1 Discover the Mystery of the Deep Dark Sea

Background information

The deep ocean is like a black box. It is dark, packed with mystery, and inaccessible without the help of technology. In *Volcanoes of the Deep Sea*, the film crew shed light on some of the mysteries that lie more than two miles beneath the ocean's surface. The *Alvin* submersible, equipped with high-tech cameras and lights, carried the crew down to capture amazing new footage of a world that has existed in darkness for billions of years.

The oceans cover over 70% of Earth's surface and contain about 328 million cubic miles of water. While explorers have roamed the surface of that volume for thousands of years, the deep ocean remained an untouched, unseen mystery. Deep ocean exploration is still in its infancy, a much younger sibling of space exploration. In fact, scientists have explored and mapped far more of outer space than the deep ocean.

The deep ocean, Earth's 'inner space,' is a wonderfully diverse and surprisingly dynamic place. One of the most important deep ocean discoveries was the *Mid-Ocean Ridge*. About 12,000 feet (3658 m) down and 40,000 miles long (64,374 km), this underwater geologic structure is the longest mountain range in the world. It wraps continuously around the world like a global zipper. In 1977, *hydrothermal vents* were discovered along the ridge. Vents are cracks in the seafloor that billow super-hot water packed with minerals, metals and bacteria.

The vents and the extreme environment around them are home to bizarre animals, living in conditions in which no other living things we know of could survive. At 12,000 feet down, the pressure is about 3500 pounds per square inch (240 times what we feel on Earth's surface), the temperature ranges from 2° to 400° C (35 – 750° F), and there is absolutely no light. Scientists were astounded that despite the pitch-black environment in which they sit, vents erupt with life! Discovering animals in this environment has caused scientists to reexamine the very definition of life, and has offered us clues to finding life in other extreme parts of the universe.

Recent advances in technology have enabled scientists to study vents in the deep ocean more often and more thoroughly than ever before, but it is very challenging work. Scientists rely on the *scientific method* to guide their exploration. They form a hypothesis as to where a vent may be, develop a method for their experiment or trip, test their ideas by collecting data, formulate a conclusion, and communicate their findings.

Discovering vents like those seen in *Volcanoes of the Deep Sea* is tricky business because the deep ocean is tough to reach. Hydrothermal vents are first located by sending temperature probes into the water column. Usually, deep water is colder than shallower water. When scientists find warmer temperature readings at depths they expect to be cold, they hypothesize that a vent could be nearby. Based on the temperature data, scientists plan a voyage to the abyss using Alvin to observe the vent up close.

Scientists have mapped nearly 100% of the surface of Venus (26 million miles from Earth) but only .001 to 1% of the ocean floor.

exploration

2 Get the Drift on the Mid-Ocean Rift

Why Isn't the Earth Getting Bigger? PAGE 30

Background information

The Earth is made of a thin *crust* that surrounds a thicker *mantle* and super-hot *core*. The crust is made up of twelve major solid rock plates called *tectonic plates*, which are either 'continental' (forming the continents) or 'oceanic' (forming the sea floor) in nature. Tremendous energy in the form of heat and pressure rises from the core, causing circular movements in the mantle called *convection currents*. The convection currents cause the tectonic plates of the Earth's crust to move around. The plates move in different ways: oceanic plates slide apart from each other, continental plates slide past each other, and oceanic plates slide under continental plates.

In *Volcanoes of the Deep Sea*, we see what happens when oceanic plates move apart from each other. Along the ocean floor are areas called *seafloor spreading centers* or *divergent plate boundaries*. In these areas, *lava* (melted mantle rock) rises between two plates, causing the plates to slide away from each other. When the hot lava meets the cold seawater it solidifies into new crust, continually growing and forming the Mid-Ocean Ridge, the world's longest mountain range. Zigzagging along 40,000 miles (64,374 km) of ocean basins worldwide, the Mid-Ocean Ridge resembles a zipper.

Two sections of the Mid-Ocean Ridge featured in *Volcanoes of the Deep Sea* are the Mid-Atlantic Ridge and the East Pacific Rise. In and around these ridges are cracks in the crust where seawater is heated and forced back out of the crust in a way that creates solid structures called *hydrothermal vents*. As the hot lava rises and pushes apart the oceanic plates, it causes new cracks to form in the ocean crust. Ice-cold seawater rushes down through the cracks and meets the hot *molten rock*, instantly heating the water to temperatures as high as 400° C (750° F). That is hot enough to melt lead! The hot water rises again and reactions occur when it reaches the cold seawater at the ocean floor. Minerals such as sulfur and metals such as copper, zinc, gold and iron from the crust *precipitate* out and settle, forming a mineral-rich hydrothermal vent *chimney*. Active vents are sometimes called *black smokers* or chimneys because of the thick, dark smoke-like plumes of particles they jet into the ocean. Some chimneys have grown as tall as a 15-storey building!

