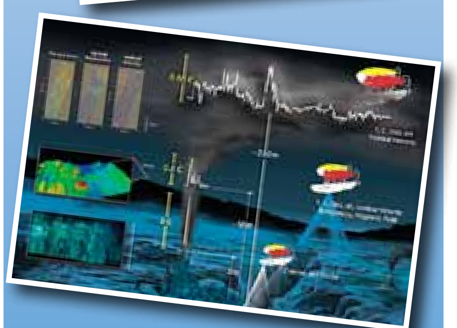
INSPIRE: Chile Margin 2010

A Hydrothermal AdVENTure



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lesson plan

Focus
Hydrothermal vents

Grade Level
5-6 (Physical Science)

Focus Question
What causes hydrothermal vents to form?

Learning Objectives
- Students will be able to describe the overall structure of hydrothermal vents.
- Students will be able to explain the relationship between hydrothermal vents and the motion of tectonic plates.
- Students will create a model of a hydrothermal vent.

Materials
- (Optional) Materials for demonstrating hydrothermal circulation; see Learning Procedure, Step 4
- (Optional) Materials for modeling hydrothermal vents; poster materi-als, colored markers, modeling clay

Audio-Visual Materials
- (Optional) Video or computer projection equipment; see Learning Procedure Step 1.

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Hydrothermal vent
Magma
Mantle
Tectonic plate

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

Earthquakes and volcanoes are among Earth's most spectacular and terrifying geological events. The Mount St. Helens eruption of 1980 and the Haiti (7.0 magnitude) and Chile (8.8 magnitude) earthquakes of 2010 are recent and memorable examples of the extreme power that often accompanies these events. The Indian Ocean tsunami of 2004 was caused by an underwater earthquake that is estimated to have released the energy of 23,000 Hiroshima-type atomic bombs, and caused the deaths of more than 150,000 people.

Volcanoes and earthquakes are both linked to movements of tectonic plates, which 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. These 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). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary. As the plates rub against each other, huge stresses are set up that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. A well-known example of a transform plate boundary is the San Andreas fault in California. View animations of different types of plate boundaries at: http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html.

A convergent plate boundary is formed when tectonic plates collide more or less head-on. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building. (The Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. 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

Images from Page 1 top to bottom:
Map of the Southeast Pacific Ocean and South American continent showing the Chile Rise spreading center, the Peru-Chile Margin, and the location of the Chile Triple Junction. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/geology/media/geology1.html

Our 3-phased approach to ocean exploration with ABE. First, guided by chemical measurements made aboard ship, we program ABE to fly around within the water column "sniffing" for where the chemical signals are strongest using specialized in situ sensors. Second, once we know where the strongest chemical signals from a hydrothermal vent are, we program ABE to fly closer to the seafloor, making detailed maps of the seabed and, ideally, also intercepting the stems of hot buoyant hydrothermal plumes of water rising up above the seafloor. Third, and finally, we program ABE up once more to descend to right above the seabed and drive to and fro, very carefully – using obstacle avoidance techniques to stop it from crashing into the rough rocky terrain it finds – while taking photographs of whatever it is we have found: hydrothermal vents, cold seeps, and whatever new and unique animals they might host. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html

