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Biology and Chemistry of a Deep-Sea Hydrothermal Vent on the Galapagos Rift; the Rose Garden in 1985

by

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Biology and chemistry of a deep-sea hydrothermal vent on the Galapagos Rift; the Rose Garden in 1985. Introduction

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DISCOVERY of deep-sea hydrothermal vents and the associated biological communities on the Galapagos Rift in 1977 (CORLISS *et al.*, 1979) profoundly and permanently changed our view of the deep sea. In addition to the typical, sparsely populated, vast deep-sea habitats, we learned that there were small "oases" around the vents where the density of animal life was extremely high. While the vent communities were initially viewed as isolated, rare phenomena, ensuing geological expeditions have found them to be associated with virtually all areas of tectonic activity throughout the deep sea. This includes subduction zones, fracture zones and back-arc basins as well as the rifts themselves. In addition, similar communities have been found around hydrocarbon and other seeps. We now view such communities as widespread in the deep sea, although it is clear that while the major taxa of sessile animals are usually similar between distant sites, the species and relative abundances of different taxa often are different.

The food source for these populations was initially a mystery (LONSDALE, 1977), but shortly after the first biological expeditions to the Galapagos Rift hydrothermal vents in 1979, a variety of evidence pointed to a primarily non-photosynthetic source for the organic carbon in the vent organisms. Initially this was attributed to fixation by free-living chemolithoautotrophic bacteria, but in early 1980, it was realized that the major sessile animal species had sulfur-oxidizing chemoautotrophic bacteria as endosymbionts (CAVANAUGH *et al.*, 1981; FELBECK, 1981). The discovery of this type of symbiosis in hydrothermal vent animals was quickly followed by many discoveries of similar symbioses in animals living in other reducing habitats (FELDBECK *et al.*, 1981; CAVANAUGH, 1985). In all of the symbiont-bearing hydrothermal vent species studied to date, reduced sulfur compounds (HS^- and $\text{S}_2\text{O}_3^{2-}$) are the energy source for the symbiotic bacteria. However, methanotrophic symbionts have been documented in three species from other habitats (CHILDRESS *et al.*, 1986; CAVANAUGH *et al.*, 1987; SCHMALJOHAN and FLÜGEL, 1987).

The unique environment of the hydrothermal vents and the chemolithoautotrophic symbioses of some species have proven an exciting area for physiological and biochemical studies. These studies have revealed that the symbiont-containing species have high autotrophic potentials and are elaborately adapted to provide sulfide as well as oxygen to their symbionts. Given the complex nature of the symbionts' requirements, it was clear that these organisms must require rather specific environments. It also seemed likely that the dense populations observed would have significant effects on the chemistry of

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the water issuing through their aggregations. Another facet of the vent communities that quickly became apparent was that even in a small area, such as the part of the Galapagos Rift explored in 1977 and 1979, there were considerable differences in the relative abundances of the fauna at different vent sites (DESBRUYÈRES *et al.*, 1982; HESSLER and SMITHEY, 1985; FUSTEC *et al.*, 1987). The observed range included "dead" sites having only clam and mussel shells, sites with many shells and a few live mussels and dandelions, sites dominated by mussels and or clams, and sites dominated by vestimentiferan tubeworms. The early conviction was that these differences were probably the result of differences in vent flow or water chemistry. The areas of dead shells also suggested the relatively short-lived, transient nature of these habitats.

The Galapagos "85" Hydrothermal Vent Biology Program was created with the conviction that understanding these habitats required a coordinated description of the distribution of the vent species in relation to the water chemistry around them and their physiological ecology, all within the context of changes over time. The major coordinated components of this program consisted of large- and small-scale photographic mapping, description of the water chemistry around the animals with *in situ* and conventional methods, measurement of short time interval temperature fluctuations around the animals, estimation of growth rates of the clams, and collection of animals from known locations and water chemistries for extensive physiological and biochemical studies. In addition there was a substantial effort to study the physiology and biochemistry of the symbiont-containing species, in the belief that a thorough understanding of the symbioses is essential to an understanding of the vent communities. This program worked at the Rose Garden site on the Galapagos Rift during March 1985 using the submersible *Alvin* (dives 1513–1531). The major results of the field program are published together with this volume, while other results have been published separately.

