances, only the tops of the mounds are exposed because of the formation of extensive sediment aprons on their flanks.

Megasite 3 contains mounds like those in both Megasites 1 and 2. Two broad, low carbonate hard-grounds occur, forming platforms consisting of hundreds of small mounds, 10-20 m in diameter and less than a few meters in height. Like Megasite 1, several flat-topped mounds appear in the eastern part of the survey. In the west, linear, medium-sized mounds form a WNW-trending lineament. As in Megasite 1, the high-backscatter haloes around the mounds are asymmetric and show erosion on the southwest sides of the mounds. Many mounds also display the high-backscatter tails.

Megasite 4 also contains patches of high backscatter, but none are obviously mounds. Some, small subcircular features, less than 10-20 m across, may be low mounds, but this has not been confirmed. Because of the apparent absence of mounds like those in the other megasites, Megasite 4 was not studied further.

Megasite 5 contains large and small mounds, most of which are aligned in a curvilinear band that is nearly isobath-parallel. This band contains at least two flat-topped mounds near its center. In addition, a large, rough, linear mound, over a kilometer in length and over 12 m in height, forms the northwest end of the group. As in megasites 1 and 3, asymmetric high -backscatter haloes and tails are seen on the southwest sides of most mounds.

Although the carbonate mounds vary widely in size, we can divide the mounds into three types of morphology: (1) broad, low, mostly flat hard-grounds, (2) tall, steep-sided, irregular mounds, and (3) steep-sided, subcircular, mounds. The low hard-grounds are usually several meters in height and several hundred meters or more across. These hard-grounds are often the base for other mounds of types 2 and 3, some attaining large sizes. Often the hard-ground tops seem to be composed of hundreds of small, steep-sided, subcircular mounds. It is not clear whether these small mounds formed on top of the hard-ground or whether they coalesced to form the hard-ground. The tall, steep-sided, irregular mounds are the "pinnacles" and found only in Megasite 2. They are typically less than 100 m in diameter and with heights of 5-18 m. Frequently, these mounds form irregular chains and have a low hard-ground base. Subcircular mounds come in many sizes, from a few meters across to several hundred meters. Heights range from one to more than 15 m. Most of these mounds are small, with diameters of several to several tens of meters and heights of only a few meters. Some larger mounds appear to consist of amalgamations of tens of smaller, subcircular mounds, and we speculate that these mounds grow together to form the largest mounds, including the flat-topped mounds. These mounds are found in megasites 1-3 and 5.

Because it was not a direct goal of this project, we do not have the data to make firm conclusions about the origin and evolution of the carbonate mounds on this shelf. It appears that many of the large mounds formed atop an erosional conformity cut during the lowstand of the last ice age. This indicates that these mounds formed after the ice age, during the last 18 kyr (radiocarbon years). In addition, several radiocarbon dates from the mound tops are from 11 - 13 kyr, implying the mounds formed earlier, during the early part of the deglaciation. Additionally, since the mounds are concentrated in isobath-parallel groups, it appears they may have formed near sea-level during periods of slow sea-level rise or sea-level standstill.

Sediments from the study area show three main components: (1) sand, (2) clay, and (3) biogenic debris. Most samples contain mainly sand with variable amounts of clay. Plotted on a sand-silt-clay ternary diagram, all the samples give compositions that fall along a mixing line from sand to clay. Furthermore, box core samples show the clay and sand to be well-mixed (as opposed to forming layers). That sand and clay have very different sensitivities to currents suggests that the sediments were laid down in energetic redeposition events, perhaps associated with storms. The third component, biogenic debris, generally takes the form of carbonate fragments or shells. Although there is some indication that these were shed from the mounds, the relation is not simple since samples adjacent to mounds can contain highly variable amounts of biogenic debris. It appears that the coarse component of these sediments is a combination of shells, shell fragments, and carbonate crusts formed in place in addition to carbonate debris from adjacent mounds.

Comparison of grain-size data with side-scan sonar images indicates that the high-backscaner haloes and tails near many of the mounds are caused by a coarsening of the sediments. Although silt and clay fractions change little from low to high backscatter areas, sediments from high backscatter zones typically contain 40-60% sand and 15-30% gravel as compared with 60-80% sand and negligible gravel contents for samples from low backscatter areas. Thus it appears that the high backscatter occurs because of the concentration of gravel. These zones also usually show evidence of erosion, implying that the formation of a lag deposit caused by current scour. This hypothesis is strengthened by the observation that the high-backscatter tails (which are erosional troughs) have directions that correspond to rapid currents recorded during the passage of two hurricanes through the study area. Apparently, the tails were created during storms by erosion resulting from current eddies downstream from the mounds.

REFERENCES

Brooks, J.M., ed. 1991. Mississippi-Alabama Continental Shelf Ecosystem Study: Data Summary and Synthesis, Volume I: Executive Summary, Volume II: Technical Narrative, Volume III. U.S. Department of the Interior. Minerals Mgmt. Service, Gulf of Mexico OCS Regional Office, New Orleans, LA., 43 pp.(I), 862 pp.(II), 1001 pp. (Ill-i), and 1001 pp. (111-2).

Continental Shelf Associates. 1992. Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study. U.S. Dept. Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 75 pp.

Ludwick, J.C., and W.R. Walton. 1957. Shelf-edge, calcareous prominences in northeastern Gulf of Mexico. American Association of Petroleum Geologists Bulletin 41:2054-2101.

Sager, W.W., W.W. Schroeder, K.S. Davis, and R. Rezak. 1999. A Tale of Two Deltas: Seismic Mapping of Near Surface Sediments on the Mississippi-Alabama Outer Shelf and Implications for Recent Sea Level Fluctuations. Marine Geology 160:119-136.

Sager, W.W., W.W. Schroeder, J.S. Laswell, K.S. Davis, R. Rezak, and S.R. Gittings. 1992. Topographic features of the Mississippi-Alabama outer continental shelf and their implications for sea level fluctuations during the Late Pleistocene-Holocene transgression. Geo-Marine Letters 12:41-48.

Schroeder, W.W., M.R. Dardeau, J.J. Dindo, P. Fleischer, K.L. Reck, Jr., and A.W. Schulz. 1988. Geological and biological aspects of hardbottom environments on the L'MAFLA shelf, northern Gulf of Mexico. Marine Technological Society, Proceedings of Oceans '88 Conference, Baltimore, MD, 17-21.

Schroeder, W.W., S.R. Gittings, M.R. Dardeau, P. Fleisher, W.W. Sager, A.W. Schulz, and R. Rezak. 1989. Topographic features of the L'MAFLA continental shelf, northern Gulf of Mexico. Marine Technological Society, Proceedings of the Oceans '89 Conference, Seattle, WA, 54-58.

LONG LIVES AND DEEP ROOTS: TUBEWORMS IN GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES

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Vestimentiferan tubeworms were first discovered associated with hydrothermal vents, and the species found on most mid-ocean ridges are adapted to the energy-rich ephemeral vent environment. Species like *Riftia pachyptila* take up necessary dissolved gasses, including hydrogen sulfide (the energy source required by their symbionts), from the rich hydrothermal fluid bathing their plume. Individual sites may only last months to years, and *R. pachyptila* is one of the fastest growing invertebrates known. The tubeworms found around cold seeps in the Gulf of Mexico (GOM) are similar to their vent relatives in that they have not mouth, gut or anus and rely on their chemoautotrophic bacterial symbionts for nutrition. However, we have found that the most abundant cold seep vestimentiferan species, *Lamellibrachia* cf *luymesi*, has a very different physiological ecology and life history. Using a new tube staining technique to determine growth rates, we have found that *Lamellibrachia* cf *luymesi* grows very slowly. Using data on almost 600 individuals from over 20 distinct aggregations we have determined that individuals of *Lamellibrachia* cf *luymesi* live in excess of 170 – 250 years. Based on our studies of intact tubeworm aggregations (described in part below), the co-occurring Escarpid-like species lives at least as long.

As part of this project, numerous water samples were taken around vestimentiferans. Sulfide was undetectable (<0.1μm) in the gross majority of samples taken near the plumes (gill-like gas exchange organs) of the tubeworms and in most samples taken from points closer to the sediment. On the other hand, sulfide was consistently present in substantial quantities (up to millimolar) in the interstitial waters around the buried posterior ends of the tubeworms. Using new collection devices, we were able to collect intact communities of vestimentiferans and found that each tubeworm had grown a long tortuous posterior extension to its tube (a "root"), which is freely permeable to sulfide. We have demonstrated that at least one species, *Lamellibrachia* cf *luymesi* can take up sulfide across the roots at rates sufficient to fuel net inorganic carbon uptake by the worm. This adaptation provides the tubeworms access to a much more stable and longer lasting source of sulfide and provides the explanation for the growth and abundance of tubeworms in areas where sulfide is not detectable in the water above the sediments. It also has significant implications for the structure of the associated faunal communities.

Using growth data and analyses of aggregation size and age structure, we have been able to study the life history of the second species of vestimentiferan, "the Escarpid-like species," which co-occurs with *L.* cf *luymesi*. The two species settle together over a period of about 10 – 20 years when the settlement substrate is exposed and the seepage can support new recruits. The Escarpid-like species grows more slowly than *L.* cf *luymesi* as a juvenile and then growth slows even more when it reaches an anterior tube length of about 50 cm. It persists at least as long as *L.* cf *luymesi*; in fact aggregations consisting of only very large individuals of the Escarpid-like species indicate it may live even longer than *L.* cf *luymesi*.

To obtain collections that allowed a quantitative analysis of vestimentiferan communities, we had new collection equipment designed and built. The collectors, Bushmaster Sr. and Bushmaster Jr., are hydraulically actuated nets that can be placed over vestimentiferan aggregations and allow collection of the entire aggregation and all fauna associated with the aggregation. Three collections were made with a prototype device in 1997. The devices were modified by adding a 64µm mesh liner and four collections were made in 1998. A total of 55 species of animals from 11 phyla (4,624 individuals) were collected with the four aggregations. Thirty-five species had not been documented from previous collections of seep fauna, and many of those may turn out to be new species. Although the total number of collections is too small to test hypotheses concerning community succession in the long-lived vestimentiferan habitat, several patterns emerge from analysis of the collections of different aged vestimentiferan aggregations which are consistent with our working model of cold seep tubeworm life history.

The community associated with the juvenile aggregation was similar to the communities associated with mussel beds (which were also characterized as part of this project). Mussel bed communities were not very diverse, but had a substantial biomass of a few species of endemic animals. A total of 12 species of animals were found in ten collections from eight different mussel beds (a maximum of seven species was found in any single collection). A collection of juvenile tubeworms yielded 19 species of associated fauna, and the highest biomass of associated fauna of any collection. Most of this biomass was a result of the very high numbers of a few species of endemic animals. Communities associated with adult aggregations are much more diverse, with about twice the species richness of the juvenile community. The communities are still dominated by endemic species, but numerous species of non-endemic animals are present in small to moderate numbers. The biomass of associated fauna is almost one order of magnitude less (per unit area) than in the juvenile aggregation. A single collection of a senescent aggregation contained 20 species, half of which were represented by a single individual. This aggregation was supporting about 20% the biomass of the adult aggregations, and 69% of that biomass was found in two fish and one crab. Even endemic fauna were only present in small numbers if present at all.

Our current working model for seep tubeworm life history and community succession begins with larval tubeworms settling in areas of active seepage, where precipitation of carbonate forms the hard substrate they need for recruitment. For 10 to 20 years, the high level of seepage is maintained at this point, the carbonate the first recruits have settled on may continue to grow, and recruitment to this aggregation continues as long as sulfide is released from the seafloor and the carbonate remains exposed. Because the young aggregation is in a microhabitat of active seepage, only fauna that can tolerate these conditions are associated with the young aggregations. These fauna include the animals found in mussel beds and are dominated by endemic seep animals. During this period, the very young tubeworms are obtaining sulfide across their plume, but also growing a posterior extension of their tube (a "root") and begin supplementing their sulfide uptake from interstitial pools. Over the next century or two, the tubeworms continue to grow while seepage of sulfide from the sediment into the water column progressively decreases. During this period there is sufficient primary production associated with the aggregation to maintain a moderately high biomass community, and yet the toxicity of the habitat has decreased to the point that a wide variety of non-endemic fauna can colonize or visit the aggregations. At this point the analogy between the tubeworms and long-lived ecosystem-structuring plants is quite strong. Although they may not be the prime food source for most of the associated fauna, they are providing a habitat for numerous species. As the aggregation continues to age, flow of sulfide into the water column continues to decrease and some thinning of the aggregation occurs. The tubes are often colonized heavily by non-endemic non-mobile fauna, primary production by free-living bacteria associated with the aggregation decreases significantly, and the biomass of the associated community drops significantly. This stage in their life history may also last a very long time because the tubeworms in these less dense, old aggregations, continue to grow and are in very good condition, presumably in part because of reduced competition from the remaining vestimentiferans.

It should be noted that the age estimates given above are for two-meter long tubeworms. Our data are limited to animals below this size because of difficulties inherent in collecting larger animals. However, we have occasionally collected animals over three meters in length, and the data on the senescent bushes collected to date does not suggest that these animals are dying. This all implies that seep tubeworms may in fact live considerably longer than 170 – 250 years, and that the ecosystems they create are equally long lived.

Three areas of future research important to MMS management concerns were identified over the course of the work by the Ecology component of this project:

- The first is to determine the biogeographic and phylogeographic distribution of the seep fauna (exactly who is out there and where are they?). Although not discussed above, molecular tools were developed over the course of this study that allow determination of gene flow between populations of tubeworms and mussels. The relatively small geographical area covered by this project found relatively high levels of gene flow among populations, but the few samples we have obtained from outside of our primary study sites suggest that there are significant differences in the communities found in different areas of the GOM. For example, we know that there are at least five species of tubeworms found in different seep areas of the GOM, and that very different communities of associated fauna occur at different depths. It is very possible that tubeworms may be absent from seeps in large areas of the

GOM, based on the recent observations by MacDonald *et al.* during the 2000 MMS Alvin cruise, and by our group during the 2000 Harry Roberts JSL cruise. We have the database, the field tools and the laboratory tools to not only document the biogeography of the seep fauna in the GOM, but also to use the data we collect to explain the biogeographic patterns and therefore predict distributions in other areas.

- The second is to determine the source of the sulfide that sustains the seep vestimentiferans around their roots. We now know it is there and that they use it, but how the sulfide gets there is not understood. Until this is understood, one cannot predict where tubeworms will occur or how long they will last in a given location. One cannot model productivity or nutrient flow. It is a key question remaining in our understanding of the occurrence, persistence and stability of lush tubeworm communities in the GOM.

- The third research direction of importance to MMS management concerns is really a type of research approach. Modelers should guide a Chemo III program. We now have detailed and testable qualitative models of seep vestimentiferan life history and seep community succession. These need to be tested in the context of different species of tubeworms and types of communities (are our current models valid and generally applicable). We are also on the cusp of having the data necessary to construct quantitative models of sulfide and methane needs, productivity (tubeworm and mussel), and nutrient (C and N) flow on the scale of entire seep communities (and by extrapolation the entire GOM). Among other things, these models can be used to quantitatively evaluate the importance of seep primary production to the surrounding fauna and the Deep Gulf in general.

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INORGANIC BIOGEOCHEMISTRY OF COLD SEEP SEDIMENTS

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OVERVIEW

During the first phase of this project, we recognized that a more detailed examination of the inorganic biogeochemistry occurring in cold seep sediments would be necessary to clarify the processes responsible for the existence of cold seep benthic communities and their unique characteristics. Therefore, a team of specialists in this field was assembled, and an integrated research program was added to the second phase of this research.

The primary focus of the new research was on understanding the processes influencing the carbon dioxide and sulfide systems. This research is presented in sections that have been divided according to major activity. Later, these results are included a general synthesis of overall findings. The major sections are

- Pore water and solid phase chemistry: This section uses a "classical" approach in which cores were sectioned to establish depth profiles of dissolved and solid phase chemical components of interest.

- Sulfate reduction rates: It is possible to measure the rates at which bacteria convert dissolved sulfate into hydrogen sulfide by using a radiotracer technique. Both depth profiles and "integrated" rates were determined at most sites.

- Stable isotope chemistry: Fractionation of the stable isotopes of carbon, oxygen and sulfur occurs by both biotic and aboitic processes. Stable isotope ratios of these elements were determined at selected sites for both dissolved and mineral phases to aid in the interpretation of the processes occurring in cold seep sediments.

- Microelectrode profiling: An emerging technology was utilized to obtain detailed depth profiles of dissolved sulfide near the sediment-water interface. This profiling was done to obtain better estimates of fluxes across the sediment-water interface and behavior of sulfide in the highly dynamic region.

PORE WATER AND SOLID PHASE CHEMISTRY

Approximately 120 push cores were collected at four primary chemosynthetic sites (GC233, GC234, GB425, and GC185) comprising 28 distinct stations (BHAT1, BHAT2, BHB3, BHBC2, BHBXC1, BHM3, BHM4, BHST1, BHST2, BHUN1, BHUN2, BPAT1, BPB2, GBM1, GBM2, GBB1@GBM2, GBUN1, GCAT1, GCB1@GCAT1, GCAT2, GCB3 (Orange, White, and Offmat), GCBX2, GCBXC1, GCJT1, GCJT2, GCST1). Cores were sampled at 2 cm intervals, and over 30 different analyses were performed on extracted porewater and solid phases yielding a large data set (~10,000 analyses).

An important geochemical process that discriminates stations is the extent of sulfate reduction. The reduction and depletion of seawater sulfate in these porewaters yields dissolved H_2S, which is absent in the overlying oxic water column, and an increase in dissolved inorganic carbon(DIC). Elevated DIC concentrations in turn promote production of solid phase calcium carbonate at the expense of dissolved calcium. The basic stoichiometry of these coupled reactions is easily identified within the data set and supports a basic scheme of grouping stations according to the overall extent of reduction (see discussion in following subsection).

Observed porewater nutrient and DOC variations with depth are generally complex and do not form a clearly recognizable pattern. Relationships within solid-phase properties and between solid and porewater parameters are also generally more complex than those existing within the porewater data set.

All sediment recovered is distinctly fine-grained. Generally positive relationships are observed between the abundance of solid phase sedimentary carbon (both total organic and inorganic) and porewater DIC. Good correlation is also seen within solid phase metal extractions (iron and manganese). Acid volatile sulfide concentrations are everywhere less than 40 µmols/g (4 µmols/g average). Total reduced sulfur (TRS) concentrations average 108 µmols/g. The low abundance of extractable iron indicates that it probably limits the extent of solid phase sulfide formation and is in part responsible for the very high levels of dissolved sulfide observed at certain stations.

SULFATE REDUCTION RATES

Sulfate reduction rate measurements were made at selected sites. When these data are combined with those from the porewater and solid phase geochemistry, they suggest the following organization:

- Inactive station porewaters show little significant departure from ordinary seawater in composition, with only slight increases in DIC (up to ~ 4mM, a twofold increase), small (<10%) to negligible depletions of sulfate and calcium, and sulfide concentrations less than ~250 µM (often below our detection limit of 3 µM). These stations also show integrated sulfate reduction rates of <10 to 55 mmoles m^{-2} day^{-1}. Chloride and other major ion concentrations are within 10% of standard seawater compositions. This group comprises the largest number of stations, and with the possible exception of bacterial mats, does not distinguish itself biologically in any obvious way. These stations are variously dominated by adult, juvenile, and senescent tubeworms and mussels.

- Active stations show clear evidence of intense sulfate reduction, either in terms of a high integrated sulfate reduction rate (>55 mmoles m^{-2} day^{-1}), or in terms of depleted sulfate and calcium. These stations include BHUN2 (1998 core), BHM4 (dive 4046), BHB3, GCAT1 (dive 2880), GCAT2, GCB3, and GCJT2. In addition, integrated rates at certain active sites are so high as to merit further division of this category to high (50—1000 mmoles m^{-2} day^{-1}) and extreme (>1000 mmoles m^{-2} day^{-1}). Active-high stations thus include BHUN2 (1998 core), GCAT2-dive 4048 and GCB3 (orange *Beggiatoa* mat); active-extreme stations are limited to GCAT2 (dives 2872, 2886, 4029). The depth at which sulfate is depleted is variable and ranges from 5-10 cms below the sediment-water interface. Stations dominated exclusively by *Beggiotoa* (GCB3) exhibit sulfate depletion curves that are markedly less in slope compared with those found at GCAT2. In addition, the stoichiometry of sulfate-DIC relationships in samples for which the extent of sulfate reduction is greater than 90% is consistent with the organic matter undergoing oxidation being methane.

- Brine stations show clear evidence of mixing between seawater and Na-Ca-Cl brine compositions, and these stations (GBM2 and BPB2) form a separate category. Although sulfate reduction in these stations may also be very high, it is limited to the shallow interval just below the sediment-water interface. Variations in sulfate and sulfide can be understood in terms of a simple mixing model, in which the brine end member contains zero sulfate and 3x normal seawater sodium chloride.

STABLE ISOTOPE MEASUREMENTS

Based on the above observations, stable isotope measurements were made on selected samples. Carbon isotope ratios were determined on DIC and calcium carbonate, where oxygen isotopes were also measured. Sulfur isotope ratios were measured on total dissolved hydrogen sulfide and total reduced sulfide (dominated strongly by pyrite). Calculating these measurements is a difficult and laborious task. These results comprise, to the best of our knowledge, the only existing data set for marine sediments where both major dissolved and solid phase isotope data coexist for the sulfide and carbonate systems.

A strong correlation (R^2 =0.85) was observed between solid phase carbon and oxygen isotopes. This correlation is interpreted as a mixing line between biogenic carbonates formed in near-surface waters and authigenic carbonates formed in sediments that have more positive oxygen and more negative carbon isotopes. The relative abundance of the authigenic component increases with increasing sediment calcium carbonate and organic carbon concentrations. There was no obvious relationship between the carbon isotope ratio in DIC to that of the calcium carbonate. This probably reflects a variable fraction of authigenic carbonates in the solid fraction; it also suggests that these carbonates did not entirely form from the current DIC pool.

As is often the case because of the complexities of biogeochemical processes in the sedimentary sulfur system, there are generally no clear patterns or relationships among the sulfur isotope ratios in different phases or with other probably important sediment parameters. However, in some cases much of the data closely clump together in a narrow range with other data radiating in a loosely preferred orientation.

MICROELECTRODE PROFILES

As part of the geochemistry program, a new solid state microelectrode technology was employed to obtain millimeter scale profiles of dissolved oxygen, O_2, and reduced metabolites, primarily H_2S, in sediment pore waters. The microelectrode system made possible the simultaneous determination of O_2, H_2S, reduced iron (Fe^{2+}) and reduced manganese (Mn^{2+}) concentration. However, Mn^{2+} and Fe^{2+} concentrations were typically below the analytical detection limit of the system, and the O_2 concentration was difficult to quantify because of sampling problems associated with the time between collection and analyses. The primary focus thus became documenting the distribution of H_2S in sediments to obtain improved estimates of sediment-water fluxes.

Thirteen cores from tube worm bushes, bacterial mats, or control sites (no chemosynthetic fauna) were microprofiled in 1997. Three cores were from along the drip line of adult tube worm bushes (BHAT2-2; BHAT1-4; GCAT1-8) and one core was from the drip line of a senescent tube worm bush (GCST1-5). Twenty-five cores were profiled during the 1998 cruise. Seven drip line cores and five peripheral cores were sampled from tube worm bushes. Three orange bacterial mats and four white bacterial mat cores were collected. Two of those cores were collected along a transition zone from an orange to white bacterial mat. One core was collected from an uninhabited site and three cores were sub-cored from box cores.

Results of sulfide flux calculations are presented in Table 2D.1. Although there are certainly a few exceptions that bear close scrutiny, e.g., GCAT2A-3) from both the chemical and biological perspectives, there are certainly strong tendencies for

1. Controls to have small to negligible sulfide fluxes, as they should in this area;
2. Algal mats to have moderate to very high sulfide fluxes; and
3. Tube worm sites to have negligible to very low sulfide fluxes.

SUMMARY OF RESULTS

The studies of the inorganic benthic biogeochemistry went well and were very close to the initial plans. The results comprise a unique and large data set documenting the complexity and heterogeneity of these chemosynthetic communities. These results will subsequently be synthesized with the other components of this project.

RETROSPECTIVE

A concerted sediment biogeochemical study was not part part of the original Chemo program and did not commence until the Chemo 2 phase of the study. The sediment biogeochemistry program

Table 2D.1. Calculated approximate H_2S fluxes for sampling events in 1997 and 1998. A * indicates an apparent small influx of sulfide due to storage problems. Fluxes at these sites can generally be expected to be small.

1997 H_2S FLUX (UMOL CM^-2 DAY^1)		1998 H_2S FLUX (UMOL CM^-2 DAY^1)	
Tube Worm Bush		**Tube Worm Bush – Drip Line**	
GCST1-5	0.0	BHAT1-3	0.0
BHST2-7	-760	BHST1-5	0.0
BHAT2-2	*	GCAT2-1	-0.1
GCAT1-8	*	BPAT1-4	0.0
BHAT1-4	*	BHAT2-2	0.0
		GCJT2-4	0.0
		BHM3-8	-350
		Tube Worm Bush – Peripheral	
		BHAT1-6A	0.0
		GCAT2A-3	-3600
		GCST1-5	0.0
		GCAT1-9A	0.0
		BHAT2-7A	0.0
Orange Mat		**Orange Mat**	
GBM2-6	-810	GCB1-4	-110
GCAT2-6	-260	BPB2-5	-1400
GCAT2-3	-1100	GCB3-4	-660
White Mat		**White Mat**	
GCB-6	-480	BHB1-3	-540
GCB-1	-1900	BHB3-2	-300
BHST1-5	-62	GCB1-3	-2100
		GBM2-5	-3200
Controls		**Controls**	
BHBC2-4	*	GCBX2-5	*
BHUN1	0.0	BHBXC1-4	0.0
		GCBXC1-3	-3.3
		GBUN1-5	-60

was largely designed to establish how the C & S systems varied in relationship to the distributions of different macro-epifaunal organisms. This significantly limited the extent to which processes and the basis for high-chemical heterogeneity could be studied. In hindsight, a much better effort was needed on organic geochemistry and microbiology.

RECOMMENDATIONS FOR FUTURE STUDIES

To better understand the biogeochemistry of the system, we need

- a better sampling plan not driven so strongly by the distribution of macro-fauna;
- to focus on parameters that were established as important;
- more emphasis on organic geochemistry;
- a specialist in methane oxidation;
- to reprioritize objectives based on what was learned from present study; and
- to look into cheaper non-submersible sampling.

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PROGRAM SYNTHESIS AND RECOMMENDATIONS FOR FUTURE WORK

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INTRODUCTION

This contract has considered results from an extensive program of field collections and laboratory analysis that spanned numerous disciplines within marine science. A team of sixteen investigators and their students or associates from seven separate institutions was assembled to formulate and carry out the work. During the course of two ambitious field seasons, program investigators collected samples from over fifty stations distributed among four principal sampling sites with use of the submarine Johnson Sea Link. Extensive additional collections were made with use of the R/V Gyre and vessels of opportunity including the U.S. Navy Submarine NR-1. The primary geochemical samples included more than fifty sediment cores, which were extensively sub-sampled by sediment depth. Extensive collections of chemosynthetic and heterotrophic animals were obtained for a diverse array of investigations to determine, among other objectives, growth rates, health, genetic diversity, and food-web structure. A regional context for the targeted sampling was established through geophysical survey, sediment coring, and layered comparisons between community and regional-scale data with use of geographic information system (GIS) tools. Although regional-scale physical oceanography was beyond the scope of the program, valuable time-series records of current, water temperature, and fluid discharge properties of the seep environment were obtained from in-situ instruments and moorings. Serendipitously, remote sensing records were obtained through cooperation with industry. These data illustrated large scale changes in hydrocarbon discharge at one of the study sites. Throughout the program, the investigators benefited from similar cooperative arrangements with other agencies and interests. Mention should be particularly made of assistance received from the NOAA National Undersea Research Center at the University of North Carolina, Wilmington, the Naval Research Laboratory Washington DC laboratory, and the U.S. Navy SUBLANT group, all of whom assisted with obtaining ship and submarine time over and above what would have been possible under the contract. Data sharing was an important component that enriched the program data resources. Contributions by Western Geophysical, Inc. and Unocal, Inc. are particularly noted.

Results from the main body of program efforts have produced a substantial body of research results, which include numerous peer-reviewed publications and student theses in addition to the results detailed in the preceding chapters of this report. Given the pace of publication, it is likely that this productivity will continue for some time to come. The purpose of this section is to revisit the individual investigations of the program with a interdisciplinary perspective. The major program objectives, as specified in the request for proposal and contract are reviewed below and briefly reprised. Wherever practical, this section will attempt to synthesize the separate results into themes that address MMS concerns. Finally, recommendations for future study will be outlined.

PROGRAM OBJECTIVES

The request for proposal that initiated this program specified the following objectives for study (taken verbatim from solicitation number 3813):

1. Review biotic and abiotic features of existing conceptual models of chemosynthetic communities which explain observed patterns of distribution and abundance, in order to develop an effective, refined plan for continued research.

2. Further evaluate the physical-chemical factors (e.g., depth, temperature, water chemistry, sediment types, and dissolved gasses) which influence, limit, enhance, or control the distribution, abundance and growth of chemosynthetic communities.

3. Further investigate the sources (e.g. deep versus shallow, or petrogenic versus biogenic) of any necessary dissolved gasses and the likelihood that petroleum production may ultimately deprive the animals of an energy source.

4. Further determine whether chemosynthetic communities are robust or fragile and whether they are essentially permanent or ephemeral; characterize age, growth rate, turnover rates, reproduction and recruitment, and patterns of senescence and death in the dominant chemosynthetic animals; further examine recovery rates of communities damaged by physical disturbance.

5. Further determine the reliability of methods for detecting chemosynthetic communities using remote acoustic and/or geophysical devices, imaging instrumentation, hydrocarbon measurements, and/or other available technologies.

In considering objective number one, a thorough review of published literature and reports was completed. A principal conclusion was that the chemosynthetic fauna from hydrothermal vents (tube worms and mussels) were taxonomically and functionally similar to that of vents, but inhabited an ecosystem that was fundamentally distinct. Therefore, new conceptual models of colonization, persistence, and interaction would have to be developed to describe seep chemosynthetic communities. The plan for further research needed to reference the ambitious goals laid in the remaining objectives. It was determined that most of the sampling would have to be carried out within a few discrete sampling areas. Four sites were selected because they represented two pairs of distinct habitat types (brine pooling and sediment diffusion), because previous work provided a strong basis for further study, and because they were close enough together for effective field sampling (Figure 2D.1). The plan specifically did not allow for sampling communities occurring at depths greater than 1000m (the maximum depth for available submarines) nor did it permit broad survey of the northern Gulf of Mexico in attempts to define the overall prevalence of communities.

Objective two was addressed by deploying a current meter mooring at one of the study sites (GC185) and by deploying bottom thermistors at two other sites (GC234 and GB425). These instruments showed that the currents at the relevant depths are of sufficient magnitude to disperse the larvae chemosynthetic fauna across the entire upper slope. Additionally, the variation in bottom

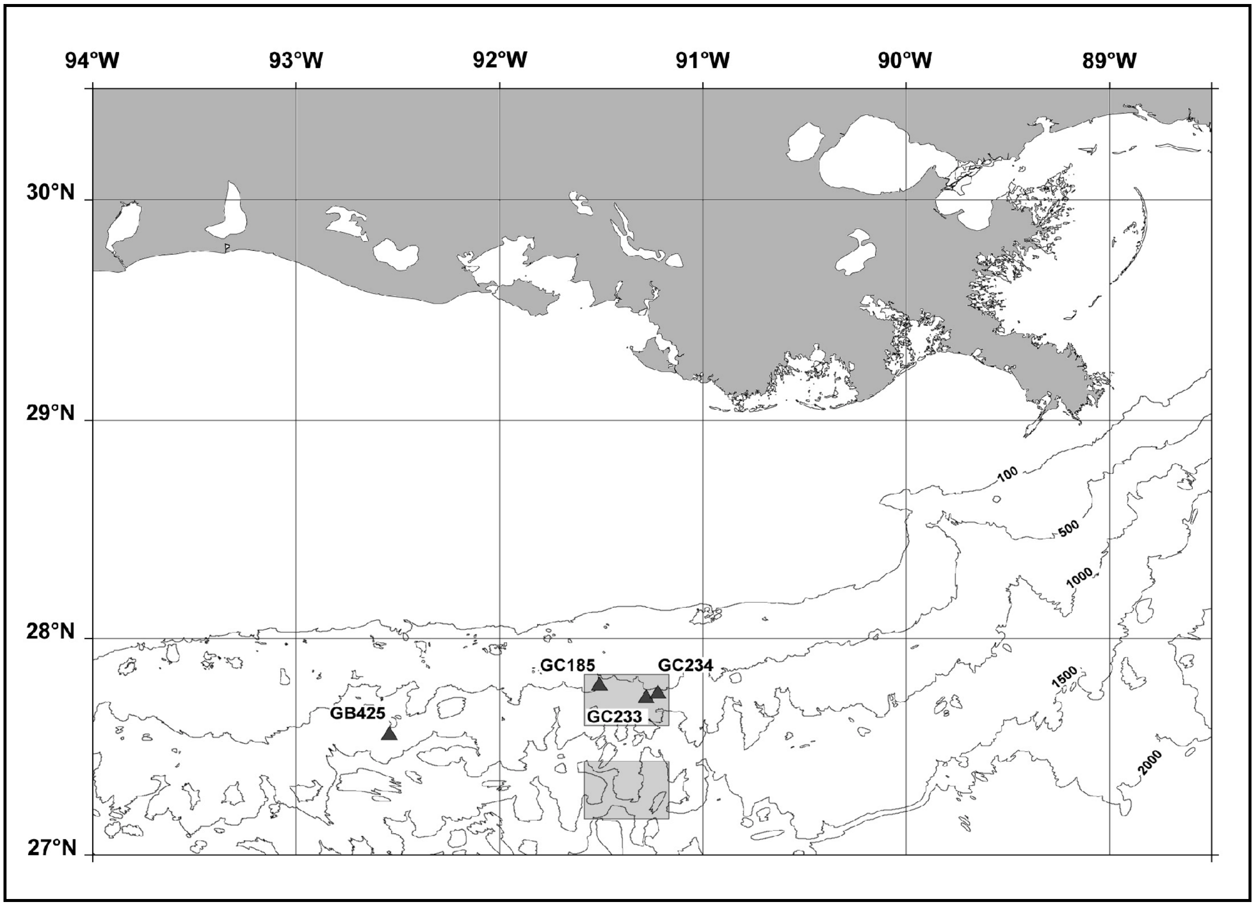


Figure 2D.1. Map of the northern Gulf of Mexico showing locations of program study sites (triangles) and mega-sites for geophysical survey (stippled boxes).

water temperatures indicate that the study sites are sufficient to provide the organisms with distinct environmental cues concerning timing of stronger currents. This temperature variation will also potentially define the stability envelope for shallow gas hydrate. Thermistor records from the seeps provide some long term information on the discharge rates from the brine-pooling type habitats.

Objectives three and four were addressed through a program of sample collection with submarine *Johnson Sea Link.* Noteworthy results include the confirmation of extreme longevity among seep tube worms and the prevalence of parasitism among seep mytilids—in many cases, the parasite load was great enough to significantly affect the health of the infected animals. Diverse investigations examined the geochemical processes that support chemosynthetic species. Sulfide-dependent chemosynthetic species are found among sediments that sustain sulfate reduction rates that are two orders of magnitude greater than anything previously reported. Rates of this magnitude are patchily distributed and can only be sustained with some process to mix seawater sulfate down into the sediments. A biological mediation is indicated. Gas hydrate, while recognized as being a component of seep communities, was not anticipated to play a major role in seep ecology during the course of the program; however, a new species of polychaete worm (*Hesiocaeca methanicola*) was found to make extensive burrows in shallow hydrate deposits. Preliminary evidence points to hydrate as a possible intermediate source for necessary dissolved gasses at seeps. The question of whether seeps are robust or fragile was addressed in two ways. By examining the DNA fingerprints of seep mussels and tube worms, it was possible to determine that genetic exchange among study sites is in all cases adequate to sustain species integrity across the sites. This indicates that larval recruitment from external locations could recolonize sites that had suffered a loss of population. Trophic studies show that although seep fauna do provide a source of food for animals living away from seeps, there is no sign that non-seep fauna depend exclusively on seep productivity as a food supply.

Objective five was addressed through compilation of a side-scan sonar mosaic over two mega-site regions. This geophysical data was then extensively ground-truthed at multiple scales with use of GIS techniques and additional survey with submarine *NR-1*. Additional geophysical characterizations were obtained by selective reprocessing of industry multi-channel. These results narrowed and refined the search pattern for chemosynthetic communities, but did not demonstrate that any remote sensing survey could provide absolute certainty regarding the presence or absence of chemosynthetic communities. Additional work underlined the usefulness of satellite remote sensing data for determining the areal and temporal distributions of natural oil discharges.

RECOMMENDATIONS FOR FUTURE WORK

The program investigators agreed that new approaches would be needed for future studies. Two principal directions were indicated. Detailed studies, which extend sampling deeper into the sediment column beneath clusters of chemosynthetic fauna, are needed to delineate the bacterial and metazoan consortia and the elemental cycling that were indicated by results to date. New sampling techniques will be needed for this work. Broad area surveys will be required to characterize the regional distribution and variability of chemosynthetic ecosystems. The results from the present study indicate that a more robust and cost-effective suite of geochemical samples could provide a basic screening for areas affected by seepage. Much sampling could probably be conducted from surface ships. However, the 650-m maximum depth of the site examined during the present study leaves much of the lower slope unexplored—and this at a time when exploration and production on the lower slope is expected. New studies should focus on the deeper areas. This work will probably have to be done from ROVs rather than occupied submarines and will require careful planning to ensure that the results are comparable with previous work.

Ian R. MacDonald is an Research Scientist at the Geochemical and Environmental Research Group of Texas A&M University. His primary research interest is the application of imaging and GIS techniques for marine ecology. He is the program manager for the Stability and Change in Gulf of Mexico Chemosynthetic Communities Program. MacDonald received a Ph.D. in oceanography in 1990 from Texas A&M University.

SESSION 2E

NEW INITIATIVES IN MODELING OF OIL SPILLS

Chair: Ms. Gail Rainey, Minerals Management Service
Co-Chair: Dr. Walter Johnson, Minerals Management Service

Date: December 6, 2000

Presentation	Author/Affiliation
Modeling a Deep Water Oil/Gas Spill under Conditions of Gas Hydrate Formation and Decomposition	Mr. Fanghui Chen Mr. Li Zheng Dr. Poojitha D. Yapa Department of Civil and Environmental Engineering Clarkson University
SINTEF's DeepBlow Model	Dr. Mark Reed SINTEF Applied Chemistry, Norway
The Fate and Effects of Barium and Radium-Rich Fluid Emissions from Hydrocarbon Seeps on the Benthic Habitats of the Gulf of Mexico Offshore Louisiana	Dr. Paul Aharon Mr. Dan VanGent Dr. Baoshun Fu Department of Geology and Geophysics Louisiana State University Dr. L. Max Scott Radiation Safety Office, Nuclear Science Center Louisiana State University
NOAA's Other Oil Modeling Initiatives (GNOME/Wizards/TAP)	Ms. Debbie Payton National Oceanic and Atmospheric Administration
ASA Oil Spill Models: Modeling the Movement of Oil and Gas Released from Deep Well Blowouts	Mr. Eric Anderson Applied Science Associates, Inc.
ASA Oil Spill Models: 3-D Fates and Effects Modeling Applications for Gulf of Mexico Spills	Dr. Deborah French McCay Applied Science Associates, Inc.

MODELING A DEEPWATER OIL/GAS SPILL UNDER CONDITIONS OF GAS HYDRATE FORMATION AND DECOMPOSITION

Mr. Fanghui Chen
Mr. Li Zheng
Dr. Poojitha D. Yapa
Department of Civil and Environmental Engineering
Clarkson University

INTRODUCTION

Oil exploration and production from deepwater locations are increasing steadily. As the production increases, the potential for an oil/gas spill increases. Major concerns from a deepwater oil/gas spill are fire hazard to the people working on the surface installations and loss of buoyancy of ships and any floating installations. For this purpose it is important to know if, when, and where the gas may surface and how much it will be. Another environmental concern is the issue of whether oil will surface and if so, where, when, and what the oil slick thickness will be. To meet these new challenges, spill response plans need to be upgraded. An important component of such a plan would be a model to simulate the behavior of oil and gasses, if accidentally released, in deepwater.

In deepwater, the pressure is high and the temperatures are low. In these conditions two aspects of gas behavior differ significantly when compared with a release from relatively shallow depths. First, under these high-pressure conditions, the gases may not behave according to ideal gas conditions. Our computations showed that at depths of 1,000 m water depth, the behavior of methane and natural gas deviate significantly from the ideal gas conditions. Second, in these high-pressure and low-temperature conditions the gases are likely to form “gas hydrates.” Hydrate formation is a physical process that is reversible. As these buoyant hydrates travel upwards, they encounter regions of lower pressure. The hydrates can decompose into free gas under these conditions. The presence or absence of hydrates has a significant impact on the behavior of the jet/plume due to the alteration of the buoyancy. The free gas may dissolve in water.

Studies on gas hydrates could be divided into two categories: thermodynamics and kinetics. Thermodynamic studies focus on the conditions of hydrate formation, such as equilibrium temperature and pressure. Kinetic studies focus on the rate of formation and decomposition. The actual existence of hydrates depends on not only the thermodynamics but also the kinetics of formation. The latter aspect is important to deepwater spills.

This paper describes a computer model developed to simulate the behavior of oil and gas released from deepwater locations in the ocean. The model integrates the hydrodynamics and thermodynamics of the jet/plume with kinetics and thermodynamics of hydrate formation/decomposition. Model formulation and comparison of results with laboratory data for hydrates is presented. Scenario simulations show the behavior of oil/gas under different deepwater conditions. These include the jet/plume reaching a neutral buoyancy level before continuing to travel upward.

CONCERNS

- Fire hazard for the surface installations/crew
- Loss of buoyancy for floating objects
- Because of toxic effects of gases - need to know how much, where, and when (or if) will they surface
- Oil concentration distribution, area, and time for surfacing

What's Different in a Deepwater Oil/Gas Model

In deep water the pressure is high and the the temperatures are low.

Gases may not follow the ideal gas law.

Gases released can be converted to "gas hydrates"

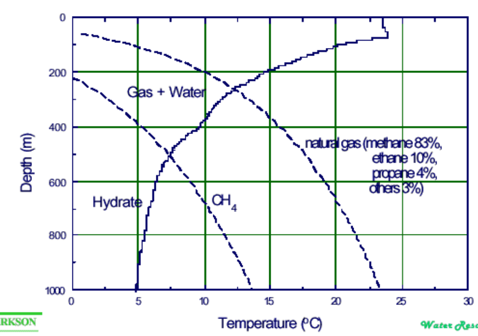
What are Gas Hydrates

"Gas Hydrates" are clathrate type compounds of a mix of water and gas. The density of consistency is similar to Frazil ice.

Natural "gas hydrates" are buoyant– CO_2 hydrates are heavier than water

$$(CH_4)_{gas} + n_h(H_2O)_{water} \leftrightarrow (CH_4 \cdot n_h H_2O)_{hydrate}.$$

Hydrate Phase Equilibrium Diagram & Temperature Distribution in GOM



Conservation of water mass in the jet/plume

$$\frac{dm_l}{dt} = \rho_a Q_e - \frac{Nh}{w+w_b} n_h \frac{dn}{dt} M_w$$

dn/dt = hydrate formation/decomposition rate; n_h=hydrate number; N=flux; h=height of CV

Loss of gas mass due to hydrate formation

$$\Delta m_b = -\frac{Nh}{w+w_b} \frac{dn}{dt} M_g \Delta t$$

M_g=Molar Weight

Conservation of Momentum

$$\frac{d}{dt}[m_l w + (m_b + m_h)(w + w_b)] =$$

$$w_a \rho_a Q_e + (\rho_a - \rho_l) g \pi b^2 (1 - \beta^2 \varepsilon) h$$

$$+ (\rho_a - \rho_{com}) g \pi b^2 \beta^2 \varepsilon h$$

m_h = hydrate mass in a CV

$$= \frac{Nh}{w+w_b} \rho_h \cdot \frac{4}{3} \pi (r_h^3 - r_b^3)$$

Conservation of Heat

$$\frac{d}{dt}[(C_{pl}m_l + C_{ph}m_h)T] = C_{pl}T_a\rho_a Q_e + \frac{Nh}{w+w_b}\frac{dn}{dt}\lambda$$

λ=latent heat of hydrate formation/decomposition; C_{pl}, C_{ph} = heat capacity of liquid, hydrate; m_h=hydrate mass

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Computing gas velocity

Previous approach

$$U_T = \frac{gd^2\Delta\rho}{18\mu} \quad \text{and} \quad U_T = \left(\frac{8gd\Delta\rho}{3\rho}\right)^{\frac{1}{2}}$$

$$d_c = \frac{9.52\mu^{2/3}}{(g\rho\Delta\rho)^{1/3}}$$

New approach

Using 8 equations – account for larger variations in size and shape

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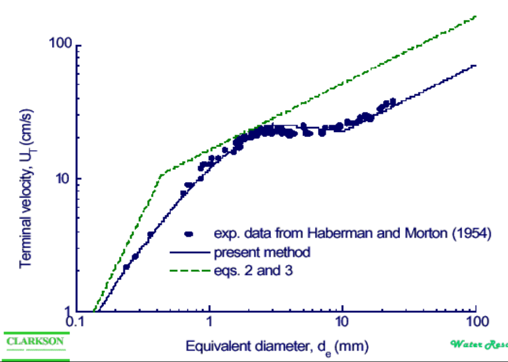
Comparing computed & observed gas velocity



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Early Simulations : (before integrating hydrate modules)

- Many comparisons with laboratory data
- Comparisons with several field experiments using compressed air
- Comparisons with North Seas Field experiments

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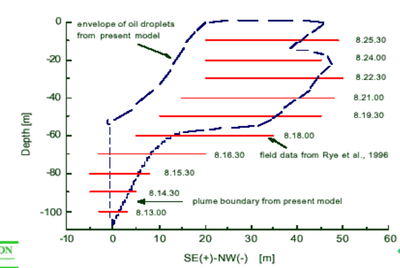
Comparisons with North Seas Field Experiments

Model by Yapa and Zheng (1997, 1998)

- 1995 Oil Jet in North Seas
  - Rye *et al.* (1996)
- 1996 Oil/Gas Jet in North Seas
  - Rye and Brandvik (1997)

Comparison with Field Expt. 1

	Neut Buo. level	Time to reach surface
Observed	50-60 m.	10.0 min.
Model	54.9 m.	10.6 min.