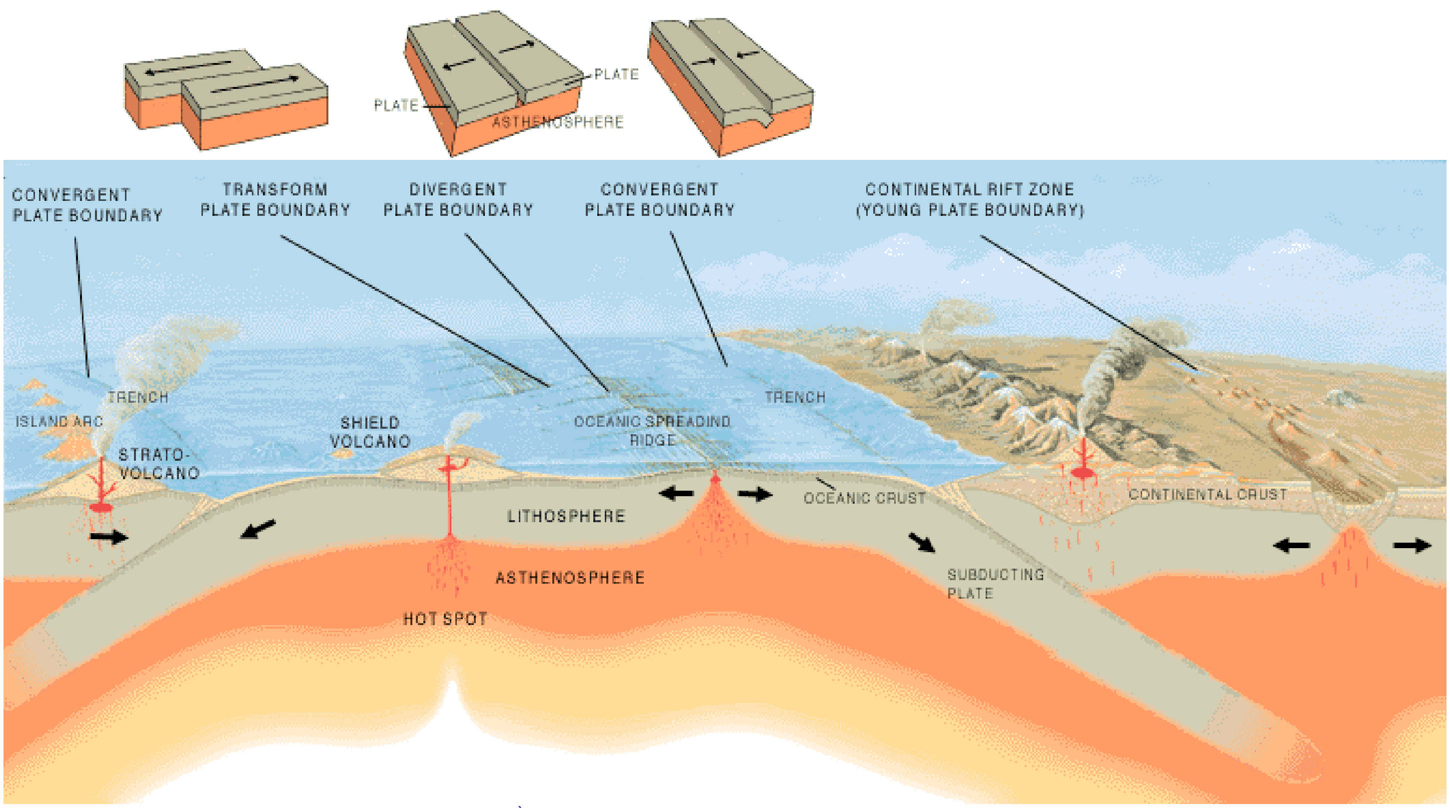
The ABE (Autonomous Benthic Explorer) autonomous underwater vehicle (free-swimming robot) about to be set loose to explore the bottom of the SW Indian Ocean from aboard the Chinese research ship RV Da Yang Yi Hao in Spring 2007. Over the past 5 years, ABE has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/plan/media/missionplan3.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

along the convergent boundary. These island arcs are always landward of the neighboring trenches. View the 3-dimensional structure of a subduction zone at:
http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html.

Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and 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. View the 3-dimensional structure of a mid-ocean ridge at:
http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

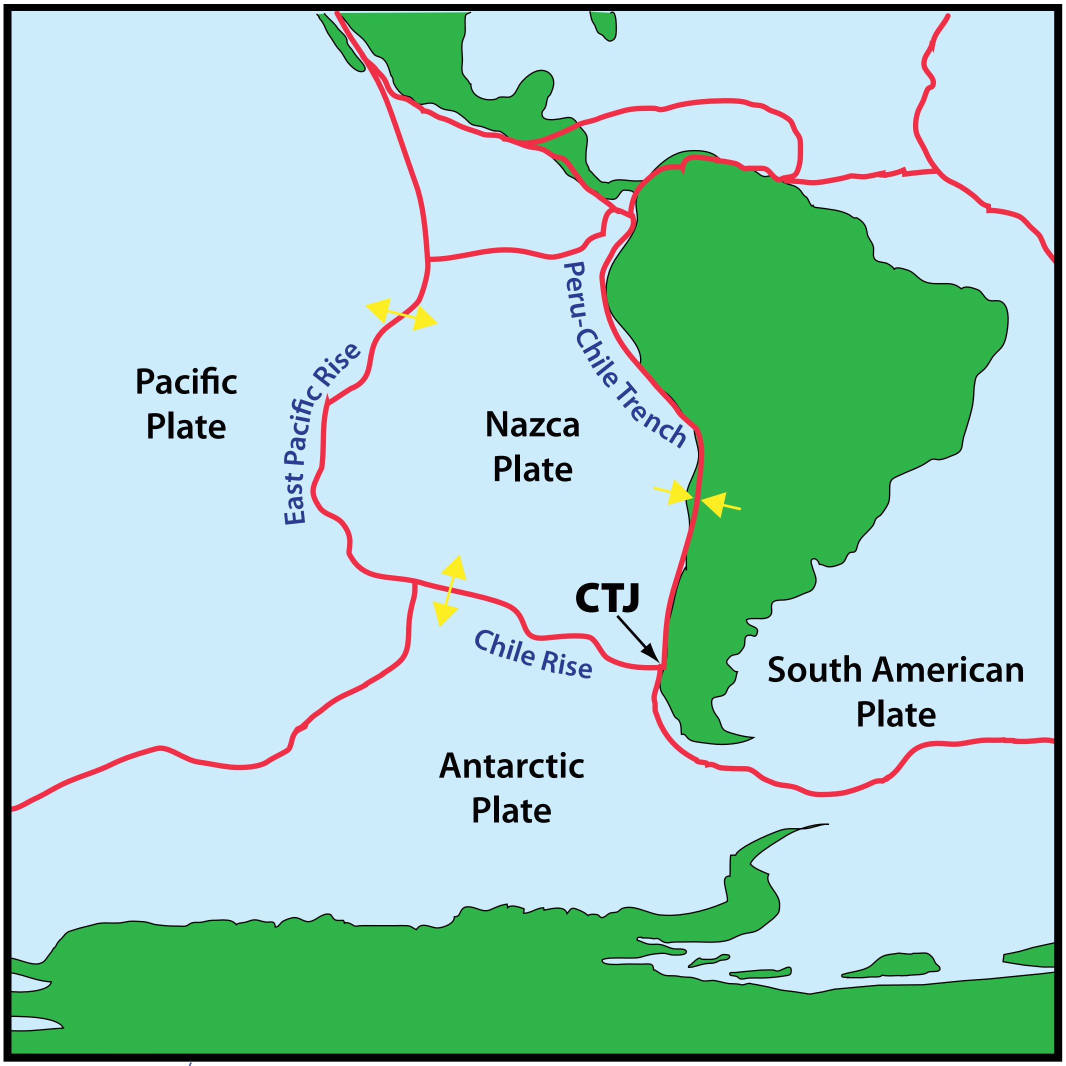
Figure 1: Types of Plate Boundaries



Artist's cross section illustrating the main types of plate boundaries. (Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.)
http://pubs.usgs.gov/gip/dynamic/Vigil.html

Along the western coast of Chile, three of Earth's tectonic plates intersect in a way that does not occur anywhere else on the planet (see Figure 2). Chile, and the other countries of South America, lie on top of the South American tectonic plate. To the west of Chile, the Nazca Plate extends beneath the Pacific Ocean and meets the Pacific Plate along a divergent plate boundary called the East Pacific Rise. The southern edge of the Nazca Plate adjoins the Antarctic Plate along another divergent plate boundary called the Chile Rise. The eastern edge of

