Cah. Biol. Mar. (2002) 43 : 231-234

Cold seep research: resource management applications

Thomas E. AHLFELD
United States Department of the Interior
Minerals Management Service - Environmental Sciences Branch
381 Elden Street - Herndon, Virginia, USA 20170
E-mail: thomas.ahlfeld@mms.gov

Introduction

Since the 1984 discovery of chemosynthetic communities associated with cold seeps in the northern Gulf of Mexico (Paull et al., 1984 ; Kennicutt, et al., 1985), the Minerals Management Service (MMS), an agency of the U.S. Department of the Interior, has sponsored several multidisciplinary research projects designed to detect, locate, and describe these unusual communities. Chemosynthetic communities have been defined as persistent, largely sessile assemblages of marine organisms dependent upon chemosynthetic bacteria as their primary food source (U.S. Department of the Interior, 1992).

At depths greater than 400 m in the northern Gulf of Mexico, below the influence of sunlight and photosynthesis, cold seeps provide a source of reduced compounds, predominantly methane and hydrogen sulphide, for chemosynthetic microorganisms living symbiotically with invertebrate hosts. Various adaptations have been identified among invertebrate hosts but the chemosynthetic bacteria generally live in specialized cells within the host. Hosts supply symbiotic bacteria with oxygen and reduced compounds often through specialized blood chemistry (Arp et al., 1984, 1987). The energy released through this microbial oxidation process is the principal mechanism for production of carbohydrates, proteins and other organic compounds (MacDonald, 2000). The major groups of invertebrates comprising the Gulf of Mexico chemosynthetic communities include vestimentiferan tubeworms, mytilid mussels, vesicomyid and lucinid clams, polychaete “ice worms” (*Hesiocaeca methanicola* Desbruyères & Toulmond, 1998) living in burrows on gas hydrates, and the free-living autotrophic bacteria *Beggiatoa* spp. found in orange or white mat-like colonies (MacDonald, 2000). A variety of heterotrophic fauna frequently found in association with Gulf of Mexico oil and gas seep sites include tunicates, squid, fishes (*Hoplostethus* sp., *Chaunax pictus* Lowe, 1846, *Urophycis cirratus* Goode & Bean, 1896, *Peristedion greyae* Kanazawa, 1952), decapod crabs, shrimp, and the isopod *Bathynomus giganteus* Milne-Edwards, 1879 (MacDonald, 1989). The bivalve *Acesta bullisi* (Vokes, 1970) has been observed attached to the end of *Lamellibrachia* sp. tubes (Boland, 1986). Other epifauna including hydroids, sponges, and nerite gastropods have also been found living on tubeworms and seep mussels (MacDonald, 2000).

Chemosynthetic communities appear to be widely distributed in association with major hydrocarbon fields at depths below 400 m in the northern Gulf of Mexico. Confirmed direct observations of 43 chemosynthetic communities in the northern Gulf were compiled by MacDonald et al. (1996). It should be noted, however, that these submersible and photo-survey observations are biased to water depths of less than 1000 m due to depth limitations of available submersibles and cost considerations (MacDonald, 2000).

The MMS is responsible for permitting and regulating oil and natural gas activities in the U.S. offshore waters within its Exclusive Economic Zone. An element of the MMS mission is “to manage the mineral resources of the Outer Continental Shelf (OCS) in an environmentally sound and safe manner”. To assure that offshore development occurs under these guidelines, MMS inspects all offshore facilities, reviews plans of exploration and development, performs environmental analyses, and funds environmental and engineering research related to OCS mineral development. Results of deepwater environmental studies in the Gulf of Mexico have been used by MMS in Environmental Impact Statements (EIS) to describe the environment potentially affected by offshore oil and gas leasing, exploration, and development activities and to assess the possible environmental consequences of those activities. These results have also been used by MMS to develop protective measures designed to prevent potential impacts or to minimize and mitigate unavoidable impacts to high-density assemblages of benthic organisms in areas of natural hydrocarbon seepage.

Material and methods

The MMS has sponsored three major research projects on chemosynthetic communities and gas hydrates in the Gulf of Mexico. The *Chemosynthetic Ecosystems Study* produced a Final Literature Review and Data Synthesis Report in 1992 and a Final Technical Report in 1995. The final report for the four-year study *Stability and Change in Gulf of Mexico Chemosynthetic Communities* was completed during 2002. This study was designed to address the five major objectives listed below:

1. Review biotic and abiotic features of available conceptual models of chemosynthetic communities that explain the observed patterns of distribution and abundance;
2. 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. Investigate the sources (e.g. deep versus shallow, petrogenic versus biogenic) of any necessary dissolved gasses and the likelihood that petroleum production may ultimately deprive the animals of an energy source;
4. Determine whether chemosynthetic communities are robust or fragile and whether they are essentially permanent or ephemeral (characterize the age, growth rate, turnover rates, reproduction and recruitment, and patterns of senescence and death in the dominant chemosynthetic animals); and
5. Determine the reliability of methods for detecting chemosynthetic communities using remote acoustic and/or geophysical devices, imaging instrumentation, hydrocarbon measurements, and other available technologies.