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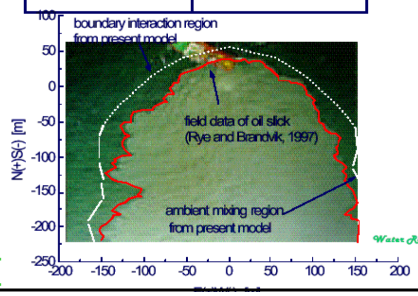
Comparison with Field Expt. 2

	Upstream intrusion	Slick width at 200 m d/s
Observed	40-50 m.	300 m.
Model	57.5 m.	310 m.



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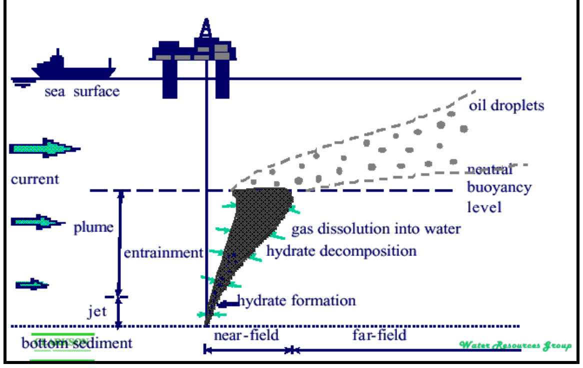
Data from Deep Spill

Expected soon

Will be used for comparison of model results

PROBLEM DESCRIPTION



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REVIEW: Deepwater Spill Models

Developer	Hydrodynamics of jet/plume	Hydrate formation	Hydrate decomposition	Latent heat exchange	Free gas dissolution
Topham (1984)	2-D, no ambient currents	Semi-empirical kinetics*	No	No	No
Barbosa et al. (1998)	2-D, with ambient currents	Semi-empirical kinetics*	No	No	No
Johansen (1999)	3-D, with ambient currents	Thermodynamics	Thermodynamics	Yes	Yes

* Vysniauskas - Bishnoi (1983)

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OBJECTIVE:

Develop a comprehensive model to simulate the behavior of oil and gas released from deep water

MODEL COMPONENTS:

+ Hydro/thermo dynamics of jet/plume
+ Hydrate formation (thermodynamics & kinetics)
+ Hydrate decomposition (thermod…. & kinetics)
+ Free gas dissolution into sea water
+ Oil and gas transport in the far-field

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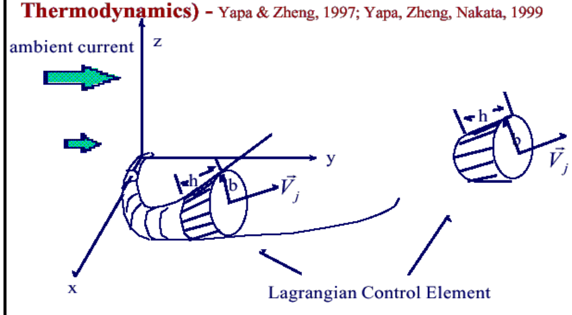
Jet/Plume Dynamics (Hydrodynamics and Thermodynamics) - Yapa & Zheng, 1997; Yapa, Zheng, Nakata, 1999



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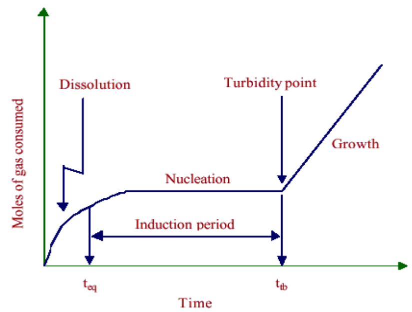
HYDRATE FORMATION PROCESS



(after Bishnoi et al., 1994)

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GAS CONSUMPTION RATE

(Bishnoi - Englezos, 1987)

$$6H_2O(water) + CH_4(gas) \Rightarrow 6H_2O \cdot CH_4(hydrates)$$

$$\frac{dn}{dt} = K^* S(f - f_{eq})$$

Gas consumption rate

Rate const

Formation surface area

Fugacity difference

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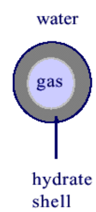
Other Factors in Modeling Hydrate Formation

- Mass transfer: transport materials for hydrate formation to the point of reaction.
- Heat transfer: re-distribute the temperature around the hydrate shell.
- Shape factor: non-spherical shape of gas bubbles.
- Compressibility factor: non-ideal gas



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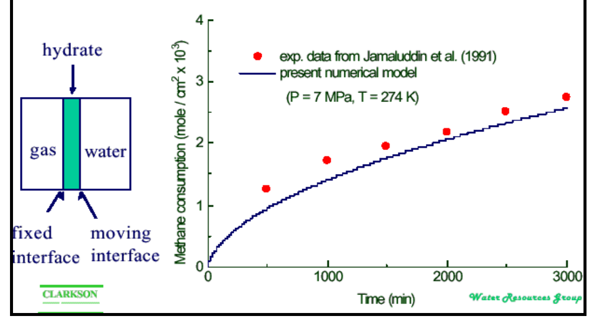
Hydrate Module Verification

(hydrate slab growth - gas consumption)



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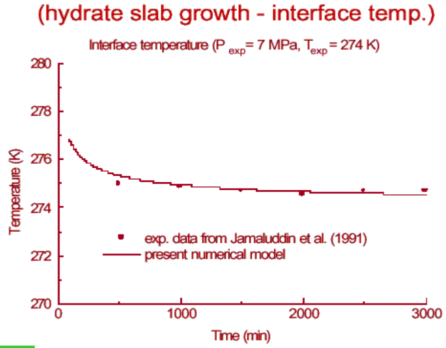
Hydrate Module Verification

(hydrate slab growth - interface temp.)



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HYDRATE DECOMPOSITION

(Bishnoi - Kim, 1987)

$$6H_2O \cdot CH_4(hydrates) \Rightarrow 6H_2O(water) + CH_4(gas)$$

$$\frac{dn_H}{dt} = K_d A_s(f_{eq} - f)$$

gas generation rate

rate const

surface area of a hydrate particle

fugacity difference

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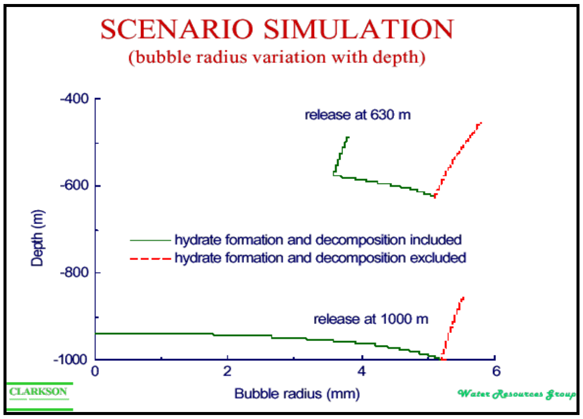

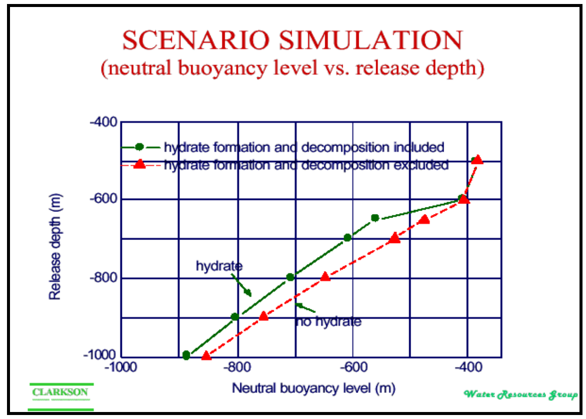

SUMMARY

- A comprehensive 3-D model development in progress to simulate the behavior of oil and gas released from deep water
- Comparisons with experimental data are made where available - reasonably good agreement with experimental data
- Dissolution has an effect similar to that of hydrate formation
- Scenario simulation is presented
- Work is in progress

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SINTEF'S DEEPBLOW MODEL

Dr. Mark Reed
SINTEF Applied Chemistry, Norway

DeepBlow

Lagrangian Integral Plume Model for Oil and Gas Blowouts in Deep and Shallow Waters

Mark Reed (for Øistein Johansen)
mark.reed@chem.sintef.no

Senior Research Scientist
SINTEF Applied Chemistry
Trondheim, Norway

Goals of DeepBlow Model Development

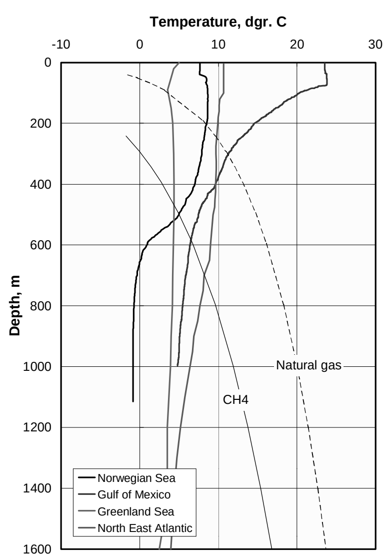
- **<u>Health and safety:</u> risks at the sea surface from underwater gas and oil releases**
  - **shallow or deep**
  - **arbitrary mixture of gases, oil, and water**
- **<u>Spill response:</u> distribution of oil thickness and weathered state on the sea surface following an underwater release**
  - **blowout**
  - **pipeline leak**
  - **gas, oil or a combination**

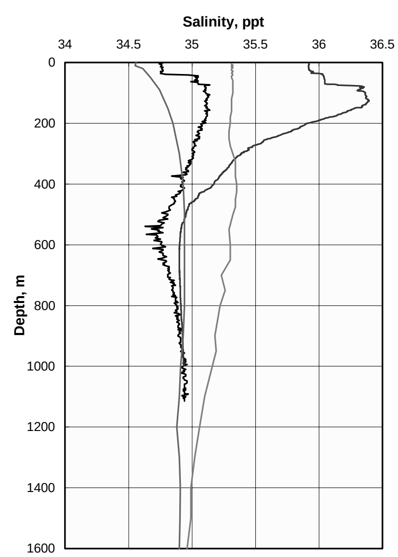
What's special about deep waters?

High pressures: **1000 m = 101 atmospheres**
Cold water: **-1 to 5°C**
Which implies:

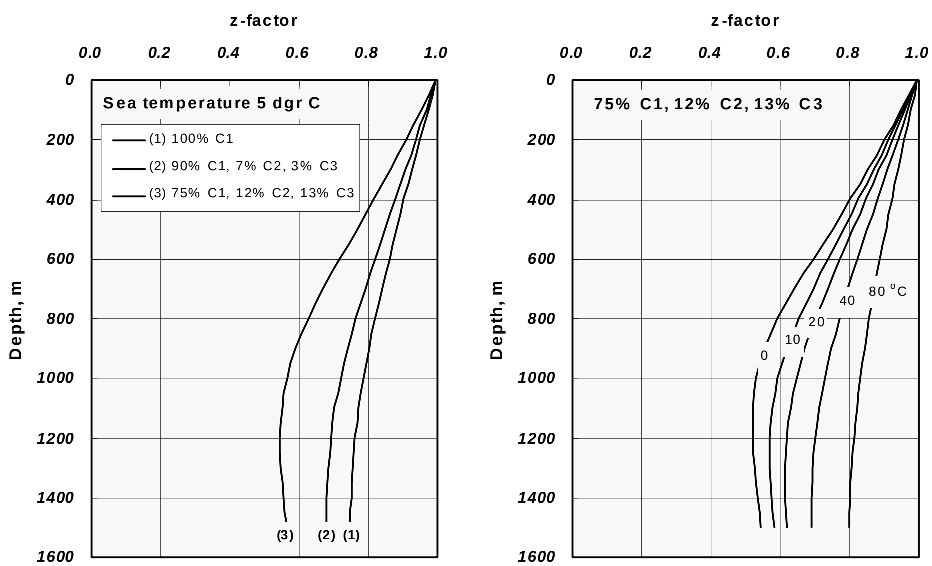
- **Non-ideal gas behavior**
- **Increased solubility of gas in sea water**
- **Gas may combine with sea water and form hydrates**
- **Effects of cross-flow increase with depth**

Hydrographic profiles

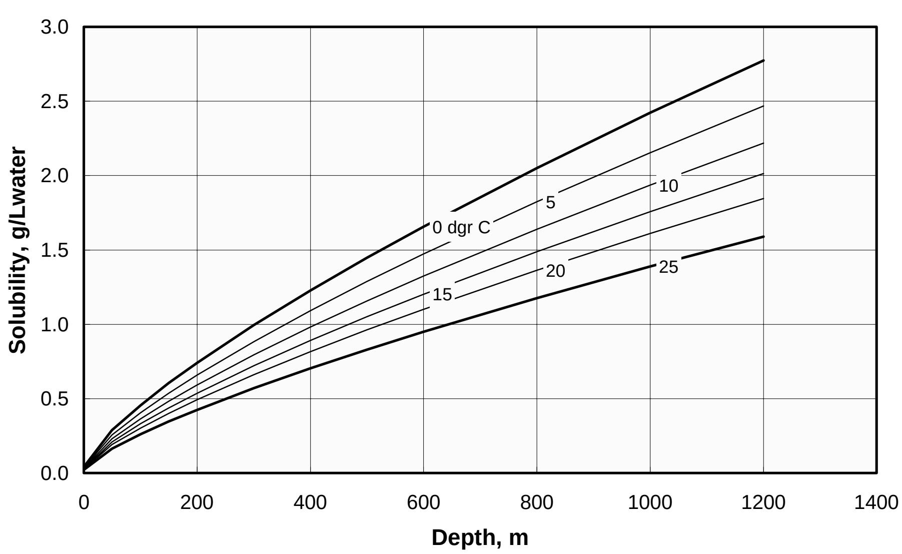




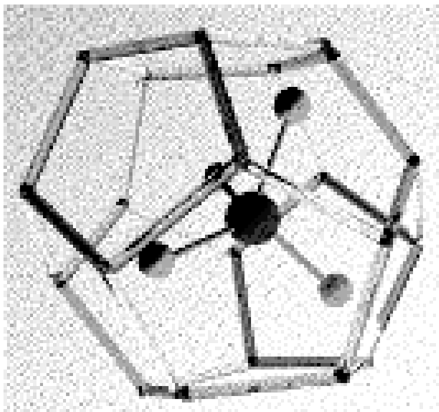
Compressibility (z-factor)



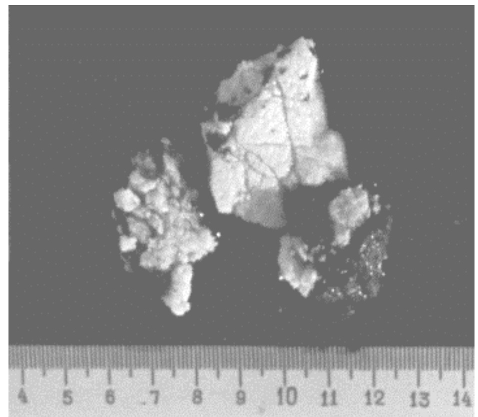
Solubility of methane



Natural gas hydrates



Methane molecule trapped in ice cage



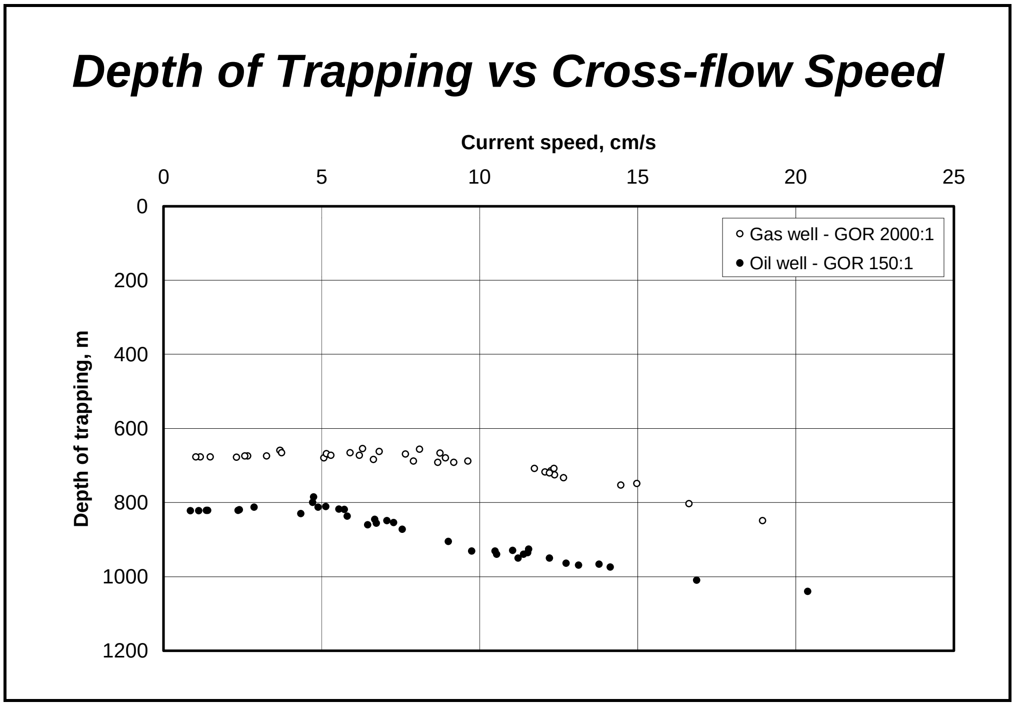
Sample of hydrate from sediments

Gas hydrates

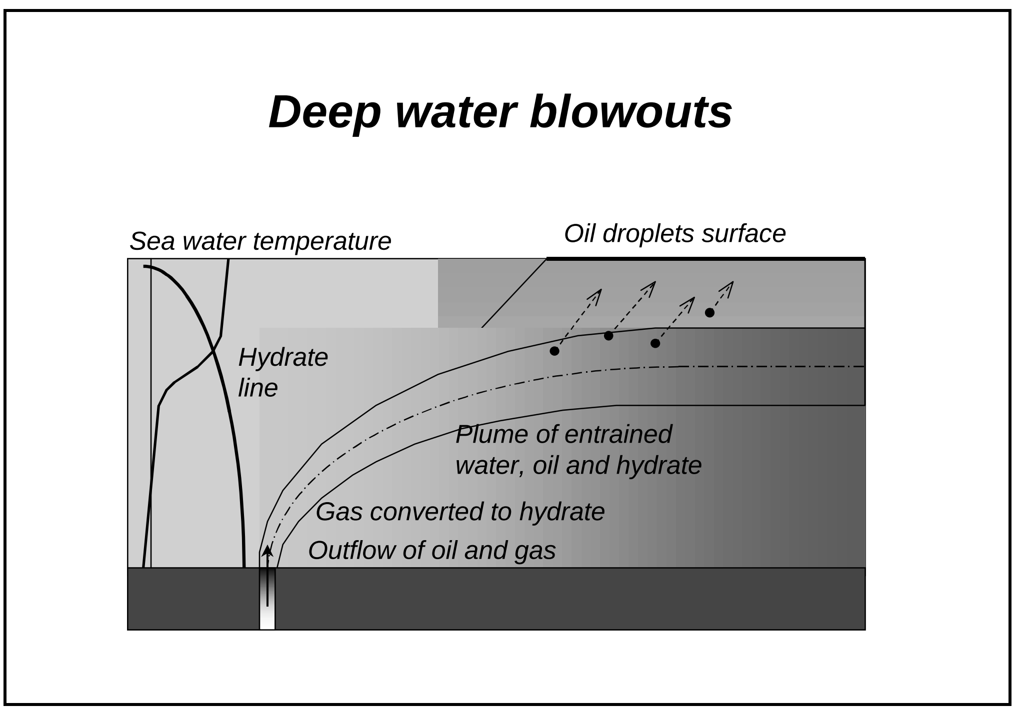
Some facts:

- **<u>Equilibrium temperature</u> depends on pressure and composition of gas**
- **Density of ice matrix: 780 kg/m^3**
- **Gas to water ratio (moles): 15% gas/85% water**
- **Density of hydrate: ≈ 900 kg/m^3**
- **Latent heat of freezing*): 440 kJ/kg hydrate**

***)Latent heat of freezing for water/ice: 335 kJ/kg water**



Depth of Trapping vs Cross-flow Speed
Current speed, cm/s
0
5
10
15
20
25
0
200
400
600
800
1000
1200
Depth of trapping, m
Gas well - GOR 2000:1
Oil well - GOR 150:1

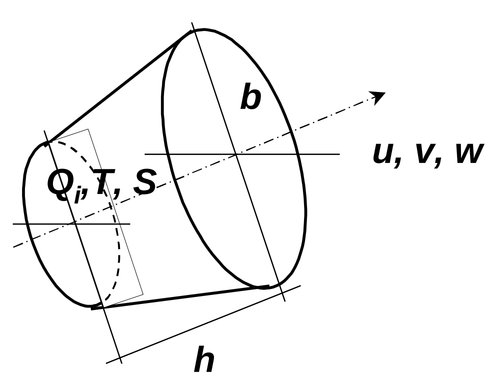


Deep water blowouts
Sea water temperature
Oil droplets surface
Hydrate
line
Plume of entrained
water, oil and hydrate
Gas converted to hydrate
Outflow of oil and gas

Key concepts affecting plume and surface slick formation:

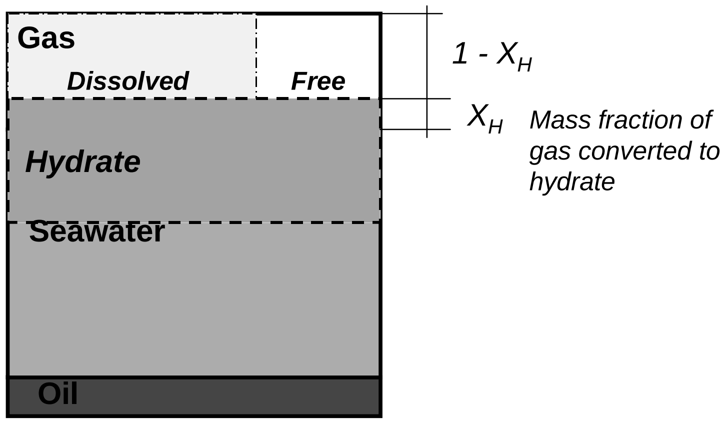
- **compressibility of gas (not ideal gas)**
- **hydrate formation (and melting!)**
- **gas dissolution**
- **effects of cross-flow**
  - **depth of trapping**
  - **horizontal displacement**
- **oil droplet size distribution**

DeepBlow: Lagrangian plume model for deep waters



Lagrangian plume element

Composition of plume element

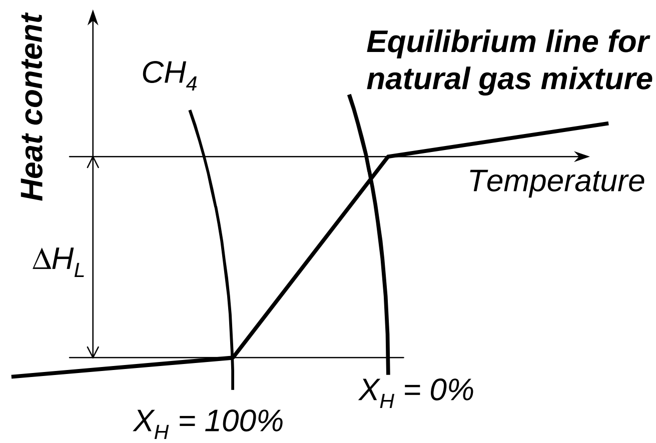


Buoyancy

- **Volume of plume element:** $$V = \sum \frac{Q_i}{\rho_i}$$
  - **Q_i = mass of component *i***
  - **ρ_i = density of component *i***
- **Archimedes law: Buoyancy =**

  volume of element × specific weight of sea water

Latent heat of hydrate formation released over a temperature interval



Input to DeepBlow

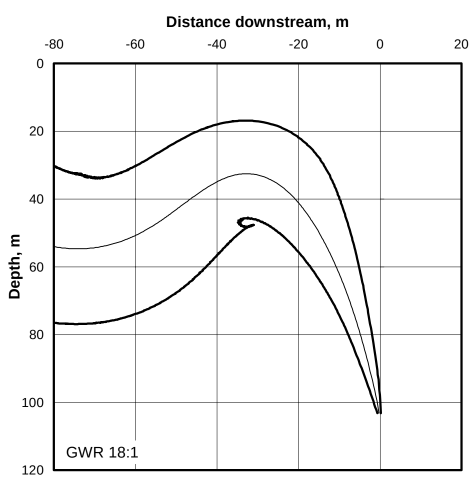
- **Discharge data:**
  - **Depth (m)**
  - **Oil rate (m^3/hour)**
  - **Gas-to-oil ratio (GOR)**
  - **Oil density (kg/m^3)**
  - **Gas density (kg/Sm^3)**
  - **Temperature**
  - **Outlet diameter**
- **Environmental data:**
  - **Hydrographic profiles**
  - **Current profiles: Simultaneous time-series of ocean currents measured at different depths**

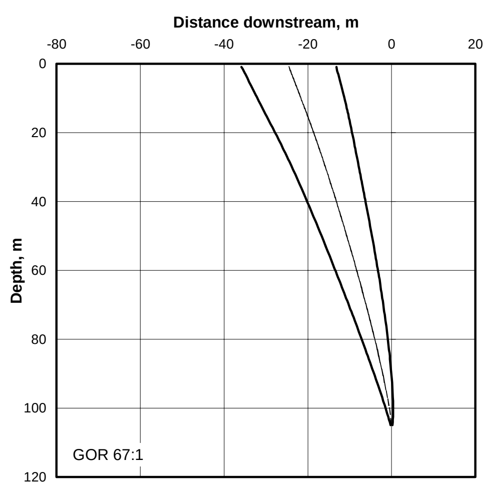
Output from DeepBlow

- **Summary results for different current situations:**
  - **Depth of trapping (DOT)**
  - **Rise time to DOT**
  - **Plume radius at DOT**
  - **Concentration of oil at DOT**
  - **Mass fraction of gas converted to hydrate and/or dissolved in water at DOT**
- **Detailed description of each simulated plume:**
  - **Plume trajectory (x, y z)**
  - **Plume radius**
  - **Plume velocities (u, v, w)**
  - **Plume composition, temperature etc.**

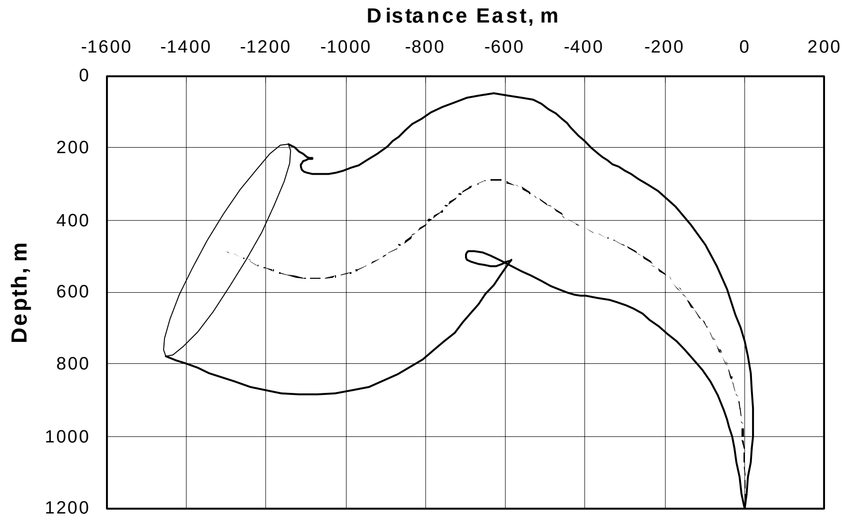
Plume geometry

Calibrated to field trials; Discharges from 105 m depth





Plume trajectory from 1200 m

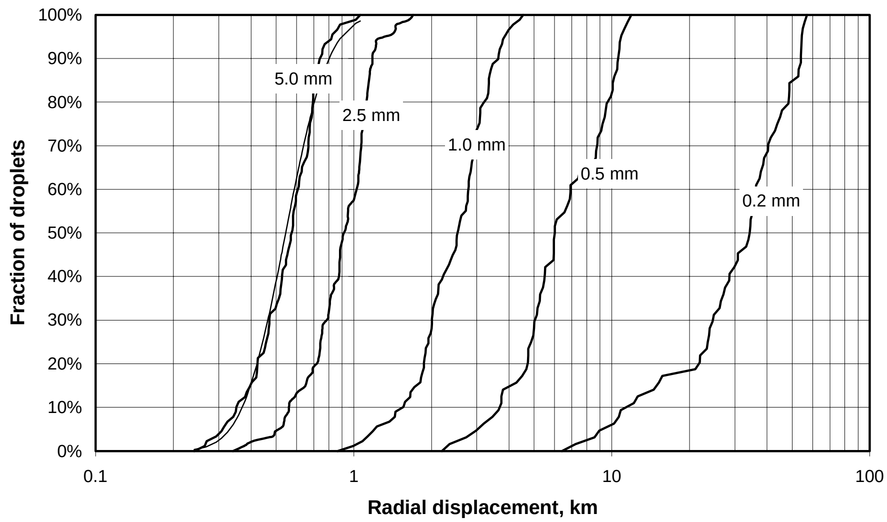


Formation of surface slick

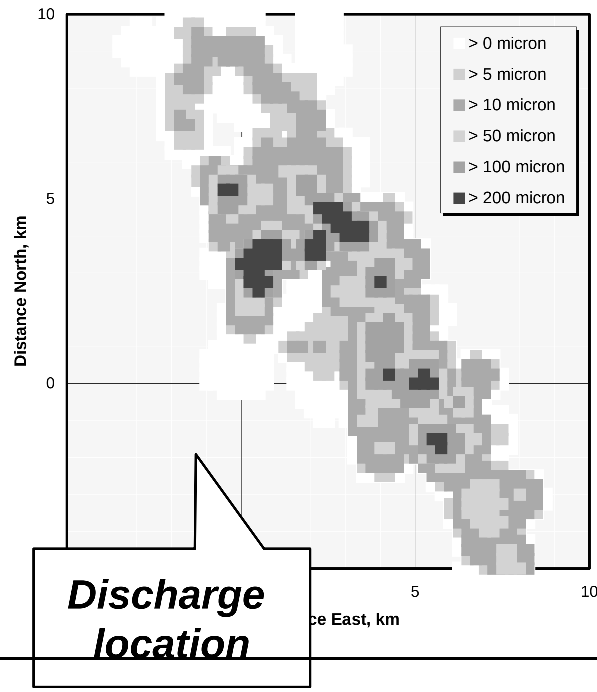
- **Plume trapped below surface; “flags” with the cross-current**
- **Oil droplets of different sizes rise to the surface through a depth- and time-variable current field**
- **Oceanic diffusion contributes to horizontal spreading (especially for droplets with long settling times)**

Oil droplets rising from 600 m depth.

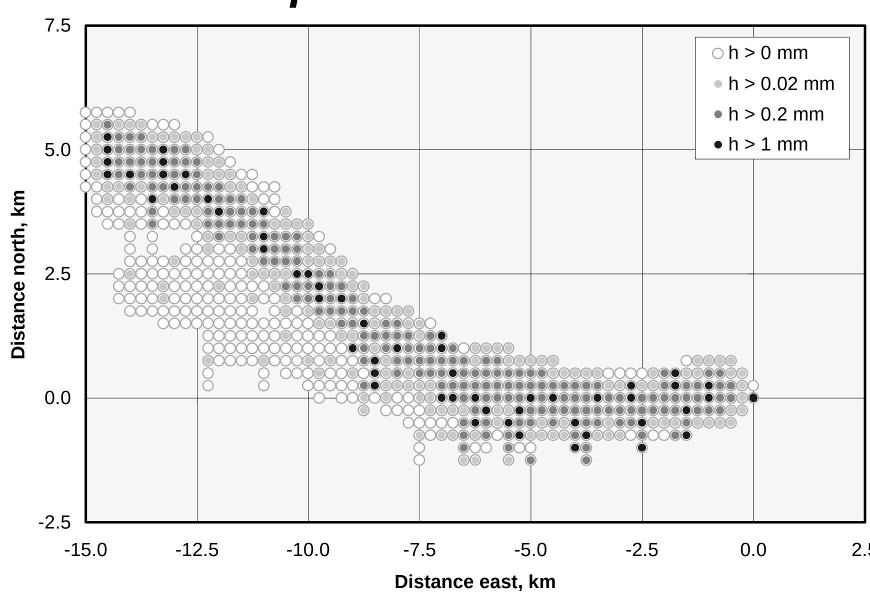
(*Current measurements from Gjallarryggen*)



Oil slick from marine diesel experiment



Example computed surface slick, release of oil and gas from 800 m



Summary

Key concepts affecting plume and surface slick formation:

- compressibility of gas (not ideal gas)
- hydrate formation (and melting)
- gas dissolution
- effects of cross-flow
  - depth of trapping
  - horizontal displacement
- oil droplet size distribution

Final Query:

- Can we use simple models, accounting only for:
  - compressibility of gas (not ideal gas)

- … and then define the envelope of possible answers by assuming extreme values for
  - hydrate formation and melting
  - gas dissolution
  - effects of cross-flow varying in time and vertical location (entrainment, displacement)
  - oil droplet size distributions

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THE FATE AND EFFECTS OF BARIUM AND RADIUM-RICH FLUID EMISSIONS FROM HYDROCARBON SEEPS ON THE BENTHIC HABITATS OF THE GULF OF MEXICO OFFSHORE LOUISIANA

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During routine submersible dives in 1993 followed by additional targeted dives in 1997, we discovered that in addition to hydrocarbons some of the seeps occurring at upper bathyal depths (510 to 657 m) in Garden Banks-382 (27° 37.77' N; 92° 28.08' W), Garden Banks-338 (27°37.79'; 92°28.12') and Mississippi Canyon-929 (28° 01.46'N; 89°43.63'W) are also issuing copious amounts of barium and radium-rich fluids. Upon their exit on the seafloor, these fluids were likely to constitute the primary source for the extensive radium-rich barite deposits of varied morphological shapes documented by us on the seafloor. At the time of the submersible observations, the impact of the excess barium and radium on the benthic habitats was unknown.

The inference that hydrocarbon seeps may act as additional sources and sinks for barium and radium in the benthic environment of the OCS Gulf of Mexico complicates previous assessments concerning the fate and effects of offshore drilling. These assessments have assumed that the only external source for these toxic/radioactive elements is derived from the drilling muds and produced waters, respectively. Therefore, to establish a technical basis for decisions concerning possible impact of deepwater drilling offsetting the subsurface hydrology and industrial discharges on the deepwater marine habitats, it was necessary to evaluate the contribution of barium and radium derived from seeps, their removal into the sediment, and their uptake by the chemosynthetic communities associated with the seeps.

In contrast to the shelf area, where 50 years of drilling and production of hydrocarbons occurred, the deepwater habitats along the slope are relatively pristine. However, as the oil and gas industry is moving its exploration and production main activities to deepwaters, the habitats' present pristine status is likely to change. It is, therefore, important to explore the natural processes occurring in deepwaters ahead of the anticipated anthropogenic complications.

The primary objectives of this study were to document products and processes related to naturally occurring barium and radium-rich fluid emissions from hydrocarbon seeps and to assess their impact on the offshore habitats in deepwater Gulf of Mexico. The specific questions we have addressed are as follows:

1. What are the levels of barium and radium in the pore fluids underlying seeps, in the barite deposits forming around the seeps, and the chemosynthetic communities?

2. What are the nature and origin of barite deposits and the processes promoting their formation?

3. What are the timing and duration of emissions? Are these emissions altered or accelerated by anthropogenic activities?

4. Do recently discovered radium-rich fluid emissions pose a significant internal and/or external radiation threat to the existing seep communities?

The first and second questions were addressed by a direct approach involving (1) specific determinations of barium, radium, and selected chemical elements and their isotopes in pore fluids squeezed from sediment cores taken with the submersible robot arm from barite-bearing seep sites; (2) measurements of barium, radium, and selected chemical elements and their isotopes in solid barites, and (3) determinations of radium and barium in both soft tissues and hard skeletons from methanotrophic mussels and heterotrophic fauna living in the proximity of the barite seeps. These results were compared and contrasted with radium and barium determinations from pore fluids and fauna from carbonate-bearing seeps that appear to represent natural, unperturbed, background radioactive and chemical emission sites. We found that pore fluids contain important information concerning their source and migration pathways, and their chemical fingerprinting allowed us to identify their subsurface source/s with a fair degree of certainty. The third and fourth questions are much more difficult to resolve definitively within the time-limited scope of this study. An indirect approach to the problem was taken, which involved inferences from spatial and temporal distribution patterns of barium and radium within the barite deposits. Radium and barium in growth increments from the barite chimneys were used as an archived history and record of episodic venting whose chronology was derived from the radium-decay series isotopes. The youthfulness of all the barite deposits may be taken as an indication of possible accelerated emissions from the seeps, implicating unusual nonuniform disturbances of the subsurface hydrology increasing formation water ascent to the seafloor through normal faults from deep reservoirs. To resolve the fourth question, external gamma ray and internal alpha radiation (derived by ingestion of radioactive barite) exposure and dose to epifauna inhabiting the barite seeps, consisting of vagrant heterotrophs (galatheid crabs, starfishes) and sessile methanotrophic mussels, was estimated from measured radium-decay series-specific concentrations by means of a computerized dose calculation program (Microshield 5.0).

The results of our investigation can be summarized as follows:

1. Three chemical types of pore fluids associated with hydrocarbon seeps occur in the deepwater Gulf of Mexico. Two are derived from the ambient seawater and their chemical compositions are altered by microbial interactions and by dissolution of sub-seafloor salt diapirs. The third type, highly enriched in Ba and Ra, is derived from deep-seated formation waters and its advection on the seafloor through fault conduits associated with salt diapirism impacts adversely the ambient benthic habitats.

2. Formation-water-derived fluids emerging on the seafloor are anomalously enriched in Ra and Ba relative to seawater by factors of up to 4.5×10^4 and 15×10^4, respectively. Their migration time from the source to the seafloor is established to be < 20 years on the basis of the relatively short-lived ^{228}Ra isotope content.

3. Barite ($BaSO_4$) deposits consist of chimneys, crusts blanketing mud volcanoes, and unconsolidated sands infilling gulleys. The chimneys are dominated by the mineral celesto-barite (i.e., Sr-rich barite), whereas the crusts consist of both barite and calcite. The Gulf of Mexico seep barites are anomalously enriched in Sr, Ca and Ra by comparison with barites from normal marine settings elsewhere.

4. Sulfur, oxygen and strontium isotope compositions indicate that the Gulf of Mexico seep barite deposits form by the mixing of sulfate-rich seawater with Ba-, Sr-, and Ca-rich formation fluids seeping with gaseous hydrocarbons, primarily thermogenic methane. The chimneys are erected vertically above the seafloor whereas the crusts drape mud volcanoes and/or form pavements at the sediment/water interface.

5. Both ^{226}Ra and ^{228}Ra are "orphans" in the sense that their respective parents ^{238}U and ^{232}Th are practically absent in the fluids and barites. The "orphan" property of Ra affords radiometric dating of the barites by $^{210}Pb/^{226}Ra$ and $^{228}Th/^{228}Ra$ daughter/parent isotope pairs. The assays indicate that chimney ages range from 0.5 to 6.5 years whereas the crust ages range from 9.0 to 23.1 years. The growth rates of the chimneys vary from 4.4 cm/yr to 9.1 cm/yr. These results indicate that the Ba-Ra-rich fluid expulsion on the seafloor, triggering barite deposition, is a rapid and recent event. At this point, we cannot discern whether or not the intensified emissions are related to disturbances in subsurface hydrology triggered by exploration and production from deepwater platforms. This question must be addressed responsibly in future studies.

6. The uptake of Ba and Ra by the fauna inhabiting the barite-bearing seeps was found to be proportional to the Ba/Ra ratio in the pore fluids. Mussels harboring methanotrophic endosymbionts average 0.6 dpm/g and 0.5 dpm/g ^{226}Ra for soft tissues and calcareous shells, respectively, which are significantly higher than those reported for shallow marine mussels. Vagrant, heterotrophic, fauna living around the seeps yield ^{226}Ra and Ba up to 10.7 dpm/g and 4,319 ppm, respectively. The considerably higher levels of Ra and Ba in the heterotrophs are probably acquired through ingestion of barite particles.

7. The largest possible radiation dose to fauna from Ra-rich barites (0.0128 mGy/day) is substantially lower than the threshold of detrimental radiation effects for aquatic animals. However, the cumulative radiation dose and consequential genetic effects over a mean lifespan of 25 years for mussels could be substantial. These estimates have not considered the radiation exposure derived from ^{222}Rn gas dissolved in the surrounding bottom waters because of absence of data. There is a need to determine the level of radon in the ambient seeps to properly assess the impact of radon radiation hazards.

NOAA'S OTHER OIL MODELING INITIATIVES (GNOME/WIZARDS/TAP)

Ms. Debbie Payton
National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) conducts a number of modeling activities in the Hazardous Materials Response Division (HAZMAT). These modeling activities range from real-time operational support during spills of oil and other hazardous materials to modeling for drills and planning. Our focus for the past year has been in three areas: (1) improvements in trajectory analysis; (2) development of tools for end-users other than HAZMAT; and (3) development of planning tools.

To improve our present trajectory analysis capabilities, we have been investigating implementation of 3-D modeling, improving weathering estimates, developing an extended outlook approach, and improving our circulation models. For 3-D modeling, we are focusing on the application of 3-D models to dispersant application. We have been involved in a number of Environmental Risk Workshops around the country to look at the tradeoffs of dispersant use during oil spills. As part of these workshops, HAZMAT has been providing estimates of dispersed oil concentrations in the water column. We have been using a number of models to accomplish these estimates. Our efforts for the present and through the next two years will be on coupling these models together so that they can be more readily used operationally. Weathering improvements are discussed in a separate presentation.

In providing operational trajectory analysis, we are often limited by the time-scale of the available reliable weather forecast. Typically we provide estimates for up to two days in the future. In some instances, particularly large spills, spills of very persistent oils or vessels that are endangered but have not yet lost their cargo, it is useful to have longer trajectory estimates. We are developing an "extended outlook" that will be based on the standard trajectory analysis assumptions for the first 48 hours or so and transition to climatological data beyond that time. This will provide us with the capability to generate useful trajectory information beyond the standard 48 hours.

The circulation used in most of our trajectory analysis is based on models that we have developed in-house for certain hydrodynamic regimes. The results from these hydrodynamic models are scaled using on-scene observations, literature or local expertise. We are working on both expanding the types of regimes we can reasonably model and developing methods to use results from other hydrodynamic models to drive the circulation needed as part of the trajectory.

The General NOAA Oil Modeling Environment (GNOME) has been under development for the last few years. It is now our operational model as well as a model that others can use to investigate potential pollutant movement. We have developed 15 locations around the United States that have "pre-loaded" data for use with GNOME. For the standard user interested in specific scenarios for drills, intuition building or exploring uncertainty, these location files can be quite useful. Location files are distributed over the internet with a "wizard" front-end that leads the user through important questions to define the necessary conditions (river flow rates, location to start spill, amount and type of oil spilled, etc.). We expect to continue development of these location files over the next three years, until we have completed all 38 locations identified by the USCG as high-priority sites. Used in a more advanced mode (diagnostic mode), GNOME provides the necessary tools for a trajectory analyst to estimate movement during an actual spill event.

In the past, trajectory models, such as GNOME, were used to address planning needs as well. “Worst Case” scenarios were developed, run through a model, and one component of planning was based on what the threats were estimated to be. NOAA/HAZMAT has been working on the development of a Trajectory Analysis Planner (TAP) to more completely address spill planning needs. TAP is model that uses climatological data and runs hundreds (or thousands) of spill scenarios to define potential threats. TAP has been developed for San Francisco, San Diego and Kaneohoe Bay. HAZMAT is working with the Navy to improve TAP in San Diego so that allowances for booms, skimming or other removal processes can be reflected in the ultimate fate of the oil. At present, TAP is still in the research and development phase. When it becomes operational, we anticipate TAP to provide significant contributions to the planning process.

