TEACHER'S GUIDE

VOLCANOES OF THE DEEP SEA

Inside

Dear Educator

Have you ever wondered if there is anything on Earth scientists *haven't* explored? The answer sits just two miles beneath the ocean surface: a sunless world that has evolved in ways we never dreamed possible. The deep sea and its magnificent volcanic ridge system is a testament to the fact that discovery is far from dead. In fact, it is just beginning! Join us on our voyage to this virtually unexplored wet n' wild world, a place as black as a moonless midnight, where life teems and Earth is born.

Once thought to be a barren desert of mud, marine carcasses and shipwrecks, the deep sea was dismissed by early scientists as an opportunity for discovery. While the oceans have served as a worldwide highway to and from new lands to be explored, the deep sea remained a world no one had ever seen in person. Until recently.

Scientists first laid eyes upon the spectacular world of the deep-sea vents in the late 1970s when the Alvin submersible carried them to the largest mountain range on Earth. Here, geological processes sparked by hot energy from Earth's belly give shape to magnificent structures that are home to animals making a living in ways that boggle the mind and challenge us to wonder: where else might these strange worlds exist, and what might we learn from them? Since the first dive to this world, we have started to unravel some of the mysteries, but so many questions remain. Ten years in the making, *Volcanoes of the Deep Sea* is the first larger-than-life look at a world that could very well be one of the last frontiers.

Words in blue italics are defined in the Glossary on page 31

Welcome to our Teachers' Guide, designed for your use before and/or after you and your students see *Volcanoes of the Deep Sea*. We began developing this guide while participating in one of the major filming expeditions that physically carried us from the Azores to Bermuda, and intellectually carried us inside and out of the process of real scientific discovery. We designed the guide in a way that is accessible to any schoolteacher. Feel free to work through it cover to cover, thereby embracing a wide scope of deep-ocean science in a linear order. Or, tackle just one chapter or activity based on your needs as a teacher, already entrenched in a sea of 'things to do'. As we catch your drift on that point, we've fashioned the activities to adhere to the National Education Standards and the 'No Child Left Behind' mandate. Emphasizing a commitment to science communication, we have included opportunities for science reading and writing all throughout the guide. Many activities consist, in part, of a writing element; most chapters contain a reference to a 'Writing Prompt', a paragraph or two that will inspire students to think beyond the topics covered in the activities, and then write about them. This Guide is targeted at middle school students, but is easily adapted to higher and lower grades.

The Teachers' Guide is the foundation of an entire Education Outreach Program, which includes an interactive website and a Project Oceanography broadcast. At www.volcanoesofthedeepsea.com, you'll find information and resources to compliment and supplement the Teachers' Guide, intended to take you even deeper into the magic of deep-sea volcanoes. Be sure to tune in to the 1/2 hour Project Oceanography show, produced especially for release in conjunction with *Volcanoes of the Deep Sea*. The episode, called 'Voyage to the Abyss,' features the story of 9°n, a jaw-dropping place that Dr. Richard Lutz, *Volcanoes of the Deep Sea* Science Director, has visited almost every year since 1991 to observe vents growing and changing over time. You can download the show directly from the website, or watch it when it airs. Visit www.marine.usf.edu/pjocean for broadcast dates and more information.

Thanks for joining us on our plunge to one of the greatest mysteries on Earth! If you have any questions, or wish to share some of your own ideas with us, please contact us through www.volcanoesofthedeepsea.com.

Yours in abyssal thought,
The *Volcanoes of the Deep Sea* Education Outreach Team

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.

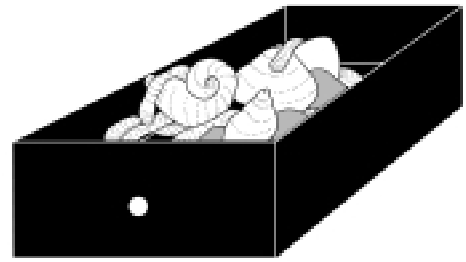
Recent advances in technology have enabled scientists to study vents in the deep ocean more often and more thoroughly than ever before, but it is very challenging work. Scientists rely on the *scientific method* to guide their exploration. They form a hypothesis as to where a vent may be, develop a method 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.

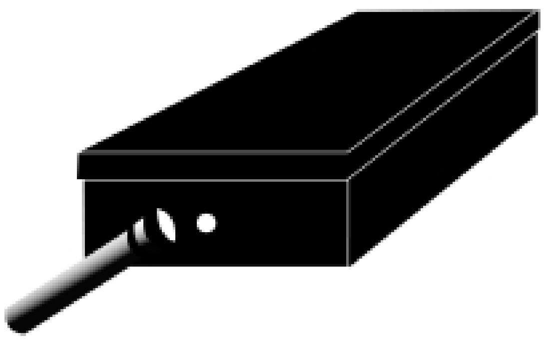
Scientists have mapped nearly 100% of the surface of Venus (26 million miles from Earth) but only .001 to 1% of the ocean floor.

exploration

1.1 The Deep Ocean: a Black Box



Materials (per lab group)
Black box with lid (shoebox or plastic storage bin, painted black)
Awl, knife or other hole poke
Assorted materials to hide in boxes (gummy worm, small rock, plastic egg filled with sand, sea shells, plastic bait critters, foam fish, glitter, etc.)
Black duct tape
Stop watch, or clock with a second hand
Paper
Pencils or pens
Wooden skewers with pointed tips cut off
Flashlights
Kitchen tongs



Prep Notes
Prior to class, assemble as many Black Boxes as you have lab groups. Cut or poke a hole approximately 1 cm (3/8 inch) in diameter in one short end of the box using the awl or knife. Cover the hole with black duct tape. Place assorted materials inside the box, sprinkle with glitter (to represent microbes), and replace the lid.

What To Do
Using the Background Information (page 4) discuss the Black Box metaphor, and the difficulty in exploring the deep ocean. Divide the class into lab groups, giving each group an assembled Black Box, some paper and pens or pencils. Explain the rules of the activity: the Black Box must stay flat on the table at all times; no one can pick up, open or alter the box unless they are instructed to. At each step in this activity give students a set amount of time to complete the task, and instruct them to record all their observations in writing and with diagrams.

Step 1: Tell students they are to write a list of observations about their Black Box. They can pick up the box, shake it, estimate its weight, observe sounds it makes, etc. They are NOT permitted to open the box, remove the tape, throw the box or alter it in any way. Allow 30 seconds for this step.

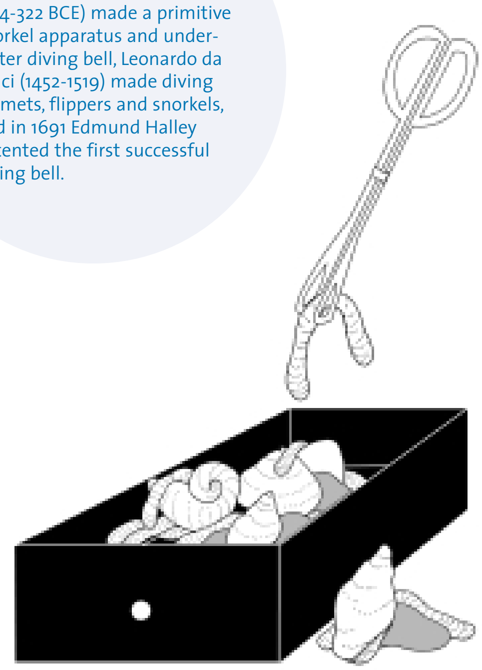
Step 2: Provide each group with a deep ocean probe (meat skewer). Have students remove the duct tape from the hole and use the skewer to 'probe' inside their Black Box and write down their findings. Allow 30 seconds for this step.

Step 3: Provide each group with a flashlight. Darken the classroom as much as possible and ask students to shine the light through the hole of their Black Box and record their observations. Allow 45 seconds for this step.

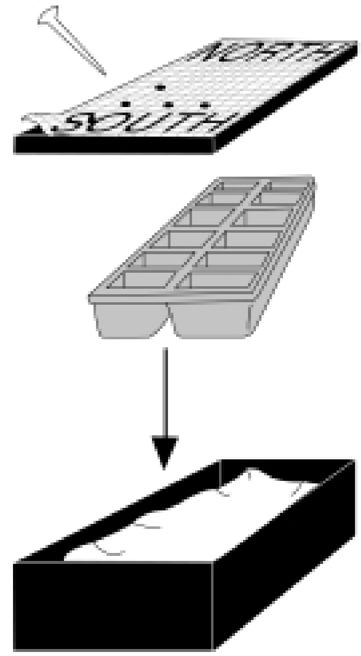
Step 4: Provide each group with a manipulator arm (kitchen tongs). Explain that only the manipulator arm can retrieve objects from their Black Box. With the lights still out, and on your signal, have students remove the lid and retrieve objects with the manipulator arm. Some students may figure out that using their flashlight will make retrieval easier, but allow them to determine this on their own. Allow 45 seconds.

Step 5: Class discussion: what was observed at each step? What were the challenges in exploring the Black Box? How are these challenges similar or different to those faced by deep ocean explorers?

The desire to explore the oceans is ancient. Aristotle (384-322 BCE) made a primitive snorkel apparatus and underwater diving bell, Leonardo da Vinci (1452-1519) made diving helmets, flippers and snorkels, and in 1691 Edmund Halley patented the first successful diving bell.



1.2 Searching for Vents

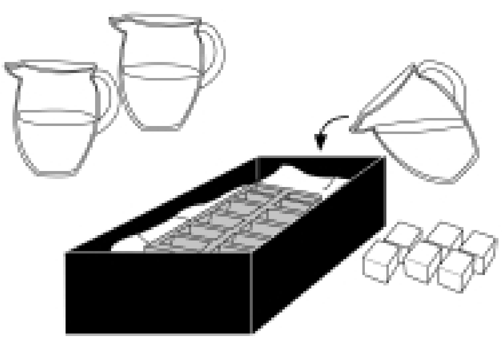


Materials (per lab group)
Black box (cardboard shoe box painted black) and removable lid with grid holes punched into top (directions below)
Waterproof lining (plastic garbage or grocery bag)
Plastic ice cube tray
Scissors
Thermometer (Celsius)
Cup with pour spout
Containers of (1) ice water, (2) room temperature water, (3) hot water
2 sheets of graph paper per student
Pencils
Paper towels (and clean up supplies)

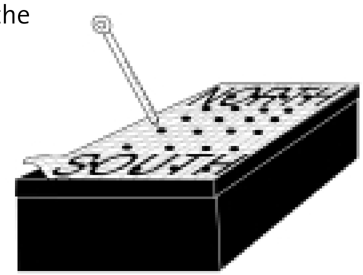
Prep Notes
In this simulation activity a Black Box represents the deep ocean, and a section of an ice cube tray filled with hot water represents a hydrothermal vent in the deep ocean. Prior to class, assemble as many Black Boxes as you have lab groups. Using a piece of graph paper as a guide, poke 24 holes (4 by 6) through the top of the box lid. The holes should be small, but just wide enough for the thermometer to fit through. Label one end of the grid 'North' and the other 'South'. To prevent the box from getting wet during the activity, place the waterproof lining at the bottom. Sit the ice cube tray inside the box and, if necessary, trim it with the scissors. Replace the top back on the Black Box.

What To Do
Divide the class into lab groups giving each group one assembled Black Box, one thermometer, one pouring cup, three containers of water at the different temperatures, and some paper towels. Give each student two sheets of graph paper and a pencil. Have students perform the following steps:

Step 1: On one sheet of graph paper, sketch the grid pattern from the box top. Then, work as a group to hide a vent in the Black Box by filling one section of the ice cube tray with the very hot water, then the rest with tap water and ice water. Remember: water near the vent is warm, and gets colder the further away you go. If there is space around the edges of the tray, fill it with ice cubes. On the grid, record where the vent is hidden. Replace the top back on the box.



Step 2: Switch places with another lab group so that each group is working with another's Black Box. Begin by each sketching the grid on the second sheet of graph paper. Explore the Black Box as a group to find the hidden vent. Using proper techniques for taking temperature, insert the thermometer into the holes, making sure it goes all the way to the bottom. Record the temperature on the grid, then wipe off the probe and continue until the whole box has been explored.



Step 3: Using the data gathered in the exploration, formulate a hypothesis as to where a vent might be.

Spaced Out: Time for Devotion to the Ocean PAGE 30

1.3 Defining the Deep

Scientists have visited about 1% of the Mid-Ocean Ridge in a submersible.