The Rose Garden site was chosen for this study for a variety of reasons. It was discovered on 14 February 1979 by G. Ellis, T. van Andel and R. Holcomb on *Alvin* dive 889. It was featured in the National Geographic television production "Dive to the Edge of Creation" which was shot in January and February of 1979. This site was further studied in 1979 by geochemists in March and by biologists in November and December. Thus the Rose Garden site was almost certainly the best described vent site in the world. In 1979 this site was dominated by giant vestimentiferan tubeworms (*Riftia pachyptila*), with vent mussels (*Bathymodiolus thermophilus*) and vent clams (*Calyptogena magnifica*) apparently present in lesser numbers and at sizes well below their species maxima. [Pictures of Rose Garden in 1979 can be found in ANONYMOUS (1979) and RONA *et al.* (1983)]. This differed from other sites observed in 1979 on the Galapagos Rift where the tubeworms were minor components of the fauna, with large mussels and clams dominating. In addition, water chemistry observations from 1977 and 1979 indicated that temperatures and sulfide levels were generally higher and ferrous iron lower at Rose Garden. These various observations led to the belief that Rose Garden might be a younger site than the others. However, even in December 1979, I observed a dense stand of dead tubes (probably southwest of the main clump) with no apparent vent flow, indicating the dependence of these animals on the venting fluids, and that flow had already changed in part of the vent field.

From the first *Alvin* dive in March 1985, it was apparent that the biology of the Rose Garden site had changed dramatically since November 1979. The tubeworms were greatly reduced in numbers and extent of coverage, while the clams and mussels

appeared to be larger individually and more abundant. However, the water chemistry at Rose Garden appeared to be essentially the same as in 1979, so this was not the cause of the shift. The studies carried out in 1985 and presented here clearly indicate that the distribution of the mussels, clams and tubeworms is dependent upon the presence of sulfide-containing vent water. However, these species have different microhabitat requirements. The tubeworms appear to be restricted to areas of relatively high water flow, temperature and sulfide. In contrast, the clams appear restricted to areas of low flow and lower temperature where their feet can be inserted into sulfide-bearing water in cracks, obsidian gravel or under mussel piles. The mussels live over a much wider range of conditions, including attaching to vestimentiferan tubes at one extreme, to living in small groups at the periphery of the vent field. The mussels' nutritional status appears comparable over most of the range where they are found, perhaps due to an ability to filter-feed as well as to support from the symbiosis. In addition the mussels are quite mobile, often making their way onto pieces of apparatus deployed on the bottom within a few hours; this presumably optimizes their exploitation of even small vent discharges.

The *in situ* analytical system demonstrated the consumption of sulfide and oxygen by aggregations of each of the three major sessile species (JOHNSON *et al.*, 1986) and indicated that these consumptions were separated in time or space. The rapid temperature fluctuations observed around the mussels and tubeworms indicate incomplete mixing of vent and ambient water around these species and provides the possibility of temporal separation for oxygen and sulfide uptake.

The intensive studies of the three major sessile species suggest that *Riftia pachyptila* is the most autotrophically active. The growth data for *Calymene magnifica* indicate a relatively rapid growth rate and suggest that the largest individuals of this species settled at the Rose Garden site in the early 1970s. This coincides with the observation of seismic activity at this site in 1972 (MACDONALD and MUDIE, 1974).

The papers presented here lead to the following view of the evolution of the Rose Garden community. Hydrothermal venting probably started at this site in the early 1970s. While tubeworms, mussels and clams probably settled quickly, the much greater autotrophic potential of the tubeworms led to their rapid growth in size and domination of the site before 1979. After 1979, as the mussels began to reach their maximum sizes, they packed tightly around the worms, altering the flow patterns of vent water so that much of it was diverted away from the plumes of the tubeworms. The active mussels also attached to the tubes of the worms and may have physically interfered with the growth of smaller *R. pachyptila*. The decline in the tubeworm population clearly was not due to changes in water chemistry, although changes in flow may be a contributing factor. The clams also grew towards their maximum sizes and became much more apparent after 1979, although because of their habitat requirements they seldom came in contact with the tubeworms.

We can conclude that all three major sessile species are dependent on vent flow, but the tubeworms require higher levels of flow than the other species. At high flow rates the tubeworms will quickly dominate a site, but if the flow remains stable, mussels, as they mature, will largely displace the tubeworms. If vent flows decline gradually, one would expect to see mussels and clams persist much longer than tubeworms.