ASA OIL SPILL MODELS: MODELING THE MOVEMENT OF OIL AND GAS RELEASED FROM DEEP WELL BLOWOUTS

Mr. Eric Anderson
Applied Science Associates, Inc.

INTRODUCTION

Over the past twenty years, Applied Science Associates has developed a system of models which evaluate the fates and biological effects of oil and chemical spills. The models use a common framework of geographical and current databases for input data, and outputs are displayed in a Windows interface that shows surface oil distributions and concentrations of oil and chemicals in the water and sediments.

In the last five years, offshore drilling of oil wells has moved to deeper and deeper continental shelf areas, with several existing and planned drilling operations at depths beyond 1,000 meters. When oil and gas are released from a subsea blowout, the movement of the oil and gas mixture is defined as a plume emanates from the release location. At the relatively shallow water depths (less than 500m) previously drilled, the gas commonly released with the oil has driven the upward movement of the oil and gas plume. Equilibrium theory and observations show that methane (the primary gas released) will form a hydrate at the pressures and temperatures existing at these depths. The specific gravity of the gas hydrate is very close to the specific gravity of oil. Therefore, if hydrates form during a deep water blowout, the driving force behind the rapidly rising oil and gas plume is dissipated, and the travel time of the released oil is markedly increased. Interest in the modeling of potential blowouts from such drilling operations now includes the modeling of the formation of these hydrates. The basic framework for the model system is described in previous works, both in the manuals for the systems themselves (ASA 1996, 1997), and in published hindcast studies of previous well-studied oil spills (Kolluru *et al*. 1994; Spaulding *et al.* 1992a, 1992b, 1993, 1994, 1996).

SUBSURFACE PLUME MODEL

The plume generated from an oil and gas blowout is a mixture of gases, liquids, and solids which has coherent spatial volume and definable spatial movement. In the region immediately near the release point, the movement of this plume is governed by the momentum of the released materials. Due to the relatively high mass of the receiving water, this phase of the plume is very short (on the order of one to a few meters). After the initial momentum-forced stage, the movement of the plume upward is governed by the differential in the density of the material inside the plume boundary and the density of the receiving water outside the plume. The greater the differential densities, the greater the speed of plume rise. When gas and oil are released from a well that is blowing out, typical volume ratios of gas to oil are in the range of hundreds to one. Thus a hundred cubic meters of gas may be released with a single cubic meter of oil. ASA's plume model has been in use over the past fifteen years with applications to sub-sea blowouts without hydrate formation, drill cuttings and mud dispersion, and produced water dispersion modeling.

In 1999, ASA engaged a leading expert in the deep sea hydrate formation process, Dr. Raj Bishnoi of the University of Calgary, to include the potential for the hydrate formation process in the plume model dynamics. Dr. Bishnoi and his associates generated a model for the formation of methane hydrates at the pressures and temperatures to be found in the drilling regimes to be studied (Figure 2E.1). Figure 2E.2 shows an example of this equilibrium solution. Increasing water depth is represented as positive change on the vertical axis. Increasing water temperature is positive horizontal change. If methane gas is released in the zone to the left and above the red curve (marked with circles) and sufficient water is available, hydrates will be formed. If methane hydrates move to the region to the right and below the hydrate curve, these hydrates will revert to gaseous form and release water. Adding this hydrate formation to our existing plume model, we find that the mixing of water into the methane-oil-water plume is the limiting factor for the formation of hydrates.

PLUME TRAPPING

A good deal of attention has been paid to the phenomenon of plume trapping. The term “trapping” here implies that the forcing mechanism that causes the mixture of gas and fluid in the rapidly rising plume diminishes to the point that there is no difference between the density of the outside fluid and the density of the mixture in the plume mass. If the gas that is forcing upward plume movement changes state to hydrate form, the primary forcing for the upward movement of the plume will be lost,

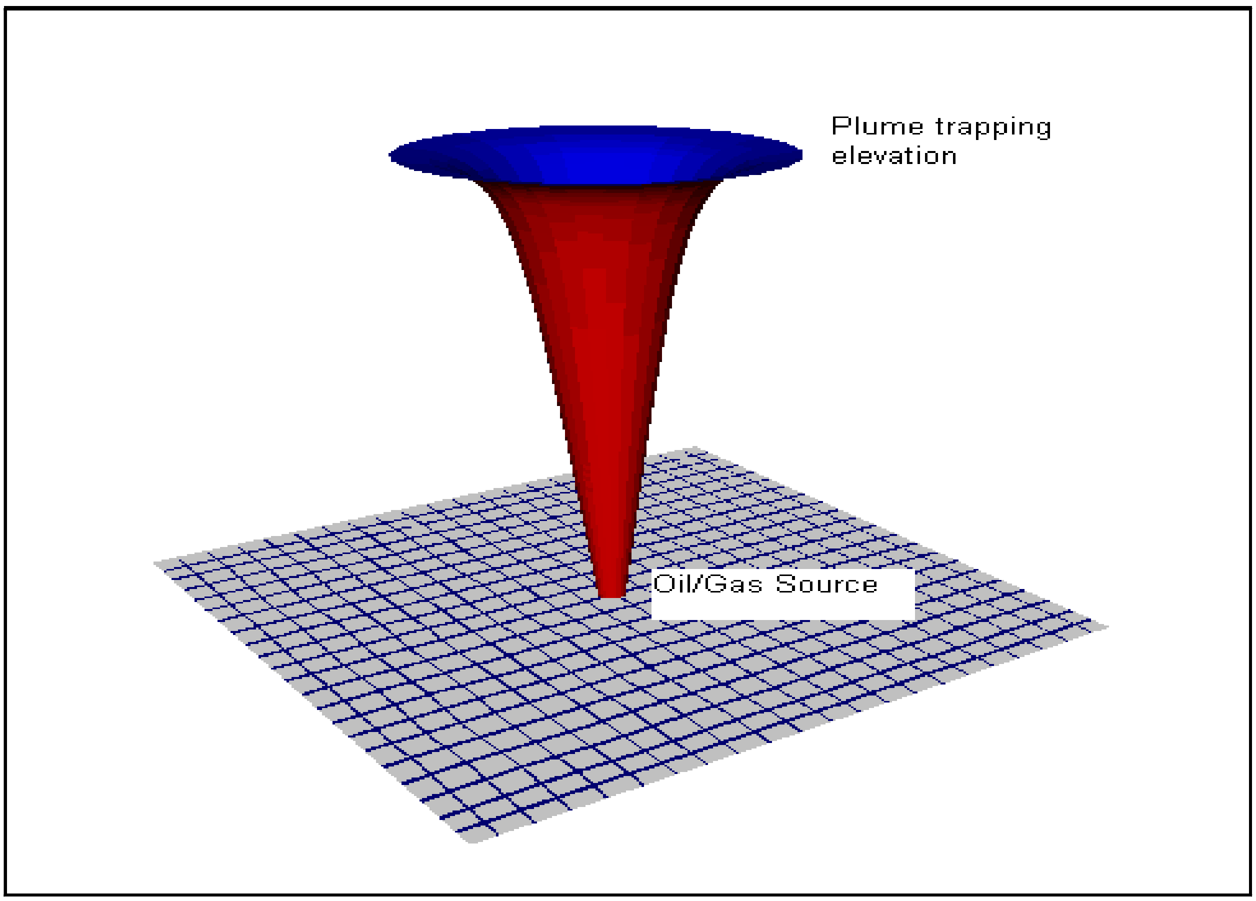

Figure 2E.1. The model for the formation of methane hydrates.

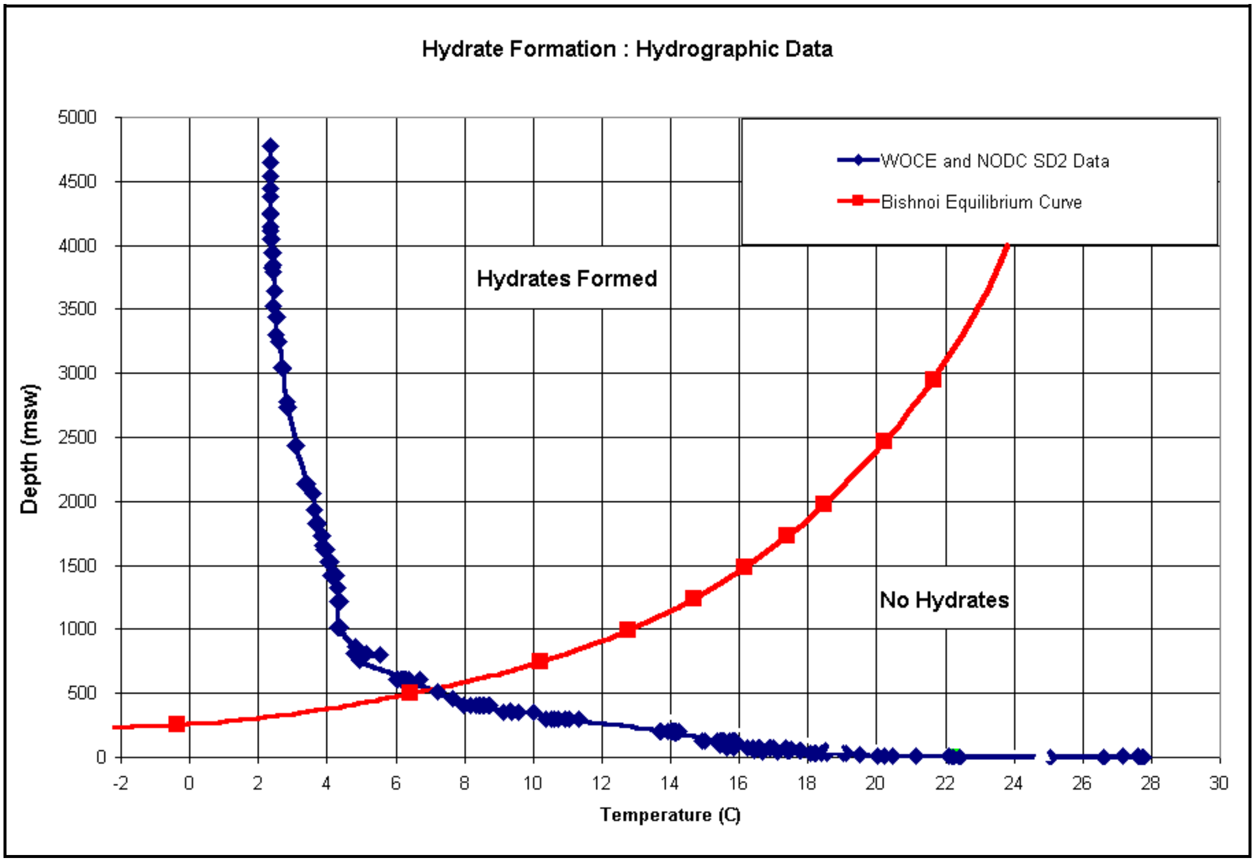

Figure 2E.2 An example of the equilibrium solution.

and the plume is likely to disappear. The oil and hydrates released at the end of the plume movement will generally be of lower density than the surrounding water and will continue toward the surface at the rise rates for the individual particles themselves. The hydrate particles are generally not of great concern. We follow the movement of the oil particles to predict the time when these particles will reach the surface. The larger the particle size for these oil particles, the faster will they rise. Thus, the particle size distribution for these oil droplets is of great concern. Table 2E.1 below shows some examples of computed rise times for a release of Foinaven crude from the top of a trapped plume at 890m below the sea surface. The range of droplet sizes assumed is from experimental work done by Delvigne and Sweeney (1998). One can see that if the majority of oil droplets are in the range of 500 micrometers, the oil will rise to the surface in about one day. If the majority of the droplet sizes are on the order of 100 micrometers, the mean rise time will be more like a month. ASA has applied this model system to several potential blowout locations in drilling areas off the Americas, the UK, and Africa. The need for validating data, both for hydrate formation and for released oil particle sizes is demonstrated by these model simulations.

CONCLUSIONS

A model of the movement of oil and gas plumes released at depths more than 500m below the sea surface has been developed and applied to several potential scenarios in oil-producing areas

Table 2E.1. Rise velocities and times from 890 m depth for various size oil droplets. Droplets are assumed to have the Foinaven crude specific gravity of 0.902 in seawater with a specific gravity of 1.026. Rise velocities are computed using the Stokes formula with a dynamic viscosity of 1.8 x10^{-6} (m^2/s).

Droplet diam. (μm)	Oil Specific Gravity	V (cm/s)	V (m/day)	Rise Time from 890m (days)
50	0.902	0.00886	7.7	116.3
100	0.902	0.03544	30.6	29.1
200	0.902	0.1418	122.5	7.3
300	0.902	0.3189	275.6	3.2
400	0.902	0.567	489.9	1.8
500	0.902	0.8605	743.5	1.2

throughout the world. The importance of the droplet size distribution for oil released during these blowouts is shown. The need for field data of natural or simulated oil blowouts is needed for the calibration of such deep blowout models.

REFERENCES

Applied Science Associates, Inc. (ASA). 1996. Technical Manual for Spill Impact Modeling (SIMAP). Version W1.0, Applied Science Associates, Inc., Narragansett, RI.

Applied Science Associates, Inc.(ASA). 1997. OILMAP Users Manual Applied Science Associates, Inc., Narragansett, RI.

Bishnoi, P.R. and B.B. Mainik. 1979. Laboratory study of behaviour of oil and gas particles in salt water, relating to deepwater blowouts. Spill Technology Newsletter, 4:1, pp. 24-36.

Bishnoi, P.R., A.K. Gupta, P. Englezos, Kalogerakis. 1989. N. Fluid Phase Equilibria, 83, 97.

Delvigne, G.A.L., and L.J.M. Hulsen. 1994. Simplified laboratory measurement of oil dispersion coefficient – application in computations of natural oil dispersion. Proceedings of the Seventeenth Arctic and Marine Oil Spill Program, Technical Seminar, 8-10 June 1994, Vancouver, British Columbia, Canada, pp. 173-187.

Delvigne, G.A.L., and C.E. Sweeney. 1988. Natural dispersion of oil. Oil & Chemical Pollution 4, 281-310.

Kolluru, V., M. L. Spaulding, and E. Anderson. 1994. A three-dimensional subsurface oil dispersion model using a particle based technique, 17th Arctic and Marine Oil Spill Program, Technical Seminar, 8-10 June 1994. Vancouver, British Columbia, Canada, pp. 767-784.

Spaulding, M.L., P. R. Bishnoi, E. Anderson, and T. Isaji. 2000. An Integrated Model for Prediction of Oil Transport from a Deep Water Blowout. 23rd Arctic and Marine Oil Spill Program, Technical Seminar, 14-16 June 2000, Vancouver, British Columbia, Canada, pp. 611-635.

Spaulding, M.L., E. Howlett, E. Anderson, and K. Jayko. 1992a. OILMAP a global approach to spill modeling. 15th Arctic and Marine Oil Spill Program, Technical Seminar, 9-11 June 1992. Edmonton, Alberta, Canada, pp. 15-21.

Spaulding M.L., E. Holwett, E. Anderson, and K. Jayko. 1992b. Oil spill software with a shell approach. Sea Technology, April 1992. pp. 33-40.

Spaulding, M.L., E. Anderson, T. Isaji, and E. Howlett. 1993. Simulation of the oil trajectory and fate in the Arabian Gulf from the Mina al Ahmadi spill. Marine Environmental Research, 36:2, pp. 79-115.

Spaulding, M.L., V. S. Kolluru, E. Anderson, and E. Howlett. 1994. Application of three dimensional oil spill model (WOSM/OILMAP) to hindcast the Braer spill. Spill Science and Technology Bulletin, 1:1, pp. 23-35.

Spaulding, M.L., T. Opishinski, E. Anderson, E. Howlett, and D. Mendelsohn. 1996a. Application of OILMAP and SIMAP to predict the transport and fate of the North Cape spill, Narragansett, RI. 19th Arctic and Marine Oil Spill Program, Technical Seminar, 12-14 June 1996. Calgary, Alberta, Canada, pp. 745-776.

Spaulding, M.L., T. Opishinski, and S. Haynes. 1996b. COASTMAP: An integrated monitoring and modeling system to support oil spill response. Spill Science and Technology Bulletin, 3:3, pp. 149-169.

ASA OIL SPILL MODELS: 3-D FATES AND EFFECTS MODELING APPLICATIONS FOR GULF OF MEXICO SPILLS

Dr. Deborah French McCay
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INTRODUCTION

Over the past twenty years, Applied Science Associates has developed a system of models that evaluate the fates and biological effects of oil and chemical spills. The models use a common framework of geographical and current databases for input data, and outputs are displayed in a Windows interface that shows surface oil distributions and concentrations of oil and chemicals in the water and sediments.

SIMAP (for oil) and CHEMMAP (for chemicals) were originally developed from ASA's oil trajectory models and the fates and biological effects submodels in the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME). The NRDAM/CME was developed by ASA for the U.S. Department of the Interior. The NRDAM/CME (Version 2.4, April 1996) was published as part of the CERCLA type A Natural Resource Damage Assessment (NRDA) Final Rule (Federal Register, 7 May 1996, Vol. 61, No. 89, p. 20559-20614). However, considerable further development beyond that contained in the NRDAM/CME has been accomplished in SIMAP (French *et al.* 1999) and CHEMMAP (French 2001), including incorporation of hydrodynamic modeling for currents, specific model tracking of subsurface oil, and probabilistic modeling for both oil and chemicals.

The presentation and summary below include

- Descriptions of the models
- Validation studies
- Applications to the Gulf of Mexico (GOM)

PHYSICAL FATES MODEL

The physical fates model estimates distribution (as mass and concentrations) of contaminant on the water surface, on shorelines, in the water column, and in sediments. The model is three-dimensional, using a latitude-longitude grid for environmental data and projecting model results into that grid. A geographical information system (GIS) database supplies values for water depth, sediment type, ecological habitat, shoreline type, and ice cover throughout the gridded domain. The chemical database supplies physical-chemical parameters required by the model. The user supplies a wind time series and current data set specific to the time and location of the spill.

The physical fates model tracks the center and surrounding distribution of mass for a large number of "spillets" (sub-lots of the total mass spilled). If the density of a spilled chemical is less than or equal to that of water (e.g., oils) the model estimates surface spreading, slick transport, entrainment into the water column, and evaporation, to determine trajectory and fate at the surface. Surface slicks interact with shorelines, depositing and releasing material according to shoreline type. A contaminant heavier than water is initially modeled as a convective plume which may reach an equilibrium position in a stratified water column or sink to the bottom.

The processes modeled include spreading, evaporation, transport, dispersion, emulsification, entrainment, dissolution, volatilization, partitioning, sedimentation, and degradation. For oil, mass is tracked separately for low molecular weight aromatics (monoaromatics, BTEX, and 2 to 3-ring polynuclear aromatic hydrocarbons, PAHs) which cause toxicity, other volatiles, and non-volatiles.

The physical fates model computes concentrations in the water column and sediments, and the area of water and shoreline covered by surface slicks in space and time. This information is passed to the biological effects model, which then calculates biological effects of those concentrations and areas of coverage.

BIOLOGICAL EFFECTS MODEL

The biological effects model calculates the portion of a population affected by slicks and subsurface contamination. Habitat-specific estimates of fish, shellfish, bird, mammal, and reptile abundance, and productivity of plant and animal communities at the base of the food chain, are used to determine biomass lost as a result of the spill. A rectangular grid of habitats represents the area potentially affected by the spill, with each grid cell coded for habitat type. Habitats include deepwater, nearshore, wetland, and shoreline environments. Fish, birds, and mammals are assumed to move at random within each habitat. Planktonic stages (eggs and larvae in the water column) are moved with the currents.

In the model, surface slicks (e.g., oil and petroleum products) interact with wildlife (birds, mammals, reptiles). A portion of wildlife in the area swept by the slick are assumed to die based on probability of encounter with the slick, dosage, and mortality once oiled. Estimates for these probabilities are derived from information on behavior and field observations of mortality under similar circumstances.

The biological model estimates acute toxic response of aquatic biota. Fish and their eggs and larvae are affected by dissolved contaminant concentration (in the water or sediment). Mortality is calculated using laboratory acute toxicity test data (LC50, concentration lethal to 50% of test individuals) corrected for temperature and duration of exposure, and assuming a log-normal relationship between percent mortality and dissolved concentration.

The effects of oil on aquatic organisms may be quantified as a function of (1) low molecular weight aromatic content and composition in the oil and (2) the fate and partitioning of those components in the environment. Low molecular weight aromatics have a narcotic mode of action. Thus, an additive toxicity model may be used to estimate the toxicity of the aromatic mixture in oil. Estimated toxicity of the individual aromatics is based on a regression against the octanol-water partition coefficient (K_{ow}), a measure of solubility. This model was verified with available oil bioassay data. Both volatility and solubility decrease with increasing K_{ow}, while toxicity increases strongly with K_{ow}. The aromatics with the lowest K_{ow} dissolve the fastest, but are also rapidly lost from the water due to volatilization. If the dissolution of higher K_{ow} aromatics is enhanced by submergence of the oil and high turbulence, which greatly increases the surface area of the oil-water interface, the concentrations of the higher molecular weight aromatics (i.e., PAHs) can become high enough to cause significant acute toxicity.

Movements either of biota, active or by current transport, are accounted for in determining concentration and duration of exposure. Organisms killed are integrated over space and time by habitat type to calculate a total kill. Lost production of plants and animals at the base of the food chain is also computed. Lost production of fish, shellfish, birds, and mammals due to reduction or contamination of food supply is estimated using a simple food web model.

In addition to the direct kill and food-web losses of eggs and larvae, fish young-of-the-year may be lost via habitat disruption. This loss is included in the model for wetland and other nursery habitats destroyed by lethal concentrations or oiling. Losses are related to the habitat loss. Thus, recovery of spawning and nursery habitat in wetlands follows recovery of plant biomass and production.

The biological effects model computes reduction of fish and shellfish catch in the present and future years using standard fisheries models. Lost catch includes losses due to mortality of adults, juveniles and larvae due to the spill. Relatively high natural mortality rates of fish eggs and larvae are considered in the model, since a high number killed at the time of the spill would have died anyway. Young-of-the-year (eggs, larvae, and juveniles less than one year old) of each fish species category are tracked as percents of the one-year-old population. Young-of-the-year and older age classes are not assumed to inhabit the same environment concurrently, and their losses are calculated separately.

Using similar models, the numbers of birds and mammals missing and not hunted in present and future years are also calculated. For all fish and wildlife, population losses are the number not left alive in present and future years as the result of the spill, after constant natural mortality (and hunting mortality) is subtracted.

SIMAP MODEL VALIDATION

The physical fates and biological effects models in SIMAP have been validated using data from twenty-eight oil spills. For twenty-seven of these case histories (French and Rines 1997), observational data were available for surface oil impacts, as field observations after spills focus on these effects. The validation studies show that the model is capable of hind-casting the oil trajectory and shoreline oiling, given (1) accurate observed wind data following the spill and (2) a reasonable depiction of surface currents, both tidal and background. As winds and currents are the primary forcing variables on oil fate, obtaining accurate data on these is very important to the accuracy of any simulation.

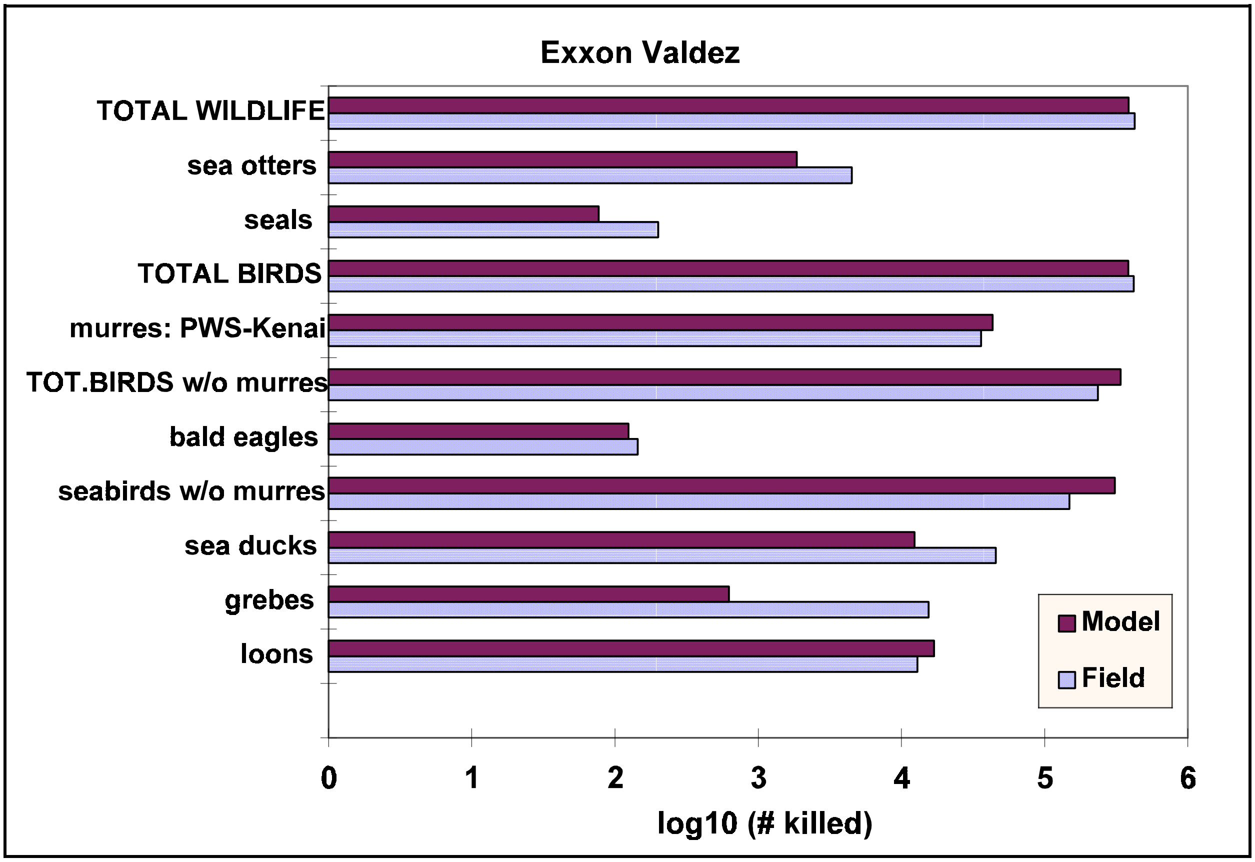

Figure 2E.3. Model and field data on the Exxon Valdez oil spill.

In most cases, impact information for the spill consists primarily of counts of rescued or dead wildlife. The model results either agree well with field estimates or underestimate the observed kill, as with the Exxon Valdez spill shown in Figure 2E.3. The cases where wildlife kills are underestimated are those in which an unusually high abundance of certain species occurred in the spill path, or in which data on abundance of animals were not available. Many of these cases were in fact considered highly significant spills both because of the size of the spill and of the presence of unusually high aggregations of certain wildlife species. Modeling results show that the impact algorithms in the model are valid when input data on abundance are accurate.

In one case, the *North Cape* oil spill of January 1996 in Rhode Island, field observations were available for both surface and subsurface fates and impacts. The model's prediction of the oil's fate agreed with observations of surface oil movements and measurements of total hydrocarbons and aromatics in the water. The model estimate of birds oiled was 2,200-4,400, depending on the pre-spill abundance data assumed. The mid-point of this range is 8.5 times the number of birds collected on beaches, in agreement with estimates for other spills. (The negotiated settlement used a factor of six for this spill.) Impacts on water column organisms were validated by comparison of the model estimate to the field observations of the lobster kill (8.3 million and 9 million, respectively). The model estimates of impacts to other marine species were used in the government's natural resource damage claim to the responsible party. This claim was settled based on these estimates of injury.

Success of a model simulation is dependent on both the algorithms and the accuracy of the input data. Results of the validation exercises verified the model algorithms. The most important input data in determining accuracy of results are winds, currents, and biological abundances of the affected species. Thus, the model system applied with accurate environmental and biological data inputs, can quantitatively and objectively estimate the impacts of spills into aquatic systems.

STOCHASTIC MODEL APPLICATIONS FOR ECOLOGICAL RISK ASSESSMENT

Stochastic modeling is used to quantify the probability of impact from an oil or chemical discharge. These data provide needed information for risk assessments and contingency planning. Stochastic modeling consists of running the model many times, varying key parameters, such as environmental conditions and spill amount, to create a picture of the most probable impacts from expected spills.

For SIMAP and CHEMMAP applications in the GOM, long-term (>10 year) historical wind and current data are assembled for the area of interest. The model is run multiple times, randomizing the start date and time within a specified range of months of the year. The spill volume is either held constant or randomized from 0% to 100% of the worst-case amount each run. An effects endpoint is selected, which provides a threshold above which probabilities are to be reported.

Model output includes maps of oil/chemical

- mass on the water surface,
- mass on shorelines,
- dissolved concentration in the water column,
- concentration of submerged particles in the water column, and
- mass in the sediments.

Statistics are produced for each location (cell) in the model grid, including

- probability of (any) mass or concentration exceeding the threshold,
- time when mass or concentration first exceeds threshold,
- mean expected maximum mass or concentration (i.e., mean of all runs), and
- worst-case (maximum possible) mass or concentration (i.e., maximum of all runs).

The worst-case spill conditions is identified from the probability analysis described above. The worst-case is for those wind and current conditions that maximize exposure to sensitive resources near the spill site. A specific worst case scenario may then be forecast using the three-dimensional fates and biological effects models in SIMAP or CHEMMAP. This quantifies the worst possible concentrations and biological effects for a spill site (see Figure 2E.4). Sensitivity analysis provides measures of uncertainty for these predictions.

Spill Consequence Modeling for the NRC Double-Hull Tanker Committee

The U.S. Coast Guard commissioned a National Research Council (NRC) committee to evaluate the cost-benefits of double hull tankers as opposed to other tanker designs. At the request of the NRC Double-Hull Tanker Consequences Sub-Committee, ASA performed oil spill consequence modeling using SIMAP in stochastic mode. The purpose of the spill modeling was to develop quantitative estimates of the relationship between spill size and consequences. *Consequences* include all of the economic, financial and environmental implications of a spill. Spill modeling provided measures of oil-impacted areas and volumes to be used in these calculations.

The modeling was performed for spill sites in different regions of the US, including the GOM near Galveston. Model scenarios included two oil types and seven volumes. The results showed that the impact (consequences) of one large spill is less than the sum of several smaller spills totaling the same volume (French *et al.* 2000). The NRC committee is evaluating the over-all risks for double hull tankers, where spills would be larger and less frequent, versus other designs.

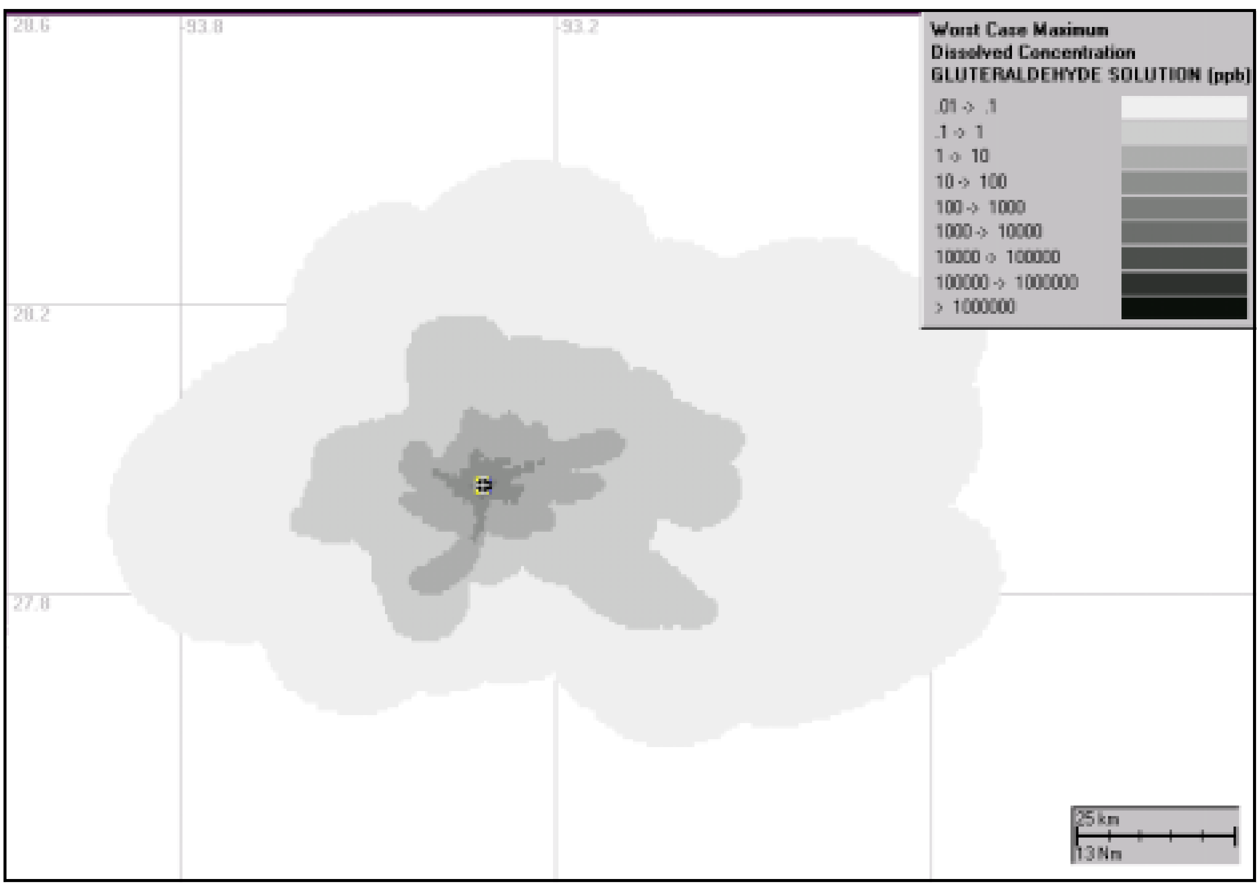

Figure 2E.4. Sample worst-case scenario map from chemical spill.

Chemicals Related to Deepwater Oil and Gas Operations in the Gulf of Mexico

ASA performed chemical spill modeling with CHEMMAP, which was used to analyze environmental risks associated with chemical products used in deepwater oil and gas operations in the GOM. The team lead by A.D. Little used the model results to evaluate risks of impacts from spills. Seventeen scenarios were run for hypothetical spills in the offshore GOM. An assessment of potential ecological risks is based on these modeling results (Boehm *et al.* 2001).

CONCLUSIONS

Numerical models offer a powerful range of tools to better assess the consequences of spill incidents whether this be at the planning stage or to evaluate a specific spill incident. These integrated model systems may be used to quantify environmental impacts of real hazardous spill events (for natural resource damage assessment and other purposes), of hypothetical spills (probabilities in a risk assessment) and of response management strategies (contingency planning). Embracing the traditional scientific methods of collecting and analyzing relevant environmental data, these tools can convey to interested parties answers to important marine-related environmental issues, which can be complex and often difficult to assimilate.

REFERENCES

Boehm, P., D. Turton, A. Raval, D. Caudle, D. French, N. Rabelais, R. Spies, and J. Johnson. 2001. Deepwater Program: Literature Review, Environmental Risks of Chemical Products Used in Gulf of Mexico Deepwater Oil & Gas Operations, Final Report to US Department of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, February 2001, OCS Study MMS 2001-011, 326 pp. plus appendices.

French, D. P. 2001 Chemical Spill Model (CHEMMAP) for Forecasts/Hindcasts and Environment Risk Assessment. Proceedings of the 2001 24th Arctic and Marine Oil spill Program (AMOP) Technical Seminar 13-15 June 2001.

French, D.P. and H. Rines. 1997. Validation and use of spill impact modeling for impact assessment. *In* Proceedings of the 1997 International Oil Spill Conference, American Petroleum Institute, Fort Lauderdale, Florida, Publication No. 4651, pp. 829-834, 1997.

French, D., H. Schuttenberg, and T. Isaji. 1999. Probabilities of oil exceeding thresholds of concern: examples from an evaluation for Florida Power and Light. in Proceedings of the 22nd Arctic and Marine Oil Spill Program (AMOP) Technical Seminar, 2-4 June 1999, Environment Canada, pp.243-270.

French, D., H. Schuttenberg, T. Isaji, C. Galagan, and D. Field. 2000. Final Report of the National Research Council Double-Hull Tanker Consequences Sub-Committee. 28 June 2000. ASA report 99-149.

SESSION 2F

SOCIOECONOMIC MODELING

Chairs: Ms. Stephanie Gambino, Minerals Management Service
Ms. Vicki Zatarain, Minerals Management Service

Date: December 6, 2000

Presentation	Author/Affiliation
Modeling the Economic Impact of Offshore Activities on Onshore Communities	Dr. David E. Dismukes Econ One Research, Inc. and Center for Energy Studies Louisiana State University Williams O. Olatubi Center for Energy Studies Louisiana State University
The Minerals Management Service's New Consistent Approach to Modeling Regional Economic Impacts	Ms. Vicki Zatarain Mr. Kim Coffman Minerals Management Service
An Analytical Model of Operating Platforms on the U.S. Gulf of Mexico Outer Continental Shelf (OCS), 1947-1997	Dr. Omowumi O. Iledare Dr. Allan G. Pulsipher Dr. Dmitry V. Mesyanzhinov Dr. Alan Dupont Ms. Qiaozhen "Lucy" Zhu Center for Energy Studies Louisiana State University
Modeling of Platform Installations and Removals: The MMS Perspective	Mr. Thierry DeCort Ms. Stephanie Gambino Minerals Management Service
The Offshore Environmental Cost Model	Dr. William King Minerals Management Service

MODELING THE ECONOMIC IMPACT OF OFFSHORE ACTIVITIES ON ONSHORE COMMUNITIES

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Econ One Research, Inc. and
Center for Energy Studies
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INTRODUCTION[1]

The economic impact of offshore activities has become an increasingly important issue to the Department of Interior, Minerals Management Service (MMS). A very large portion of this research is subsumed within the agency's Environmental Studies Program (ESP) and defined in its National Strategic Plan (NSP):

> The ESP Strategic Plan addresses a wide variety of environmental concerns and issues on a national scale by identifying emerging and ongoing program areas. It complements and builds upon broader strategic plans that set Agency-wide policies and directions. Within these broad issues or themes, multi-disciplined studies will be developed, as budget allocations allow (LTG Associates, Inc. 2000).

The socioeconomic studies component of the program

- Provides information essential to understanding the consequences of OCS-related activities for the populations, economies, and social and cultural systems in areas where the activities occur;
- Supports the MMS's planning and management processes; and
- Provides information essential for effective interaction with the public about the effects of OCS activities (LTG Associates, Inc. 2000).

The MMS's primary legal mandate to analyze the socioeconomic impacts of natural resource management issues is provided in both the Outer Continental Shelf Lands Act, as amended in 1978 (OCSLAA), and the National Environmental Policy Act of 1969 (NEPA).

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[1] A similar, but slightly different, version of this paper was presented and published in the proceedings of the International Association of Energy Economics Annual Meetings of September 2000.

Over the past several years, the ESP has been becoming increasingly more engaged in the socioeconomic research of coastal communities in support of its EIS mission. In the past 10 years, the quantity of research funded under this program has tripled. While one cannot predict the levels of funding that will be provided in years to come, a recent meeting of social scientists and researchers indicated that both interest in and commitment to these issues would continue to be strong. Of the three major MMS regions (Alaska, Pacific, and Gulf of Mexico), the Gulf of Mexico (GOM) would appear to have a pressing need for continued socioeconomic impact analyses. The Gulf, in addition to providing a significant number of reserves and production, is also undergoing unique developments in both deepwater activity (900 meters and above) and the potential development of frontier areas in the eastern Gulf off the coast of Florida.

As early as the mid-1980s, the MMS Gulf of Mexico region began its efforts to model the implications that offshore development had on coastal communities. For close to 10 years, however, a good portion of these regional modeling initiatives focused more on past consequences of outer continental shelf (OCS) oil and gas development than on predictive methods. These initiatives could be broken into two general categories: (1) individual historic "consequences" analyses and (2) the development of baseline analyses (Lutton and Cluck 2000). Information from both types of studies were regularly used to examine economic impacts to local communities for EIS purposes.

In the past several years, however, there has been a concerted effort by the MMS to develop more sophisticated modeling approaches that incorporate both more quantitative rigor and applied realism. One of the first studies to examine offshore activities from a more rigorous and applied perspective was conducted by Foster Associates (Ongoing) for the federal waters off the coast of Alabama Wade and Mott 1998). This study revealed a number of unique expenditure patterns that were required to support production of caustic (high H_2S) natural gas. The results of this study help move the agency in the direction of (1) employing Input-Output (IO) models as a basis for measuring the economic impact of all offshore activities and (2) incorporating real-world differences in the production characteristics of particular offshore areas.

One of the major advantages of moving forward with the use of IO models was their ability to allow a researcher to simulate the effects that a change in one or several economic activities has on the entire regional economy. It is more predictive in the sense that the economic impacts associated with hypothetical events, like the opening of several new offshore blocks in the GOM, can be modeled.

A shortcoming with most IO analysis is that the impact drivers (or multipliers) in the model are typically taken from national, as opposed to regional, trends and industries. Such an approach assumes, among other things, that industries in any given area will use inputs in the same proportion as the national average. The concept of multipliers plays key roles in the understanding of regional economic models because they define and form the basis of impact analysis. Multipliers are based on the fundamental notion that one person's expenditure is another's income, and since consumption usually increases when income increase, any extra expenditure feeds through into further expenditure. These effects become smaller and smaller amounts each time around because of leakages of income outside the region or system.

For oil and gas firms operating in the Gulf OCS, the standard IO and hence, its accompanying multiplier analysis (i.e. impact estimation), assumes that input expenditures are made in the same proportion as the national oil and gas industry average. Not only does such an approach assume regional similarities, but it also assumes that onshore and offshore production functions are similar. It is this last problem that causes the most difficulty in using existing regional IO models to examine the economic impacts of offshore activities. The purpose of this paper is to discuss methodological and data collection methods that can help remedy this potential problem.

MODELING METHODS AND ISSUES

There are a number of methodological issues associated with modeling something as complicated and multifaceted as the offshore oil and gas industry. Our research goal has not been to address every methodological issue, but to concentrate on four of the more important issues that were identified by MMS:

1. Can unique offshore expenditure profiles be defined and incorporated into a standard economic input-output framework;

2. Can these expenditure profiles be separated into individual offshore activity phases;

3. Can these expenditure profiles be defined for a given water depth; and

4. How should these offshore expenditure profiles be allocated to onshore areas?

Defining Offshore Expenditure Profiles

The exploration, development, and operation of offshore facilities present considerable logistical challenges. These challenges can be inferred from the types of expenditures made by offshore operators. Thus, the first step in the analysis of offshore activities was to define a relevant set of expenditures, taking into account many of the unique expenditures required this special sector of the oil and gas industry. Some of the expenditure categories with unique implications for offshore activities include:

- Water and Air Transportation—Transportation is important in moving both personnel and equipment from onshore supply and staging bases to areas supporting offshore activities.

- Food and Catering Services—Often food and catering services are contracted by offshore operators to feed crews supporting exploration, development, and production activities;

- Water Supply—Potable water for drinking, as well as water for certain types of drilling muds, lubricants, and fluids, has to be transported to offshore areas;

- Waste Disposal—While this activity is important to both onshore and offshore activities, transportation and onsite storage can create a number of unique logistical challenges to offshore activities;

- Turbines and Fuel—Most offshore platforms have both primary and secondary power generation equipment as well as primary, and in some cases secondary, fuel to operate these generators; and

- Communications, Instrumentation and SCADA Systems—Digital and mobile technologies have had a growing importance for offshore activities.

Our primary IO modeling approach relies on IMPLAN. IMPLAN is an input-output modeling system that belongs to the class of ready-made approaches, originally developed by the U.S. Forest service. However, our subsequent analysis supplemented the existing IMPLAN data with other primary or secondary data; hence, it is classified as a hybrid approach. Such an approach improves impact estimates considerably because of reliability engendered by more realistic 'local' conditions as opposed to 'average' national outlook.[2]

During the course of our research, we provided the MMS with a comprehensive listing of the unique expenditure categories, and their IMPLAN sector identifications. The categories used in modeling the economic impacts of offshore activities have been provided in Table 2F.1.

Defining Offshore Activity Phases

Another important area of examination is defining the relevant phases of offshore activity. Most IO models, as well as National Income and Product Accounts (NIPA), treat oil and gas activities in a highly aggregated form. As noted before, onshore and offshore activities are rarely separated, and even then, are aggregated into either drilling or production activities. MMS, however, must consider a range of offshore oil and gas activities over relatively long periods of time in the EIS evaluation.

The activities that were defined by MMS as being important for socioeconomic modeling purposes include: exploratory drilling; development drilling; platform fabrication and installation; pipeline fabrication and installation; gas processing installation; production; workovers; oil spills; and platform removal & abandonment. For typical EIS analyses, socioeconomic analyses will begin with a forecast of activities (in units) for each of the above activity phases. The Resource Evaluation Division within MMS develops these forecasts independently. These units, when multiplied by total costs, yield the total potential economic shock resulting from that activity. Thus, if a given potential lease sale is forecasted to yield five (5) new exploratory wells at an average total cost of $2 million per well, then the total direct economic shock would be $10 million. The next step in the process is to allocate this $10 million impact by the expenditure profile developed for exploratory drilling.

