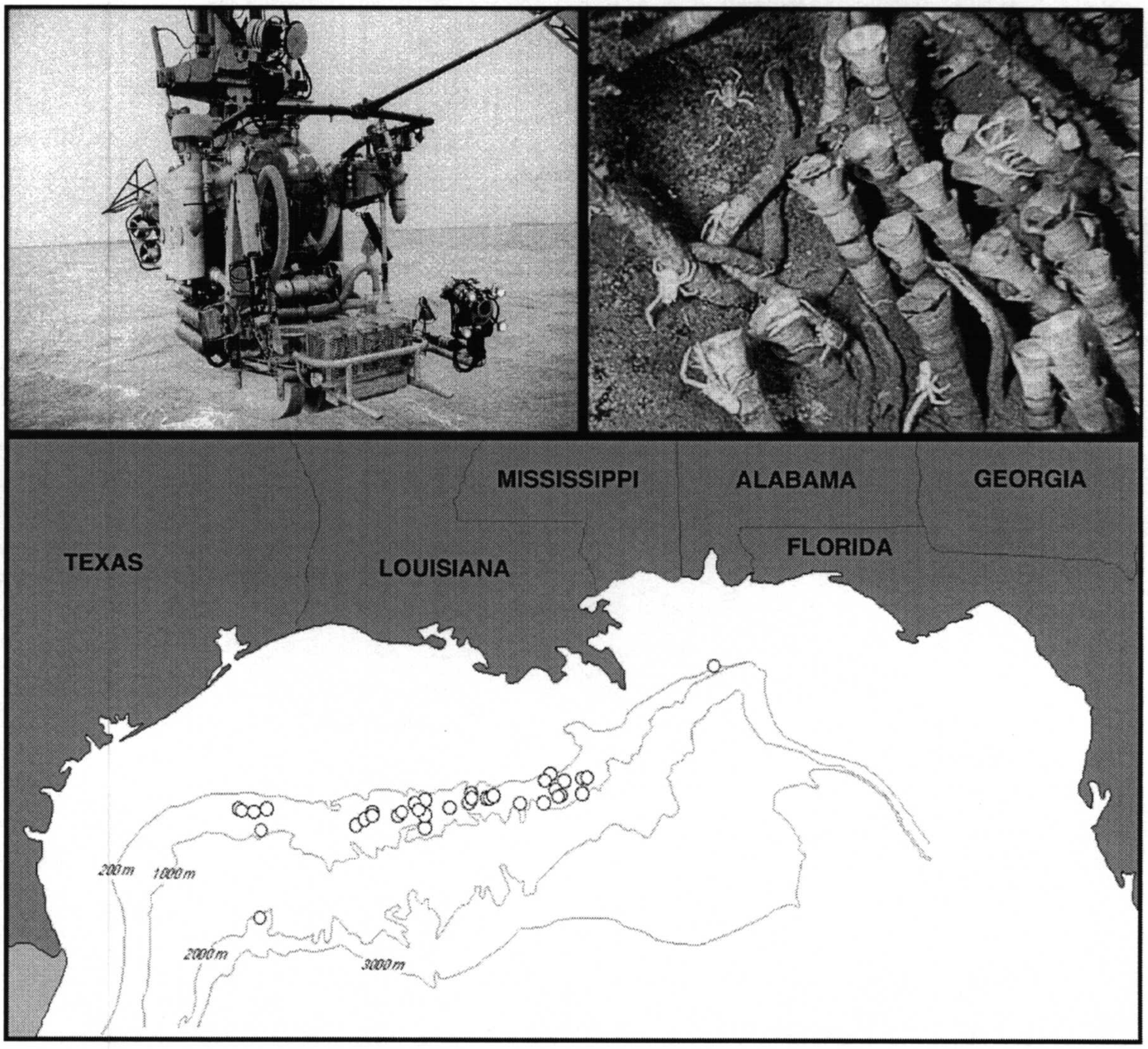
OCS Study
MMS 95-0021

Northern Gulf of Mexico

Chemosynthetic Ecosystems Study

Final Report

Volume I: Executive Summary



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

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Prepared under MMS Contract
14-35-0001-30555
by
Geochemical and Environmental Research Group
Texas A&M University
Texas A&M Research Foundation
College Station, Texas

Published by

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

New Orleans
May 1996

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CITATION

Suggested Citation:

MacDonald, I.R., W.W. Schroeder, and J.M. Brooks. 1995. Chemosynthetic Ecosystems Study Final Report, Volume I: Executive Summary. Prepared by Geochemical and Environmental Research Group. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 95-0021. 33 pp.

COVER PHOTOGRAPH

The foreground photograph shows the submersible *Johnson Sea-Link I* preparing for one of its many dives to study chemosynthetic ecosystems. The map depicts the locations of known chemosynthetic ecosystems in the northern Gulf of Mexico.

