The Gold-footed Snail

by
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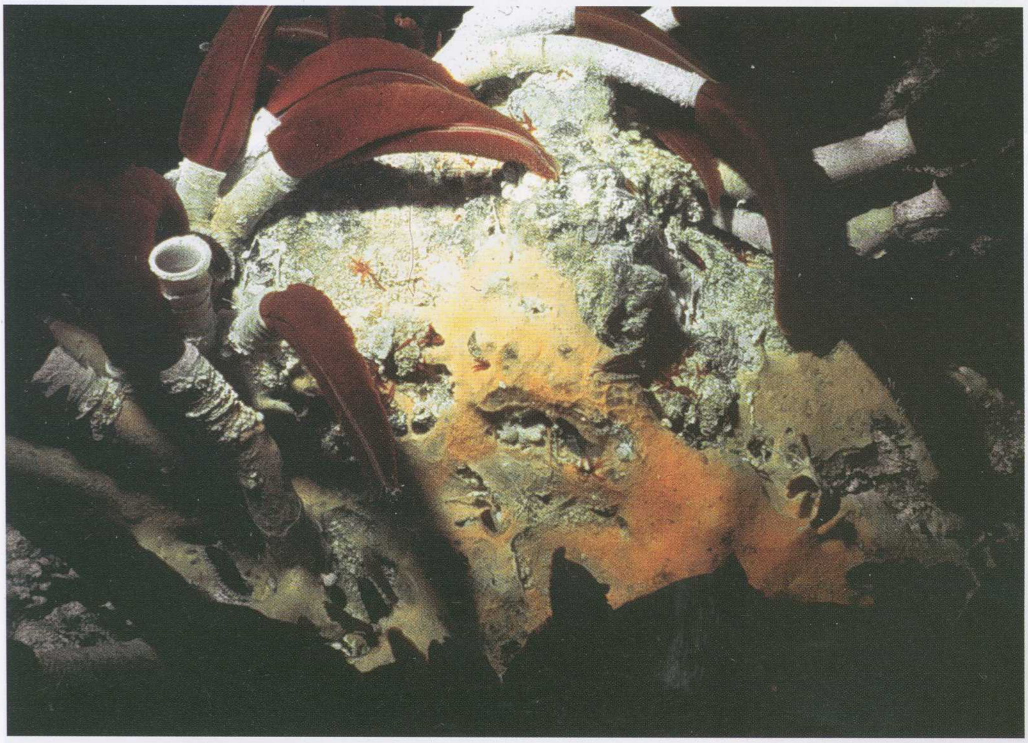
Few people, even among deep-sea scientists, find themselves blessed with an opportunity to visit the deep ocean floor beyond the continental shelf. I count myself lucky to be among the few who have witnessed this habitat first hand in a submersible. Most of our understanding of the deep sea, the seafloor beyond the continental shelf, does not come from submersible dives but rather from dropping or dragging sampling gear on or across the ocean bottom. Both submersible dives and the deployment of gear from research vessels require massive technological feats and major financial expenditures. A colleague of mine once compared deep-sea research to sampling forests from a hot air balloon. For myself, I find a useful analogy in the controlling of the Mars Rovers from Earth. Understanding and exploring an environment covered by thousands of meters of water continues to present a formidable challenge. Predictably, the deep sea remains the least explored environment on earth. Only a small fraction, estimated to be less than 5%, of the total deep-sea floor has been sampled or observed.

My first experience in a submersible occurred near the Bahamas in the Johnson *Sealink* operated by Harbor Branch Oceanographic Institute. As a young graduate student I was elated by the prospect of viewing my study habitat for the first time. This excitement was soon replaced with anxiety as I packed myself into the small titanium sphere of the submersible that houses the crew. Our dive was only to 700 meters, shallow when compared to dives in the *Alvin* that can be over 5 times this depth. Even for a dive this shallow it took approximately an hour to reach the bottom and an additional hour to resurface. At the bottom we spent barely an hour before rising again. Most of us would not consider making a trip in our cars where we spent more time in transit than at the actual destination (though I do remember an eight-hour road trip as an undergraduate in Arkansas to see a now non-existent band). Upon reaching the surface, we bobbed like a buoy for some time before being returned to the deck of the ship. All research subs, including the *Sealink*, are designed for submergence and not for prolonged periods at the surface. The roll and pitch of the submersible at the surface, even in light seas, is often enough to make even those with sea legs turn green.