Materials

One copy of page 8, cut into indicated sections
Pencil or pen and paper for each student
Resource information and tools (encyclopedias, science and math texts, calculators, rulers, thermometers, art supplies, Guinness Book of World Records, Internet access, etc.) for brainstorming and research

Prep Notes

This is a team brainstorming and research activity that will help students problem solve and understand technology. Teams will develop simple mathematic equations and comparisons that describe the extreme nature of the vent environment in terms everyone can understand. Before dividing the class into groups, discuss the extreme nature of the vent environments seen in *Volcanoes of the Deep Sea*. Emphasize the depth, pressure and temperature of the deep ocean, with examples like the following:

Depth: 12,000 feet (3658 m) is like 2400 5-foot (1.52 m) tall students balanced on each other's head.

Pressure: 3500 pounds of pressure per square inch (PSI) is equal to 240 atmospheres (atm). In other words, 3500 PSI is 240 times greater than what we feel on land at sea level.

Temperature: Vent fluid at 400°C (750°F) is four times greater than the temperature at which water boils.

Scientists have mapped nearly half of the Mid-Ocean Ridge, which means there are still about 20,000 miles to go!

What to do

Step 1: Divide the class into three groups, each of which represents a different characteristic of the deep ocean vent environment: depth, pressure and temperature. Give one sheet section to each group and tell students they will use the information provided to become an expert on their extreme characteristic. Have students follow the instructions to brainstorm and discuss their characteristic, then write comparisons and equations to describe it. Encourage students to think of and research their own examples, as well as using those provided on the sheet. All students must take notes and become an expert on their topic.

Step 2: Jigsaw the class into three new groups so at least one member from each of the original groups is now in each of the new groups. This way, all characteristics are represented by an 'expert.' Instruct students to take turns teaching the rest of their new team about their own characteristic using the comparisons and equations they developed.

Step 3: Once all the experts have presented their work and all the characteristics have been discussed, have the teams brainstorm what a submersible requires to be able to explore the deep sea under such extreme conditions.

1.2 Defining the Deep

Depth team

The vents featured in *Volcanoes of the Deep Sea* found are at a depth of approximately 12,000 feet (3658 m) at the bottom of the ocean. Your group's job is to find a creative way to express how deep that is, compared to depths and heights that we are more familiar with. You may choose to consider some of these examples:

Height of the Empire State Building: 1250 feet (381 m)
If you could make a chain of Empire State Buildings and hang it down into the ocean from sea level, how many would you need to reach that depth?

Average diving depth of a sperm whale (deepest diving mammal): 3280 feet (1000 m)
How much deeper are vents than the average diving depth of a sperm whale? Double? Triple?

Your height: ______________________
Average height of your classmates: ____________
If you made a human chain of fellow students, standing on each other's shoulders, to reach a height of 12,000 feet, how many students would you need? (Don't forget: you need to measure height from floor to shoulders, not the top of the head!)

Working as a team, brainstorm three more creative examples to explain how deep 12,000 feet is.

Temperature team

At vent sites in the deep ocean, the water temperature ranges from 2° to 400° C (35° to 750° F). Your group's job is to find a creative way to express how extreme that is, compared to examples of temperatures that we are already familiar with. You may choose to consider some of these examples:

Temperature at which water boils: 100° C (212° F)
How much hotter is the hottest vent fluid than boiling water?

Temperature at which water freezes: 0° C / 32° F
What is the temperature difference between freezing water and the coldest vent fluid?

Temperature at which lead melts: 327.46° C (621.43° F)
How does the temperature of hot vent fluid compare to melting lead?

Your classroom temperature: ______________________
How much colder, and how much hotter, would your classroom need to be to feel like the temperatures at vent sites? Is it possible to make it that cold or hot?

Working as a team, put together three more examples that clearly compare the hot and cold extremes of the deep ocean vent environment.

Pressure team

On average, the pressure around vent sites 12,000 feet (3658 m) down is 3500 PSI (pounds per square inch) or 240 ATM (atmospheres). As you descend into the ocean, pressure increases by one atmosphere every 33 feet (10 m). On land, we do not notice pressure on our bodies because we have evolved and adapted to it. Animals at the bottom of the ocean are unaffected by the 3500 pounds of pressure on their bodies, but we sure wouldn't be if we went down without a submersible! Your group's job is to find creative ways to express how much pressure that is, compared to other forms of pressure that we are more familiar with. You may choose to consider some of these examples:

Average air pressure on our bodies at sea level: 14.5 PSI (1 ATM)
How much more pressure is there at the bottom of the ocean than on land at sea level?

Average atmospheric pressure at the top of Mt. Everest: 4.35 PSI (0.272 ATM)
How much more pressure is there at a vent site 12,000 feet down than at the top of Mt. Everest over 29,000 feet (8840 m) up?

Pressure required to form a diamond from carbon: 58,015 PSI (57,256,347.67 ATM)
How much more pressure would be required at a vent site to form a diamond? How much more pressure on land?

Average recommended pressure in tires on a domestic sedan: 32 PSI (2.18 ATM)
How does the air pressure in a tire compare to the water pressure at a vent site?

Working as a team, come up with three more examples that clearly explain the pressure of the deep ocean vent environment.

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!

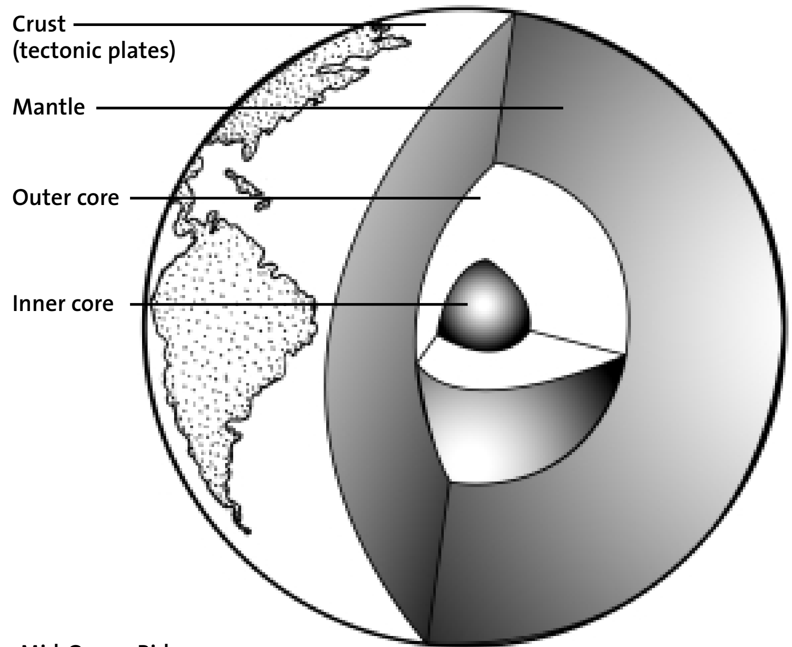
Vents in the Pacific Ocean grow differently than those in the Atlantic Ocean. The seafloor spreading center along the East Pacific Rise splits apart at a faster rate than that of the Mid-Atlantic Ridge. Due to the speed at which the sea floor splits in the Pacific, hot fluids vent more quickly from inside 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.

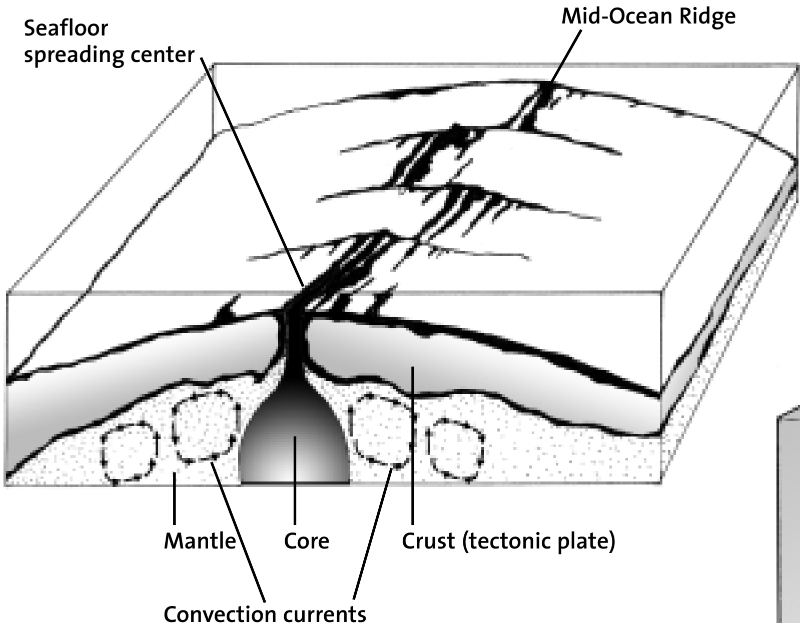
The creation of crust along the Mid-Ocean Ridge accounts for about 95% of the volcanic activity on Earth.

geology

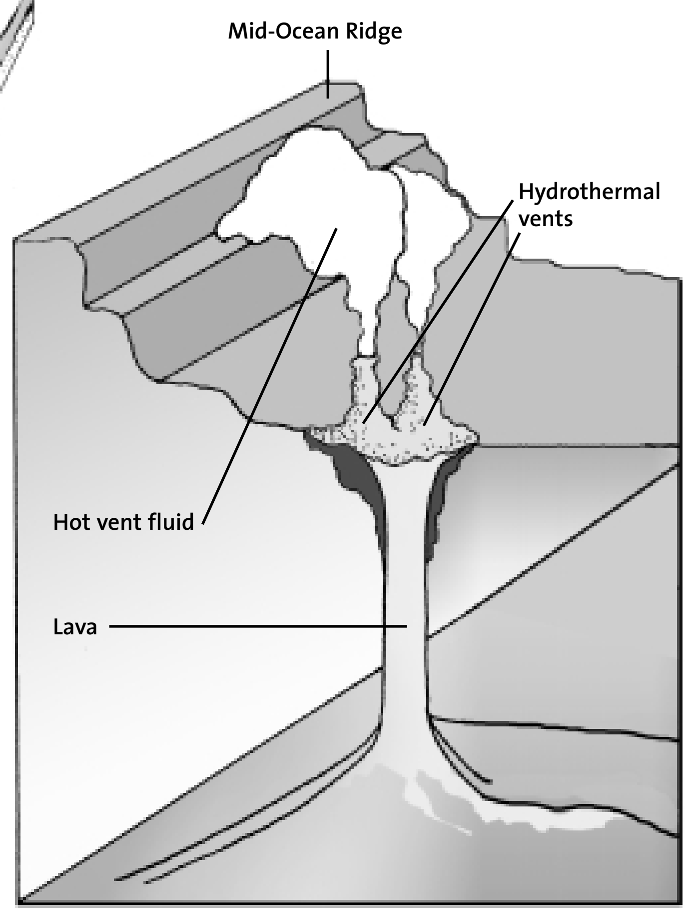
Resource Page

The Pacific spreading center is a fast-spreading zone where the tectonic plates split apart at a rate of up to 90 millimeters per year. The Atlantic spreading center is a slow-spreading zone that splits apart at a rate of 10-50 millimeters per year.





Vents remain active for a variable number of years (tens to thousands) before they become choked with minerals and the flow of warm water is blocked.



2.1 Puzzling Plates

Materials (per student)
One copy of Student Activity Sheet, 12
One copy of Geology Map, 13, cut into plate pieces
Pencil or pen
Colored pencils
Blank paper
Glue

Prep Notes
Any location on Earth can be described by *latitude* and *longitude* coordinates: latitude is a measurement of the distance in degrees north and south of the Equator; longitude is a measurement of the distance in degrees east and west of the Prime Meridian.

Prior to class, cut each copy of the Geology Map into plate pieces (indicated by the dark plate lines). Put each 'puzzle' into an envelope.

What to do
Read the background information with students and use the Resource Page (10) to discuss the basics of Earth anatomy, plate tectonics, and vent formation. Distribute all the materials. Instruct students to paste their puzzle together on the blank paper. Then, following the directions on the activity sheet, students will identify, label and color the plates and the continents, and then answer the questions.

