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## 2006 Submarine Ring of Fire

# Living with the Heat

***(adapted from the 2002 Submarine Ring of Fire Expedition)***

### Focus
Hydrothermal vent ecology

### Grade Level
5-6 (Earth Science)

### Focus Question
How is energy transferred between organisms that live close to hydrothermal vents?

### Learning Objectives
Students will be able to describe how hydrothermal vents are formed, and characterize the physical conditions at these sites.

Students will be able to explain what chemosynthesis is, and contrast this process with photosynthesis.

Students will be able to identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities.

Students will be able to describe common food pathways between organisms typically found in hydrothermal vent communities.

### Materials
- ❒ Copies of "Hydrothermal Vent Communities Worksheet," one copy for each student or student group
- ❒ (Optional) Handouts or visual materials from NOAA's vent Web site (http://www.pmel.noaa.gov/vents/home.html)

### Audio/Visual Materials
- ❒ None, unless needed for optional materials

### Teaching Time
One or two 45-minute class periods

### Seating Arrangement
Classroom groups of two to four students

### Maximum Number of Students
30

### Key Words
Hydrothermal vent
Autotroph
Chemosynthesis
Hydrogen sulfide
Magma
Vent plume
Symbiosis
Ring of Fire
Mariana Arc

### Background Information
The Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin and results from the motion of large pieces of the Earth's crust known as tectonic plates. These plates are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. The plates move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents

that can be seen if food coloring is added to a heated container of water) that cause the tectonic plates to move several centimeters per year relative to each other.

If tectonic plates are moving apart their junction is called a divergent plate boundary; if they slide horizontally past each other they form a transform plate boundary; and if they collide more or less head-on they form a convergent plate boundary. The Pacific Ocean Basin lies on top of the Pacific Plate. To the east, new crust is formed by magma rising from deep within the Earth and erupting at divergent plate boundaries between the Pacific Plate and the North American and South American Plates. These eruptions form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries.

To the west, the Pacific Plate converges against the Philippine Plate. The Pacific Plate is forced beneath the Philippine Plate, creating the Marianas Trench (which includes the Challenger Deep, the deepest known area of the Earth's ocean). As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. The Mariana Islands are the result of this volcanic activity, which frequently causes earthquakes as well. The movement of the Pacific Ocean tectonic plate has been likened to a huge conveyor belt on which new crust is formed at the oceanic spreading ridges off the western coasts of North and South America, and older crust is recycled to the lower mantle at the convergent plate boundaries of the western Pacific.

Volcanic activity near plate boundaries is often associated with "hydrothermal vents" or seafloor hot springs, which are the result of seawater penetrating cracks in the seafloor crust near magma-containing chambers. When the intruding water encounters the molten rock, a variety of chemical changes take place as the water is warmed. Oxygen in the water is virtually eliminated, while many substances from the rocks become dissolved in the water. The heated water becomes less dense, and rises upward, forming a hydrothermal vent. When the heated vent fluid (the "plume") is cooled by the cold deep ocean water, many dissolved materials quickly precipitate, and form smoke-like clouds and chimneys of rock-like deposits.

The first hydrothermal vents were discovered in 1977 on an oceanic spreading ridge near the Galapagos Islands. Hydrothermal vents were surprising, but finding large numbers of animals around the vents was an even greater surprise. This is because conditions near the vents are "extreme" when compared to places that we normally think of as being suitable for living species. Water emerging from hydrothermal vents may be as hot as 400 °C, is highly acidic, and usually contains large amounts of hydrogen sulfide which is highly toxic to many animals. Moreover, these vents occur more than a mile beneath the ocean surface, far too deep for photosynthesis which was assumed to be essential to all major biological communities. The fact that hydrothermal vents are home to thriving communities of previously unknown animals suggests that we should not be too quick to use our own needs as a basis for judging whether conditions are "acceptable" or "extreme" for all other forms of life.

The foundation for hydrothermal vent communities are bacteria that can use chemicals in the vent plume (particularly hydrogen sulfide and methane) to produce simple sugars in a process called chemosynthesis. This process closely resembles photosynthesis in which green plants use energy from sunlight to combine carbon dioxide and water to form simple sugars that are the basis for most familiar food chains. The key difference is that in chemosynthesis, energy to produce the sugars is obtained from chemical bonds in hydrogen sulfide (or another compound, such as methane) instead of from sunlight. Both green plants and chemosynthetic organisms are called autotrophs (meaning they feed themselves).

