Deep-sea Oasis

Intricate communities at seafloor vents yield clues to survival in their sulfide-rich world

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By CHERYL SIMON

In the gathering twilight enveloping the Pacific seascape, passengers aboard the R/V *Melville* cluster eagerly as a white plastic chest is lowered onto the deck. The clasps are released, the lid is raised. Inside, a rare collection of animals from the hydrothermal vents on the seafloor 2,600 meters below awaits the scrutiny of the scientists on board.

With the first plunge of hand into blood-tinged water, the air of anticipation gives way to purposeful activity as the animals are distributed among the crowd. Some of the biological experiments to be performed as part of the "Oasis" expedition require live specimens. Speed and precision are essential: Animals accustomed to ambient seawater temperatures of 2°C and pressures as great as 260 atmospheres cannot survive long on the surface.

Some of the samples, tube worms called vestimentiferans, are spirited away to a refrigerated chamber where they are stripped of their casings and slipped into pressure tanks. There they can be kept alive for a week or more. Off to one side of the main deck, a graduate student kneels over a pile of the worms, each of which is about 18 inches (45 centimeters) long. She inserts a pair of scissors just below each worm's crimson tip and snips along the length of the stiff white tube. When the skin of the animal's main organ, the trophosome, is exposed, she cuts it open. Dark red blood spurts over her hands, over the worm, and finally into a small glass vial. This work is not for the squeamish.

The tale of the expedition to the East Pacific Rise 21°N of the equator is not one of discovery or of scientific "firsts." Nor does it answer many of the questions raised during its telling.

Instead it is a tale of incremental advances, of a wide-ranging attempt to extend the boundaries of knowledge about one of the world's most bizarre and least-understood ecosystems. It also is a story of monotonous days at sea and of searing sunlight reflected by the ocean's crystal swells. It is the constant drone of ships' engines. The perpetual sway of ship and sea — a motion that insinuates itself into every thought and movement.

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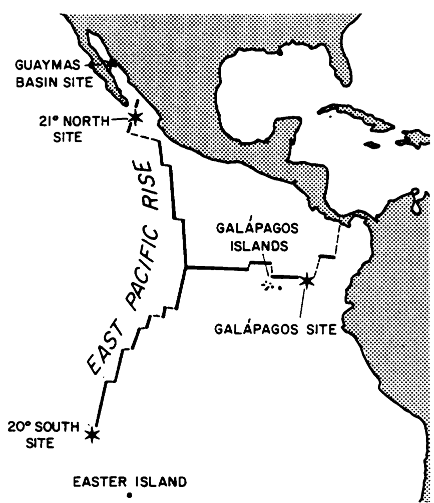
The roiling blue-gray waters give no hint that lush biological communities thrive on the seafloor below. Like other vents dotting the ragged edge of the East Pacific Rise, the vent system at 21°N is distinguished by super-heated waters that emanate from the ridge where two of the earth's crustal plates are spreading apart. Many of the 30 or so scientists on this cruise made a similar excursion in 1979 to the Galápagos Spreading Center (SN: 4/7/79, p. 231). In addition to "smokers" — vents that stream super-heated waters laden with gases and metals from the upper mantle — they saw astonishing animals unlike those found in the greater deep sea. Beds of mussels, gently swaying tube worms and giant clams were arrayed near the vents. On that trip, the scientists collected some of the animals and confirmed their suspicion that the driving force behind the deep sea "oasis" is chemicals — principally hydrogen sulfide (H_2S) — rather than the solar energy that fuels the rest of life on earth.



Scripps Institution of Oceanography

Above: Sites of known biological communities at vents along the East Pacific Rise. Top left: George Somero examines the day's haul of animals from near the vents, selecting and distributing samples for research. Top center: Alissa Arp drains sulfide-rich blood from a vestimentiferan worm, shorn of its tube.

That one discovery leads to the realm of questions that they hope to answer, at least in part, here at 21°N. How do these vent communities fit in with existing ecological theory? How do the animals spread their young to distant vent fields, a necessity since geologists find that the vents close down within decades of the time they begin emitting hydrothermal fluids? What is the nature of the symbiotic bond between the animals and the bacteria that produce energy through the oxidation of sulfur compounds? And why aren't the animals poisoned by the sulfide, which is toxic to nearly all organisms?

This ambitious inquiry takes place aboard three ships, the *Melville* and the *New Horizon*, both operated by Scripps Institution of Oceanography, and the *Lulu*, operated by Woods Hole Oceanographic Institution. Once at the research site, 120 miles (192 kilometers) south of the tip of Baja California, the three ships hover far above deep-sea vents.

