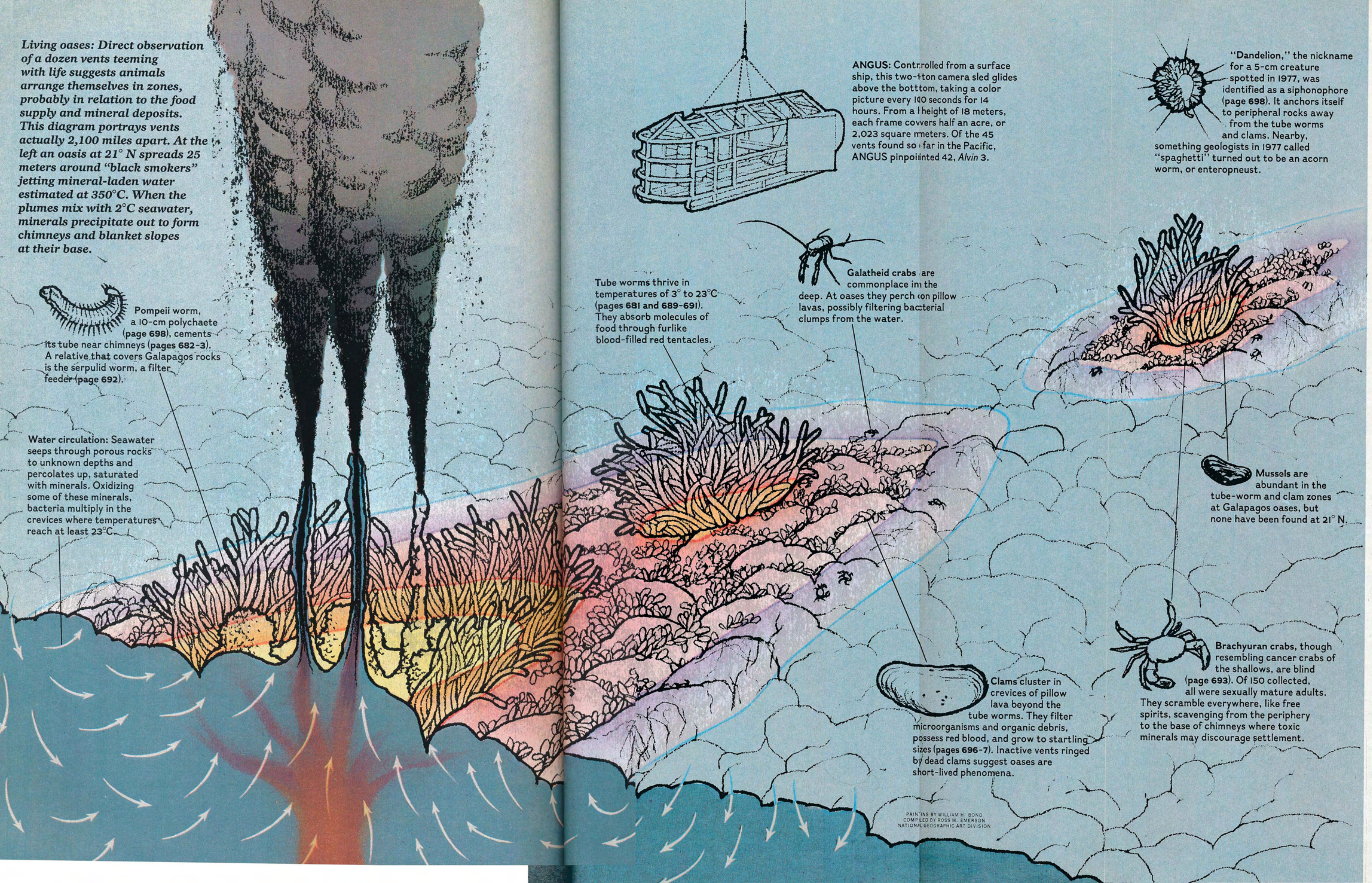


Living oases: Direct observation of a dozen vents teeming with life suggests animals arrange themselves in zones, probably in relation to the food supply and mineral deposits. This diagram portrays vents actually 2,100 miles apart. At the left an oasis at 21° N spreads 25 meters around "black smokers" jetting mineral-laden water estimated at 350°C. When the plumes mix with 2°C seawater, minerals precipitate out to form chimneys and blanket slopes at their base.

Pompeii worm, a 10-cm polychaete (page 698), cements its tube near chimneys (pages 682-3). A relative that covers Galapagos rocks is the serpulid worm, a filter feeder (page 692).

Water circulation: Seawater seeps through porous rocks to unknown depths and percolates up, saturated with minerals. Oxidizing some of these minerals, bacteria multiply in the crevices where temperatures reach at least 23°C.

Tube worms thrive in temperatures of 3° to 23°C (pages **681** and **689-691**). They absorb molecules of food through furlike blood-filled red tentacles.

ANGUS: Controlled from a surface ship, this two-ton camera sled glides above the bottom, taking a color picture every 100 seconds for 14 hours. From a height of 18 meters, each frame covers half an acre, or 2,023 square meters. Of the 45 vents found so far in the Pacific, ANGUS pinpointed 42, *Alvin* 3.

Galatheid crabs are commonplace in the deep. At oases they perch on pillow lavas, possibly filtering bacterial clumps from the water.

"Dandelion," the nickname for a 5-cm creature spotted in 1977, was identified as a siphonophore (page **698**). It anchors itself to peripheral rocks away from the tube worms and clams. Nearby, something geologists in 1977 called "spaghetti" turned out to be an acorn worm, or enteropneust.

Mussels are abundant in the tube-worm and clam zones at Galapagos oases, but none have been found at 21° N.

Clams cluster in crevices of pillow lava beyond the tube worms. They filter microorganisms and organic debris, possess red blood, and grow to startling sizes (pages **696-7**). Inactive vents ringed by dead clams suggest oases are short-lived phenomena.