MMS believed it was important for their impact modeling to develop different expenditure profiles by activity phase given their tendency for variability and substantial composition differences. In addition, there is a tendency for expenditure patterns, and activities, to shift as the development of a potential lease matures. This has implications for economic impacts since many expenditures can move from more capital intensive, construction-oriented activities in the exploration, development,

[2] Data methods underlying most input-output analysis are based on survey, nonsurvey (or ready-made), or hybrid approaches.

Table 2F.1. Offshore expenditure categories.

IMPLAN SECTORS	Sector Description		IMPLAN SECTORS	Sector Description
38	Oil & Gas Operations		399	Transportation Equipment, NEC
50	New Gas Utility Facilities		401	Lab Equipment
53	Misc Natural Resource Facility Construct		403	Instrumentation
56	Maintenance and Repair, Other Facilities		435	Demurrage & /Motor Freight
57	Other Oil & Gas Field Services		436	Water Transport
160	Office Furniture and Equipment		437	Air Transport
178	Maps and Charts (Misc Publishing)		441	Communications
206	Explosives		443	Electric Services
209	Chemicals, NEC		444	Gas Production/Distribution
210	Petroleum Fuels		445	Water Supply
232	Hydraulic Cement		446	Waste Disposal
258	Steel Pipe and Tubes		454	Eating/Drinking
284	Fabricated Plate Work		455	Misc Retail
290	Iron and Steel Forgings		459	Insurance
307	Turbines		462	Real Estate
311	Construction Machinery & Equipment		469	Advertisement
313	O&G Field Machinery		470	Other Business Services
331	Special Industrial Machinery		473	Misc. Equipment Rental and Leasing
332	Pumps & Compressors		490	Doctors & Veterinarian Services
354	Industrial Machines, NEC		494	Legal Services
356	Switchgear		506	Environmental/Engineering Services
374	Communication Equipment, NEC		507	Acct/Misc Business Services
392	Shipbuilding and Ship Repair		508	Management/Consulting Services
			509	Testing/Research Facilities

pipeline, and gas processing construction phase to more labor intensive, maintenance-oriented activities in the production, workover, gas processing and transportation activities.

For instance, steel pipe expenditures can represent close to 29% of total expenditures during platform fabrication activities yet represent only 3% of total expenditures during the production phase. Likewise, instrumentation costs can represent close to 3% of total expenditures during production, but could be a relatively insignificant cost during all other offshore activity phases.

Defining Relevant Water Depths

Another methodological challenge rests with modeling variations in expenditure profiles across water depths. For instance, should, or do, expenditure profiles change as offshore activities move into deeper waters? Conventional wisdom would tend to support the hypothesis that there is a

Table 2F.2. Expenditure profiles for development drilling by water depth.

Sectors	Sector Description	0-60 Meters	60-200 Meters	200-900 Meters	900 + Meters
38	Oil & Gas Ops	0.65341	0.52344	0.64192	0.69198
57	Other Oil & Gas Svc	0.03447	0.02107	0.04069	0.03348
210	Petroleum Fuels	0.02746	0.03349	0.03049	0.02664
232	Hydraulic Cement	0.06566	0.11871	0.07490	0.06410
258	Steel Pipe and Tubes	0.07104	0.15527	0.06077	0.05149
313	O&G Field Machinery	0.01545	0.01524	0.01039	0.00947
403	Instrumentation	0.04110	0.04222	0.04375	0.03817
436	Water Transport	0.08355	0.08276	0.08873	0.07739
437	Air Transport	0.00787	0.00780	0.00836	0.00729
Total		**1.00000**	**1.00000**	**1.00000**	**1.00000**

positive, and probably close to linear, relationship between certain relative costs and water depth. Water transportation costs come to mind as being a relative cost that should increase as water depth, and hence distance, increases. However, the unique realities of offshore activities, coupled with inconsistencies in data collection and (internal) reporting, can lead to significant challenges in what should appear to be an obvious conclusion. Table 2F.2 presents an example of expenditures for development drilling where shifts in expenditure trends are obvious for Sector 38 (oil and gas operations).

Defining the Onshore Allocation of Offshore Activities: The allocation of expenditures to onshore areas is probably one of the more important factors for determining the region-specific economic impacts associated with offshore activities. These break-outs are important because certain onshore support activities tend to be concentrated in particular geographic areas. This concentration has tended to occur in Louisiana and Texas and has continued despite the movement of offshore activities into deeper water and into the Central Eastern portions of the GOM.

The first task at hand in this portion of our analysis has been to allocate offshore expenditures, by commodity categories outlined in Table 2F.1, to the 10 major onshore regions defined by MMS. These regions are presented in Figure 2F.1. Additional regions included in the analysis include Other, Non-Coastal Gulf of Mexico and Rest of World (ROW).

DATA COLLECTION ISSUES AND CHALLENGES

During the course of our analysis, two data collection issues became particularly important:

1. How to identify, locate, and secure reliable sources of information that did not require the use of survey instruments; and

2. How to reconcile accounting classifications to economic classifications.

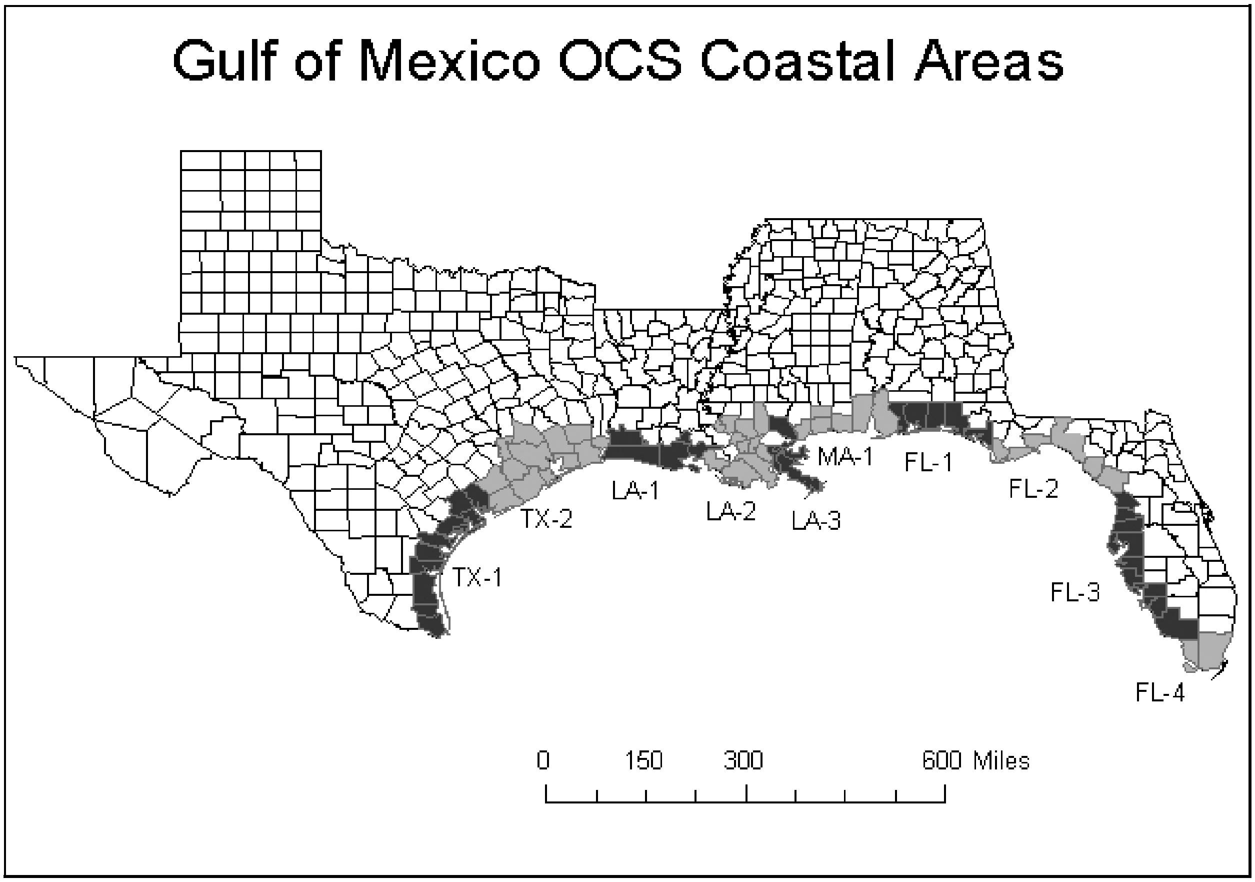

Figure 2F.1. MMS Gulf of Mexico coastal areas.

The first issue was the more problematic of the two and one that plagues ongoing MMS social science research. Our research needed to find a way to collect information that did not use survey or survey-type instruments. Therefore, mailing questionnaires to numerous companies operating offshore was not allowed. This restriction on data collection is placed on MMS by the Paper Work Reduction Act of 1980, and reauthorized in 1995.

This purpose of the Act is to minimize the paperwork burden the federal government places on the public and to improve the quality and use of federal information (Lauterback 2000). The Act also requires each federal agency to seek and obtain approval from the Office of Management and Budget (OMB) before requesting information from ten or more persons. Furthermore, any reporting, record-keeping, or disclosure requirement contained in a rule is deemed to involve ten or more persons. OMB approval is also needed to continue a collection for which OMB's approval and the validity of the OMB Control Number are about to expire. OMB usually approves a collection for a maximum of three years.

To use a survey-based approach for this research project, we would have had to enter into a survey instrument review process that, under the best of situations, would have taken six to eight months. Another four to six months probably would have been required to execute the survey, assuming the best of luck on survey responses and data collection. This project, like many MMS-funded research projects, was needed for immediate use and required completion within 12 months. OMB survey requirements, in this instance, seemed too onerous to use as a vehicle for collecting this type of information.

Our alternative approach was to compile this information from a variety of different sources, that varied by offshore activity phase. In general, we scoured all government, industry, trade, and academic publications, periodicals, and databases for relevant information. Some of these publications were readily available and straightforward. For instance, there is considerable information on drilling expenditures and patterns from the Joint Association Survey of the U.S. Oil and Gas Producing Industry compiled annual and published (jointly) by the American Petroleum Institute (API), the Independent Petroleum Association of America (IPAA), and the Mid-Continent Oil and Gas Association. Likewise, considerable information on pipeline construction costs and expenditures is filed regularly before the Federal Energy Regulatory Commission (FERC).

When direct "secondary" sources of published information were unavailable, we turned to information requests from industry or relied on trade association information and surveys previously (and independently) compiled. These requests were limited and did not violate the spirit or intent of the Paperwork Reduction Act. Information gathered in this process was simply used to fill in the blanks from our search of secondary sources of information.

The additional data issue was taking disparate documents and information, most of which were provided in accounting-based formats, and translating them into economic information for modeling purposes. Accounting information, for instance, rarely makes distinctions between fixed and variable costs or clear-cut differentiations between capital and labor. Thus, a painstaking process of reviewing accounting information on a line-by-line basis was required. Because both accounting entries, and the economic classifications included in Table 2F.1, are limited, judgment calls were required to separate a limited amount of information into limited classifications.

The process of making judgment calls on some classifications was most apparent in dealing with contracted services. Many costs associated with offshore activities would appear as contracted services from one firm to another, although both were engaged in the same activity. For instance, a company developing an exploratory well(s) would often, particularly in shallow water, contract drilling services out to a separate company. This company, in turn, would have direct expenditures for labor, materials, equipment, and other items that would "escape" our data collection ability. This has led to slight biases (overstatements) in general categories such as IMPLAN sector 38 (oil and gas operations) or 57 (other oil and gas field services).

CONCLUSIONS

The process of trying to create real-world models for offshore oil and gas activities in the GOM can yield meaningful difference from the standard approaches contained in generalized IO models. The MMS motivation for moving forward with creating these customized approaches appears to be justified. Using a hybrid approach based primarily on IMPLAN and a more realistic allocation and expenditure profiles helps to improve the existing multipliers—a crucial link in generating reliable

Table 2F.3. Estimated economic impacts for exploratory drilling, LA-2 Region.

Estimated Annual Impact -- Standard Analysis (1998 Dollars)				
	Direct	**Indirect**	**Induced**	**Total**
Output	179,502,016	16,454,092	15,543,905	211,500,011
Labor Income	14,524,824	3,839,397	5,936,279	24,300,500
Total Value Added	49,131,317	8,382,280	9,560,596	67,074,189
Employment (Number)	273	111	246	629
Estimated Annual Impact -- Modified, Gulf-Specific Analysis (1998 Dollars)				
	Direct	**Indirect**	**Induced**	**Total**
Output	178,219,407	29,111,563	21,800,854	229,131,826
Labor Income	17,490,114	8,875,273	8,325,832	34,691,221
Total Value Added	47,687,687	15,538,328	13,409,060	76,635,075
Employment (Number)	391	278	345	1,014

impact estimates. Table 2F.3 presents a summary of the IMPLAN output for the LA-2 region identified in Figure 2F.1. Two columns have been provided that present the economic output from shocking both the generalized IMPLAN model and the hybrid IMPLAN model using our specialized expenditure profiles and onshore allocations.

The differences in output, for instance, are 8% lower using our revised method of measuring economic impacts, than the standard approach included in IMPLAN. Labor income, however, is about 42% higher in our analysis relative to standard approaches. Value added is 14% higher in our model, while employment opportunities, represented by the number of jobs created by new exploratory wells, is 62% higher in our model than the standardized approach. These results, at minimum, support the notion that there are unique economic differences in the offshore industry and that further research should be conducted to better understand those differences and the impacts they have on human communities of the GOM.

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The authors would like to acknowledge the financial assistance of the Minerals Management Service in funding a portion of this study through the Coastal Marine Institute program at the Louisiana State University. We would also like to thank the additional matching financial support provided by the Center for Energy Studies, Louisiana State University and its Industry Associates Advisory Board. This paper is an abbreviated version of a much longer report on the topic that is forthcoming. This paper, its lengthier report, and underlying research could not have been possible without considerable assistance from a number industry, academic, and government professionals. While a lengthier acknowledgment will be provided in our forthcoming report, we would like to thank Kim Coffman, Stephanie Gambino, Vicki Zatarain, and Richard Deselles, all with the MMS, for their comments, suggestions, assistance, and advice. We would also like to thank Barbara Kavanaugh, Ric Pincomb, and Dmitry Mesyanzhinov, at CES/LSU, for their research assistance.

REFERENCES

Foster Associates. Ongoing. Historical and Socioeconomic Assessment of Oil and Gas Industry in Coastal Alabama. No. GM-96x6, MMS Contract No. 30829.

Lauterback, Jo Ann. 2000. Office of Management and Budget Paperwork Reduction Act Procedures Appendix. *In* LTG Associates, Inc. 2000. Report on the 1999 Minerals Management Service Social and Economic Studies Conference. OCS Study MMS 2000-016. Department of the Interior, Minerals Mgmt. Service.

LTG Associates, Inc. 2000. Report on the 1999 Minerals Management Service Social and Economic Studies Conference. OCS Study MMS 2000-016. Department of the Interior Minerals Mgmt. Service, Environmental Studies Program: 4.

Lutton, Harry and Rodney Cluck. 2000. Applied Social Science in MMS: A Framework for Decision Making. Department of the Interior, Minerals Mgmt. Service, Environmental Studies Program: 15.

Wade, William W. and Robert T. Mott. 1998. Research and modeling challenges to estimate economic effects of Mobile Bay exploration and development. MMS Workshop on Modeling Demographic and Economic Change in Local Coastal Areas. 26-27 March 1998, New Orleans, LA.

THE MINERALS MANAGEMENT SERVICE'S NEW CONSISTENT APPROACH TO MODELING REGIONAL ECONOMIC IMPACTS

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Mr. Kim Coffman
Minerals Management Service

INTRODUCTION

The U.S. Minerals Management Service (MMS) is responsible for managing mineral resources on the Federal Outer Continental Shelf (OCS). Among the many factors decision-makers must consider prior to scheduling and conducting OCS oil and gas lease sales (auctions of development rights) are the magnitude and location of economic impacts on local communities. In the late 1990s, MMS developed a new framework for estimating regional economic impacts that recognizes regional differences but provides for the development of consistent models for all coastal areas and for different levels of analysis. This paper presents a general description of that framework and the models themselves, focusing on models for Gulf of Mexico (GOM) analyses. For more details on the various activities that comprise an offshore oil and gas project, the resulting expenditures, and the allocation of those expenditures to specific industrial sectors in designated onshore economies, see David Dismukes' paper in this volume.

LEGAL MANDATE

The OCS Lands Act, as amended, established a policy for the management of oil and natural gas on the OCS and for protection of the marine and coastal environments. The mandate given MMS under the OCS Lands Act and other laws, is essentially

- to expedite exploration & development of the OCS;
- to protect human, marine, & coastal environments;
- to obtain fair & equitable return for public on OCS resources;
- to preserve & maintain competition; and
- to balance this range of objectives under all market conditions.

Regional economic impact analyses play a part in two kinds of planning to help carry out this mandate. The first is the development of a new five-year program—a five-year schedule of proposed auctions of mineral rights, which are called lease sales. The OCS Lands Act requires that a five-year program be in place and lays out a variety of considerations and requirements for developing one. After a five-year program has been approved, and prior to each lease sale, MMS conducts more detailed analyses for decision makers, who then decide whether the sale will be held as proposed, modified, delayed, or cancelled.

The regional economic impact analyses conducted in these planning phases help satisfy two primary statutory requirements. Section 18 of the OCS Lands Act requires that, in the development of a five-year program, the

> [t]iming and location of exploration, development, and production of oil and gas among the oil- and gas-bearing physiographic regions of the outer Continental Shelf shall be based on a consideration of…(B) an equitable sharing of developmental benefits and environmental risks among the various regions… . [43 U.S.C. 1344(a)(2)]

The equitable sharing analysis, which examines all coastal areas near lease sale areas on a proposed schedule, is included in the decision document for each of three stages in the development of a new five-year program.

In addition, the National Environmental Policy Act (NEPA) of 1969 states that …

> [t]he Congress authorizes and directs that, to the fullest extent possible: … (2) all agencies of the Federal Government shall…(C) include in every recommendation or report on a proposal for legislation and other major Federal Actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on (i) the environmental impact of the proposed action, … . [42 U.S.C. 4332]

To this end, MMS prepares Environmental Impact Statements (EISs) and environmental assessments (EAs); acquires marine environmental data; analyzes data, literature surveys, socioeconomic studies, and special studies; and holds public conferences. The EIS for a proposed five-year program contains a regional impact analysis for each coastal area throughout the nation near a sale on the proposed schedule, while the EIS for an individual lease sale includes an analysis for the local coastal areas.

APPLICATION OF REGIONAL ECONOMIC IMPACT ANALYSES TO MMS MANDATE

However they measure regional economic effects of new investments or activity, such as OCS oil and gas development, regional scientists generally classify the effects as direct, indirect, or induced. For the equitable sharing and EIS analyses, direct effects are those resulting from the first round of "new" spending by companies working directly on an OCS project(s). Indirect effects result from the additional project-related spending of contractors, vendors, and others who provide goods and services to the companies working directly on the OCS project(s). Induced effects result from the additional consumer spending by employees (and their families) of the businesses working directly on, or providing goods and services in support of, the project(s).

The MMS bases all its analyses of proposed lease sales, not just those of regional economic impacts, on Exploration and Development (E&D) Scenarios. The appropriate MMS regional office Resource Evaluation unit (RE) prepares an E&D Scenario for each sale or schedule of sales. In it, RE provides, by broad categories of water depth (in the GOM), annual estimates of the amount of infrastructure required for development anticipated to result from the proposal in question. For the GOM, this includes number of exploratory wells, number of development wells, miles of new pipeline, number of platforms, and other such measures of OCS activity. The E&D Scenario encompasses all anticipated projects in each OCS planning area included in pre-sale or proposed five-year program analyses. For post-lease analyses, a specific project (and often direct effects) is (are) known.

MMS refers to any model, or submodel, that translates E&D Scenario data into direct effects as a "first-step" model. For each OCS activity related to a specific OCS planning area and water depth, the first-step model must estimate the level of industry expenditure and how that spending is allocated to onshore geographic areas. Depending on the input requirements of the "second-step" model or submodel, the first-step model must implicitly or explicitly allocate spending or employment to specific industry sectors.

The second-step model or submodel is used to estimate indirect and induced effects. Such models must be developed specifically for OCS oil and gas analyses or must be customized to reflect the unique expenditure and commuting patterns of OCS-related companies and their employees in order to properly estimate indirect and induced effects. For example, OCS activities require much larger purchases of steel pipe and air and water transportation than do onshore activities, where a higher proportion of expenditures necessarily goes to the other factors, including ground transportation. Indeed, impacts may vary by how far offshore the exploration or production facilities are located. An accurate model must also reflect typical commuting patterns for workers in OCS-related industries. For example, OCS platform workers tend to spend a week or more offshore, followed by the same period at home. This allows them to commute longer distances and results in such workers spending most of their income outside the areas of analysis. Therefore, to accurately model the onshore effects of OCS activities, an analyst must know what percentage of workers spend what portion of their income where, then must use a customized model or must "recalibrate" a more general model to properly characterize certain industries.

REGIONAL ECONOMIC MODELING: PREVIOUS MMS METHODOLOGY

Prior to the Autumn of 2000, the Alaska OCS Regional Office and the GOM Regional Office used independently developed processes to estimate regional employment impacts for EISs. The equitable sharing analysis was done without the benefit of any impact models.

In the Alaska office, MMS used the "Manpower" model to convert E&D scenarios into estimates of direct employment expected to result from a proposed OCS lease sale. Manpower, which was developed by MMS employees with contractor assistance, consists of a set of simple multipliers on spreadsheet pages in a Corel Quattro Pro notebook. MMS used the Rural Alaska Model (RAM), developed by the University of Alaska, and the output from Manpower to estimate indirect and induced employment. The RAM consists of a set of worksheets in a Microsoft Excel workbook. Like Manpower, it uses simple multipliers to estimate results. The RAM is actually a collection of 10 models, one for each of 10 local onshore areas.

In the GOM office, MMS used an unnamed, staff-developed, MS-Excel spreadsheet to estimate direct, indirect, and induced employment effects. The GOM office based its direct employment and population projections on average employment requirements for OCS activities (by type of activity and water depth), determined through an informal survey of industry employment types and locations. The GOM region allocated onshore direct effects using historical data from an offshore rig locator service. The same model used exogenous "multipliers" developed and modified over time from County Business Pattern data to estimate indirect and induced employment.

Recently, there have been no models in place to estimate regional employment impacts for the Atlantic OCS region or the Pacific OCS region. The Pacific OCS Regional Office had planned to use analyses of the environmental studies products to help estimate direct employment effects and to use IMPLAN for indirect and induced employment effects, but there have been no lease sale proposals on the Pacific OCS for many years.

THE NEW MMS CONSISTENT APPROACH TO REGIONAL ECONOMIC IMPACT MODELING

In the mid-1990s, MMS formed the Developmental Benefits Model Assessment Team (DBMAT) to develop proposals to improve its regional economic impact models. The DBMAT was composed of members from each MMS OCS regional office and relevant units at MMS headquarters.

While the DBMAT researched a broad range of models used for regional economic impact analyses, it is important to note that there was, and is still, no secondary source from which MMS could obtain data showing how a given expenditure on OCS oil and gas activities reverberates through onshore economies. No standard statistical series, such as those compiled by the Departments of Commerce and Labor, gathers data on the offshore natural gas and oil industry. In every case, offshore is combined with onshore oil and gas or with all mining. To further complicate matters, MMS also must distinguish between state offshore and OCS oil and gas development. The distinction is important because the relative spending among industrial sectors and among onshore areas differs not only for onshore and offshore activities but for activities in different water depths. And the sector in which money is spent and workers are employed can strongly influence the level of indirect and induced effects. As a result, MMS must always gather or model the information it needs to estimate direct impacts from OCS activities. This would be required regardless of which model MMS employed to estimate indirect and induced effects.

The DBMAT proposed a two-step modeling process that would allow the development of region-specific models to be developed under a consistent methodology, whether for large, multi-state areas in equitable sharing analyses or for sub-state areas in specific pre-sale analyses. Given the Team's belief that there was no single readily available model adequate for all MMS analyses, this proposal called for region-specific first-step models to estimate direct effects and a single static input-output model[3] (with region-specific data bases) to estimate indirect and induced effects. Accordingly, the

[3] A static model approximates an outcome for which all changes occur at once, as opposed to a dynamic model, which is much more complex but allows for interactions over time. An input-output model estimates the monetary interactions among all industries required to achieve a specified change in output in one or more sectors.

direct-effects, or first-step, model would include a cost function[4] that not only estimated the total required annual expenditures for each of these categories but also allocated expenditures and labor among industrial sectors.

After the proposal was approved, the Center for Energy Studies at Louisiana State University was employed under a Coastal Marine Institute contract to develop the data for the cost functions and onshore allocations. (In Alaska, Jack Faucett Associates was hired to develop first-step models for the Arctic and Sub-Arctic Alaska OCS.) The DBMAT selected the IMPLAN (IMpact Analysis for PLANning) model as the universal second-step model, because it had the simplicity and flexibility to meet all MMS needs and it was the most widely used input-output model available with regularly updated data for all coastal areas. Furthermore, IMPLAN had been used to analyze impacts from oil, gas, and non-oil related economic shocks in all MMS regions.

Microsoft Access was selected as the software to link the E&D scenarios, the first-step models, and IMPLAN. Because the magnitude of the ripple effect (indirect and induced effects) for each industry varies by geographical location, MMS develops a separate MS-Access model for each onshore area in an analysis. Given the large number of inputs for the second-step model, usually numbering many thousands, IMPLAN Pro software and data are used only to provide and regularly update sets of multipliers for the MS-Access model. The software itself also could be used for analyses not requiring extensive data entry.

For GOM analyses, the two-step process is incorporated into one MS-Access model, as shown in Figure 2F.2, which shows the design view of a sample MS-Access "query" that illustrates how the GOM models work. The first box in the upper left corner of the figure represents the Exploration and Development scenario, required for any model to produce data. The second required component is the first-step model, the third box from the left, which contains the cost functions by phase (e.g., exploratory drilling) and water depth. It converts the activities into expenditures and allocates those expenditures to industrial sectors in the relevant onshore area. So for each exploratory well in 0-60 meters of water, for example, some portion of $4.25 million will be allocated to sector 38 in the group of parishes called LA-2.

The other boxes to the right comprise the second step of the model. These are the multipliers for employment, employee wages, personal income, total value added, and total economic output. They estimate, for example, the number of industry jobs created in onshore area LA-2 as a result of each million dollars spent, as well as the number of jobs created by secondary industries, and by households with industry employees.

[4] The MMS calls the spending estimation and allocation to industry sectors a "cost function" to avoid confusion with the similar "production function" for each sector in the second-step model. Because the analysis of direct effects also requires allocation of expenditures to the appropriate onshore geographic areas, this sometimes also is inferred by the term "cost function."

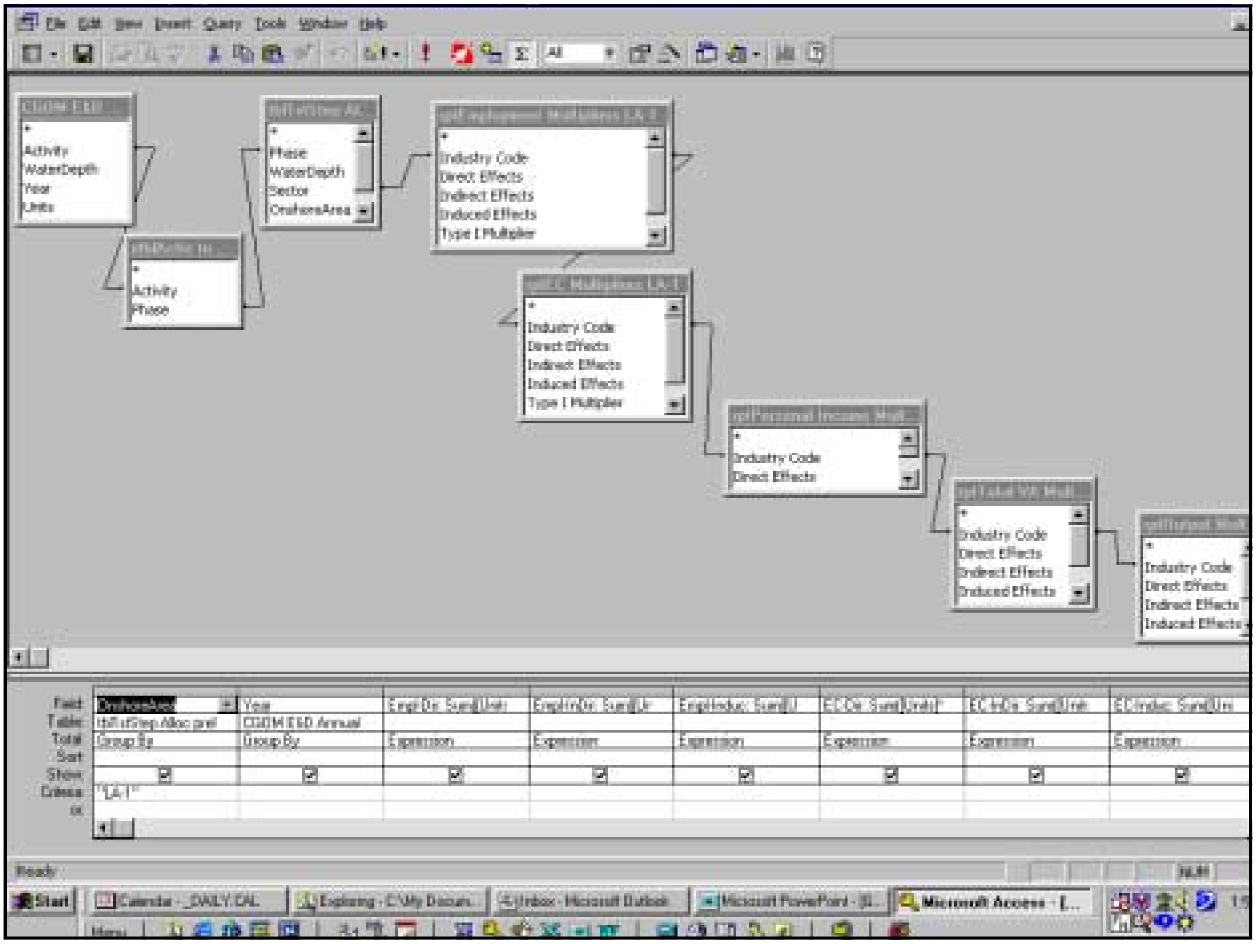

Figure 2F.2. Sample view of Microsoft Access model for Gulf of Mexico.

For the Five-Year Program's equitable sharing analysis, the models will allocate impacts to the onshore "regions" used in equitable sharing analyses previously upheld by the court. For the GOM, these would be

- Region III—Florida
- Region IV—Texas, Louisiana, Mississippi, Alabama.

The requirement for an equitable sharing analysis applies only to a new five-year program, while the NEPA analysis must be done for both the five-year program and the lease sale decision processes.

For pre-sale analyses for the GOM, the onshore areas are more narrowly defined, ranging from five to 13 coastal and near-coastal counties or parishes per area.

REGIONAL APPLICATION OF COST FUNCTION DATA AND IMPLAN MODEL

The model for the GOM has two steps. Because there are no publicly available models that estimate the expenditures resulting from OCS oil and gas activities, e.g., drilling an exploratory well, the first step estimates the expenditures resulting from all the activities in the Exploration and Development Scenario for a proposed Lease Sale and assigns these expenditures to industrial sectors in eight MMS coastal subareas. The Exploration and Development Scenario is developed internally (by the MMS's Resource Evaluation Division) which denotes the schedule of oil and gas development activities and offshore location (shallow, moderate, deep and ultradeep water) estimated for a typical OCS Lease sale. The second step in the model uses multipliers from the commercial input-output model IMPLAN to translate these expenditures into direct, indirect, and induced employment and other economic factors. Direct employment results from the first round of industry spending. It is that employment that results from the initial dollars spent by the oil and gas industry on the activities listed in the Exploration and Development scenario. Indirect employment results as the initial spending reverberates through the economy. First, the suppliers of the goods and services for the OCS development activities spend the initial direct dollars from the industry. Then these dollars are re-spent by other suppliers until the initial dollars have trickled throughout the economy. Labor income produces induced spending by the households receiving that income.

Both the level (the amount spent) and the sectoral allocation (the industry in which it is spent) of expenditures can vary considerably by the phase of OCS activity and by the water depth of the activities. For example, an exploratory well in 0-60 m of water is expected to be drilled using a jack-up rig and cost about $5 million, whereas an exploratory well in 900 m or greater water depth is expected to be drilled using a drill ship and cost about $10 million to complete. In addition, spending on materials such as steel will be much higher for platform fabrication and installation than for operations and maintenance once production begins. These data (total expenditures and sectoral allocation of expenditures by phase) are supplied from the Cost Function Study. Therefore, the model estimates and allocates expenditures by OCS development activities (exploratory drilling; development drilling; production operations and maintenance; platform fabrication and installation; pipeline construction; pipeline operations and maintenance; gas processing and storage construction; gas processing and storage operations and maintenance; workovers, and platform removal and abandonment) in four water depths categories (0-60 m; 61-200 m; 201-900 m; and >900 m). Because employment and other economic impacts occur onshore and the expenditures are associated with activities offshore, an onshore allocation matrix was developed.

Because local economies vary, a separate set of IMPLAN multipliers is used for each MMS coastal subarea to which expenditures are assigned. Each set of multipliers is based on the actual historical patterns of economic transactions in the area. Model results for employment are presented in number of jobs per year, where one job is defined as a year of employment. This does not necessarily mean only one person occupies the position through out the year. One job may be equal to two part-time positions occupied over the year or one person occupying a position for six months, while another person occupies it for the other six months. Model results are then compared to a baseline employment projection in the absence of the proposed lease sale to determine the impact of the proposed sale on the local economies.

LOOKING FORWARD

The new consistent approach to regional economic impact modeling will be thoroughly tested over the next year or two, as MMS conducts an equitable sharing analysis and EIS for the Five-Year Oil and Gas Program for 2002-2007—which must be in place by mid-2002, in addition to a multi-sale EIS analysis for GOM planning areas. During this period, MMS will be looking for ways to improve upon the initial models that have been developed under this approach.

Some of these improvements will come from better data. For example, MMS is confident that its allocation of expenditures to specific onshore areas is fairly accurate overall; however, it may be appropriate to further refine the allocations according to planning area and water depth of oil and gas resources in question, as well as by sector. For example, it’s likely that the drilling equipment and platforms for deep-water projects are likely to be manufactured in geographic locations other than those for shallow-water projects.

In other cases, these improvements may come from refinement of existing data, for example, developing cost functions for specific technology (e.g., jack-up rigs) that could be used to analyze identified projects, rather than the weighted averages for mixed technology used for more general proposals, like lease sales. Given that the existing models use a static input-output model to approximate a dynamic process, MMS intends to develop a methodology to spread E&D expenditures across years, where appropriate (e.g., for fabricating and installing platforms in deep water).

Other changes will result from the incorporation of additional research results on commuting (& spending) patterns for offshore workers, wage rates in related industries, state and local government revenue collection and expenditure patterns, and offshore contractor expenditure patterns that may be masked in existing data.

Finally, MMS hopes to take advantage of more sophisticated features of MS-Access software and improvements to IMPLAN Professional software and data. Future versions of IMPLAN Pro may allow MMS to create multi-regional models, which would capture more of the inter-regional trade interactions. MMS also can develop uniform input formats and Visual Basic programming instructions within MS-Access to make models easier to update and easier to link to new E&D scenarios, as well as to make them more user-friendly.

AN ANALYTICAL MODEL OF OPERATING PLATFORMS ON THE U.S. GULF OF MEXICO OUTER CONTINENTAL SHELF (OCS), 1947-1997 [5]

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ABSTRACT

The most common practice for firms operating on the OCS is to undergo detailed engineering and economic planning studies to schedule platform installations and removals on their leases. However, little analysis has focused on how the entire collection of offshore platforms operating on the OCS is likely to change over time and what variables are responsible for those changes. This paper presents an analytical model of offshore structures operating in the Gulf of Mexico OCS region using data on platform installations and removals from 1947 through 1997. The model framework has two behavioral equations and an identity relationship. The estimated behavioral equations explains nearly 80% and 95% of the variation in platform installations and removals from 1947-1997, respectively. The results confirm the expectations that the greater the expected size of new fields, the larger the number of platforms to be installed, but the increase in platform installation occurs at a declining rate with cumulative size of new field additions. The empirical results also show that a favorable economic environment will lead to a statistically significant but inelastic increase in the number of installed platforms. Although the empirical results are consistent with the *a priori* expectation that platform installation began to decline—since 1986 as a result of structural changes in the industry, deep water drilling techniques, and completion technology, the point estimate of the variable included in the model to capture the effects of technology and institutional changes is not statistically different from zero. It is estimated that less than 5% of platforms currently operating on the OCS are older than 33 years or more and about 65% are 21 years or less.

INTRODUCTION

The stock of offshore platforms in the U.S. Gulf of Mexico (GOM) OCS region is one of the primary components of U.S. economic and physical capital. Constructing, operating, and removing platforms interact with the economies and ecologies of adjacent coastal areas in positive and negative ways. Although firms operating in the GOM conduct detailed engineering and economic planning studies to schedule platform installations and removals on their leases, little analysis has

[5] This paper is an extract from a research report partially funded by the Minerals Management Service (MMS) of the U.S. Department of the Interior (Pulsipher *et al.*1999) . All conclusions, errors, and recommendations, however, are the sole responsibility of the authors.

focused on how the entire collection of offshore platforms is likely to change over time and what variables or influences are responsible for those changes.

This paper develops a set of equations to describe the trend in operating offshore structures on the GOM OCS region and uses the model framework to forecast the number of operating offshore structures over the next two decades. The framework adopted in this study assumes that as more fields are discovered and developed, the incentives to install new offshore structures will also increase, but at a decreasing rate. The lead time required to design, obtain permits, and install an offshore platform, even with strengthened incentives, may not lead to more platforms during a given period.

Other factors such as changes in economic conditions and expectations or cost-reducing- improvements in technologies may also affect the number of platforms and the rate at which firms may wish to install them. As economic conditions and expectations become more favorable and stable, the incentives to install new offshore structures will strengthen. Similarly, as technologies for finding and producing petroleum improve, the need for additional offshore structures may also change.

TRENDS IN OPERATING OFFSHORE STRUCTURES ON THE OCS

The number of operating platforms grew in every year except 1992, when Hurricane Andrew blew through the oil producing area in the GOM. A plateau of about 3,900 structures was reached and maintained during the 1990s; this represents the drop-off-period for the decline.

At 31 December 1997, there were about 3,900 platforms operating on the OCS. Of these, 73.9% are located in water depths of less than 400 feet and 4.6% located in waters deeper than 900 feet. Table 2F.4 presents the number of operating platforms by water depth.

Table 2F.4. Water depth of fixed offshore structures operating on the Gulf of Mexico OCS as of 31 December 1997.

Depth Ranges	Non-Major Structures	Major Structures	All Structures
0-20	17	11	28
21-50	166	44	210
51-100	388	120	508
101-150	444	210	654
151-200	369	258	627
201-300	245	255	500
301-400	132	233	365
401-500	51	184	235
501-900	117	492	609
> 900	13	167	180
Total	1942	1974	03916

MODEL SPECIFICATION AND ESTIMATION

The stock of operating platforms on the OCS in a given period can be estimated using an arithmetic identity relationship defined simply as cumulative platforms installed less cumulative platforms removed. Symbolically, the above definition translates to an identity equation of the form:

$$OPP_t = OPP_{t-1} + INS_t - REM_t \qquad (1)$$

where:

OPP(t) is the number of operated platforms in time *t*
INS(t) equals number of installed platforms in time *t*
REM(t) represents the number of platforms removed in time *t*.

The definition set forth in equation (1) forms the basis for the modeling approach to forecasting the number of platform installed, removed, and operated on the OCS in this report.

According to equation (1), the number of platforms operated in a given period depends on the number of platforms removed and installed during the period, *ceteris paribus.* To use this identity to forecast, we have to be able to model and forecast those factors that explain platform installations and platform removals. For the sake of simplicity, it is assumed that a platform installed in a given period on the OCS becomes operational during that period. It is also assumed that the number of removed platforms in a given year is some function of the stock of operating platforms at the end of the previous year as well as the age of the platform.

Thus, the number of platforms removed in year *t* can be expressed as the sum of the proportion of platforms installed in previous periods that were removed in the current period. Symbolically we may represent this proposition as follows:

$$REM_t = \Sigma\ (\alpha_j * INS_{t-j}) \qquad (2)$$

where:

α_j represents the proportion of platforms removed in year *t* that were installed in year *t-j* such that $0 \leq \alpha_j \leq 1$ and *j* represents the age of removed platform.

Planned installation of new platforms in order to explore and produce oil or gas is expected to be affected by short-run changes in the petroleum economy and political environment, and perhaps by other determinants such as structural changes in the industry in addition to the expected size of petroleum discoveries. Thus, the functional equation describing planned platform installation behavior may be specified as follows:

$$INS^*_t = \beta_0 + \beta_1 \log(CFZ_t) + \beta_2 CPR_t + \beta_3 TEK_t + \beta_4 D86 + \epsilon_t \qquad (3)$$

where:

β_i (i=0,1,2,3,4) are constant parameters to be estimated
INS^*_t = desired or planned number of installations in period *t*.

CFZ $_t$ = cumulative total field size at the beginning of period t
CPR $_t$ = the average current crude oil price on the Gulf OCS
TEK = time trend as a proxy for technical progress
D86 = dummy variable, such that, D86 = 1 for time period after 1986 and zero otherwise
ϵ_t = independent random error term

The dummy variable D86 is included to capture the effects of changes in expectations and behavior of the oil and gas industry in the GOM OCS subsequent to the collapse of the world crude oil market in the summer of 1986.

The short run adjustment process can be measured using the following partial adjustment model specification:

$$INS_t - INS_{t-1} = \lambda(INS^*_t - INS_{t-1} + \omega_t \qquad (4)$$

where:

λ represents the rate of response of the change in installed platforms to the difference between the desired installations and past value of installed platforms such that $0 \leq \lambda \geq 1$, and ω = independent random error term.

Conceptually, equation (4) measures the proportion of adjustment to the desired number of platforms achieved within a year. The error term ω measures the failure of the adjustment process to accomplish the desired number of platforms.

Substituting equation (4) into equation (3) and simplifying the new equation yields an equation describing the relationship between the number of platforms installed (or to be installed) and its determinants.

$$INS_t = \lambda\beta_0 + \lambda\beta_1 \log(CFZ_t) + \lambda\beta_2 CPR_t + \lambda\beta_3 TEK_t + \lambda\beta_4 D86 + (1-\lambda)INS_{t-1} + \lambda\epsilon_t + \varpi_t \qquad (5)$$

If $\pi_i = \lambda\beta_i$, then

$$INS_t = \pi_0 + \pi_1 \log(CFZ_t) + \pi_2 CPR_t + \pi_3 TEK_t + \pi_4 D86 + \pi_5 INS_{t-1} + \theta_t \qquad (6)$$

The independent or explanatory variables and their hypothesized relationships to the dependent variable, INS, are defined as follows:

log(CFZ$_t$)–The logarithm of cumulative field size in million barrels of oil equivalent (MMBOE). Our hypothesis is that as the size of field increases on the OCS, the number of installed platforms will increase at a decreasing rate. The coefficient π_1 is expected to be positive.

CPR$_t$–Current crude oil price on the GOM OCS. The hypothesized relationship is that the economic environment will tend to shift the long-time relationship between installed platforms and cumulative discovery outwards. This means that we expect a positive coefficient for CPR, our measure of economic conditions.

TEK_t–This is a proxy for the impact of technology on platform installations. The expectation is that the more rapid technical progress has been over the past 10-15 years the fewer the number of platforms that need to be installed to produce a given level of reserves. Less abstractly, as technologies such as horizontal and directional drilling, down-hole completion, etc., are developed, fewer platforms will be required to develop new fields in deeper water.

D86–Dummy variables for changes in expectations and behavior since the collapse of the world oil prices are expected to affect negatively the shifting effect of prices on the relationship between platforms and discovery size.

The collapse of world crude oil prices in 1986 brought with it several organizational and institutional changes on the OCS including a massive reduction in employment, an increase in the importance of independent operators, an increase in reliance on contract services, and the adoption of less hierarchical decision-making as well as technological innovations (Bohi 1997). The likely effect of these changes on platform installation on the OCS is examined by including an interaction between the 1986 dummy variable and time trend such that the interactive dummy equals 1 from 1986 forward and 0 otherwise.

The Ordinary Least Square (OLS) estimation results for equation (6) are presented in Table 2F.5. Equation (6) is a linear-log model. The general expectation from our model specification using the linear log function is that the greater the size of new fields, the larger the number of platforms to be installed, but the increase in platform installation occurs at a declining rate.

Table 2F.5. OLS Estimates of the platform installation model (t-statistics in parenthesis).

Variable	Coefficient
Intercepts	-113.931
	(-2.847)
Cumulative New Fields (CFZ)	16.618
	(3.118)
Average Current OCS Oil Price (CPR)	2.089
	(2.416)
Number of Platform Installed (INS_{t-1})	0.457
	(3.641)
Technical Progress	-0.163
(Interactive Dummy)	(-0.706)
Observations	49
Adjusted R^2	0.791
Error of Regression	27

Overall, the model results explain nearly 80% of the variation in dependent variables. The point estimate of the coefficient of the lagged value of the dependent variable is 0.463, making the adjustment coefficient 0.537. Thus, on average, firms achieve about 54% of their desired or planned number of platforms to be installed within a given year.