PREFACE

The Chemosynthetic Ecosystems Study concerns the prominent biological communities of tube worms, mussels, and clams that occur at natural hydrocarbon seeps on the continental slope and that derive their food supply from chemicals associated with the seeps. This is the Executive Summary of the Final Report that will be issued for the Study, which is sponsored by the U.S. Department of Interior Minerals Management Service (MMS), Gulf of Mexico OCS Region Office (Contract 14-35-0001-30555). The Technical Report (Volume II) provides details concerning the methods and results obtained during a three year study. Volume II covers the geology of hydrocarbon seeps, the community structure, the life history of the major fauna and evidence for the persistence of these communities over a 1 - 10 year and 100 - 1,000 year time scales. Volume II is 338 pages long. An appendix volume presents additional data from the study.

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1 Introduction

Planning for this study was initiated by MMS shortly after the 1984 discovery of chemosynthetic fauna at natural hydrocarbons seeps on the continental slope in the Gulf of Mexico (Kennicutt et al. 1985). From a management point of view, the Study was necessary because of the agency's concern that energy exploration and production could harm an important component and previously unrecognized component of the slope ecosystem.

The Geochemical and Environmental Research Group (GERG) of Texas A&M University was awarded the contract in July 1991. The Study was conducted by ten principal investigators and associates under the overall management of GERG as follows:

Principal Investigators*	Affiliation	Major Responsibility
Javier Alcala-Herrera	TAMU/GERG	Chemical Analyses
James M. Brooks*	TAMU/GERG	Project Director
Robert S. Carney*	LSU	Ecology
Charles R. Fisher*	PSU	Physiology
Norman L. Guinasso, Jr.*	TAMU/GERG	Data Analysis
Holgar W. Jannasch*	WHOI	Microbiology
Mahlon C. Kennicutt II*	TAMU/GERG	Geochemistry
Ian R. MacDonald*	TAMU/GERG	Ecology/Deputy Proj. Director
Eric N. Powell*	TAMU/OCNG	Taphonomy
William S. Sager*	TAMU/OCNG	Geology
William W. Schroeder*	UA/DISL	Geology/Ecology
Dan L. Wilkinson	TAMU/GERG	Field Logistics
Carl O. Wirsen	WHOI	Microbiology
Gary A. Wolff	TAMU/GERG	Data Management

TAMU	*Texas A&M University*;
GERG	*Geochemical and Environmental Research Group*;
OCNG	*Oceanography Department*;
LSU	*Louisiana State University*;
PSU	*Pennsylvania State University*;
WHOI	*Woods Hole Oceanographic Institution*; and
UA/DISL	*University of Alabama Dauphin Island Sea Lab*.

Collectively, this group brought to the study a mature program of research that included collaboration with investigators from several research universities in the Gulf of Mexico region and elsewhere. As a result, the team was able to proceed immediately to the fieldwork stage of the program and to build upon an existing data base acquired through several previous years of field sampling and analysis.

The Study was tasked with delineating the abiotic factors that determine why communities of chemosynthetic fauna become established and persist at hydrocarbon seeps. Assessment of the relative importance of the communities to the slope ecosystem was given a high priority. To address the question of possible harm due to human activity from primarily energy-related industry, the Study examined the growth rates of the major faunal groups, the paleontological record of the community, and the incidence and causes of short-term change.

Because the communities occur at depths of 500 m or greater and tend to be small in area, the investigations have relied heavily upon research submarines for sample collection and study. Initially, five sites located in water depths of 500 to 720 m were selected for study on the basis of their faunal composition and geographic location. The MMS contracted for 18 dive days with the submarine *Johnson Sea-Link I* and her surface support ship. Additional in kind contributions of submarine time with both *Alvin* and the U.S. Navy *NR-1*, which were facilitated through GERG, have been crucial to the success of the field program. For example, use of the *Alvin* led directly to discovery the deepest known Gulf of Mexico seep community in Alaminos Canyon (2220 m depth); and *NR-1* surveys have been responsible for the initial discovery of many of the study sites.

Preliminary reports concerning the finding were presented at the MMS Information Transfer Meeting on 5 December 1993. In general, study results show that the seep communities are a unique and important component of the slope ecosystem of the Gulf of Mexico. Although susceptible to mechanical damage by offshore drilling or production activities, the ecosystems are prevalent enough that localized disturbances should not effect the viability of these communities.