The MMS initiated a study during 2000 entitled *Improving the Predictive Capability of 3D Seismic Surface Amplitude Data for Identifying Chemosynthetic Community Sites* and a final report is due in December 2002. The results of these studies together with other available information represent the materials and methods applied to resource management decision-making in areas with chemosynthetic communities. The most recent results obtained by MMS with the completion of the project *Stability and Change in Gulf of Mexico Chemosynthetic Communities*, are the focus of the following results section.

Results

The *Stability and Change in Gulf of Mexico Chemosynthetic Communities* study was an extensive program of field collections from over fifty sampling stations in the northern Gulf of Mexico and laboratory analyses conducted by a team of sixteen principal investigators representing a broad range of marine science disciplines. The results of this research as discussed below significantly contribute to the body of information applied by MMS to decisions concerning deepwater oil and gas development activities and their potential impacts to chemosynthetic communities.

1. Chemosynthetic fauna associated with cold seeps are taxonomically and functionally similar to those of hydrothermal vents, but inhabit a fundamentally distinct ecosystem (MacDonald, 2002). Hydrothermal vents, found mostly along the mid-ocean ridges, are characterized by high temperatures (up to 400°C) and waters with high concentrations of hydrogen sulfide that are forcibly discharged through the seafloor. The cold seeps discovered in the Gulf of Mexico have been found associated with the generally slow release of brine or hydrocarbons into surrounding sediments. Although cold brine seeps have been found at depths to 3,200 m, most chemosynthetic communities associated with hydrocarbon seeps have been found in depths between 400 m and 1000 m.

2. Currents at relevant depths in the northern Gulf of Mexico are of a magnitude capable of dispersing chemosynthetic faunal larvae across the entire upper continental slope. A current meter mooring was deployed at one study site and bottom thermistors were placed at two other study sites. Higher current speeds were positively correlated with more rapid temperature changes indicating that bottom water temperature variations were sufficient to provide benthic organisms at the study sites with cues of strong current events (MacDonald, 2002).

3. The upper depth limit for Gulf of Mexico chemosynthetic communities is between 400 m and 500 m, corresponding to the isotherm above which sustained exposures to temperatures >10° C will occur (MacDonald, 2002). The two principal physical factors controlling the distribution of chemosynthetic communities are temperature and water circulation patterns dispersing larvae as discussed above. The temperature tolerances of dominant tube worms and seep mussels are narrow. Live seep mussels (*Bathymodiolus childressi* Gustafson et al., 1998) have been collected and laboratory observations showed that exposure to temperatures greater than 10° C caused hosts to expel symbionts (Fisher, 1990).

4. Remote sensing surveys can narrow and refine search patterns for chemosynthetic communities, but do not provide certainty of their presence or absence. In this study a side-scan sonar mosaic was compiled and extensively ground-truthed through Geographical Information System (GIS) techniques and submersible surveys. Reprocessing of available multi-channel data sets provided additional geophysical characterizations that further narrowed the search patterns. The investigators also discussed the application of satellite remote sensing in determining the distributions of natural oil seeps. It was concluded that direct observations from submersible, ROV, or camera sleds were required to determine whether chemosynthetic organisms inhabited a given area (MacDonald, 2002).

5. Larval recruitment from external locations could recolonize chemosynthetic community sites that had suffered a loss of population. DNA fingerprinting of seep mussels and tubeworms demonstrated that genetic exchange among study sites is adequate to sustain species integrity across the sites (MacDonald, 2002).

6. Gas hydrates are more important to seep community ecology than anticipated. Hydrates appear to be an intermediate source for dissolved gasses necessary to seep communities and a new species of polychaete, *Hesiocaeca methanicola* (Desbruyères & Toulmond, 1998), was discovered living in burrows on shallow hydrate deposits (Fisher et al., 2000) (Fig. 1). As a byproduct of the microbial metabolism of hydrocarbons at seep sites, a consortium of

Figure 1. Polychaete "iceworms", *Hesiocaeca methanicola*, living in burrows on gas hydrate (Photo by Ian MacDonald, Texas A&M University).

microorganisms produces H_2S through the reduction of SO_4 in seawater. Dominant seep community tubeworms (*Lamellibrachia* sp. and an Escarpid species) possess posterior tube extensions, or "roots", which serve as the primary site for sulphide uptake from the sediments through much of their life. The vascularized red anterior plume is more important to sulphide uptake earlier in the life of tubeworms. The tubeworms accumulate sulphide for oxidation by symbiotic chemoautotrophic bacteria. Seep mussels (*B. childressi*) host methanotrophic symbionts in their gill linings, but cannot bind methane. Consequently, these mussels occur only in areas with active hydrocarbon seepage (MacDonald, 2002).

