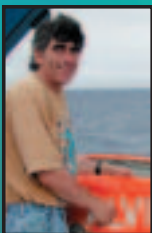




EXTREME 2002

MISSION TO THE Abyss

Dive Mission



Dr. Craig Cary

On October 20, a research team led by University of Delaware marine scientist Craig Cary will set sail from San Diego, California, on the 24-day expedition *Extreme 2002: Mission to the Abyss*.

Their mission will be to explore one of the most demanding environments on Earth — super-hot hydrothermal vents nearly 2 miles deep on the Pacific Ocean floor.

The scientists will sail aboard the 274-foot research vessel *Atlantis* to their dive site in the Pacific and then descend to the vents in the famous deep-sea sub *Alvin*. Both vessels are operated by the Woods Hole Oceanographic Institution.

Under Dr. Cary's direction, the researchers will study the vents and the strange organisms that inhabit them, including the Pompeii worm — Earth's "hottest" animal, able to withstand temperatures up to 80°C (176°F).

For daily logs, photos, and videos of the scientists' activities, details about the marine life they are studying, and the latest expedition news, dive into:

www.ocean.udel.edu/extreme2002



Pompeii worm

The Pompeii worm pokes its head out of its sweltering tube home at the base of a hydrothermal vent in the Pacific Ocean.

What's Inside



Geology: Find out what a hydrothermal vent is and how it forms.



Biology: Take a look at some of the strange creatures that inhabit the deep.



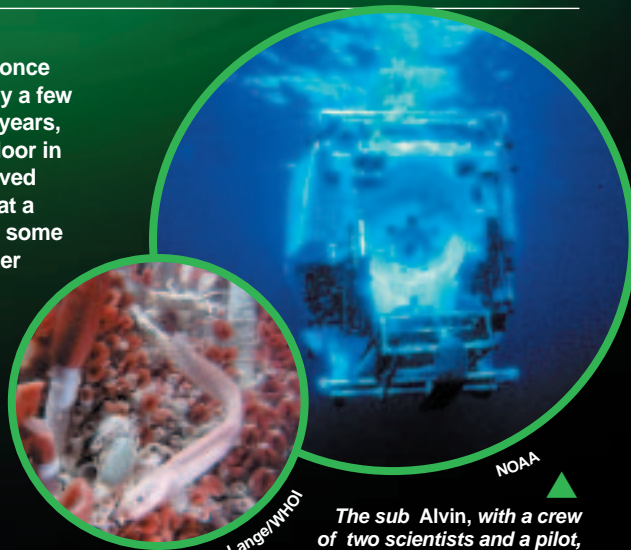
Technology: Learn more about *Alvin* and the tools for deep-sea research.

The ocean's greatest depths once were believed to support only a few organisms. But in the past 25 years, intrepid explorers, diving to the seafloor in high-tech submersibles, have disproved that notion. They have discovered that a number of unusual creatures inhabit some areas of the deep sea — at underwater geysers called *hydrothermal vents*.

Here, over a mile beneath the ocean's surface, live dinner-plate-sized clams reeking of sulfur, towering tubeworms resembling giant lipsticks, ghost-white crabs prowling for prey, pinkish eel-like fish, and the microscopic bacteria that hold together this strange web of life.

Currently, scientists are exploring hydrothermal vent sites to learn more about this "extreme" environment and its unique community of organisms.

After all, vent dwellers thrive under some of the most demanding conditions on the planet. They live in a world of total darkness. They are constantly bathed in toxic chemicals that rocket out of the vents. And some vent organisms — tiny microbes — can survive water hotter than boiling!



NOAA

The sub *Alvin*, with a crew of two scientists and a pilot, begins its descent to the seafloor.

▲ An eel-like zoarcid, the most common fish found at vent sites, swims by a clump of tubeworms.

What's more, the atmospheric pressure exerted on these organisms from the weight of the vast ocean above is more than 250 times the pressure we feel on land.

Turn the page and learn more about hydrothermal vents, the creatures that inhabit them, the technology that makes deep-sea research possible, and the discoveries that marine scientists are making. Let's dive in!

Geology of the Ocean Floor

To someone who can't swim, the "deep sea" may be just above ankle level in the ocean. So what do scientists mean when they refer to the "deep sea"?

The ocean floor is divided into three major areas: the continental shelf, the continental slope, and the deep ocean basin.

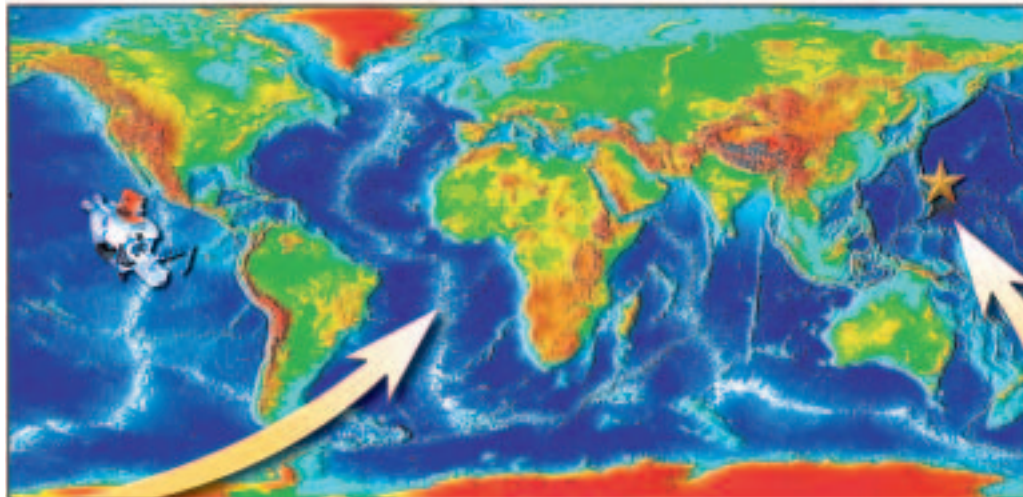
The continental shelf extends underwater from each of the major land masses. It's the submerged portion of the continents. The shelf has features similar to those we see on land, including hills, ridges, and canyons.