In vent communities, chemosynthesis takes place in the cells of certain bacteria, where oxygen reacts to release energy from chemical bonds in hydrogen sulfide, and the energy is used to create simple sugars from carbon dioxide and water. These chemosynthetic bacteria are specially adapted to life in hydrothermal plumes, and thrive at temperatures exceeding 110° C.

Chemosynthetic bacteria are the base of a food web that includes many types of animals. In one of the most direct relationships, the bacteria live inside the tissues of giant tubeworms and clams. The animals' blood carries carbon dioxide, oxygen, and hydrogen sulfide to the bacteria and receives nourishment from the sugars produced by the bacteria. This is a true symbiosis (a mutually beneficial relationship between organisms) because the bacteria also benefit from having a sheltered environment inside the clams and tubeworms that provides protection from sudden changes in temperature and chemical composition of the vent fluid. Tubeworms have no mouth or gut; they depend entirely upon their symbiotic bacteria for survival.

Most pathways in vent food webs do not involve this type of symbiosis. Some chemosynthetic bacteria float freely in the vent plume, and provide a food source for plankton. Organic materials, including the remains of bacteria and plankton float in the cooler water beneath the plume and are a food source for filter feeding organisms such as mussels and a species of limpet (another mollusc). Other chemosynthetic bacteria form mats on hard surfaces, and are grazed by snails. All of these animals may become food for predators such as polychete worms, crabs, fishes, and octopi. Some of these predators may spend most of their time outside the vent community, and visit only briefly to find food. Most species found in vent communities, though, are not found anywhere else. Many new species of animals have been found as more hydrothermal vents are explored.

In 2003, the Ocean Exploration Ring of Fire expedition surveyed more than 50 volcanoes along the Mariana Arc, and discovered that ten of these had active hydrothermal systems (visit http://oceanexplorer.noaa.gov/explorations/03fire/welcome.html for more information on these discoveries). The 2004 Submarine Ring of Fire Expedition focussed specifically on hydrothermal systems of the Mariana Arc volcanoes, and found that these systems are very different from those found along mid-ocean ridges (visit http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html for more information). The primary focus of the 2006 Submarine Ring of Fire Expedition is interdisciplinary investigations of the hydrothermal and volcanic processes on the submarine volcanoes of the Mariana Arc. In this lesson, students will hypothesize possible food pathways between organisms typically found in hydrothermal vent communities.

## Learning Procedure

1. To prepare for this lesson, read the introductory essays for the 2006 Submarine Ring of Fire Expedition at http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html, and review the NOAA Learning Object on Hydrothermal Vent Life at http://www.learningdemo.com/noaa/.

2. Review the concepts of plate tectonics, being sure that students understand the processes that take place at convergent and divergent boundaries, and why these boundaries are often the site of volcanic activity. Introduce the Submarine Ring of Fire, and tell students that the focus of the 2006 Submarine Ring of Fire Expedition is interdisciplinary investigations of the hydrother-

mal and volcanic processes on the submarine volcanoes of the Mariana Arc. Describe hydrothermal vents, and the types of animals that are found there. Describe how animals acquire their nutrition, but don't discuss details of vent food webs. You may want to use resources from NOAA's hydrothermal vent Web site (http://www.pmel.noaa.gov/vents/home.html) to supplement this discussion. Be sure students understand that conditions around vents can be very unpredictable, and that animals may be killed by sudden releases of very hot fluid and toxic chemicals or the eruption of magma.

Discuss chemosynthesis, and contrast this process with photosynthesis. Be sure students recognize that energy is required to synthesize simple sugars; simply bringing carbon dioxide and water together won't get the job done! You might ask them to predict whether sugars are formed when dry ice (frozen carbon dioxide) bubbles through water. If dry ice is available, you could test their hypothesis. The key difference between photosynthesis and chemosynthesis is where the energy comes from.

You may also want to mention and discuss the idea that chemosynthetic bacteria may be one of the earliest forms of life. See "Rock Eaters of the Gulf of Alaska" (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/rock_eaters9_12.pdf) for a discussion of this concept.

