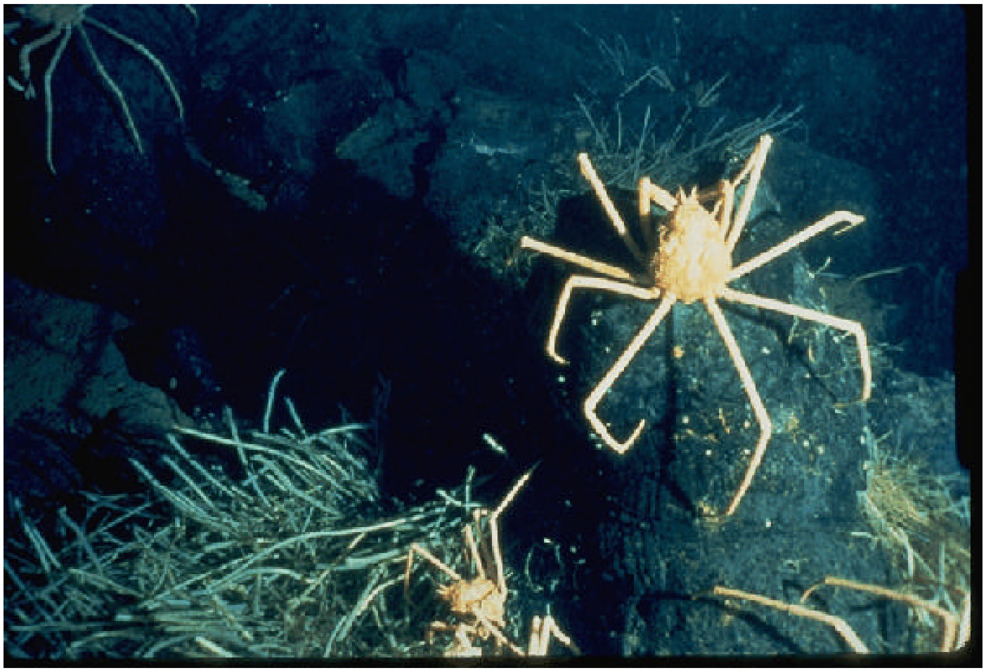


Ocean Biodiversity

Once considered a barren desert, the deep sea now reveals its richness. From the hydrothermal vents of the mid-ocean ridges to the cold seeps in the Gulf of Mexico, scientists are discovering unique life. Here, in total darkness fed by chemicals in the vent fluids, are virtually undescribed communities—perhaps the precursors of life on Earth. Called extremophiles for their ability to flourish in the world's most extreme environments, microbes and animals from the deep sea can be tapped for potential commercial and biomedical applications.

In this chapter of the report, explore with NURP researchers the unique chemistry and organisms of hydrothermal vents, cold seeps, and hot spots. Extreme environments are now the focus of scientific study because they're a novel source of chemicals to oceans and lakes, and a unique source of organisms totally isolated from all other strands of evolution.

Spider crabs around vent sites on Juan de Fuca Ridge.

Hot Vents

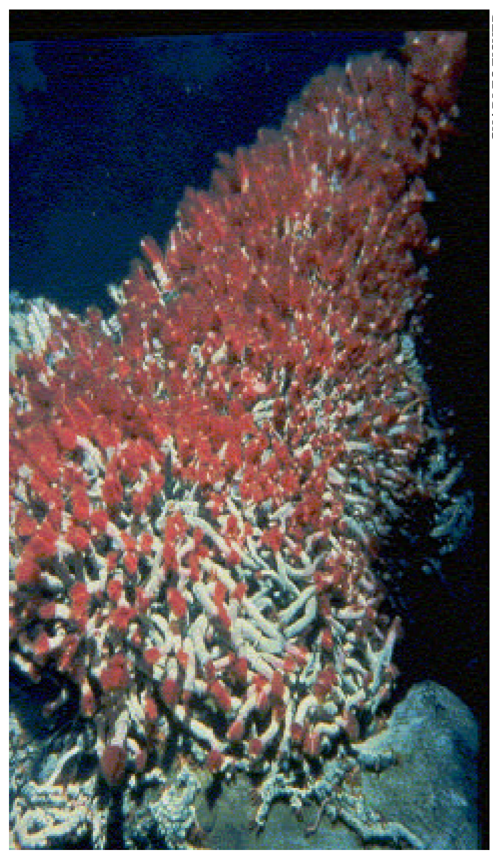
The existence of life in the ocean abyss was a recent discovery that revolutionized scientific theory in the 20th century. Likened to the “hideous sights of ugly death” by oceanographer Matthew Fontaine Maury a century ago, the deep ocean bottom was largely ignored. But in the past two decades, undersea technology has enabled marine scientists to explore the seafloor in detail previously impossible. Across the globe from the hydrothermal vents of the Mid-Atlantic Ridge to the hot springs of Yellowstone Lake, unique ecosystems are being discovered in aquatic environments previously considered barren. Here, in total darkness fed by chemicals in the vent fluids, live virtually undescribed communities—may be the precursors of life on Earth.