On the map to your right, the continental shelf is the light-blue area that edges the continents. The shelf varies in size. It may be virtually non-existent in some areas; elsewhere it may extend a great distance from shore. The shelf's average distance is about 64 kilometers (40 mi).

It is beyond the continental shelf that the "deep sea" begins. The shelf ends at a depth of about 200 meters (660 ft), giving way to the steeper continental slope, which descends about 3,700 meters (12,000 ft) to the deep ocean basin.

Here, the ocean floor deepens sharply and its features resemble those on land, only on a much larger scale, with great plains and

Adapted from NOAA



▲ Did you know that the Earth's longest mountain range is underwater? The Mid-Ocean Ridge system, shown above snaking its way between the continents, is more than 56,000 kilometers (35,000 mi) long. It marks the areas where the Earth's crustal plates are moving apart. This is where most hydrothermal vents are located. The Extreme 2002 dive site, marked above by the submersible Alvin, is in an active vent field in the Pacific Ocean west of Costa Rica.

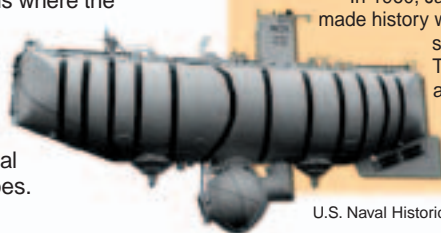
mountains. In fact, the Earth's longest mountain range is underwater. Over 56,000 kilometers (35,000 mi) long, this mountain range, called the Mid-Ocean Ridge system, snakes around the globe.

The Mid-Ocean Ridge marks one of the most geologically active areas on Earth. It is where the planet's crustal plates are moving apart. It is where new seafloor is being born, giving rise to hydrothermal vents and volcanoes.

How Deep Is the Ocean?

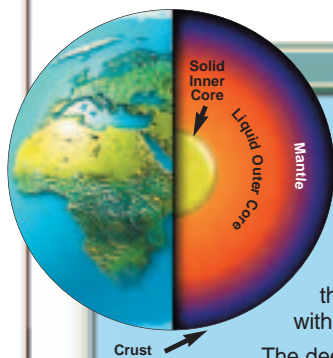
The Mariana Trench is a depression in the Pacific Ocean, east of the Mariana Islands. It is 1,554 miles long and averages 44 miles wide. Within it, about 210 miles southwest of Guam, lies the deepest known point on Earth. Named the "Challenger Deep" for the British survey ship *Challenger II* that located it in 1951, this underwater gorge plunges to a depth of nearly 7 miles!

In 1960, Jacques Piccard and Navy Lt. Donald Walsh made history when they descended in the U.S. Navy bathyscaphe *Trieste* (left) to the bottom of the Mariana Trench. The divers were housed in the sphere at the bottom of the sub.



U.S. Naval Historical Center Photograph

Students, can you convert the measurements into metric units?



Earth's Moving Crust Spawns Vents, Volcanoes & Quakes

Understanding where hydrothermal vents occur requires a closer look at the Earth's structure and the forces at work deep within the planet.

The deeper you go inside the Earth, the hotter it gets. Scientists have calculated that the Earth's inner core — a solid sphere composed primarily of iron — is about 5,500°C (10,000°F). That's about the same temperature as the surface of the sun. The solid inner core is about 2,400 kilometers (1,500 mi) in diameter. It is surrounded by a liquid outer core about 2,225 kilometers (1,380 mi) thick.

Bordering the liquid outer core is the mantle, which is composed of hot, molten rock called *magma*. The churning of the magma generates pressure on the Earth's

surface layer, or crust. The crust is very thin and brittle compared to the other layers. It ranges in thickness from only about 3 kilometers (2 mi) in some areas of the ocean floor to some 120 kilometers (75 mi) deep under mountains on the continents.

According to the theory of plate tectonics, the Earth's crust is made up of about a dozen plates on which the continents and the oceans rest. These plates are continually shifting because the surface beneath them — the hot, magma-filled mantle — is moving slowly like a conveyor belt, driven by the heat in the Earth's core. The plates currently move about a centimeter (0.5 in) to 15 centimeters (6 in) per year in different directions (see map at right).

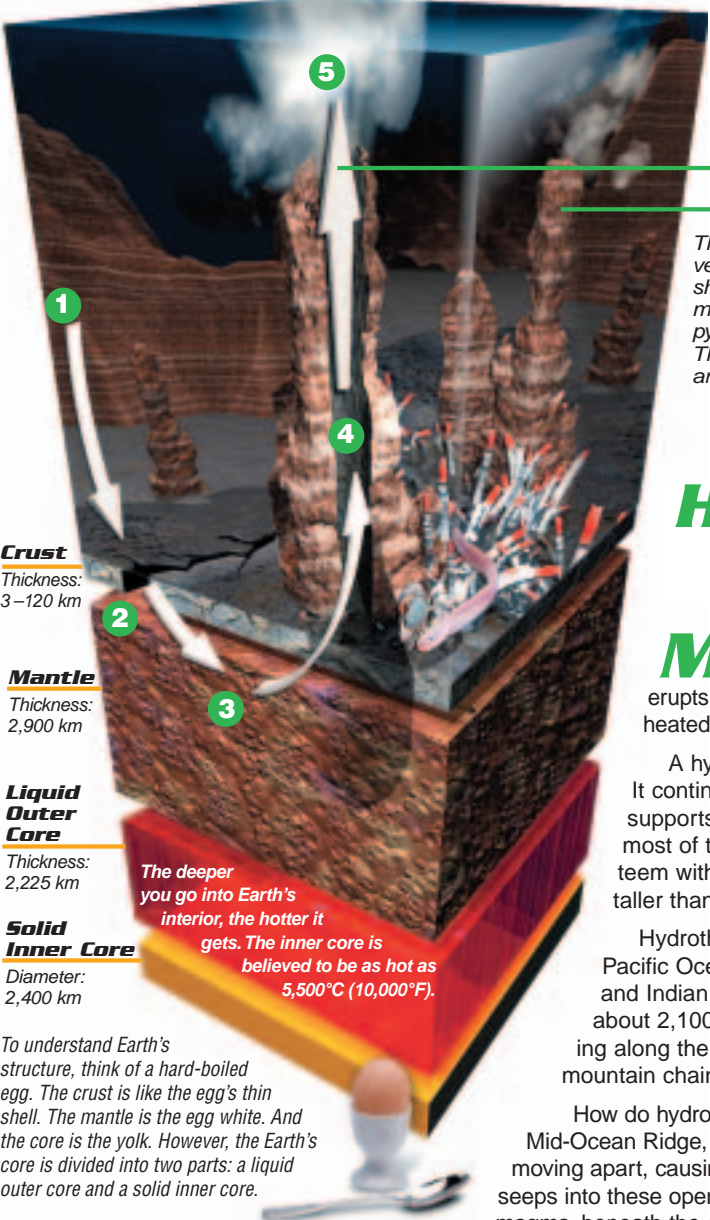
The Earth's tectonic plates can move apart, collide, or slide past each other. The Mid-Ocean Ridge system — the Earth's underwater mountain range — marks where the plates are moving apart.