2 Regional Distribution of Hydrocarbon Seepage and Seep Fauna

The vestimentiferan tube worms, mussels (seep mytilids), and the vesicomyid and lucinid clams that colonize natural hydrocarbon seeps are able to exploit the chemical enrichment that occurs in localized zones when oil and gas arrive at the seafloor to varying degrees. Regionally, a map of the known seep communities indicates a broad belt of occurrence across the upper to mid-continental slope (Figure 1). While the distribution of communities is related to the frequency and mode of sampling, the landward limits of seep communities appear to be definable and restrict the occurrence of seep fauna to water depths less than about 500 m. The physiological and ecological causes of this restriction are not understood. The seaward and east-west extents of this distribution are artificially constrained by the limits of exploration. The presence of perennial oil slicks, which form over many seeps and can be detected by satellite remote sensing, indicate that seeps are present across the entire continental slope of the northwestern Gulf of Mexico. Collection of oil-laden surface sediments by piston coring also indicates the general prevalence of seepage on the Gulf slope. One deep water (2200 m) seep site has been explored in the Alaminos Canyon lease area and the thriving chemosynthetic community found at that site (Brooks et al. 1990) supports the theory that seeps of the lower continental slope have the potential to be colonized. To the east, the Mississippi Fan and Mississippi Canyon regions appear to have more limited seepage. This is confirmed by the general lack of surface slicks and the lower concentrations in sediment hydrocarbons. The Florida Escarpment limits the eastward occurrence of known seep communities; however, the first documented discovery of tube worms and mytilids in the Gulf of Mexico was at the base of the Florida Escarpment, at a depth of 3600 m (Paull et al. 1984). The escarpment communities have been linked not to thermogenic hydrocarbons, but to connate fluid seepage from the highly porous Florida carbonate platform. The eastern most

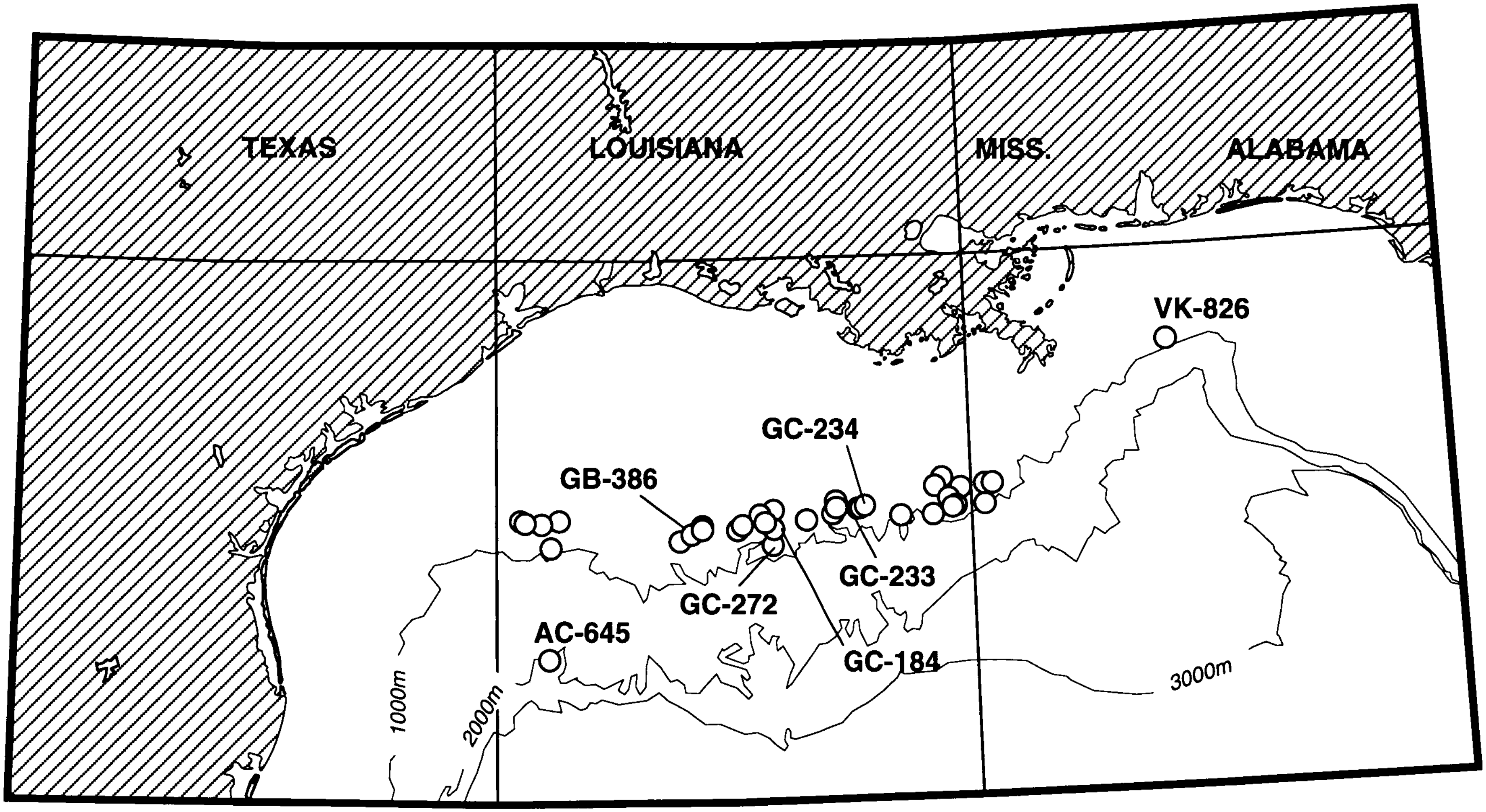

Figure 1. Map showing the locations of known chemosynthetic communities at hydrocarbon seeps. Labels indicate the seven selected as study sties for the Chemosynthetic Ecosystem Study.

occurrence of hydrocarbon fauna is in the Viosca Knoll area (88° W). The oil reserves offshore Mexico and the similarities between the Yucatan and Florida Escarpments suggest the potential distribution of seep communities across the entire Gulf of Mexico.