The parameter estimate for the variable representing the economic environment—the average current price of OCS crude oil—is positive, as expected. Therefore, we conclude that a favorable economic environment, according to our model, leads to a statistically significant increase in the number of installed platforms. The short-run price elasticity of platform installation on the OCS is estimated as 0.25; and since the adjustment coefficient is 0.537, the long-run price elasticity of platform installation by our model estimate is approximately 0.46. This means that a 10% increase in the current average price of OCS crude oil will lead to about 4.6% increase in the number of platforms installed over the long run compared to a short-run increase of about 2.5%.

The results show that cumulative field size is an important determinant of the number of platforms installed. As expected, the coefficient is positive and statistically significant at the 99% significance level. However, the short run and long run elasticity of cumulative reserves is on average significantly less than unity.

The empirical result is consistent with our expectation that since 1986, platform installation did decrease as a result of structural changes in the industry, deepwater drilling techniques and completion technology. However, the point estimate of the interactive dummy included in the regression to capture the effects of technology and institutional changes, although negative as expected, is not statistically different from zero. Figure 2F.3 shows that the prediction using the estimated equation (6) presented in Table 2F.5. The predicted trend tracks the actual trend in platform installation closely.

In order to model the physical reality in which only installed platforms can be removed, we selected a specification with a suppressed intercept. Thus, when values for both independent variables are set to zero, the value for the dependent variable is also equal to zero. The statistical equation applied for predicting platform removals is a reduced form of equation (2) reproduced below in an estimated form as equation (7):

$$REM_t = 0.953 INS_{t-33} + 0.351 INS_{t-21} \tag{7}$$

Of the several alternative forms of equation (2) that we examined, equation (7) yields the best statistical fit to the available historical data on removed platforms.[6]

[6] For every observation in the series (1947-1997), new variables were created. These variables represented consecutive lags for the installed platforms. For example, lag_1 for 1948 contains platforms installed in 1947; lag_2 for 1950 contains platforms installed in 1948, and so forth. In certain cases, statistical software created missing values. For example, lag_2 for 1948 is a missing value, because there were no platforms installed in 1946. All missing values were substituted with zeroes. Then, a step-wise OLS regression was performed with the annual number of removed platforms as a dependent variable and 40 lags (lag_1, lag_2,…, lag_40) of installed platforms as independent variables. Out of the 40 independent variables, the step-wise regression procedure selected, based on the resulting R square, ten best models. The first model included only one independent variable, the second model included two independent variables, and so

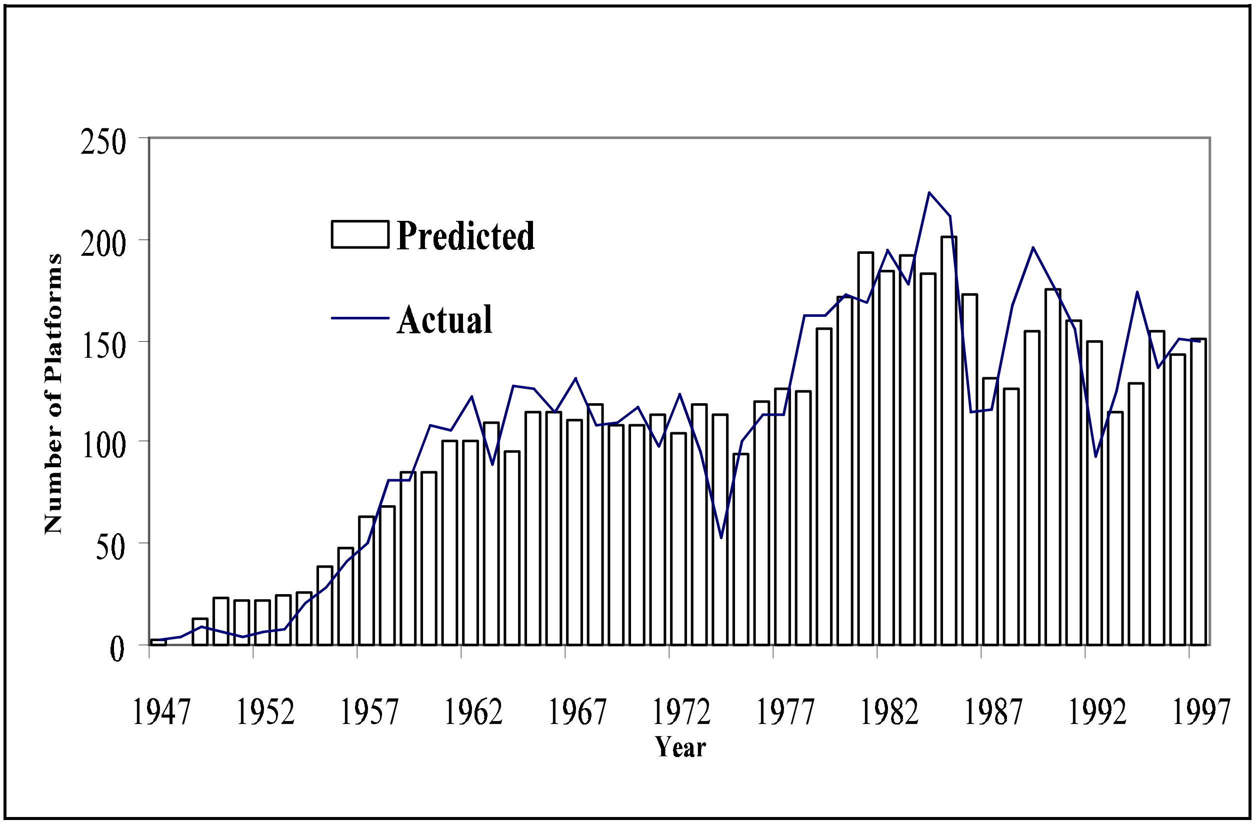

Figure 2F.3. Actual and predicted number of platforms installed.

The above estimated removal equation (7) is obtained using a statistical method that lacks the conceptual foundation that the forecasting equation for platform installations enjoys. The final relationships estimated in the equation state that 95.3% and 35.1% of platforms installed in year (t-33) and (t-21), respectively, are removed in year *t*. The model explains more than 95% of the observed variation in platform removal. Parameter estimates of the independent variables are also statistically significant. However, the mean absolute percent error and the root mean square percent error of the predicted values are a high 22% and 21%, respectively. Figure 2F.4 plots the actual and predicted number of removed platforms for the period 1947 - 1997.

Using equations (6) and (7) in combination with the identity equation (1), predicted values of operating platforms were calculated. Figure 2F.5 shows a pictorial view of the predicted number of operating platforms over the period for which we have data. The predicted values tracked the actual values quite well, with the moving average percent error (MAPE) for the period 1947-1997 being 7.75% while the root mean square is approximately 4.48%.

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forth up to ten. The model with two explanatory variables provided a much better fit than the model with just a single explanatory variable; however, a model with three explanatory variables provided only a marginal improvement over the model with two explanatory variables. Therefore, the model with the two lags–lag_32 and lag_21– was selected as the most parsimonious.

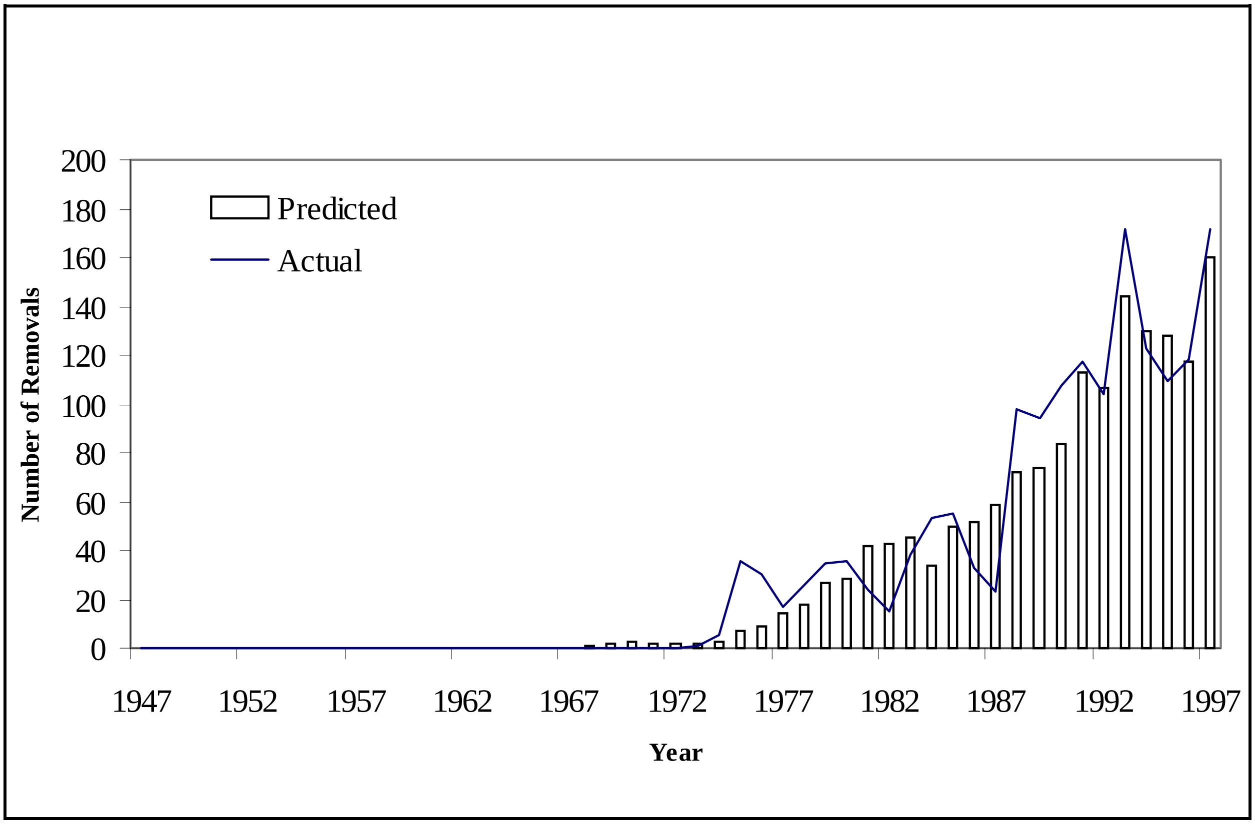

Figure 2F.4. Actual and predicted number of platforms removed.

The model results in Table 2F.5 were also used to generate annual forecasts of the number of platforms installed for the period 1999-2023. The values assumed for all the parameters and variables used to forecast platform installations are reported in Table 2F.6. Equations (6) and (7) were subsequently applied to calculate future removals and installations, and the corresponding number of platforms operating annually was estimated using the identity equation (1).

The reference forecast, or the forecast that in our view is the most likely, is summarized in Table 2F.7. During the forecast period new platforms are projected to be installed at an annual rate of about 142 platforms per year. Over the 25-year period, 3,543 platforms would be installed. A total of 4,645 platforms are forecast to be removed, which is an approximate annual rate of about 186 over the forecast period. Operating platforms are predicted to decrease from 3,687 in 1999 to 2,612 in the year 2023. This is a decline of 1,075 or about 29%. Figure 2F.6 presents a pictorial view of the trends in operating platform forecasts under a reference case scenario and two alternative scenarios.

SUMMARY AND CONCLUSIONS

An analytical model of operating offshore structures in the GOM OCS region using data on platform installations and removals from 1947 through 1997 has been developed. The model framework has two behavioral equations and an identity relationship. The framework adopted in this study assumes that as more fields are discovered and developed, the incentives to install new offshore structures

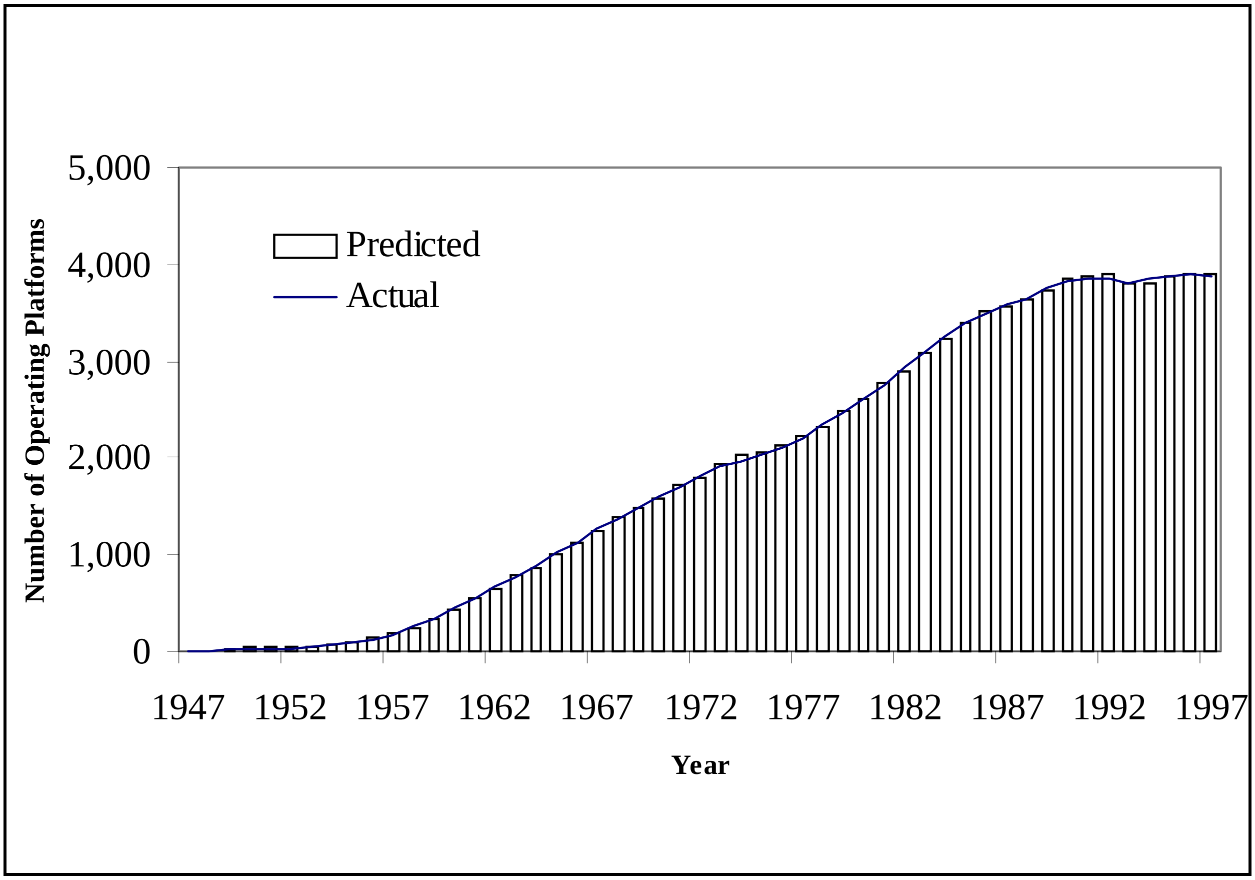

Figure 2F.5. Actual and predicted number of operating platforms.

will also increase, but, at a decreasing rate. It is also assumed that other factors such as changes in economic conditions and expectations or cost-reducing improvements in technologies may also affect the number of platforms and the rate at which firms may wish to install them.

The estimated behavioral equations explains nearly 80% and 95% of the variation in platform installations and removals from 1947-1997, respectively. The results confirm the expectations that the greater the expected size of new fields, the larger the number of platforms to be installed, but the increase in platform installation occurs at a declining rate with cumulative size of new field additions. The empirical results also show that a favorable economic environment will lead to a statistically significant but inelastic increase in the number of installed platforms.

The total number of oil and gas platforms located in the U.S. GOM OCS region is forecast to begin a slow but steady decline over the first quarter of the next century. The plateau of about 3,900 structures that was reached and maintained during the 1990s is a peak, according to the forecast, and the drop-off-period for the decline.

By the year 2023 the number of platforms in the Gulf is forecast to be roughly 2,600, a drop of 1,075 platforms for a total that will be about 29% below the current peak. Alternative forecasts made by changing the values of the forecasting variables did not result in major differences from the

Table 2F.6. Estimated values of model variables and parameters used to forecast the number of platforms installed from 1998 – 2023.

Year Wells #	Wildcats Fields (MMBOE)	New Fields Size Rate	Field Size Head Price (Dollars/Bbl)*	Success	Avg. Well
1998	110	18	24.5	0.16	15.74
1999	114	14	15.4	0.12	15.96
2000	101	14	13.1	0.14	16.17
2001	104	12	16.9	0.12	16.38
2002	100	12	21.0	0.12	16.61
2003	103	13	34.8	0.13	16.83
2004	109	14	12.4	0.13	17.05
2005	102	11	17.6	0.11	17.28
2006	99	12	14.2	0.12	17.40
2007	101	10	15.2	0.10	17.52
2008	96	11	21.7	0.11	17.64
2009	102	11	14.6	0.11	17.77
2010	98	10	14.8	0.10	17.89
2011	96	10	38.4	0.10	17.99
2012	105	11	13.9	0.11	18.06
2013	97	8	9.3	0.08	18.19
2014	90	10	14.8	0.11	18.29
2015	98	7	5.4	0.07	18.39
2016	86	9	16.2	0.10	18.49
2017	97	9	8.8	0.09	18.59
2018	92	9	16.4	0.10	18.69
2019	96	8	4.9	0.08	18.80
2020	89	9	16.2	0.10	18.90
2021	97	8	9.3	0.08	19.00
2022	90	6	1.8	0.07	19.11
2023	84	9	32.3	0.11	19.22

* See Pulsipher, *et al.* (1999) for detailed discussion on forecasting model variables.

Table 2F.7. Forecasts of the number of platforms to be installed, removed, and operated on the Gulf of Mexico OCS, 1999 - 2023 – Reference Case.

Year	Platforms Operating	Platforms Installed	Platforms Removed
1999	3,687	137	165
2000	3,642	138	183
2001	3,623	138	158
2002	3,605	139	157
2003	3,566	140	178
2004	3,550	140	157
2005	3,498	141	193
2006	3,475	141	165
2007	3,529	142	87
2008	3,534	142	136
2009	3,510	142	166
2010	3,475	142	177
2011	3,402	142	215
2012	3,342	143	203
2013	3,292	143	192
2014	3,233	143	202
2015	3,130	143	246
2016	3,064	143	208
2017	2,957	143	251
2018	2,855	143	245
2019	2,849	143	149
2020	2,834	143	158
2021	2,772	144	206
2022	2,682	144	234
2023	2,612	144	214

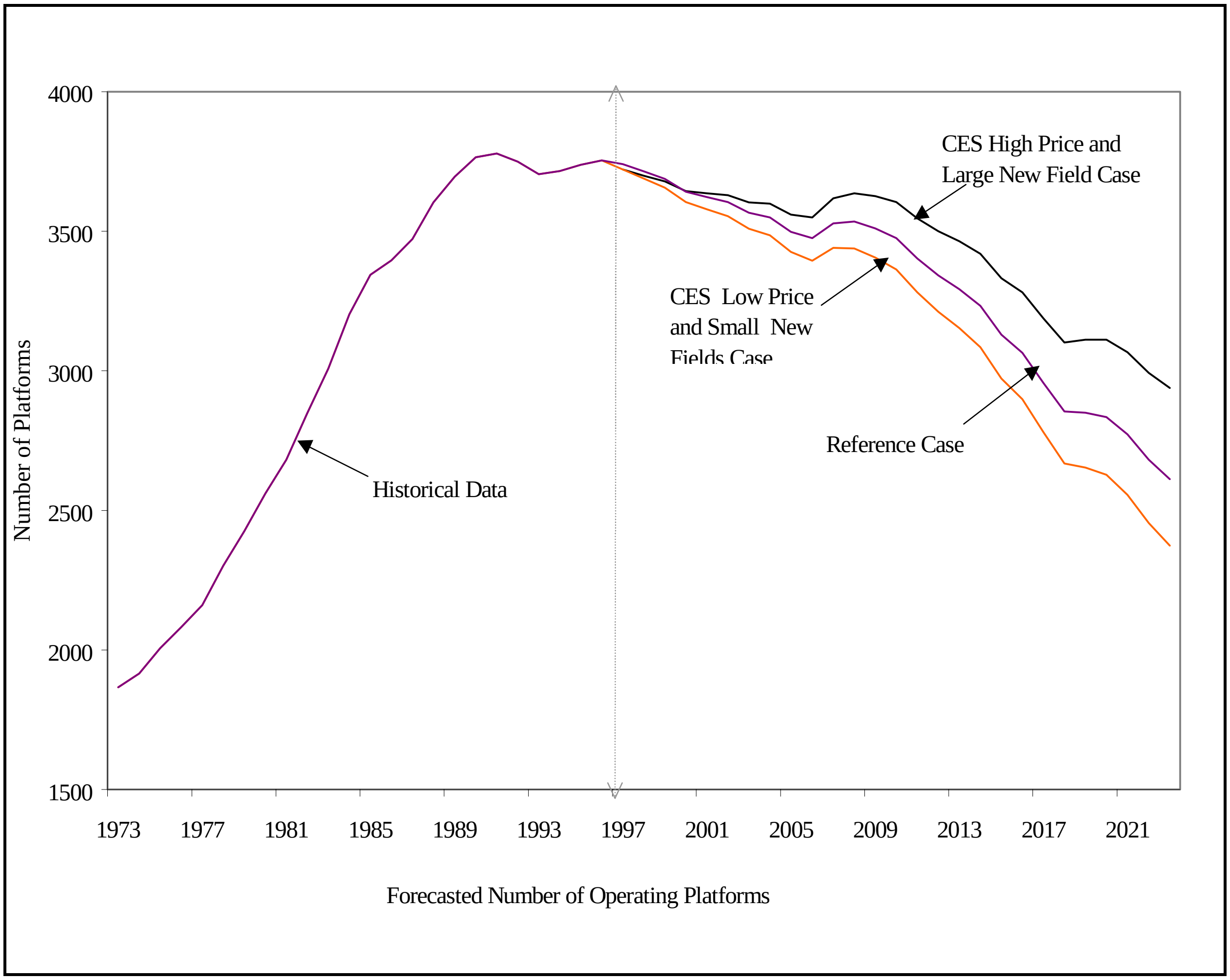

Figure 2F.6. Forecasted number of operating platforms.

reference forecast. The decline in operating platforms in high forecast was still more than 20%, as compared to 29% in the reference forecast. The decline in the corresponding low forecast was about 35%.

REFERENCES

Bohi, Douglas R. 1997. Changing Productivity of Petroleum Exploration and Development in the U.S. Resources for the Future Discussion Paper, January 1997, Washington D.C.

Pulsipher, Allan G., *et al*. 1999. Forecasting the Number of Offshore Platforms on the Gulf of Mexico OCS to the Year 2023. OCS Study report prepared by the Center for Energy Studies, Louisiana State University, Baton Rouge, LA.

MODELING OF PLATFORM INSTALLATIONS AND REMOVALS: THE MMS PERSPECTIVE

Mr. Thierry DeCort
Presented by Ms. Stephanie Gambino
Minerals Management Service

The office of Resource Evaluation (RE) in the Gulf of Mexico Region (GOMR) currently has a process in place where one of the products is a forecast of platform installations and removals by water depth and planning area. RE's forecast of platform installations and removals is used by RE for preparation of the National Assessment. The forecast is also used by Leasing and Environment (LE) in the GOMR as well as Headquarters in Herndon, Virginia, for preparation of each Five-Year Leasing Program and for Environmental Impact Statements.

The MMS will benefit from and RE will support and participate in a new platform installation and removal-forecasting project that focuses on improving our current forecasting methods, models, techniques, and data types used. This study, to begin in January of 2001 by the Center for Energy Studies at Louisiana State University, will focus on identifying the best platform forecasting methods and techniques worldwide rather than just on the result of a forecast. This will help RE to improve our current forecasting process and models, thereby providing years of improved forecasting results for both the GOMR and Headquarters.

The objectives of the new study are the following:

1. to identify, develop, and investigate alternate platform installation and removal forecasting methodologies from around the world – i.e. best practices and benchmarks. This would also include RE's methodology;

2. to identify the best data variables to use for platform forecasting. This includes identifying the data MMS currently possesses and how this data can be put to its best use; and

3. the development of a modern forecasting model that employs the most relevant data and the best statistical and econometric modeling techniques – i.e. sensitivity analysis.

THE OFFSHORE ENVIRONMENTAL COST MODEL

Dr. William King
Minerals Management Service

The essential question this paper addresses is, “What is the OCS program worth?” MMS is mandated to consider this question by the OCS Lands Act as Amended. Section 18 of that act requires the Department of the Interior, through the MMS to prepare a Five-Year Program. The first subsection of section 18, states:

> (a)(1) Management of the outer Continental Shelf shall be conducted in a manner which considers economic, social, and environmental values of the renewable and nonrenewable resources contained in the outer Continental Shelf, and the potential impact of oil and gas exploration on other resource values of the outer Continental Shelf and the marine, coastal, and human environments.

MMS has decided (and the Courts have sanctioned) the use of cost-benefit analysis (CBA) as the form of economic analysis to be used to estimate the social and economic value of the program.

The Five-Year Program process produces the following sets of documents, which include CBA:

- The Draft Proposed Program, which ranks all active planning areas based on total available resources

- The Proposed Program, which ranks relevant program areas based on total available resources and evaluates program alternatives based on anticipated production

The theory and practice of CBA has sanctioned a specific measure for determining the desirability of a public action. This measure is the present value of the future stream of net social benefits (gross benefits minus gross costs) from the investment or policy. In this case, the net benefits under consideration are those that would accrue to society from the OCS natural gas and oil leasing included in the Five-Year Program. These benefits and costs are counted over the life of the project or action and discounted to the present to account for the time value of money.

The CBA MMS performs for the Five-Year Program builds on results from three models:

- NEV

- OECM

- MktSym2000

NEV, which Larry Slaski created and runs, is a discounted cash flow spreadsheet that estimates the gross producer surplus from the OCS program.

The OECM has a fairly long history in MMS and the Department. Among the early environmental cost calculations upon which it is based is the original Natural Resources Damage Assessment Model (NRDAM), whose original development is linked to the name Tom Grigalunas. This was followed by the General Purpose Environmental Cost Model (GPECM) prepared by A.T. Kearney and used by MMS for the past two Five-Year Programs. Unfortunately, the GPECM would only run reliably in Lotus123 release 2.2. It was further burdened with a strange structure, bizarre programming, quirky results, and an outdated empirical basis. The GPECM included the following sectors:

- OCS Air Emissions
- OCS Effluent Discharges
- Spill Avoidance
- Infrastructure
- Preemption/Gear Loss
- Wetland Losses
- Property Value Losses
- Oil Spill Control/Clean-up
- Recreation/Tourism Losses
- Commercial Fishery Losses
- Wildlife/Ecological Losses
- Subsistence Losses
- Legal Costs
- Administrative/Research Costs

This would never do for the upcoming Five-Year Program. MMS needed something new to estimate environmental costs in the new millennium.

MMS's response was to contract with Foster Associates for the Offshore Environmental Cost Model (OECM). Bill Wade has been the Project Manager, Jay Plater, a Resource Economist, has been the team modeler, and Brian Roach of the University of Maine has done the majority of the research on which the model is based.

The new model has the following sectors:

- Air quality
- Water quality
- Fauna
- Faunal habitat and flora
- Recreation
- Commercial fishing
- Subsistence
- Onshore infrastructure and fiscal impacts
- Onshore property values

Clearly, this model offers less than the GPECM.

In this short paper it is impossible to show how the model works or much of its structure. Table 2F.8 shows what one of the results panels looks like following a recent run for the Draft Proposed Program.

Reviewing where we are now, we calculated gross producer surplus using NEV. If we now subtract environmental costs that we obtain from OECM we get what economists call net producer surplus. Most other people know it as pure economic profit.

Several years ago the National Committee on Oil Import Dependency looked at the costs and benefits of oil imports versus domestic oil production. After extensive study, this team came to the conclusion that the only benefits from domestic oil production are producer surplus and consumer surplus. We have calculated net producer surplus, but we still need an estimate of consumer surplus. But what is consumer surplus? It is the difference between what consumers pay for a good or service and what they would be willing to pay.

The original Market Simulation Model contained a simultaneous equation system of up to nine constant elasticity equations with a manually triggered convergence algorithm. While it was a clever spreadsheet model, it was unlikely that anyone other than the creator would ever be able to run it. Jay Plater of Foster Associates performed his magic on the system and the result is MktSym2000, which is a slick system of three spreadsheets. One is for inputs, one is the model itself, and displays the summary of results.

Table 2F.9 shows the oil submodel at a single point in time (2010).

Table 2F.8. A results panel following a recent run for the Draft Proposed Program.

	DPP – Low		
	Annual Environmental Costs		
	National Cost Allocation/Import Backout Enabled - Base		
	Summary of Environmental Costs - All Cost Sectors		
	($2002) (in $000)		
	OCS Region		**Present Value**
		Planning Area	
N	**ATL**	North Atlantic	-
		Mid-Atlantic	-
A		South Atlantic	-
		Straits of Florida	232
T	**G**	Eastern Gulf	4,111
	o	Central Gulf	140,704
I	**M**	Western Gulf	109,852
	PAC	Southern California	-
O		Central California	-
		Northern California	-
N		Washington/Oregon	-
		Gulf of Alaska	-
A		Cook Inlet	9,164
	A	Kodiak	-
L		Shuimagin	-
	L	North Aleutian Basin	-
		Aleutian Arc	-
	A	St. George Basin	-
C		St. Matthew Hall	-
	S	Bowers Basin	-
O		Aleutian Basin	-
	K	Navarin Basin	-
S		Norton Basin	-
	A	Hope Basin	(0)
T		Chukchi Sea	5,331
		Beaufort Sea	10,180
S		**Total**	**279,575**

Table 2F.9. The oil submodel at a single point in time, 2010.

Oil Submodel 30-Jan-01						
A Constant Price Elasticity Model To Estimate Consumer Surplus Benefit Losses Associated With Program Alternatives						
Year Of Analysis - 2010						
			No Action Alternative			
Assumed Oil Price	$18.00		Production Loss		0.5935	18.08
(2002 $/BBL)			(MMBPD)			
No Action Price	$18.08		Consumer Surplus Loss		$483.91	
(2002 $/BBL)			(2002 $MM)			
P R O D U C T I O N						
Producing Region	**DPP Low**			**No Action Alternative**		
	Price Elasticity	Quantity Produced	Constant	Quantity Produced	Difference (Base - NA)	
		(MMBPD)		(MMBPD)	(MMBPD)	
OCS	0.64	2.08	0.33	1.49	(0.59)	
Onshore Domestic	0.58	6.64	1.24	6.66	0.02	
OPEC	1.10	42.16	1.75	42.37	0.21	
Rest Of World	0.65	43.85	6.70	43.98	0.13	
Stock Change		0.30		0.30	-	
Total Production		**95.03**		**94.80**	**(0.23)**	
C O N S U M P T I O N						
Producing Region	**DPP Low**			**No Action Alternative**		
	Price Elasticity	Quantity Consumed	Constant	Quantity Consumed	Difference (Base - NA)	
		(MMBPD)		(MMBPD)	(MMBPD)	
US	-0.50	22.70	96.31	22.65	(0.05)	
Rest Of OECD	-0.65	28.04	182.99	27.96	(0.08)	
OPEC	-0.36	7.78	22.02	7.77	(0.01)	
Rest Of World	-0.50	36.51	154.90	36.43	(0.08)	
Total Consumption		**95.03**		**94.80**	**(0.23)**	
US Imports		**13.98**		**14.50**	**0.52**	
Discrepency		-		0.000		

The summary sheet looks like Tables 2F.10 AND 2F.11.

Table 2F.10. Sample summary sheet, part 1.

NPV of Consumer Surplus Benefits from OCS Production				
DPP Low vs. No Action Alternative				
OCS Region		Oil Production	Gas Production	Total Oil & Gas
	Planning Area			
		($ MM)	($ MM)	($ MM)
A	North Atlantic	-	-	**-**
T	Mid-Atlantic	-	-	**-**
L	South Atlantic	-	-	**-**
	Straits of Florida	6.4	0.1	**7**
G	Eastern Gulf	183.0	68.55	**252**
o	Central Gulf	2,057.6	1,344.9	**3,403**
M	Western Gulf	1,399.8	1,026.3	**2,426**
P	Southern California	-	-	**-**
A	Central California	-	-	**-**
C	Northern California	-	-	**-**
	Washington/Oregon	-	-	**-**
A	Gulf of Alaska	-	-	**-**
L	Cook Inlet	374.2	62.6	**437**
A	Kodiak	-	-	**-**
S	Shuimagin	-	-	**-**
K	North Aleutian Basin	-	-	**-**
A	Aleutian Arc	-	-	**-**
	St. George Basin	-	-	**-**
	St. Matthew Hall	-	-	**-**
	Bowers Basin	-	-	**-**
	Aleutian Basin	-	-	**-**
	Navarin Basin	-	-	**-**
	Norton Basin	-	-	**-**
	Hope Basin	-	0.6	**1**
	Chukchi Sea	479.8	-	**480**
	Beaufort Sea	1,016.4	213.6	**1,230**
Total Benefits - All Regions		**5,517**	**2,717**	**8,234**
Consumer Surplus Benefits		$ / bbl	$ / mcf	$ / boe
	Per Unit Of Production	$2.14	$0.28	$1.91

Table 2F.11. Sample summary sheet, part 2.

Production and Consumption Effects
DPP Low vs. No Action Alternative
(2002 - 2056)

Sector	DPP Low	No Action Alternative	Change In Sector	% Change In Sector	% Of Lost OCS Production
	DPP Low	No Action Alternative			
	DPP Low	No Action Alternative			
OIL (BBO)					
Production Effects					
OCS Production	45.4	34.8	(10.6)	(23.3%)	(100.0%)
Onshore Production	141.1	141.4	0.3	0.2%	2.5%
Imports	390.5	399.8	9.4	2.4%	88.4%
Consumption Effects					
U.S. Consumption	576.9	576.0	(1.0)	(0.2%)	
Conservation					5.5%
Switch To Gas					3.6%
GAS (TCF)					
Production Effects					
OCS Production	791.8	764.5	(27.2)	(3.4%)	(100.0%)
Onshore Production	1,048.9	1,056.6	7.7	0.7%	28.3%
Imports	344.9	349.4	4.4	1.3%	16.3%
Consumption Effects					
U.S. Consumption	2,185.6	2,170.5	(15.1)	(0.7%)	
Conservation					16.1%
Switch To Oil					39.3%

Returning to our review of where we are now: We have producer surplus from NEV. From that we subtract environmental costs from OECM. This gives us net producer surplus. To that we add consumer surplus benefits from MktSym200, which gives us the total net benefits of the OCS program. Details of this process can be found in Economic Analysis for the OCS 5-Year Program 1997-2002: Theory and Methodology. OCS Report MMS 96-0048.

These models are not only used in the Five-Year Program. They can also be applied to policy analysis questions. For instance, OECM was used to estimate the environmental costs of gas developments on Destin Dome for the Coastal Zone Consistency Report. When Congress asked how large a decrease in oil prices could be attributed to increased OCS production attributable to royalty rate reduction, MktSym2000 was used to estimate the decrease in price and the value to society.

SESSION 1G

ENVIRONMENTAL SCIENCES

Chair: Mr. Greg Boland, Minerals Management Service
Co-Chair: Ms. Debra Vigil, Minerals Management Service

Date: December 7, 2000

Presentation	Author/Affiliation
Long-Term Monitoring at the East and West Flower Garden Banks National Marine Sanctuary 1998-1999	Dr. Quenton R. Dokken Dr. John W. Tunnell Mr. Carl R. Beaver Ms. Susan A. Childs Mr. Thomas W. Bates Dr. Kim Withers Center for Coastal Studies Texas A&M University-Corpus Christi Dr. Ian R. MacDonald Dr. Terry Wade Geochemical Environmental Research Group Texas A&M University
Surveys and Satellite Tracking Loggerhead Sea Turtles (*Caretta caretta*) in and around the Flower Garden Banks, Northwest Gulf of Mexico	Ms. Emma L. Hickerson Flower Garden Banks National Marine Sanctuary Texas A&M University
Platforms for Research: The “Migration Over the Gulf” Project	Dr. Robert W. Russell Center for Coastal, Energy, and Environmental Resources (CCEER) Louisiana State University
Effects of Oil and Gas Exploration and Development at Selected Continental Slope Sites in the Gulf of Mexico	Dr. Alan D. Hart Continental Shelf Associates, Inc. Jupiter, Florida
Bluewater Fishing and Deepwater OCS Activity: Interactions Between the Fishing and Petroleum Industries in Deepwaters in the Gulf of Mexico	Mr. David B. Snyder Continental Shelf Associates, Inc. Jupiter, Florida

(continued on next page)

Presentation	Author/Affiliation
Evaluation of Oil and Gas Platforms on the Louisiana Continental Shelf for Organisms ith Biotechnology Potential	Dr. Lawrence J. Rouse Department of Oceanography and Coastal Studies Institute Louisiana State University

LONG-TERM MONITORING AT THE EAST AND WEST FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY 1998-1999

Dr. Quenton R. Dokken
Dr. John W. Tunnell
Mr. Carl R. Beaver
Ms. Susan A. Childs
Mr. Thomas W. Bates
Dr. Kim Withers
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INTRODUCTION

Deep-water coral habitats in the northwestern Gulf of Mexico, the Flower Garden Banks (FGB) were given “National Marine Sanctuary” status in 1992. The FGB are located on the edge of the outer continental shelf of the Gulf of Mexico (GOM). East Flower Garden Bank (EFGB) located at 27° 54.5' North latitude and 93° 36.0' West longitude is approximately 193 km southeast of Galveston, Texas. West Flower Garden Bank (WFGB) is located approximately 172 km southeast of Galveston at 27° 52.4' North latitude and 93° 48.8' West longitude (Figure 1G.1). Both banks are topographic highs created by uplift of underlying salt domes of Jurassic, Louann origin (Rezak 1981). These domes of bedrock overlying uplifted salt domes and capped by an overgrowth of calcareous marine organisms represent the largest charted calcareous banks in the northwestern GOM (Bright *et al*. 1985) and the northernmost coral reefs on the continental shelf of North America (Bright *et al*. 1984).

The coral cap varies in depth from approximately 18 to 36 m (Rezak *et al*. 1985). The pear shaped EFGB, encompassing an area of approximately 67 km^2 (Rezak *et al*. 1985) slopes from the crest at approximately 20 m to a seabed plane of terrigenous mud surrounding the banks at a depth of 100-120 m. The eastern and southern edges of the bank slope steeply while the area to the north and west of the coral cap exhibits a more gentle slope (Figure 1G.2). The major features of the 137 km^2 WFGB are three crests aligned along an east-west axis (Figure 1G.3). The middle crest rises from a depth of 100 – 150 m to within 18 m of the surface and supports a coral reef habitat (Rezak *et al*. 1985).

The FGB are unique in that they exist in the most active offshore oil/gas exploration and production area in the world. Approximately 4,000 production platforms are located in the northern GOM primarily in the northwestern quadrant with the FGB. Two kilometers to the east of the EFGB, a production platform was installed in 1982 and has been producing natural gas since installation. In

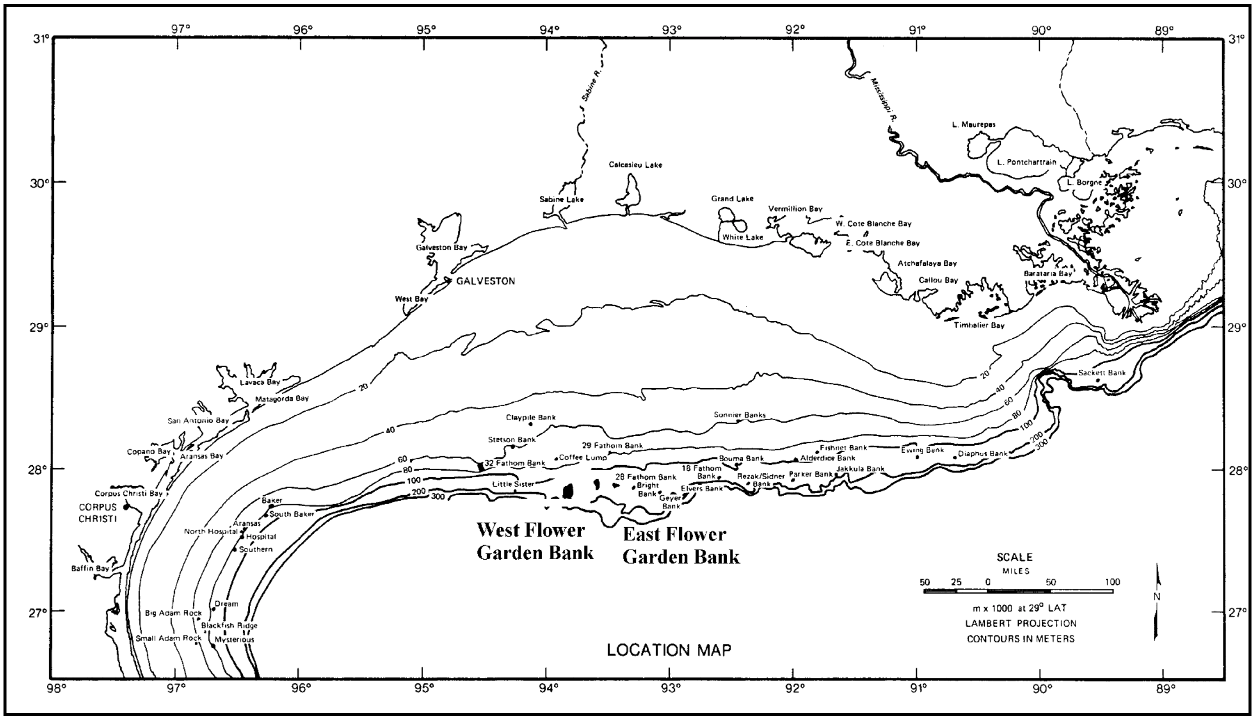

Figure 1G.1 Location map of the East and West Flower Garden Banks in relation to the continental shelf and other topographic features of the northwestern Gulf of Mexico, (from Gittings *et al*. 1992).

1998, an additional well was drilled at this production site (dry well). To date, the production of oil and gas in the near vicinity has not been demonstrated to be detrimental to the health and productivity of the FGB.

METHODS

Sampling was conducted 27 September – 1 October 1998 and 12-16 September 1999. The methods are a continuation of protocols established in 1989 by Gittings *et al*. (1992). Non-destructive photographic sampling was the primary methodology (Dokken *et al*. 1999).

Fourteen 10 m random photographic transects at each bank were conducted to provide data on coral community diversity and cover (Dokken *et al*. 1999). Transects were run both inside the designated 100 m2 study area and outside the study area to test the consistency of habitat conditions within and outside the study area.

Sclerochronology was used to measure annual accretionary growth of *Montastraea faveolata* over extended time periods. Encrusting growth of *Diploria strigosa* was measured at 60 close-up photographic stations on each bank.

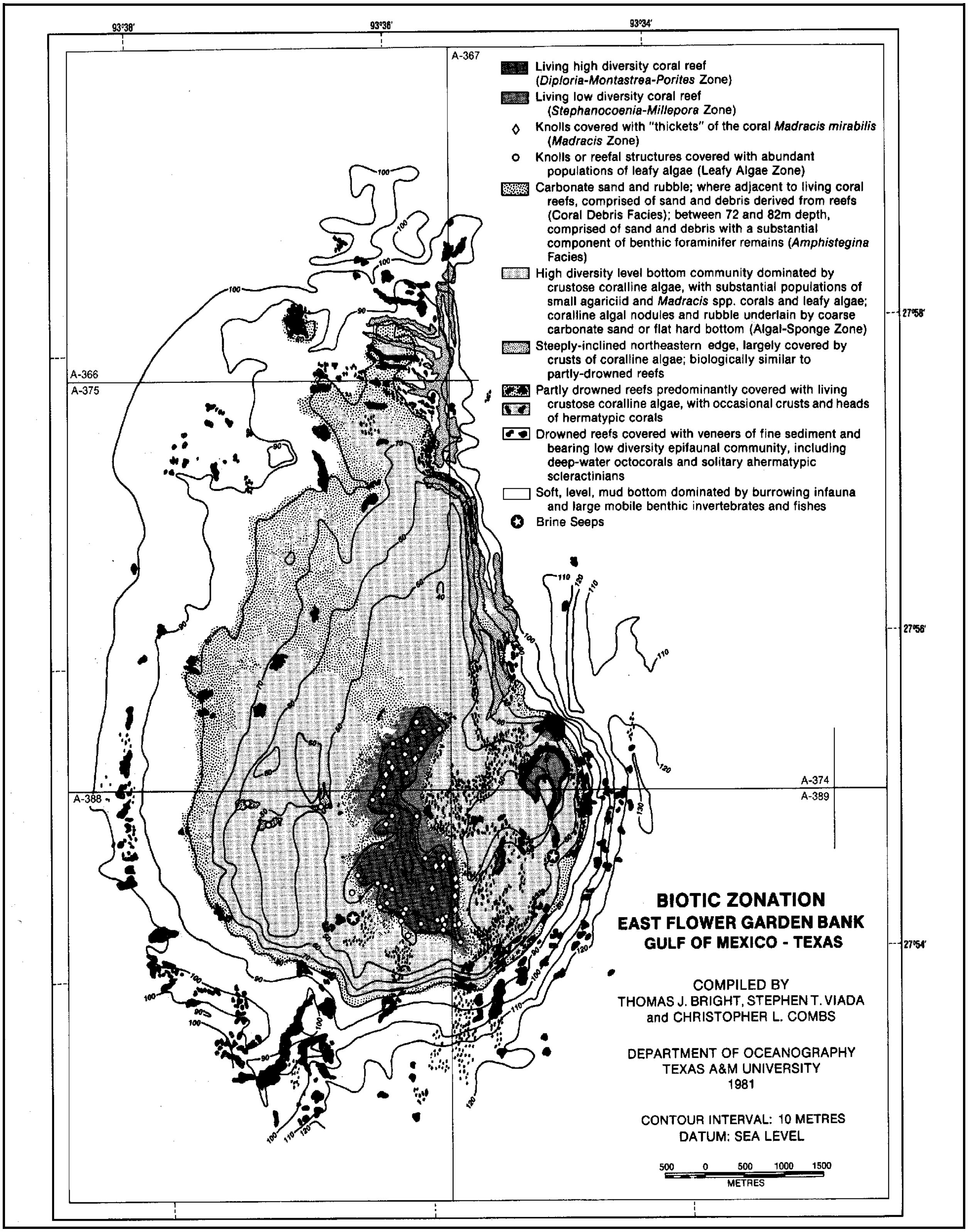

Figure 1G.2. Biotic zonation and topography of East Flower Garden Bank. The dark area depicts the high diversity coral reef zone (from Rezak *et al.* 1985).