Undersea researchers only recently began to explore the single largest mountain range on Earth called the mid-ocean ridge, covering almost 23 percent of the planet’s surface, with cliff walls that rival the Grand Canyon. The ridge is a zone where the tectonic plates that form the Earth’s surface are spreading apart and magma from the Earth’s interior is rising to create new seafloor. As the plates shift, continents are being carried on a pliable upper layer of the Earth’s mantle, like boxes on a conveyer belt. Seawater percolates down the quake-fractured ocean crust closer to the molten magma in the Earth’s interior. The heated seawater becomes buoyant and rises through cracks to the surface as hydrothermal vents. The venting of submarine volcanoes creates black smokers, named for the sulphide and oxide mineral particles billowing upward above the chimneys created by the venting.

These vents are now the focus of scientific study by marine geophysicists, geochemists and biologists funded by NURP. Vents are a novel source of chemicals to the oceans and a unique source of organisms totally isolated from all other strands of evolution. “As well as forming mineral deposits, which are analogs of deposits mined on land and potential resources for the future,” said NURP researcher Peter Rona, a marine geophysicist with Rutgers University, “the global ridge system is a safety valve for the Earth as a whole in terms of releasing and trapping heat and chemicals to keep the balance of the planet.”

Hydrothermal vents were first discovered in 1977 on an expedition to the Galapagos Rift, which lies between the East Pacific Rise and the South American mainland. An expedition led by researchers at Oregon State University in the submersible *Alvin* carried two scientists and a pilot to the 2,500 m (8,000 ft) deep rift. The research team was looking for hot springs because their heat budget and chemical signals indicated that there should be warm water flowing out of the crust. In addition to finding the vents, the scientists found abundant animal communities. The most dominant creatures were giant tube worms, dinner plate-sized clams, and mussels in striking numbers. What puzzled the scientists was that these life forms existed, especially in such biomass, in the deep sea devoid of the light and the nutrients thought necessary for life.

Even more astonishing to biologists was that the giant tube worms they found lacked mouths and digestive systems. How could such a big organism exist in thickets without taking in food? What the researchers



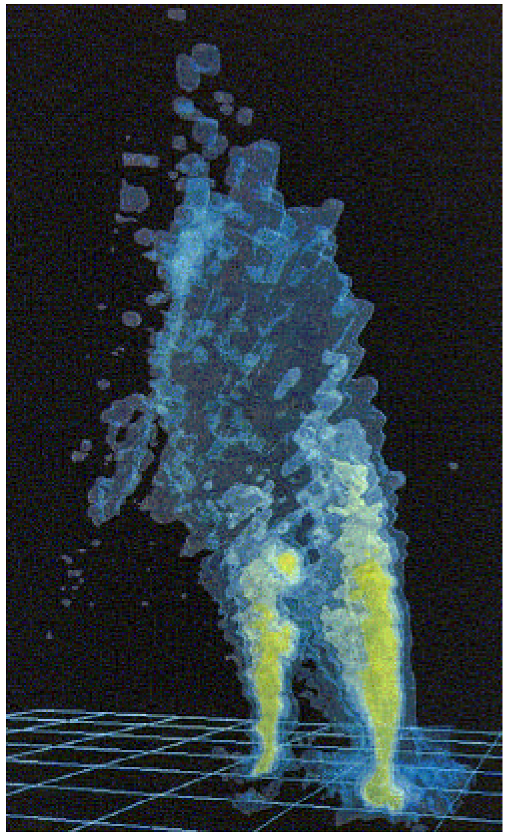
CHARLES FISHER

Tube worms feeding in foreground of black smoker, Juan de Fuca Ridge.

eventually found was that hydrothermal vent animals get their food from inorganic materials contained in the vent fluids and gases. In particular, hydrogen sulfide, a chemical that is toxic to most forms of life, is converted by sulfide-oxidizing bacteria living within the vent animals into organic matter that the animals can consume. Much like plants use light (photosynthesis) to convert water and carbon dioxide into sugar, vent animals use hydrogen sulfide in a process known as chemosynthesis.