This is being written at the conclusion of the Galapagos "88" Hydrothermal Vent Biology Expedition, which visited not only Rose Garden but also Musselbed (last visited

in 1979). The more extensive studies of these sites in April 1988 do not appear to contradict in any major way the conclusions of this issue.

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REFERENCES

- ANONYMOUS (1979) Strange World without sun. *National Geographic*, **156**, 680–688.
- 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. Bulletin of the Biological Society of Washington*, Vol. 6, M. L. JONES, editor, pp. 373–388.
- CAVANAUGH C. M., S. L. GARDINER, M. L. JONES, H. W. JANNASCH and J. B. WATERBURY (1981) Prokaryotic cells in the hydrothermal vent tube worm *Riftia pachyptila* Jones: possible chemoautotrophic symbionts. *Science*, **213**, 340–342.
- CAVANAUGH C. M., P. R. LEVERING, J. S. MAKI, R. MITCHELL and M. E. LIDSTROM (1987) Symbiosis of methylotrophic bacteria and deep-sea mussels. *Nature*, **325**, 346–348.
- CHILDRESS J. J., C. R. FISHER, J. M. BROOKS, M. C. KENNICUTT, II, R. BIDIGARE and A. E. ANDERSON (1986) A methanotrophic marine molluscan (Bivalvia, Mytilidae) symbiosis: Mussels fueled by gas. *Science*, **233**, 1306–1308.
- CORLISS, J. B., J. DYMOND, L. I. GORDON, J. M. EDMOND, R. P. VON HERZEN, R. D. BALLARD, K. GREEN, D. WILLIAMS, A. BAINBRIDGE, K. CRANE and T. H. VAN ANDEL (1979) Submarine thermal springs on the Galapagos Rift. *Science*, **203**, 1073–1083.
- DESBRUYÈRES D., P. CRASSOUS, J. GRASSLE, A. KHIPOUNOFF, D. REYSS, M. RIO and M. VAN PRAET (1982) Données écologiques sur un nouveau site d'hydrothermalisme actif de la ride du Pacifique oriental. *Comptes Rendus de l'Académie des Sciences, Paris, Série III*, **295**, 489–494.
- FELBECK H. (1981) Chemoautotrophic potential of the hydrothermal vent tube worm. *Riftia pachyptila* Jones (Vestimentifera). *Science*, **213**, 336–338.
- FELDBECK H., J. J. CHILDRESS and G. N. SOMERO (1981) Calvin–Benson cycle and sulfide oxidation enzymes in animals from sulfide-rich habitats. *Nature*, **293**, 291–293.
- FUSTEC A., D. DESBRUYÈRES and S. K. JUNIPER (1987) Deep-sea hydrothermal vent communities at 13°N on the East Pacific Rise: Microdistribution and temporal variations. *Biological Oceanography*, **4**, 121–164.
- HESSLER R. R. and W. M. SMITHEY (1985) The distribution and community structure of megafauna at the Galápagos Rift hydrothermal vents. In: *Hydrothermal processes at seafloor spreading centers*, P. A. RONA, K. BOSTROM, L. LAUBIER and K. L. SMITH Jr, editors, Plenum Press, New York, pp. 735–770.
- JOHNSON K. S., C. L. BEEHLER, C. M. SAKAMOTO-ARNOLD and J. J. CHILDRESS (1986) *In situ* measurements of chemical distributions in a deep-sea hydrothermal vent field. *Science*, **231**, 1139–1141.
- LONSDALE P. (1977) Clustering of suspension-feeding macrobenthos near abyssal hydrothermal vents at oceanic spreading centers. *Deep-Sea Research*, **24**, 857–863.
- MACDONALD K. C. and J. D. MUDIE (1974) Microearthquakes on the Galápagos spreading centre and the seismicity of fast-spreading ridges. *Geophysical Journal of the Royal Astronomical Society*, **36**, 245–257.
- RONA P., K. BOSTROM, L. LAUBIER and K. L. SMITH Jr, editors (1983) *Hydrothermal processes at seafloor spreading centers*. Plenum Press, New York, 796 pp.
- SCHMALJOHAN R. and H. J. FLÜGEL (1987) Methane oxidizing bacteria in pogonophora. *Sarsia*, **72**, 91–98.