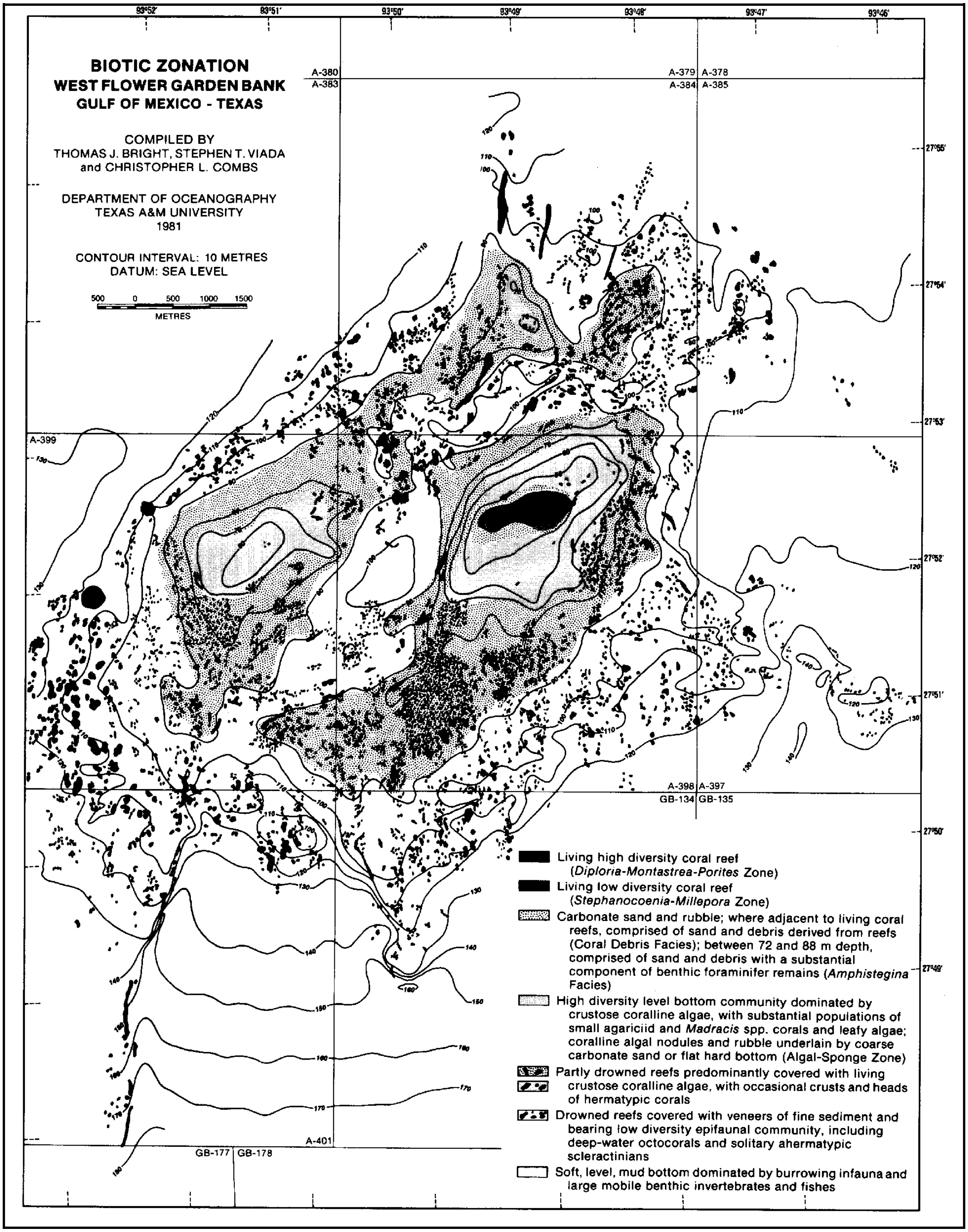

Figure 1G.3. Biotic zonation and topography of the West Flower Garden Bank. The darkest area depicts the high-diversity coral reef zone (from Rezak *et al.* 1983).

Forty repetitive quadrats were photographed at each bank to monitor changes in community structure. Permanent photographic stations were established in 1989 (Gittings *et al*. 1992). Each quadrat photographic was repeated in 1998 and 1999 to compare and contrast with prior years.
Video transects (100 m) were recorded along the boundary lines of the study area. These were compared to previous video transects and archived for historical record.

Temperature, insolation, and hydrocarbons within the water column were measured. Continuous recording thermistors were used to record temperature and Li-Cor spherical light sensor measure photosynthetically active radiation (PAR). Semi-permeable Membrane Devices (SPMD) were deployed to sample the water column for polycyclic aromatic hydrocarbons, PCB, and pesticides.

Transect surveys of herbivorous sea urchins, *Diadema* sp., were conducted. Additionally, visiting scientists conducted studies of algal ecology, carbon distribution and flow, micromollusc populations, and pore water quality.

RESULTS

The results were generally unremarkable and consistent with past data. The one notable occurrence was the increase in algal biomass at the expense of bare reef rock. The cause of this is not known. Population densities of *Diadema* sp., a primary control of algal biomass, remained very low.

The results of the SPMD (water quality) were possibly compromised due to juvenile crustaceans tearing pinholes in the membranes. Shorter deployments will be required to eliminate this occurrence. Contaminants recovered were in very small concentrations.

Guest scientists recorded 72 species of algae, more than 100 new species of micromolluscs for the FGB, and described the FGB as “autogenous” with blue-green algae the primary source of nitrogen. And, based on laboratory studies of toxicity, the pore water of the FGB sediments was found not to contain toxic levels of any contaminants.

CONCLUSION

The FGB continue to be healthy and productive. The monitoring program continues to expand one of the longest continuous databases for coral reefs in existence. Through the monitoring and associated research efforts understanding of the dynamics of the FGB is increasing.

REFERENCES

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippet. 1985. The Flower Gardens: A compendium of information. U.S. Dept. of Int. Minerals Mgmt. Service, Gulf of Mexico. OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 85-0024. 103 p.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and T.S. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: a comparison to other western Atlantic reefs. Bull. Mar. Sci. 24(3):461-476.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long-term monitoring of the East and West Flower Garden Banks 1996-1997. U.S. Dept. of Int. Minerals Mgmt. Service, Gulf of Mexico. OCS Region, New Orleans, Louisiana. OCS Study 99-0005. 101 p.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, D.K. Hagman, and B.S. Holland. 1992. Long-term monitoring at the East and West Flower Garden Banks. U.S. Dept. of the Int. Minerals Mgmt. Service, Gulf of Mexico. OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 92-0006. 206 p.

Rezak, R. 1981. Geology pp. 23-59. *In* R. Rezak and T.J. Bright, eds. Northern Gulf of MexicoTopographic Features Study. Final Report to the U.S. Dept. of Int., Bureau of Land Mgmt. Contract #AA551-CT8-35. Vol. 1. NTIS Order No. PB81-248650:23-59.

Rezak, R.,T. J. Bright, and D.W. McGrail. 1985. Reefs and banks of the northwestern Gulf of Mexico: Their geological, biological, and physical dynamics. John Wiley and Sons, New York, NY. 259 p.

SURVEYS AND SATELLITE TRACKING LOGGERHEAD SEA TURTLES (*CARETTA CARETTA*) IN AND AROUND THE FLOWER GARDEN BANKS, NORTHWEST GULF OF MEXICO

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ABSTRACT

More than five years of underwater/above water surveys resulted in 140 reports documenting 153 sea turtle sightings within the boundaries of the Flower Garden Banks National Marine Sanctuary (FGBNMS) in the northwestern Gulf of Mexico (GOM). Six large immature loggerhead sea turtles (*Caretta caretta)* with carapace lengths (CCL) ranging from 70.5-101cm were captured at depth by SCUBA divers. Five of the six were outfitted with satellite transmitters. Five of the six animals were females. Over 40% of the satellite locations fell within the Sanctuary boundaries. Geographic Information System (GIS) analysis revealed an average core range of 133.6 km^2 and an average home range of 1,074 km^2. These ranges are not significantly different from satellite tagged *C. caretta* captured underneath oil and gas platforms in the GOM. The average core ranges fell within one kilometer of the sanctuary boundaries, and the home range within 30 km of the sanctuary boundaries. Management recommendations are made to the National Oceanic and Atmospheric Administration's (NOAA's) Marine Sanctuary Division.

INTRODUCTION

This data is the result of sea turtle satellite tracking conducted at the Flower Garden Banks National Marine Sanctuary from June 1995 – August 1999.

The East and West Flower Garden Banks are located over 180km SSE of Galveston, Texas. They are separated by about 20km of open ocean - of depths around 130m. The Flower Garden Banks are the northernmost coral reefs on the North American continental shelf. The Sanctuary is one of 13 Federal Marine Sanctuaries within National Oceanic and Atmospheric Administration (NOAA). The Flower Garden Banks National Marine Sanctuary designated as a sanctuary in 1992. Stetson Bank was added to the FGBNMS in 1996. The banks themselves are the surface expression of salt diapirs capped by living coral reefs. The reefs are estimated to have been in existence for 10-15,000 years.

The West Bank is approximately 90 square km in size, with a reef crest covering 0.4 square km, rising to within 20m of the surface. The East Bank is a pear shaped dome approximately 5 km in diameter, with a square kilometer of reef crest rising from over 100m depth to within 18m of the sea surface.

Stetson Bank is composed of claystone outcroppings that have been pushed up to within 17m of the sea surface. The most conspicuous features of this bank are the pinnacles, which stretch along the northwest face for a distance of approximately 500m. They rise from about 65m on the northwest side and slope off to around 23m on the southeast side where a large, flat area dotted with small rocky outcroppings stretches out behind the pinnacles region.

At the East and West FG Banks, above 36m in depth, the hermatypic corals—four species of *Montastrea* (a star coral), and two brain corals - *Diploria strigosa and Colpophyllia natans*, dominate the landscape along with approximately 17 other species. These corals represents approximately one-third the number of species of coral found in other Caribbean reef systems such as Bonaire and Florida Keys. Monitoring efforts report over 50% coral coverage. (Similar to Bonaire, but higher than most areas of the Florida Keys).

Monitoring efforts over the past 20 years have shown that this is a very healthy reef system. It is home to many of the typical Caribbean assemblages of invertebrates and fish, but has fewer species than some: just over 200 species of fish. Usual visibility in winter is around 20m with summer visibility averaging round 30m. Seasonal occurrence of pelagic elasmobranchs at the Flower Gardens has been documented by Jeff Childs of the Wildlife and Fisheries Department at Texas A&M University. Around 27 species of elasmobranchs occur at the sanctuary, including the winter-time species. Whale sharks occur during the late summer months. These animals we refer to as the charismatic megafauna of the Sanctuary, included in this category are the sea turtles. Sea turtles are endangered and threatened species.

Life Cycle of Sea Turtles

1. The majority of sea turtle research is conducted on nesting beaches where hundreds, and sometimes thousands, of animals converge to dig holes and lay their eggs. This life history stage of sea turtles is the best documented. Unfortunately, the nesting represents but a fleeting visit by the animals—their home is in the water—where the females will spend over 95% of their time. Males may never return to land once they have left their beach of origin. The ocean environment is a difficult place to conduct research, and therefore, limited studies have been undertaken there.

2. Offshore from the nesting beach, males congregate to meet the incoming migrating females. Mating takes place either here or in unknown oceanic areas along the migration route.

3. The males head back to their adult feeding grounds after a period of mating, leaving the females to their nesting cycle. After this cycle is completed, they too head to the adult feeding grounds.

4. After 8 – 10 weeks of incubation, the eggs hatch and the hatchlings make their mad dash to the ocean. At this time, they enter a period in their lives that referred to as the “lost year”—actually, it is many years. During this period very little is known of the animals’ whereabouts. It is generally accepted that hatchlings are associated with drifting *Sargassum* mats. After possibly as many as 20 years, the animals reappear as juveniles on juvenile feeding grounds. The Flower Gardens, I believe, is one of these grounds, but for large juveniles. We have, however, documented one adult animal.

After going through several years of puberty, the now-adult animals migrate for reproduction and return to an adult feeding ground or perhaps to the same feeding ground they utilized as large juveniles.

Project Objectives

1. Determine what species of sea turtles occur at the study site;

2. Attach radio transmitters to turtles to determine whether they are resident animals and learn about their use of the Sanctuary (we are also able to learn something about how much time they spend on the surface by using transmitters);

3. Attach satellite transmitters to turtles to learn to what depths the animals descend during their dives to determine their core and home ranges and migratory routes;

4. Recommend management strategies, if needed, to the Sanctuary for necessary protection of the animals.

METHODS

Sighting Data

I relied on volunteer divers to provide much of the sighting data. To encourage recreational divers to report their sightings, I placed informational posters onboard in the galley area and other strategic places. The posters had descriptions and pictures of the five species of turtle found in the GOM, description of how to sex a turtle, and explanations of how divers could participate in the study. I placed sea turtle information sheets onboard and provided slates for their use underwater by those taking notes of their sea turtle observations—e.g. if the turtles had barnacles on their carapaces, they could document the location directly onto the slate. Census forms were also placed on board for the divers to report their observations. I asked them to attempt to identify the species and sex, to estimate carapace length and width, and to note any identifying characteristics such as barnacle patterns, missing/notched flippers and scutes. Divers were also asked to provide some details such as date, time, location, weather conditions, and their contact information. These forms were left onboard for my collection.

I encouraged the divers to provide any available photographs or videos of the turtles they encountered. With these I created a catalog of individual sea turtles—using the identifying characteristics. This is a short-term way of documenting the persistence of individuals, as barnacles are not permanent features on the shells of the animals. I hope to test this method of identification over time as I intend to place the catalog on the Sanctuary website and onboard the recreational dive vessels so that people can refer to them. Of course, missing flippers and notching of carapaces are more of a long-term identification characteristic.

Satellite Telemetry

The most challenging part of this project was finding an animal and capturing it. Both volunteers and I spent many hours for an animal to put in the net.

In the event that a resting animal was found, a designated diver would immobilize the animal by tipping it slightly forward to stop it from using its strong front flippers to start swimming. (If the animal is large enough and is allowed to start swimming forward, there is nothing to do but to let go.) A second diver was assigned to be ready with the capture net to receive the animal.

Once the turtle was in the net, ropes were tied onto the metal mouth of the bag and used by the divers to carry the net and turtle as they made their slow ascent, including a safety stop, to keep their hands out of reach of the turtle's powerful jaws.

Once the animal was safely on deck, it was checked for any injuries. Then the carapace was cleaned off and dried, biological measurements taken, including measurements of carapace and plastron length and width, size of head, tail, and claws. The animals were usually PIT tagged, as well as flipper tagged. Blood was sampled from a dorsal sinus located in the neck. The serum was used to determine the sex of the animal, and the red blood cells were stored for genetic analysis. The satellite transmitter was either fiberglassed or epoxied onto the carapace. It usually took around two hours to completely process an animal before it was released.

Several factors have to come into play for a transmission to occur. The transmitters only send a signal when the animal is on the surface and the transmitter is turned "on." The transmitters were preprogrammed with a duty cycle: some of them were set for 8 hours on, then 52 hours off, and two of them were set to transmit constantly, that is, 24 hours on. Also, the transmitters were equipped with saltwater switches that prevent transmissions when they are submerged (or, in some cases, when the animal is on the surface but the transmitter is being affected by high seas). The animals only surface for perhaps two to three minutes per hour, if that. For location information to be obtained, the animal must remain on the surface for at least that time to send off several signals. One of the two NOAA satellites must be within range of the animal—about eight minutes per satellite pass. When these factors all come together, the satellite receives several messages and relays them to the ground in real time. The satellites record the data and dump the messages as they pass over of the receiving stations. The receiving stations then pass on the raw Argos data to the processing centers, which then process the data and pass it on to the Argos user.

Argos locations are calculated by measuring the Doppler shift on the transmitter signals. The Doppler shift change in frequency of a sound wave or electromagnetic wave when a source of transmission and an observer are in motion relative to each other. Each time the satellite receives a message from a transmitter, it measures the frequency and time-tags the arrival. Argos assesses the data and allocates a Location Class to each fix, depending upon the number of messages received, the satellite and transmitter geometry during the message reception and the transmission stability.

I assessed the location data using two methods - the first was looking at core and home ranges using an extension to Arcview called Animal Movements - developed by USGS at the Alaska Biological Science Center. Based on the location points I input, this program calculated an area within which a 50% probability exists that a given point will fall—called the core range—and an area within which a 95% probability exists that a given point will fall—the home range.

The second way I assessed the location data is by a method I call the Satellite Fix Proximity Relationship. I created this method because I wanted to look at the data in relation to the National Marine Sanctuary boundaries. For this reason, I created several zones. The center of each zone is the area within the Sanctuary. Radiating outwards from the banks are the other zones, out to 1km, 5km, then 6.44km, a distance that equals 4 miles. The Flower Garden Banks lie within one of the most active petroleum fields in the world. There is an active gas platform within the Sanctuary boundaries on the East Bank, within 1 mile of the reef crest. Minerals Management Service created regulatory zones to protect many biological hardbottoms within the GOM. There is a 4-mile regulatory zone around the banks of the Flower Gardens. The oil and gas industry must adhere to special regulations within these areas, for example, they are required to shunt drilling muds to within approximately 10m of the sea floor during drilling operations. Other zones created for the purpose of this study are at 10km and 30km.

RESULTS

Sighting Data

Both untrained and trained recreational and scientific divers collected the sighting data between August 1994 and April 2000.

A total of 153 sea turtle sightings were gathered, reporting three different species, *Caretta caretta*, the loggerhead sea turtle, *Eretmochelys imbricata*, the hawksbill, and *Dermochelys coriacea*, the leatherback sea turtle.

Loggerheads comprised 87% of the animals identified. More sightings took place underwater than on the surface (where the animals are often sighted as they surface for air). The majority of the sightings took place at the East Bank. The average estimated carapace length reported by observers was around 1m. Around one-quarter of the animals reported at Stetson Bank were hawksbills. Four post-hatchlings associated with *Sargassum* were observed. Unfortunately, one of these animals was eaten by a jack while passing by the dive platform. six animals were observed on multiple occasions.

According to records from one dive charter operator, diving pressure is greatest at the East Bank and the least at the West Bank. From diver usage information I have determined that there are similar numbers of turtles at both of the Flower Garden Banks and fewer turtles at Stetson Bank. A large percentage of the observations were made during the summer season because the boats are on a more rigorous schedule during this season.

Satellite Telemetry

Over the course of the study, 6 animals with carapace lengths ranging from around 70 and 100 cm were captured, and all but one of these animals were females. The male (whom we named Triton) was captured on three occasions over a period of twenty months. Most captures were conducted at night. Three animals were captured on each of the Flower Garden Banks.

The five functioning transmitters received a total of 771 messages—426 of which did not provide a location. A total of 278 of the remaining 345 satellite fixes were accepted for analysis. Transmission days totaling 1,450 days were obtained in fairly equal portions between the seasons.

Most of the accepted fixes were received during the summer and fall because the sea conditions during the winter and spring tended to be rougher than summer and fall, not allowing for quality transmissions.

The average core range for the five turtles was around 134 km^2 and encompassed nearly the entire Flower Garden Banks National Marine Sanctuary. The average home range was 1,074 km^2.

We can use this data to assist with management decisions. For example, we can determine what percentage of the core and home ranges we are protecting now. We can see that about 72 % of the core ranges of the animals are now protected within the Sanctuary boundaries, but only 44% of the home ranges are protected within the boundaries.

During the next couple of years, the Flower Garden Banks National Marine Sanctuary will be reviewing its management plan, including regulations. It will be reviewing, for example, the current boundaries and fishing regulations.

The data collected in this study suggest that if, for example, long-line fishing regulations were implemented, or the Sanctuary boundaries were extended to the MMS 4-mile zone, nearly all of the core ranges for these animals would be protected, as well as substantially more of the home ranges. The core range protection would increase by 25% and home range by nearly 37%.

I selected the MMS 4-mile zone as it is already in place and may perhaps provide a foundation for establishing further regulations.

Renaud and Carpenter, from the National Marine Fisheries Service in Galveston, captured four loggerhead sea turtles as the animals slept underneath oil and gas platforms in the GOM. They attached satellite transmitters to their carapaces and determined their core and home ranges (using a different type of analysis than was used in this study).

One of the animals apparently responded to a cold front by moving farther offshore in search of warmer water. After the cold front passed, the animal moved east into waters off Louisiana. I considered this animal to be an outlier and did not use it in the analysis, leaving three animals in the analysis.

When I compared the core and home ranges for both sets of animals, one living in an artificial habitat and the other living on natural reef, I found that there was no significant difference between the two.

I am wary of these data because the numbers of animals are very low (5 and 3), but I felt compelled to include them in my report, as they represent information not easily obtained and not reported previously.

CONCLUSIONS

- A population of resident loggerhead sea turtles utilizes the resources of the FGBNMS.

- Female loggerheads are the most often observed turtles at the Flower Garden Banks. It is interesting to note the sex ratio of the captured animals (five females and one male), as this is the same sex ratio of the South Florida loggerhead nests (see preliminary genetic data).

- Large juvenile animals are the dominant life history stage reported, and on occasion, hatchlings and post-hatchlings pass through in *Sargassum* mats. One adult female animal was documented.

- Hawksbills occurred at Stetson Bank at a higher ratio than either the East and West Bank , probably because the available sponges growing there.

- Over the course of this study, more turtles were observed at the Flower Garden Banks than Stetson Bank.

- The carapace length reported by observers is overestimated. I believe the captured animals (average carapace length of approximately 83 cm) is a representative group of the population of loggerhead sea turtles at the Flower Garden Banks. This overestimation is probably due to the fact that observers report the entire length of the animal, including the head.

- Hatchling and post-hatchlings found in Sargassum are susceptible to predation by chubs and jacks that come off the reef to feed or are associated with the moored vessels. I have witnessed this feeding behavior adjacent to oil and gas platforms. It is my prediction that increased platform installations and creation of artificial submerged habitat increases the predation of hatchlings on the surface.

- This study suggests that loggerheads living at natural and artificial reef structures (oil and gas platforms) exhibit similar core and home ranges.

- Two methods of location data analysis may be used to evaluate the effectiveness of current protection and make recommendations for management and protection decisions.

REFERENCES

Argos. 1984. Location and data collection satellite system user's guide. Toulouse, France: Service Argos. 36 pp.

Argos. 1996. User's Manual. Largo, Maryland: Service Argos. 176 pp.

Elvers, D.J. and C.W. Hill. 1985. History of Activities at the Flower Garden Banks. *In* The Flower Gardens: a compendium of information. T.J. Bright, D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Tripett, eds. Minerals Mgmt. Service, OCS Studies/MMS 85-0024.

Hickerson, E.L. 2000. Assessing and tracking resident, immature loggerheads (*Caretta caretta*) in and around the Flower Garden Banks, northwest Gulf of Mexico. Master's Thesis. Biology Department. Texas A&M University.

Hooge, P.N. and B. Eichenlaub. 1997. Animal movement extension to arcview. Ver. 1.1. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska.

Lutz, P.L. and J.A. Musick, eds. 1997. The biology of sea turtles. Boca Raton, Florida: CRC Press, Inc.

Musick, J.A. and C.J. Limpus. 1996. Habitat Utilization and Migration in Juvenile Sea Turtles. *In* The Biology of Sea Turtles. Lutz, P.L. and J.A. Musick, eds. Boca Raton, Florida: CRC Press, Inc. 137-163.

Owens, D.W. and G. J. Ruiz. 1980. New methods of obtaining blood and cerebral spinal fluid from marine turtles. Herpetelogica. 36:17-20.

Renaud, M.L. and J.A. Carpenter. 1994. Movements and submergence patterns of loggerhead turtles (*Caretta caretta*) in the Gulf of Mexico determined through satellite telemetry. Bull. Mar. Sci. 55(1):1-15.

Rezak, R. 1985. Geology of the Flower Garden Banks area, pp. 31-50. *In* The Flower Gardens: a compendium of information. T.J. Bright, D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Tripett, eds. Minerals Mgmt. Service, OCS Studies/MMS 85-0024.

PLATFORMS FOR RESEARCH: THE "MIGRATION OVER THE GULF" PROJECT

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Each spring, roughly a billion landbirds migrate northward across the Gulf of Mexico, en route to breeding habitats from their wintering quarters in the tropics. Following a short breeding season in the north, most of these birds return southward across the Gulf, their numbers then augmented by offspring produced over the summer. Although these massive trans-Gulf migrations (TGMs) represent one of the great behavioral events of the world, basic aspects of TGM (such as species composition, flight routes, orientation tactics, and responses to weather) have been poorly known. The flight pathway of a large proportion of trans-Gulf migrants is directed over Gulf waters in which are located about 4,000 offshore oil and gas production platforms. These platforms make up the largest artificial island system in the world. In light of the absence of natural islands or other terrestrial habitats during crossings of the Gulf of Mexico, it seems inevitable that the installation of an expansive artificial archipelago in the northern Gulf must affect migrants in some fashion. However, until recently, no systematic studies had examined the interaction between platforms and migrating birds.

Our MMS-sponsored study of TGM and migrant-platform interactions began in spring 1998, and fieldwork concluded in November 2000. The study is currently based at the LSU Center for Coastal, Energy, and Environmental Resources (CCEER), and is funded by MMS through a cooperative agreement with the LSU Coastal Marine Institute. Six major petroleum companies (BP, ExxonMobil, Newfield, Phillips, Shell, and Texaco) have made platforms available to the study and have provided in-kind support in the form of helicopter transportation of personnel, boat transportation of equipment, offshore housing and meals for personnel, and other forms of logistical assistance.

The large-scale design of the study evolved over the course of the fieldwork as we discovered more about TGM. During the first three field seasons (spring and fall 1998, spring 1999), we operated on five platforms off the Louisiana coast. During that initial exploratory phase, we discovered that the largest migratory flights often occur to the east (fall) or west (spring) of Louisiana. With the aid of a second MMS contract and additional assistance from our cooperating companies, we expanded to ten platforms in fall 1999 and nine platforms in spring 2000, and also expanded the field seasons temporally to cover the migration periods more completely. This second "confirmatory" phase of the study enabled us to achieve a more Gulf-wide perspective on migration and to test some of our radar-derived hypotheses concerning flight routes and platform influences. During the concluding phase of the study (fall 2000), we reduced our coverage to three platforms where we conducted several focused studies on migrant behavior. Over the course of the study, our field team has completed the equivalent of about eight continuous platform-years of monitoring (i.e., the equivalent in effort to one observer monitoring a single platform for eight years continuously with no breaks).

Our work has demonstrated that platforms constitute a significant component of the en route environment of trans-Gulf migrants. Although a small proportion of the total numbers of birds migrating over the Gulf stops on platforms, platform use varies dramatically among species, and in some cases is of great ecological significance. The diversity of impacts is too great to summarize here, so four specific examples follow:

1. Large numbers of Peregrine Falcons—perhaps the majority of the North American breeding population of this species—use oil platforms in the northern Gulf during the fall for resting and hunting. The species was federally listed as endangered until recently. Peregrines often appeared on platforms immediately *before* weather events that induced large landbird movements. Because of their high subsequent success preying on migrants, it seems that Peregrines are now “anticipating” ephemeral periods of high resource availability. This adaptive behavior may be a precursor to more dramatic evolutionary changes in the life history of the species, since an ecologically similar species—Eleonora’s Falcon—has evolved a strategy of breeding on islands in the Mediterranean during the fall, when abundant trans-Mediterranean migrant landbird prey are available for provisioning young.

2. The archipelago of offshore oil platforms may be facilitating the natural selection of a TGM strategy in several species. One of the most common birds on platforms is the Cattle Egret, a species that colonized eastern North America in the last half-century. A rapid evolution of TGM may be implicated in what appears to be a population explosion and major range expansion of White-winged Doves into the southeastern United States. Another dove species—the Eurasian Collared-Dove—has recently colonized North America, and it began showing up on platforms in fall 1999. Platforms may facilitate the evolution of TGM strategies in certain species by providing “steppingstones” that allow incipient migrants to cross the Gulf successfully via a series of shorter flights.

3. During the fall, many short-distance migrants that spend the winter along the Gulf Coast (such as wrens, kinglets, and sparrows) inadvertently “overshoot” the coastline during nocturnal migratory flights and end up over Gulf waters. These overshoot migrants, which are evolutionarily ill-equipped to deal with the rigors of overwater migration, are among the heaviest users of platforms during the fall, and the availability of platform rest stops probably enables many individuals to return to land successfully. This reduction in selection pressure may in turn be implicated in large-scale shifts in the wintering distributions of some of these species.

4. Because platforms in the northern Gulf are located toward the tail end of a northbound trans-Gulf flight, the existence of the platform archipelago reduces the distance that a spring migrant must cross over water during one leg. Under normal weather circumstances, many spring trans-Gulf migrants do not stop when they reach the northern Gulf coast, but instead proceed inland variable distances to suitable stopover habitats or even to the breeding grounds. However, sometimes migrants unexpectedly encounter poor weather en route across the Gulf, and many individuals are then forced down and perish in the Gulf. The refuge provided by platforms can ameliorate high weather-induced mortality and can

theoretically have important population-level impacts on species with small continental populations, due to the disproportionate impact of stochastic effects on small populations.

During our first two field seasons, we discovered an unexpected abundance of terrestrial insects offshore and expanded our focus to include insect monitoring via both visual censuses and quantitative sampling with ultraviolet light traps. During both spring and fall, a large blanket of terrestrial insects—the “aerial plankton”—is transported offshore by north winds. This aerial plankton represents a significant food resource for birds that stop to rest on platforms. Many of the birds are able to forage successfully, and in fact, energy intake rates of birds on platforms have sometimes been observed to be higher than generally observed in “natural” habitats onshore. The frequent abundance of migratory moths and other insects on platforms is especially important to fuel-depleted migrant birds forced down by foul weather during the spring and to the overshoot migrants during the fall.

In addition to the passively transported insect fauna, we have found that several species of dragonflies and moths are active trans-Gulf migrants. Trans-Gulf migration in insects has important implications for understanding large-scale biogeographic patterns as well as life-history strategies of the species involved.

We have also been monitoring the occurrence and behavior of fishes and seabirds in the vicinity of our platforms. This more opportunistic work has suggested a complex series of ecological interactions centered around platforms. Platforms appear to attract macrozooplankton and “baitfish,” either by behavioral attraction or by mechanical entrainment in convergent flows induced by the platform substructures. This fauna in turn attracts predatory fishes such as Blue Runners and tunas. Obligate surface-feeding seabird species are in turn attracted to the vicinity of the schools of predatory fish, where they take buoyant scraps from the fish feeding frenzies. These relationships merit further attention, because concentration of marine bird populations in the vicinity of platforms may be a conservation concern in the event of oil spills.

Our study has yielded many new discoveries concerning TGM and has provided important information about the effects of offshore platforms on trans-Gulf migrants. Our observations also suggest that the platforms have altered the ecology of the Gulf in diverse ways, facilitating a variety of complex and multi-trophic ecological interactions among marine plankton, fish, seabirds, landbirds, and terrestrial aerial plankton. While platforms may be beneficial to some organisms, a more important impact may prove to be their tremendous value to scientists as research platforms for learning more about the ecology of the Gulf. Our study serves as a successful model for how private industry, government, and academia can join forces and work cooperatively to achieve important research and environmental goals. As we shift into the writeup phase of the program, we will highlight the issues relevant to managing the “platform archipelago” as a resource for migrating birds, and the value of platforms for research and ecological monitoring.

Robert W. Russell received his Ph.D. in ecology and evolutionary biology at the University of California at Irvine in 1994. His dissertation work involved using radars to quantify spatial distributions of birds and insects in the atmosphere and their relationships to atmospheric structure. He spent several years as a research scientist with NOAA in Seattle before moving to the Louisiana State University in January 1998 to lead the new MMS-sponsored study of bird migrations and offshore platforms in the Gulf of Mexico. His primary research interests concern the ecology of bird and insect migrations, but he has also been active in biological oceanography, studying relationships between ocean physics, zooplankton distributions, and seabird ecology in both Arctic and Antarctic seas.

EFFECTS OF OIL AND GAS EXPLORATION AND DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO

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Continental Shelf Associates, Inc. and its subcontractors/consultants are conducting a multiyear study to assess the impacts of oil and gas exploration and development at selected sites on the continental slope in the Gulf of Mexico (GOM). These sites are two exploration sites, which are being sampled before and after drilling, and three post-development sites, which are being studied once after drilling. In addition, a single site where approximately 800 barrels of synthetic based mud was spilled is also being studied. The two exploration sites, Garden Banks Area Block 516 and Viosca Knoll Area Block 916, are located in water depths of about 1,000 m. The three post-development sites are Mississippi Canyon Block Area 292, Mississippi Canyon Area Block 934, and Garden Banks Area Block 602. Water depths at these post-development sites are about 1,100 m. The water depth at the spill site, Mississippi Canyon Area Block 592, is approximately 670 m. Both water based and synthetic based muds were used in the drilling of the development wells and will be used in the drilling of the exploration wells.

The program consists of two components: physical characterization and chemical/biological characterization. The objective of the physical characterization is to determine the physical impacts of the operations including

1. areal extent and accumulation of muds and cuttings;

2. physical modification/disturbance of the sea bed due to anchors and their mooring systems; and

3. accumulation of debris due to operations.

These physical impacts will be determined from acoustic reflectivity maps produced from data collected with a deep-towed side-scan sonar and subbottom profiling system.

The objectives of the chemical/biological characterization are

1. to determine the extent of physical/chemical modification of sediments in the immediate area of the wellsites compared to sediment conditions at reference sites (and before drilling in the case of exploration sites) and

2. to conduct limited biological collections to determine biological effects related to chemical and physical impacts.

Box core samples will be collected at 12 locations within 500 m of each exploration/development site, and two box cores will be collected at each of six reference sites located at least 10 km from each exploration/development site. Sediment grain size, mineralogy, texture, radionuclides, metals, total organic carbon, and hydrocarbons will be analyzed. Samples for pore water, redox chemistry, and sediment toxicity (10 day acute test) also will be collected. Sediment profiling imagery transects will be performed near each site and at two of the corresponding reference sites. The biological community will be sampled using a box core, still photographs, and bottom traps. A number of biological parameters will be measured:

1. microbiotal activity, biomass, and community structure;

2. meiofauna taxonomy including harpacticoid taxonomy/genetic diversity/reproductive status and nematode feeding groups; and

3. megafaunal taxonomy and metal/hydrocarbon concentrations in tissues of selected animals.

Interpretation and synthesis of the data will include the testing of hypotheses concerning differences in chemical and biological parameters between areas in the vicinity of exploration, development, and spill sites and reference areas. The tests of hypotheses will provide insight into the effects on the continental slope biota. Relationships between physical/chemical variables and biological variables will also be examined. The data will be used to provide first-order estimates of the extent of impact. A screening level ecological risk assessment for the activities will also be performed.

Dr. Alan Hart is the Science Director of Continental Shelf Associates, Inc. located in Jupiter, Florida. He has 19 years of experience in marine environmental science, including major research programs for federal, state, and industrial clients. He has been involved in characterization and monitoring studies covering a wide range of human activities in the marine environment, including oil and gas operations, dredged material disposal, beach restoration, and sewage outfalls. Dr. Hart received his B.S. degree in zoology from Texas Tech University in 1973 and his Ph.D. Degree in biological oceanography from Texas A&M University in 1981.

BLUEWATER FISHING AND DEEPWATER OCS ACTIVITY: INTERACTIONS BETWEEN THE FISHING AND PETROLEUM INDUSTRIES IN DEEPWATERS OF THE GULF OF MEXICO

Mr. David B. Snyder
Continental Shelf Associates, Inc.
Jupiter, Florida

INTRODUCTION

The fishing and offshore energy industries have coexisted amicably for many years in shelf waters of the northern Gulf of Mexico (GOM). Recently, the offshore energy industry in the (GOM) has shifted its interest beyond the shelf and into deeper waters (>200 m). This shift is evidenced by over 3,800 active leases and about 50 development/production facilities in water depths greater than 200 m. Existing and future structures represent new and evolving technology that could interact with deepwater (bluewater) fisheries. All phases of industry—geophysical surveys, exploratory drilling, development/production, and abandonment—could interact with current deepwater fishing practices. In the northern GOM these practices include trapping for golden crab, trawling for royal red shrimp, bottom longlining for groupers, snapper, and tilefishes, and surface longlining for sharks, swordfish, and tunas.

The potential for interactions between bluewater fishing and deepwater energy industry was raised as a primary concern by a fisheries subcommittee during a recent deepwater workshop (Carney 1998) sponsored by the Minerals Management Service (MMS). In 1999, Continental Shelf Associates, Inc. was awarded a contract to investigate this problem for MMS. The project team consists of independent consultants with experience in fisheries, oil and gas technology, space-use problems, and Geographical Information Systems (GIS).

OBJECTIVES

We are assessing actual and potential interactions between the two industries through the following objectives:

- Determine bluewater fishing endeavors and practices and deepwater outer continental shelf (OCS) energy development activities;

- Describe and map bluewater fishing and deepwater OCS energy development activities;

- Describe current GOM and relevant world wide interactions and predict future situations that may occur in the GOM between bluewater fishing and deepwater OCS energy development activities; and

- Recommend proactive mitigation measures for MMS and for the fishing and OCS energy industries.

METHODS

The first two objectives are being addressed by gathering descriptive information and "mappable" data from a variety of sources for the two industries. Past and current information on the OCS energy industry will be obtained from MMS data sets that contain active leases, filed Plans of Exploration (POEs), existing development facilities, and existing pipelines. Existing facility descriptions will come from filed Development Operations Coordination Documents (DOCDs) or POEs, U.S. Coast Guard files, and industry operators. Descriptions of exploratory drilling rigs will come from various drilling rig contractors. Future OCS activity will be projected from the MMS data sets that include active leases with filed POEs or DOCDs, announced discoveries with filed POEs or DOCDs, and future pipelines. In addition, an analysis of lease bonuses paid on existing leases will be made to determine which lease block received high bids.

The bluewater commercial fishing industry will be described from data obtained from National Marine Fisheries Service (NMFS) data sets. Several data sets will be examined, including the longline logbook data set, the shrimp data set, and the reef fish logbook data set. These data sets provide varying levels of spatial resolution, ranging from latitude/longitude (degrees and minutes) to large scale (kms) NMFS statistical grids. Catch and effort information will be extracted from the data sets to characterize spatial and temporal patterns in the northern Gulf of Mexico. Species composition and life-history characteristics will be described for primary deepwater fisheries species.

Current domestic conflicts are being gathered from U.S. Coast Guard, Fishermen's Contingency Fund, and California Fisheries Liaison Office. Information on international interactions will be compiled from a variety of sources including Canada-Nova Scotia Offshore Petroleum Board, Fisheries and Offshore Consultative Group (North Sea), United Kingdom Offshore Operators Association Compensation Fund, and Department of Fisheries Malaysia.

RESULTS

The most common facilities used in deepwater operations are fixed platforms, semi-submersible floating production systems, compliant towers, tension leg platforms, spars, and subsea completions (Figure 1G.4). The spatial preclusion of seafloor or water column by these facilities depends upon the type of mooring system used and the water depth. For example, catenary moored systems cover much greater portions of the seafloor than do tension leg systems.

Presently there are about 3,800 active leases in waters greater than 200 m deep, with approximately 50 platforms currently operating in these water depths. Areas with the future activity are in Mississippi Canyon, Green Canyon, Garden Banks, and Viosca Knoll lease block areas. Of the 3,800 leases, about 800 received bonus bids exceeding $1 million. With the exception of Corpus Christi and Port Isabel, where there has been little if any drilling success to date, all OCS areas with less than 60% eased blocks are either relatively small in overall extent in the deepwater study area or have experienced legal constraints on leasing. The remaining eight areas have hundreds of leased blocks each. In most of these areas, between approximately 3and 6% of leased blocks received bonus bids in excess of $500 per acre. Interestingly, these include both the relatively nearshore area

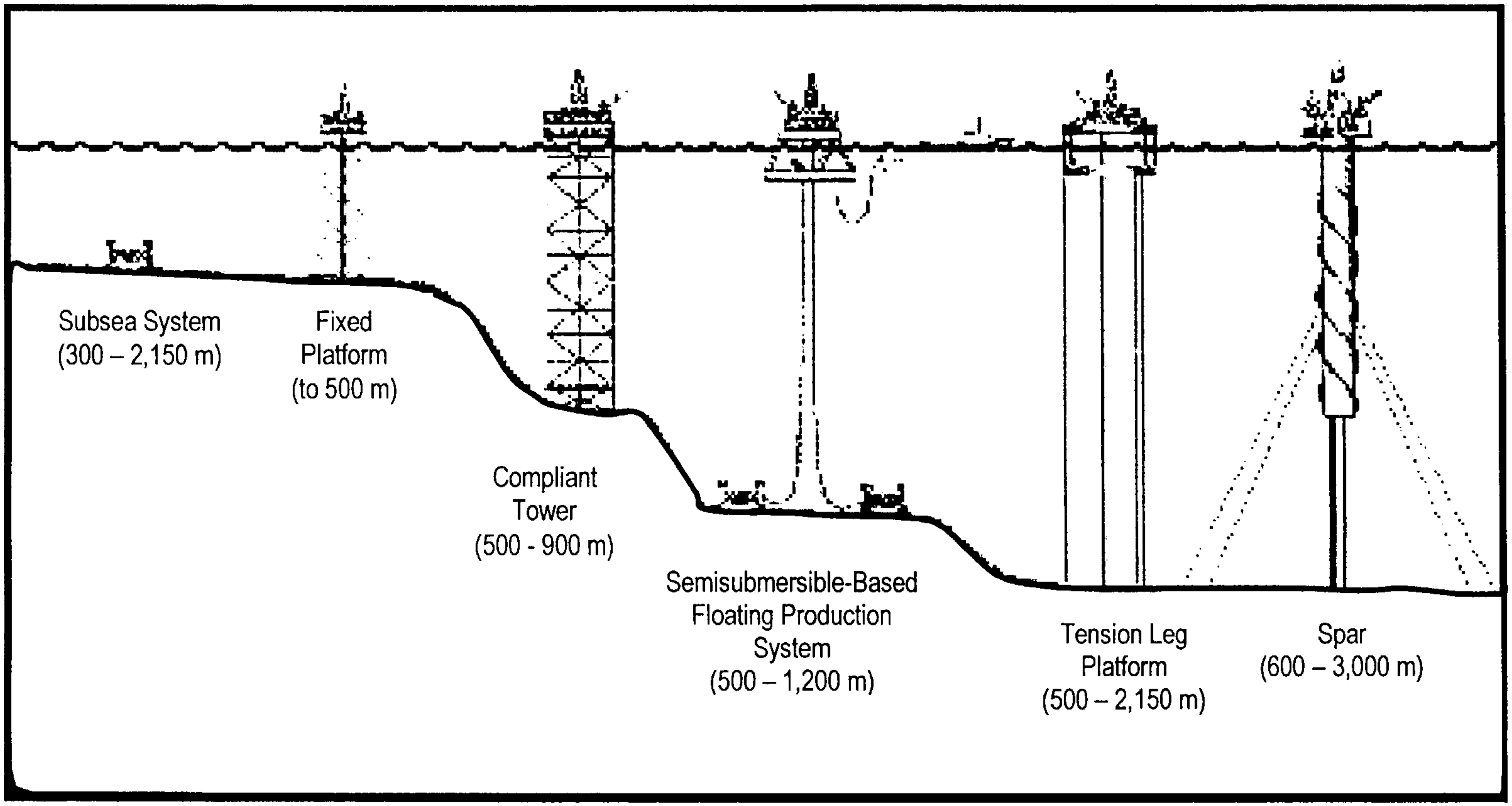


Figure 1G.4. Deepwater production systems in the Gulf of Mexico.