This broad regional distribution belies the localized occurrences of the chemosynthetic communities. Because the fauna depend upon nutrients supplied by geological processes, they are freed from the restrictions associated with increasing water depth imposed upon the photosynthetic food chain. These communities often form very dense aggregations in the otherwise food-poor deep-sea. However, because their energy source is so specific, seep communities are sharply limited by the spatial and temporal characteristics of seepage. Therefore, seep communities tend to be dense, but small in area.

On the northern continental slope, movement of the Louann Salt produces both the reservoirs and the migration conduits required for hydrocarbon seepage. Seep communities are thus inextricably linked to the underlying salt structures, but this dependence is variable on smaller scales. For example, a bathymetric chart of the Green Canyon lease area, where many of the most-studied seeps are found, was produced from a data set arrayed in a 250 m grid (NOAA 1992), and clearly shows several salt structures and slump zones produced by salt movement. However at this scale, the occurrence of seep communities do not exhibit an unambiguous preference for specific topographic features associated with salt tectonics. This is because seepage, although associated with a variety of distinctive geological features, typically occupy areas that are only a few tens to a few hundreds of meters in width.

3 Near-Surface Geology Hydrocarbon Seeps

High resolution geophysical records, submarine observations, and core data have been used to describe the geology associated with hydrocarbon seeps on the Louisiana continental slope. The slope of the northern Gulf of Mexico is a well-known site of hydrocarbon seepage and chemosynthetic communities (Brooks et al. 1986; MacDonald et al. 1990). The study areas include Green Canyon 184/185, Green Canyon 234, Garden Banks 386, Garden Banks 424/425 and their surrounding areas. The primary objective of the geologic study component was to enhance our understanding of how geological processes constrain the location and abundance of chemosynthetic communities.

The primary data base consists of 77 kHz side-scan sonar records, 25 kHz seismic reflection profiles, bathymetry data, and video tape photography, which were obtained by the research submarine *NR-1* in 1990 (GC 184/185, GC 234, and GB 386) and 1993 (GB 424/425). Other data available for these areas are push cores (GC 184/185, GC 234, and GB 386; *Johnson Sea-Link*, 1992), piston cores (GC 234, GB 386 and GB 424/425; *R/V Gyre*, 1992), 3.5 kHz and 12 kHz echo sounder records (GB 386 and GB 424/425; *R/V Gyre*, 1992), and oil company hazard survey data (GC 184/185 and GB 386). Industry data includes 3.5 kHz echo sounder records and selected multi-channel seismic lines.

Detailed bathymetric maps of each study area were made using *NR-1* depth data. Slant-range corrected side scan sonar mosaics were constructed for each site providing acoustical images of seafloor features. Acoustic reflection characters ("acoustic facies") seen in 25 kHz subbottom reflection records were mapped. Acoustic facies variations were due to changes in the texture and composition of the seafloor and sediments. Acoustic facies mapping results was correlated with video records from submarines and core samples.

Acoustic facies mapping results of 25 kHz subbottom reflection records of GC 184/185 and GC 234 sites show significant differences from those of GB 386 and GB 424/425. The flat mounds of GB 386 and GB 424/425 are mostly sediment associated with solid or porous carbonate rocks. In contrast, GC 184/185 and GC 234 sites show more variable features, less hard substrate and denser chemosynthetic communities. Chemosynthetic communities are strongly coupled with echo types that are interpreted as porous or semi-consolidated carbonate precipitates.

Push cores collected from the submarine *Johnson Sea-Link* and piston cores collected from *R / V Gyre* were analyzed for water content, bulk density, porosity and carbonate percentage with depth. The analysis results and visual description of the cores were used to interpret the acoustic facies at each study site. Several piston cores collected from the GB 424/425 site exhibited violent gas expansion inside the cores when brought on deck. This may have been caused by the rapid decomposition of gas hydrates.

Active mud slides and sediment flows on flanks of the mound in the GB 424/425 site were observed. Following these features upslope, active mud vents discharging gas, oil and mud at the perimeter of the mound top were observed. Sediments entrained by this discharge have probably contributed to the formation of the mound. Gas and droplets of oil were observed to be escaping from the vents. A temperature probe, lowered immediately beneath the surface of the fluid mud within the vent, recorded a temperature of 20°C, about 12°C warmer than the surrounding seawater.