7. In contrast to rapid tubeworm growth at hydrothermal vents, cold seep tubeworms grow very slowly. It is estimated that worms two meters in length are from 170 to 250 years old (Bergquist et al., 2000). A large cluster of tubeworms indicates an area where hydrocarbons have seeped continuously for several hundred years.

Significant production of an oil field does not appear to affect the health of chemosynthetic communities. Ten years of observations have shown that the densely populated, tubeworm-dominated "Bush Hill" community (Fig. 2) continues to flourish in an active oil field (Green Canyon Block 184) where 28 million barrels of oil and 120 trillion cubic feet of natural gas have been produced since 1989.

Figure 2. Tubeworms and mussels at densely populated "Bush Hill" chemosynthetic community in the Gulf of Mexico (Photo by Charles Fisher, Pennsylvania State University).

Discussion

One mechanism used by MMS to provide guidelines to offshore oil and gas operators regarding implementation of a special lease stipulation or regional requirement is the Notice to Lessees and Operators (NTL). There are currently two NTL's used in the Gulf of Mexico that provide protection for chemosynthetic communities. The purpose of the *Deepwater Chemosynthetic Communities* NTL (No. 2000-G20) is to provide a consistent and comprehensive approach to protecting high-density chemosynthetic communities from damage caused by oil and gas activities. This NTL requires that activities disturbing the seafloor in water depths of 400 m or greater maintain a separation distance of at least 457 m from features or areas that could support high-density chemosynthetic communities for each proposed drilling muds and cuttings discharge location. The best scientific information available at the time of NTL development indicated that surface discharge of drilling effluents would not affect bottom communities located 457 m and beyond the discharge location. This distance of separation is subject to modification based on consideration of new scientific information. A minimum separation distance of 76 m is required for all other proposed seafloor disturbances, including anchors, anchor chains, wire ropes, seafloor template installations, and pipeline construction. A state-of-the-art differential global positioning system is required on anchor-handling vessels to ensure that physical bottom disturbances do not occur within 76 m of identified chemosynthetic communities. If the offshore oil and gas industry proposes exploration or development activities that could disturb seafloor areas in water depths of 400 m or greater, this NTL requires the submission of environmental information specifically directed to chemosynthetic community identification and delineation. Maps prepared using high-resolution seismic information depicting bathymetry and seafloor and shallow geological features are required. Features such as hydrocarbon-charged sediments and acoustic void zones associated with surface faulting, mounds or knolls, and gas or oil seeps that potentially could support high-density chemosynthetic communities must be depicted on the maps. If the MMS analysis of submitted information determines that features or areas that could support high-density chemosynthetic communities are present and could potentially be harmed by proposed activities, additional requirements placed on the offshore industry would include the following:

1. Amendment of the OCS plan or pipeline application to relocate the proposed activities to avoid impacting possible high-density chemosynthetic communities;
2. Amendment of the OCS plan or pipeline application to provide additional information (including a photo-survey, a video-survey, or already available information) that documents whether high-density chemosynthetic communities exist in the areas of concern; or
3. Adherence to certain conditions of the OCS plan or pipeline application approval such as using a remotely

operated vehicle to set anchors precisely or taking other measures to ensure that the proposed anchor pattern does not impact high-density chemosynthetic communities. Other requirements include monitoring impacts caused by the proposed activities and adhering to any other condition deemed necessary by the MMS.

The *Remotely Operated Vehicle (ROV) Surveys in Deepwater* NTL (No. 2001-G04) requires the acquisition of biological and physical information from ROV surveys before and after certain oil and gas exploration and development activities in the deepwater Gulf of Mexico (water depths >400 m). This NTL provides protection to chemosynthetic communities as well as hardbottom and outcrop deepwater benthic communities that may be observed through the ROV surveys.

An ROV survey plan is required as an integral part of each offshore oil and gas Exploration Plan that proposes activities in water depths >400 m in the central and western Gulf of Mexico. An ROV survey plan is also required with the first Development Operations Coordination Document proposing a surface structure in each of 17 defined grid areas of ecological similarity. ROV surveys will be conducted in each grid to investigate the possible occurrence of high-density biological communities on the seafloor (Fig. 3). In the face of increasing development of deepwater oil and natural gas resources in the Gulf of Mexico, the MMS has carefully designed research projects to provide information needed for environmentally sound resource management. The MMS has applied new research results with the existing body of information to frame protective measures for the continued health of cold seep chemosynthetic communities in the Gulf of Mexico.