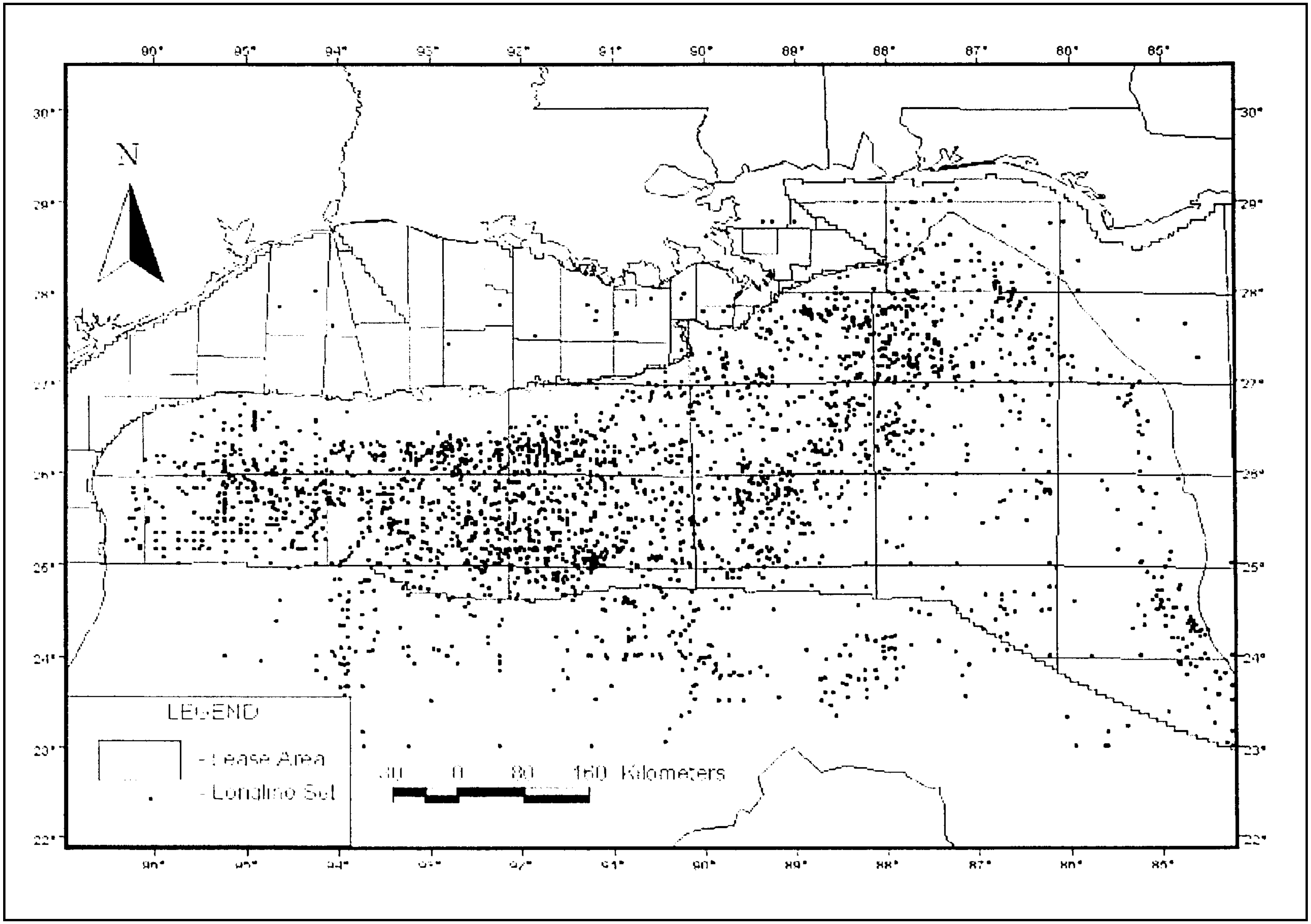


Figure 1G.5. Spatial distribution of surface longline sets made in the Gulf of Mexico during 1998 (Source: National Marine Fisheries Service longline logbook data 1999).

of East Breaks and Green Canyon, as well as the more distant and deeper water areas of Alaminos Canyon, Atwater Valley, Keathley Canyon, and Walker Ridge. In fact, the two bluewater blocks which received bonus bids in excess of $5,000 per acre are of recent vintage (1998) and are in water depths of approximately 1,500 and 3,000 m. In the Garden Banks area, which saw the first development in over 600 m, and Mississippi Canyon, which boasts several developments beyond 900 m, twice the percentage of leases received bonus bids in excess of $500 per acre.

Current deepwater fishing practices in the northern GOM include trapping for golden crab; trawling for royal red shrimp; bottom longlining for groupers, snappers, and tilefishes; and surface longlining for sharks, swordfish, and tunas. The areal extent of these fisheries varies greatly, from widespread to localized. The royal red shrimp fishery appears to be concentrated in the area south of Alabama/Mississippi corresponding to statistical grid 10, with minimal effort expended in areas off the Florida Keys and Texas. Golden crab trapping is most prevalent off southwestern Florida and the Florida Keys, with very few fishers actually participating in this fishery. There is some speculation that the deepwater crab fishery will expand in the future. The bottom longline fishery occurs near the shelf break and is legislatively mandated to remain offshore of the 102 m depth contour. Most effort by reef fish permit holders for deepwater groupers and tilefishes occurs offshore west Florida; however, appreciable effort has been expended offshore of Louisiana and Texas as well. The pelagic longline fishery is widespread in the open GOM (Figure 1G.4). Of these gear types, the pelagic longline presents the greatest possibility for interactions or space-use conflicts.

REFERENCES

Carney, R.S. 1998 Workshop on Environmental Issues Surrounding Deepwater Oil and Gas Development: Final Report. U.S. Department of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 98-0022.163 pp.

Mr. David B. Snyder is a senior staff scientist with Continental Shelf Associates, Inc. He has 18 years of experience with aquatic environmental assessment and research programs for federal, state, and industrial clients. He has participated as Research or Chief Scientist on over 50 scientific cruises conducted in domestic and international waters. Mr. Snyder has managed several fishery-related projects including bycatch studies, life history studies, and ichthyofaunal assessments in a variety of marine and freshwater habitats Mr Snyder received his B.S. in zoology from the University of Florida in 1978 and his M.S. in ichthyology/marine biology from Florida Atlantic University in 1984.

EVALUATION OF OIL AND GAS PLATFORMS ON THE LOUISIANA CONTINENTAL SHELF FOR ORGANISMS WITH BIOTECHNOLOGY POTENTIAL

Dr. Lawrence J. Rouse
Department of Oceanography and
Coastal Studies Institute
Louisiana State University

In 1998, President Clinton convened the National Ocean Conference (NOC) in Monterey, California. The report of this conference, Turning to the Sea: America's Ocean Future, identified biotechnology as a high-priority issue for the nation. The report identifies a lack of information about baseline conditions of the marine environment which makes it difficult to assess the environmental impacts of biotechnology, listing among its key recommendations:

- Increase support for sustainable harvesting and testing of marine compounds by both government agencies and commercial pharmaceutical companies as possible treatments for AIDS, inflammatory or infectious diseases, and cancers; and

- Support research on the environmental effects of extracting marine organisms for biotechnology purposes.

In response to the Minerals Management Service's recognition that offshore oil and gas platforms may serve as a harvestable source of organisms with pharmaceutical or other commercial application, this proposal will address the NOC report's recommendations. Our initial effort will be to answer the following questions:

- What organisms make up the biofouling communities on the platforms?

- Are any of these organisms potential sources of pharmaceuticals or other natural products?

- How do the organisms populate the platforms? What is the distribution and relative abundance of the organisms on a platform and how does this distribution vary between platforms and with depth and time?

The Investigators assembled for this project have expertise in a number of organisms that are potential sources of useful natural products. Our effort will, therefore, focus on a specific set of organisms. The team of scientists and their expertise includes:

- Dr. Fred Rainey – Bacteria

- Drs. Russell Chapman and Suzanne Fredericq – Algae

- Dr. Michael Hellberg – Bryozoans

- Dr. Barun Sen Gupta – Benthic foraminifers
- Dr. Laurie Anderson – Molluscs
- Dr. Dave Foltz – Genetic analysis: foraminifers and molluscs

Dr. Larry Rouse will be the project director and oversee the collection of samples from the offshore platforms.

The sampling scheme will be to obtain samples at six to seven oil and gas platforms east and west of the Mississippi River delta. The platforms will be in a variety of water environments: a blue-, a green-, and a brown-water. At each platform samples will be acquired from an easternmost and a westernmost leg at or near the surface, 10 meters, and 20 meters. At each level, all the encrusting organisms in three 25 by 25 cm squares will be scraped off and stored in plastic bags. The samples will be sorted and preserved as appropriate. Laboratory analysis will identify the organisms by morphology and/or by DNA sequencing techniques.

At the present time, we expect to carry out the first field sampling in the spring of 2001. A second sampling effort is scheduled for 2002. The specific program for the second year will be determined based on the results of the first year’s study.

SESSION 1H

MMS SPONSORED OIL SPILL RESEARCH

Chair: Ms. Darice Breeding, Minerals Management Service

Date: December 7, 2000

Presentation	Author/Affiliation
DeepSpill 2000: Experimental Deepwater Blowouts	Dr. Mark Reed SINTEF Applied Chemistry, Norway
In-Situ Burning of Oil Spills in the Marshland Environment	Mr. Nelson P. Bryner Mr. William D. Walton Mr. Laurean A. DeLauter Mr. W. H. Twilley National Institute of Standards & Technology U.S. Department of Commerce Dr. Irving A. Mendelssohn Dr. Qian Xin Lin Dr. Kenneth R. Carney Wetland Biogeochemistry Institute Louisiana State University Mr. Joseph V. Mullin Technology Assessment and Research Branch Minerals Management Service
Technology Assessment of the Use of Dispersants on Spills from Drilling and Production Facilities in the Gulf of Mexico Outer Continental Shelf	Dr. Ken Trudel Dr. Sy Ross Mr. Randy Belore S.L. Ross Environmental Research Ltd.
Study to Compare the Effectiveness of Chemical Dispersants When Applied Neat vs. Dilute: Mesoscale Tests	Mr. Randy Belore Dr. Sy Ross Dr. Ken Trudel S.L. Ross Environmental Research Ltd

DEEPSPILL 2000: EXPERIMENTAL DEEPWATER BLOWOUTS

Dr. Mark Reed
SINTEF Applied Chemistry, Norway

DeepSpill Experiment June 2000

Objectives

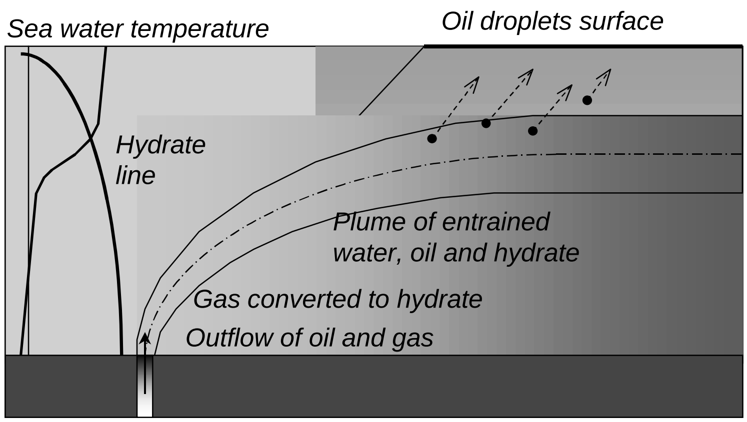
- to obtain data for verification and testing of numerical models for simulating accidental releases in deep waters;
- to test equipment for monitoring and surveillance of accidental releases in deep waters;
- to evaluate the safety aspects of accidental releases of gas and oil in deep waters.

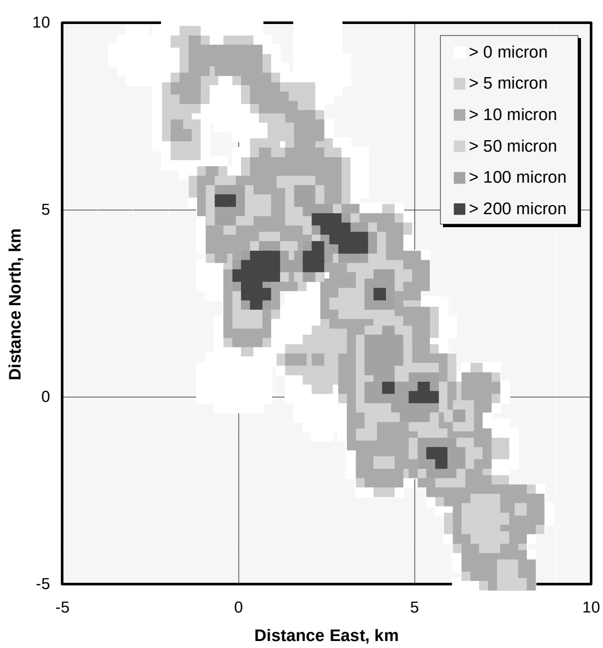
Deepwaters:

High pressures:	1000 m = 101 atmospheres
Low temperatures:	-1 to 5^{o}C

- Non-ideal gas behavior
- Increased solubility of gas in sea water
- More gas dissolved in oil
- Gas may combine with sea water to form hydrates
- Cross-flow important for determining surface oil distribution

Deepwater blowouts





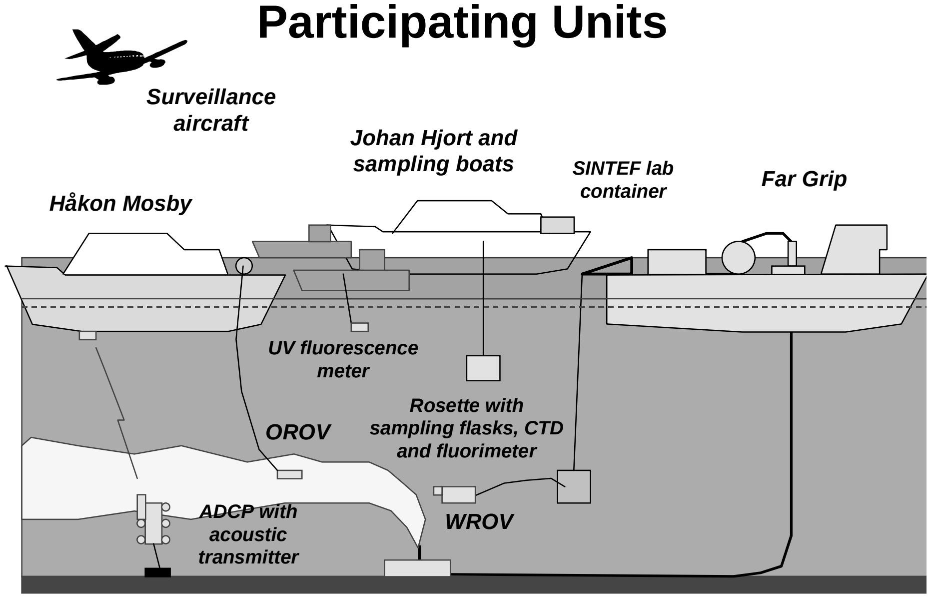
Example Computed Surface Slick

DeepSpill JIP

Background

- Feasibility study conducted by SINTEF on behalf of Chevron: June - September 1999
- Joint Industry Project initiated by Chevron: September 1999
- Decisive participation by MMS
- Eventual participation from 22 oil companies and MMS
- Total budget ~ $2 million
- SINTEF Applied Chemistry acted as principal contractor
- Various subcontractors: design and operation of gas and oil transport, pumping systems, equipment for subsea monitoring, research ships
- Four experimental discharges conducted in the Norwegian sea June 2000

Participating Units

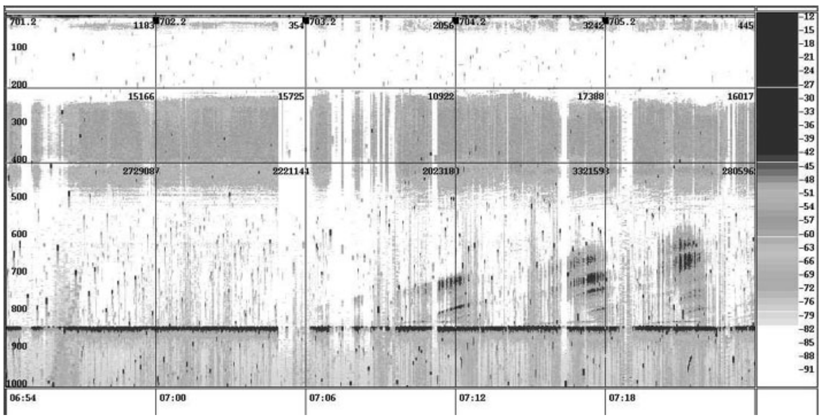


Discharge platform at sea bed

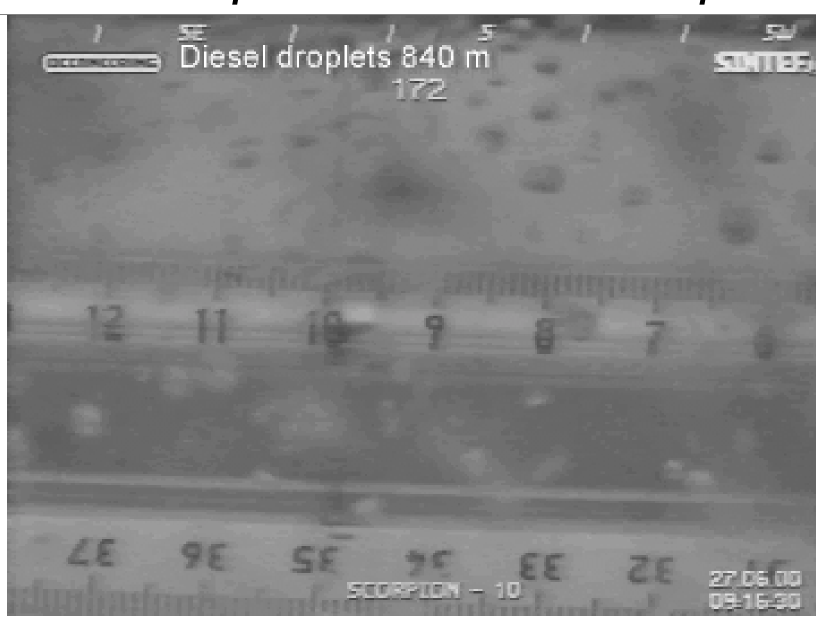
Observing plume by echo-sounder

Echo-sounder image from Håkon Mosby (38 kHz)

Example from start of LNG discharge



Gas and oil droplets from marine diesel experiment

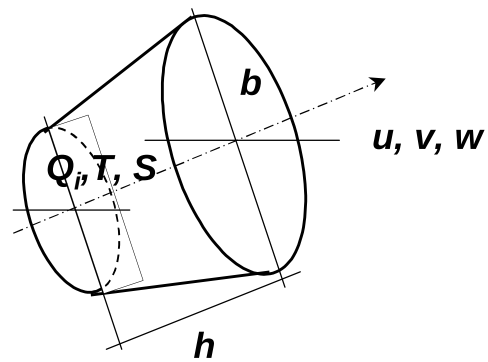


Oil slick from marine diesel experiment

Major findings

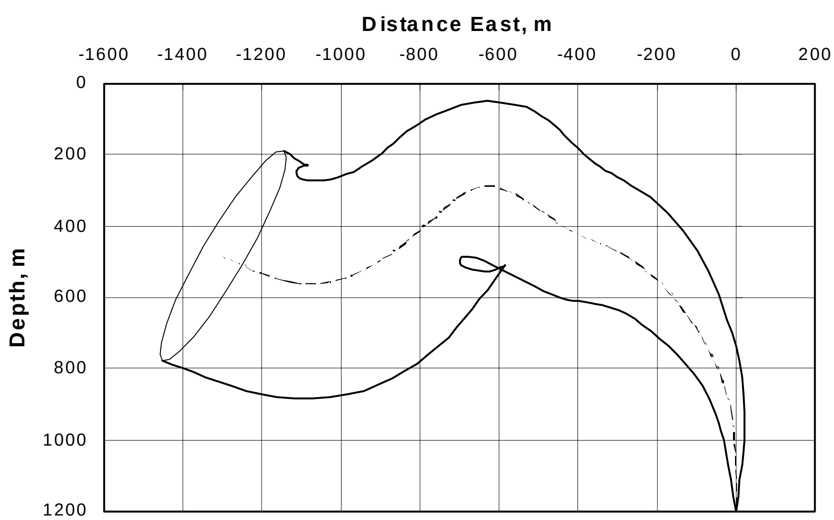
- **Oil discharges**
  - **Oil surfaced and started forming a slick about one hour after start of experiment;**
  - **Surface slick built up in area with time as oil droplets of diminishing size arrived at the surface;**
  - **Surface slick of variable thickness with patches of thicker oil;**
  - **Water - in - oil emulsion formed in the thicker patches of the crude oil slick.**
- **Gas discharges**
  - **Gas bubbles did not reach surface probably due to dissolution of gas in seawater;**
  - **No hydrate formation was observed (!)**

DeepBlow: Lagrangian integral plume model for deep waters



Lagrangian plume element

Plume trajectory



Dr. Mark Reed is Senior Scientist at SINTEF Applied Chemistry, Division of Environmental Engineering in Trondheim, Norway, where he has been since 1992. Prior to that, he worked at ASA in Rhode Island. His area of specialization is marine environmental modeling. Dr. Reed received his Ph.D. from the University of Rhode Island in 1980 in oil spill-fishery interactions and did post-doctoral work in Trondheim, Norway in fish migration modeling.

IN-SITU BURNING OF OIL SPILLS IN THE MARSHLAND ENVIRONMENT

Mr. Nelson P. Bryner
Mr. William D. Walton
Mr. Laurean A. DeLauter
Mr. W. H. Twilley
National Institute of Standards & Technology
U.S. Department of Commerce

Dr. Irving A. Mendelssohn,
Dr. Qian Xin Lin
Dr. Kenneth R. Carney
Wetland Biogeochemistry Institute
Louisiana State University

Mr. Joseph V. Mullin
Technology Assessment and Research Branch
Minerals Management Service

BACKGROUND

Oil spills of crude or refined hydrocarbons in environments such as salt marshes provide unique challenges for oil spill response teams. If the oil is not removed from the marsh, the toxic properties of crude oil and many refined oil products are likely to kill a majority of the plants within the initial spill boundary. However, access to spills in wetlands can be difficult and may force oil spill response teams to utilize heavy equipment to gain access to the affected wetlands. It has been noted that mechanical remediation techniques can do more damage to these highly fragile wetland systems than the oil toxicity itself. The oil spill response community, including the Minerals Management Service, US Coast Guard, NOAA, EPA, and private oil spill remediation companies, is constantly seeking cleanup technologies that are less intrusive to the environment. *In-situ* burning of oiled wetlands potentially provides such a technique. Wetlands, both inland and coastal, are often burned on an annual cycle to provide better wildlife habitat. However, the effects of burning on wetland recovery have been variable, and the factors controlling this differential response to burning have not been adequately addressed. Even less is known about the primary variables determining the successful recovery of wetland subjected to *in-situ* burning after an oil spill. Yet, this information is essential if we are to consider, on a regular basis, *in-situ* burning for the remediation of oil contaminated wetlands. The data collected by this project will help fill this information gap.

EXPERIMENTAL METHOD

A series of 22 tests burning diesel fuel and Louisiana crude oil were conducted in a 6 m diameter tank to examine the effects of water level, duration of burn, and pre-oiling on *Spartina Alterniflora*, *Spartina Patens,* and *Sagittaria Lancifolia,* all common marsh species. Over 300 plant sods, each

Figure 1H.1. Plants in tank at different elevations.

30 cm in diameter and 30 cm of soil depth, were harvested from south Louisiana wetlands. Thermocouple arrays were inserted into 100 sods in order to track soil temperatures. During the burn tests, marsh sods with intact soil and vegetation, were positioned at -10 cm, -2 cm, 0 cm, + 2 cm, and + 10 cm relative to the water level (Figure 1H.1). To simulate initial exposure to oil before the arrival of oil spill response teams, half of the sods were pre-oiled with either diesel fuel or crude oil 24 hours before the test burn. Diesel fuel or crude oil was added to the surface of water, ignited, and allowed to burn (Figure 1H.2) for periods of either 400 s, 700 s, or 1,400 s. Once the plant sods were exposed to an *in-situ* burn, the specimens were returned to Louisiana State University greenhouses and monitored for plant response and soil physical-chemistry. The effects of water level, burn duration, and pre-oiling on burn dynamics and wetland vegetation recovery were assessed.

RESULTS

Soil temperatures versus time are plotted for 400s (diesel) exposures for *Spartina Alterniflora* in Figures 1H.3a, 1H.4a, 1H.5a, and 1H.6a, for soil elevations of +10 cm, 0 cm, -2 cm, and –10 cm, respectively. Soil temperature plots for 1,400 s (diesel) exposures *for Spartina Alterniflora* are plotted in Figures 1H.3b, 1H.4b, 1H.5b, and 1H.6b, for soil elevations of +10 cm, 0 cm, -2 cm, and

Figure 1H.2. Plants exposed to *in-situ* burning of diesel/crude oil.

–10 cm, respectively. All sod elevations are relative to water level; for example + 10 cm indicates that the soil line was 10 cm above the water surface and -10 cm indicates that the soil line was 10 cm below the water surface. For each plot, ignition occurred at 600 s and the fire extinguished itself at 1,000 s for the 400 s exposure and at 2,000 s for the 1,400 s exposure. Ten centimeters of water overlying the soil surface was sufficient to buffer soil temperature even during a 1,400 s burn (peak soil temperatures of 40°C (Figure 1H.6b). In contrast, a water table 10 cm below the soil surface resulted in peak soil temperatures of 580 o C at the surface (Figure 1H.3b). Since lethal temperatures to vascular plants have been cited in range of 60°C to 65°C, the temperature data suggests that 2 cm of water probably provides sufficient protection from temperatures higher than 60°C. Even 0 cm or + 2 cm of water appears to prevent the 60°C isotherm from penetrating more than 1cm or 2 cm down into the soil. It is not clear whether 60°C temperatures for brief periods of time 2 cm below the soil surface are sufficient to prevent the plant from recovering from the thermal exposure.The plant survival and growth responses (plots not included in this presentation) to the water level treatments support the temperature data although the presence of diesel fuel in the soil made

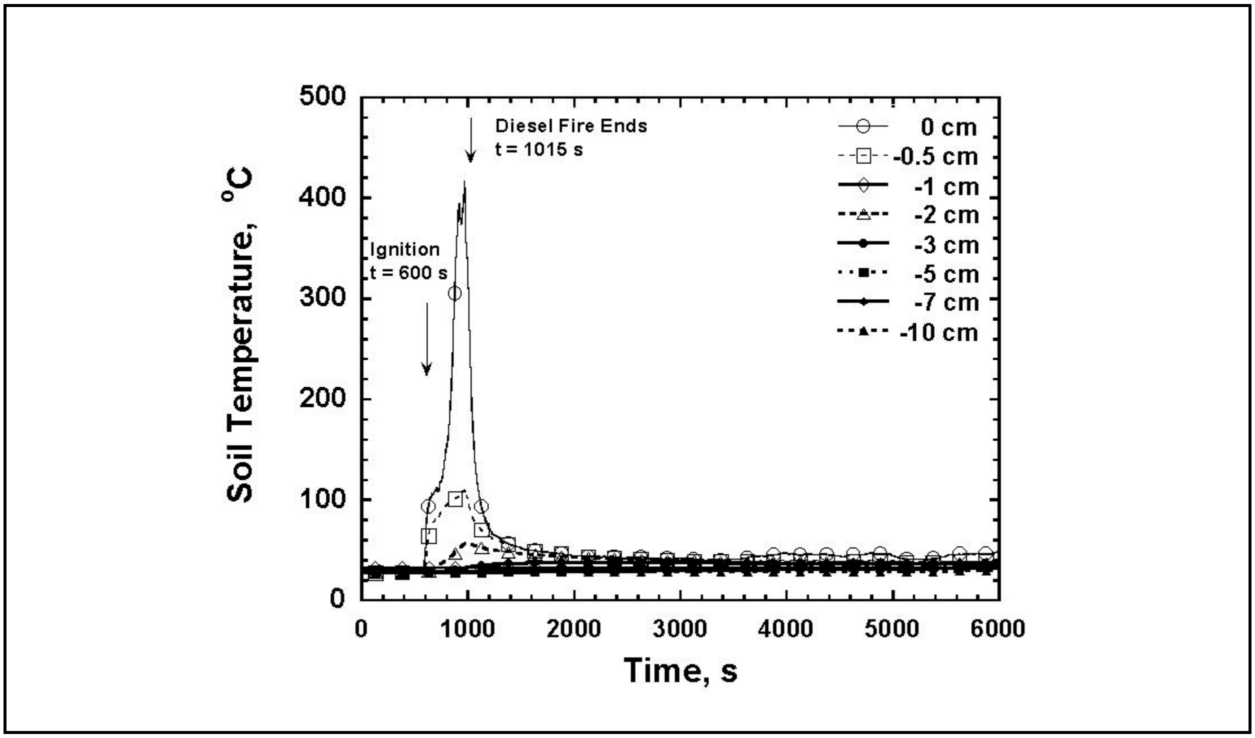


Figure 1H.3a. Soil evaluation + 10 cm 400 s burn exposure.

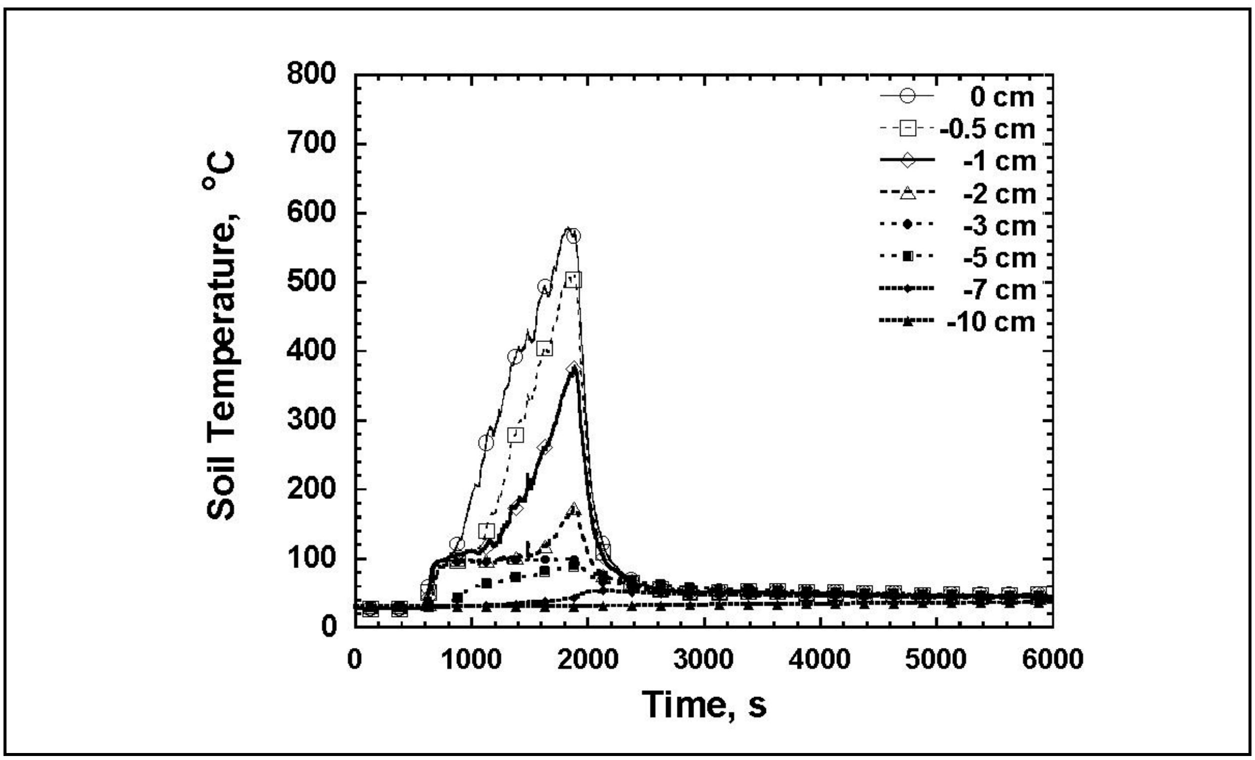


Figure 1H.3b. Soil evaluation + 10 cm 1,400 s burn exposure.

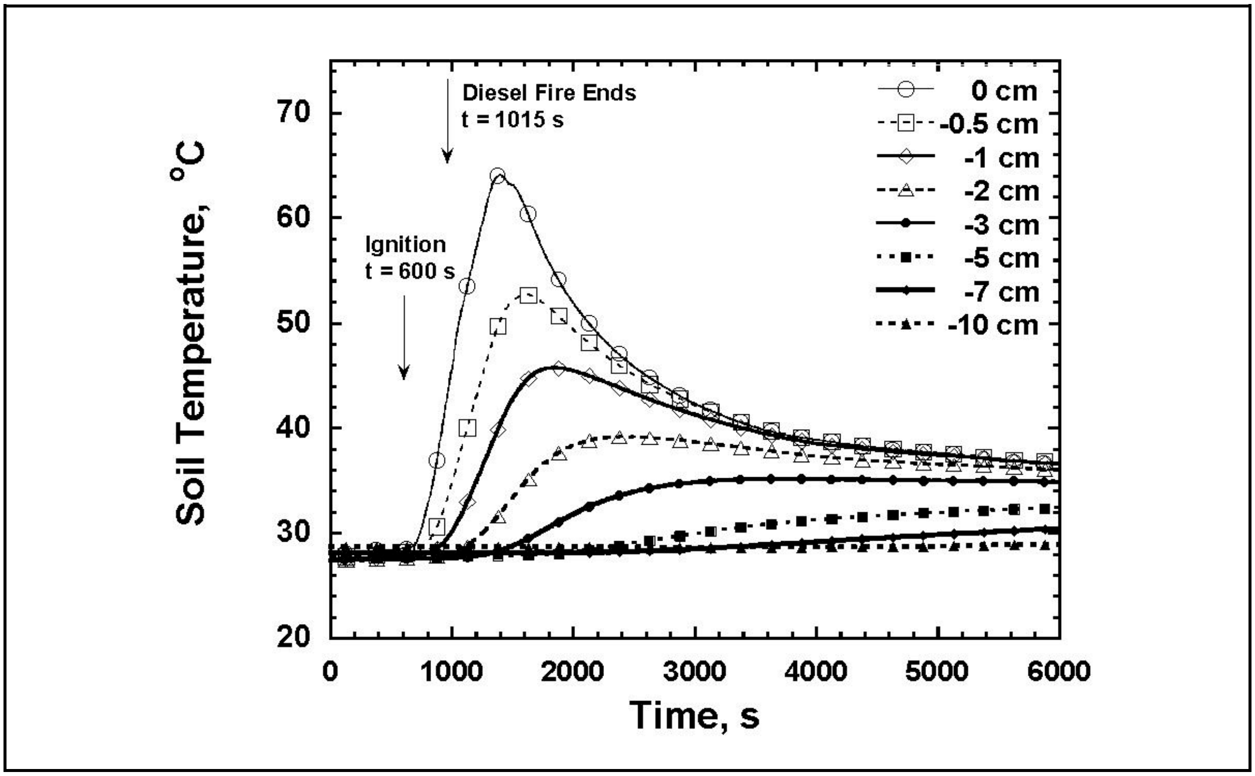


Figure 1H.4a. Soil evaluation 0 cm 400 s burn exposure.

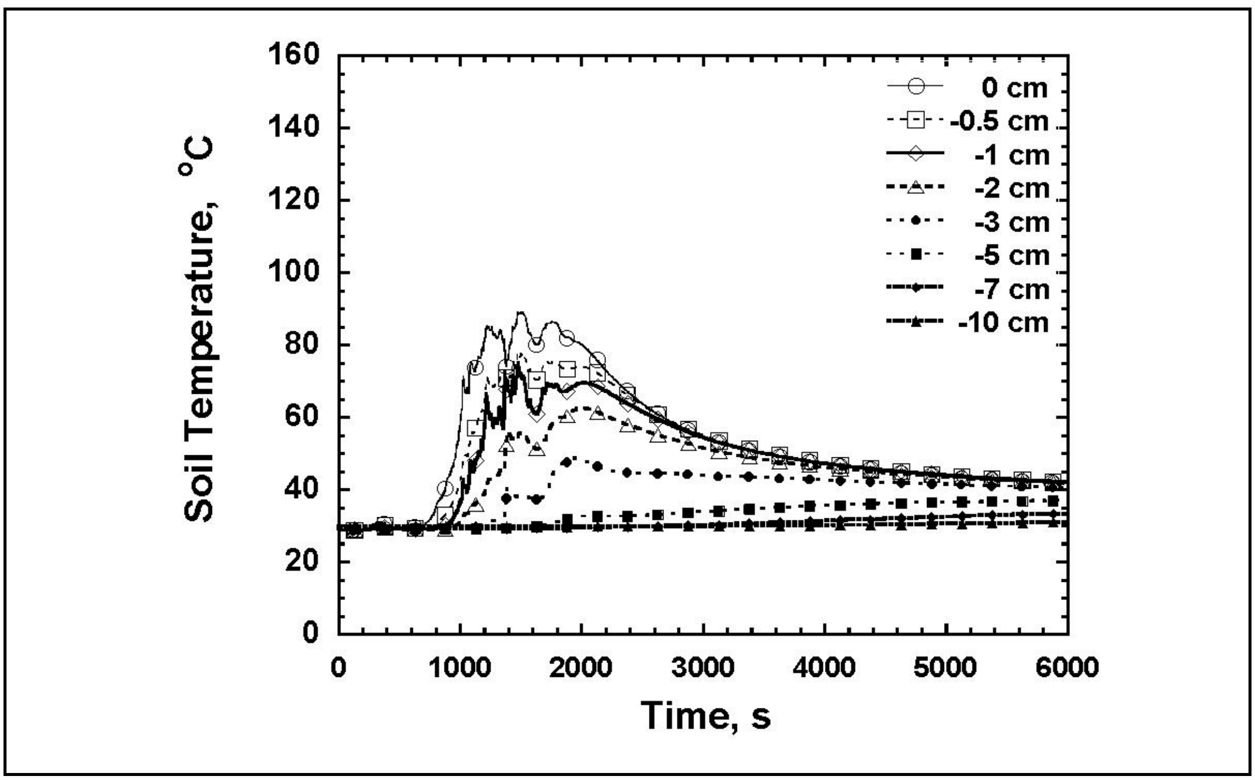


Figure 1H.4b. Soil evaluation 0 cm 1,400 s burn exposure.

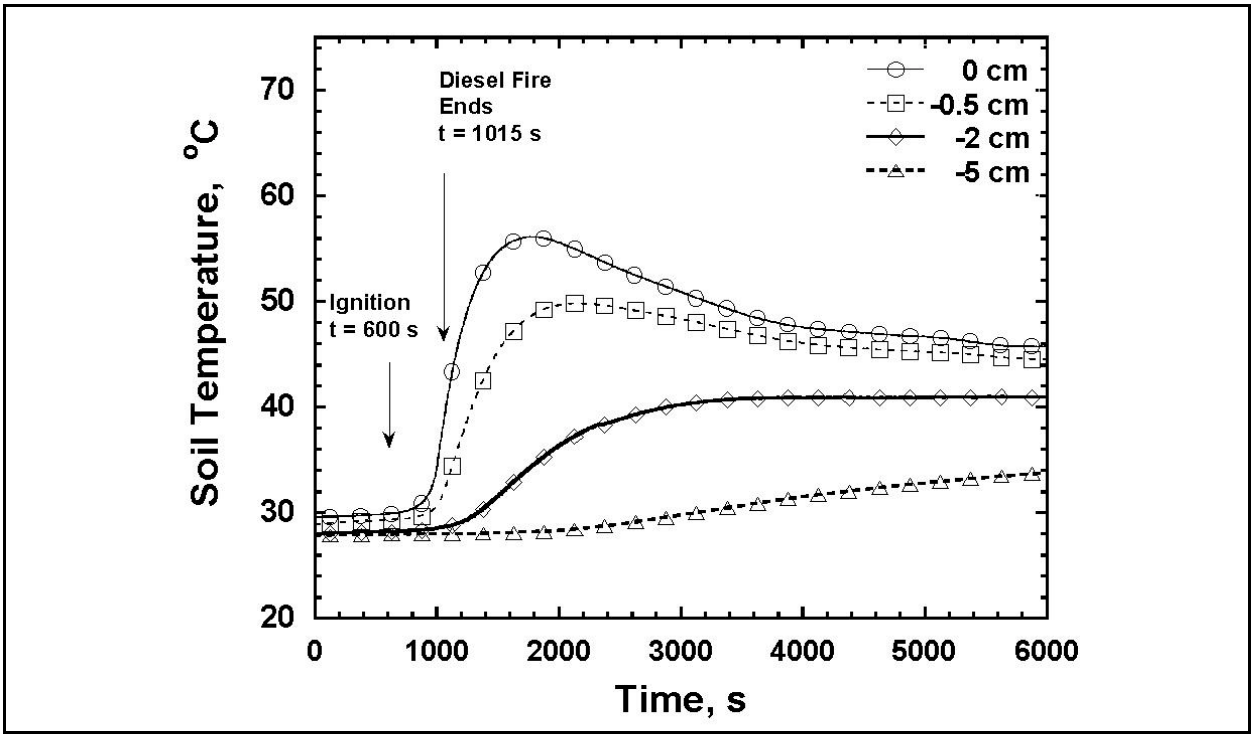


Figure 1H.5a. Soil evaluation -2 cm 400 s burn exposure.

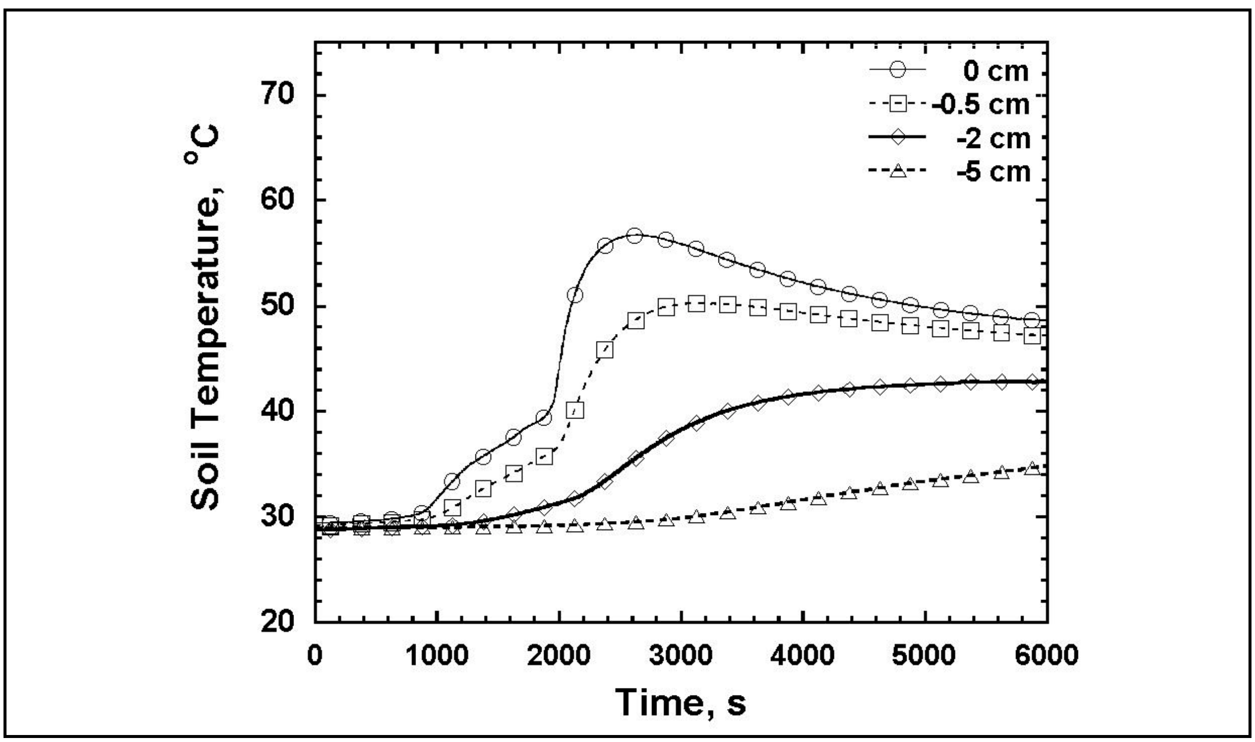


Figure 1H.5b. Soil evaluation -2 cm 1,400 s burn exposure.