As the plates part, the seafloor cracks. Cold seawater seeps deep down into these cracks, becomes super-heated by magma, and then gushes back out into the ocean, forming hydrothermal vents.

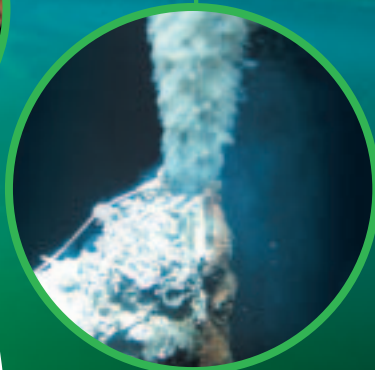
As the plates move farther apart, magma from the Earth's interior percolates up to fill the gap, sometimes causing earthquakes and the eruption of undersea volcanoes. This process, called *seafloor spreading*, is how new seafloor is formed.

The Earth's size is constant, so as the crust expands through seafloor spreading in one area, crust must be swallowed up elsewhere. Crust is destroyed when the edge of one tectonic plate is forced underneath another. This dynamic process is called *subduction*.





This is the inside of a vent chimney. The shimmering gold material is the mineral pyrite, or "fool's gold." The orange areas are oxidized iron.



Hydrothermal Vents

Many of us are familiar with "Old Faithful" in Yellowstone National Park. This famous geyser erupts several times a day. It spouts a column of water heated by volcanic rock deep within the Earth's crust.

A hydrothermal vent is a geyser on the seafloor. It continuously gushes super-hot, mineral-rich water that supports a diverse community of organisms. Although most of the deep sea is sparsely populated, vent sites teem with a fascinating array of life, from tubeworms taller than you to ghost-white crabs.

Hydrothermal vents were discovered in 1977 in the Pacific Ocean. They also have been found in the Atlantic and Indian oceans. Most occur at an average depth of about 2,100 meters (7,000 ft) in areas of seafloor spreading along the Mid-Ocean Ridge system — the underwater mountain chain that winds around the globe.

How do hydrothermal vents form? In some areas along the Mid-Ocean Ridge, the huge plates that form the Earth's crust are moving apart, causing deep cracks in the ocean floor. Seawater seeps into these openings and is heated by the molten rock, or magma, beneath the crust. As the water heats up, it rises.

When this "hot spring" gushes out into the ocean, its temperature may be as high as 400°C (750° F). Yet this water does not boil because it is under so much pressure from the tremendous weight of the ocean above.

Chimneys top some vents. These smokestacks are formed from dissolved metals that precipitate out (form into particles) when the super-hot vent water meets the surrounding seawater, which is only a few degrees above freezing.

Geologists are intrigued by how rapidly vent chimneys grow — up to 9 meters (30 ft) in 18 months. A scientist at the University of Washington has been monitoring the growth of "Godzilla," a vent chimney in the Pacific Ocean off the coast of Oregon. It reached the height of a 15-story building before it toppled. It is now actively rebuilding.

There are many other reasons why scientists want to learn more about hydrothermal vents. These underwater geysers are believed to play an important role in the ocean's temperature, chemistry, and circulation patterns.

Scientists also are fascinated by the unusual life that inhabits vent sites. These creatures who live in darkness, from bacteria to tubeworms, may light the way to the development of new drugs, industrial processes, and other products useful to us all.

How Does a Vent Work?

- 1 As the Earth's crustal plates move apart, the ocean floor cracks. Cold seawater seeps deep down into the openings.
- 2 The seawater is heated by molten rock in the Earth's mantle, below the crust. As the water heats, chemical reactions occur. Oxygen, magnesium, potassium, and other minerals are removed from the seawater.
- 3 The deeper the fluid goes, the hotter it gets. Copper, zinc, iron, and sulfur from the crust dissolve into the fluid. The super-heated fluid, now laden with dissolved metals, rises.
- 4 As the hot fluid gushes out onto the ocean floor, it meets cold, oxygen-rich seawater, which spurs more chemical reactions. Hydrogen sulfide (a compound toxic to most organisms) forms, and minerals "rain out" from the fluid. These minerals build the vent chimneys.
- 5 "Black smokers," represented in this illustration, spew hot fluid (350°C) filled with metals (mostly iron) and sulfur, which combine to form black minerals called metal sulfides. These compounds give the smoker its black color.

"White smokers" generally are smaller, release fluid more slowly, and are cooler (250° – 300°C) than their cousins. The fluid contains compounds of barium, calcium, and silicon, which are white.