ANSWERS
1. **Pacific Plate**
2. **The continents are smaller than the plates**

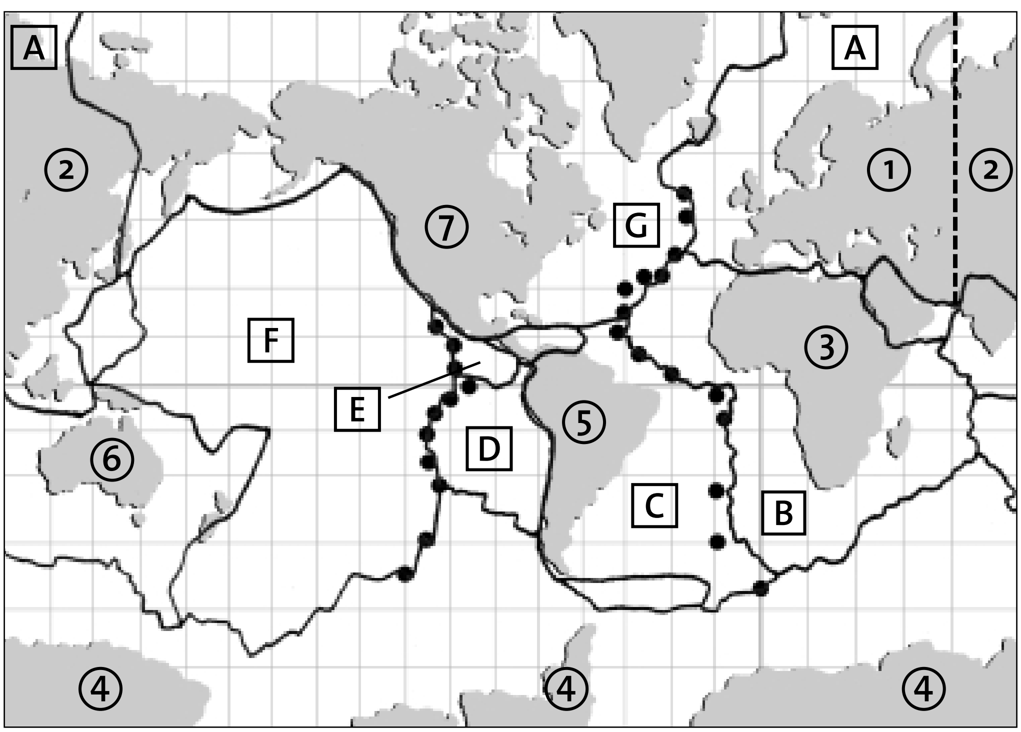
2.2 Finding the Global Zipper

Materials (per student)
Student Activity Sheet from previous activity
Geology Map completed in previous activity
Pencil or pen

What to do
Have students use their assembled Geology Map and activity sheet. Following the directions on their sheet, they will plot the provided coordinates and draw the Mid-Ocean Ridge, and then answer the questions.

ANSWERS
1. **Cocos Plate and the pacific Plate**
2. **North America Plate and Eurasian Plate**

Twenty cubic km of new oceanic crust are created along the Mid-Ocean Ridge every year. If all this new rock were poured into the Grand Canyon, it would fill up every 9 nine years.



TECTONIC PLATES
- A Eurasian Plate
- B African Plate
- C South American Plate
- D Nazca Plate
- E Cocos Plate
- F Pacific Plate
- G North American Plate

CONTINENTS
1. Europe
2. Asia
3. Africa
4. Antarctica
5. South America
6. Australia
7. North America

2.1 Puzzling Plates

Put together your Geology Map from the puzzle pieces to see how the tectonic plates fit together. Paste your map onto blank paper. Then, using the coordinates below, locate and label these seven tectonic plates on your Geology Map. Color each of the labeled plates a different color.

1	Eurasian Plate	western point: 58°N, 32°W	southern point: 36°N, 10°E
2	African Plate	northern point: 36°N, 10°W	southern point: 45°S, 30°E
3	South American Plate	northern point: 20°N, 50°W	southern point: 52°S, 45°W
4	Nazca Plate	northern point: 0°, 90°W	southern point: 42°S, 80°W
5	Cocos Plate	northern point: 19°N, 110°W	southern point: 0°, 90°W
6	Pacific Plate	northern point: 55°N, 140°W	southern point: 70°S, 170°W
7	North American Plate	western point: 60°N, 150°E	eastern point: 80°N, 7°E

Next, label the seven continents: Europe, Asia, Africa, Antarctica, South America, Australia, and North America.

1 Which is the largest tectonic plate? ______________________________

2 What is the relationship between the size of the continents and the plates on which they sit? ______________

____

2.2 Finding the Global Zipper

Draw the Mid-Ocean Ridge!

Making a dot on your map at each location, plot the following latitude and longitude coordinates.

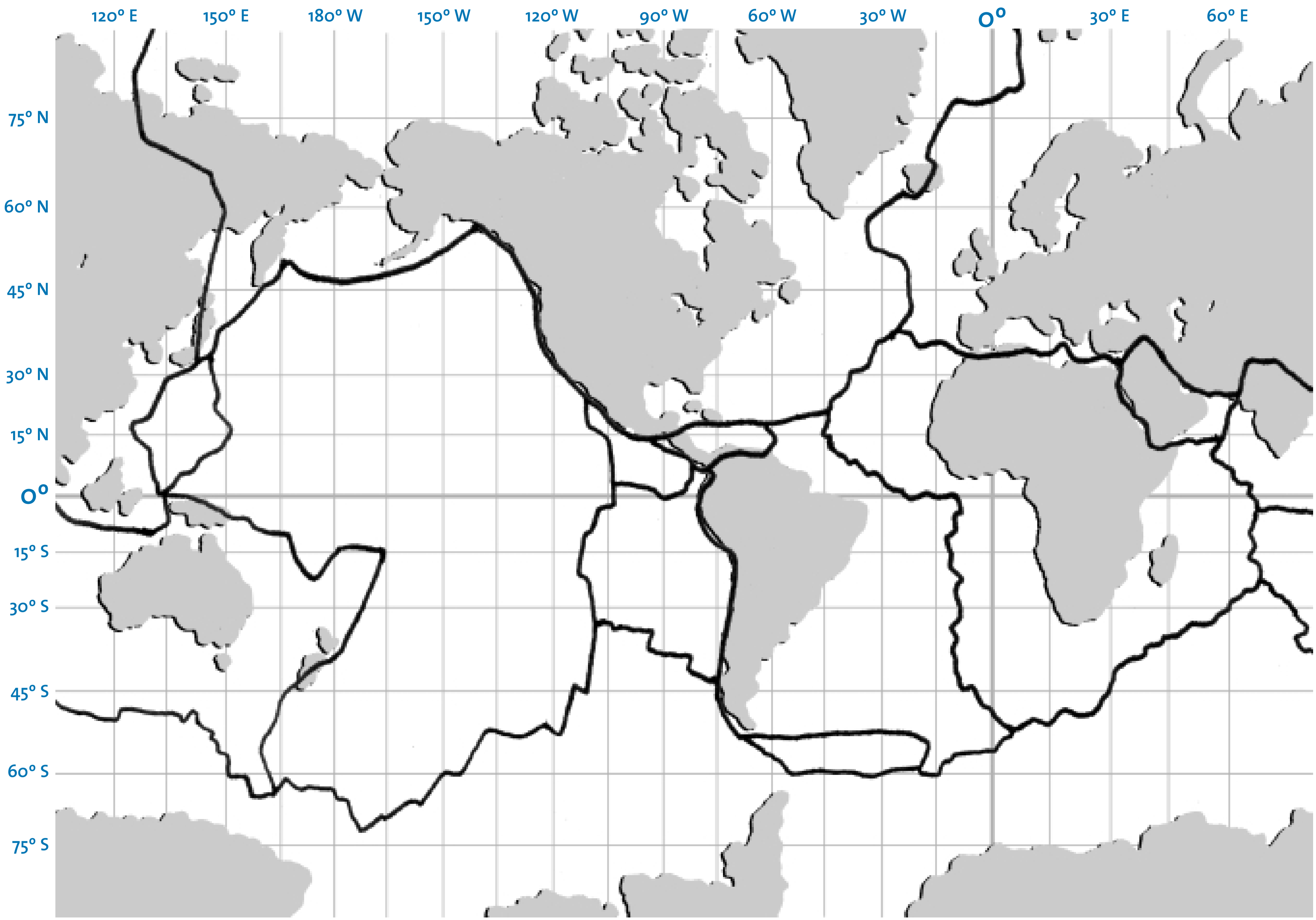
Then starting from the top of the East Pacific Rise coordinates, connect the dots in descending order. Repeat for the Mid-Atlantic Ridge coordinates. Label these lines as the East Pacific Rise and the Mid-Atlantic Ridge.

East Pacific Rise	Mid-Atlantic Ridge
19°N, 107°W	50°N, 28°W
11°N, 105°W	45°N, 28°W
9°N, 105°W	40°N, 30°W
0°, 102°W	35°N, 35°W
5°S, 105°W	35°N, 40°W
10°S, 110°W	30°N, 45°W
15°S, 115°W	25°N, 45°W
25°S, 115°W	15°N, 47°W
35°S, 114°W	10°N, 40°W
45°S, 115°W	4°N, 30°W
50°S, 120°W	5°S, 15°W
	20°S, 13°W
	35°S, 15°W
	45°S, 15°W
	55°S, 0°

1 Which two plates are spreading apart to form 9°N on the East Pacific Rise? ______________________

2 Which two plates are spreading apart to form the Mid-Atlantic Ridge, due east of Canada? ______________

Geology map

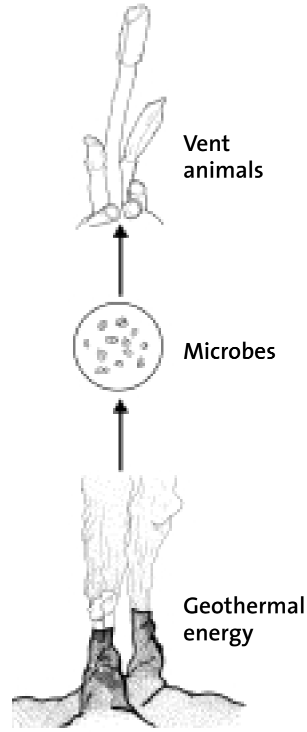

120° E
150° E
180° W
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
75° N
60° N
45° N
30° N
15° N
0°
15° S
30° S
45° S
60° S
75° S

3 Who's Who in the Sunless Deep?

Background information

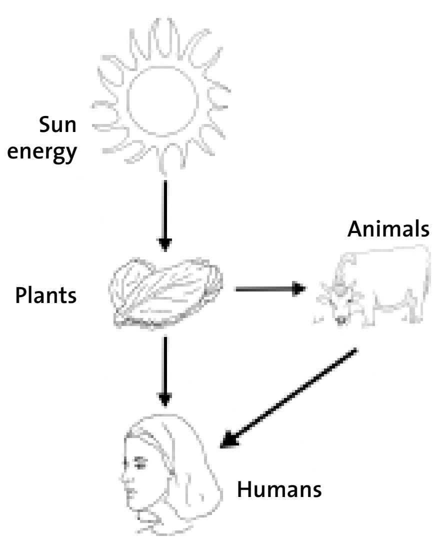
A wildly diverse cast of characters lives around hydrothermal vents at great depths, extreme pressure and in pitch darkness. More than 95% of these life forms are new to science, and scientists find new species on almost every dive.

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

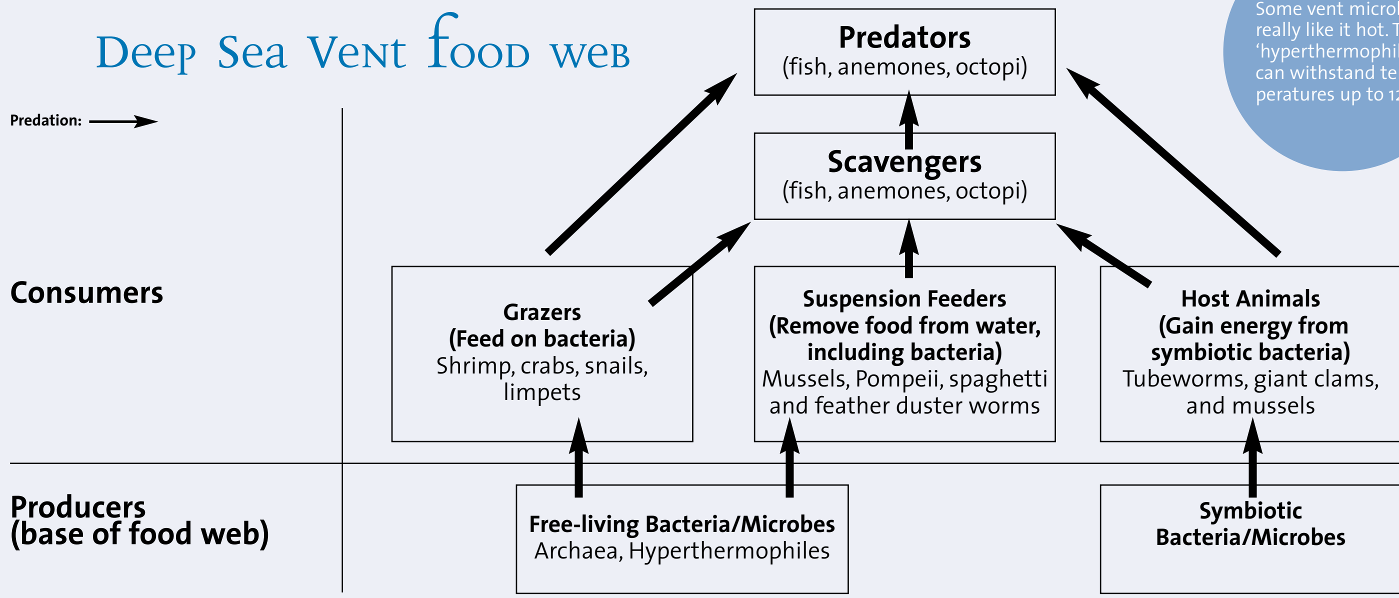
The order in which vents are colonized by animals over time is called *succession*. Life around vents first appears as a mat of bacteria that creeps over the freshly baked lava on the ocean floor. The small-but-mighty microbes soon become dinner for tiny shrimp-like animals such as amphipods and copepods 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!