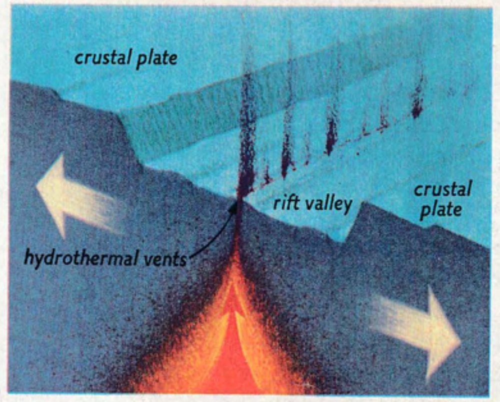
Brachyuran crabs, though resembling cancer crabs of the shallows, are blind (page **693**). Of 150 collected, all were sexually mature adults. They scramble everywhere, like free spirits, scavenging from the periphery to the base of chimneys where toxic minerals may discourage settlement.

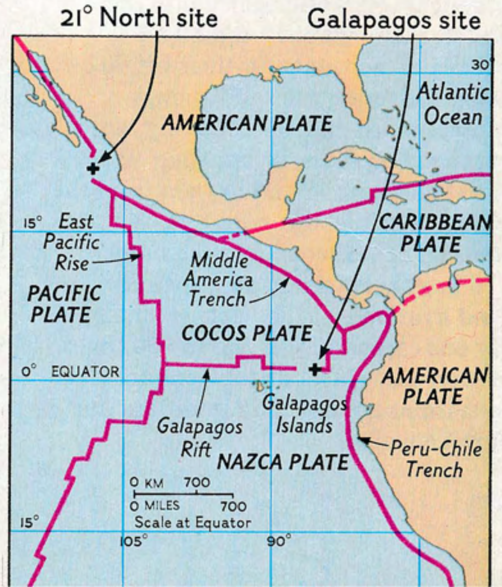
PAINTING BY WILLIAM H. BOND
COMPILED BY ROSS M. EMERSON
NATIONAL GEOGRAPHIC ART DIVISION

In total darkness, a new chain of life

Warm-water vents overgrown with organisms (left) *occur at both dive sites visited by scientists along rifts in the Pacific floor* (map)*. The oases were found along spreading centers where earth's crustal plates pull apart a few centimeters a year* (below)*. Seawater seeps into cracks, becomes superheated, and picks up minerals from the crustal rock. As solutions of hydrogen sulfide rise to the ocean floor, bacteria metabolize it and multiply, creating the primary food source for higher organisms.*

The discovery of an ecosystem based on chemical synthesis overturns the conventional idea that sunlight is always the main source of energy for life. Oases probably occur along many stretches of the Mid-Oceanic Ridge.





Fountains of life in the abyss

WE LOOK directly into the heart of an active vent as *Alvin*'s heat probe, at left, registers up to 13°C (55°F), much warmer than the usual deep-sea chill of 2°C. Yet heat is not the main lure for the flowerlike sea anemones, brown mussels, curling serpulid worms, and blind crabs gathered here, 2.5 kilometers below the surface. Sparse populations of similar animals survive the cold even at the sea's deepest point, 11 kilometers, existing on whatever organisms drift down from the sunlit surface.

Animals congregate at vents because of the enormous food supply based on bacteria. The bacteria, sulfur, and heat give the vent water its milky blue shimmer. Microbes exist everywhere in the sea, often in a state similar to suspended animation. Some types can metabolize hydrogen sulfide; when they

find that nourishment here in vent water, they proliferate, providing food for clams, worms, and mussels.

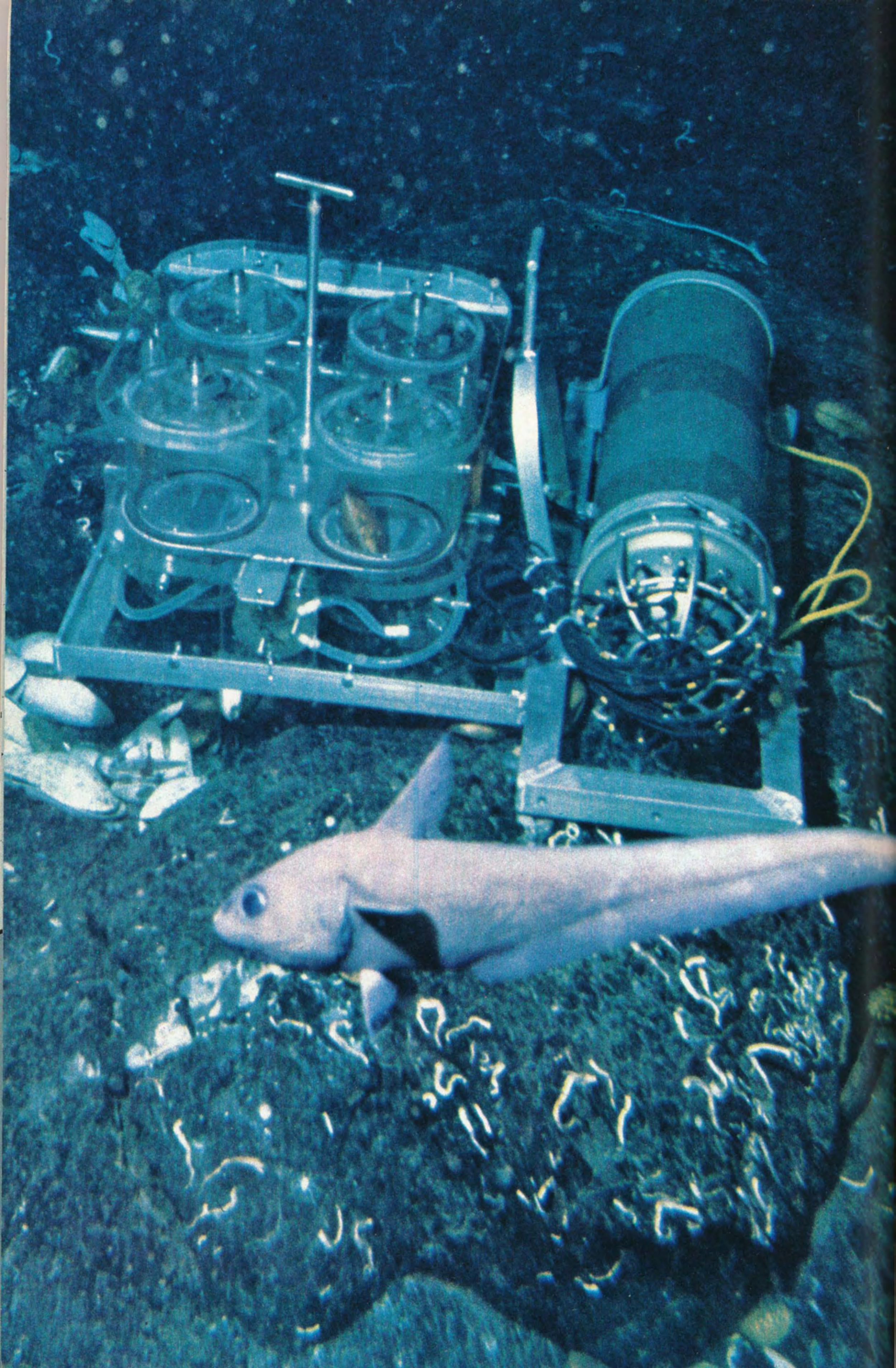
We find that the mussels have a long larval stage. Such larvae, drifting great distances in ocean currents like plant seeds riding the wind, could start a community whenever a vent opens up. Then dead mussels, in turn, become food for scavengers, such as crabs.