4 Geochemical Processes in Chemosynthetic Communities

Chemosynthetic communities are closely linked to a number of geochemical phenomena or processes. Directly or indirectly, these processes are primarily the result of oil and gas seepage. Historically, the recognition of oil seepage, gas-charged sediments (seismic wipeout zones), and hydrates lead to the discovery of seep communities. This fundamental coupling of biochemical processes and the chemical environment is at best incompletely understood. A common feature at both cold seeps and hot vents is the co-occurrence of anoxic and oxic conditions that allow for the storage of reduced compounds in close proximity to oxygenated waters. This dynamic system can only be maintained through an active supply of reduced compounds. The supply of these reduced compounds can result from seepage or venting (a deep source) and/or bacterial processes (aerobic and anaerobic). The seepage of oil and gas provides an unconventional source of carbon and possibly some portion of the hydrogen sulfide needed for the community's energy and nutrition requirements. Oil and gas are readily available to hydrocarbon oxidizing bacteria that naturally occur in the marine environment. Microbial processes form the basis of the ecosystem and provide the mechanism to transform chemical energy into biochemical energy, mediated by free-living as well as endosymbiotic bacteria.

All locations studied have a number of common features including oil seepage; gas charged sediments; hydrates; authigenic carbonate; active hydrocarbon oxidation; chemosynthetic biomass (not only in the symbiotic organisms but also in background fauna); elevated EOM, TOC, and salinity; and biodegraded oil. While it is still not clear which of the features are essential, it is clear that all of these attributes are closely related. A supplementary source of carbon is provided by oil and gas seepage. The oxidation of hydrocarbons contributes to maintaining anoxic conditions. Most, if not all, carbon and energy transformations are mediated by bacteria. Sulfur, an important element, and hydrate formation/decomposition are intimately associated with the continuous supply of natural gas. It is also clear that pore waters are the main repository of reduced compounds and bottom waters supply oxygen. Steep gradients are present in almost all chemical properties and areal (including vertical) patchiness and heterogeneity are extreme.

The progressive overprinting of precipitated carbonates, biologically degraded hydrocarbons, gas hydrates, and active seepage or venting that can occur within a given portion of a community makes it difficult to determine what critical, or essential, geochemical requirements are needed for proliferation and maintenance of communities. However, the presence of oil and gas seepage is a fundamental process in creating the chemical environment that fosters these unusual accumulations of biomass in the deep ocean.

Careful sampling of the local environment associated with individual biological components suggests that there are predictable geochemical associations. It appears that *Beggiatoa* mats and other bacteria play a role in starting a process of seafloor modification in areas of long term thermogenic seepage. Tube worms, in contrast, appear to occupy environments that have been modified by thermogenic seepage effects over a long span of time. Tube worms appear to need a hard substratum as a point of attachment. Authigenic carbonate rock provides such a substratum in an otherwise unfavorable, mud-dominated environment. A long span of time is required to precipitate enough carbonate rock to serve large populations of tube worms. Seep mussels are methanotrophic and the potential sources for methane at seeps are quite diverse. Methane may have biogenic or thermogenic origins. It can be obtained in mytilid micro-habitats as a dissolved fraction of hypersaline brines or dissolved in sea water as a result of active gas venting. Formation and dissociation of gas hydrates further complicates the picture by alternately sequestering or releasing methane.

5 Growth rates of Symbiont-Containing Fauna at Hydrocarbon Seeps

The "robustness" of a community of animals is related to the growth rates and the population structure of the community: A community of fast-growing young animals will recover from physical disturbance much more quickly than a community of slow-growing older individuals. In the case of animals which rely on chemoautotrophic or methanotrophic symbionts, another piece of information basic to understanding the community dynamics is the nature of the animals reliance on the reduced chemicals which are the primary substrates of their autotrophic symbionts. The primary goals of this portion of the Study was to determine the growth rates of the key ecosystem organisms.

There are three main groups of chemosynthetic metazoans endemic to the hydrocarbon seep sites on the Louisiana Slope of the Gulf of Mexico: vesicomyid clams, vestimentiferan tube worms, and mussels which are provisionally designated "seep mytilids" (Brooks et al. 1987). Each group employs a distinct strategy to obtain the chemical substrates required by its symbionts. *In situ* growth experiments were designed based on our knowledge of each group. A set of devices were also designed and constructed for this Study to collect small volumes of water from specific physiologically relevant points in the animals immediate habitat. These samples were then analyzed for the chemical substrates of the symbionts.

The two species of tube worms present at these sites are in two different families (Escarpidae and Lamellibrachidae) but have similar gross anatomy, physiology, and lifestyles (Jones 1985). The worms attach to hard substrate when they settle and are immobile after metamorphosis to the adult form. The adults have no mouth, gut, or anus and apparently depend entirely on their symbionts to meet their nutritional needs. The bacterial symbionts require sulfide, oxygen, and inorganic carbon for chemoautotrophy (Fisher et al. 1988). Due to its immobility, the host tube worm can only live in an environment with a constantly replenished supply of nutrients. It is well documented that the hydrothermal vent vestimentiferans take up these dissolved gases across their plumes; however, these hydrocarbon-seep animals may acquire sulfide by diffusion across the portions of their tubes that is buried in sediments containing large concentrations of reduced compounds (MacDonald et al. 1989; Fisher 1990).