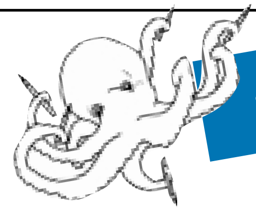
Deep Sea Vent food web



Some vent microbes really like it hot. These 'hyperthermophiles' can withstand temperatures up to 121° C!

Making Connections: Coral Reef versus hydrothermal vent

Common	Unique to vents	Unique to corals
Hard Structure	• Metal sulfides form basis of vent structure	• Calcium carbonate forms shell of coral structure
Symbiosis • Both systems are highly dependent on photosynthesis	• Tubeworm tissue hosts chemosynthetic bacteria • Mussels & clams also host bacteria	• Animal tissue of coral hosts a plant-like symbiont called zooxanthellae
Special Adaptations/Requirements	• Do not require sunlight • Withstand being bathed in mineral-rich water that is toxic to other life forms • Tubeworms extract hydrogen sulfide from the water to nourish symbiotic bacteria	• Require sunlight, low energy water movement, and warm shallow water
Who's Who • Same major animal groups exist in both habitats, for example: snails, limpets, worms, crabs, amphipods, shrimp	• A few examples of 'vent-adapted' animals: Tubeworms Blind shrimp Eelpouts	• Coral reefs are home to their own set of 'reef-adapted' inhabitants
Zonation (where animals settle on the structure)	• Critters form concentric rings around vents, and thrive in vent fluid temperatures (3-300° C) • See page 14 for succession details	• Critters zoned within various fore-reef, reef, and back-reef areas based on unique characteristics
Energy Source	• Geothermal energy supports chemosynthesis	• Solar energy supports photosynthesis
Physical Setting	• No light, high pressure, low temperatures	• Abundant light, low pressure, high temperatures
Critters	• Large sizes, low diversity (number of species per unit area), large numbers, low predation	• Small sizes, high diversity, few in number, high predation
Nutrients	• Nutrients available to support photosynthesis but no source of sunlight • Nutrient base is from the vent fluids rich in iron and sulfur chemicals that are used by bacteria	• Nutrients are not abundant (phosphate and nitrogen) but there is abundant sunlight • Nutrient base is from symbiosis between zooxanthellae and coral tissue



3.1 Cast of Characters: Critter Cards

Materials (per student)
One set of Critter Cards and Data Cards (pages 17-18), copied on cardstock
Scissors
Coloring pencils, crayons or markers
Glue stick or clear tape

The giant tube-worm is the fastest growing marine invertibrate. It can grow a whopping 2 to 3 millimeters a day, up to 2.4 m tall!

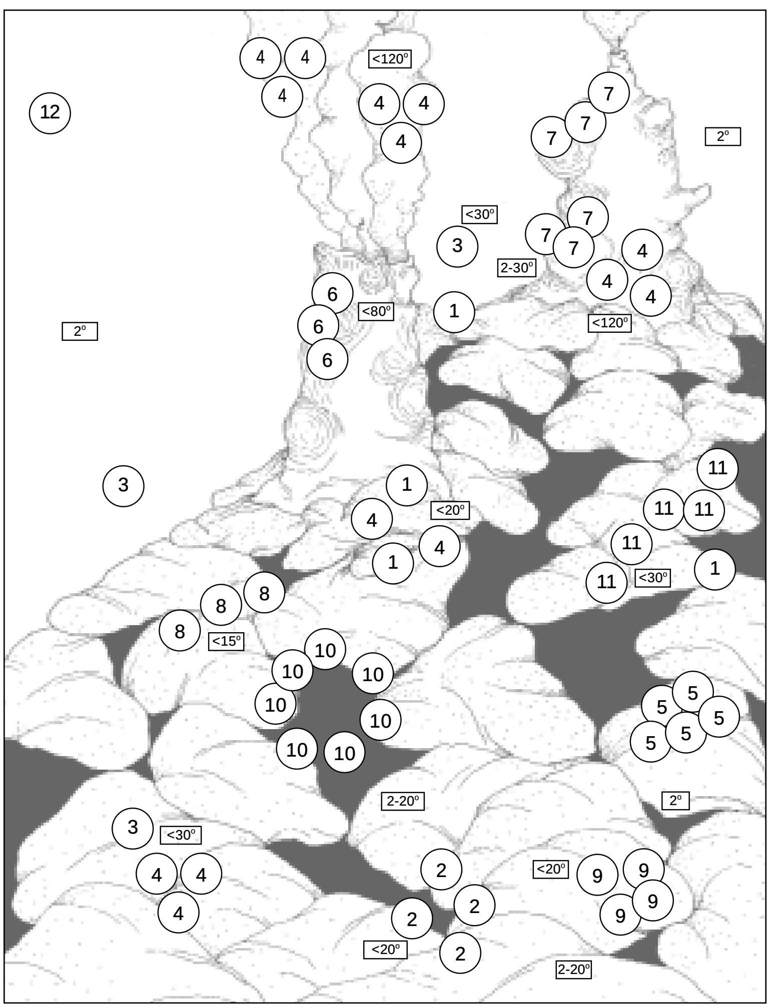
Prep Notes
The critter cards in the following activity focus on vent animals found in the Atlantic and Pacific Oceans. Recently, some similar vent animals have been found along vent sites in the Indian Ocean. Visit www.volcanoesofthedeepsea.com for a gallery of spectacular critter images in full color.

What to do
Have students do the following:

Step 1: Cut out the critter cards and data cards, match each animal to the appropriate data card, and then color the animal. Glue the critter cards back-to-back with the right data card.

Step 2: Once the cards are assembled, work in pairs to test each other's knowledge of the animals by placing all cards critter-side down and taking turns to correctly identify which animal is related to specific data. Switch partners and repeat the game.

ANSWERS
1 Tubeworms
2 Clam
3 Eelpout fish (Zoarcid)
4 Microbes (Bacteria)
5 Spaghetti worm
6 Pompeii worm (Alvinella)
7 Vent shrimp
8 Squat lobster (Galatheid crab)
9 Anemone
10 Mussel
11 Brachyuran crab
12 Octopus



3.2 Where to Rent on a Vent

Materials (per student)
Rent on a Vent sheet, page 19
Assembled critter cards from previous activity

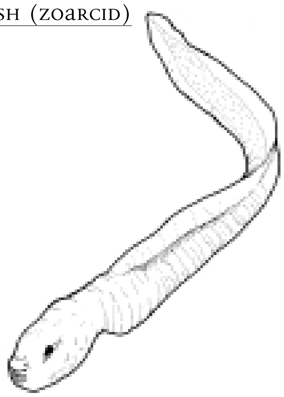
Prep Notes
Vent structures in the Pacific and the Atlantic oceans grow differently and are home to different animals. Some animals are only found in one ocean or the other. However, for this activity the illustration serves as a general vent environment to help students relate each animal's physical characteristics to their particular 'home' in the habitat. For more specific information on the different sites and their specific inhabitants, visit www.volcanoesofthedeepsea.com.

What to do
Distribute the 'Rent on a Vent' diagram. Using the information on the data card and the temperatures in the diagram, students are to find the best homes for the critters. Have them write the number of the critter in the blank circles on the diagram wherever they think the critter could live. (The key, at left, shows probable locations where the animals are likely to live. There is more than one right answer for every animal!)

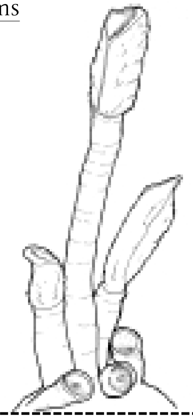
Critter Cards

NOT DRAWN TO SCALE

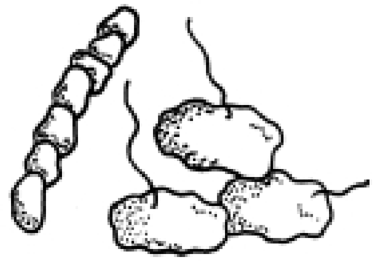
eelpout fish (zoarcid)



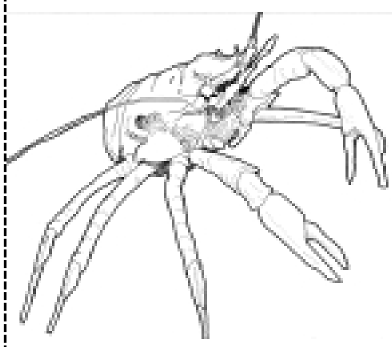
tubeworms



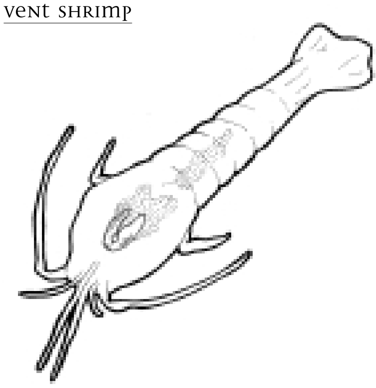
microbes (bacteria)



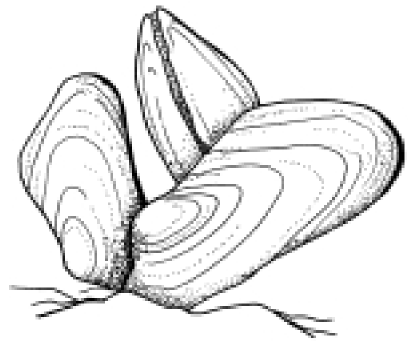
squat lobster (galatheid crab)



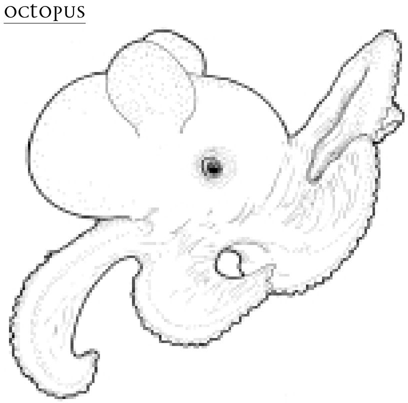
vent shrimp



mussel



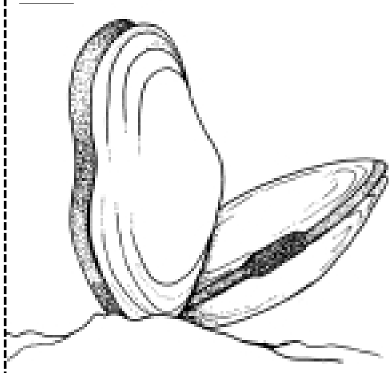
octopus



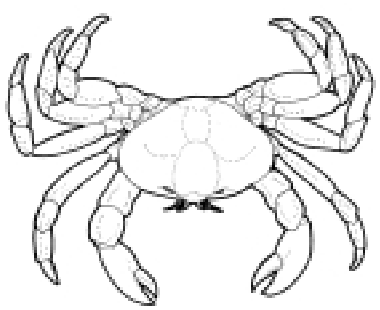
pompeii worm (alvinella)

anemone

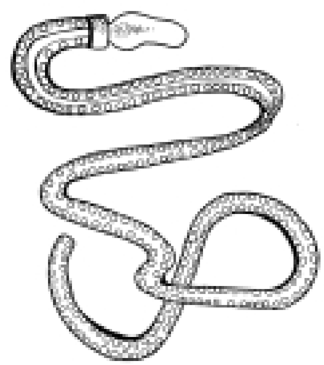
clam



brachyuran crab



spaghetti worm



Data Cards

Ocean: Pacific
Home: close to vents; in cracks and crevices
Preferred temperature: up to 30° C
Description: up to 2.4 m; red worm with feathery fringes inside white cylindrical tube
Food: microbes in special tissue (trophosome)
Facts: live in tube for whole life; one of the first life forms to colonize new site; tissues are blood red from hemoglobin, similar to human hemoglobin; fastest growing marine invertebrate; no gut, anus or mouth; energy comes from symbiotic bacteria
Scientific name: *Riftia pachyptila; Tevnia jerichonana*

1

Ocean: Atlantic and Pacific (though mostly in Pacific)
Home: in cracks along the seafloor and on hard substrate
Preferred temperature: 2-20° C
Description: up to 26 cm; thick white shells; tissues red with hemoglobin
Food: microbes in gill tissue
Facts: these critters are not featured in *Volcanoes of the Deep Sea* because they are some of the last animals to colonize a new vent and had not arrived in time for filming. However, they are very important vent animals
Scientific name: *Calyptogena* sp.