The white brachyuran crabs—of a crustacean family not previously known—scramble into our fish-baited traps. In insulated containers kept at 2°C, dozens survive decompression on the hour-and-a-half ascent with *Alvin*. So we select this animal as the best living subject for studies on the relationship of temperature and pressure to metabolism, investigations pursued in a laboratory at the University of California at Santa Barbara.

When kept at sea-surface pressure of one atmosphere, the crabs did not live long. But those placed in a pressure vessel set at 250 atmospheres, the same as their home environment, behave normally and easily tolerate changes in temperature. The last survivor (***below***) lived for more than six months.

ROBERT R. HESSLER, SCRIPPS INSTITUTION OF OCEANOGRAPHY

ROBERT B. EVANS



New ways to study a new world

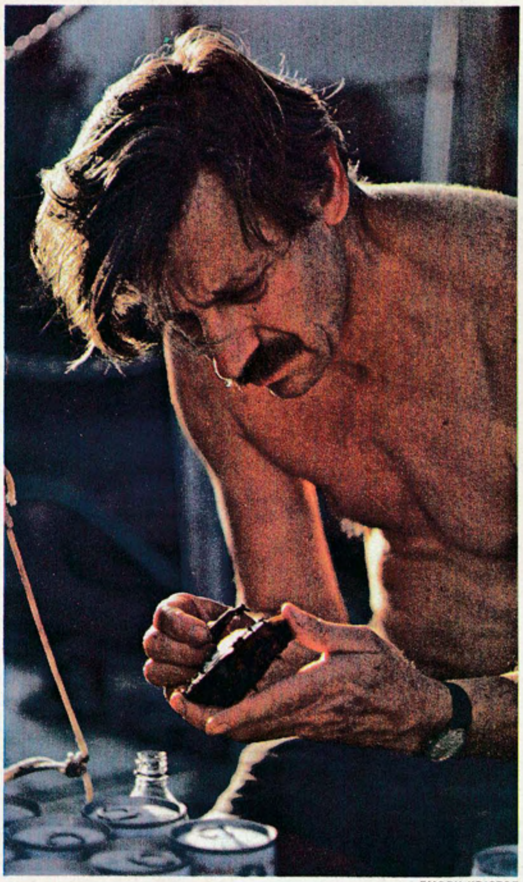
A JOURNEY to the deep sea is a little like going to the moon. We spend months preparing for an unknown realm, but can stay only a few hours on the spot. And we have not just a new geology but also a complex, unfamiliar ecosystem to investigate.

Biologists are especially curious about respiration and growth rates at the vent, since elsewhere in the abyss metabolism slows down. Using *Alvin*'s claw, we place mussels for 48 hours in a chambered respirometer to check oxygen uptake (***left***); others we leave in wire cages to test when we return this fall. The grenadier fish—common in the depths—may be attracted by *Alvin*'s lights.

Everywhere we look for new life forms. Microbiologist Holger W. Jannasch (***top right***) searches for bacteria in water samples, on rocks, and here on a mussel shell. Later a scanning electron micrograph of the mussel's shell (***center***) raises questions. The strings are stalks of bacteria. But what are the strange protuberances? Geologists thought they might be minute manganese nodules. Dr. Jannasch has found they are bacterial cells coated with manganese and iron.

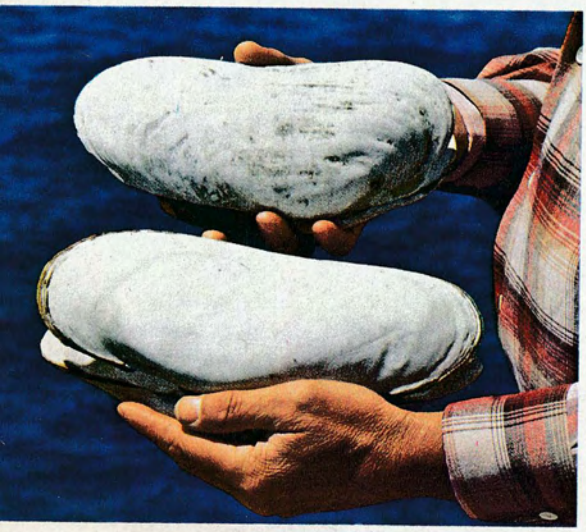
Filtered vent water yields solid evidence that bacteria multiply rapidly within the vents by metabolizing hydrogen sulfide, carbon dioxide, and oxygen. Bacteria grow in mats and clumps (***bottom***) in the subsurface spaces of porous rocks until the flowing water peels them off. The bacteria count is high, up to a million per cubic centimeter (less than a quarter teaspoonful). More than 200 different strains of bacteria are being kept alive at Woods Hole. The pink fish that we observed head down in vents may be feeding on bacterial masses.

KENNETH L. SMITH, SIO



EMORY KRISTOF

CARL D. WIRSEN, WHOI: MAGNIFIED 4,200 X (ABOVE), 8,000 X (BELOW)

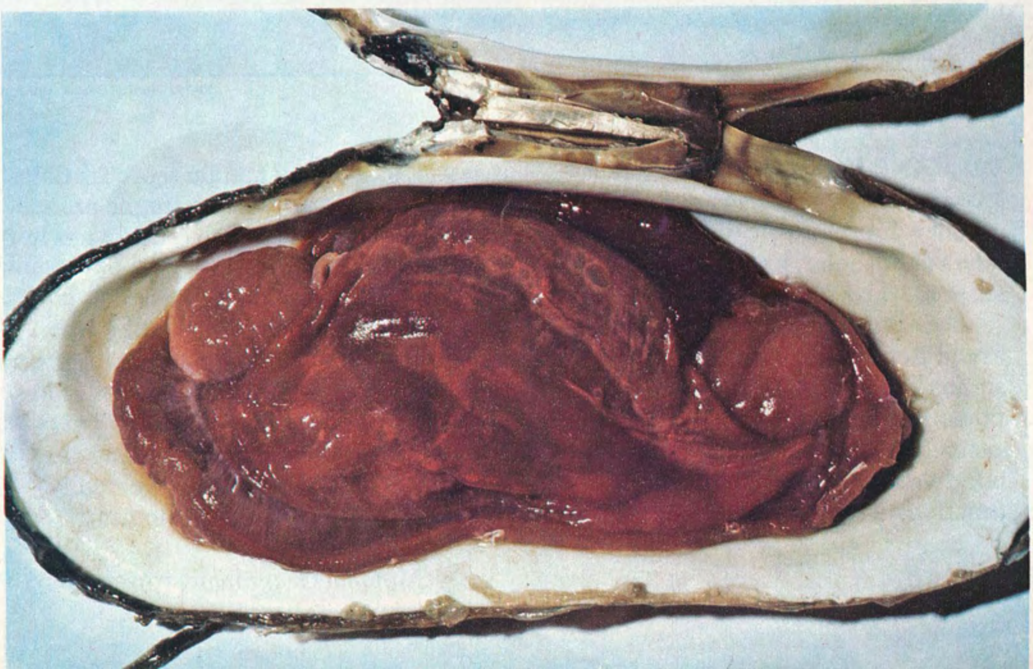


EMORY KRISTOF

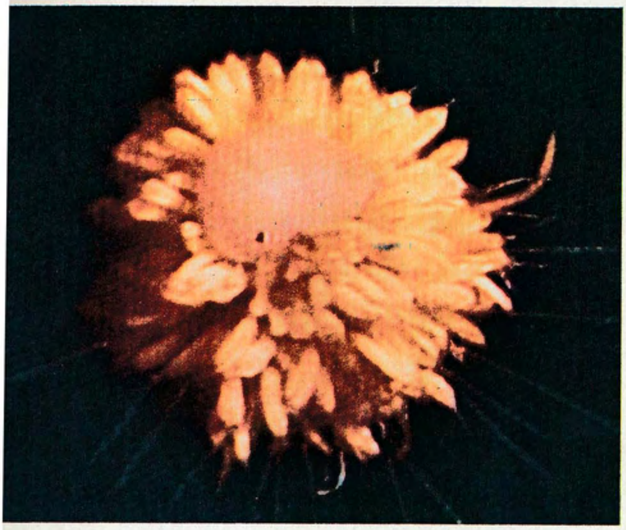
FIELDS OF FOOT-LONG CLAMS, overrun by galatheid crabs, populate active vents along the rifts (***above***). A smooth-shelled individual from 21° N proves slightly larger than an eroded Galapagos specimen (***left***). Radiochemical dating at Yale University shows vent clams grow four centimeters a year, 500 times faster than a small deep-sea cousin which can live as long as a century. Galapagos clams have numerous large and yolky eggs, but we have not yet found how the clams disperse.

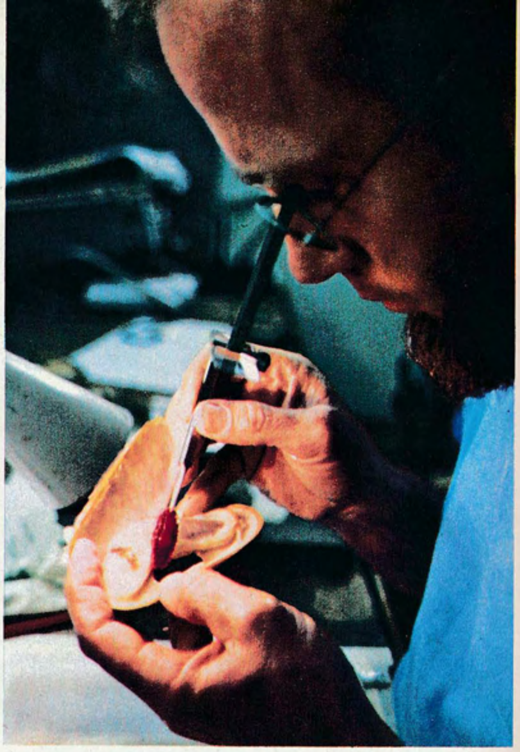
The meat inside is startlingly red (***right***), a rare sight in clams. Their hemoglobin has an unusually high affinity for oxygen, possibly an adaptation to periods of low oxygen.

CALYPTOGENA ELONGATA, EXTERNAL ALVIN CAMERA, WHOI (ABOVE); AL GIDDINGS, SEA FILMS, INC.



A marvelous multitude





RHODALIIDAE, AL GIDDINGS, SEA FILMS, INC. (ABOVE) AND WITH CCD CAMERA (TOP)

EMORY KRISTOF (ABOVE AND TOP)

TO MARINE BIOLOGISTS, vent communities are as strange as a lost valley of prehistoric dinosaurs. The "dandelion," first spotted suspended by filaments above the seafloor during the 1977 Galapagos expedition, proved to be a new siphonophore (***top left***). Related to the Portuguese man-of-war, it consists of a gasbag for buoyancy, surrounded by hundreds of members with specific functions—some capture food, others ingest it, still others handle reproduction. Brought to the surface, the fragile animal started to fall apart, so we quickly put it in a fixative (***lower left***).

Another unusual animal, a small worm (***lower center***) forms a tube from minerals in the water, cementing itself near the chimneys at 21° N that spew solutions hotter than 350°C (***pages 682-3***). This effluent cools so quickly on meeting the seawater that the worms don't actually live in the hottest water. Geologists

JOHN D. DONNELLY, WHOI

dubbed them Pompeii worms, since they must survive a constant rain of metal precipitates. They turn out to be bristle worms, or polychaetes, which probably consume bacteria with feeding tentacles.

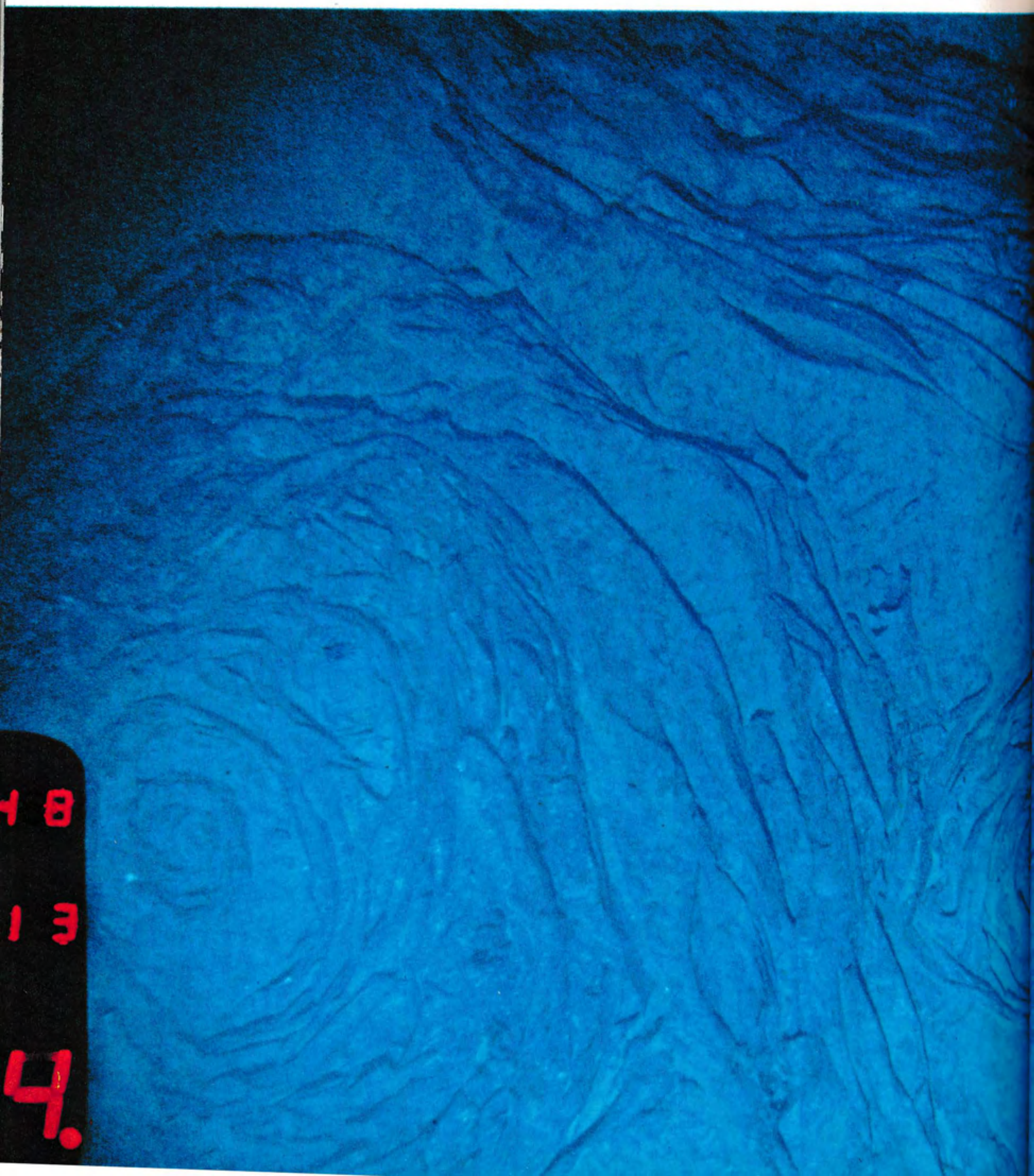
Among hundreds of specimens collected, we discover even more new species of whelks, barnacles, leeches, and a red-blooded bristle worm. While dissecting mussels, invertebrate zoologist Carl Berg (***top center***) finds the worm living in the mantle cavity. On videotape from the CCD camera (***page 705***) we can see such worms leaving the mussels we collect.

On board *Lulu,* geologist-author Ballard (***above***) examines the largest tube worm brought to the surface; its body fills more than half of the 2.5-meter tube. Several juveniles had cemented themselves to this adult. We also find on such tubes a new variety of filter-feeding limpet, a living representative of fossils from the Paleozoic era.

THE SEAFLOOR near the vents gives us a big surprise. Geologists had believed that lava underwater always flowed slowly, forming bulbous pillows. Instead, we find, lava lakes fill depressions, much as on land (***below***). This means molten magma rushed up with such ferocity that cold seawater could not immediately harden it. The flow swirled and coiled before solidifying, a few hundred to a few thousand years ago, only yesterday in geologic time.

As it advanced across the cold seafloor, the lava capped water-filled cracks. This water heated and rose in a jet, hardening the lava it touched. After the lava lake drained, the hollow pillar—the mold of a water column—remained, with ledges like bathtub rings (***lower right***). Similar ledges line the lake edge three meters beyond.

On top of the pillar we see animals, perhaps tube worms. Sediments begin to collect, snowing down at the rate of five centimeters every 1,000 years, eventually



blanketing the bottom as it moves away from the rift.

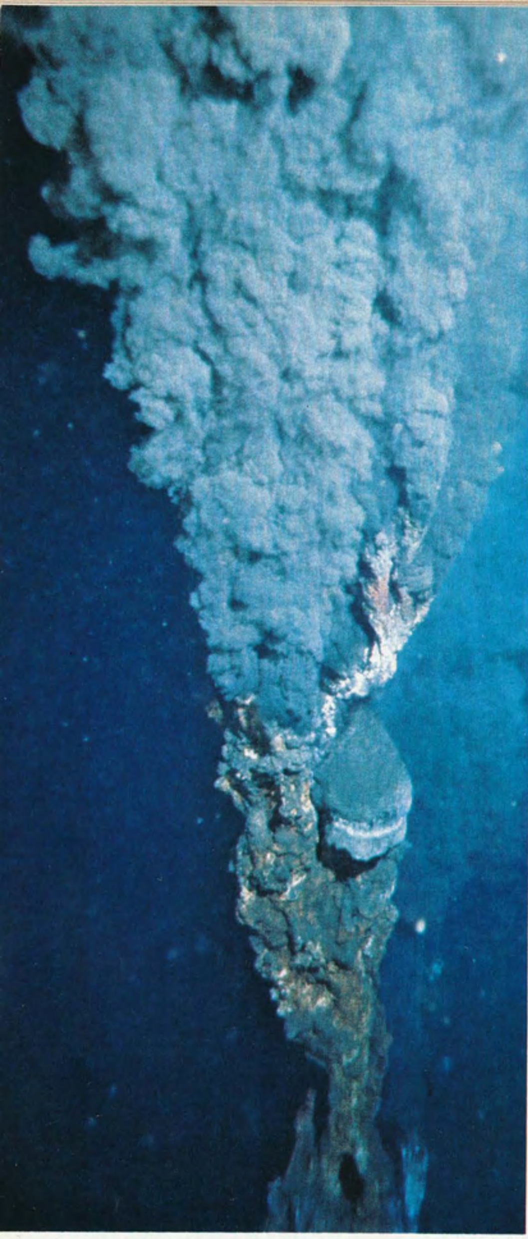
Quiet for now, the ocean-floor crust will undergo intermittent rifting and eruption on a cycle of about 10,000 years. With time the lava cracks, and water circulates down and up again, creating new vents. When cracks go deep enough, magma will again be released, and the cycle will repeat.

Our findings clear up major mysteries about the composition of ocean water. We once assumed all its minerals had to come from river runoff. Yet the elements in the ocean were out of balance—not enough magnesium and too much manganese. Direct sampling of vent water proves that during circulation deep in the ocean crust, seawater drops off magnesium and picks up manganese. John Edmond, geochemical leader of the Galapagos II expedition, calculates that all the world's oceans circulate through the crust once every ten million years.

TOWED ANGUS CAMERA, WHOI

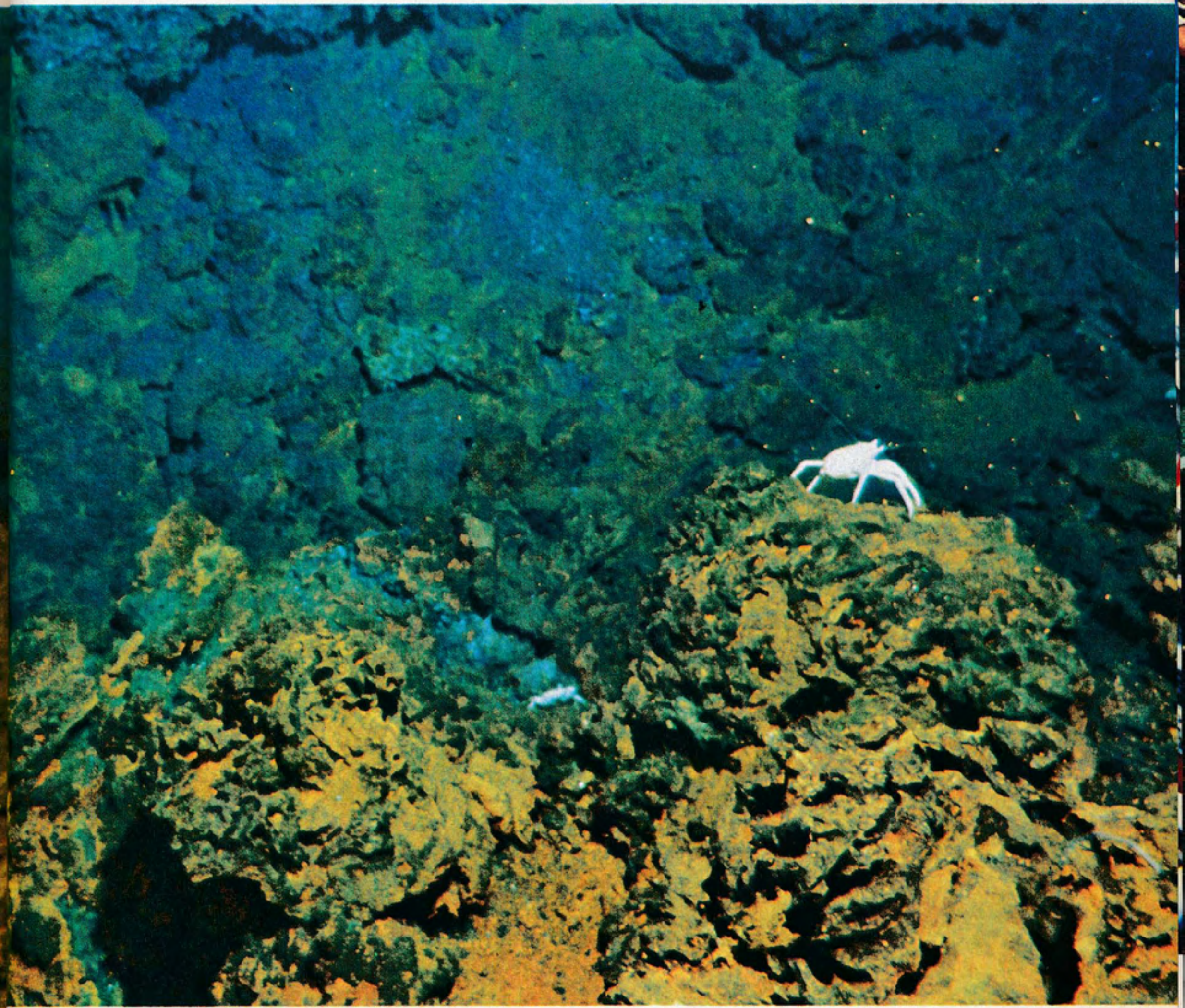
JEAN FRANCHETEAU, CENTRE NATIONAL POUR L'EXPLOITATION DES OCÉANS

Lava lakes and frozen pillars



LIKE A FACTORY at full throttle, a submarine chimney at 21° N belches hot mineral-laden water that rises through cold seawater pressing down at nearly two tons per square inch (***upper left***). As the solution mixes with the near-freezing water, it precipitates yellow, ocher, and reddish brown deposits of iron, copper, and zinc sulfides (***above***). When *Alvin* breaks off and

Minerals erupt at hot spots

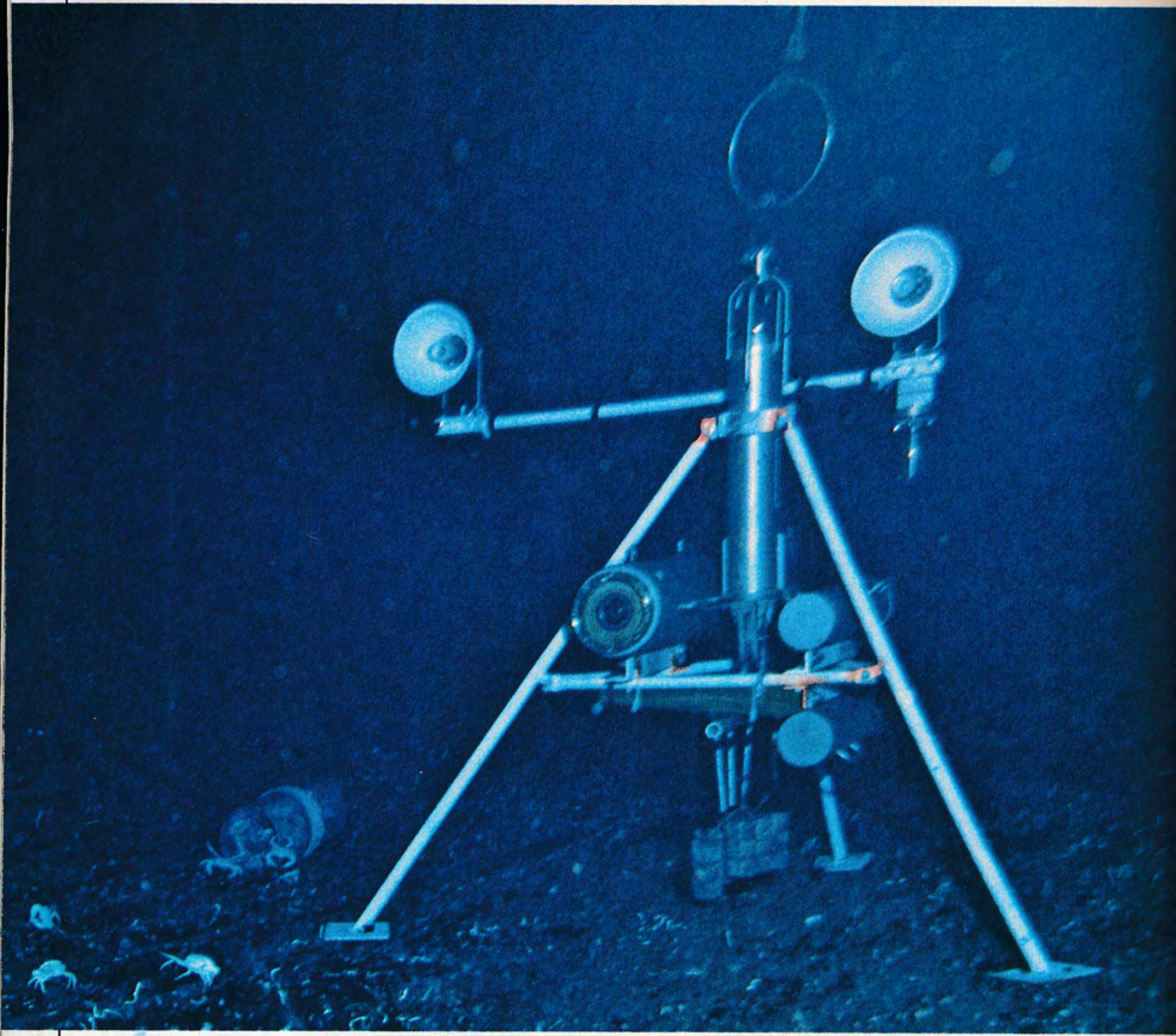


ROBERT D. BALLARD, WHOI (ABOVE AND FAR LEFT); EMORY KRISTOF (CENTER AND LOWER LEFT)

retrieves a fragment (***left***), we learn its dull exterior is sphalerite, a zinc sulfide, while its bright interior is chalcopyrite—fool's gold.

With *Alvin*'s claw, we insert a temperature probe vertically into a "black smoker." The readout inside the sub spins off scale. Later we determine that the water must be hotter than 350°C (650°F). But only one end of the plastic rod has melted (***above, center***). The far end is unaffected, showing that the solution cools instantly as it mixes with seawater.

As Mid-Oceanic Ridge exploration has shifted from relatively quiet spreading centers in the Atlantic to the Pacific's more active rifts, our anticipation has grown. Will we finally actually see molten lava erupting, and more exotic animals thriving, when we dive to the fastest spreading center known, off Easter Island on the East Pacific Rise? □

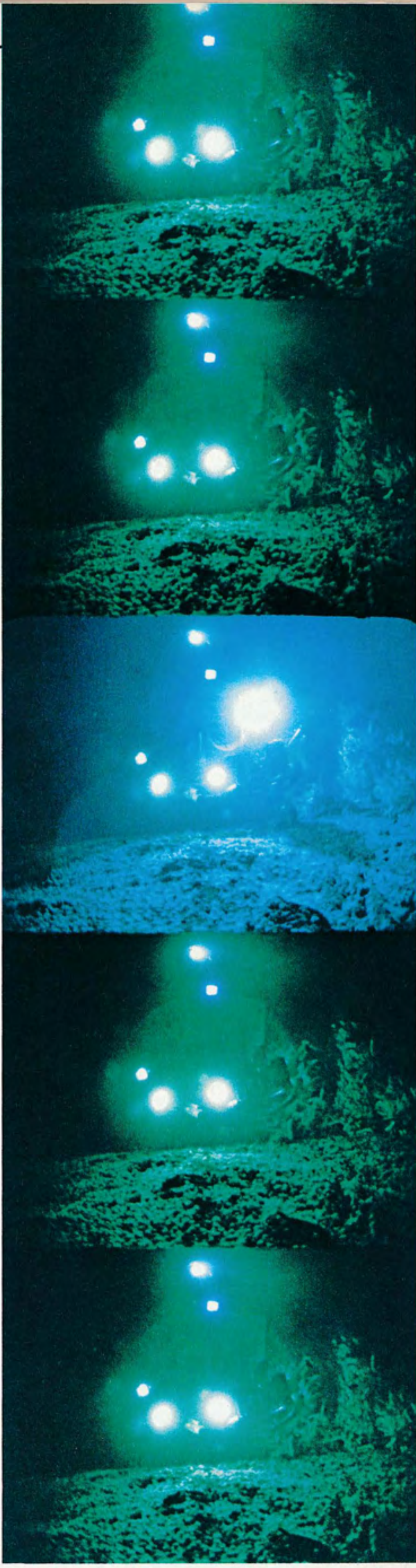


EMORY KRISTOF

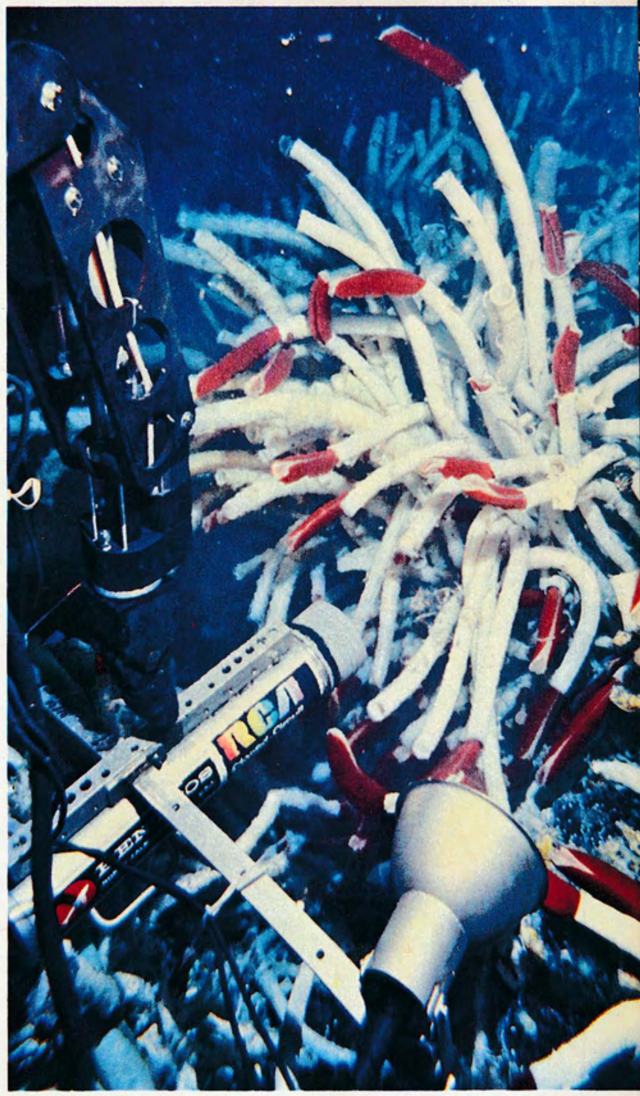
AMADEO BASILE

Rescue of a camera

SHOOTING by remote control, this motion-picture rig performed perfectly. Its 16-mm camera recorded the eerie spectacle of Alvin's *approach* (right). *Then on command the rig released weights, and glass floats provided lift. But 150 meters from the surface, it disappeared. Sixty-six days later, 490 kilometers north, tuna-boat Capt. Andjelko Valcic* (left) *spotted a float on the surface. Here he returns the camera to National Geographic photographer Emory Kristof, its film miraculously intact.*



EMORY KRISTOF AND ALVIN M. CHANDLER



AL GIDDINGS, SEA FILMS, INC.

A new undersea eye

ON ITS FIRST deep-sea mission, a lightweight color video system produced close-ups of unusual clarity. Inside the four-inch-diameter pressure housing from Benthos, Inc., a camera developed by RCA carries three integrated circuits. These charge-coupled devices, or CCD's, convert reflected light directly to electrical signals that can be viewed and taped inside Alvin. *Later, images can be enhanced for study. Assisted by a Society grant, this TV camera becomes a permanent tool of* Alvin.