Vents in the Pacific Ocean grow differently than those in the Atlantic Ocean. The seafloor spreading center along the East Pacific Rise splits apart at a faster rate than that of the Mid-Atlantic Ridge. Due to the speed at which the sea floor splits in the Pacific, hot fluids vent more quickly from inside Earth causing the hydrothermal vent chimneys to be taller. Along the Mid-Atlantic Ridge, hydrothermal vent structures build up more slowly because it takes longer for the fluids to vent onto the deep ocean floor. This results in structures that are wider and shorter than in the Pacific.

The creation of crust along the Mid-Ocean Ridge accounts for about 95% of the volcanic activity on Earth.

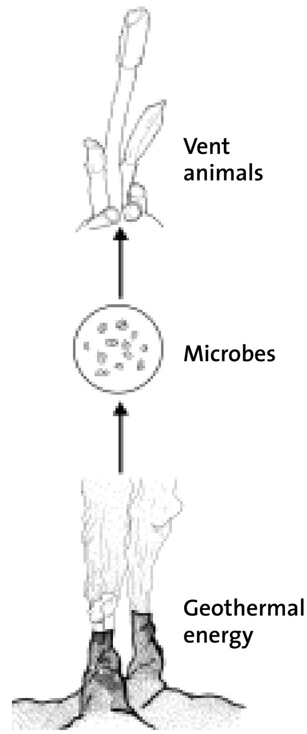
geology

3 Who's Who in the Sunless Deep?

Background information

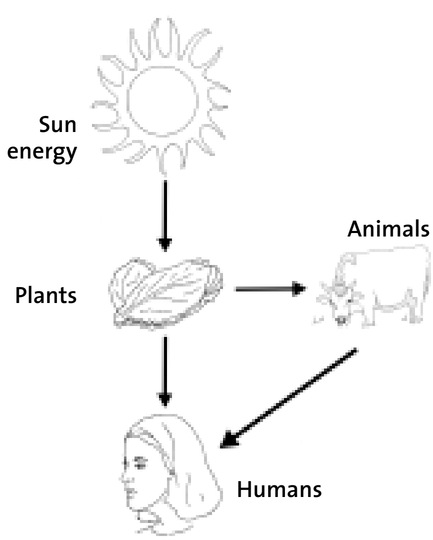
A wildly diverse cast of characters lives around hydrothermal vents at great depths, extreme pressure and in pitch darkness. More than 95% of these life forms are new to science, and scientists find new species on almost every dive.

All living things need energy to survive. For those of us who live on Earth's surface, or in shallower parts of the oceans and other aquatic habitats, energy comes from the sun. Through the process of *photosynthesis*, the sun's energy is converted into usable energy by plants, which provide food for all other animals. However, the sun's rays do not reach the bottom of the ocean where vent creatures live. Instead of photosynthesis, the vent community harnesses energy from chemicals in a process called *chemosynthesis*.



CHEMOSYNTHESIS

Chemosynthesis relies upon *geothermal* (heat) energy from inside the Earth's core, instead of energy from the sun. In the way that plants are the heroes in photosynthesis, microbes are the heroes of the deep, carrying out chemosynthesis at the base of the food web. The water spewing from vents is loaded with *hydrogen sulfide*, a molecule that is toxic to almost all other living systems. Hydrogen sulfide is the key ingredient in chemosynthesis. Bacteria process the hydrogen sulfide to provide energy for all other vent creatures. Without chemosynthetic microbes, life could not exist in the deep.



PHOTOSYNTHESIS

The order in which vents are colonized by animals over time is called *succession*. Life around vents first appears as a mat of bacteria that creeps over the freshly baked lava on the ocean floor. The small-but-mighty microbes soon become dinner for tiny shrimp-like animals such as amphipods and copepods that graze on the bacteria, as well as for brachyuran crabs and eelpouts (zoarcid fish). Snail-like limpets, shrimp and tubeworms usually come in next, followed by squat lobsters (galatheid crabs), feather duster worms, and octopi. Mussels and clams are among the last to arrive, and usually signify a more developed vent community.

Some vent organisms graze on the bacteria mats for energy or absorb the chemicals released when the bacteria die. Other animals maintain a *symbiotic* relationship with the bacteria, where both the bacteria and the animal benefit from association with the other. The association between bacteria and tubeworms is a good example of symbiosis. Tubeworms live close enough to the vents to absorb lots of hydrogen sulfide, which feeds the bacteria. Bacteria live inside the tubeworm and convert the hydrogen sulfide to food for the tubeworm. Tubeworms provide a convenient home and lots of food for bacteria, and bacteria in turn provide food for tubeworms and themselves.

