HYDROTHERMAL VENTS: more than just a lot of hot water!

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Abstract: The biological problems faced by organisms inhabiting hydrothermal vents can lead to lively discussions in introductory biology. Current research investigations and controversies centered on this unusual habitat are described for those wishing to consider incorporating this topic into their classes or learning more about phenomena first discovered in 1977.

Key Words: hydrothermal vents, introductory biology, habitats, electron transport chain, island biogeography, origin of life.

A few years back, when I had first thought (with some prodding) to write this article, I could safely say to my introductory biology students that hydrothermal vents were an especially exciting topic because they had first been discovered so recently to be within the student’s own lifetime. This year, I realized that this approach could no longer work because the majority of my incoming freshman class had a birth year of 1978! This makes them no less exciting, however, and they are still a very active, viable research environment in fields such as biology, chemistry, and geology. Each year, numerous scientific papers, reviews and general articles illustrate new findings about the biology of hydrothermal vent organisms, including descriptions of novel species with each new vent site explored.

What is a hydrothermal vent? Vents occur on the deep sea where continental plates are spreading apart (rift zones and spreading centers) or pushing together. Ambient seawater seeps downward through cracks on the ocean floor, is superheated and transformed by its contact with magma, and is then expelled, sometimes seeping and sometimes with great force, in hydrothermal vent fields. Hydrothermal vents were first discovered in 1977 off the Galapagos Islands by a team of geologists (Cone, 1992). They had been hoping to find temperature anomalies on the ocean floor in areas of continental plate contact; if so, this evidence would lend further support to plate tectonic theory. What was not expected, however, was the dense assemblage of initially bizarre animals that they encountered in regions of higher temperatures. The 1977 expedition paved the way for subsequent biological expeditions to the original site and to dozens of other sites throughout the world’s oceans.

You may well ask, “why would she be talking with her introductory biology students (in Missouri) about hydrothermal vents in the first place?” There are, I counter, many ways to use the exciting discoveries from hydrothermal vents to illustrate various points in biology. Comparisons with photosynthesis and the C4 carbon fixation pathways, and the effects of hydrogen sulphide on the functioning of the electron transport chain are the most obvious ones. Hydrothermal vents and the organisms that dwell there also provide interesting examples of island biogeography, evolution, symbiosis, surviving in “toxic” environments, and the ideas of origin of life on earth. In short, virtually any topic of interest to a biology major can be linked to hydrothermal vents!

When discussing the environment surrounding hydrothermal vent organisms, it is tempting to use terms such as “harsh” and “toxic.” In fact, the first thing one must remember is that something that may seem toxic to a human (e.g., micro-molar concentrations of hydrogen sulphide, low partial pressures of oxygen and rapidly fluctuating temperatures) is absolutely essential to the survival of another animal, e.g., a hydrothermal vent tubeworm with bacterial endosymbionts that are sulphide dependent. Humans can detect the odor of hydrogen sulphide at concentrations less than 0.01 µmol L⁻¹ and find the odor offensive at concentrations as low as 0.15 µmol L⁻¹. Despite external sulphide concentrations commonly as high as 300 µmol L⁻¹, vent animals including the tubeworms, clams and crabs have oxygen consumption rates comparable to similar species inhabiting non vent deep sea environments.

These questions, and many more, have been addressed by ecological physiologists from around the world, including the work of Jim Childress, Charles Fisher, Horst Felbeck and George Somero and their colleagues.

One way to teach students about the electron transport chain and oxidative phosphorylation is to discuss what might happen if various components of these systems were removed or disabled. Hydrogen sulphide, in addition to being a potent inhibitor of various enzymes and respiratory proteins, binds to the cytochrome c oxidase complex and thereby interferes with the production of ATP. This presents a dilemma
How do these organisms balance the uptake of oxygen and hydrogen sulphide (not known for maintaining their independence when mixed!), both of which are needed by the aerobic endosymbionts? How do animals which have sulphide requiring symbionts keep the sulphide from poisoning their own systems? How do animals without sulphide oxidizing endosymbionts, which still live as scavengers within the hydrothermal vent environment, detoxify the sulphide that they are unable to prevent from crossing their epidermis or respiratory surfaces?

for organisms such as the hydrothermal vent tube worm Riftia pachyptila. These tube worms harbor endosymbiotic chemolithoautotrophic (students are most impressed with this term) sulphide oxidizing bacteria that need hydrogen sulphide as an energy source. They are also obligate aerobes - they utilize oxygen as the terminal electron acceptor. Scientists first wondered if the cytochrome c oxidases in these organisms were somehow different than those of organisms not dwelling in high concentrations of hydrogen sulphide. This proved not to be the case; instead, in endosymbiont containing animals, hydrogen sulphide is bound by the haemoglobin (e.g., Riftia) or a separate binding factor (e.g., the vent clams) and transported efficiently to the endosymbionts.

