

**STUDY TITLE:** Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico

**REPORT TITLE:** Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico, Volume I: Final Report and Volume II: Appendix

CONTRACT NUMBER: M05PC00018

SPONSORING OCS REGION: Gulf of Mexico

APPLICABLE PLANNING AREAS: Central and Western

FISCAL YEARS OF PROJECT FUNDING: 2005; 2006; 2007; 2008, 2009

COMPLETION DATE OF REPORT: July 2014

COSTS: FY 2005 - \$842,977; FY2006 - \$798,028; FY2007 - \$625,367; FY2008 - \$443,147; FY2009 - \$649,716. TOTAL \$3,359,235.

PROJECT MANAGER: James M. Brooks, Ph.D.

AFFILIATION: TDI-Brooks International Inc

ADDRESS: 1902 Pinon Dr, College Station, TX 77845

PRINCIPAL INVESTIGATORS: Brooks, J. M.<sup>1</sup>, C. Fisher<sup>2</sup>, H. Roberts<sup>3</sup>, B. Bernard<sup>1</sup>, I. McDonald<sup>4</sup>, R. Carney<sup>3</sup>, S. Joye<sup>5</sup>, E. Cordes<sup>7</sup>, G. Wolff<sup>1</sup>, M. Bright<sup>8</sup>, P. Girguis<sup>6</sup>, L. Gehring<sup>2</sup> (<sup>1</sup>TDI-Brooks International Inc, <sup>2</sup> The Pennsylvania State University, <sup>3</sup> Louisiana State University, <sup>4</sup> Florida State University, <sup>5</sup> The University of Georgia, <sup>6</sup> Harvard University, <sup>7</sup> Temple University, <sup>8</sup> University of Vienna Austria)

**KEY WORDS:** Gulf of Mexico, chemosynthetic communities, habitat, AUV, ROV, submersible, biology, photography, tubeworms, mussels, bacterial mats, heart urchins, education, population dynamics, food web, life histories, biodiversity and biogeography

**BACKGROUND:** The largest oil reserves in the continental United States are found in the Gulf of Mexico. BOEM is responsible for overseeing the responsible extraction of these natural resources. By the early 1980s, energy companies had developed the technology to explore and extract oil and gas in waters up to 1,000 m deep and have continued to develop the technology to extract oil and gas from deeper water. They now have the capability to drill oil wells in all water depths in the GoM Outer Continental Slope.

During the mid to late 1980s, the Minerals Management Service (now Bureau of Ocean Energy Management) contracted with the Geochemical and Environmental Research Group (GERG) at Texas A&M University (TAMU) to collect animals from areas of the deep sea floor associated with active oil and gas seeps. Bush Hill, a site that became one of the best-studied seep sites in the world, was populated with giant tubeworms and

mussels, which had only recently been discovered at deep-sea hydrothermal vents in the Pacific Ocean. Since that time, similar (but different) cold-seep and hydrothermal-vent communities have been discovered in many different geological settings in the world's oceans.

Over the last 20 years, these animals and communities have been studied at moderate depths in the Gulf of Mexico (GoM), along with the geology, geochemistry, and microbiology that allows them to flourish. The hydrocarbon seep communities in water depths less than 1,000 m on the Upper Louisiana Slope of the Gulf of Mexico are the most intensively studied and most understood of any deep-sea cold-seep communities in the world. The basic biology of the dominant animals, their life histories, and the biodiversity and biogeography of the seep and coral communities on the Upper Louisiana Slope is now understood. The successional processes that lead to the eventual development of coral communities on carbonates created during periods of active hydrocarbon seepage is understood. Also discovered are new communities, such as the ice worms that inhabit methane ice and the mussels that ring the Brine Pool NR-1.

Although several GoM hydrocarbon seep sites at depths greater than 1,000 m have been visited by scientists, only a single site has been the focus of more than a few exploratory dives. This site, at 2,200 m in Alaminos Canyon, has lush communities of tubeworms and mussels that are reminiscent of more well-known shallower sites. However, the underlying geology and almost all of the species present at Alaminos Canyon are different. Preliminary studies indicate that the structure of the communities associated with the tubeworms and mussels is also quite different. The normal "background" fauna are different at this depth, and different patterns of interaction between these animals and the seep-specific animals are expected.

**OBJECTIVES:** The primary purpose of this research was to discover and characterize the sea floor communities that live in association with hydrocarbon seepage and on hard ground in the deep Gulf of Mexico. The sites studied were in areas energy companies will drill for oil and gas. Advances in understanding and knowledge of the ecology of this deep community and the types of communities that exist at depths greater than 1,000 m are the goals of this contract.