In subsequent expeditions, researchers found chemosynthetic communities at ocean floor hot springs along the spreading centers of the world's plates. So many new fauna are being discovered that many new names and classifications for the animals have to be created. Despite the similarities among vent communities, there is also great biodiversity in the vent fauna around the globe. For example, no giant tube worms have been found in hydrothermal fields in the North Atlantic Ocean. This leads to the conclusion that some of these biological communities have evolved independently for perhaps millions of years. Another mystery is how hydrothermal organisms can survive through the generations. Vent fields and chimneys remain active for a finite period ranging from years to centuries, so for any one species to survive they must have the ability to migrate to another vent site. How this works is still a mystery because the mode of reproduction and the mechanism for the distribution of vent animals is unknown. Since the vent communities are stationary as adults, the species must produce planktonic larvae capable of migrating along the ridge axes to colonize new vent fields.

A recent NURP-funded study aims to determine how vent animals reproduce. Cindy Lee Van Dover, a biological oceanographer currently at the College of William and Mary, and Paul Tyler, a deep sea reproductive biologist at the Southampton Oceanography Center, collected and sampled hundreds of vent animals in 1995. Even at such depths, it has been proposed that vent animals reproduce in response to some lunar tidal cycle, the same phenomenon that bivalves respond to in shallow water. Van Dover, a former Alvin pilot, describes her voyages to hydrothermal vents in a book called *The Octopus's Garden*.


PETER RONA

A three-dimensional acoustic image of two hydrothermal plumes discharging from adjacent black smoker vents on the East Pacific rise.

The effects of hydrothermal activity on ocean chemistry go well beyond the immediate vicinity of vent sites. A three dimensional acoustic imaging system, mounted onto the Navy submersible *Turtle* on NURP-supported dives at 2,600 m (8,530 ft) on the East Pacific Rise, helped Rona capture just how far the plumes of two black smoker vents traveled in the water column. The image, obtained using sonar, showed the plume of shooting mineral particles more than 40 m (130 ft) into the water column. Physical oceanography models show how mineral particles and animals from hydrothermal vents might be pulled away from their original sources along the world's mid-ocean axes and distributed.

Scattered around the Earth under continents and oceans, in the center of plates, and at midocean ridges are specific areas of isolated volcanic activity known as hot spots.Yellowstone Lake, the largest high altitude lake in North America, is one of the most tectonically active regions in the world. The lake lies above magma chambers that are the source of heat for geysers, hot springs, fumaroles, and mud pots that typify the park. James Maki, a microbial ecologist at Marquette University and colleagues

Charles Remsen, Val Klump, and Russell Cuhel from the University of Wisconsin-Milwaukee, are currently studying hydrothermal activity in the lake and its influence on the distribution of organisms. These researchers use a remotely operated vehicle (ROV) rigged with cameras and sampling devices to view and collect fluids from vents 100 m (328 ft) deep. The hydrothermal springs, which are 112° C and hot enough to boil an egg, create a range of thermal and chemical conditions that promote the growth of a wide variety of bacteria and microorganisms. Some of these organisms resemble the sulfide-oxidizing bacteria found near mid-ocean hydrothermal vents. However, in contrast to the deep-sea vents, larger vent animals like tube worms and clams are not associated with the hydrothermal activity in Yellowstone Lake.

Maki was also able to isolate and characterize a new genus of sulfate-reducing bacterium. "The isolation and characterization of this bacterium underscores the importance of hydrothermal environments of Yellowstone Lake as a source of novel microorganisms," Maki said. This group's research points to a whole diverse community of microorganisms that are still unknown, and whose enzymes may have some biotechnological use. The vents appear to play a very important role in the lake basin as a whole. Cuhel has observed that chemosynthetic activity appears to be a more important contributor to primary production throughout the lake at certain times of the year than photosynthesis, and could be an important underpinning of the entire food chain. The lake is one of the great reservoirs for cutthroat trout in North America, and trout are a very important food source for eagle, osprey, and bear. Researchers hypothesize that particulate material spewed up by lake geysers, may fuel the food chain that help support the trout.