Crust
Thickness:
3–120 km

Mantle
Thickness:
2,900 km

Liquid Outer Core
Thickness:
2,225 km

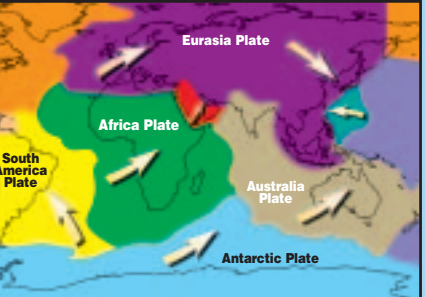
Solid Inner Core
Diameter:
2,400 km

To understand Earth's structure, think of a hard-boiled egg. The crust is like the egg's thin shell. The mantle is the egg white. And the core is the yolk. However, the Earth's core is divided into two parts: a liquid outer core and a solid inner core.

It results in earthquakes, volcanoes, and the formation of deep ocean trenches.

Presently, the Pacific Ocean basin is shrinking as other ocean basins expand. There are so many volcanoes along the perimeter of the Pacific Ocean basin the area is known as the "Ring of Fire."

This map shows the major tectonic plates that make up the Earth's crust and the directions in which they are moving.



Adapted from NOAA

Biology of Deep-Sea Life

They can withstand a broad range of temperatures (even hotter than boiling), eat toxic chemicals for breakfast, bear the weight of the ocean on their shoulders, and never see the light of day. Such is the life of the organisms that inhabit hydrothermal vent sites!



▲ Tubeworms (*Riftia pachyptila*) may grow to about 3 meters (8 ft) tall. They have no mouth, eyes, or stomach. They depend on bacteria living inside them for survival. The microbes convert chemicals spewing out of the vents into worm food.

These creatures, from microscopic bacteria to towering tubeworms, thrive under some of the most demanding conditions on the planet. And what further distinguishes them from other life on Earth is their energy source. They are the only complex ecosystem known to live on energy from chemicals rather than energy from the sun.

On land, our food chain is based on photosynthesis, the process by which green plants use the energy from the sun to make food. However, at deep-sea vent sites, where the sun's rays never reach, organisms make food from chemicals — a process called *chemosynthesis*.

Bacteria Play Mighty Role

The hydrogen sulfide and other chemicals that rocket out of the vents would be poisonous to most organisms. But exotic animals flourish here thanks to unique adaptations. Some also have a special relationship with the tiniest vent life: bacteria.

While vent crabs and fish prey on other animals for food, other vent dwellers depend on bacteria for survival because the microbes can convert the toxic chemicals released by the vents into food and energy. Thus, some vent dwellers must either consume bacteria or harbor bacteria in their bodies so that the microbes can make food for them.

For example, tubeworms have no mouth, eyes, or stomach ("gut"). Their survival depends on a symbiotic relationship with the billions of bacteria that live inside of them. These bacteria convert the chemicals that shoot out of the hydrothermal vents into food for the worm.

Since a tubeworm has no mouth, how do bacteria enter the worm? Scientists have found that, during its earliest stages, the tubeworm does have a mouth and gut for bacteria to enter. But as the worm grows, these features disappear!

Frontiers of Science

Scientists are particularly interested in vent bacteria because these primitive microbes can withstand high temperature and pressure, giving them many valuable uses in industry. For example, some bacteria can convert harmful chemicals to safer forms, making them ideal for cleaning up oil spills and hazardous waste.

Scientists are also curious about the deep sea's tiniest life because these organisms are among the oldest on Earth. In fact, an ancient life form — Archaea ("ark-ee-uh") — has been found at vent sites. Previously, these microscopic organisms had been discovered in another "extreme environment": hot springs in Yellowstone Park.

Some astrobiologists speculate that if there is life on other planets, it might be vent bacteria. Europa, one of Jupiter's moons, is covered in ice. Recent findings suggest that portions of the ice move, which is strong evidence that liquid water lies beneath it. The water may be maintained in its liquid state by hydrothermal vents. If vents exist on Europa, vent bacteria might live there, too!



▲ Magnified view of vent bacteria on the surface of pyrite. The cylinder-shaped microbes are 4 microns long. Do hydrothermal vents, and microbes, lie beneath the frozen surface of Europa, one of Jupiter's moons?

Creatures of the Deep

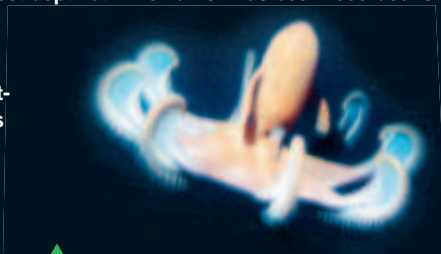
As they descend to the deep ocean bottom, marine scientists might encounter any number of bizarre-looking organisms, illuminated in their submersible's headlights. These photos are a few of the deep-sea dwellers that UD marine scientists have seen en route to vent sites nearly 3,000 meters (9,842 ft) down.

While few deep-sea fish live at hydrothermal vent sites — with the exception of pale eel-like zoarcids, also known as eelpouts — fish have been found at great depths elsewhere in the ocean. How low can they go? The greatest depth at which a fish has been recorded is 8,370 meters (27,460 ft).

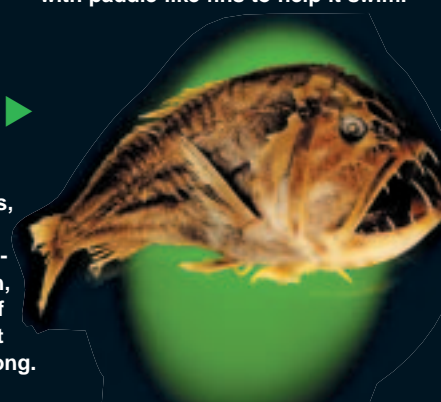
▼ **Dragonfish.** Since there is no natural light in the ocean below 1,000 meters (3,300 ft), many deep-sea fish rely on bioluminescent (light-producing) organs to find a mate and lure prey. This fish has a long chin barbel that glows in the dark.



▶ **Fangtooth.** Food is scarce in the deep sea. The fish that live there must rely on what little food floats down from above — or eat their neighbors! Deep-sea fish typically have big mouths, long sharp teeth, and stretchy stomachs to catch prey in the dark and swallow it whole. This ferocious-looking fish, called "fangtooth," is found at depths of 800 to 1,524 meters (2,600 to 5,000 ft). It grows to about 25 centimeters (10 in) long.