**DESCRIPTION:** Preparation for this program began in the fall of 2005, when Harry Roberts began to study a variety of types of information that would help discover new hydrocarbon seep and hard-ground communities in the deep Gulf of Mexico. Information from thousands of cores was collected by the TDI-Brooks International, Inc. group, along with satellite images of persistent oil slicks on the surface of the Gulf, extensive collections of geophysical data, and maps of the sea floor that were made available for this project by the Mineral Management Service. Fourteen sites with a high potential to host lush chemosynthetic and/or deep-water coral communities were identified.

The Reconnaissance Cruise (RC) was conducted on the TDI-Brooks research vessel R/V Gyre from 11 to 25 March 2006 and was the initial cruise conducted for this contract. The cruise was completed in two week-long legs with an interim port call in

Venice, LA. Leg I (11-18 March) was dedicated to drift camera work to survey the seabed at selected sites. Leg II (19-25 March) involved both drift camera and trawling/box core work efforts. Thousands of pictures of the sea floor were taken at locations identified by Roberts and his team. Some sites revealed little except a muddy sea floor. At most of the sites there was strong evidence of seepage, and at least scattered occurrence of bacterial mats or the types of animals expected at seep sites. In one case there were abundant soft corals, and at a few, there were large communities of seep animals.

Based on the Reconnaissance Cruise Report, the images of the sea floor, previous knowledge of the geophysics and geochemistry of the sites, and a desire to explore over a wide depth and geographic range, the cruise and dives on the Deep Chemosynthetic Community Characterization Cruise (DCCC) were planned. The DCCC was conducted on the Wood's Hole Oceanographic Institute (WHOI) research vessel R/V *Atlantis* and the *Alvin* Deep Submergence Vehicle (DSV) from 7 May – 2 June 2006.

From June 4 - July 6, 2007, TDI-Brooks' project team conducted a month-long ROV cruise at deep-water seep and hardground sites in the Lower Continental Slope of the Gulf of Mexico. The project utilized the NOAA ship the R/V *Ron Brown* and the *Jason-II* ROV from Woods Hole Oceanographic Institute (WHOI). Data were collected by the geologists, geochemists, microbiologists, physiologists, and ecologists in the scientific party.

#### **SIGNIFICANT CONCLUSIONS:**

- Site characterization and evaluation was completed on 24 sites.
- Multiple dives and process-oriented studies were conducted at four key sites and the geology, geochemistry, microbiology and biology of the sites thoroughly characterized.
- Longer-term studies were established at these sites to determine growth rates of some of the animals, monitor for visitation by mobile deep-sea fauna such as larger fishes and crabs, and follow the fine-scale changes in seepage patterns and community composition.
- A camera dedicated to taking down-looking pictures was used to construct mosaics of several new animal communities discovered and markers deployed so these can be revisited in the future.
- Push cores were collected for geological, geochemical, and microbial analyses and for the study of the meiofauna (tiny animals) that live between the sand grains at the deep-seep sites.
- A chemical analyzer was used to characterize seep habitats.
- Communities with full mosaics were revisited and chemical analyzers used to characterize the chemistry in and around individual animals identified in the images.
- Quantitative collections of other tubeworm communities, mussel beds, and clam beds were made using specialized collection tools built specifically for this task and the communities associated with each type of megafauna were characterized.

- Traps, cameras, and trawls were used to capture and identify the visitors to the seep and coral communities being studied to aid in characterizing the more mobile fauna around the sites.
- More than 14,000 down-camera and 400 macro images were recorded.
- Acoustic Doppler Current Profilers (ADCP) were operated on station and with the ship underway to obtain an integrated picture of current direction and velocity in the upper 1,000 m of the water column.
- 107 new species including 24 undescribed species that do not fit into any described genera have been confirmed; these include 18 new genera and 77 new species of copepod, one new genera and 17 new species of ostracod, four new species of tanaidacea, three new species of halacarids, and more than five new genera of nematodes
- A new type of seep community, dense aggregations of heart urchins, *Sarsiaster griegii*, in highly reduced sediments at several of the deeper sites was discovered and studied (greater than 2,200 m).
- Sites AT340, GC852, WR269, and AC601 were mapped in great detail using the C&C Technologies Autonomous Underwater Vehicle (AUV) in February 2007. The AUV was equipped with instrumentation for collecting high-resolution multibeam bathymetry, chirp sonar sub bottom profiles, and side-scan sonar swaths. These data are well constrained with excellent navigation and the data sets are acquired as the AUV travels at a constant height, 40 m, above the seabed. The data sets were used during the 2007 cruise and seep faunal community occurrences correlated with the features identified by the AUV data.