Despite the obvious obstacles, deep-sea scientists are driven by unanswered scientific questions and the potential to find one of the improbable creatures that inhabit this dark expanse. Collecting or observing a new organism from the deep is highly problematic. This reflects the aforementioned constraints on deep-sea research, but in part also reflects the infancy of the field. It was only in the late 1960's that Robert Hessler and Howard Sanders called attention to the remarkably high species diversity found in the mud on the ocean floor. This vast environment has more species per square meter than any other habitat, including tropical rainforests. The consequence of these factors, combined with the relatively few deep-sea taxonomists, is the reason a majority of deep-sea species are undescribed or unknown to science. It is not shocking then that recent deep-sea samples from vents in the Indian Ocean would yield new species. The find described here, however, is remarkable in that the newly discovered gastropod possesses morphological features unlike any previously described by biologists.



A cluster of *Rifitia pachyptila* at the hydrothermal vent from the Guaymas Basin. Noticeable are the bright red plumes or branchial organs extending out of the chitinous tubes. Also pictured are several yellow bacterial mats. *Picture courtesy of Cindy Lee Van Dover.*

Hydrothermal vents were discovered in 1976 in deep waters near the Galapagos Islands. Lonsdale and colleagues found evidence of pockets of extremely warm water and giant bivalves, an astonishing breakthrough considering a majority of the seafloor deeper than 200m is extremely cold (less than 5°C) and dominated by taxa less than 5mm in size. These findings, and subsequent dives in the submersible *Alvin* in the following years by Corliss and others, revealed an entirely new habitat located 2.5km below the sea surface. Multiple hydrothermal vents were soon discovered in other areas on the seafloor with high tectonic activity. Almost 30 years and 2000 scientific articles later, vents are known from nearly every part of the sea floor where oceanic ridge spreading is identified to occur.

A swarm of amphipod crustaceans (white cloud) over small bed of vent bivalves (yellow) at the East Pacific Rise. *Picture courtesy of Cindy Lee Van Dover.*

Hydrothermal vents arise from ruptures in the newly created basalt along mid-oceanic ridges. These fractures allow the surrounding cold water to penetrate the crust (upwards of 2-3km thick) and mix with hot basalt. This mixture emerges through three distinct hot spring types on the seafloor. In some cases the liquid simply emerges through a crack or crevice at temperatures ranging from 5-250°C. In other areas, the vent liquid emerges though chimney structures formed from precipitated minerals that collect due to the surrounding low temperature and extreme pressures (1atm for 10 meters of water). These can be either black smokers (270-380°C) or white smokers in which the vent liquid escapes as a cloudy plume at slightly cooler temperatures.

The lack of light at these extreme depths precludes plant life. Deep-sea organisms, except those at specialized habitats such as vents, are completely reliant on a flux of organic matter that sinks from overhead surface waters. This flux has been estimated to be quite small; consequently most of the deep sea is characterized by both a low number of individuals and relatively low biomass when compared to other environments. The exceptions are hydrothermal vents (methane seeps as well, though not discussed here) and have led authors to refer to them as oases. The vent liquid provides a rich source of sulfur that chemoautotrophic bacteria can utilize as an energy source to change carbon dioxide and methane into a usable carbon sugar. This contrasts with plants that use light as an energy source to change carbon dioxide into usable sugars. Several vent species, ranging from bivalves to marine worms, have evolved symbiotic relationships with these chemoautotrophic bacteria.

The geological and chemical distinctiveness of hydrothermal vents is paired with a fauna that can be equally termed unique. One of these organisms, the tube-dwelling worm *Riftia pachyptila* Jones, 1981, lacks both a mouth and digestive track at the adult stage. Instead, *R. pachyptila* possesses a specialized organ, the trophosome that houses a symbiotic microbe (estimated at 285 billion bacteria per ounce of tissue). Extending out of their chitinous tubes is a bright red retractable plume. This is an organ of gas exchange between *R. pachyptila* and the surrounding water and allows for the acquisition of oxygen (for aerobic metabolism of the worm), hydrogen sulfide (as the energy source for the symbiotic bacteria), and carbon dioxide (the source of carbon for food). The anomalous morphology and anatomy are unlike most other marine worms and have caused some contention on the taxonomic placement of *R. pachyptila* and other vestimentiferan worms. Some consider the Vestimentifera a separate phylum and others place it as a class within the phylum Pogonophora, a group that includes other gutless marine worms.