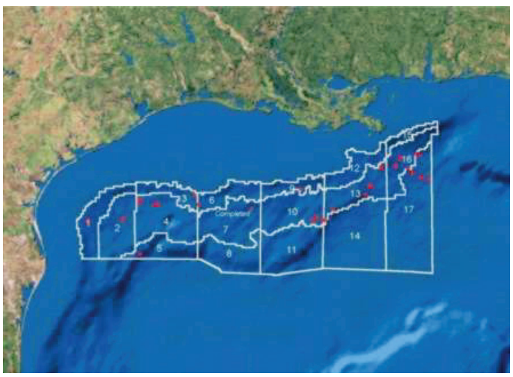

Figure 3. Grid Map for ROV Surveys showing 17 established grid areas in the Central and Western Planning Areas of the Gulf of Mexico. Red points indicate lease blocks with ROV survey requests issued (one survey in Grid 7 has been completed as indicated). Bathymetry is shown at 400 m, 1000 m and 2000 m.

Acknowledgements

I would like to thank Robert Avent and Greg Boland of the MMS Gulf of Mexico Region who provided ideas and information for this paper. Ian MacDonald, Texas A&M University and Chuck Fisher, Pennsylvania State University, provided encouragement to prepare this management oriented paper as well as insights from their extensive experience in sampling and analysing samples and data from Gulf of Mexico cold seep chemosynthetic community sites. The manuscript also benefited from review comments provided by Jim Kendall and Jim Cimato of the MMS Environmental Sciences Branch and Kay Briggs of the MMS Environmental Assessment Branch.

References

Arp A.J., Childress J.J. & Fisher C.R. 1984. Metabolic and blood gas transport characteristics of the hydrothermal vent bivalve *Calyptogena magnifica*. *Physiological Zoology*, **57**: 648-662.

Arp A.J., Childress J.J. & Vetter R.D. 1987. The sulfide-binding protein in the blood of the vestimentiferan tube-worm, *Riftia pachyptila*, is the extracellular haemoglobin. *Journal of Experimental Biology*, **128**: 139-158.

Bergquist D.C., Williams F.M. & Fisher C.R. **2000**. Longevity record for deep-sea invertebrate. *Nature,* **403**: 499-500.

Boland G.S. 1986. Discovery of co-occurring bivalve *Acesta* sp. and chemosynthetic tube worms *Lamellebrachia. Nature*, **323**:759

Desbruyères D. & Toulmond A. 1998. A new species of hesionid worm, *Hesiocaeca methanicola* sp. nov (Polychaeta: Hesionidae), living in ice-like methane hydrates in the deep Gulf of Mexico. *Cahiers de Biologie Marine,* **39**: 93-98.

Fisher C.R. 1990. Chemoautotrophic and methanotrophic symbioses in marine invertebrates. *Reviews in Aquatic Sciences*, **2**: 399-436.

Fisher C. R., MacDonald I.R., Sassen R., Young C. M., Macko S., Hourdez S., Carney R., Joy S. & McMullin E. 2000. Methane ice worms: *Hesiocaeca methanicola* colonizing fossil fuel reserves. *Naturwissenschaften*, **87** : 184-187.

Kennicutt M.C., Brooks J.M., Bidigare R.R., Fay R.R., Wade T.L. & McDonald T.J. 1985. Vent-type taxa in a hydrocarbon seep region on the Louisiana slope. *Nature,* **317**: 351-353.

MacDonald I.R. 2000. Chapter 8: Seep Communities in: *Deepwater Gulf of Mexico environmental and socioeconomic data search and literature synthesis. Volume I: Narrative report,* pp. 209-230. MMS Report OCS Study MMS 2000-049.

MacDonald I.R. ed. 2002. *Stability and change in Gulf of Mexico chemosynthetic communities*. **II**: Technical report. Prepared by the Geochemical and Environmental Research Group, Texas A&M University. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico Region, New Orleans, LA. OCS Study MMS 2002-36: 438 pp.

MacDonald I.R., Reilly J.F., Best S.E., Venkataramaiah R., Sassen R., Amos J., & Guinasso N.L. 1996. A remote-sensing inventory of active oil seeps and chemosynthetic communities in the northern Gulf of Mexico in: *Hydrocarbon migration and its near-surface expression - American Association of Petroleum Geology Reports* (D. Schumacher and M.A. Abrams, eds.) pp. 27-37.

Paull C.K., Hecker B., Commeau R., Freeman-Lynde R.P., Neumann C., Corso W.P., Golubic S., Hook J.E., Sikes E. & Curray J. 1984. Biological communities at the Florida Escarpment resemble hydrothermal vent taxa. *Science*, **226**: 965-967.

U.S. Dept. of the Interior, Minerals Management Service. 1992. *Chemosynthetic ecosystems study literature review and data synthesis*, **1**: Executive summary. Prepared by Geochemical and Environmental Research Group (I.R. MacDonald ed). U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 32 pp.