On this trip the *Melville*, a U.S. Navy-owned ship capable of hosting 22 crew members and 26 scientists, functions as much as a hotel as it does a floating laboratory. The *New Horizon*, a smaller, faster, more modern ship (whose excellent cook is coveted by crew and researchers lodged on the other boats) is home, temporarily, to microbiologists whose research into the physiology of the vent organisms requires use of radioactive isotopes. Substances used in their research could contaminate other experiments so the *New Horizon* contingent works and lives happily in relative isolation.

The third ship, the *Lulu*, is a catamaran, the sole purpose of which is to launch and service the undisputed star of the whole show: the *Alvin*. This manned, Navy-owned submersible, seven meters long, is scheduled to dive 20 times during the trip. On each of the 18 dives ultimately completed (one was cut short by problems with the hydraulic system, and one was canceled due to bad weather) *Alvin* carries two scientists and a steel-nerved pilot on a cramped but exhilerating excursion to the vents. Chief scientist Kenneth Smith of Scripps is the only scientist lodged on the *Lulu*.

The cumulative goal of the research projects is to understand the physiology and ecology of the vents — how the systems work, and how they relate to life in the world ocean.

According to classical views of life in the deep sea, biological processes there are slow. Pressures are high, temperatures and food supplies low. These stable environments are sparsely populated and low in biomass. Because the environment changes little, the animals are free from the need to change rapidly. Instead they diversify to fill highly specialized niches. The animals grow and respire at a fraction of rates common among surface fauna.

Yet here at the vents, pressures also are high and temperatures low. Even the hydrothermal waters — exiting at temperatures from 3°C to a scalding 350°C — cool quickly to the 2°C of the surrounding water. But unlike in the greater deep sea, there are huge quantities of animals. . .and relatively few species. What's more, they are growing and reproducing to beat the band. Physiologists find that metabolism rates at the vents are comparable to those of animals in surface waters.

The difference here is that some of the animals live by chemosynthesis, using chemicals from the vents as an energy source in producing usable organic compounds. Food is plentiful, both for the chemosynthetic animals and for those that eat them. Animals outside the vents must rely on the sparse supply of organic matter that trickles down from light-infused waters where photosynthesis is the rule of life.

"When geologists first came back from the vents, they made a lot of claims about how this was going to overturn neo-Darwinism and completely revise our ideas about the deep seas from a faunal point of view. This hasn't happened," says Robert Hessler of Scripps. "This environment is 'the exception that proves the rule.' The reason why there wasn't much life in the deep sea at any one spot is that there wasn't much food. Now you can say, 'Show me a spot in the deep sea where there is plenty of food, and I'll show you lots of life.'"

"We think that what happens is these animals grow like hell, reach sexual maturity, and disperse their seed as soon as possible," says Richard Lutz of Rutgers University. "These localities are restricted and very widespread. The only way to preserve the community is for the animals to disseminate huge numbers of offspring." He peers at slivers of clamshell, he and his microscope swaying with the same lazy rhythm to the ship's motion. He hopes to glean some information that might tell him more about the vent animals' growth rates, and about how they propagate their young to other vents and their implied wealth of food.

A few yards away in another small laboratory, Carl Berg of the Marine Biological Laboratory in Woods Hole, Mass., opens a clam six inches (15 cm) long. He slices out the meat and, along with some formaldehyde solution, places it into a jar. Many researchers will receive pieces of the same tissue. As he scrutinizes the hinge of each clam, he pokes with a tweezer at anything that might be larvae. By the trip's end, plankton tows and larvae traps will have yielded crab larvae, tiny floating crustaceans called copepods, and eggs that "probably came from a clam."

Larvae can do "amazing things," he explains. For instance, they can grow to a certain size and remain in a steady state until they encounter a signal, such as chemicals or heat. Perhaps the larvae of vent fauna do this, rising to the surface and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Before Alvin *dives, engineers test all equipment and systems on the submersible.*

then dropping down to a vent where they resume their development. Only a tiny fraction of the larvae, probably less than one-tenth of a percent, ever reach maturity. But, as one scientist quipped, "Once a larva finds a vent, it's Fat City."

Eventually, results of other studies of metabolism and respiration will be combined to work out an energy budget for the system.

The *Alvin* is an essential tool not only for harvesting the animals but for gathering information about the distribution of different animals with respect to the vents. This site, for example, is dubbed "Clam Acres" because oversized clams cluster near fissures caused by volcanic activity along the spreading center. Hot, mineral-laden water rises from the cracks. Water temperatures, which can be as hot as 350°C, seem to determine which animals live where.

