HYROCARBON SEEP COMMUNITIES: FOUR YEARS OF STUDY

By Mahlon C. Kennicutt II, James M. Brooks and Robert R. Bidigare

The enhanced productivity and biomass of these communities was directly linked to symbiotic relationships between bacteria and invertebrates.

A trawl retrieval of nearly two tons of organisms and shell debris in 500m of water at a location of known natural petroleum seepage in the Gulf of Mexico in 1984 marked the beginning of four years of interdisciplinary studies (Kennicutt *et al.*, 1985). It was soon recognized that the assemblage of organisms recovered was similar to that reported at the hydrothermal vents and the Florida Escarpment (Corliss and Ballard, 1977; Paull *et al.*, 1984). These and other discoveries have now become referred to as the contrasting ecological niches of "hot vent" and "cold seep" communities. Hot vent areas are characterized by elevated temperatures caused by the recirculation of seawater through zones heated by magmatic intrusions. No temperature anomalies are apparent at the cold seep sites, but they have in common with hot seeps a supply of reduced compounds that creates a tenuous balance between oxic and anoxic conditions (Paull *et al.*, 1984; Cavanaugh, 1985). Early studies at both types of sites revealed that the enhanced productivity and biomass of these communities was directly linked to symbiotic relationships between bacteria and invertebrates. The Gulf of Mexico petroleum seep sites are in relatively shallow water, which allows for extensive and repeated samplings as well as maintenance of living organisms at shore-based laboratories. The Louisiana seep organisms require water temperatures of 5-7°C and a supply of reduced compounds and dissolved oxygen for their survival in the laboratory.

An integrated approach of enzymatic and isotopic analysis of organisms' tissue has been especially useful in understanding the dynamics of chemosynthetic-based communities (Kennicutt *et al.*, 1985; Childress *et al.*, 1986; Brooks *et al.*, 1987). Initial results showed that clam and tubeworm tissues were isotopically "light," with $\delta^{13}C$ values indicative of sulfide-utilizing endosymbionts. The seep tubeworms were enriched in ^{12}C, compared to the hydrothermal vent tubeworms. This difference is as yet unexplained, although CO_2 limitation has been invoked as a cause for ^{13}C enrichment (Rau, 1981). Further sampling recovered a species of mussel that was enriched in ^{12}C, and its $\delta^{13}C$ values(-40 to -55‰) approached those of the Florida Escarpment mussel (Paull *et al.*, 1984, 1985). While the use of methane by endosymbionts had been suggested for organisms collected at the Florida and Oregon sites, no supporting biochemical studies were available. Extensive enzymatic, electron microscopic and $^{14}CH_4$-uptake studies have demonstrated the occurrence of a methane-based endosymbiotic relationship between a bacterium and a molluscan (Childress *et al.*, 1986; Brooks *et al.*, 1987). Follow-up laboratory studies suggest that the symbiosis may potentially satisfy the mussels' carbon needs solely from methane oxidation (Childress *et al.*, 1986; Carey *et al.*, 1988). Physiological and biochemical findings for the sites include: a direct correlation between oxygen tension and carbon fixation in isolated vestimentiferan symbionts; a demonstration of carbon transfer, its time course, and the mechanism of carbon transfer within a mussel; demonstrated shell growth with methane as the sole carbon source; the possible presence of multiple symbionts in a single host (CH_4 and H_2S); and a preliminary study of genetic relatedness between populations of mussels at seep sites.

The composition and spatial distribution of seep faunal assemblages are much more complex than previously realized. Mussel density significantly correlates with water methane levels, and tubeworm cover correlates with sediment petroleum loading. At least five basic assemblages have been recognized, including mussel beds, tubeworm clumps, clam beds, epifaunal brachipod-solitary coral assemblages, and gorgonian fields. These assemblages overlap spatially and have some shared dependence on chemosynthetic processes. The recent retrieval of sulfide-based, endosymbiont-containing bivalves on the northern California slope suggests that hydrocarbon seep communities may be widespread in the major offshore petroleum provinces of the world. A chemical environment very similar to that of the Louisiana site (including the presence of gas seepage and hydrates) was documented for this California upper slope site (water depth 420 - 600m). Such reports confirm that the deep-sea chemical environ-

Mahlon C. Kennicutt II, James M. Brooks and Robert R. Bidigare, *Texas A&M University, Geochemical and Environmental Research Group, Texas A&M University, 10 S. Graham Rd., College Station, TX 77840.*

Figure 1. Mussels, tubeworms, and background fauna are often closely associated with hard substrate derived from the oxidation of gas and oil.

Figure 2. Dense clusters of mussel, several individuals deep, are closely huddled around natural gas seeps. This supply of natural gas is an essential nutrient for the organisms.

The ecological significance of chemosynthetic processes in the deep ocean needs to be resolved and quantified through further interdisciplinary studies.

ment is an important factor controlling the distributions of these communities, and that the mechanisms that maintain the oxic-anoxic conditions can be highly variable. The processes are now thought to occur quite frequently in the world's oceans. The ecological significance of chemosynthetic processes in the deep ocean needs to be resolved and quantified through further interdisciplinary studies. The common biological components (clams, mussels, tubeworms) at these sites raise significant questions as to the interrelatedness of seep and vent organisms. The evolutionary relationship between these communities is still an open question. The results of initial studies, summarized here, have advanced our understanding of the complex interactions among chemical, biological and geological processes in these unique environments.

References

Brooks, J.M., M.C. Kennicutt II, C.R. Fisher, S.A. Macko, K. Cole, J.J. Childress, R.R. Bidigare and R.D. Vetter, 1987: Deep-sea hydrocarbon seep communities: evidence for energy and nutritional carbon sources. *Science 238*, 1138-1142.

Cary, S.G., C.R. Fisher and H. Felbeck, 1988: Mussel growth supported by methane as a sole carbon and energy source. *Science 240*, 78-80.

Cavanaugh, C.M., 1985: Symbioses of chemoautotrophic bacteria and marine invertebrates from hydrothermal vents and reducing sediments. In: The Hydrothermal Vents of the Eastern Pacific: An Overview (ed. M.L. Jones). *Bull. Biol. Soc. Wash. 6*, 373-388.

Childress, J.J., C.R. Fisher, J.M. Brooks, M.C. Kennicutt II, R.R. Bidigare and A. Anderson, 1986: A methanotrophic marine molluscan (*Bivalvia Mytilidae*) symbioses: mussels fueled by gas. *Science 233*, 1306-1308.

Corliss, J.B. and R.D. Ballard, 1977: Oases of life in the cold abyss. *National Geographic 152*, 441-453.

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

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

Rau, G.H., 1981: Hydrothermal vent clam and tubeworm $^{13}C/^{12}C$: further evidence of non-photosynthetic food sources. *Science 213*,338-340.

Suess, E., B. Carson, S. Rilger, J.C. Moore, M.L. Jones, L.D. Kulm and G.R. Cochrabe, 1985: Biological communities at vent sites along the subduction zone off Oregon. *Bull. Biol. Soc. Wash. 6*, 475-484.