Sulfide was undetectable in 8 of 9 samples taken around the plumes of the vestimentiferans and in 15 of 17 samples taken between the plumes and the sediment. However, over half of the samples of interstitial water 10 cm below the sediment-water interface contained detectable sulfide, with concentrations ranging from a few micromolar to over one millimolar. These data tend to support the hypothesis that seep vestimentiferans can acquire sulfide by diffusion across the portion of their tube buried in sediment.

To determine the growth rates of the vestimentiferans, numbered bands were placed around the tubes, close to the anterior ends. The location of the bands was documented using video, and their yearly growth determined by subsequent visits to video or collect the banded animals The growth rates of both species was determined to be extremely slow. The fastest growing individual laid down 2 cm/yr of tube material and the average for both species was near 0.5 cm/year. This is in stark contrast to their hydrothermal vent tube worms which can grow one hundred times faster. Because individuals of Lamellibrachia sp. are between 2 and 3 meters in length, it can be concluded that individuals in excess of 200 years old are present in many of the large tube worm aggregations.

The undescribed hydrocarbon seep mussel (seep mytilid Ia) contains methane oxidizing symbiotic bacteria in its gills that provide the bulk of the animal's nutrition (Childress et al. 1986). Because of the relative ease in handling methane (as compared to hydrogen sulfide) and the fact that this mussel can be maintained in the laboratory at ambient pressures for extended periods, this species has proven amenable to laboratory study, and there is the isolated symbionts (Fisher et al. 1987; Cary et al. 1988). Although these bivalves are mobile they occur in dense "beds" attached to rocks or each other by byssal threads. In fact the results of a transplant experiment conducted as part of this study suggests that appropriate physical substrate as well as high levels of methane are necessary for establishment of mussel beds.

Experiments were designed to chemically characterize the animals micro habitat, determine the density and population size structure of beds, and measure the mussels *in situ* growth rates. A bed of mussels was marked with a float and numerous water samples were taken from precise locations among the mussels. Animal collections were then made within a 0.5 m diameter ring that was temporarily positioned on the mussel beds. All of the animals collected were measured and 150 were individually tagged and returned to the point of collection. This procedure was repeated in two subsequent years at several sites. In addition to determining growth rates of the marked and recollected animals, the physiological condition of a subset of each mussel collection was determined using three different indices.

The results of this work element can be summarized as follows: 1) The mussels flourish in sites with very high levels of methane (>1 mM) immediately below the bed and high levels (>60 mM) among the animals. 2) At active sites, the juveniles grow very quickly (up to 2 cm/yr in shell length) and adults grow at rates comparable to healthy intertidal mussels at similar temperatures. 3) Populations at sub-optimal conditions can be in good health but grow at very slow rates, suggesting that these animals can live a long time (50 to 100 years). 4) Because of the high densities of animals in some beds, biomass can be quite high (up to 20 kg/m^2) and the potential methane oxidation rates of these beds are the highest ever measured in any environment on the planet (up to 200 $g/m^2/day$). 5) Significant differences were found in two of the sites in subsequent years (in chemistry, growth rates, and physiological condition of the animals) which suggests significant variability in the habitat on a one to ten year scale.

6 Heterotrophic Fauna Associated with Hydrocarbon Seeps

All chemosynthetic assemblages clustered within the emissions of hydrogen sulfide and methane, at both cold seeps and hydrothermal vents, are in dramatic contrast to the surrounding deep-sea benthos. High population densities are found for both heterotrophic and chemoautotrophic species. This suggests that the heterotrophic components of chemosynthetic communities are not independent of the ecology of the surrounding sea floor. The deep-sea is not an ecologically monotonous desert, but is characterized by bathymetric and latitudinal gradients of biomass, species diversity, and species composition (Carney et al. 1983; Gage and Tyler 1990; Rex et al. 1993). If these factors influence vent and seep ecology, then consistent geographic and bathymetric patterns should emerge as the number of regions studied increases. The goal of this work element was to study the interaction between seep fauna and background heterotrophic fauna. The origin and characteristics of the heterotrophic fauna is an important aspect of this interaction.

There is an abundant heterotrophic fauna exploiting both the food source and habitat of the upper slope seeps. This fauna is numerically dominated by gastropod mollusks (summarized in Warén and Bouchet 1993). In approximate sequence of dominance, the most common species present are *Bathynerita naticoidea, Provana sculpta, Cataegis meroglypta*, and *Buccina canatae.* Less common gastropods include *Cancellaria rosewateri, Cantrainia macleani, Gymnobela extensa, Hyalorisia galea, Gaza fisheri*, a chiton *Ichnochiton* sp., and a rare undescribed limpet. All except *G. fisheri* have been collected directly from mussel mats. A limid bivalve, *Acesta bullisi* is found attached by byssal fibers to the rocks, or enclosing the anterior opening of tube worms.

