OCEANOGRAPHY

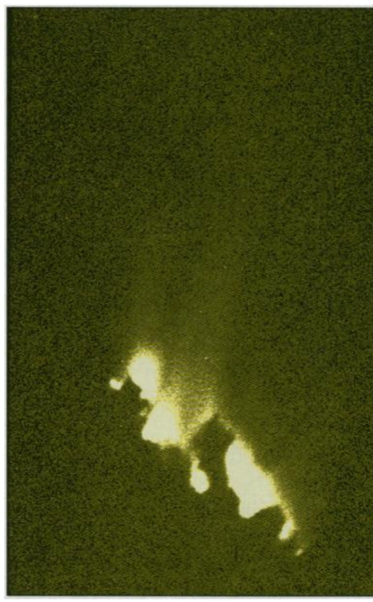
Probing the Unsolved Mysteries of the Deep

Far below the ocean's surface, the ocean floor is a lifeless, lightless watery desert. At least that was the picture oceanographers kept in view until a few decades ago. But that desolate portrait began to change dramatically in the 1970s when deep-sea submersibles such as "Alvin" gave researchers and their cameras the ability to inspect the deep ocean floor more closely. Far from being lifeless or lightless, the new seascape depicts mats of bioluminescent bacteria, strange new shrimp and other animal species, gushing hot springs, and ocean sediments teeming with a variety of life that could equal the diversity of tropical rain forests. And it uncovered a challenging surprise as well: Emanating from some of the hydrothermal vents is a ghostly halo of light—"vent glow"— that brightens the eternal undersea night.

So far, researchers have been frustrated in their efforts to understand the how and why of the vent glow. But this year, they may at last have an opportunity to solve those mysteries. In March, the deep-sea remotely operated vehicle called Jason will visit hydrothermal vents in the Pacific; 3 months later, Alvin will dive to similar sites in the Atlantic. And, on those voyages, researchers have a long list of questions they want answered. First and foremost: What produces the glow? Marine biologists also wonder if the glowing deep-sea vents might be nourishing photosynthetic organisms, a seeming impossibility given the lack of sunlight and harsh conditions at the vents. And they are also curious whether animals near the vent, particularly a recently discovered species of shrimp, can actually see the glow.

To make the most of their upcoming research opportunities, a diverse group—including marine biologists, chemists, astronomers, and geologists—gathered last month at the Woods Hole Oceanographic Institution (WHOI) for a meeting sponsored by the National Science Foundation, its mid-ocean ridges research initiative called RIDGE, and the National Aeronautics and Space Administration.* The meeting's participants reviewed what's known so far, speculated on what might be going on at the deep-sea vents, and charted a course of research for the upcoming dives and beyond. "It was a whole group of people who had never talked to each other," says oceanographer Cindy Van Dover of WHOI, who along with geologist Joe Cann of the University of Leeds, England, organized the workshop.

The largest and most diverse working group at the recent conference was the one whose mission was to address the causes of the glow, which is associated with "black smokers," hydrothermal vents that emit plumes of dark, mineral-laden water. The difficulty of their task was increased by the fact that they had only a few pieces of data to work with, the most important being the images Van Dover, and geologists John Delaney and Milton Smith, both of the University of Washington in Seattle, took 5 years ago when they discovered the glow during an Alvin dive. Those images were made with a CCD camera, the sensitive, light-gathering instrument that has revolutionized astronomy. Their CCD images revealed a dim light source dominated by red to near-infrared wavelengths of 770 to 850 nanometers.



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Ghostly glow. Alvin captures the surprising light from a 10-centimeter vent.

The group agreed that the simplest explanation for that light is thermal radiation: light emitted by anything hot. And black smokers definitely qualify. The vents form on mid-ocean ridges, where magma rises up between tectonic plates and comes close to the surface. As 2° Centigrade seawater seeps through the porous ocean floor there, it reacts chemically with the intensely hot rock underneath, producing a buoyant, acidic stream of 350° to 400° C seawater, laden with sulfur and metals, that bubbles up, forming the unique dark plumes that define black smokers. Providing some support for the idea that thermal radiation is the source of vent glow are the Alvin CCD images: ones made through color filters indicate that the distribution of wavelengths in the glow roughly match what would be expected from the thermal radiation of a 350° C object.