One of the many puzzles of the vent fauna is how the animals adapt to an environment where conditions, such as temperature and food supply, almost certainly fluctuate. "The amount of hydrogen sulfide coming out of the vents controls the size of the community," says Holger Jannasch of Woods Hole. Some concentrations are so high that nothing can live, he says, which is why the bacteria live inside the clams and worms. "They find the right concentrations in there," he says. In turn, the animals have learned that if they provide a congenial environment for the bacteria, they need not gather all of their food from the seawater — they can simply grow their own.

Studies of metabolism and enzyme activity focus largely on the clams and the vestimentiferan worms. As Jim Childress of the University of California at Santa Barbara waits aboard the *Lulu* for his first dive of the trip, he comments that he would like to turn a vestimentiferan worm around to learn how the worm functions when the end that usually is furthest from the hot temperatures is placed nearest the vent. At higher temperatures, these worms, which lack mouth and gut, display a lower affinity for oxygen.

"The idea is that they take oxygen in through the plume [at the worm's tip]. As the oxygen circulates into the regions of the worm closer to the heat, a gradient is created," says Alissa Arp, a graduate student working with Childress. "When the temperature is too warm, the blood offloads the oxygen to the bacteria that need it in order to convert the sulfide to sulfate" (SN: 7/18/81, p. 38).

Childress and company are firmly entrenched in the main laboratory on the *Melville*. Most of the researchers are labeling and preserving specimens for colleagues or for later examination in more complete home laboratories. The Santa Barbara group, though, brought along state-of-the-art equipment (as well as a stereo system). The room has been converted into a specialized, somewhat frenetic place where experiments can be conducted on live animals as soon as they arrive.

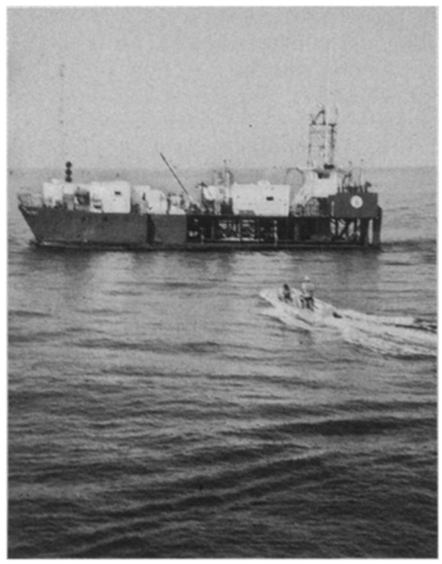
In one set of experiments, the researchers subject blood from the vestimentiferan worms, *Riftia pachyptila* Jones, to a series of tests to learn its affinity for oxygen, hydrogen sulfide and carbon dioxide, the trio of compounds the worms need in order to live. They find that the animals stockpile the sulfide at levels 25 to 50 times those found in the seawater. Further, in normal animal systems the presence of H_2S inhibits the binding of oxygen in the hemoglobin. Oxygen affinity in these worms, however, is unaffected.

While questions remain, the scientists are a step closer to understanding why the animals are not poisoned by the sulfide. What actually kills most organisms in the presence of H_2S is inhibition of cytochrome oxidase. This is the enzyme that uses the oxygen at the end of the metabolic process. The presence of this enzyme in the vent fauna shows that the animals have conventional oxidative metabolisms, as opposed to "some bizarre metabolism associated with a sulfide-rich environment," says George Somero of Scripps.

When Somero and colleagues isolated the enzyme and exposed it to H_2S, they found that the enzyme in the vent animals also is sensitive to sulfide, and shows no apparent adaptation. It appears that there is a protein in the blood that binds the sulfide, holding it where it cannot inhibit metabolism.

"This is the first protein we know of that binds sulfide in a reversible way," Childress says. The protein was found in at least two kinds of vent animals — clams and vestimentiferan worms. It picks up the sulfide and then, when the sulfide level in the blood is low enough, unloads it to enzymes that have an even higher affinity for the gas. The protein, Childress says, may be fundamental in controlling where the sulfide goes and how the animals obtain it.

So far it looks as though the high pressure at the vents barely inhibits metabolic