▲ **Deep-Sea Octopus.** Hair-like projections ("cirri") line the webbed arms of this octopus. These projections may help it sense food in the darkness. This species is also equipped with paddle-like fins to help it swim.



Exploring the Sea

▼ The four long tails on the vent microbe (*Arcobacter sulfidicus*) are whip-like flagella that help propel it through the water.



Craig Taylor and Carl Wisen, WHOI

Deep-Sea Vents Harbor Earth's Hottest Animal

In 1998, University of Delaware marine biologist Craig Cary and his colleagues made national headlines when they discovered that hydrothermal vents harbor the most heat-tolerant animal on Earth.

The Pompeii worm (*Alvinella pompejana*) — a fuzzy, gray critter about 4 inches long, sporting tentacle-like, scarlet gills on its head — can survive a bath as hot as 176° F.

While some bacteria can live at even higher temperatures, Dr. Cary says the Pompeii worm ranks as the most heat-tolerant among higher-order life forms. It beat out the Sahara Desert ant, which formerly held the record at 131° F.

"For most of us, a hot shower is around 100°F," says Dr. Cary. "How the Pompeii worm survives the nearly boiling water emanating from the vents is a mystery."

The worm also displays a remarkably broad temperature gradient along its hairy body.

"The Pompeii worm makes paper-like tube colonies attached to hydrothermal vent chimneys," says Dr. Cary. "While the very hottest water shoots out the top of the chimneys, these structures are so porous that hot water also seeps out the chimney sides and through the worm's tube home."

By inserting a temperature probe called "the Mosquito," from the submersible *Alvin* into the worm's tube, Dr. Cary found that the worm's rear end sits in water as hot as 176° F, while its gill-covered head, which often pokes out of the worm's tube home, rests in much cooler water, only about 72° F.

As chief scientist for the Extreme 2002 expedition, Dr. Cary says the research team's chief objective will be to learn more about the Pompeii worm's incredible heat tolerance by studying its unique biology and the bacterial colony that lives right on its back.

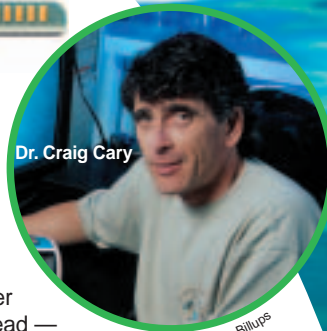
"The gray fleece, or 'hair,' that you see on the worm's back is actually bacteria," he notes. "Tiny glands in the worm's skin secrete a mucous that the bacteria appear to live and feed on."

These bacteria are of particular interest to science and industry because the microbes may harbor enzymes capable of operating in hot, corrosive, high-pressure environments. Such enzymes can help dislodge oil inside wells, convert cornstarch to sugar, process food and drugs, and support a number of other industrial processes by speeding up chemical reactions.

"Every time we visit the vents, we find something new," says Dr. Cary. "By studying 'extremophiles' like the Pompeii worm, we can better understand this amazing ecosystem and the human benefits it may yield." His research is funded by a grant from the National Science Foundation.



▲ Magnified view of a baby Pompeii worm.



Dr. Craig Cary

Steven Billups

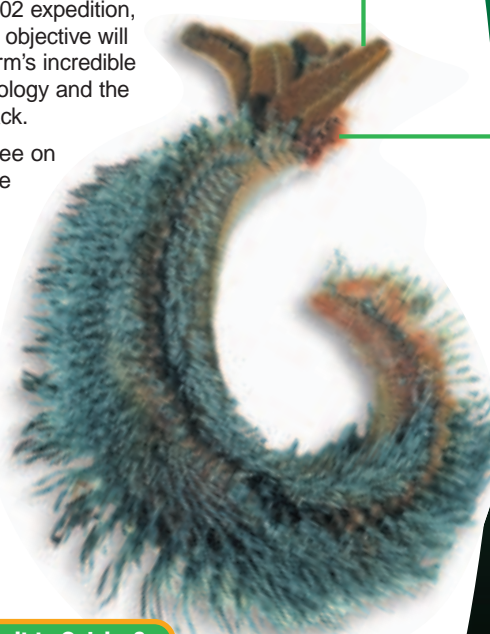
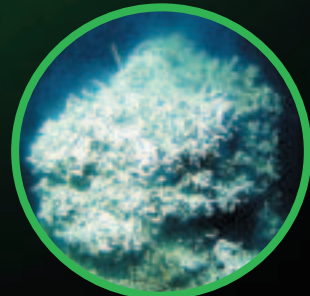


Dr. Richard A. Lutz & Andrew Reed

▲ The Pompeii worm breathes through the red tentacle-like gills that cover its head.

◀ Below these gills is a structure that resembles a ball of yarn when it's not in use: the buccal feeding tube. The worm extends this tube to eat microscopic bacteria that grow in long filaments.

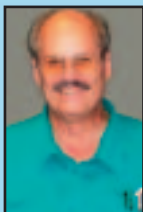
▼ Papery tube colonies attached to hydrothermal vents house dozens of Pompeii worms.



Students, can you convert the temperatures from Fahrenheit to Celsius?

crets of the Tiniest Life at the Vents

Exploring hydrothermal vent sites in the submersible *Alvin*, Dr. Craig Taylor, a scientist at Woods Hole Oceanographic Institution, sometimes wishes his eyeglasses were equipped with the lenses of a high-powered microscope to expose the fascinating invisible life that inhabits the vents. He and his research team have built specialized equipment to collect microbes from vent chimneys during the Extreme 2002 expedition.



Dr. Craig Taylor

Pictured at left is one of the microbes that Dr. Taylor and his colleagues Carl Wirsén and Stefan Sievert are studying. Resembling a hot dog with four long tails, this organism thrives on the poi-

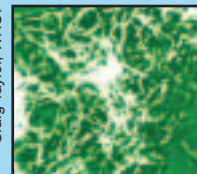
sonous hydrogen sulfide that shoots out of the vents. Its "tails" are actually whip-like appendages called *flagella* that help propel it where it can access what it needs to survive: the sulfide from the vents and the oxygen in seawater.