But the case for thermal radiation—at least thermal radiation alone—is far from air-tight. One factor that makes it less than conclusive is a tale that began before the discovery of the vent glow: the story of the deep-sea shrimp, *Rimicaris exoculata*, with its mysterious "eye patches." Originally thought to lack eyes altogether, these small creatures, just a few inches long, were discovered in the vicinity of vents in 1985. Van Dover, who had taken up the challenge of analyzing the new species, became especially interested in an unusual reflective structure on the shrimp's back. Further study showed a bundle of nerves running from it directly to the brain, like an optic nerve, a discovery that led her to hypothesize that, despite its anomalous location, the organ is an eye.

To bolster her case, she turned to a Woods Hole colleague, biochemist Ete Szuts of the Marine Biological Laboratory, and asked him to study the shrimp. He found that the mysterious organ contains large amounts of rhodopsin, the light-sensing pigment found in the eyes of all creatures. Furthermore, certain structural aspects of the organ suggested that it is a photoreceptor designed to detect dim light. Those discoveries were startling, since at the time researchers believed deep-sea animals had no use for a functioning visual receptor. And the unearthing of the putative eye patches led directly to the discovery of vent glow in 1988, because a curious Van Dover asked Delaney and Smith to look for light in the black smokers during their dives.

Intriguing as they are, however, the shrimp's eyes create problems for those who think the glow is nothing more than thermal radiation from the vent plumes. The rhodopsin in the shrimp's eye patches is designed to best absorb greenish-blue light, while the light produced by thermal radiation from a 350 °C object is mostly reddish—with little radiation at green and blue wavelengths.

Could the shrimp be viewing sources of light other than those produced by heat? Perhaps. The working group came up with plenty of other candidates, all of which could emit greenish-blue light. Some argued that the rock chimneys that belch out the plumes could discharge a glowing stream of burning methane. Alternatively, Jeffrey Zink of the University of California, Los Angeles, suggested that the smokers emit many compounds known to form crystals very quickly and that, therefore, crystalloluminescence —light emitted from rapidly crystallizing compounds—could be a source. Then there is sonoluminescence (light caused by the

* The meeting on "Light in Thermal Environments (LITE)" was held from 10 to 12 January in Woods Hole, Massachusetts.

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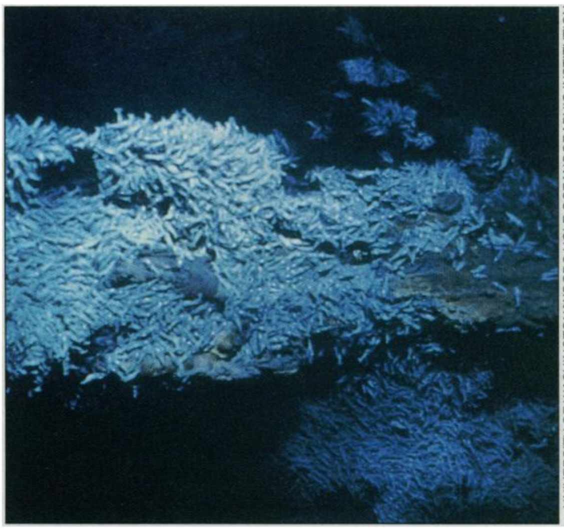
Black smoker. Mineral-laden water billows from a vent.

implosion of bubbles in a liquid) and triboluminescence (light caused by mechanical stresses on a solid). And that doesn't by any means exhaust the list of possibilities.

The meeting participants therefore had a clear view of one major priority for upcoming missions. "The first thing that needs to be done is to get a good spectrum," says Zink. Measuring the exact intensities of vent glow at wavelengths from 400 to 1100 nanometers is crucial to identifying its sources. But researchers will probably have to wait until at least 1994 for the gold mine of information that a spectrum would bring, since there isn't the money or the time to build the needed instruments for Alvin's summer dives.

Naturally, since the shrimp are such key figures in understanding the vent glow, meeting participants also put a high priority on getting specimens of the shrimp from the Alvin dives so their anatomy can be better studied. The few specimens retrieved in past dives had been collected by geologists without specialized equipment and were in poor shape. Looking at well-preserved specimens is important, says Steve Chamberlain of Syracuse University's Institute for Sensory Research, because the shrimp's rear-mounted eye might contain smaller amounts of a red-absorbing rhodopsin whose presence was masked in the earlier analysis by the large quantities of green-absorbing pigment. If that is true, the eye may actually be capable of detecting a vent glow due simply to heat—although the fact that the shrimp's photoreceptor is primarily tuned to blue and green light would still have to be explained.