Crustacea living in closest association with mussel clumps and worm bushes are a common galathetiid, *Munidopisis* sp.; a much rarer galatheiid *Eumunida picta*.; and the shrimp *Alvinocaris stactophila*. Large mobile crustaceans are conspicuous in seep areas, but less commonly in direct contact with tube worms and mussels, include the decapods *Paralomis cubensis, Rochina crassa, Chaceon quinquedens, Chaceon fenneri*, and the giant isopod *Bathynomus giganteus*. Echinoderms are represented by a common predatory sea-star, *Sclerasterias* sp; a filter feeding sea-star of the family Brisingidae, and sea urchin *Echinus* sp. More than 10 species of fish have been sighted during dives, but only five seem to show a consistent affinity for the seep communities: *Eptatretus* sp. (hagfish), *Synaphobranchus* sp. (cutthroat eels), *Urophycis cirratus* (Gulf hake), *Hoplostethus* sp., and *Chaunax pictus* (pancake batfish).

The principle description of the fauna of the West Florida Escarpment has been given by Hecker (1985). The associated heterotrophs are dominated by gastropods. An undescribed trochid is very abundant. A limpet has been named and described (McClean 1990). A neogastropod was reported. The crustacea collected consist of a species of *Munidopsis* and a bresilliid shrimp. Unidentified ophiuroids and a vermiform holothuroid identified from photographs as *Chiridota* were present. The associated heterotrophic fauna of the 2000 m deep Alaminos Canyon shares some elements in common with shallower seeps but also has distinctive components. The gastropod fauna is markedly reduced. Archaeogastropod limpets predominate to the virtual exclusion of all other forms. A single crushed specimen of a buccinid differing slightly from *B. canatae* was collected. Bresiliid shrimp apparently of the same species as common shallower species were present, but reached larger size. Large (1 cm) amphipods were abundant. Galatheiid crabs were observed, but only a single specimen was recovered. It was not the *Munidoposis* sp. found shallower. Large decapod crustaceans appeared to be absent, and only a single fish was collected, an eel pout. Authigenic carbonate rocks in the seeps had scattered specimens of a verrusamorph barnacle and small ophiuroids.

It is to be expected the associated heterotrophic species at cold seeps, like those at hydrothermal systems (Tunnicliffe 1991), reflect mixed sources; some may be truly endemic to chemosynthetic communities; some may be colonists from the surrounding benthos which have established resident seep populations, while still others are vagrants making temporary use of the seep site without developing resident populations.

The Gulf of Mexico sites afford a special opportunity to examine the following question: How many of the seep associated heterotrophs are endemic, colonizing, or vagrant? The Gulf has been extensively sampled and the bathymetric distribution of the larger normal (megafauna) benthos well documented (Pequegnat 1983; Galloway and Pequegnat 1988). Therefore, it is possible in many cases, to determine which of the species collected at seeps are colonists, and which are vagrants.

Several observations are readily apparent. First, the upper slope and Alaminos Canyon heterotrophic fauna are very dissimilar and may share only the shrimp *Alvinocaris stactophila* in common. If other elements are shared, their relative abundance at the two sites must be so dramatically different as to have escaped detection at the level of sampling performed. Second, endemism is low at the species level, comprising five endemics out of 39 species. At the level of genus, only the two coiled gastropods *Bathyneritia naticoidea* and *Provanna scuplta*, possibly the Alaminos canyon limpet, and the shrimp *Alvinocaris stactophila* are endemic. Third, the colonizers and vagrants comprise about 10% of the surrounding species richness, 23 species in seeps at the upper slope sites and 251 species in the background fauna. Fourth, the distinction between vagrant and colonizer seems to be related to size and mobility. Colonizers tend to be smaller, slower, and subdominant in the background. Vagrants tend to be larger, highly mobile, and may include dominant elements from the background.

The low endemism of the Gulf of Mexico seep sites, especially the upper slope, and the high degree of colonization by fauna from the surrounding sea floor is markedly different from the hydrothermal vent systems where 95% of the species are endemic (Tunnicliffe 1991; 1992). This difference may be attributable to the fact that seep sites lie within the biodiversity gradients of the continental margins, while vents tend to be located away from the continents. The abundance, diversity, and nature of the species on continental slopes afford a much higher opportunity for colonization and exploitation by vagrants.

7 Temporal Stability of Chemosynthetic Communities

Life spans of the Gulf chemosynthetic fauna, where they can be determined by growth experiments, are on the order of tens to possibly hundreds of years. Short-term change in their communities should therefore result from variation in fluid flow or other seep-related processes. Successful settlement events should be relatively rare and the effects of predation relatively limited. Comparison of seep communities photographed at intervals of up to three years reveals little direct evidence for change in either community composition or density. This is in marked contrast with the chemosynthetic communities at the Galapagos hydrothermal vent, where entire aggregations of tube worms were replaced with mussels over a period of less than five years (Hessler et al. 1988). Indirect evidence, on the other hand points to change and various rates. Most rapid change will undoubtedly result from catastrophic events such as blow-outs and slumping. Upended carbonate slabs and sharp sided pockmarks are clear indicators that such blowouts do occur. Over a circa-annual time scale, variation in water temperature can destabilize near-surface hydrates and greatly increase local seepage (MacDonald et al. 1993). Finally, rechannelization of fluid-flow may choke off fluid flow in a highly localized area; evidence for this can be seen in the defunct mussel beds that are commonly found in the vicinity of living beds. In general, however, the incidence of short term change seems to be sufficiently low that detection is unlikely in the short-term.