2

Ocean: Atlantic and Pacific (different species in each),
Home: in and near vent fluids
Preferred temperature: up to 30° C
Description: up to 40 cm; whitish-pink eel-like body
Food: bacteria, shrimp, amphipods; scavenges on dead organisms
Facts: top carnivore predator; moves very slowly and lethargically
Scientific name: *Thermarces cerberus* (Pacific); *Pachycara thermophilum* (Atlantic)

3

Ocean: Pacific and Atlantic
Home: on rocks, in and around vents, inside animals (Pacific: inside tubeworms, mussels, clams; Atlantic: inside mussels and clams)
Preferred temperature: 2-120° C
Description: various shapes: ball and rod shaped, 2-5 micrometers; filamentous mats, 100-200+ micrometers
Food: hydrogen sulfide
Facts: base of food chain; carry out chemosynthesis; free-living or symbiotic; some Archaea also known as 'extremophiles' as they prefer extreme environments; Archaea look like bacteria but are not; among oldest organisms known to date;
Scientific name: *Methanococcus* sp.

4

Ocean: Pacific
Home: on pillows and other lava structures near, but not in vent areas
Preferred temperature: 2° C
Description: up to about 1 m in length; long body with white spots along the length
Food: bacteria on surfaces and in water column
Facts: contains certain chemical substance (phenols) which may be why these soft-bodied animals are not consumed by predators
Scientific name: *Saxipendium coronatum*

5

Ocean: Pacific
Home: on sides of chimneys
Preferred temperature: up to 80° C
Description: up to 20 cm long; burgundy-colored worm with palm tree-shaped appendages inside white tubes
Food: symbiotic bacteria live on outside; little is known about their specific eating habits.
Facts: named after a submersible; have been observed leaving their tubes periodically; may withstand hottest temperature of any marine invertebrate
Scientific name: *Alvinella pompejana*

6

Ocean: Atlantic and Pacific
Home: Atlantic: dominant species lives in swarms on the sides of vents; Pacific: dominant species lives close to tubeworms and mussels
Preferred temperature: 2-30+° C
Description: up to 15 cm; light-sensitive patch on back; juveniles of main species are pink, adults are white
Food: microbes
Facts: Atlantic species are blind, the light-sensitive patch on their back may be able to detect light emitted from vent fluid; swarms of up to 30,000 animals per square meter
Scientific name: *Rimicarus exoculata*; *Alvinocaris lusca*

7

Ocean: Atlantic and Pacific
Home: in and around vents
Preferred temperature: up to 15° C
Description: up to 30-60 mm; pale white
Food: scavenge on limpets, polychaetes, bacteria and other dead animals
Facts: blind; fierce predators as well as scavengers
Scientific name: *Munidopsis* sp.

8

Ocean: Atlantic and Pacific
Home: on top of lava structures, near the outer edges vent sites
Preferred temperature: around 20° C
Description: tentacles up to 1 m; various colors
Food: shrimp, amphipods, copepods, small fish
Facts: use stinging cells that look like tiny harpoons in their tentacles to stun and capture prey; top carnivore
Scientific name: *Cerianthus* sp.

9

Ocean: Atlantic and Pacific
Home: on surface of lava and sulfide deposits, attached to hard substrates such as tubeworms and lava rocks
Preferred temperature: 2-20° C
Description: up to 16 cm; bivalve; yellowish-white to brownish in color
Food: microbes in gill tissues; microbes filtered from water
Facts: polychaete worm often found living inside mantel cavity; they put a foot down in the sediment and secrete a substance which hardens in seawater and attaches to the ocean bottom; they move along the bottom by using their foot; relatively late colonizer of a new vent.
Scientific name: *Bathymodiolus* sp.

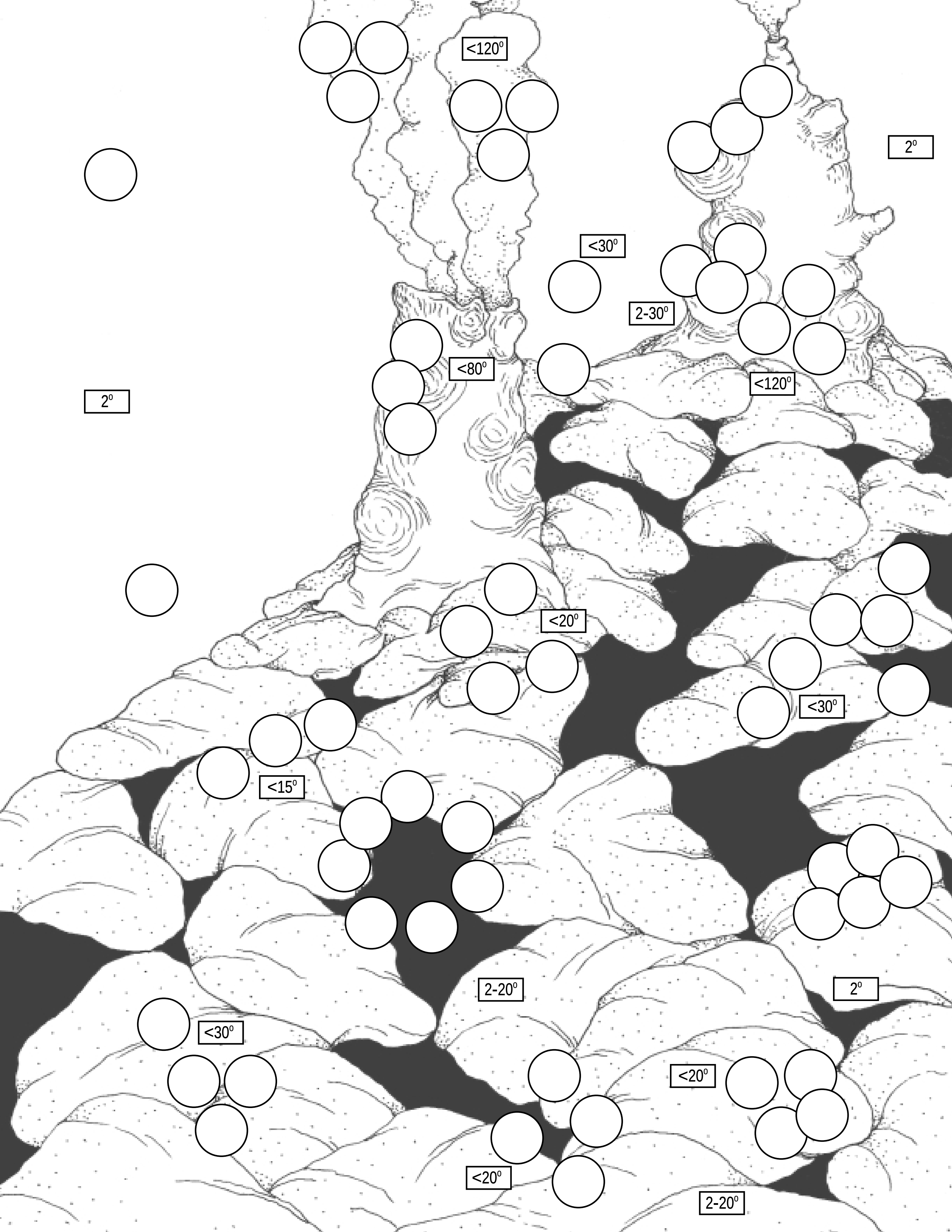
10

Ocean: Atlantic and Pacific
Home: in and around vents, near tubeworms
Preferred temperature: up to 30° C
Description: body up to 60 mm; ghostly-white body with dark tipped claws
Food: bacteria, shrimp, clams, mussels, tubeworms and each other
Facts: possibly blind; one of the first life forms to colonize a new vent; these critters have been found eating each other
Scientific name: *Bathograea* sp.

11

Ocean: Atlantic and Pacific
Home: outer boundary of vent community; live away from vent sites but are often seen in areas close by
Preferred temperature: 2° C
Description: 30 cm; whitish to reddish-orange in color; one species has elephant ear-shaped flaps on sides of head
Food: mussels, crabs, clams, snails and limpets
Facts: powerful beak-like jaw; top predator
Scientific name: *Vulcanoctopus hydrothermalis*, *Grimpoteuthis* sp.

12



<120°
2°
<30°
2-30°
<80°
<120°
2°
<20°
<30°
<15°
2-20°
2°
<30°
<20°
<20°
2-20°

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!

paleontology

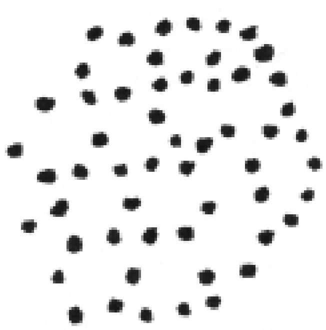
4.1 Creating a Deep-Sea Paleodictyon

Materials (per student)
1 Styrofoam tray
1 disposable plate
Scissors
Pencil
Toothpick
Ruler
1/2 cup clay cat litter
1/2 cup water

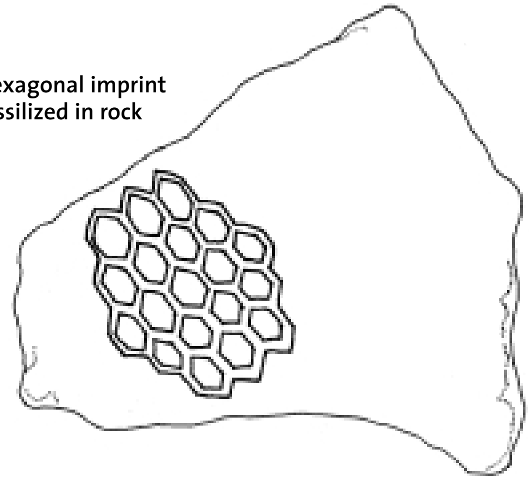
Prep notes
Scientists create models (such as the burrows of the Paleodictyon) to help them visualize the problem they are trying to solve. When this guide was published in 2003, scientists still had not discovered the creature that makes Paleodictyon tracks in deep ocean sediment. What a wonderful opportunity to present students with an actual on-going science mystery! Remind students that scientists certainly do not have all the answers. Discovery is far from dead and much remains to be explored!

Students and teachers are encouraged to send their theories on the Paleodictyon to the actual scientists who study it, through www.volcanoesofthedeepsea.com.

Hexagonal imprint in seafloor sediment



Hexagonal imprint fossilized in rock



What to do
Have students do the following:

Step 1: Use a pencil and ruler to draw a hexagon on the Styrofoam tray, approximately 4 cm across, then carefully cut it out. Punch holes in a symmetrical pattern over the whole hexagonal model with the larger end of the toothpick.

Step 2: Spread cat litter evenly onto the disposable plate and sprinkle the surface with water until it has a clay-like texture, simulating deep ocean sediments. Carefully place the Styrofoam model on the kitty litter and push down to make an imprint, reinserting the toothpick so that each hole is defined in the sediment. Remove the Styrofoam model and allow the Paleodictyons to dry. When they are hard, they should look very much like the Paleodictyon patterns found at the bottom of the ocean along the Mid-Atlantic Ridge.