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A thousand points of light. Shrimp with their reflective eye patches cluster near a vent.

But the biology of the vents—as exemplified by the deep-sea shrimp—isn't interesting solely because of what it has to say about the physics of that system. The shrimp, and other living creatures that cluster around the vents, are also intriguing within their own, biological, realm. The hope is that the diving team will be able to bring live shrimp aboard the submersible as well as dead ones. Researchers then might be able to do behavioral tests to find out what purpose the shrimp's eyes serve, assuming that the creatures aren't blinded by Alvin's intense lights.

At the beginning of the workshop, there seemed to be two clear choices for the eye's function. Most participants probably would have said the shrimp's eye is either a protective device, allowing it to see the vent glow and avoid the scalding water of the black smokers, or a short-range detector to keep it close to the vent where the shrimp's food source presumably is. But Edith Widder of Harbor Branch Oceanographic Institution in Florida confounded the majority by offering a very different proposal, one that could also solve the green-red light paradox.

Widder argued that the shrimp eye appears perfectly designed for the long-range detection of vents. When a particular black smoker peters out, she says, the shrimp would need to find a new, warm home. Away from the immediate vicinity of the vents, the longer, more predominant wavelengths of a thermal radiator are absorbed by seawater, making the radiator's shorter green-blue wavelengths, which the shrimp eye appears designed to detect, the principal light available. If so, the shrimp could use their eye to find a new home. With live specimens, scientists might be able to test Widder's hypothesis by placing the shrimp in a long trough containing a greenish-blue or reddish light. The shrimp's reaction, whether they move toward or away from the lights, should reveal how they use the eyes.

The workshop scientists tackling questions of sensory physiology and sources of light no doubt thought ideas were flying fast and furious—and they were. But even bigger questions were being flung around among their colleagues addressing whether the vent glow has given birth to photosynthetic organisms. The black smokers are home to an amazing variety of bacteria, many of which get their energy by digesting sulfur through chemosynthesis. But no one had imagined that photosynthetic bacteria might live near the ocean floor. The discovery of the vent glow changed that. Calculations showed that it may produce enough light to support photosynthesis, albeit slowly. If such novel bacteria exist, it would throw a curveball to those studying the evolution of photosynthesis, now assumed to be driven only by the sun, and might even bolster the case of a growing group of scientists who suggest that the deep ocean may be where life on Earth originated. "From the moment a photosynthetic organism is isolated from the deep sea, there will be huge interest," says Johannes Imhoff of the Institute for Microbiology and Biotechnology in Bonn.

But while there may be enough light to support photosynthesis, it could prove deadly to bacteria who try to take advantage of it. Because seawater strongly absorbs light, they would have to live within centimeters, perhaps millimeters, of the vents to get enough light to survive. That might be a problem, given that vent temperatures are four to five times higher than the maximum that the known photosynthetic bacteria are able to tolerate. Yet, perhaps the steepest thermal gradients on the planet are found in these vents: The temperature can drop from 350° to 2° C in centimeters. As a result, there may be safe havens in the harsh living conditions of the hydrothermal vents, concluded the faithful at the workshop. Nature is endlessly inventive, they point out. "I'm still enthused. It's still in the realm of possibility," says microbiologist Colleen Cavanaugh of Harvard University.

Workshop participants nevertheless remained aware of how chancy a proposition deep-sea photosynthetic life is. In fact, a number cautioned that requesting federal money solely to look for such microorganisms would be irresponsible. "If we say that it is *likely* that [photosynthesis] occurs down there, we make fools of ourselves," warns microbiologist Rolf Goericke of WHOI.

Still, his reasonable caution did little to dampen the enthusiasm evident at the workshop. After a frustrating hiatus, the sleuths are ready to gather more clues about the origins of vent glow and the other mysteries of the deep-sea vents. And while the answers they find may prove less interesting than the provocative questions raised at the workshop, this is a field that has already proved full of surprises—starting when people told Van Dover that *Rimicaris exoculata* couldn't possibly have eyes.

–John Travis