An unusual characteristic of the microbe is that it excretes its metabolic waste as rigid filaments of sulfur. "These sulfur filaments form an entangling matrix or mat that in 3-D looks pretty much like raw wool," he says. "This mat helps the microbes maintain their position in high fluid-flow environments like hydrothermal vents."

According to Dr. Taylor, the formation of the sulfur filaments is a team effort involving many microbes. Once one microbe excretes a filament, the other microbes latch onto the filament to help

build it up. They attach themselves along the length of the filament and excrete tiny sulfur droplets that make the initial thread up to 25 times thicker, from about 0.2 micrometers up to 5 micrometers.

Craig Taylor, WHOI



▲ This mat of sulfur filaments excreted by vent microbes acts like a net, helping the organisms maintain their position in the toxic vent fluid.

"It's an interesting story," he notes. "These microbes as a community build their house out of their own waste. We have seen this species — *Arcobacter sulfidicus* — in several locations now, including hydrothermal vents and even coastal salt-marsh ecosystems."

Exploring the Deep



Throughout history, scientists have relied on a number of specialized tools to measure, map, and view the ocean's depths. These are a few highlights.

One of the first instruments used to investigate the sea bottom was the *sounding weight*. Viking sailors took measurements of ocean depth and sampled seafloor sediments with this device, which consisted of a lead weight with a hollow bottom attached to a line. Once the weight reached the ocean floor and collected a sample of the seabed, the line was hauled back aboard ship and measured in the distance

between a sailor's outstretched arms — a 1.83-meter (6 ft) unit called a *fathom*. This term is still used today for nautical depth.

Cornelius van Drebel, a Dutch inventor, is credited by many historians with building the first submarine. His underwater vessel consisted of a wooden frame sheathed in leather. Oars extending out the sides propelled the craft through the water, at depths up to 4.6 meters (15 ft). The oar openings were sealed with tight-fitting leather flaps. Drebel tested the sub in the Thames River in England between 1620 and 1624. King James I is said to have taken a short ride in the craft.

From 1872 to 1876, a landmark ocean study was undertaken by British scientists aboard HMS *Challenger*, a sailing vessel that was redesigned into a laboratory ship. The *Challenger* expedition covered 127,653 kilometers (68,890 nautical miles) and is credited with providing the first real



Divers do a final safety check of Alvin's hatch before the crew inside begin their descent to the seafloor.



In the lab onboard R/V Atlantis, scientists analyze samples of vent chimney rock for bacterial analysis.

view of major seafloor features such as the deep ocean basins. The researchers used wire-line soundings to determine depths and collected hundreds of water, sediment, and biological samples from all the oceans except the Arctic. They discovered more than 4,700 new species of marine life, including deep-sea organisms.

Deep-sea exploration advanced dramatically in the 1900s with a series of inventions, ranging from *sonar* — a system for detecting the presence of objects underwater through the use of sound — to manned deep-diving submersibles such as *Alvin*.

Owned by the U.S. Navy and operated by the Woods Hole Oceanographic Institution, *Alvin* can carry a crew of one pilot and two scientists to a maximum depth of 4,500 meters (14,764 ft). The sub is equipped with lights, cameras, computers, and highly maneuverable arms for collecting samples in the darkness of the ocean's depths.

However, the voyage to the ocean floor takes time in a submersible. A typical dive to a vent site 2,400 meters (1.5 mi) below the surface takes about eight hours, including two hours to descend, four hours to work on the seafloor, and two hours to return to the surface. With the expanded use of fiber optics and robotics, scientists hope to someday explore the deep sea from a computer screen in the lab rather than out of a porthole.

In fact, a team of researchers from several U.S. and Canadian institutes is now in the design phase of "Project Neptune," a bold plan for installing remote-controlled instruments across Juan de Fuca Plate, a tectonic plate that lies off Canada, the Pacific Northwest, and California. The project is expected to be in operation by 2006.



Getting to the Bottom of It: The Ocean

Because of the tremendous pressure, the depth to which a diver can descend without special equipment is severely limited. The deepest recorded dive by a skin diver is 127 meters (417 ft). The deepest recorded dive by a scuba diver is 282 meters (925 ft).

NOAA



Inventor Salim Joseph Peress's diving suit, "Tritonia," with its reticulated joints, explored the wreck of the Lusitania in 1937. This suit was the forerunner of the "Jim suit."

Revolutionary new diving suits, such as the "Jim suit," enable divers to reach depths up to about 600 meters (2,000 ft). Some suits feature thruster packs that can boost a diver to different locations underwater.

To explore even greater depths, deep-sea explorers must rely on specially constructed steel chambers to protect them. In 1934, American oceanographer William Beebe and engineer Otis Barton were lowered to about 1,000 meters (3,280 ft) in a round steel chamber called a *bathysphere*, which was attached to a ship on the surface by a long cable. During the dive, Beebe peered out of a porthole and reported his observations by telephone to a colleague, Miss Hollister, who was on the surface.

In 1948, Swiss physicist Auguste Piccard began testing a much deeper-diving vessel he invented called the *bathyscaphe*. (This word

is derived from the Greek words *bathos* — "deep" and *scaphos* — "ship.") On an unpowered dive in the Cape Verde Islands, his invention, named *FNRS 2*, successfully withstood the pressure on it at 1,402 meters (4,600 ft), but its float was severely damaged by heavy waves after the dive.

In the 1950s, Jacques Piccard joined his father in building new and improved bathyscaphes including *Trieste*, which dived to 3,139 meters (10,300 ft) in field trials. The U.S. Navy acquired *Trieste* in 1958 and equipped it with a new cabin to enable it to reach deep ocean trenches. In 1960, Jacques Piccard and Navy Lieutenant Donald Walsh descended in *Trieste* to the deepest known point on Earth — the Challenger Deep in the Mariana Trench. The two men made the deepest dive in history: 10,915 meters (35,810 ft).