Another 'worm' phylum is Annelida, the segmented worms, divided into the Oligochaeta (earthworms), Hirudinea (leaches), and Polychaeta (marine worms). Hotter vents typically possess the polychaete *Alvinella pompejana* Desbruyeres and Laubier, 1980 or 'Pompeii worm' discovered in the 1980's by French scientists. Unlike *R. pachyptila*, these worms possess guts and filter-feed on the free-living bacteria found in the water around hydrothermal vents. They usually grow over 10cm in length and reside in tubes that form a honeycomb structure around both vent openings and white smokers. Their proximity to the hot fluids of the vent makes them the most heat-tolerant organism on earth (near 55° Celsius or 131° Fahrenheit). In part this heat tolerance is due to a brilliant adaptation. Bacteria feed on mucus secreted by the back of the Pompeii worm and form strand-like colonies that provide insulation to the worm.

Inspired by multitudes of vent worms, scientists have given names such as 'Garden of Eden' and 'Rose Garden' to many hydrothermal vents. Other names, like 'Lucky Strike' and 'Broken Spur,' reflect the geological features at or near the vents. Dense aggregations of two common species of bivalves *Calyptogena magnifica* Boss and Turner, 1980 (Vesicomyidae) and *Bathymodiolus thermophilus* Kenk and Wilson, 1985 (Mytilidae) have inspired the names of 'Clam Acres,' 'Clam Bake,' and 'Mussel Bed.' These vent mussels and clams are the giants of deep-sea bivalves. I have personally worked with typical deep-sea bivalves in which an entire sample of individuals could fit on a dime. Both *C.*

Left: Ventral view of the 'Gold-footed Snail' newly discovered from Kairei vent field. Sclerites are visible and have a rusty color from storage in lab grade ethanol. Scales are normally black to dark gray in color. *Picture courtesy of Anders Warén.*

Below: Multiple views of the empty shell of the 'Gold-footed Snail.' Of note is the large aperture, the strong spiral cording, and the rounded axial ridges. *Picture courtesy of Anders Warén.*

magnifica and *B. thermophilus* also possess symbiotic bacteria that reside in their gills. Bacterial densities can reach such high numbers that over 75% of the gill tissue can be bacteria.

Hydrothermal vents possess a molluscan fauna that is both unique and fascinating. This fauna includes over 30 limpet species and several new described species of gastropods. One such newly discovered gastropod might be the most interesting find thus far at a hydrothermal vent. I admit my bias here, as most of my interest lies with studying deep-sea gastropods. Nonetheless, the discovery of 'gold-footed' snails at the Kairei vent field in the Indian Ocean is fascinating (*Science* 2003, v.302, pg. 1007). The Kairei vent field had been discovered by the Japanese a few months prior to its investigation by Cindy Lee Van Dover, a hydrothermal vent biologist. "We used *Jason* [a remote operated vehicle] and were funded to undertake a geological and ecological description of the site and to relate the Indian Ocean fauna to other vent faunas around the world," states Van Dover. When samples of another gastropod from near the base of the sulfide mounds where brought aboard the research vessel, several specimens of this new snail were in the same bin. "I was sure that such a snail was not previously known from any vent site. What I did not realize for a long time was that this [unique] morphology was unknown throughout all of the mollusca, fossil and modern." Recognizing it was something unique, Van Dover sent specimens to Anders Warén, a deep-sea gastropod specialist, for identification.

At this point I should note that the foot of the snail is mineralized with pyrite and greigite. (Many of you might note the misnomer here, as pyrite is only 'Fool's Gold,' but in deciding on a temporary common name for the article, 'Fool's Gold-footed Snail' seemed too long. I hope all will forgive the intentional misnomer for the sake of creative writing.) The scales or sclerites can be up to 8mm long and cover the length of the foot. Each sclerite possesses an inner core of pedal tissue that extends to just short of the tip. Between this inner pedal tissue and outer mineralized layer is conchiolin, the fibrous protein that creates the inner shell, embedded with iron sulfide granules. The presence of mineralized scales is remarkable in itself, but the existence of iron sulfide as a skeletal material is unknown from any other animal. The researchers report that the purity of the sulfides, among other lines of evidence, suggests this process is controlled by the gastropod itself. Based on mitochondrial DNA sequences, the 'Gold-Footed Snail' is currently placed in the order Neomphalina with other hydrothermal vent snails that possess a conchiolin operculum. It is believed that the sclerites in this newly discovered species evolved recently and are homologous to the operculum.

Undoubtedly, the forthcoming taxonomic description will further elucidate the uniqueness of the 'Gold-Footed Snail' (and, I hope, provide a better name). Despite the technological advances that have bolstered deep-sea research, we have as yet uncovered only a small portion of the mysteries likely to be found in the abyss. It is probable that further exploration of the deep will continue to yield new species that challenge our views, with respect not only to the limits of adaptation by organisms in extreme environments but also on life in general.

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