**STUDY PRODUCTS:** Becker, E., R. Lee, S. Macko, B. Faure, C. Fisher. Stable carbon and nitrogen isotope compositions of hydrocarbon-seep bivalves on the Gulf of Mexico lower continental slope, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1957-1964, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.002.

Becker, E. L., S. A. Macko, R. W. Lee and C. R. Fisher. 2011. Stable isotopes provide new insights into vestimentiferan physiological ecology at Gulf of Mexico cold seeps. *Naturwissenschaften*. 98: 169-174.

Becker, E. L., E. E. Cordes, S. A. Macko, R. W. Lee, and C. R. Fisher. Trophic interactions in mussel, vestimentiferan, and clam communities at Gulf of Mexico lower-slope cold seeps. In Revision for *Mar. Ecol. Prog. Ser.* 11/12.

Bright, M., C. Plum, L.A. Riavitz, N. Nikolov, P. Arbizu, E. Cordes, S. Gollner. Epizooic metazoan meiobenthos associated with tubeworm and mussel aggregations from cold seeps of the northern Gulf of Mexico, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1982-1989, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.003.

Brooks, J.M., C. Fisher, H. Roberts, B. Bernard, I. McDonald, R. Carney, S. Joye, E. Cordes, G. Wolff, E. Goehring. 2014. Investigations of chemosynthetic communities on the lower continental slope of the Gulf of Mexico: Volume I: Final report and Volume II:

Appendix. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2014-0650, 560 pp. and BOEM 2014-0651, 442 pp.

Carney, R. Stable isotope trophic patterns in echinoderm megafauna in close proximity to and remote from Gulf of Mexico lower slope hydrocarbon seeps, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1965-1971, ISSN 0967-0645, 10.1016/j.dsr2.2010.09.027.

Cordes, E., S. Carney, S. Hourdez, R. Carney, J. Brooks, C. Fisher. 2007. Cold seeps of the deep Gulf of Mexico: Community structure and biogeographic comparisons to Atlantic equatorial belt seep communities. *Deep-Sea Research I* 54 (2007) 637–653.

Cordes, E., E. Becker, S. Hourdez, C. Fisher. Influence of foundation species, depth, and location on diversity and community composition at Gulf of Mexico lower-slope cold seeps, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1870-1881, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.010.

Demopoulos, A. D. Gualtieri, K. Kovacs. Food-web structure of seep sediment macrobenthos from the Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1972-1981, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.011.

Feng, D., H. Roberts. Initial results of comparing cold-seep carbonates from mussel- and tubeworm-associated environments at Atwater Valley lease block 340, northern Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 2030-2039, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.004.

Feng, D., H. Roberts, H. Cheng, J. Peckmann, G. Bohrmann, R. Edwards, D. Chen. U/Th dating of cold-seep carbonates: An initial comparison, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 2055-2060, ISSN 0967-0645, 10.1016/j.dsr2.2010.09.004.

Fisher, C., H. Roberts, E. Cordes and B. Bernard, 2007. Cold Seeps and Associated Communities of the Gulf of Mexico. *Oceanography Vol 20 Num 4*, pp 68-79.

Garcia-Pineda, O., I. MacDonald, B. Zimmer, B. Shedd, H. Roberts. Remote-sensing evaluation of geophysical anomaly sites in the outer continental slope, northern Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1859-1869, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.005.

Joye, S., M. Bowles, V. Samarkin, K. Hunter, H. Niemann. Biogeochemical signatures and microbial activity of different cold-seep habitats along the Gulf of Mexico deep slope, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues

21–23, November 2010, Pages 1990-2001, ISSN 0967-0645, 10.1016/j.dsr2.2010.06.001.

Kellogg, C. Enumeration of viruses and prokaryotes in deep-sea sediments and cold seeps of the Gulf of Mexico, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 2002-2007, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.006.

Lessard-Pilon, S., M. Porter, E. Cordes, I. MacDonald, C. Fisher. Community composition and temporal change at deep Gulf of Mexico cold seeps, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1891-1903, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.012.

MacDonald, I., M. Smith, F.W. Huffer. Community structure comparisons of lower slope hydrocarbon seeps, northern Gulf of Mexico, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1904-1915, ISSN 0967-0645, 10.1016/j.dsr2.2010.09.002.

Miglietta, M. P., S. Hourdez, D. Cowart, S. Schaeffer, C. Fisher. Species boundaries of Gulf of Mexico vestimentiferans (Polychaeta, Siboglinidae) inferred from mitochondrial genes, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1916-1925, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.007.