The deep-sea vent community is one type of *benthic*, or bottom-dwelling, community. Another more commonly known benthic community is the coral reef. The major difference between these two environments is that the coral reef depends upon sunlight to survive, whereas the vent environment does not.

Vent animals live in a world of extremes. Water at the bottom of the ocean is about 2º C (35º F), whereas vent fluids released from chimneys can reach 400º C (750º F), which is hot enough to melt lead. Tubeworms, shrimp, Pompeii worms and other vent creatures often live on the sides of black smoker chimneys, not too far from the scorching fluids. Despite the vastness of the ocean floor, livable space is extremely limited for vent animals. For example, a tubeworm has to live close enough to a vent to absorb hydrogen sulfide, but just far enough away to avoid getting scorched. Vent creatures have to pick their deep-sea real estate carefully!

4 Unsolved Mysteries of the Deep

Background information

The story of the *Paleodictyon* (pronounced 'pal-ee-oh-DIK-tee-on') began with the discovery of small hexagonal imprints in rock formations in Europe. The imprints, about the size of a poker chip, average 1.18 to 1.57 inches (3 to 4 cm) and are made up of dozens of smaller hexagons. Dr. Dolf Seilacher, a paleontologist and geologist, first discovered these mysterious structures in the 1950s. Identifying the patterns as *trace fossils*, Dr. Seilacher collected and analyzed samples, dated them to be 60 million years old and named them *Paleodictyon nodosum*.

The mystery picked up in 1977, far away from the mountains in Europe. From a video camera towed behind a submersible, marine geologist Dr. Peter Rona observed hexagonal imprints made up of tiny holes in the sediment near hydrothermal vents, deep in the Atlantic Ocean. Dr. Rona nicknamed these formations 'Chinese Checkerboards' because they resemble the board of the popular game. These strangely uniform shapes also averaged 1.18 to 1.57 inches across the middle. As the patterns in the ocean were in sediment, not in rock, Dr. Rona concluded that they had been made recently by a creature very much alive.

Unable to identify the organism that had made these patterns, Dr. Rona published pictures of the mysterious checkerboards in a scientific journal, describing what he had found and where he had found them. Dr. Seilacher read the article and contacted Dr. Rona immediately, explaining he had found the same hexagonal pattern 25 years earlier, but fossilized in rocks. Together, Dr. Rona and Dr. Seilacher hypothesized that the same species that left the trace fossil in the European mountaintops made the identical imprint in the sea floor. Now the questions remain: what is the animal making this pattern? Why does it create this pattern?

Paleodictyon nodosum is a member of a fossil group that dates back 300 to 500 million years. That's 70 to 270 million years older than the earliest known dinosaurs!

One hypothesis at the time *Volcanoes of the Deep Sea* was made is that the animal making the Paleodictyon pattern on the bottom of the ocean is a *living fossil* (a prehistoric species that still lives today), having survived in the deep for many millions of years. Scientists including Dr. Seilacher have hypothesized that the six-sided patterns may indicate a sophisticated form of farming carried out by worm-like animals that secrete mucous to keep their burrows intact. He theorizes that the worm makes hollow shafts in each corner of the structure to trap its prey of bacteria and other microbes. Once its prey is caught, the worm backtracks into the burrow and eats its meal. Most of this tunnel is beneath the sediment; the six-sided checkerboard pattern of holes on the seafloor is the visible entry-way to a similarly symmetrical series of underground tunnels.

Other scientists have other theories as to what makes the pattern at the bottom of the ocean. For example, Dr. Rona posits an alternative theory that a jelly-like creature houses in the imprints, instead of building them to catch its prey.

In *Volcanoes of the Deep Sea*, Drs. Rona and Seilacher team up in the spirit of scientific inquiry to solve the mystery of who made the checkerboards in the deep. They dive to the bottom of the ocean in search of the elusive creature that has been decorating the Mid-Atlantic Ridge with hexagonal patterns. Finding the maker of the imprint is of key importance, yet extremely difficult as deep-sea sediments are fragile, and difficult to core and retrieve from the deep sea for study in a laboratory. And even after doing all the work, there are no guarantees you will find what you are looking for!

5 Get the Scoop on the Deepest Story Ever

Background information

The deep ocean is a unique environment that harbors many mysteries. Exploring the abyss may lead to amazing breakthroughs, from the discovery of new chemicals that can improve our health, to insights on how life on Earth began. However, the deep ocean is a tough place to visit, and it has only been seen in person by a lucky few who have dived in Alvin or another submersible.