3. Distribute copies of "Hydrothermal Vent Communities Worksheet" to each student or student group. Have each group discuss and predict what types of feeding paths may exist among the animals described on the worksheet. Tabulate each group's results, and lead a discussion of the reasoning behind their conclusions. If you want to use this exercise for evaluation, collect the worksheets before discussion.

## The Bridge Connection

www.vims.edu/bridge – Select Ocean Science Topics, then select Ecology, then Deep Sea

## The "Me" Connection

Have students write a first-hand account of life near a hydrothermal vent, describing what conditions are like, and what adaptations are needed to live there. The students may write their story from the standpoint of an explorer in a submersible, or from the perspective of an animal living in a vent community.

## Connections to Other Subjects

English/Language Arts, Earth Science

## Assessment

The worksheet may be used to evaluate students' understanding of the concepts presented. Students also may be asked to define key words, and/or describe one or more nutritional strategies used by animals living in a vent community.

## Extensions

Visit http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html for daily logs and updates about discoveries being made by the 2006 Submarine Ring of Fire Expedition.

Have students research a hydrothermal vent animal on the internet, and write a report about its life habits and relationships with other organisms.

Discuss the idea that chemosynthetic bacteria were the first life forms on Earth (see "Rock Eaters of the Gulf of Alaska" (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/rock_eaters9_12.pdf) for more information).

## Resources

**Multimedia Learning Objects**

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 1, 2, 4, and 5 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, and Chemosynthesis and Hydrothermal Vent Life

**Other Relevant Lesson Plans from the Ocean Exploration Program**

**The Biggest Plates on Earth** http://www.ocean-explorer.noaa.gov/explorations/02fire/background/education/media/ring_big_plates_5_6.pdf (7 pages, 192k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Plate tectonics – movement of plates, results of plate movement, and magnetic anomalies at spreading centers.

Students will be able to describe the motion of tectonic plates and differentiate between three typical boundary types that occur between tectonic plates, infer what type of boundary exists between two tectonic plates, understand how magnetic anomalies provide a record of geologic history around spreading centers, infer the direction of motion between two tectonic plates given information on magnetic anomalies surrounding the spreading ridge between the plates, and describe plate boundaries and tectonic activity in the vicinity of the Juan de Fuca plate.

**Unexplored!** http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf (7 pages, 724k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Scientific exploration of deep-sea volcanoes (Life Science/Physical Science/Earth Science)

Students will be able to compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

**Island, Reefs, and a Hotspot** http://www.ocean-explorer.noaa.gov/explorations/02hawaii/background/education/media/nwhi_hot.pdf (8 pages, 484kb) (from the 2002 Northwestern Hawaiian Islands Expedition)

Focus: Formation of the Hawaiian archipelago (Earth Science)

Students will be able to describe eight stages in the formation of islands in the Hawaiian archipelago and will be able to describe the movement of tectonic plates in the Hawaiian archipelago region. Students will also be able to describe how a combination of hot-spot activity and tectonic plate movement could produce the arrangement of seamounts observed in the Hawaiian archipelago.

**AdVENTurous Findings on the Deep Sea Floor** http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l2.pdf (5 pages, 536k) (from the 2002 Galapagos Rift Expedition)

Focus: Vent development along the Galapagos Rift

Students will conduct investigations to observe the formation of precipitates; students will create a model of a developing hydrothermal vent; students will generate comparisons between the created hydrothermal vent model and the actual hydrothermal vents developing along the Galapagos Rift.

**Other Links and Resources**

http://www.oceanexplorer.noaa.gov/explorations/04fire/background/marianaarc/marianaarc.html – Virtual fly-throughs and panoramas of eight sites in the Mariana Arc http://www.oceanexplorer.noaa.gov/explorations/02fire/logs/magic-mountain/welcome.html – Magic Mountain Virtual Web site, featuring animations and videos of the Magic Mountain hydrothermal field

http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html and http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – Animations of the 3-dimensional structure of a mid-ocean ridge and subduction zone

http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 – On-line version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience

http://pubs.usgs.gov/pdf/planet.html – "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

http://www.pmel.noaa.gov/vents/nemo/education.html – Web site for the New Millennium Observatory Project, a long-term study of the interactions between geology, chemistry, and biology on Axial Seamount, an active volcano on the Juan de Fuca Ridge that is part of the mid-ocean ridge system

http://vulcan.wr.usgs.gov/ – USGS Cascades Volcano Observatory, with extensive educational and technical resources

http://volcano.und.edu/ – Volcano World Web site at the University of North Dakota

http://nationalzoo.si.edu/publications/zoogoer/1996/3/lifewithout-light.cfm – "Life without Light: Discoveries from the Abyss," by Robin Meadows; Smithsonian National Zoological Park, Zoogoer Magazine, May/June 1996

http://www.ngdc.noaa.gov/mgg/image/2minrelief.html – Index page for NOAA's National Geophysical Data Center combined global elevation and bathymetry images (http://www.ngdc.noaa.gov/mgg/image/2minsurface/45N135E.html includes the Mariana Arc)

http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm – Web site with background information on 15 of the Mariana Islands.

http://volcano.und.nodak.edu/vwdocs/volc_models/models.html – U of N. Dakota volcano Web site, directions for making various volcano models

http://volcano.und.nodak.edu/vw.html – Volcano World Web site

http://www.extremescience.com/DeepestOcean.htm – Extreme Science Web page on the Challenger Deep

http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html – Web page for the 2005 Galapagos Spreading Center Expedition

http://www.divediscover.whoi.edu/ventcd/vent_discovery – Dive and Discover presentation on the 25th anniversary of the discovery of hydrothermal vents

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ps_vents.html – Article, "Creatures of the Thermal Vents" by Dawn Stover

http://www.oceansonline.com/hydrothe.htm – "Black Smokers and Giant Worms," article on hydrothermal vent organisms

Corliss, J. B., J. Dymond, L.I. Gordon, J.M. Edmond, R.P. von Herzen, R.D. Ballard, K. Green, D. Williams, A. Bainbridge, K. Crane, and T. H. Andel, 1979. Submarine thermal springs on the Galapagos Rift. Science 203:1073-1083. – Scientific journal article describing the first submersible visit to a hydrothermal vent community

Shank, T. M. 2004. The evolutionary puzzle of seafloor life. Oceanus 42(2):1-8; available online at http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf.

Tunnicliffe, V., 1992. Hydrothermal-vent communities of the deep sea. American Scientist 80:336-349.

Van Dover, C. L. Hot Topics: Biogeography of deep-sea hydrothermal vent faunas; available online at http://www.divediscover.whoi.edu/hottopics/biogeo.html

## National Science Education Standards

**Content Standard A: Science As Inquiry**

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

**Content Standard C: Life Science**

- Structure and function in living systems
- Populations and ecosystems
- Diversity and adaptations of organisms

**Content Standard D: Earth and Space Science**

- Structure of the Earth system

## Ocean Literacy Essential Principles and Fundamental Concepts

**Essential Priniciple 1.**
**The Earth has one big ocean with many features.**

- *Fundamental Concept b.* An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

**Essential Principle 2.**
**The ocean and life in the ocean shape the features of the Earth.**

- *Fundamental Concept e.* Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

**Essential Principle 4.**
**The ocean makes Earth habitable.**

- *Fundamental Concept b.* The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

**Essential Priniciple 5.**
**The ocean supports a great diversity of life and ecosystems.**

- *Fundamental Concept b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.
- *Fundamental Concept c.* Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
- *Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
- *Fundamental Concept g.* There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

**Essential Principle 7.**
**The ocean is largely unexplored.**

- *Fundamental Concept a.* The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
- *Fundamental Concept b.* Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

- *Fundamental Concept d.* New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
- *Fundamental Concept f.* Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

## For More Information

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# Student Handout

## Hydrothermal Vent Communities Worksheet

| ***Organism*** | ***Feeding Adaptations*** | ***Potential Food Source(s)*** |
|---|---|---|
| Autotrophic Bacteria | chemosynthesis | ______________________<br>______________________ |
| Zooplankton | particle feeding | ______________________<br>______________________ |
| Clams | filter feeding, may be symbiotic with bacteria | ______________________<br>______________________ |
| Mussels | filter feeding | ______________________<br>______________________ |
| Bacterial mats | chemosynthesis | ______________________ |
| Snails | grazing | ______________________<br>______________________ |
| Tubeworms | symbiotic with bacteria | ______________________<br>______________________ |
| Ploychete Worms | strong jaws | ______________________<br>______________________ |
| Crabs | strong jaws and claws | ______________________<br>______________________ |
| Octopus | powerful suction discs on "arms;" strong jaws ("beak") | ______________________<br>______________________ |