McMullin, E. R., K. Nelson, C. R. Fisher and S. W. Schaeffer. 2010. Population structure of two deep sea tubeworms, *Lamellibrachia luymesii* and *Seepiophila jonesi*, from the hydrocarbon seeps of the Gulf of Mexico. Deep Sea Research I. 57: 1499-1509.

Olu, K., E. E. Cordes, C. R. Fisher, J. M. Brooks, M. Sibuet, and D. Desbruyeres. 2010. Biogeography and potential exchange among Atlantic Equatorial Belt cold-seep faunas. PLoS One 5(8): e11967.doi:10.1371/journal.pone.0011967.

Orcutt, B., S. Joye, S. Kleindienst, K. Knittel, A. Ramette, A. Reitz, V. Samarkin, T. Treude, A. Boetius. Impact of natural oil and higher hydrocarbons on microbial diversity, distribution, and activity in Gulf of Mexico cold-seep sediments, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 2008-2021, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.014.

Roberts, H., R. Carney, M. Kupchik, C. Fisher, K. Nelson, E. Becker, L. Goehring, S. Lessard-Pilon, G. Telesnicki, B. Bernard, J. Brooks, M. Bright, E. Cordes, S. Hourdez, J. Hunt Jr., W. Shedd, G. Boland, S. Joye, V. Samarkin, M. Bernier, M. Bowles, I. MacDonald, H. Niemann, C. Petersen, C. Morrison, J. Potter. 2007. Alvin Explores the Deep Northern Gulf of Mexico Slope. EOS Vol 88 (35), 28 August 2007, pp 341–348.

Roberts, H., G. Boland. Preface, Deep Sea Research Part II: Topical Studies in Oceanography, Volume 57, Issues 21–23, November 2010, Pages 1835-1836, ISSN

0967-0645,10.1016/j.dsr2.2010.05.001.

(<http://www.sciencedirect.com/science/article/pii/S0967064510001657>).

Roberts, H., D. Feng, S. Joye. Cold-seep carbonates of the middle and lower continental slope, northern Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 2040-2054, ISSN 0967-0645, 10.1016/j.dsr2.2010.09.003.

Roberts, H., W. Shedd, J. Hunt Jr. Dive site geology: DSV ALVIN (2006) and ROV JASON II (2007) dives to the middle-lower continental slope, northern Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1837-1858, ISSN 0967-0645, 10.1016/j.dsr2.2010.09.001.

Ross, S., A. Quattrini, A. Roa-Varón, J. McClain. Species composition and distributions of mesopelagic fishes over the slope of the north-central Gulf of Mexico, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 1926-1956, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.008.

TDI-Brooks International Inc. 2006. Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico. Reconnaissance Cruise Report for the U.S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region, Metairie, LA. Contract No. 1435-01-05-39187. 58 pp.

TDI-Brooks International Inc. 2006. Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico. Deep Chemosynthetic Community Characterization Cruise Report for the U.S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region, Metairie, LA. Contract No. 1435-01-05-39187. 225 pp.

TDI-Brooks International Inc. 2007. Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico. An interim report for the U.S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region, Metairie, LA. Contract No. 1435-01-05-39187. 338 pp.

TDI-Brooks International Inc. 2007. Investigations of Chemosynthetic Communities on the Lower Continental Slope of the Gulf of Mexico. Deep Chemosynthetic Reconnaissance II (DCR2) Post-Cruise Report for the U.S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Region, Metairie, LA. Contract No. 1435-01-05-39187. 317 pp.

Thiel, V., M. Hügler, M. Blümel, H. I. Baumann, A. Gärtner, R. Schmaljohann, H. Strauss, D. Garbe-Schönberg, Sven Petersen, D. A. Cowart, C. R. Fisher, and J. F. Imhoff. Widespread occurrence of two carbon fixation pathways in tubeworm endosymbionts: lessons from hydrothermal vent associated tubeworms from the Mediterranean Sea. Accepted for publication; *Frontiers in Microbiology*, 11/12.

Wankel, S., S. Joye, V. Samarkin, S. Shah, G. Friederich, J. Melas-Kyriazi, P. Girguis.

New constraints on methane fluxes and rates of anaerobic methane oxidation in a Gulf of Mexico brine pool via in situ mass spectrometry, *Deep Sea Research Part II: Topical Studies in Oceanography*, Volume 57, Issues 21–23, November 2010, Pages 2022–2029, ISSN 0967-0645, 10.1016/j.dsr2.2010.05.009.



\*P.I.'s affiliation may be different from that listed for Project Managers.