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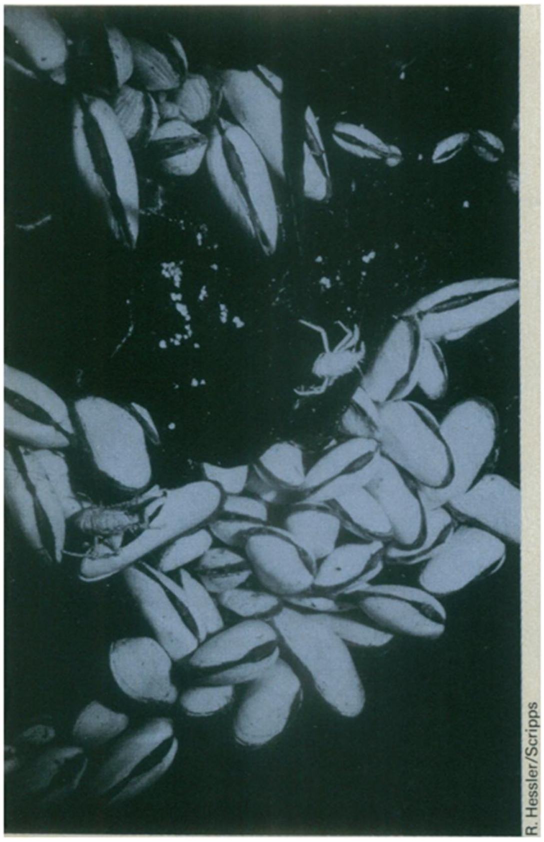
Above: A shuttle boat transports researchers and their gear from the main research vessels to the Lulu.
Bottom: The Alvin *hovers briefly between the pontoons of her tender vessel, the* Lulu, *just before an early-morning launch. Divers will secure the* Alvin's *hatch once the submersible is freed from its restraining ropes.*



R. Hessler/Scripps

A scavenging crab, Bythograea thermydron, *traverses a field of clams. Their mosaic distribution marks warm water exiting from cracks between basalt pillows.*

At sea, normal routines surrender to the quixotic demands of science. The *Melville*'s fantail, or "steel beach" as it is called, is nearly deserted late one afternoon after a night when animals were retrieved. Some researchers had been up all night, running experiments or preserving specimens.

Others, such as deep-sea ecologists Fred Grassle and Howard Sanders, both of Woods Hole, rescued and counted small animals, such as limpets and worms, that are brought to the surface along with those animals deliberately harvested. In a tedious process called "washing mud," whatever soft sediments happen to be collected from the site's rocky bottom are rinsed and re-rinsed, and passed through screens of successively smaller mesh. The animals gleaned from the mud are an unglamorous source of information that may tell scientists as much as the large animals do about the diversity and concentrations of fauna at the vents.

Now, except for a sunbather or two, the deck is lifeless. Lockers and coils of rope wait, poised for utility. In a few hours the deck again will be an island of light and activity, shrouded by the moonless Pacific night.

In the distance the *Lulu* is visible, bobbing with her typical, gut-wrenching lurch. The scene there is less idyllic. All hands—crew and scientists—are on deck, eyes riveted to the blank waters. Any minute, *Alvin*'s orange hood will bob to the surface. A motorboat, ready with divers in wet suits who will secure lines to the submersible, is the only craft nearby.

Once the *Alvin* appears the elevators on the *Lulu* descend. The switch is reversed and the lift rises, bearing the stalwart submersible, the pilot and a small cargo of weary scientists. With each successful dive, the harmony of the cruise is extended for another day. A single hitch in the dive schedule, failure of equipment, or a change from good sea state to bad quickly can convince a researcher that time and precious research dollars bestowed by the National Science Foundation are being wasted.

This was the last dive on Leg One of the "Oasis" expedition. The general tenor as the three ships head for a port call in Mazatlán, Mexico, is that the trip is a success. One has the impression that 10 more days at 21°N will be plenty for most of the participants, at least for the time being. The research site, the company and the featureless horizon are familiar now. The researchers already are fitting newly gained insights into a broader picture of life at the deep-sea vents.

There is talk, though, of the next cruise, this time to a spot in the Gulf of California (SN: 2/13/82, p. 103). There, another vent and its intricate biology beckons. "The Guaymas Basin," the scientists say. "1984." □

activity, Somero says. When the animals are brought to the surface, they die because diminished pressures may affect some other parts of the organisms, such as membranes, that require pressure. The enzymes, though, are unaffected.

It is the combination of high pressures and high temperatures that is critical to life at the vents. John Baross of Oregon State University previously collected bacteria from the inside of a black smoker—the hottest form of vent emitting minerals and hydrothermal fluids. He finds that the bacteria do not grow at temperatures cooler than 80° C. They do grow very fast at temperatures up to 300° C (and possibly greater) and at pressures higher than 200 times that on the earth's surface.

"This is certainly the hottest temperature that any organism has been shown to tolerate," Somero says. The tolerance is possible because pressures are so high that the water remains liquid rather than boiling out into water vapor as it would under normal pressure. "This puts a whole new light on what the limits are for tolerance for temperature and pressure," he says. "There may be bacteria living in extremely hot water below the crust down here." Protein usually dies by 50° C or 60° C, he says, whereas these bacteria flourish at 300° C.

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