Writing extension
Ask students to examine their Paleodictyon and hypothesize about what kind of animal may make this impression, and how. Have them write an essay to explain their hypothesis, and develop an argument that the Paleodictyon imprint is one of the following:

a) footprint
b) feeding pattern
c) a house
c) other

Hexagons are seen all throughout nature. Bees make hexagonal cells in their hives, compound eyes of amphipods are made up of hexagonal lenses, and all the ice crystals in snowflakes are hexagonal.

4.2 Telling Real Life Stories of Trace Fossils

Materials (per student)
White paper
String
Scissors
Craft stick
Diluted acrylic paint in a wide bowl
Stapler, glue or other adhesive
Styrofoam pieces (balls, craft shapes, etc.)
Pipe cleaners

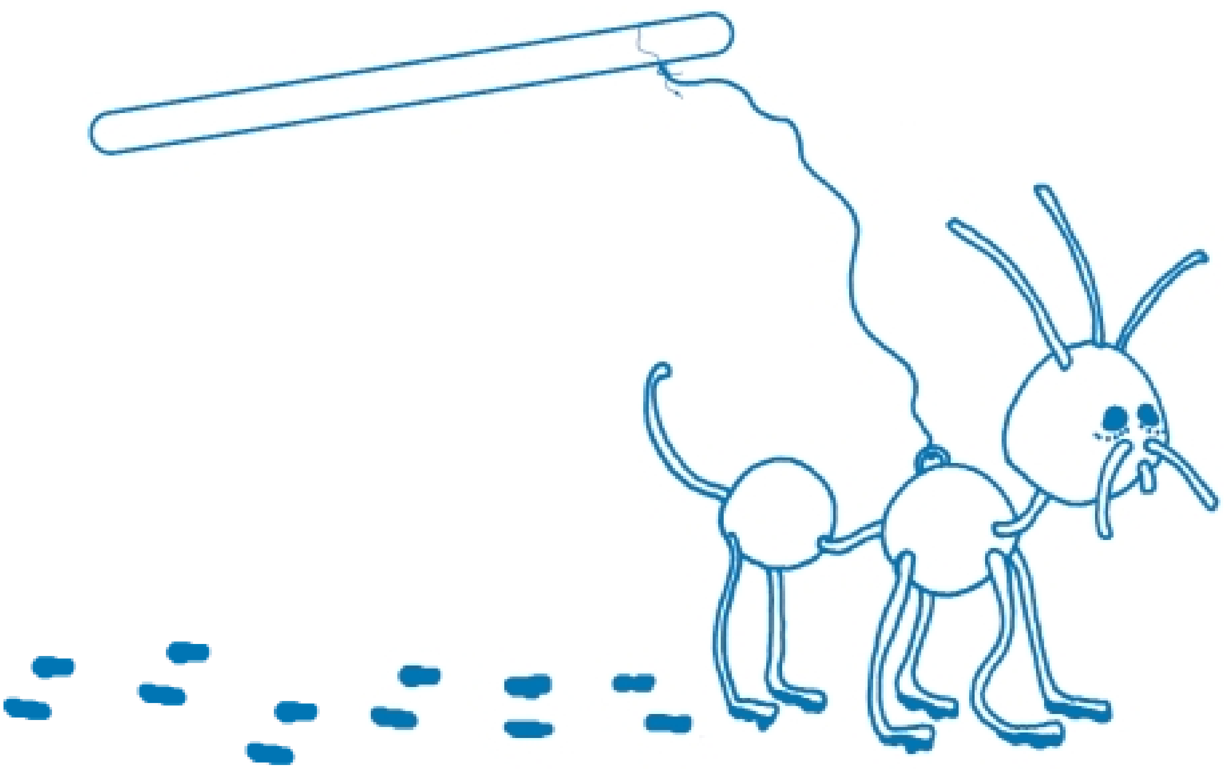
Prep Notes
Trace fossils record the movement and behavior of living things that existed long ago. In ocean sediments, any animal that lives in or on the bottom will create some kind of disturbance in those sediments. When the disturbances fossilize, we are left with a record we can use to study and understand the animal who left it.

What to do
Have students do the following:

Step 1: Construct a deep-sea creature with pipe cleaners and Styrofoam pieces, focusing on how the creature will move (walk, run, scurry, hop, slither, or glide) across ocean sediment. Attach several pieces of string to the deep-sea creature, then staple the free ends of the string to a craft stick. Name the creature (genus and species) after the person who discovered (invented) it, or to reflect a unique characteristic that it exhibits (example: Alvinella was named after Alvin).

Step 2: Holding the deep-sea creature by the craft stick, dip its feet and body into the bowl of diluted paint, carefully shaking off excess paint. Using a steady motion, move the creature over the white paper in one direction. Write the creature's name on the paper. The paper is now a trace fossil record of the pattern that this creature might make on the ocean sediment.

Step 3: While the creatures and trace fossil records dry, discuss as a class the interesting patterns created by animals, and which variables in the deep ocean may cause these patterns to change over time (deep sea currents, geologic activity, etc.). How does this make the job of a paleontologist challenging?



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

5.1 Dr. Nimbus & Dr. Lucidus

Materials
Pen or pencil (for all students)
Paper (for all students)
Script of Dr. Nimbus for one student, 25
Script of Dr. Lucidus for one student, 25

What to do
Elect two students to role-play as scientists who have just returned from an Alvin dive to a hydrothermal vent site. One will be Dr. Lucidus (Latin for clear), who has very good communication skills, and the other will be Dr. Nimbus (Latin for vague and cloud), whose explanations are not as descriptive or helpful. The rest of the class members are journalists who are sitting in on a press conference to learn about the vent the scientists saw on their dive, using pen and paper to take notes. Ask Dr. Nimbus to read her/his description of the dive, while the journalists take notes. Then ask Dr. Lucidus to read her/his description while the journalists take notes again. Ask some journalists to read their notes aloud. Discuss which scientist gave the most helpful descriptions, emphasizing the challenge in describing a new world – even Dr. Lucidus has trouble! Discuss why it is important for scientists to speak, read and write well.

Have students write and illustrate a story about how a vent forms for tomorrow's newspaper based on their notes from the press conference.

Alternatives
Combine activities 5.2 and 5.3 by having students work in pairs. One student from each pair writes a description of the image in activity 5.2, while the other student draws the site described in activity 5.3. They then switch pages. The student with the written description must draw the image described. The student with the drawing must write a description based on the drawing. Ask each pair to evaluate how similar the drawing or written description is to the original. Compare the student's description to the scientist's and discuss when and how mistakes were made, what was easy, what was difficult.

5.2 Finding the 'Write' Words

Materials (per student)
Pen or pencil
Paper
Student activity sheet, 26

Prep Notes
Until *Volcanoes of the Deep Sea* was made, not many people were able to see how spectacular the Mid-Ocean Ridge environment really is. It is always a treat to hear a first-time Alvin diver's account of the bizarre biology and geology that characterize the ridge environments. Descriptions of the geology range from 'sand-dripped castles', to Greek or gothic architecture, to 'poisonous gardens'. The compelling photo provided in this activity serves as a fun platform to get students writing and imagining that they, too, are divers.

What to do
See instructions on the Student Activity Sheet. Discuss how important it is for scientists to communicate effectively to a wider audience, especially when it comes to describing a place very few have seen.

5.3 Drawing the Deep

Materials (per student)
Pencil
Colored pencils
Paper
Student activity sheet, 26

What To Do
See instructions on the Student Activity Sheet.

Dr. nimbus

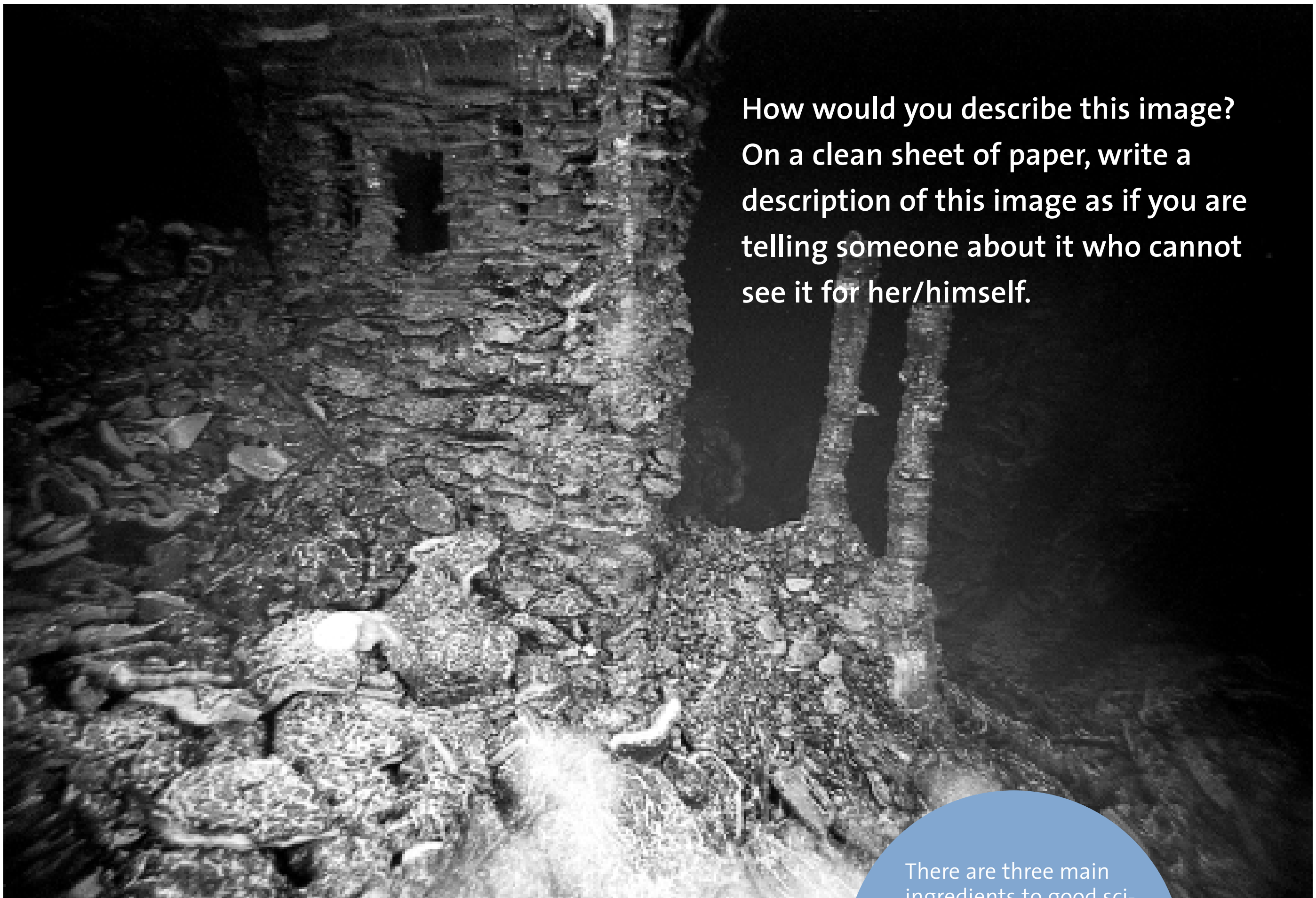
We went down to the ocean bottom, and turned on the lights. We saw a vent spitting out hot water that looked like smoke. It was really big. I was just amazed at the height of the vent considering it was formed from precipitation, which I expect you all know about. Here we were, more than 2 miles down and there were all these life forms I'd never seen before living around a hydrothermal vent. Picture a factory smokestack – that's what a vent looks like except it isn't smooth. The water coming out was really hot according to our temperature probe. We had some problems at first with taking a reading because we had to maneuver it to the right spot. It takes some getting used to. We were also looking at these bizarre animals around the vents. There were these tubeworms waving around. Being able to reach the bottom of the ocean and film it represents a great day for science.

Dr. Lucidus

After a 2-hour descent into the Pacific Ocean, we turned on Alvin's lights and saw a hydrothermal vent that was 150 feet, 46 meters, or 15 storeys tall! You may want to know how this hydrothermal vent, sometimes called a 'chimney' or 'black smoker,' forms at the bottom of the ocean under such tremendous pressure. You see, when two slabs of seafloor crust spread apart because of the heat churning deep inside Earth's belly, hot magma or lava comes up from the mantle to the Earth's crust. The crust cracks at points where that really hot magma meets the cold ocean bottom water. Seawater seeps down into the cracks, where it heats up to temperatures as high as 400 degrees Celsius or 750 degrees Fahrenheit, a temperature reading that we verified with a temperature probe on this dive. Minerals in the rocks around these cracks are dissolved into the seawater and make their way up to the ocean floor. When this super-hot water hits the cold ocean water, the minerals come out as solids, a process we call precipitation. The minerals build up over time to form a hydrothermal vent.

The vents we saw were shaped more or less like upside-down snow cones; they were rounded at the bottom and tapered to a tip. The hot water continues to spew out of the vent, and lots of iron mixes with an element called sulfur to make the water look like black smoke coming out of the tip. That's why vents are also called 'chimneys' or 'black smokers.' A group of animals were living all around the vents including red tubeworms, yellow mussels and white crabs. It was an extraordinary opportunity to see how the energy provided from within the Earth also supports life. It was a highly successful dive!

5.2 Finding the 'Write' words



How would you describe this image? On a clean sheet of paper, write a description of this image as if you are telling someone about it who cannot see it for her/himself.

There are three main ingredients to good science writing: plan the structure before you start to write, think about your reader, and choose the right words for your audience.

5.3 Drawing Prompt

When a first-time Alvin diver came up from a dive, he wrote down all he could remember about what he saw. Using his description below, draw the scene as clearly as possible.

"It was almost as you would imagine a moonscape. There were these tall mushroom structures with the domed head where the pillow lava had come up and drained back … like a statue. At one point we flew along East Wall and I was looking straight down into the ridge. It was absolutely nothing like I had imagined, and it was everything I had imagined. It was really powerful. And yet life was just going on down there, just completely oblivious to us. I saw the mixtures of different species … the tubeworms and mussels … The funniest thing I saw was this octopus that made a bee-line to the equipment we deployed. Then it just slowly swam away. The eelpouts and the rattails [eel-like fishes] – the fish that we saw down there – everything moves incredibly slow because they have to conserve energy and only move quickly when they have to. But some of them would just hang upside down in the water, almost like Christmas decorations in a tree. There was this crab right in the middle with his claw jammed up the inside of a tubeworm, trying to pull it out. We were down for 9 hours, but it went like that!"

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.

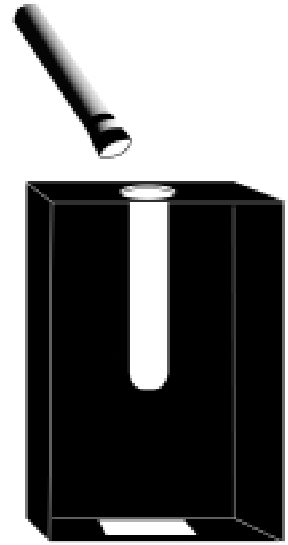
The physical nature of how light travels through water presented yet another challenge. Light does not travel through water as easily as it does through air because water is denser than air. Particles in ocean water, including sediment, structures and living things, also absorb and scatter light, which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

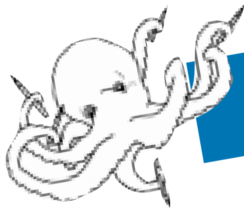
Charles Martin and William H. Longley took the first underwater color photos in 1926. Longley walked along the bottom under 15 feet of water while Martin waited at the surface with a half pound of magnesium flash powder. At the tug of a rope from Longley, Martin set off the flash powder, burning himself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

technology

6.1 Lights, Camera, Action!



Materials (per lab group)
Cardboard shoebox without a lid
Three test tubes, each 6 inches (15 cm) tall
Tap water
1 teaspoon table salt
1 eyedropper
Small flashlight
White paper
Pencil



Inner Space in Outer Space? PAGE 30

Prep Notes
This exercise requires the room to be as dark as possible. If you have access to a sealed darkroom, do this activity in it. Before class, prepare a box and materials for each lab group. Stand the box on a short end with the open side facing you. Make a hole on the top side, wide enough that the test tube will fit through it and be suspended. Cut out three pieces of white paper per box that fit inside the bottom. Label the papers ‘Test Tube #1’, ‘Test Tube #2’ and ‘Test Tube #3’. Prepare a simple saltwater solution (1 teaspoon of salt per 1 cup of water).

What to do
Divide the class into lab groups giving each group an assembled Black Box and all the materials. Have students do the following:

Step 1: Insert one test tube into the hole, and place the paper labeled ‘Test Tube #1’ at the bottom of the box. One student shines the flashlight down through the test tube, aiming at the white paper. Another student uses the pencil to trace the outline of the beam that is emitted on the white paper. Remove the test tube and paper. Fill the second test tube with tap water, leaving a small amount of space at the top, and insert it into the hole. Place the paper labeled ‘Test Tube #2’ at the bottom. Shine the flashlight down through the test tube and trace the beam on the white paper. Remove the test tube. Fill the third test tube with the saltwater solution, leaving space at the top, and insert it into the hole. Place the paper labeled ‘Test Tube #3’ at the bottom. Shine the flashlight down through the test tube and trace the beam on the white paper.

Step 2: Class discussion: determine the relationship between the test tube contents and the width of the light beams emitted by examining the shapes cast by the light on the paper.

RESULTS
The light beam shone through test tube #1 should look like a sharp bulls-eye: large, bright, well-defined rings. With test tube #2 (water), the light circle is smaller, not as bright, rings not as well defined. This signifies that the water absorbs and scatters the light. With test tube #3 (saltwater), the salt absorbs and scatters the light beam even more. Just a hint of circle from the light beam should be visible.

6.2 Simulate, Calculate, Create...a New, Improved Alvin

Materials (per lab group)
Student Activity Sheet, 29
Calculator
Scale
Blank sheet of paper

Prep Notes
This exercise is designed to give students a sense of the technological limitations that are a part of every Alvin dive, and inspire them to design a new, improved Alvin submersible. The first part of the activity focuses on Alvin’s payload – a precise calculation that varies with every dive depending on the weight of the equipment, passengers, etc. – and one that Alvin pilots calculate before every single dive. Read the background information with students and discuss the effects of technology on scientific progress before completing the exercise. Have students present their dive plans, payload calculations, and new Alvin design to the class when complete.

Extension: Have students compare air versus water weight using these materials: spring balance, beaker of salt water, rock, string. Wrap the string around the rock so you can attach it to the spring balance. Record the weight of the rock in air. Record the weight of the rock in salt water. Ask students: Do objects weigh more or less in water compared to air?

What to do
Divide the class into lab groups and distribute the materials. Instructions are on the Student Activity Sheet.

6.2 Simulate, Calculate, Create...a New, Improved Alvin

Part 1: Designate two people from your lab group to serve as pilot and IMAX camera operator for an imaginary dive to the deep. First, outline your goal for your film dive: what do you want to film? Is it a structure, a critter, something else? What science equipment do you need to bring down to help you complete your mission? Make sure one group member records a basic dive plan on the paper provided. Next, work as a team to calculate Alvin's payload for your IMAX dive simulation. Alvin's payload cannot exceed 1500 pounds for your dive. This includes the weight of the crew, cameras, film cans, one manipulator arm, one 'super' light, and science basket (used to carry science experiments to the ocean bottom). Fill in the chart appropriately.

Weight Chart

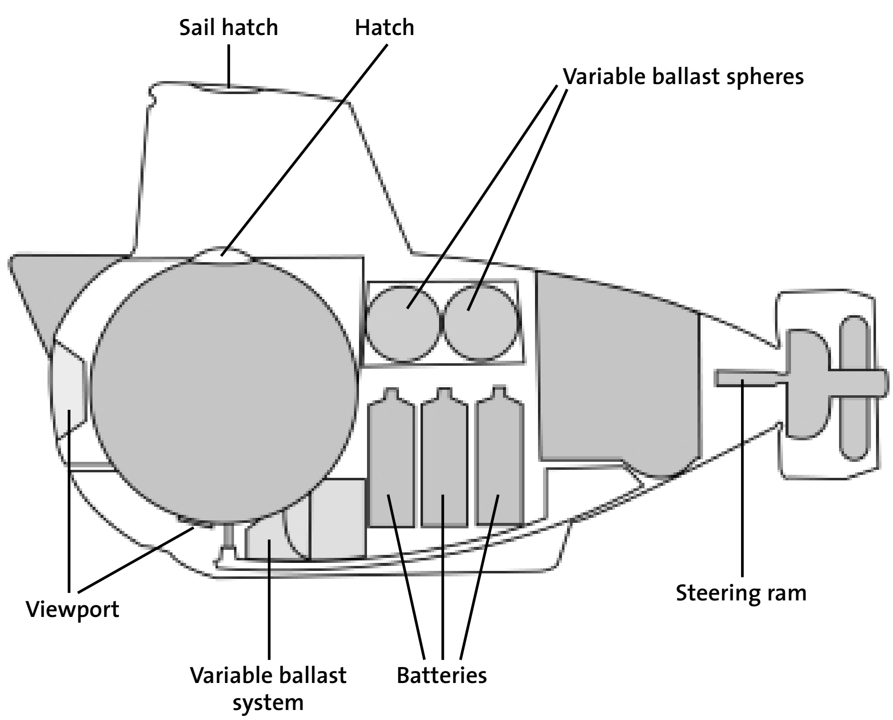
Inside diving sphere	Air weight
Pilot	
Camera operator	
IMAX camera body	80 lb
Camera accessories (batteries, film magazines, support equipment)	110 lb
6 film cans/dive (containing 1000 feet of 65-mm film per can; each can weighs 10 pounds)	
TOTAL WEIGHT	
Outside mountings	**Water weight**
Manipulator arm (Alvin usually carries two, but only one when the super light is used!)	117 lb
Super light (1200 watts)	50 lb
Science basket (45 pounds empty) Note: Don't forget to include the weight of the items you add to the basket!	
Ascent weights: 208 pounds each (2 weights are required for each dive. These are dropped on the bottom when Alvin ascends at the end of the dive.)	
TOTAL WEIGHT	

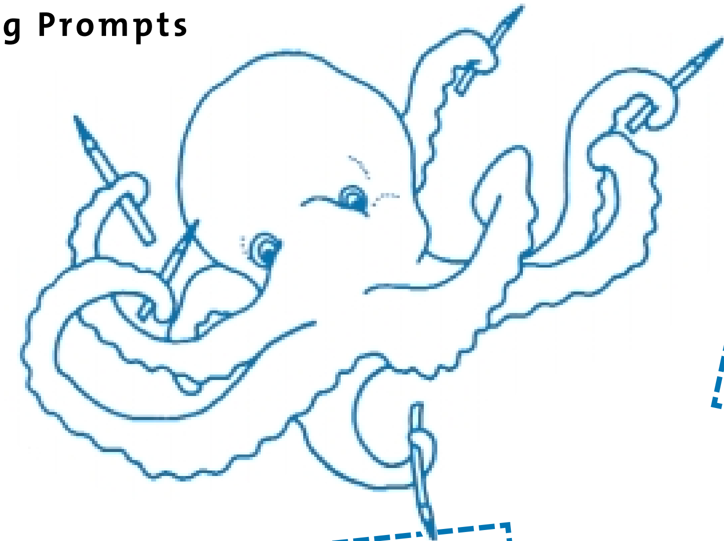
What is your total payload weight (weight inside plus weight outside)? ______________________

Did you exceed 1500 pounds? If so, you just sunk Alvin on your dive! If not, would you want to add equipment for your dive? Why or why not? ______________________

Part 2: Design a new and improved Alvin. Pick out two ideas from the list below, and draw and explain your modifications by making notes on the Alvin diagram.

- Increased depth capability
- Increased bottom time (presently, Alvin can remain on the bottom for about 4 hours)
- Increased energy capacity
- Improved fields of view
- Improved interior design
- Increased science payload





Spaced Out: Time for Devotion to the Ocean
Imagine you are the president of a local Deep Ocean Explorers Club. Your friend is the president of the Outer Space Explorers Club across town. You are both initiating a funding drive to raise money for your next excursion. Write a one-page essay that persuades the community to fund your trip to the ocean bottom instead of your friend's trip to space.

Why isn't the Earth getting bigger?
According to part of the theory of plate tectonics, when the seafloor splits apart, new crust is generated along the Mid-Ocean Ridge. Therefore, some scientists used to think the Earth must be getting bigger. They theorized that if new crust was continuously generated at divergent plate boundaries, then planet Earth must be growing all the time. They called it the 'Expanding Earth' hypothesis. However, scientists could not figure out how the Earth could expand without anyone realizing it. In fact, most geologists now believe that the Earth's size has remained fairly constant since its formation 4.6 billion years ago. While The 'Expanding Earth' hypothesis has been 'de-bunked', it is still a fact that new Earth is born regularly at divergent plate boundaries. This raises a key question: Why *isn't* the Earth getting bigger? How can new crust be continuously added along the oceanic ridges without increasing the size of the Earth?

Seeing in a Sunless Sea
Since most sunlight is absorbed in the top 100 feet of seawater, there is no sunlight 12,000 feet down. Isn't it interesting that the diverse deep-sea vent animal community carries on quite well without light? Can you imagine never seeing the light of day? How do you think the eel-like fish that live around hydrothermal vents deal with the darkness at the bottom of the ocean? How do they manage to see in a sunless sea, and avoid running into the hot vents or other animals? How do they find their meals?

Inner Space in Outer Space?
Prior to the discovery of the first hydrothermal vent, no one could have predicted that such an extreme environment could sustain life. For years, humankind has longed to discover new worlds, both terrestrial and extraterrestrial, with the hope of finding life. With the assistance of a variety of scientific tools – the Hubble telescope, satellites, shuttles and more – we continually find new information about the incredible variety of environments that exist throughout the universe.

In particular, the Galileo probe has provided tremendous amounts of detailed information about the planet Jupiter and its moons. Two of Jupiter's four moons, Io and Europa, may hold some of the key ingredients necessary for the development of life as we know it on the vents. Io is rich with volcanic activity (there's even a vent site named after it along the East Pacific Rise!), and Europa has an ocean under a thick layer of ice. Given the fact that these two moons have very similar orbits around Jupiter, it is possible that both moons have volcanic activity. In fact, according to Dr. Richard Lutz of Rutgers University, 'It would be a huge leap of faith to say there is NOT any volcanic activity on Europa.' So it is possible that there are similarities between Earth's deep-sea vent environments and the 'other worldly' environment on Europa. Isn't it amazing that Europa is about 417,000 miles away from Jupiter, and Jupiter is about 484 million miles from Earth, but is it possible that we might learn something about the possibility of life on Europa by studying our own deep ocean, just two miles beneath Earth's ocean surface?

Do you believe there is life on Europa? If so, what does it look like? Where does it form? How does it survive? Write a persuasive essay that explains your position, and include a drawing of 'life' as you think it might exist on Europa.

Glossary

Alvin – a deep-sea submersible operated by Woods Hole Oceanographic Institute in Massachusetts

Bathysphere – a strongly built steel diving sphere historically used for deep-sea observation

Benthic – a community that dwells at the bottom of a body of water

Black smoker – smokestack-like structure composed of a variety of mineral deposits (especially sulfur minerals) found in and around the Mid-Ocean Ridge; emits hot, dark particles that resemble black smoke; also called hydrothermal vents and/or chimneys

Body fossil – actual matter from the remains of an animal or plant – including bones, teeth, shells, and leaves – that have been recorded in rock or sediment

Chemosynthesis – the process of using chemical energy (specifically hydrogen sulfide) to create food; carried out by bacteria at the base of the vent food web

Chimney – see black smokers/hydrothermal vents

Convection current – circular patterns that transfer heat from the hot, softened mantle rock (lava) to the surface and back down again. The heated rock rises, cools as it surfaces, and sinks back down in a circular motion that is repeated.

Core – Earth's innermost layer consisting largely of metallic iron; the radius of the core is approximately 1864 miles (3000 km)

Crust – the outermost and thinnest layer of the Earth; the crust consists of rocky material that is less dense than the rocks of the mantle below it; includes oceanic and continental crust; ocean crust is younger and thinner than continental crust

Divergent plate boundary – areas between two tectonic plates where new crust is formed as two plates diverge, or move apart by the action of magma pushing up from the mantle; examples are the Mid-Atlantic Ridge and East Pacific Rise; also called seafloor spreading centers

Geothermal – heat energy from inside the Earth

HMI Light – a type of mercury-halide discharge lights/lamps that are standard equipment in deep-sea photography; HMI stands for Hydragyrum Medium arc-length Iodide; they are four times more powerful than standard fluorescent lights

Hydrogen sulfide – (H_2S) a molecule (chemical compound) made of hydrogen and sulfide that is colorless, toxic to most living things, and has an odor similar to rotten eggs; produced when seawater reacts with sulfate in the rocks below the ocean floor; the source of energy that fuels vent food webs and the most plentiful compound in vent emissions; primary chemical dissolved in vent water

Hydrothermal vent – ('hydro' means water, 'thermal' means heat); a hot mineral water geyser on the ocean floor that occurs where volcanic activity is intense, such as seafloor spreading zones along oceanic ridges

Ichnofossil – another name for trace fossils

Latitude – a measurement of the distance in degrees north and south of the Equator

Lava – molten rock that emerges up through the surface of the Earth's crust

Living fossil – a newly found specimen that was thought to be extinct; a prehistoric species that still lives today (i.e. horseshoe crab, gingko tree, Paleodictyon)

Longitude – a measurement of the distance in degrees east and west of the Prime Meridian

Magma – molten (melted) rock beneath the surface of the earth

Mantle – the thick shell of dense, rocky material that surrounds the core and lies beneath earth's crust; the mantle is approximately 1740 miles (2,800 km) thick

Mid-Ocean Ridge – a vast underwater mountain range that zig-zags more than 40,000 miles (64,374 km) around the earth; located at the seafloor spreading boundaries where tectonic plates spread apart from the action of magma rising from the mantle

Molten rock – melted mantle rock

Paleontology – the study of fossils

Photosynthesis – the process by which plants use the energy from the sun to convert carbon dioxide and water to make carbohydrate food

Precipitation – the process by which a solid (such as a mineral) is separated out from a solution (such as seawater); a hydrothermal vent forms when minerals precipitate near volcanic seafloor spreading centers (cold sea water seeps down through the cracks in mid-ocean ridges, many minerals are transferred from the hot liquid magma into the water, the hot water gushes back up through the cracks and escapes, it comes in contact with near-freezing water of the ocean bottom and the minerals quickly 'rain out' or 'precipitate out' of their solution)

Scientific method – a process followed by scientists including: observation, formulation of hypothesis, testing of hypothesis, interpretation and analysis of data, communication of findings

Seafloor spreading zone – areas between two tectonic plates where new crust is formed as two plates diverge, or move apart by the action of magma pushing up from the mantle; examples are the Mid-Atlantic Ridge and East Pacific Rise; also called divergent plate boundaries

Succession – change in a vent community over time, specifically a change in species composition and community structure

Symbiosis – a mutually beneficial relationship in which each organism benefits from the association with the other

Tectonic plate – a large, rigid slab of rock that floats and moves across the earth's mantle; Earth is made of about 12 main plates, which are continental or oceanic in nature

Trace fossil – signs of the remains of a prehistoric plant or animal that have been recorded in rock or sediment, including patterns that record the movement and behavior of living things (e.g., burrows, tracks, footprints)

Water pressure – the force exerted by the weight of water around an object; measured in units of force/weight per area (e.g. pounds per square inch); pressure in the ocean increases steadily as we move down the water column: pressure increases by 1 atmosphere for every 33 feet (10m) of depth

NATIONAL EDUCATION STANDARDS	CHAPTERS 1	2	3	4	5	6
SCIENCE						
National Science Education Standards for grades 5-8.						
Source: http://www.nap.edu/readingroom/books/nses/html/6a.html						
Content Standard A: Science as Inquiry	✔	✔	✔	✔	✔	✔
Content Standard B: Physical Science	✔	✔				✔
Content Standard C: Life Science			✔	✔		
Content Standard D: Earth and Space Science		✔		✔	✔	✔
Content Standard E: Science and Technology	✔				✔	✔
Content Standard F: Science in Personal and Social Perspectives	✔				✔	✔
Content Standard G: History and Nature of Science	✔	✔		✔	✔	✔
MATH						
National Math Education Standards for grades 6-8.						
Source: http://standards.nctm.org/document/chapter6/index.htm						
Numbers and Operations	✔	✔		✔		✔
Algebra	✔					
Geometry		✔		✔		
Measurement	✔	✔		✔		✔
Data Analysis and Probability	✔	✔	✔	✔		
Problem Solving	✔	✔		✔		✔
Reasoning and Proof	✔					
Communication	✔					✔
Connections	✔	✔		✔		✔
Representation	✔	✔		✔		✔
TECHNOLOGY						
National Technology Education Standards for grades 6-8.						
Source: http://cnets.iste.org/students/s_profile-68.html						
1 (standards category 1)						
2 (standards category 2)					✔	✔
3 (standards category 2)						
4 (standards categories 3 and 5)	✔	✔	✔	✔		✔
5 (standards categories 3 and 6)	✔		✔	✔		✔
6 (standards categories 4, 5 and 5)					✔	✔
7 (standards categories 4 and 5)	✔		✔	✔		✔
8 (standards categories 5 and 6)	✔		✔	✔	✔	✔
9 (standards categories 1 and 6)						
10 (standards categories 2, 5 and 6)						
ENGLISH						
National English Education Standards for grades 6-8.						
Source: http://www.ncte.org/standards/standards.shtml						
Standard 1	✔	✔	✔	✔	✔	✔
Standard 2						
Standard 3						
Standard 4	✔		✔	✔	✔	✔
Standard 5	✔	✔	✔	✔	✔	
Standard 6					✔	
Standard 7						
Standard 8	✔	✔	✔	✔	✔	✔
Standard 9	✔		✔	✔		✔
Standard 10						
Standard 11						
Standard 12	✔	✔	✔	✔	✔	✔
GEOGRAPHY						
National Geography Education Standards for grades 5-8.						
Source: http://www.ncge.org/publications/tutorial/standards/						
Standards 1-3: The World in Spatial Terms	✔	✔	✔		✔	
Standards 4-6: Places and Regions	✔	✔				✔
Standards 7-8: Physical Systems		✔				
Standards 9-13: Human Systems						
Standards 14-16: Environment and Society						✔
Standards 17-18: The Uses of Geography		✔				
ART						
National Art Education Standards for grades 5-8.						
Source: http://www.artteacherconnection.com/pages/5-8th.html						
Content Standard 1: Understanding and applying media, techniques			✔	✔	✔	✔
Content Standard 2: Using knowledge of structures and functions			✔	✔	✔	✔
Content Standard 3: Choosing and evaluating a range of subject matter, symbols and ideas			✔	✔	✔	✔
Content Standard 4: Understanding the visual arts in relation to history and cultures			✔	✔	✔	
Content Standard 5: Reflecting upon and assessing the characteristics and merits of their work and the work of others		✔	✔	✔	✔	✔
Content Standard 6: Making connections between visual arts and other disciplines		✔	✔	✔	✔	✔

EDUCATION OUTREACH PROGRAM DIRECTOR, UNIVERSITY OF SOUTH FLORIDA
Kristen Kusek

EDUCATION OUTREACH TEAM
Nancy Doolittle
Teresa Greely
Kristen Kusek
Kathleen Heidenreich
Sande Ivey
Kristin Thoms

CURRICULUM CONSULTANT
Joan Butterworth

SCIENCE DIRECTOR
Dr. Richard A. Lutz, Rutgers University

EDITOR, THE STEPHEN LOW COMPANY
Gillian Crouse

ILLUSTRATOR
Diane Leyland

DESIGN
David LeBlanc

ADDITIONAL ILLUSTRATION
Sarah Lutz

COVER
Publicité Piranha

On the deck of the *Atlantis*

Education Outreach Team (left to right): Sande Ivey, Nancy Doolittle, Teresa Greely, Kristen Kusek, Kristin Thoms, Kathleen Heidenreich
Volcanoes of the Deep Sea Director (far right): Stephen Low
Atlantis Captain (front): Gary Chiljean

The *Volcanoes of the Deep Sea* Education Outreach Program was developed in partnership by University of South Florida College of Marine Science and Center for Ocean Technology, The Stephen Low Company and Rutgers University.

A STEPHEN LOW FILM NARRATED BY ED HARRIS EXECUTIVE PRODUCER JAMES CAMERON

PRODUCED BY PIETRO L. SERAPIGLIA AND ALEXANDER LOW SCIENCE DIRECTOR RICHARD A. LUTZ SUPERVISING PRODUCER EMORY KRISTOF DIRECTOR OF PHOTOGRAPHY WILLIAM REEVE C.S.C

MUSIC COMPOSED BY MICHEL CUSSON ASSOCIATE PRODUCER /FILM EDITOR JAMES LAHTI A PRODUCTION OF THE STEPHEN LOW COMPANY AND RUTGERS UNIVERSITY

Canada The Canadian Film or Video Production Tax Credit

National Science Foundation

THE STATE UNIVERSITY OF NEW JERSEY RUTGERS

SODEC SOCIÉTÉ DE DÉVELOPPEMENT DES ENTREPRISES CULTURELLES Québec

FIDEC