Today, scientists are making exciting discoveries about the ocean floor, thanks to deep-sea submersibles such as *Alvin*. Operated by the Woods Hole Oceanographic Institution in Massachusetts, this three-person sub made its first dive in 1964. Since then, *Alvin* has made more than 3,700 dives to an average depth of 2,068 meters (6,785 ft).

Alvin has conducted a wide variety of research missions, from discovering giant tubeworms on the Pacific Ocean floor near the Galápagos Islands, to locating the wreck of HMS *Titanic* in the Atlantic Ocean.

Alvin has met some amazing life on its travels, but so far it has not encountered one of the deep sea's most mysterious inhabitants — the elusive giant squid. However, *Alvin* once was attacked by a swordfish, which became trapped between two pieces of the sub's fiberglass skin. The fish was brought back to the surface and cooked for dinner!

Tools of the Trade



Students, can you convert the measurements into metric units?

Facts about Alvin

How did Alvin get its name?

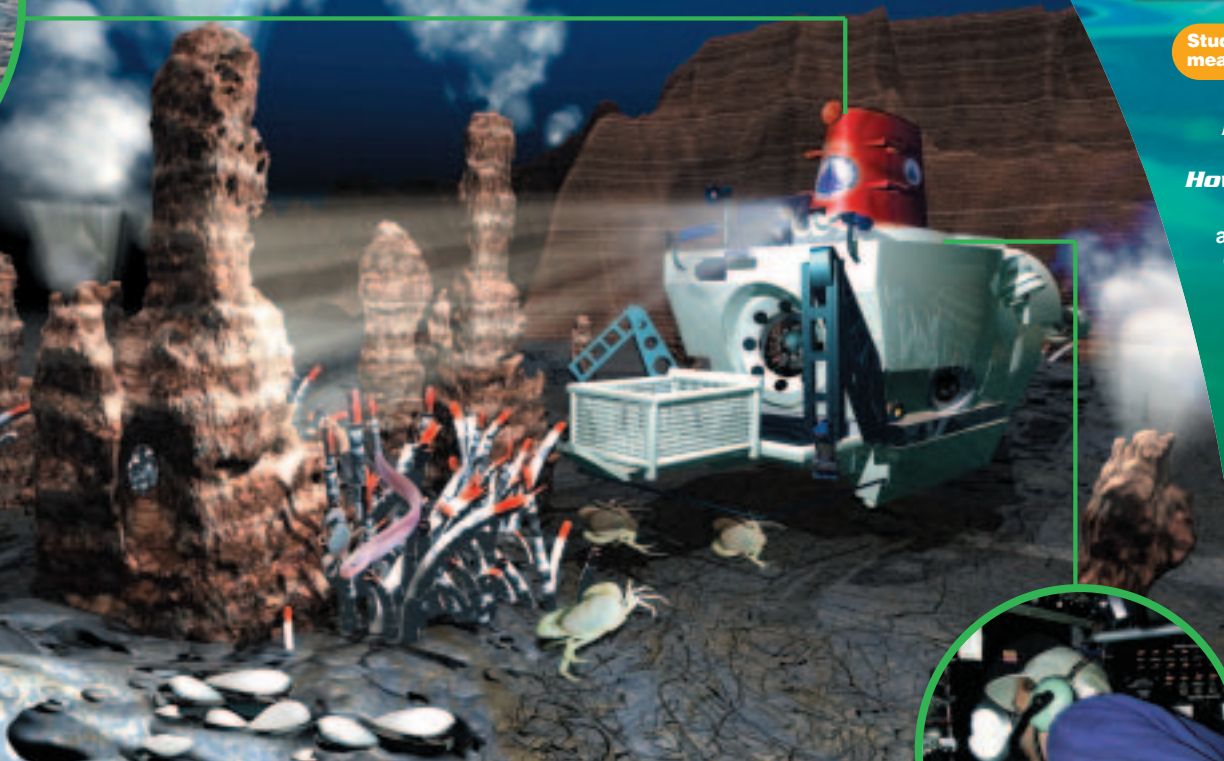
Alvin is owned by the U.S. Navy and operated as a national oceanographic facility by the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. The sub was christened in 1964. The Deep Submergence Group at Woods Hole named *Alvin*. It was both a contraction of their colleague Allyn Vine's name (he worked tirelessly to make the submersible a reality) and a reference to the popular cartoon chipmunk.

How big is Alvin?

The sub (its official title is "Deep Submergence Vehicle") is about 23 feet long and 12 feet high. The 6.5-foot-diameter sphere in which the scientists work is made of titanium.

What equipment does Alvin have?

Its tools include sonar, a computer/data display/recording system, video cameras, a telephone, a magnetometer, and more. *Alvin* has two long, clawed arms called manipulators that are used to collect scientific specimens and place them in the sub's collecting basket. The longer of the two arms, the portside manipulator, can extend 74 inches and lift up to 150 pounds.



The 83-meter (274-foot) research vessel *Atlantis* is the platform from which *Alvin* operates. *Atlantis* can carry up to 60 people, including crew, scientists, and technicians. The ship features hangars for *Alvin* and ROVs (remotely operated vehicles), portable labs, a machine shop, library, laundry, and inflatable rescue boats.

Alvin's pilot navigates the submersible along the seafloor. It's very cramped inside the sub, which typically carries two scientific observers in addition to the pilot. The scientists sit with their legs alongside each other while the pilot sits on a tiny padded bench. A typical dive lasts eight hours.

Frequently Asked Questions About Alvin

Liz McCliment, a graduate student at the University of Delaware College of Marine Studies, answers your questions about working in the sub *Alvin*.



Liz McCliment

Q. What's it feel like when you're descending?

A. You actually sense very little motion inside the sub, except when you're bobbing on the surface. Mostly, you can tell you're descending by the color of the water outside your porthole. It gets dark pretty quickly — within about 10 minutes.

Q. How long does it take to get to the ocean bottom?

A. About one to two hours, depending on how deep you're going.

You usually work for four hours or so on the bottom before ascending. A typical dive generally lasts eight hours.