8 Paleontology of Seep Bivalve Communities

Six distinct biofacies have been recognized from petroleum seep assemblages; dominated respectively by mytilid mussels, vesicomyid clams, *Lucinoma* clams, thyasirid clams, vestimentiferan tube worms, and the normal slope fauna. A long term history of these seep assemblages is not well known. This component was designed to examine the long term record of seep assemblages by comparing guild and tier structure, paleoenergetics, and changes in community composition of the six biofacies at a number of petroleum seep sites.

Autochthonous seep assemblages (those that develop in place) are characterized by a unique tier and guild structure, size-frequency composition, and animal density that together identify the paleoenergetic's structure of these communities and distinguish them from other autochthonous assemblages of the shelf and slope. All seep assemblages were dominated by primary consumers, whereas the non-seep assemblage was dominated by carnivores. Carnivore dominance seems to be typical of shelf (or euhaline) death assemblages. Seep assemblages, in contrast, retain the theoretically-expected rarity of predaceous forms in fossil assemblages. The infaunal tier was well represented in most petroleum seep assemblages because a large fraction of the shelled biota were infauna or semi-infauna. Dominance by shelled infauna is unusual. Local enrichment of food resources and the dominance of shelled primary consumers explain the guild and tier structure of seep assemblages. Nearby autochthonous assemblages relying on planktonic production are substantially different in each of these criteria. The non-seep autochthonous assemblages were dominated by epifauna and semi-infauna as is typical for continental shelf and slope assemblages.

A hindcasting paleoenergetics model was used to estimate the energy demand of both seep and non-seep assemblages. The two important products of the hindcasting model are paleoproduction and paleoingestion. Paleoproduction is equal to the individual's biomass-at-death, while paleoingestion is the amount of energy consumed by the organism over its life span, which is the assimilated energy divided by the assimilation efficiency. Hindcasting of energy demand based on the observed biomass as preserved and an estimate of sedimentation rate shows that energy demand by the community exceeds the supply from plantkonic rain in seep communities, a crucial verification of the adequacy of the hindcasting model.

Bathymodiolus sp., *Lucinoma atlantis*, and *Thyasira oleophila* shells were radiocarbon dated from the seep sites at GC 234, GC 184, and GB 425, respectively. A calibration curve of amino acid dating was used to increase the number of lucinids and thyasirids that could be aged. Piston cores from the "Mussel Beach" area of GC 234 recovered two buried mussel beds. The first bed, centered at about 95 centimeters depth, contained shells estimated to be between 2000 and 3000 years old. Mussels from the deeper bed, at about 195 centimeters, were estimated to be between 3000 and 4000 years old. Thus, the two mussel beds were approximately 1000 years apart in age. Both of these beds contained individuals in life position, and some of the mussels still had byssal thread attachments, indicating the importance of catastrophic burial in the preservation of mussel beds. The lucinids from GC 184, at 68 centimeters depth, were calculated to be over 3500 years old, while the GB 425 thyasirids at 40 centimeters depth were 500 to 1000 years old. The lucinids from a depth of 10 centimeters at GC 272 were found to be modern in age, and no deeper individuals were encountered.

Change in community composition rarely occurred over the length of the cores (about 200 centimeters) taken from the mussel, lucinid, and thyasirid beds. Even at GC 234, an alternative seep fauna did not occupy the site between the times of mussel bed burial. In the other cases (thyasirid and lucinid biofacies), sites were occupied more or less continuously, but with varying infaunal densities. Thus individual seep communities are unique, persistent and resilient over long time scales. A transition from non-seep to seep biofacies was never evident in any of the cores; accordingly the ages previously mentioned represent minimal ages of the seep sites studied.

Finally, a computer program was designed to reconstruct the original abundance and size-frequency distribution from a collection of bivalve fragments. The need for this shell reconstruction program comes from the fact that many seep bivalves are obtained in fragmented condition due to taphonomic processes (processes which alter the fossil record). A primary attribute of the program design was the use of simple readily measured characters (shell length, width, thickness, weight) allowing rapid analysis of shell fragments. The program was tested using a mussel, two lucinids, and an arc shell. In each case, the whole shells were measured and then broken into a minimum of three to four pieces, and then re measured. Numerical abundance was slightly overestimated and size-frequency skewed slightly towards smaller size classes. In terms of paleoproduction and paleoingestion, these errors proved of little consequence. Accordingly, this modeling approach shows promise as a way to reconstruct the original size-frequency and abundance of shells from their fragments permitting their use in this type of paleoecological analysis.

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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 **Royalty Management Program** 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.