Explorers who visit the deep ocean need to make sure they accurately describe what they see on every dive so scientists, journalists and science communicators can accurately report discoveries for the general public. To make things easier in Alvin's cramped quarters, divers often speak their notes into a small tape recorder, and then transcribe them after the dive.

In the very early days of ocean diving, there were no tape recorders or computers so explorers relied on other methods of communication. For example, in 1934 William Beebe and Otis Barton made the first recognized deep dive off the coast of Bermuda. Alvin was not around back then. Instead, they dived in a *bathysphere*, a clunky looking metal sphere that was lowered by cable to a depth of half a mile (.80 km). Barton and Beebe documented their dive by describing what they saw from the bathysphere over a telephone hookup to a colleague on land. She took notes and an artist then did a series of paintings based on the reported observations.

Although we have more advanced technology today to use in exploration, strong, effective communication skills are still important for any deep ocean scientist. The scientists in *Volcanoes of the Deep Sea* have the benefit of seeing their discoveries and dives stored on film and communicated to people that way. Most scientists, however, rely on other methods of communication to record their dive discoveries, such as still photographs, tape recording, writing notes, and publishing papers in science journals.

As the final part of the process of scientific inquiry, effective communication is the lifeblood of science. Scientists observe, question, hypothesize, investigate, interpret/analyze, and then communicate!

Science journalists often work for newspapers, magazines, television or news-related websites. Other science writers work in museums, science centers, and aquaria and serve as interpreters of science for the general public.

In 1865, French novelist and playwright Jules Verne wrote about the possibility of life existing in extreme environments we never thought possible. He predicted we would find fish swimming happily in poisonous water near volcanoes, and other aquatic animals surviving in temperatures hotter than boiling springs and colder than the Polar Sea.

communication

6 Flip the Switch and See What You've Been Missing

Background information

Affectionately called 'the ball' by many scientists, Alvin has served the scientific community for about four decades. Like all submersibles, Alvin has certain limitations imposed by its design. The National Science Foundation, Woods Hole Oceanographic Institute and the National Oceanic and Atmospheric Administration are currently brainstorming ways to improve Alvin's design and, therefore, its capabilities.

Filming *Volcanoes of the Deep Sea* was challenging on many fronts. The scientists and filmmakers worked in a symbiotic relationship to ensure the adventure was successful: the team lit and filmed a spectacular world that had never been captured so clearly before, creating an invaluable tool for scientists that allows them to see an environment they might never get to visit firsthand. To do this, the film team relied on scientists to guide the expeditions, explain the science behind the subject of the film, and collaborate on overcoming the obstacles of filming in the deep ocean.

One challenge of filming the vents was Alvin's size limitations. The diameter of the diving sphere (Alvin's working space) is only about six feet – not much working space for three full-grown adults! This confining space was even further constrained during dives with the IMAX camera. Because the 200-pound IMAX camera is so bulky, only the camera operator and the pilot could dive when the camera was on board. The camera sat in the pilot's seat, but it made the pilot's job extra challenging. The pilot had to steer Alvin by looking out of one of Alvin's side windows!

By far the greatest challenge the film team faced was light. In order to capture an object well on film, it must be properly lit. With zero light at the bottom of the ocean, the filmmakers needed to provide their own. In total, the team took 4400 watts of light to the ocean floor, which enabled them to illuminate an area approximately three quarters the size of a football field. This was a much greater area than divers had ever been able to see from Alvin in the past.

> "Basically, people think the deep ocean is the Titanic. But to me, that's like Martians arriving on Earth one night, landing in a parking lot, and leaving with the impression that that's all Earth is. When you can actually *see* what is down there you can't help but be fascinated."
>
> *Volcanoes of the Deep Sea* Director, Stephen Low

Another challenge associated with light was working within Alvin's energy limitations. Alvin runs on two batteries with enough energy for an eight or nine-hour dive. However, lights consume energy, and to provide enough power for 4400 watts of light, the filmmakers had to use more of Alvin's light energy than ever before. The Alvin divers had to shine an adequate amount of light on the right subjects and film them long enough to get shots to make the movie, while at the same time conserving enough energy to power their ascent back to the ship.

The physical nature of how light travels through water presented yet another challenge. Light does not travel through water as easily as it does through air because water is denser than air. Particles in ocean water, including sediment, structures and living things, also absorb and scatter light, which makes filming problematic.

By working together, scientists and filmmakers were able to find solutions to all the challenges of lighting and filming in the deep.

Charles Martin and William H. Longley took the first underwater color photos in 1926. Longley walked along the bottom under 15 feet of water while Martin waited at the surface with a half pound of magnesium flash powder. At the tug of a rope from Longley, Martin set off the flash powder, burning himself in the process. Still, the experiment proved that with enough light, color photography is possible.

technology