Q. Do you have to wear anything special in the sub?

A. It gets very cold in the sub. The temperature of the water is just above freezing, so you have to bring a few layers of wool or cotton clothing, including extra pairs of socks. You cannot wear shoes, jewelry, or any synthetic material (like nylon or Lycra) in the sub. Shoes would just get in the way. Jewelry might scratch *Alvin's* window. Synthetic clothes are not permitted for fire safety reasons.

Q. How much room do you have in the sub?

A. It's very cramped. There's enough room for two scientists

to sit with their legs alongside each other, and the pilot to crouch on a tiny padded bench. If you want to stretch out, it is possible for one (short) person to stand up with their head in the hatch. You also spend a lot of time laying on your side or stomach, looking out your porthole, operating your equipment and conducting experiments.

Q. What do you have for lunch in Alvin?

A. There's a traditional lunch served to the scientists and crew on a dive: one peanut butter and jelly sandwich, one "mystery meat" sandwich, a candy bar, and a piece of fruit. Since you're generally very busy and lose track of time while you're working, you tend to eat when you're in transit between sites!

Alvin Statistics

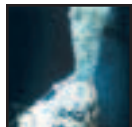
- Length:** 23.3 feet
- Height:** 12 feet
- Draft:** 7.5 feet
- Gross Weight:** 35,200 pounds
- Operating Depth:** 14,764 feet
- Cruising Speed:** 0.5 knot
- Maximum Speed:** 2 knots
- Max. Cruising Range:** 3 miles
- Payload:** 1,500 pounds
- Dive Duration:** 6 – 10 hours
- Life Support:** 216 man-hours (72 hours x 3 persons)
- Complement:** 1 pilot, 2 observers
- Propulsion:** Six reversible, electric thrusters



Delve Deeper!

This eight-page resource guide is designed to serve as a brief introduction to the deep sea and hydrothermal vents. Additional information including photos, video clips, journals, and other news from the Extreme 2001 expedition can be found on our Web site: www.ocean.udel.edu/extreme2002.

The following list of suggested classroom activities and resources may help expand your deep-sea learning experience. Use it as a starting point to your own voyage of discovery!



Geology

Word Definition

Here are some terms to define:

bathymetry	Pangaea
continental shelf	precipitate
continental slope	Ring of Fire
deep ocean basin	seismology
ocean trench	volcanism

Math Activities

Let's test your knowledge of the metric system. Convert the British units of measure in the "How Deep Is the Ocean?" article in the Geology section to metric units.

Can you calculate what the atmospheric pressure is at the Earth's deepest known point, at the bottom of the Mariana Trench?

Extra-Credit Essay Topics

Why are hydrothermal vents important?

How does Old Faithful geyser work?

Compare it to a hydrothermal vent.



Biology

Word Definition

Here are some terms to define:

bioluminescence	Pompeii
chemosynthesis	photosynthesis
eelpout	sulfur
larval crab	symbiosis
microbe	tubeworm

Go Fish!

Many deep-sea fish look monstrous! Your mission is to find pictures and descriptions of at least five different deep-sea fish. What special adaptations do these fish have for living in their demanding environment?

Extra-Credit Essay Topics

Compare and contrast photosynthesis and chemosynthesis.

Oceanographer William Beebe wrote the book *Half Mile Down* about his descent to the seafloor in 1938. Read a chapter and report on his observations.

Exploring the Deep

Word Definition

Here are some terms to define:

bathyscaphe	magnetometer
bathysphere	ROV
Jim suit	scuba
electrode	sediment core
fiber optics	sonar



Design a Diving Vessel

If you could design a deep-sea diving vessel, what would it look like? Sketch it!

Extra-Credit Essay Topics

Jason is used in deep-sea research.

Do some research and tell us all about it.

What other scientific tools are revolutionizing our study of the ocean?

Two divers help steady the submersible Alvin as it is lowered into the Pacific from the research vessel Atlantis.



Resources

Many excellent resources were used to develop this guide and may help you in your search for more information.

Web Sites

The Bridge — Ocean Sciences Education Teacher Resource Center
www.vims.edu/bridge

Encyclopedia Britannica
search.eb.com

Jones & Bartlett Publishers — *Invitation to Oceanography* by Paul Pinet
www.jbpub.com/oceanlink2e

"Deep Sea Vents: Science at the Extreme"
www.nationalgeographic.com/ngm/0010/feature6

"Neptune's Web: Get the Facts on Oceanography"
pao.cnmoc.navy.mil/Educate/Neptune/Neptune.htm

Nova Online — "Into the Abyss"
www.pbs.org/wgbh/nova/abyss

Smithsonian Institution's "Ocean Planet"
seawifs.gsfc.nasa.gov/ocean_planet.html

U.S. Geological Survey — *This Dynamic Earth: An Introduction to Plate Tectonics* by W. J. Kious and Robert Tilling
pubs.usgs.gov/publications/text/dynamic.html

U.S. Naval Historical Center
www.history.navy.mil/index.html

Woods Hole Oceanographic Institution — "Dive and Discover" Expeditions
www.divediscover.whoi.edu

Books & Magazines

Davidson, Keay, and A. R. Williams. "Under Our Skin: Hot Theories on the Center of the Earth." *National Geographic* 189, no. 1 (Jan. 1996): 100–112.

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Earle, Sylvia A., and Al Geddings. 1980. *Exploring the Deep Frontier: The Adventure of Man in the Sea*. National Geographic Society.

Greene, Thomas F. 1998. *Marine Science*. New York: Amsco School Publications.

Lemonick, Michael D. "The Last Frontier." *Time*, Aug. 14, 1995, 52–60.

Van Dover, Cindy Lee. 2000. *The Ecology of Deep-Sea Hydrothermal Vents*. Princeton University Press.

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For more information about the University of Delaware's "Extreme 2002" deep-sea research expedition, dive into www.ocean.udel.edu/extreme2002.

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For information about other educational publications and programs available from the University of Delaware Graduate College of Marine Studies and the Sea Grant College Program, please visit us online at www.ocean.udel.edu. Or contact University of Delaware, Marine Public Education Office, 222 S. Chapel Street, Newark, DE 19716-3530. Phone: (302) 831-8083. E-mail: MarineCom@udel.edu.