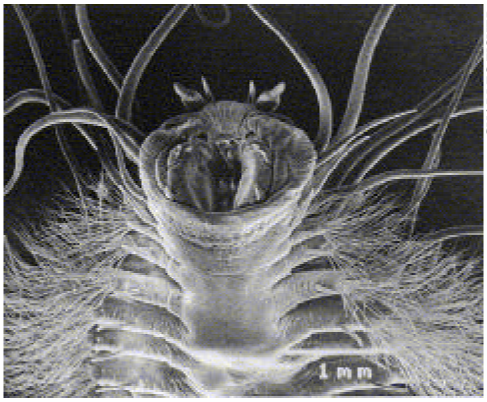
Cold Seeps

Oceanographer Ian MacDonald of Texas A&M University and marine biologist Charles Fisher of Pennsylvania State University were surprised to find similar animals using chemosynthesis to feed off the hydrocarbon gas seeps on the seafloor in the Gulf of Mexico. They've spent ten years studying the tube worms and mussels that colonize over hundreds of square miles at depths down to 3,600 m (11,800 ft) in the Gulf of Mexico with NURP support. The seep community attracts other animals including snails, eels, crabs, and fish, raising questions of how far the food web extends in the deep ocean and how it affects the health of the ocean. Then by accident came a remarkable discovery in 1997. On a planned mission to continue studies of oil seep communities, Fisher and MacDonald discovered a new species of worm living within mounds of frozen natural gas on the sunless floor of the ocean. MacDonald had taken photographs of the worms before, but neither he nor Fisher expected to find a huge colony of the worms living on and in the gas hydrates.

While scientists have found extremophiles—organisms named for their capacity to survive, even fluorish, in the ocean's most extreme freezing, scalding, and acidic waters—most have been microbes, not animals. Dubbed the ice worm until a scientific name can be given to the new species, these pink-colored worms that look like two-inch long centipedes are a variety of the common aquatic worms known as polychaetes. What makes the iceworms such interesting subjects is that these animals can survive in such potentially toxic environments.

Recently, gas hydrates worldwide have generated a great deal of interest. The hydrates are lattices of ice, inside of which are trapped molecules of methane, that form under extreme pressure trapping the methane gas. Huge reserves of natural gas methane

A reservoir greater than all the retractable reserves of oil are bound in gas hydrates.



CHARLES FISHER

A closeup of iceworm.

are bound in these gas hydrates, a reservoir greater than all the retractable reserves of oil and as much as two to three times the carbon that exists in all the living biosphere, MacDonald said. “There’s a wonderful irony in this discovery,” MacDonald said. “While we’re considering the impact of human activity in the deep sea related to oil production, we find a natural presence (iceworms) already at the resource we’re beginning to exploit. Gas hydrates like hydrocarbon seeps are ecosystem shaping processes.” These hydrates may enable hydrocarbon seep communities to survive. As gas hydrates are formed, blocking and releasing hydrocarbon gas and dispersing oil onto sediments like a drape, broad communities of fauna exist. The tube worms that establish themselves in an area of several hundreds of meters wide, are receiving a steady supply of gas through the hydrate, MacDonald said.

Scientists also theorize that by consuming methane, a greenhouse gas, these vent animals may be contributing to the health of the planet. “The question that comes to mind is what’s going to happen if bottom water temperatures increase as a result of global warming,” MacDonald said. “The seep communities are intricately linked to the system extracting gases through the hydrate and changing the temperature flux of the sediment layer. There’s a whole biological interaction, we just have to understand it.”

Why The Interest?

It might sound far fetched, but researchers are turning to places like the boiling waters of Yellowstone Lake or inside the frozen layers of Antarctic ice to find extremophile microbes that might be used in applications ranging from the production of sweeteners and stone washed jeans to diagnostic tests for infectious and genetic diseases. Extremophiles have unique enzymes, called “extremozymes,” which enable them to function in such forbidding environments. The biomedical field and other industries worldwide spent more than $2.5 billion last year looking for ways to use extremozymes. Since extremozymes tolerate extreme temperatures, they have an edge over other enzymes. Heat loving microbes like those found at mid-ocean ridges are used to increase the efficiency of “DNA fingerprinting” to stabilize volatile food flavorings, improve the uptake of medicines by the body, and mask unpleasant odors.

Extremophiles like those found within Antarctic sea water are also of interest to manufacturers who need their enzymes to make products like fragrances and laundry detergents that last longer when kept in colder conditions. While chemicals from land-based plants and microbial fermentation are on the decline, scientists have barely scratched the surface of the seas’s molecular potential. One marine microbe that recently proved to be a potent killer of cancer cells, as well as an active agent against tissue inflammation, was isolated from the surface of a jellyfish. Blue-green algae are being studied to prevent strokes or heart attacks. These are just a few examples of how compounds from the sea can be tapped for human use.