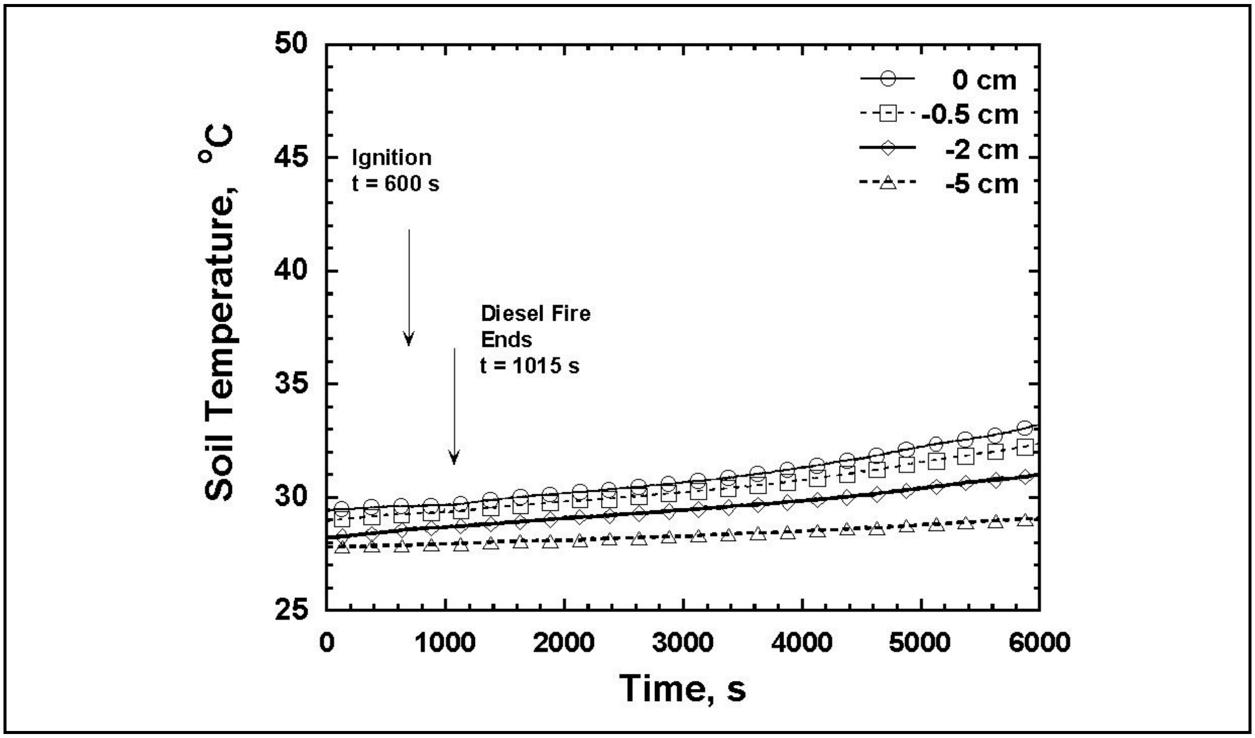


Figure 1H.6a. Soil evaluation -10 cm 400 s burn exposure.

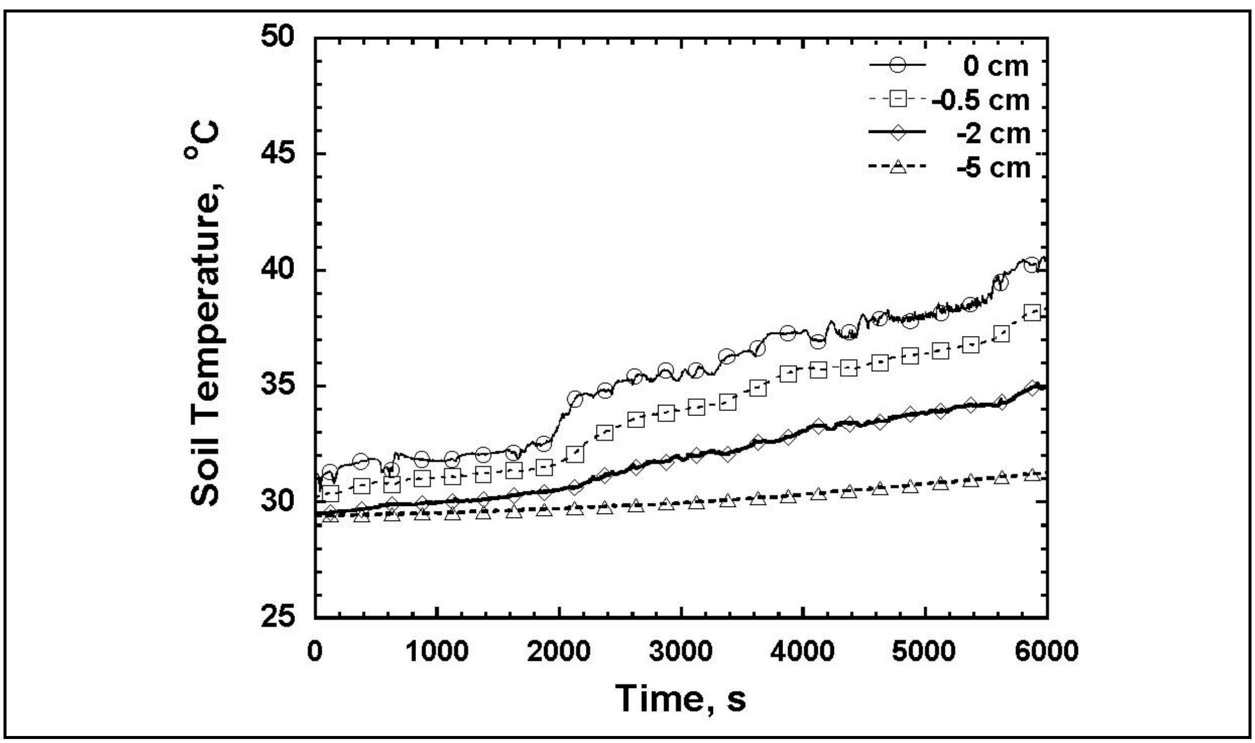


Figure 1H.6b. Soil evaluation -10 cm 1,400 s burn exposure.

analysis more difficult. In year 1, diesel fuel was allowed to mingle with the sods during the burn. A significant number of plants at the 0 cm and - 2cm levels appeared to suffer negative effects because of diesel fuel within the soil. In year 2, the diesel fuel was prevented from mingling with the plant sods during the burn exposure and plants at the + 2 cm, -2 cm and -10 cm are recovering much better than in year 1. Exposing the plant sods to burning diesel fuel (year 1) and burning diesel fuel and South Louisiana crude oil (year 2) appeared to produce similar temperature profiles in the soil.

CONCLUSIONS

Peak soil temperatures in excess of 550°C were recorded at the soil surface in plant sods located at 10 cm above the water surface. A water thickness of 2 cm provided sufficient protection to prevent peak soil temperatures from exceeding 60°C. Spartina alterniflora exhibited good vegetative re-growth at - 2cm and -10 cm water levels as long as diesel fuel had not entered the soil.

ACKNOWLEDGMENTS

Funding was provided by the U.S. Minerals Management Service and the Louisiana Applied Research and Development Program. We extend our appreciation to LSU’s Fire and Emergency Training Institute for insuring safe and successful burns at their facility and to graduate students at LSU for their assistance.

TECHNOLOGY ASSESSMENT OF THE USE OF DISPERSANTS ON SPILLS FROM DRILLING AND PRODUCTION FACILITIES IN THE GULF OF MEXICO OUTER CONTINENTAL SHELF

Dr. Ken Trudel
Dr. Sy Ross
Mr. Randy Belore
S.L. Ross Environmental Research Ltd.

INTRODUCTION

This paper briefly summarizes this S.L. Ross (2000) project. The project examined the technical issues surrounding the use of dispersants to clean up spills from U.S. MMS-regulated facilities in the Gulf of Mexico Region (GOMR). Issues included: a) amenability of GOMR oils to chemical dispersion; b) logistic capabilities and limitations of existing dispersant spraying platforms: and c) the net environmental benefits or environmental trade-offs associated with chemical dispersion of spills in the GOMR. This project was sponsored by Engineering and Research, Minerals Management Service.

DISPERSIBILITY OF GOMR OILS

An analysis was performed to assess the general applicability of dispersants on spills involving oils that are produced in the GOMR. Many distinct oils must be considered because thousands of wells are in operation. A publicly available MMS database, which provides average API oil gravities for all plays in the GOMR, shows that the vast majority of GOMR oils are relatively light (average API gravity is about 33° = 0.86 specific gravity). This is generally favorable, but more information is required to evaluate an oil's likely chemical dispersibility, especially data on the tendency of the oil to emulsify as a function of weathering (evaporation). Although such information is generally not available, it is for 28 specific GOMR oils that were thoroughly analyzed and modeled in previous projects funded by MMS. The oils are listed in Table 1H.1, ranked according to emulsion formation tendency. Batch spills of size 1,000 barrels and 10,000 barrels are used as examples to calculate windows of opportunity for using dispersant.

If these 28 oils are representative of the Gulf oils in general, the following conclusions can be made regarding the dispersibility of GOMR oils with respect to batch spills in the size range shown. Fourteen percent of GOMR-OCS oils (four of the 28 oils) are highly emulsifiable and will have a very narrow "window of opportunity" for treatment with chemical dispersants. These are called Hi-E oils in this study. They are defined as oils that will start to emulsify either immediately or after up to 10% of the spill has evaporated. The next category is for Av-E oils (29% of total). For these, there is a relatively narrow time-window for effective dispersant response, but still significantly more time available than the Hi-E oils. For Low-E oils (32% of total) the "window of opportunity" for effective dispersant use becomes wide, and one has several days to respond to the spill. Finally, No-E oils

Table 1H.1. GOMR crude oils that have undergone spill-related testing (1 of 2 pages).

Crude Oil Name	API Gravity	Fresh Oil Pour Point EF	Oil Viscosity @ 60EF at Various Weathered States			Emulsion Formation Tendency*	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
								1,000 Barrel Batch Spill			10,000 Barrel Batch Spill		
			0%	~ 15%	~ 25%			2,000 cP	5,000 cP	20,000 cP	2,000 cP	5,000 cP	20,000 cP
HIGHLY EMULSIFIABLE OILS (Hi-E Oils) (Emulsion forms at 0 to10 % spill evaporation)													
Green Canyon 65	20	-18	177	800	4250	yes @ 0 %	very narrow	3.3	5	11	3.9	6	15
Miss. Canyon 807 (1999)	28	?	33	404	2237	yes @ 8%	very narrow						
Miss. Canyon 807 (1998)	28	-29	41	491	3454	yes @ 0%	very narrow	3.2	4	9	3.7	5	12
West Delta 143	29	?	32	-	1572	yes @ 6 %	very narrow	5	7	30	5.9	9	54
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % spill evaporation)													
Green Canyon 205	29	?	26	157	543	yes @ 23%	narrow						
Green Canyon 109	27	-33	39	225	690	yes @ 22 %	narrow	33	35	45	53	55	72
Garden Banks 387	30	-38	29	181	579	yes @ 23%	narrow	15.5	17	28	23	25	45
West Delta 30	11-23?	-9	1180	-	1350	yes @ 24 %	narrow	67	68	73	109		117
Mississippi Canyon 72	32	-18	16	34	195	yes @ 18%	narrow						
Main Pass 69/225	34	?	13	-	118	yes @ 25 %	narrow						
Viosca Knoll 826 #1	32	25	16	132	325	yes @ 24%	narrow						
Viosca Knoll 826 #2	31	?	17	84	186	yes @ 15%	narrow						

* The percentage value refers to the amout of oil evaporation that must occur to start the emulsification process.

Table 1H.1.(continued). GOMR crude oils that have undergone spill-related testing (2 of 2 pages).

Crude Oil Name	API Gravity	Fresh Oil Pour Point EF	Oil Viscosity @ 60EF at Various Weathered States			Emulsion Formation Tendency*	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
								1,000 Barrel Batch Spill			10,000 Barrel Batch Spill		
			0%	~ 15%	~ 25%			2,000 cP	5,000 cP	20,000 cP	2,000 cP	5,000 cP	20,000 cP
SLOWLY EMULSIFIABLE OILS (Low-E Oils)(Emulsion forms at 30 to 50+ % spill evaporation)													
Garden Banks 426	39	-8	6	13	34	yes @ 38%	wide	48	52	246	78	82	>360
Green Canyon 184	39	-47	5	11	31	yes @ 38%	wide	141	143	162	234	236	267
Main Pass 37	39	27	7	16	36	yes @ 50 %	wide	disperse @117			disperse @186		
Ship Shoal 239	26	5	34	70	74	yes @ 50 %	wide						
South Pass 49	29	?	23	-	146	yes @ 30 %	wide						
South Pass 93	33	5	19	23	32	yes @ 34 %	wide						
South Pass 67	16	16-55?	39	-	110	yes @ 45 %	wide						
South Pass 60	36	16	1	22	41	yes @ 38 %	wide	40	45	215	65	69	360
Viosca Knoll 990	38	?	7	12	31	yes @ 35%	wide						
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Main Pass 306	33	-63	9	19	54	no	very wide	341	>360	>360	>360	>360	>360
Eugene Island 43	37	32	13	36	65	no	very wide	306	>360	>360	>360	>360	>360
Eugene Island 32	37	45	10	16	21	no	very wide	231	>360	>360	>360	>360	>360
Mississippi Canyon 194	35	-40	7	15	21	no	very wide	disperse @117			disperse @197		
Ship Shoal 269	39	-44	5	7	18	no	very wide						
South Timbalier 130	35	-17	7	10	19	no	very wide						
West Delta 97	50	-17	1		1	no	very wide						

(25% of total) are ideal dispersant-use candidates because they do not emulsify regardless of the extent of evaporation. This class of oils would also include diesel oils.

In summary, the opportunity for using dispersants effectively on the example oils shown in the table is very good. Only the Hi-E oils, representing 14% of the total, present problems due to their tendency to emulsify rapidly, thus quickly closing the window of opportunity for effective dispersant use. The remaining 86% offer a reasonable chance of being good targets for a dispersant response program. Indeed, both Low-E oils and No-E oils, representing 57% of all spill possibilities, are excellent candidates for responding with dispersants. There is generally much time available for dispersing such spills before the oils become too viscous, at least when considering batch spills in the spill size range of 1,000 bbl to 10,000 bbl.

For other spills the dispersant-use time window will vary as a function of spill type (e.g., blowout vs. batch spill), spill size and environmental conditions. To analyze this variation, a detailed modeling exercise was initiated.

SPILL SCENARIO MODELING

This analysis assessed the potential influence of the spill conditions on the weathering, emulsion formation and time window for chemical dispersion in spills that are typical of GOMR conditions. Representatives of each oil category in Table 1H.1 were selected for modeling purposes (these are highlighted) and a number of spill scenarios were developed to reflect the range of spill possibilities associated with OCS installations. These scenarios are shown in Table 1H.2. The following describes the predicted effects of spill conditions and oil types on the time windows in GOMR spills.

Batch Spills: Scenarios 1 through 3

Batch spills involving diesel oil and No-E oils (scenarios 1a, 1b and 2a) have large windows of opportunity for the use of dispersants because of the low tendency of these oils to form emulsions. The batch spill involving Av-E oil (scenario 2b) is a good candidate for dispersant use because it is relatively persistent (> 30 days)—and, thus, a threat to even distant shorelines—and yet it does not emulsify quickly (96 hours), allowing ample time to implement a spraying operation. Such time is not available in scenarios 2c and 3 where emulsion viscosities for the batch spills involving Hi-E oil will exceed chemically dispersible levels within only 10 to 15 hours.

Above-Sea Blowouts: Scenarios 4 and 5

The primary difference between the above-sea blowout results and the batch spills of similar oil and total spill volume is the initial small thickness and widths of the oil slicks and the long-term release characteristics of the blowouts. An above-sea, low-flow blowout involving Lo-E oil (scenario 4a) will disperse quickly on its own (within 15 hours). The same blowout involving an Av-E oil (4b) will emulsify relatively rapidly (10 to 15 hours), as it did in the batch spills, but because this spill is continuous and lasts over a period of four days it is possible to mount a spraying operation to treat the freshly released oil during daylight hours.

Table 1H.2 GOMR spill scenarios.

#	Spill Description	Spill Volume	Model Oil	Comments
1	Batch Spill	(1a) 2000 bbl and (1b) 20,000 bbl	(1a) Diesel (1b) No-E Oil	Demonstrates the large dispersant-use *time window* for spills of diesel and crude oils that do not emulsify.
2	Batch Spill	20,000 bbl	(2a) Lo-E Oil (2b) Av-E Oil (2c) Hi-E Oil	Could be tank rupture on platform or "dead crude" pipeline spill. Shows the effect of oil type on *time window*, as compared to Spill#1.
3	Batch Spill	100,000 bbl	(3) Hi-E Oil	Could be worst-case FPSO spill or shuttle tanker spill.
4	Surface Blowout, average rate, short duration	20,000 bbl = 5,000 BOPD* x 4 days	(4a) Lo-E Oil (4b) Av-E Oil	Demonstrates the fast initial evaporation of oil in air, and its effect on *time window.*
5	Surface Blowout, high flow rate	1,400,000 bbl = 100,000 BOPD x 14 days	(5a) Hi-E Oil (5b) Av-E Oil	Extremely large spill that will challenge all countermeasures methods for Hi-E oils and even Av-Oils and lighter.
6	Subsurface Blowout, shallow water, low flow	20,000 bbl = 5,000 BOPD x 4 days	Av-E Oil (6a) 35 m deep (6b) 50 m deep (6c) 150 m	Shows the differences between same-sized batch spill (Spill#2) and surface blowout (Spill#4). Could also represent Alive crude@ pipeline spill.
7	Subsurface Blowout, shallow water, high flow	100,000 bbl = 7,200 BOPD x 14 days	Av-E Oil (7a) 35 m deep (7b) 50 m deep (7c) 150 m	Worst-case, but more manageable than surface blowout (Spill#5) because no fast initial evaporation in air.
8	Subsurface Blowout, deep water, high flow	9,000,000 bbl = 100,000 BOPD x 90 days	(8a) HI-E Oil (8b) Av-E Oil	Represents worst-case blowout in deep water, and 90 days to drill relief well

* BOPD = barrels of oil per day

The above-surface, high-flow blowout involving Hi-E oil (scenario 5a) emulsifies very quickly and provides a window of opportunity for dispersant application of only five hours. Much of the oil that is released overnight during this blowout will not be amenable to effective dispersant treatment the next day. The fresh oil released will be relatively thick (2.5 to 4 mm) and narrow (<100m) making this spill a good candidate for vessel-based dispersant application as long as the dispersant is applied very close to the source.

Scenario 5b has the same high flow rate as 5a, but the lighter oil (Av-E) results in a larger window of opportunity for dispersant application (up to 36 hours). This scenario is also a good candidate for dispersant use because the slicks will survive a long time if left untreated (> 30 days), but dispersants should be effective on all of the oil, even that discharged over night.

Subsea Blowouts: Scenarios 6 and 7

In these scenarios the a, b and c designations refer to the different release depths of 35, 50 and 150 m, respectively. As the release point gets deeper, the surface slick becomes wider (increasing from approximately 300 m to 750 m) and thinner (decreasing from about 0.15 mm to 0.05 mm). The higher flow rates of scenario 7 increase the slick widths and thicknesses somewhat, but not radically. The window of opportunity for dispersant application in these scenarios is between four to seven hours. Because these spills are all continuous releases, the fresh oil emanating from the blowout site during the day will be treatable as long as it can be dosed within about six hours of its release. However, much of the oil released overnight will not be chemically dispersible the following morning. The dispersant application system used to apply the dispersant will have to be designed to properly dose the relatively thin slicks that result from these blowouts.

ANALYSIS OF DISPERSANT LOGISTICS

A detailed analysis of the above scenarios was performed with respect to dispersant-use logistics and factors that affect operational efficiency. The objective was to assess the current level of dispersant capability in the Gulf as tested against the selected spill scenarios. Two key factors are the availability of dispersant and the capability of various platforms for delivering and applying the dispersant.

Dispersant Availability

The quantities of dispersant immediately available to fight spills in the GOM area are of the order of 183,000 gallons (147,000 gallons from Region 6 and 36,000 gallons from Region 4). At least a portion of the remaining 222,000 gallons of dispersant located elsewhere could be made available for use on spills in the Gulf within 24 hours. In addition to the stockpiles already in place, dispersant manufacturers claim to be capable of producing approximately 44,000 gallons per day on an emergency basis.

Application Platforms

A crucial component of the dispersant response system is the spraying platform used to apply dispersants. Key features of the available platforms are outlined as follows.

C-130/ADDS Pack. The C-130 aircraft, equipped with the ADDS Pack (Airborne Dispersant Delivery System) has the greatest overall dispersant delivery capacity of any existing platform. This is by virtue of its high payload, spray rate, swath width and transit speed. At present, its main drawback in the Gulf of Mexico is that start-up times may be lengthy. At present (December 2000), spraying would not begin until the morning of the second day of the spill, in most cases.

DC-4. This platform is modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated of Houma, LA. This aircraft has the greatest delivery capacity of any dedicated aircraft application system currently available in the U.S. The key feature of the system is that it operates on a “firehouse” basis, meaning that it is dedicated to the task of dispersant spraying and is in a constant state of readiness. Its start-up time is one hour or less.

DC-3. This platform is also modeled after the dedicated dispersant spraying aircraft owned by Airborne Support Incorporated. The aircraft has the second greatest delivery capacity of the dedicated aircraft systems. This system also reports a start-up time of one hour or less.

Cessna AT-802 (Agtruck). These are small, single engine aircraft that are purpose-built for aerial spraying. In the U.S., a group of operators have organized to offer a dispersant spraying service using this aircraft. A number of these are available in the Gulf area. These operators guarantee a start-up time of four hours or less. These have a lesser payload capacity than certain of the larger aircraft, but this deficiency is somewhat compensated for by availability of multiple platforms. These have a somewhat more limited range over water than the large, multi-engine aircraft.

Helicopter. Helicopters equipped with spray buckets have the advantage of availability. They are limited by their small payload and limited range. They are highly maneuverable and capable of being re-supplied near a spill site, which greatly increases their operational efficiency.

Vessels. There are a number of vessel systems currently available in the Gulf area. These vary widely in terms of their payloads, pump rates and swath widths. Certain of the response vessels have relatively low payloads, which severely limits their capabilities. However, the recent addition of larger, high-speed crew-cargo vessels, equipped with portable dispersant spray systems and deck-mounted marine portable tanks have greatly improved the response capability of this group.

RESULTS OF ANALYSIS

The following are the main results of the logistics analysis:

1. In the batch spill scenarios, the rate of emulsification exerts a very strong influence over dispersion efficiency. In scenarios involving oils that have little tendency to emulsify, the oil dissipates naturally within hours or days and dispersants reduce the persistence of oil only slightly. In scenarios involving oils with a high tendency to emulsify, the time windows are very short, approximately seven hours. For some platforms, this interval allows time for one or two sorties at most, while for others the time window is too brief to complete even a single sortie. Even systems with the largest payloads (e.g., C-130) reduced the volume of persistent oil present by a few tens of percentage points in the smallest spill scenario (20,000 bbl scenario).

2. The impact of dispersants is most evident in scenarios with oils that do emulsify, but also do have a relatively long time window, up to 58 hours. In the smallest of these scenarios (Scenario 2b, 20,000 bbl), the platforms with the highest delivery capacities (C-130 and DC-4) are capable of dispersing the entire spill, but the smaller platforms are capable of dispersing only a portion of the spill. When the capacities of all platforms to deliver dispersant over a 12-hour period and a 30-mile distance were compared to the C-130, their

relative performances would be as follows: DC-4, 0.57 times the C-130, DC-3, 0.23; Agtruck AT-802, 0.25; helicopter,0.12; and surface vessels , 0.08 to 0.73.

3. Both helicopter and vessel systems have the advantage of being capable of being re-supplied at the spill site, thus avoiding the necessity of traveling to their base of operations. Because they can re-supply at the spill site, their performance can be improved by factors of 2.7 (helicopter) and 4.5 (vessel). The performance of these platforms relative to the C130, when supplied at site, would be 0.32 and 0.36, respectively.

4. The distance from the spill site to the base of re-supply influences performance. Increasing the operating distance from 30 miles to 100 miles reduces performance of most platforms to 50 to 75% of their capacities at 30 miles. By increasing the operating distance to 300 miles, delivery capacities are reduced to 40 to 60% of their capacities at 30 miles. The helicopter system could not be used for responses at 100 miles, nor the AT-802 at 300 miles because of range limitations.

5. For blowout spills, as with batch spills, the effects of dispersant use on oil fate depend on the properties and behavior of the oil. Blowouts of oils that do not emulsify or that emulsify very slowly will disperse quickly by natural means, and dispersants may not affect their persistence greatly. Other oils which emulsify relatively quickly can be strongly affected by dispersant operations.

6. Blowouts that emulsify quickly cannot be fully dispersed because dispersant operations must be suspended at night and a portion of the oil spilled overnight will emulsify to undispersible levels. When a blowout and batch spill of identical size (20,000 bbl) and oil type (Av-E) are compared, the batch spill can be fully dispersed, but the blowout cannot because of the "overnight effect." The more quickly the oil emulsifies, the greater the proportion that will become undispersible.

7. When surface and subsea blowouts of identical size and oil type are compared, dispersion of the subsea blowout is much less effective operationally than the surface blowout due to its larger width, smaller oil thickness and more rapid emulsification.

8. Payload and operating distance control overall operational effectiveness in blowout spills as in batch spills, but these influences are less evident when blowout rates are of the order of 5,000 BOPD or less. At these discharge rates, the larger platforms have excess capacity: therefore, their logistic advantage over the smaller platforms is less pronounced.

9. Overall, the results of the scenarios analyzed suggest that the largest spill that can be fully treated using existing response capabilities lies in the area of 3180 m^3 for batch spills or 800 m^3 /day for 4 days for continuous spills.

10. Response to the large, deepwater blowout scenarios (Scenarios 8a and 8b) is difficult for several reasons. First, these spills occur farthest from any base of operations. At this long

distance, a spill of even modest size is beyond the capabilities of single units of most aerial systems, except the C-130/ADDS Pack system. In theory, the amount of oil discharged each day, 100,000 barrels, is within the operating capacity of all of the large fixed-wing response resources in the GOMR, provided this were supplemented with two, preferably three, of the ADDS Pack systems from outside the region. This assumes that the operation achieves both a very high level of dispersant effectiveness and operational efficiency. Second, these two scenarios involve extremely large amounts of oil. The daily discharge rates for oil are so large that they would exhaust the North American stockpiles of dispersant within the first two to six days of the spill, assuming that the dispersant could be delivered to the spill that quickly. The operation would prove extremely difficult because the daily dispersant requirements vastly exceed the available delivery capability by many times (from 5 to 19 C-130/ADDS Pack systems would be needed).

NET ENVIRONMENTAL BENEFIT OF DISPERSANT USE

A detailed analysis of selected scenarios was conducted to study the environmental risks associated with untreated and chemically dispersed spills from offshore MMS-regulated facilities in the Gulf of Mexico. The objective was to determine whether or not dispersants offered a net environmental benefit in treating spills from these facilities. The key variables in these assessments were spill location, distance from shore, and the type of spill (i.e., batch spill versus blowout spill).

An important variable in the environmental assessment was the location of the spill. At the initiation of the project, six launch sites were suggested by Minerals Management Service for consideration, including: a) shallow water off Texas; b) shallow water off Louisiana; c) a mid-shelf site part-way between sites a) and b); d) the Flower Gardens Area; e) a deepwater offshore site; and f) the Destin Dome Area. Upon consideration of the fate and movement of oil and a preliminary assessment of environmental issues, spills from three sites; a), c) and f) were considered in detail.

RESULTS OF THE ANALYSIS

From the perspective of environmental risk and potential net environmental benefit of dispersant-use, the scenarios analyzed here fall into three categories.

a. One group includes oils that disperse very quickly, by natural means. Regardless of launch point, these spills disperse naturally in offshore waters; do not threaten shorelines or nearshore waters; and pose only very modest environmental risks. Chemical dispersion does little to reduce the impact of these spills and therefore offers little in the way of a net environmental benefit.

b. A second group of scenarios includes those in which the oils are persistent and could cause significant impact if untreated, but in which spills are small enough and time windows are long enough to permit dispersant operations to disperse all or most of the oil. In these spills, dispersants can greatly reduce the risks associated with the untreated slick and can offer a net environmental benefit provided the risks posed by the dispersed oil are low. Net environmental benefit issues are clearest in these scenarios.

c. The last group includes all of the spills in which oils emulsify too quickly for dispersant operations to be mounted or in which spill volumes greatly exceed the capability of platforms. In these scenarios, dispersants do little to reduce the impact of the untreated spill and therefore offer little net environmental benefit.

The main conclusion from this work is that if dispersants are used to treat spills from MMS-regulated offshore facilities in the Gulf of Mexico, there will be a net environmental benefit in almost every case. The reason for this is that the launch sites considered in this study are all offshore. If spills from these sites are sprayed with dispersants near the spill site (as they must be if the dispersant is to be effective), the spraying will take place offshore and the environmental risks from the dispersed oil will be very low or at least lower than the risks from the untreated spill.

The detailed analysis of a spill from an offshore launch site, Mid-Point, showed that there was a net environmental benefit of dispersant use. In this case, the untreated slick persisted to reach the shoreline and caused damage, while the same spill dispersed offshore caused far less damage. This situation is likely to hold in many other locations in the Gulf, even near the shallowest of the offshore hard-bottom communities, such as the Flower Garden Banks. The latter are deep enough to be relatively safe from damage in cases where dispersants are used nearby.

The spill from a near-shore launch site, Texas Nearshore, was unique because only in this scenario were there significant drawbacks from using dispersants. However, despite this, dispersants still offered a net environmental benefit. In this case, the untreated spill posed important risks to both economic and biological resources. However, unlike all other scenarios in which the dispersed case posed very few risks, in the Texas Nearshore case, the dispersed case posed a significant risk to at least one major economic resource, namely the shrimp fishery. On balance dispersants still appeared to offer a net environmental benefit, but there is some uncertainty surrounding this result. The risk posed by the dispersed case involved the shrimp fishery. The dispersed spill posed no biological risk to the shrimp stock, but the cloud of dispersed oil might result in a temporary and localized closure to the fishery. The local policies toward fishery closures and local attitudes toward the valuation of economic and biological resources could have a bearing on the analysis of net benefit.

The Destin Dome scenario demonstrated that the benefits of dispersants vary from place to place in the Gulf. This is because there are wide variations in the sensitivities of coastal zones to the effects of untreated oil. There are also spatial variations in the sensitivity of the offshore community to dispersed oil, as well, but these differences appear to be less dramatic. This supports the conclusion that there will be a net benefit of using dispersants on offshore spills throughout most of the study area. The only variation appears to be in the size of the benefit.

The blowout scenario showed that the net environmental benefit of using dispersants is far greater in blowout spills than in batch spills of the same size. This is because the impact of an untreated blowout spill can be far greater than for a batch spill. The damage caused by an untreated batch spill will involve only a small, localized area, while that from a blowout will cover a larger area and be greater as a consequence. On the other hand, when a blowout is treated with dispersants, any resulting damage is restricted to the vicinity of the spill site and is no greater than in the case of the batch spill.

While spills will certainly fall into these categories, at present the behavior of any given spill cannot be accurately predicted. It is important to recognize that the results of the scenarios analyzed here were based on computer simulations and assumptions concerning dispersant effectiveness rates and rates of emulsification. Many of the processes involved cannot be estimated precisely enough to allow a prediction of the effectiveness of a dispersant operation in advance. Rather, during an actual spill, it will be necessary to make decisions about the potential usefulness of dispersants and the effectiveness of dispersant applications based on direct real-time observations rather than on computer simulations. For this reason, it will be necessary to have these monitoring capabilities in place to use dispersants effectively.

For purposes of future work, it is important to recognize that natural resource databases such as Gulf-Wide Information System and Texas Coastal Oil Spill Planning and Response Toolkit contain little information concerning resources, such as fish, shellfish and fisheries, that are at risk from chemically dispersed oil. As a consequence, assessments of risk and net environmental benefit that are based solely on these sources would under-represent risks to these groups and would be biased in favor of dispersants.

REFERENCES

S.L. Ross Environmental Research Ltd. 2000. Technology Assessment of the Use of Dispersants on Spills from Drilling and Production Facilities in the Gulf of Mexico Outer Continental Shelf, Report to Minerals Mgmt. Service, Engineering and Research Branch, Herndon, VA.

STUDY TO COMPARE THE EFFECTIVENESS OF CHEMICAL DISPERSANTS WHEN APPLIED NEAT VS. DILUTE: MESOSCALE TESTS

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Many of the dispersants currently available in North America are "concentrate" products. These dispersants are suitable for spraying from all types of application platforms, including aircraft and surface vessels. They are invariably sprayed neat (undiluted) from aircraft, but a number of vessel-based systems dilute the dispersant before spraying. This dilution is done by educating the dispersant into a water stream during the spraying operation. The present study was undertaken to determine whether dilution had any effect on dispersant effectiveness. This project was one of a series undertaken to improve dispersant spraying technology for vessel systems.

Effectiveness testing was conducted in a test tank to simulate real-world conditions, as closely as possible, as described below. The following variables were examined:

1. effect of oil-to-dispersant ratio;
2. effect of dispersant type (Corexit 9500 and Corexit 9527);
3. method of diluting the dispersant (premixing vs. educting); and
4. type of oil.

Other conditions in the test were controlled, including: water-to-dispersant dilution rate; slick thickness; and mixing energy.

METHODS

Details of the methods are provided in Belore *et al.* (2000a,b,c) and SL Ross (1999).

The method was as follows:

- All tests were conducted in a wave-tank at SL Ross facilities.
- In each test run, a slick of known volume and thickness was laid down on the surface of the water in the tank.
- Dispersant was applied at a known dose rate using a spray boom apparatus.

- The wave generator was then engaged. Slicks dispersed rapidly initially, but after a few minutes of agitation, dispersion slowed and then ceased entirely.

- After 30 minutes of agitation, the test was stopped and the oil remaining on the surface was collected using sorbants and was weighed.

- Dispersant effectiveness was expressed as the percent of the oil that dispersed during the test.

In all studies, pre-tests were undertaken in which the dispersant was pre-mixed with the oil at a range of oil-to-dispersant ratios (DOR). Dispersion rates were measured using these pre-mixed oils to determine the critical minimum DOR at which the test slick was 100% dispersed. The minimum effective DOR was referred to as the “target” and this DOR was used for most subsequent testing.

COMPARISON OF COREXIT 9500 and COREXIT 9527

The first set of tests determined whether dilution of the dispersant with seawater prior to spraying had any effect on dispersant effectiveness. Tests were conducted using Alaska North Slope crude oil, dispersed with Corexit 9500 or Corexit 9527. The “target” DOR was determined for each dispersant, as described above, and all subsequent testing was performed at that DOR. In both cases the “target” DOR was 1:75. All “diluted” runs were conducted at a dilution ratio of 1 part dispersant to 10 parts water.

The results of these tests showed that the effectiveness of Corexit 9527 was not affected by dilution with water prior to spraying. However, the performance of Corexit 9500 was significantly reduced under the same conditions (Table 1H.3).

It must be noted that in the above tests, the “diluted” dispersant was prepared by pre-mixing dispersant with seawater in a reservoir several minutes prior to spraying, rather than educating it into the water stream during the spraying operation. A second set of tests was conducted to verify that the influence of dilution on the effectiveness of Corexit 9500 was the same whether the dispersant was educted or pre-mixed with water. The tests showed that effectiveness of Corexit 9500 was reduced to the same degree whether dilution was by education or pre-mixing.

Table 1H.3. Influence of dilution on effectiveness of dispersant on ANS crude oil.

Dispersant	Effectiveness of Treatment	
	Neat	Diluted (1:10)
Corexit 9527	99	97
Corexit 9500	97	17

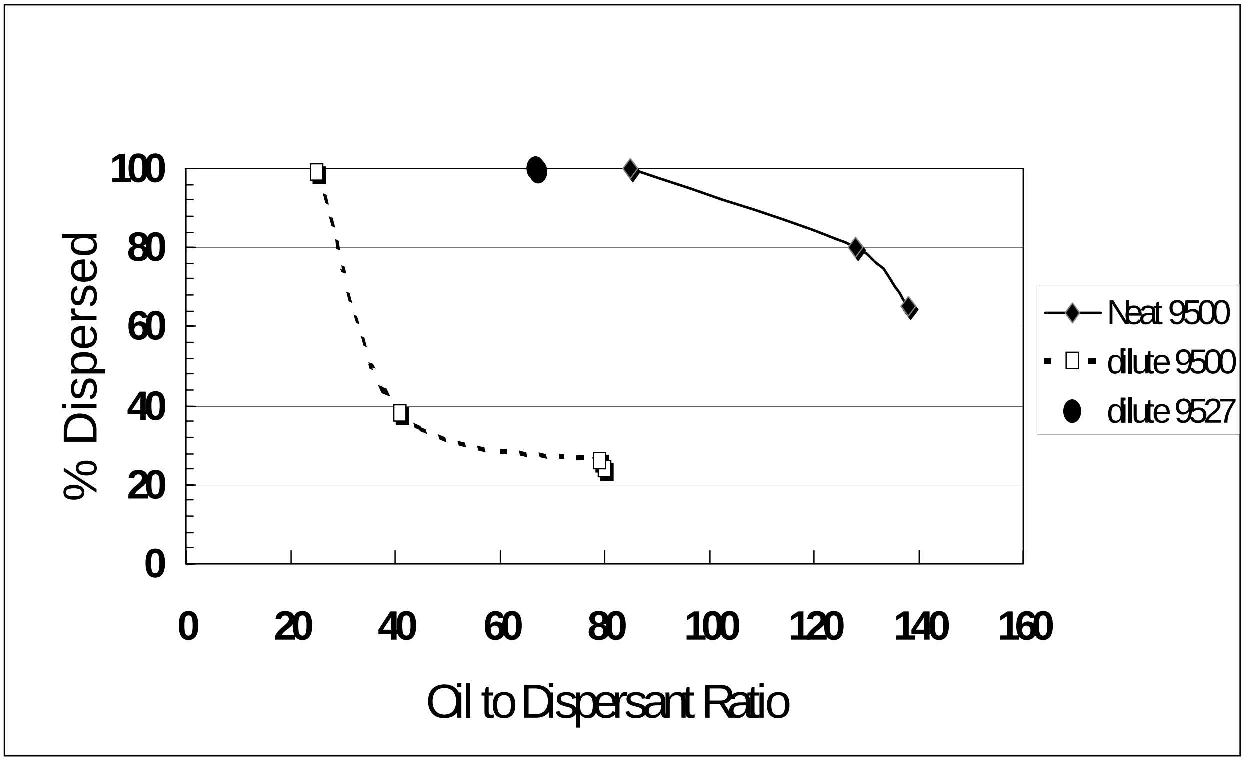

Figure 1H.7. Effect of oil-to-dispersant ratio on neat and dilute dispersants.

EFFECT OF DISPERSANT-TO-OIL RATIO (DOR)

A further series of tests was conducted to determine whether the effect of dilution on effectiveness of Corexit 9500 was influenced by the DOR. Tests were conducted using ANS crude oil. Dispersant effectiveness was tested at DORs of 1:25 and 1:40, as well as 1:75. The results of these tests are summarized in Figure 1H.7 below. These tests showed that the effectiveness of diluted Corexit 9500 increased when the DOR was increased, to the point that diluted Corexit 9500 was 100% effective at a DOR of 1:25.

EFFECT OF OIL TYPE

This series of tests was conducted to determine whether diluting Corexit 9500 reduced its effectiveness on oils other than ANS crude oil. Tests were run on five additional crude oils, including: Gulfaks, Green Canyon, Bonny Light, Hibernia and South Louisiana. The target DOR for each oil was determined in pre-mixed tests, as described above. The target DOR or minimum DOR required to cause 100% dispersion in premixed tests, differed markedly among the oils (Table 1H.4).

The results of the study showed that dilution had little effect on the effectiveness of Corexit 9527 on any oil (Figure 1H.8). It also showed that while the effectiveness of Corexit 9500 was reduced by dilution in tests with certain oils (Gulfaks, Green Canyon and Bonny Light), its effectiveness was undiminished in tests with other oils, such as Hibernia and South Louisiana crude (Figure 1H.9).

Table 1H.4. Target DORs as determined in pre-mixed tests.

Oil Type	Target DOR Corexit 9500	Target DOR Corexit 9527
Gulfaks	1:80	1:85
Green Canyon	1:60	1:50
Bonny Light	1:80	1:75
Hibernia	1:120	1:110
South Louisiana	1:100	1:80

CONCLUSIONS

In conclusion, these test results showed that the operational effectiveness of Corexit 9500 may be diminished somewhat by diluting it prior to application. The effect of dilution varied with the type of oil being treated. With Corexit 9500, the effect of dilution depended on the dispersant dose rate, and with some oils, increasing the dispersant dose rate could compensate for the loss of effectiveness caused by dilution. Effectiveness of Corexit 9527 was not affected by dilution.

ACKNOWLEDGMENTS

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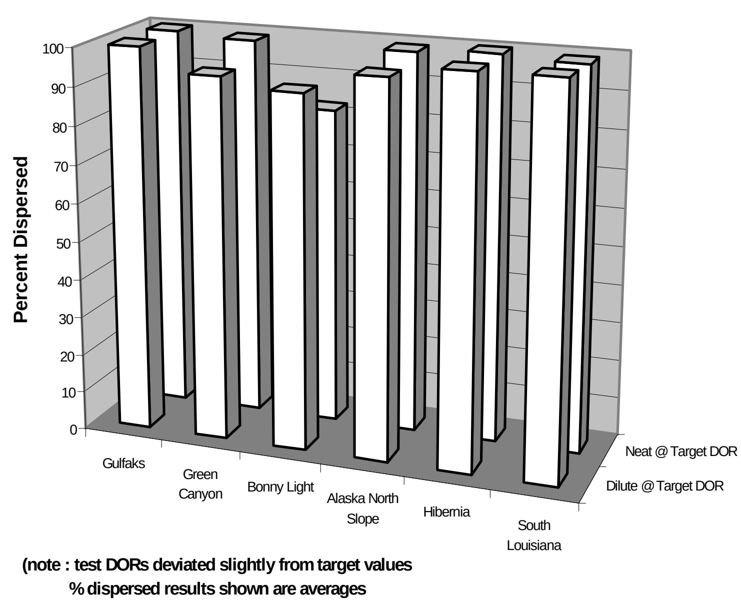

Figure 1H.8. Dispersing efficiency neat vs. dilute: Corexit 9527.

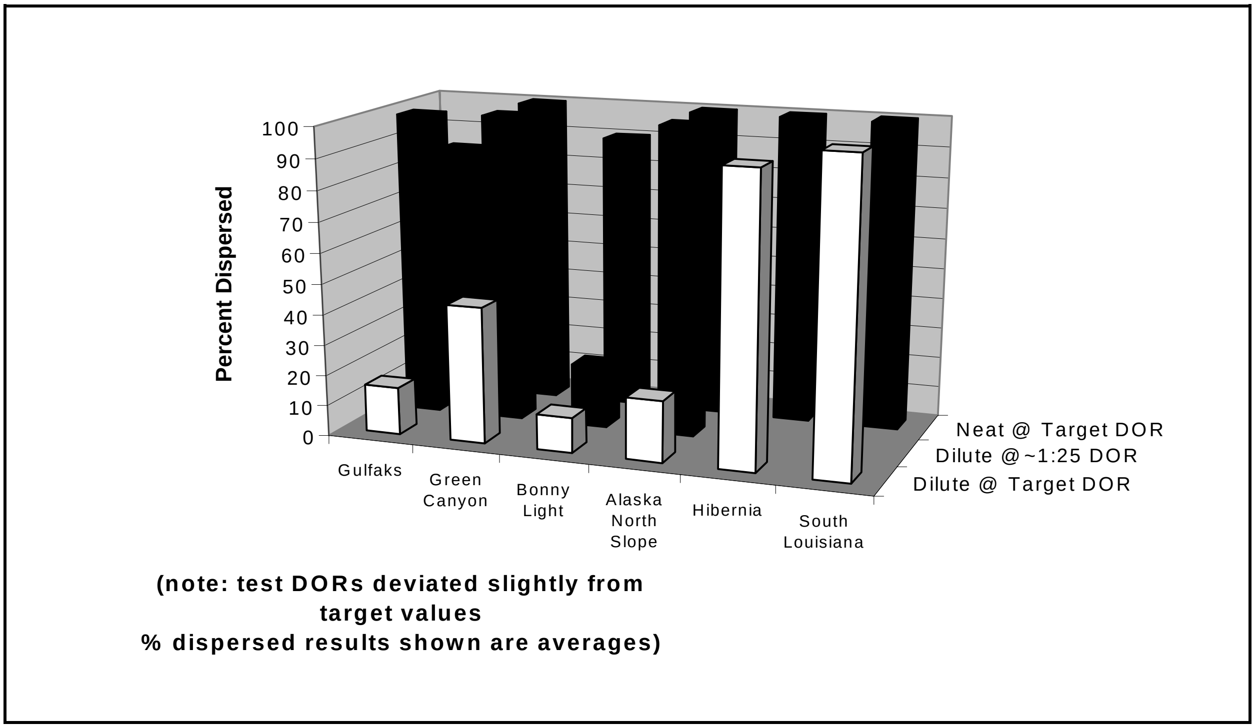

Figure 1H.9. Dispersing efficiency near vs. dilute: Corexit 9500.

REFERENCES

Belore, R.C. and S.L. Ross. 2000a. Laboratory study to compare the effectiveness of chemical dispersants when applied dilute versus neat. Proceedings of the Arctic and Marine Oil Spill Program Technical Seminar, Environment Canada.

Belore, R.C. 2000b. Laboratory study to compare the effectiveness of chemical dispersants when applied dilute versus neat: part 2. ExxonMobil Research and Engineering Company, Florham Park, N.J.

Belore, R.C. 2000c. Laboratory study to compare the effectiveness of chemical dispersants when applied dilute versus neat: part 3. ExxonMobil Research and Engineering Company, Florham Park, N.J.

Ross, S.L. Environmental Research Ltd. 1999. Laboratory study to compare the effectiveness of chemical dispersants when applied dilute vs. Neat. Project Report prepared for Minerals Mgmt. Service, Herndon, VA, 26 pp.

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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.