Animals without symbionts, such as the vent crab Bythograea thermydron, also do not have cytochrome c oxidase systems that are resistant to sulphide poisoning. In these animals, it would not be desirable, however, to have a sulphide binding factor, because as haemoglobin does for oxygen, the binding factor serves to concentrate the substance it binds. The strategy used by these animals is to detoxify hydrogen sulphide to a less toxic form, e.g., thiosulphate, that can then be excreted. This allows the crabs to maintain aerobic respiration (the electron transport chain using oxygen as the terminal electron acceptor) even approaching μmol l⁻¹ concentrations of hydrogen sulphide. Truly remarkable!

Looking out the window of a submersible, and seeing dense assemblages of bizarre living creatures at depths of 2700 meters and beyond, is truly an awe inspiring experience. For geologist John Corliss, present in the submersible D.S.R.V. Alvin on the first dive to a hydrothermal vent site teeming with life, this proved to be a life changing moment. Corliss, along with colleagues John Baross and Sarah Hoffman, a short time later proposed new ideas on the origin of life on earth - where else, but at hydrothermal vents (Corliss, Baross, and Hoffman, 1981). The vent environment is ideal in many respects for the development of life according to some current scientific models for the origin of life on earth. Although there are some very hot hydrothermal sites, with chimneys blasting out water up to several hundred degrees Celsius, most of the vent fields are more habitable, a comfortable 10 - 30°C. The geological development of hydrothermal vent sites leads to many crevices, caves and overhanging ledges where the water is still and warm. Vent water is heavily laden with inorganic molecules. There is an energy source - hydrogen sulphide. Oceanic hydrothermal vents have been around a long time - as long as the seas and oceans have been in existence. Not that this idea of origin of life at hydrothermal vents is without controversy! Many authors have supported or countered the first publications on this topic. It makes an ideal example for students to examine how scientists go about defending their hypotheses when their ideas are criticized by other scientists with very different ideas.

Hydrothermal vents are interesting examples of island biogeography (MacArthur and Wilson, 1967). How isolated is a hydrothermal vent site? How do sessile organisms colonize new vent habitats? One can ask many questions concerning evolutionary biology in this context as well. Recent articles by Tunnicliffe (1991, 1992, 1996), Lutz (1997), Mullineaux (1995, 1996) and Hart (1997) address these topics in some detail. Each new major hydrothermal vent field explored by scientists yields new species, and sometimes genera, families, orders, classes, and some would argue, phyla, of organisms. These exotic residents have evolved in relative isolation in the depths of the ocean; each major vent field is generally isolated by tens of kilometers or more from their nearest neighbors. Hydrothermal vent sites are dominated by animals from the phyla Annelida, Mollusca and Arthropoda, which is very different from the faunal composition of the surrounding deep sea. The vast majority of hydrothermal vent organisms are endemic - currently about 95% of the species found at hydrothermal vents are known from no other habitat. Intriguing questions concerning larval transport, and colonization of new hydrothermal vent sites are actively pursued avenues of research.

Currently, just twenty years after scientists first viewed a hydrothermal vent site from a submersible port, new and exciting discoveries characterize research in hydrothermal vent biology and related fields. Although it is rare now to find a textbook that proclaims "all life on earth depends upon sunlight," this was the prevailing view just a few short years ago. Many introductory level textbooks now have a photo or two of vents organisms, but video (available commercially) filmed at deep sea hydrothermal vent sites amazes even the most complacent students. Our own, often narrow, perspective of life is challenged by organisms thriving under almost unimaginable conditions. Take a dive with your students!
My own experiences at the hydrothermal vents have certainly shaped my career as a scientist, and my ways of thinking about living things. On the evening prior to every submersible dive, scientists climb inside the submersible for a pre dive checkout. The excitement just at this stage is almost overwhelming for a first time diver. Climbing into the sub in the morning, the sensory stimuli of every kind during the launch phase, the final okay to dive, traveling through water with every shade of blue as you descend, and bioluminescence once the sunlight is no longer detectable to the human eye - these are no less exciting than the first glimpse of the bottom of the ocean. The hydrothermal vent sites were to me the capstone of my dive experiences, I think because there is more animal and bacterial life packed into small spaces than one could hardly imagine. As I sit in Northeast Missouri reflecting on my experiences of another place and time, I appreciate the privileged life I had as a graduate student which allowed me several trips to the bottom of the sea. In my classes I am able to inspire my students with "home movies" and personal stories of my experiences. My respect for life in all its forms has been deepened by these and other hands on adventures, and I share this with my students in whatever ways I can. Whatever our hands on experiences as biologists, our students are ultimately the recipients of our enthusiasm and knowledge. Perhaps one of my Truman students will go on to be part of the next generation of submersible divers!

References


Biology Review Articles:


