The Discovery of Hydrothermal Vents

25th Anniversary CD-ROM

Notes on a Major Oceanographic Find

by

Robert D. Ballard

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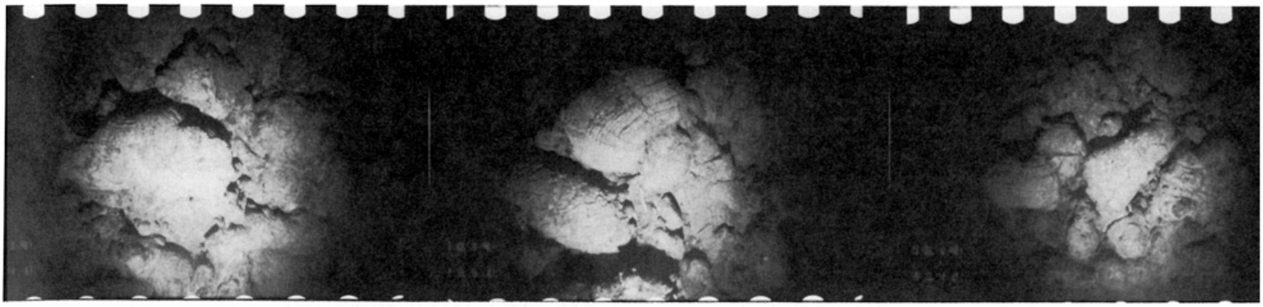
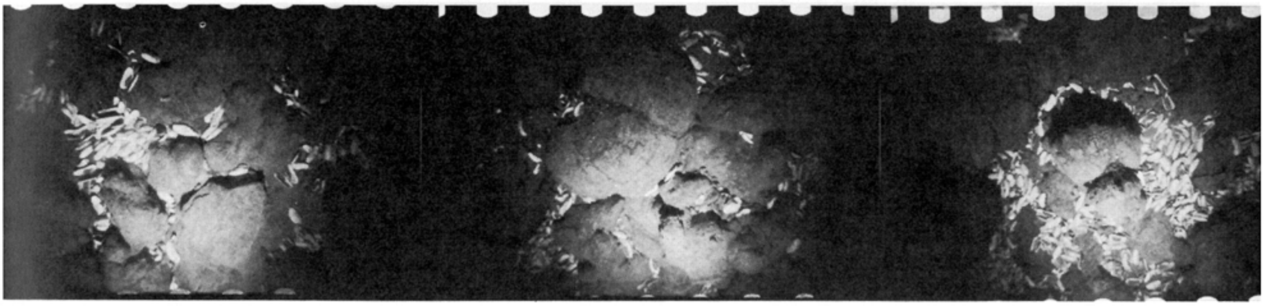


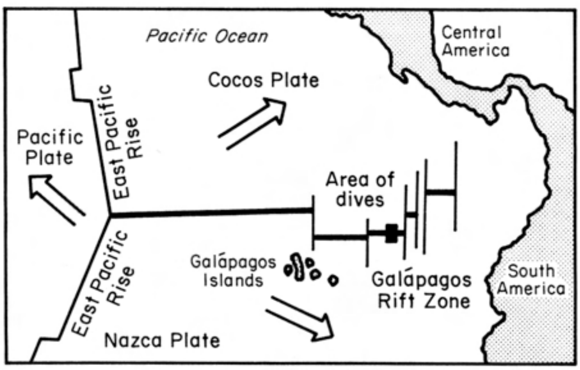
NOTES ON A MAJOR OCEANOGRAPHIC FIND

by Robert D. Ballard



Editor's Note: Since 1974, there have been a series of scientific expeditions to deep-sea areas to explore firsthand the centers of sea-floor spreading (see Oceanus, *Winter, 1974). That year the area for exploration was the Mid-Atlantic Ridge, last year it was the Cayman Trough near Cuba, and early this year it was the Galápagos Rift, a name that evokes the memory of Darwin and his* Origin of the Species. *Some 30 scientists and three research vessels participated in the expedition this February and March, where, for the first time, colonies of marine animals, some as yet unidentified, were found thriving around four hot-water geysers on what was thought to be a barren ocean floor. What follows is a description of that significant discovery. The Galápagos Rift expedition, which was part of the International Decade of Ocean Exploration sponsored by the National Science Foundation, was followed in the summer of 1977 by a return to the Cayman Trough area, where a series of dives were planned by the U.S. Navy Bathyscaph* Trieste II *to approximately twice the depth of the Galápagos dives. The search to find more life existing without the aid of sunlight is under way.*

The research vessel *Knorr* of the Woods Hole Oceanographic Institution steamed out of the Panama Canal February 8, 1977, headed for the Galápagos Rift in the Pacific Ocean some 330 kilometers northeast of the Galápagos Islands and 640 kilometers west of Ecuador. The vessel was on a mission to make a detailed study of several hot water vents on the ocean floor in depths of between 2,500 and 2,700 meters. The voyage marked the third major expedition in the last four years to spreading centers where molten lava from the earth's mantle periodically erupts and pushes adjacent crust



aside. *Lulu,* the mother ship of the Institution's submersible *Alvin,* was scheduled to follow four days after the *Knorr* finished its preliminary work.

On February 12, after four days at sea, a series of fixes taken on orbiting satellites indicated that the *Knorr* was in the general area of the Rift. With speed reduced and the ship's forward cycloidal propellers secured for quieter running, the bottom echo sounder was turned on and the ship began making a series of north-south runs across the rift valley floor. Among the principal members of the scientific party aboard were: Dr. Richard Von Herzen and myself from the Woods Hole Oceanographic Institution; Dr. John B. Corliss, Dr. Jack Dymond and Dr. Louis Gordon of Oregon State University; Dr. John Edmond and Dr. Tanya Atwater of the Massachusetts Institute of Technology; Dr. Tjeerd H. van Andel of Stanford University; and Dr. David Williams of the United States Geological Survey.

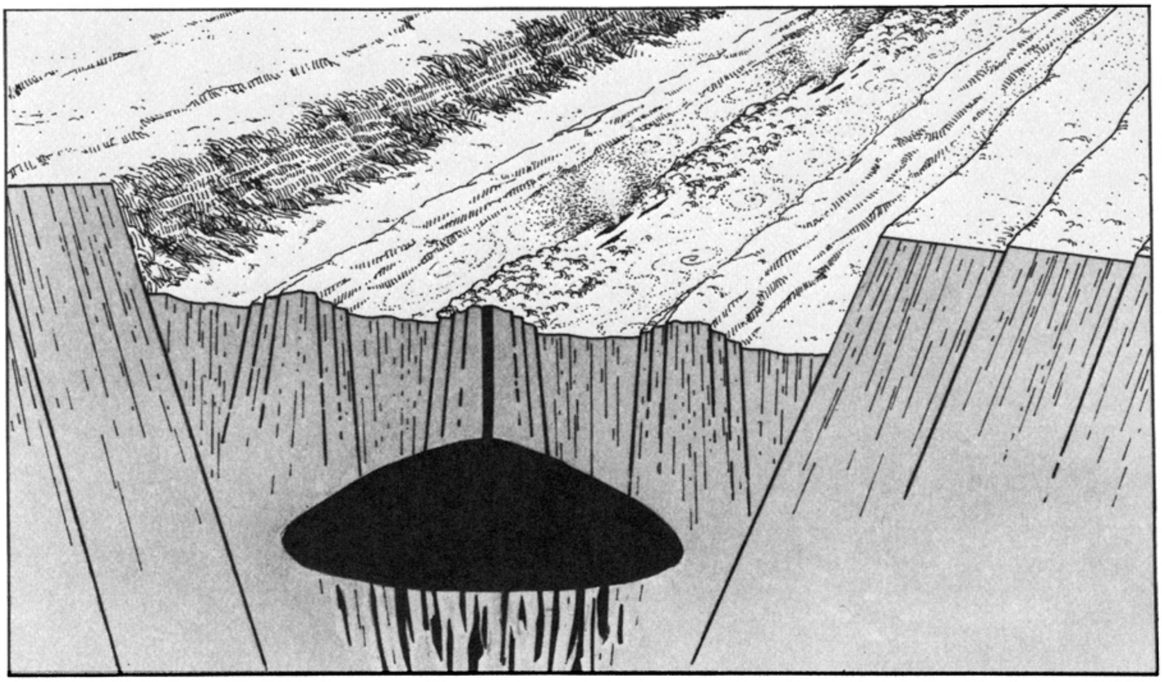
In 1976, the U.S. Navy conducted a detailed bathymetric survey in the area of the Rift, using a highly sophisticated multi-narrow-beam mapping system. As a result, the *Knorr* had aboard fine-scale topographic maps of the valley. As the ship crossed back and forth, the echo-sounding profiles were compared to the maps. Slowly, features on the ocean floor became recognizable. The north and south walls that flank the inner rift valley were located, as well as the central axis running down the middle of the valley. Later, individual volcanoes were identified. Assured by these profiles that the ship was in the proper area, preparations were made to install a network of bottom transponders that would serve as reference beacons once work began (see *Oceanus,* Sound in the Sea, Spring 1977). Both *Alvin* and the unmanned *Angus* (Acoustically navigated geophysical underwater system) sled would be tracked by this network of acoustic transponders.

The network consisted of a grid pattern of transponders installed in the valley and on its flanking walls. The exact shape of the pattern was determined by the proposed tracks and the nature of the bottom relief. Since acoustic signals would be used to communicate with the transponders, it was important that they be emplaced on high ground to insure that each transponder could acoustically "see" either *Alvin* or *Angus.* Once the beacons were dropped into position, the ship moved to a number of different locations and ranged on the transponders. It sent out a 7.5-kilohertz (kHz) signal that traveled through the water to the various transponders, each of which returned a signal having a different frequency — Sleepy at 13.5 kHz, Dopey at 13.0, and Bashful at 12.5. After several hours of ranging, the data were fed into a computer and the precise configuration of the transponder net was determined.

Earlier Trips to the Rift

From the results of earlier studies in the Galápagos Rift area we can reconstruct an interesting story. The Rift, for example, is part of a global mid-oceanic ridge system. In this system, the crust of the earth is separating under the influence of what are thought to be convective processes within the earth's interior. Previous studies indicate that not only is the Galápagos Rift similar to other regions of crustal separation, such as the Mid-Atlantic Ridge and the East Pacific Rise, but that the temperature of the crust in this region showed unusual patterns when measured by heat flow probes. As further expeditions were made to the Rift, it became clear that hydrothermal circulation within the upper segment of the newly formed oceanic crust might be responsible for the pattern of heat flow values. If this proved to be true, the possibility would exist that hot water could be flowing out of the crust into the sea at the bottom interface. This condition was discovered in 1972 by the Woods Hole Oceanographic Institution and confirmed in 1976 when the Deep Tow system of the Scripps Institution of Oceanography detected warm water anomalies within the Rift valley, among other means by collecting samples having an unusual chemistry suggestive of hot-water discharge from the crust.

When the Deep Tow operation was completed in 1976 aboard Scripps' *R/V Melville* (sister ship to the *Knorr*), two of their acoustic transponders were left on the bottom to mark the area where these anomalies were recorded. While the *Knorr* was echo sounding and the transponder net was being installed, ranging on the Scripps transponders further pinpointed the ship's location.



An artist's rendering of the Galápagos Rift valley, showing hot vent areas in the center of the valley. These vents are located along the boundary between the Cocos and Nazca plates, which are slowly moving apart. The valley is caused by this pulling apart. Due to a release in pressure related to this rifting, the hot plastic interior of the earth undergoes a partial melting process. This hot magma then rises up the rift or crack to form a magma chamber that feeds the volcanic eruptions on the floor of the valley.

Search Begins for Vents

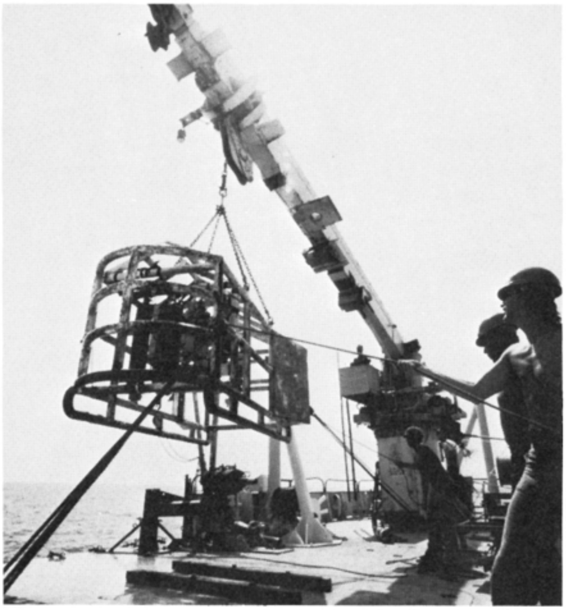
After the net was installed and surveyed, the search began for the hot-water vents. The two-ton *Angus* sled was readied; its camera and strobe lights were checked, as well as its bottom pinger and water temperature telemetry unit. The first lowering lasted 12 hours and was conducted in a weaving pattern back and forth across the central axis of the valley floor. This was the region where the most recent volcanic eruptions were thought to have occurred.

Getting the *Knorr* into position took some time. Although the surface of the ocean was flat with very little wind blowing, the ship's tracking data indicated a 1½-knot current was pushing the ship to the west. Using the ship's two cycloidal units, fore and aft, the *Knorr* was brought into a stationary position and the heavy *Angus* sled was lowered over the side. At the same time, the tracking system was shifted to the ship/fish mode, and a second dot tracing began to appear on the television screen in the main lab.

The ship began a tracking cycle by sending out its 7.5-kHz signal to which the transponders replied. These data were automatically fed into a computer, and a dot came on the screen. The ship then sent out another signal at 8.0 kHz. The transponders ignored this signal, but the sled did not. It responded by sending out its own 7.5-kHz signal that traveled directly back to the ship, as well as to the transponders that then responded to the ship. These data (along with the ship's position, which was determined seconds earlier) were used by the computer to calculate the location of the sled within a three-dimensional frame of reference.

As the sled was lowered, its altimeter telemetered back the distance to the bottom. At 90 meters off the bottom, the winch operator was told to slow the descent. From this point on, we began carefully to lower the sled the remaining distance. With the bottom near, we started moving the ship forward, increasing the speed over the bottom until the computer indicated both ship and sled were moving about three-quarters of a knot across the floor.

Forty-five minutes into the lowering, the camera automatically turned on and began taking pictures by strobe light every 10 seconds. At the selected speed, this gave us a continuous photographic strip beneath the camera some 6 meters in width as we raised and lowered the sled, trying to keep it no more than 4.5 meters above the bottom. Periodically, the bottom would suddenly rise,



Deck hands steady Angus sled. (© National Geographic Society)

and, if the winch operator did not raise the sled fast enough, it would crash into the bottom. On numerous occasions, the tension of the wire rose rapidly; if it had exceeded 20,000 pounds, the cable would have snapped with the loss of approximately $100,000 in equipment.

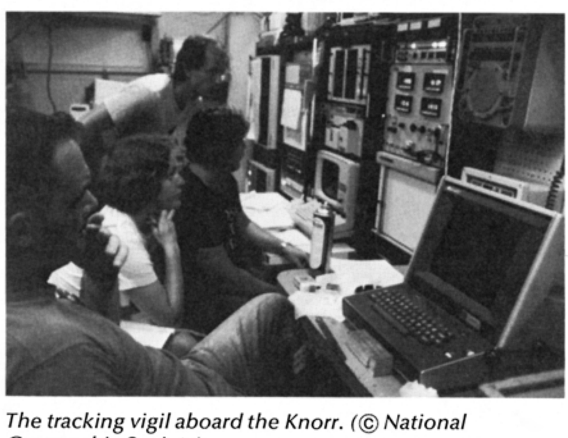
Fortunately, it never did. Within a few minutes the towing operation had stabilized, and we settled into an all-night vigil — one person monitoring the sled altitude and telling the winch operator "up one, down two, up fast, damn!"; another watching the computer plots, asking the bridge to "change course to 150, reduce speed on the aft cycloid," or "secure the forward cycloid, we're losing tracking"; and a third watching the temperature of the water that the sled was passing through.

Six hours into the watch — after a lot of coffee, popcorn, and listening to record albums — the telemetered water data indicated a major temperature anomaly that lasted less than three minutes. The precise time was noted, the computer print-out of the navigation data was reviewed, and the X and Y coordinates of the time of the temperature anomaly were circled. When the temperature returned to normal (approximately 2.01 degrees Celsius), the vigil began again.

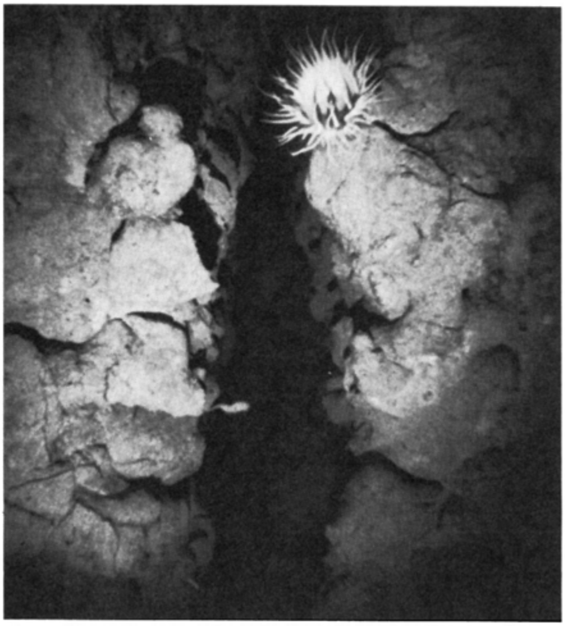
After 12 hours, the *Angus* sled camera was out of film, having taken 3,000 color photographs. Sixteen kilometers of bottom terrain had been traversed, with only one temperature anomaly recorded. The order was given to raise the sled; an hour later it was aboard. The sled had been in near-freezing water, so, to prevent condensation from damaging the film, we waited two hours for the camera housing to warm up before unloading the film. The 400-foot roll was then taken to the film lab for processing. In the meantime, the ship had been turned over to the heat flow team, while the *Angus* crew caught some sleep. By mid-morning, the film had been developed, dried, and was ready for viewing.

The first few frames were blue because the camera had turned on just before reaching the bottom. The first picture of the sea floor showed that it was covered by a massive and complicated pile of fresh "pillow" lava. As the crust of the earth is pulled apart under the forces of sea-floor spreading, cracks develop in the floor of the rift valley. These cracks widen and deepen with time, eventually releasing pressure at depth, which leads to a partial melting of the hot interior. The newly formed magma rises up through the fractured crust to the valley floor, where it flows out as lava at a temperature of 1,250 degrees Celsius. The lava comes into contact with cold seawater that has a temperature of 2 degrees Celsius; it quickly cools, forming pillows that resemble mounds of toothpaste.

We viewed this barren lava terrain frame after frame, witnessing an endless variety of sculptured pillow forms. After about an hour, we noted that the sled had moved out across a



The tracking vigil aboard the Knorr. (© National Geographic Society)



Normal volcanic landscape in a tectonic plate spreading zone. The single sea anemone is typical of the sparse occurrence of living creatures. Scientists think that these large open fissures are the avenues through which seawater enters the crust at near-freezing temperatures. It is warmed by the hot magma beneath the crustal surface and emerges through hot geysers in the center of the Galápagos Rift valley at temperatures up to 17 degrees Celsius.

massive flat-lying surface to the south of the pillowed central axis. Here, the lava forms were quite different. Instead of pillows, the lava resembled forms previously observed near Hawaii called "pahoe-hoe" flows. Having a fresher and glassier outer surface, these flows were clearly younger in age. Their smooth surface and ropey, often whirly features suggested a much faster outpouring of magma.

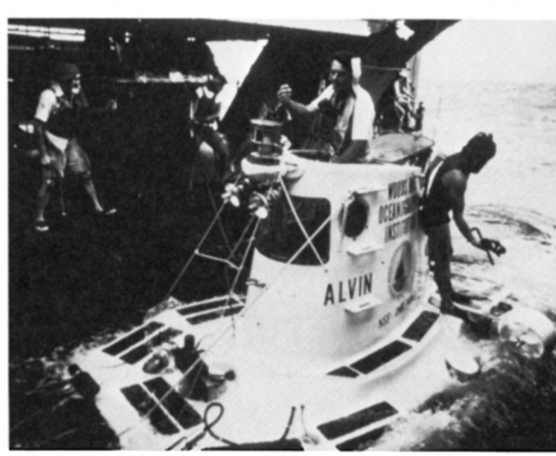
The 13-Frame Discovery

The sled soon crossed back into pillow lava terrain, which made up the low relief volcanoes running down the central axis. As we watched the film, we also kept an eye on the time (in the lower left hand corner of each frame there was a notation of the precise time). As midnight of the previous night approached, we knew the camera was nearing the point where the temperature anomaly had taken place. The photograph taken just seconds before the temperature anomaly showed only barren, fresh-looking lava terrain. But for thirteen frames (the length of the anomaly), the lava flow was covered with hundreds of white clams and brown mussel shells. This dense accumulation, never seen before in the deep sea, quickly appeared through a cloud of misty blue water and then disappeared from view. For the remaining 1,500 pictures, the bottom was once again barren of life.

By the time the review of the film was completed, *Lulu* had arrived on station and *Alvin* was ready to dive. With the X and Y coordinates of the thirteen frames in their back pockets, Corliss, Dymond, and Edmond jumped into a Boston Whaler and headed over to *Alvin's* support ship. With the transfer completed, the locus of activity shifted to *Lulu* as the *Knorr* headed south to begin work in another region 16 kilometers away suspected to be hydrothermally active.

While the final checks were being made on *Alvin,* the science navigator moved *Lulu* to the launch site over the location of the clam and mussel pictures. Using the transponder tracking system, a final check was made on the current drift. *Alvin* was then lowered on its cradle, and Corliss and van Andel climbed aboard, along with the pilot of the submersible, Jack Donnelly. When the launch was completed and the handling lines removed, the submersible flooded its air tanks and sank toward the bottom at the rate of 30 meters per minute. After an hour and a half, *Alvin* reached the bottom (approximately 2,700 meters) about 270 meters south of the target.

Driving first across the fresh, glassy pahoe-hoe flows and then up onto the pillow



Alvin preparing to leave mother ship Lulu prior to dive in the Cayman Trough. Jack Donnelly, the pilot, is in the conning tower. (© National Geographic Society)

Alvin, beginning a descent into the Cayman Trough. (Photo by John Porteous)

lavas of the central axis, the scientists inside the submersible observed the same features that had been captured through the lens of the *Angus* camera the night before. But when they reached their target coordinates, *Alvin* and its three-man crew entered another world. Coming out of small cracks cutting across the lava terrain was warm, shimmering water that quickly turned a cloudy blue as manganese and other chemicals in solution began to precipitate out of the warm water and were deposited on the lava surface, where they formed a brown stain. But even more interesting was the presence of a dense biological community living in and around the active vents. The animals were large, particularly the white clams (up to 30 centimeters or 12 inches). This basis of life was only 50 meters across and totally different from that of the surrounding area. What were the organisms eating? They were living on solid rock in total darkness.

An answer to this question began to emerge later when the water samples obtained from inside the vents by *Alvin* were opened for analysis aboard the *Knorr*. As the chemists drew the first water sample, the smell of rotten eggs filled the lab. Portholes were quickly opened. The presence of hydrogen sulfide was the key. The cracks in the floor of the rift valley provided avenues for cold seawater to enter and circulate within the hot, newly formed crust. As the seawater traveled deeper into the hot crust, the water temperature rose and its chemical composition began to change. Losing some chemicals to the rock, the seawater picked up others. The sulfate in the seawater was converted to hydrogen sulfide. Now heated, this altered water began to rise back to the surface, mixing with fresher seawater from above. Traveling up the small cracks, some of the warm water flowed out of the rock at 8-16 degrees Celsius to form a series of vent areas. The hydrogen sulfide in this warm water was quickly taken up by bacteria that rapidly multiplied. A food chain was thus initiated in total darkness independent of the sunlight at the surface.

Giant mussel, top, and clam taken from near Galápagos Rift vent area. Samples show that the water welling up through the vents is rich in hydrogen sulfide, which scientists think might provide the bacteria that support marine life in the area. (Photo by Emory Kristof © National Geographic Society)

Five Vent Areas Probed

By early into the second leg of the expedition, *Alvin* and *Angus* had located and investigated four more vent areas along an 8-kilometer stretch of the central axis. Four of the vents were active, while one vent was inactive with only dead clam and mussel shells found scattered over the lava flows. A massive kill apparently had taken place when the vent was closed off, and the bottom organisms were unable to move to an active vent, some 225 meters to the east.

Another interesting aspect of these isolated worlds was that no two were alike. The first vent area was dubbed "Clambake I." It was characterized by large white clams, brown mussels, and numerous white crabs. In addition, a purple octopus, one of the few predators in the area, was observed. The second vent region was called "Clambake II," but no warm water was found, and all the animals were dead. Hundreds of clam and mussel shells were observed slowly dissolving in the cold water, which was unsaturated in calcium carbonate. The third site was termed the "Dandelion Patch" for its abundance of a small animal (still unidentified at this writing), about 2.5 centimeters in diameter, that resembled a dandelion gone to seed. Instead of being on a stalk, however, this organism held itself in place several centimeters above the bottom, using an intricate pattern of radiating fiber elements up to 16 centimeters long. This vent area, having a fairly simple population, appeared to have become active relatively recently. The fourth site, called the "Oyster Bed," did not have any oysters, but what's a geologist to know (there wasn't a single biologist on the entire cruise — only geologists, geophysicists, chemists, geochemists, physicists, and a science writer).

The fifth vent area was the most interesting. It was one of the larger areas and had several active vents. It was termed "the Garden of Eden" for its numerous and interesting life forms. Saturation photographic runs by *Angus* showed this vent area to have distinct rings about the active vents in which certain organisms dominated. The outer ring consisted of dandelions and white crabs. The next ring contained a small worm attached to the rock surface. The dandelions then disappeared close to the vent. Limpets, pink fish, and tall, white-stalked worm tubes with bright red tops were observed at the entrance to the vents themselves.

(Editor's Note: The following italicized material is part of a memorandum sent to Dr. Paul M. Fye, Director of the Woods Hole Oceanographic Institution, on March 10, 1977, from Corliss and Ballard. It gives a sense of the scientific procedures that were followed by the cruise participants.)

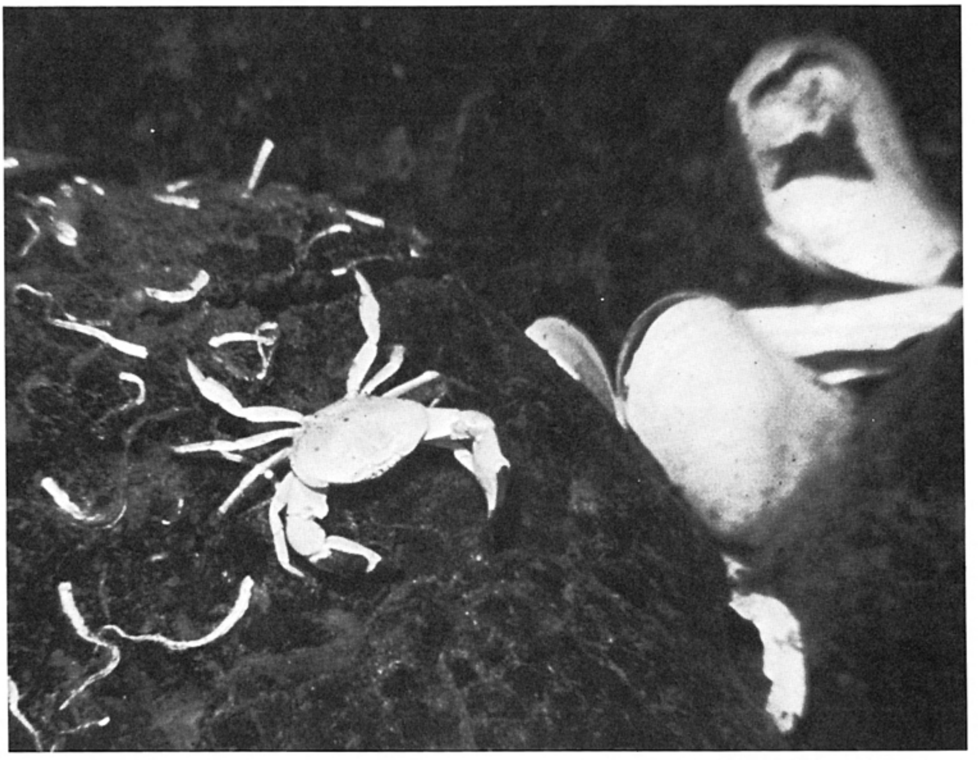
As a part of our overall scientific investigation of the hydrothermal regions within the Galapagos Rift, we are presently carrying out a comprehensive series of geological, geophysical, geochemical, and biological studies.

To date we have located and investigated four regions of active hydrothermal vents within the rise crest. All of these sites are located with fresh lava terrain containing no sediment pockets; thus, the collection of routine sediment samples is impossible.

At each of these sites we have obtained 50-100 liters of water, ranging in temperature from 8 to 16 degrees Celsius. The samples were taken from directly within the active vents. At all times and particularly during the sampling periods, the following parameters were displayed in real time and recorded within the pressure sphere on magnetic tape 10 times per second: conductivity, temperature within the vent to .002 degrees Celsius, temperature of the water flowing through the sampling system to the same precision, dissolved oxygen content, pH, precision depth, altitude, and precision time. The precision time base is then used to tie this information to color photographs of the bottom being taken every 10 seconds . . . .

The water samples collected have been analyzed aboard ship within a 24-hour period for the following parameters: salinity, chlorinity, dissolved oxygen, phosphate, silica, nitrate, nitrite, ammonia, hydrogen sulfide, pH, alkalinity, total carbon dioxide, dissolved hydrogen, radon, calcium, and magnesium. During the sampling period in situ filtrations at .4 microns have been made in each area.

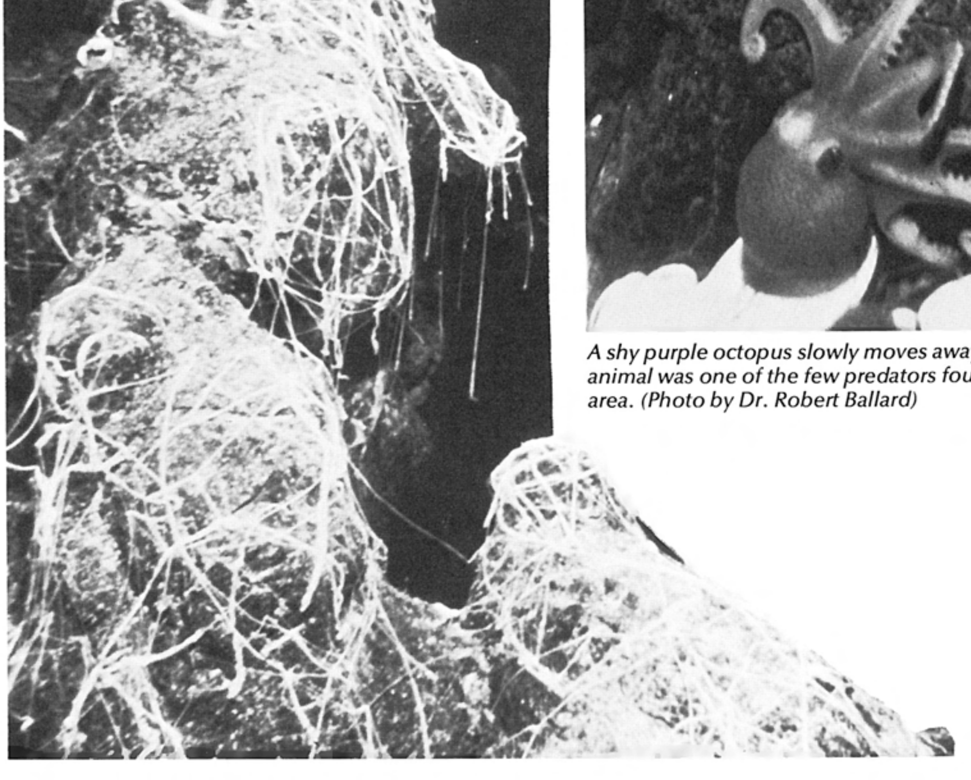
In addition, we have placed a long-term ocean bottom monitoring system at two vent areas. Lowered to the bottom by the Knorr *and placed over an active vent by* Alvin, *this system*



Crab, 15 centimeters across (about 6 inches) crawling across a pillow lava rock covered with worm tubes and brown manganese oxide, which precipitates out of the water. In the upper right hand corner, there is a dead clam shell that is slowly dissolving in the water, which is low in calcium carbonate. (Photo by Dr. Robert Ballard)

A shy purple octopus slowly moves away from Alvin. This animal was one of the few predators found in the geyser area. (Photo by Dr. Robert Ballard)

Unusual spider-like tube worms that were found near the geyser region, but not within it.



Stalk-like worm tubes found close to the vent areas. These were 36 to 46 centimeters (14 to 18 inches) long, much larger than those generally known to marine biologists. Limpets, crabs, sea worms and as yet unidentified fish can also be seen. The photograph was taken by Dr. John Edmond of the Massachusetts Institute of Technology, using a hand-held camera from inside Alvin.

The first organism found on the outer perimeter of the geyser was a small spherical animal that researchers dubbed "dandelion." These animals, which are 2.5 to 5 centimeters (1 to 2 inches) across, used web-like fibers to position themselves above the bottom in an apparent feeding position. (Photo by Dr. John Corliss)

Alvin's mechanical arm picks up large clam specimen from Clambake I. Clam measured 30 centimeters (about 12 inches). (Photo by Dr. Robert Ballard)

measures the water flowing vertically out of the vent and the temperature on four thermistors nearby every 14 seconds for 10 days.

To determine the flux of biogenous and inorganic detritus to the benthic environment, Alvin *closed and recovered three large, near-bottom sediment traps that had been installed seven months earlier by the* R/V Melville . . . .

More specifically, the following biological samples have been collected in this total rock terrain; at two sites water samples were drawn by Alvin *and bacteria cultures prepared in accordance to instructions given to us prior to the cruise; at three sites samples of water were drawn and filtered in situ to collect the slimy material covering the rock surface near the vent. This material was later refrigerated. At least three species of both living and dead pelecypods, two species of living gastropods, arthropods, and a variety of tube worms were collected and either frozen or placed in a buffered formalin.*

In addition, a wide-angle time-lapse camera system with color film has been placed in one vent area by Knorr *to take pictures every four minutes for two days. The camera is baited and in one instance included a baited trap to collect specimens. . . .*

At this point in time we have five more potential dives remaining; three in the vent region and two in the mounds area. . . .

In all, two months were spent investigating the Galápagos Rift and the hydrothermal deposits to the south. Twenty-four dives were made, numerous samples were collected, and more than 100,000 color pictures were taken. The discoveries made on this expedition will likely have a major effect on all disciplines of oceanography.

Robert D. Ballard is an Associate Scientist in the Department of Geology and Geophysics at the Woods Hole Oceanographic Institution. He has made numerous dives in Alvin and other submersibles.