Figure 2: Chile Triple Junction



the Chile Rise is being subducted beneath the South American plate at the Chile Triple Junction (CTJ), which is unique because it consists of a mid-oceanic ridge being subducted under a continental tectonic plate. The eastern portion of the Nazca Plate is also being subducted along the Peru-Chile Trench, and the Andes mountains are one consequence of this process. Not surprisingly, complex movements of three tectonic plates at the CTJ result in numerous earthquakes. In fact, the largest earthquake ever recorded (magnitude 9.5) occurred along the Peru-Chile Trench in 1960. While earthquakes and volcanoes are often associated with massive destruction and loss of human life, the same processes that cause these events are also responsible for producing unique habitats for very different life forms.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977 at a divergent plate boundary near the Galapagos Islands. Here, researchers found large numbers of animals that had never been seen before clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been found in many other locations where underwater volcanic processes are active. Hydrothermal vents are formed when the movement of tectonic plates causes deep cracks to form in the ocean floor. Seawater flows into these cracks, is heated by magma, and then rises back to the surface of the seafloor. The water does not boil because of the high pressure in the deep ocean, but may reach temperatures higher than 350° C. This superheated water dissolves minerals in Earth's crust. Hydrothermal vents are locations where the superheated water erupts through the seafloor. The temperature of the surrounding water is near-freezing, which causes some of the dissolved minerals to precipitate from the solution. This makes the hot water plume look like black smoke, and in some cases the precipitated minerals form chimneys or towers.

A primary purpose of the INSPIRE: Chile Margin 2010 Expedition is to locate new hydrothermal vent ecosystems near the CTJ, and investigate whether the complex and unique interaction between ridge and trench tectonic processes at the CTJ produces different types of hydrothermal vent systems than have been found in other areas (INSPIRE stands for INternational Southeast Pacific Investigation of Reducing Environments). In this activity, students will create models of hydrothermal vents, and use these models to explain the overall structure of hydrothermal vents as well as the relationship between hydrothermal vents and the motion of tectonic plates.

Learning Procedure

[NOTE: Because the discovery of hydrothermal vents was so significant and exciting, there is a wealth of information available on the geology and ecology of vent ecosystems. Several sources and potential activities are highlighted below, and educators are encouraged to investigate these, and select combinations that are most appropriate to their own students and specific curriculum needs.]

1. To prepare for this lesson:
   (a) Review introductory essays for the INSPIRE: Chile Margin 2010 Expedition at http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html.
   (b) Review background information on hydrothermal vents from one or more of these Web sites:
   - http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – This site links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, about 150 miles west of Vancouver Island, British Columbia, Canada. Explorer Ridge is a spreading center where two tectonic plates are spreading apart and there are active eruptions of submarine volcanoes.

- http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates. The "Explore" section of the site offers images and essays that include mid-ocean ridges, hydrothermal vents, and seafloor animals. The "Education" section of the site provides Powerpoint® presentations and curriculum materials.
- http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, "We're in Hot Water Now: Hydrothermal Vents"; includes links to National Geographic magazine articles and video with an emphasis on geography and geographic skills.
- http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents: includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977.

If video or computer projection facilities are available, you may also want to bookmark selected Web pages or download some images from these sites to show your students.

(c) Review Multimedia Discovery Missions [http://oceanexplorer.noaa.gov/edu/learning/welcome.html] Lessons 1, 2, 4, and 5 on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, and Chemosynthesis and Hydrothermal Vent Life. Decide how much of this material to use with your students.

(d) Review the *Hydrothermal Vent Inquiry Guide*, and note any vocabulary in the background reading that may require additional explanation.

(e) Review optional hydrothermal modeling activities in Step 4, and decide whether you will use these, either as demonstrations or student activities.

2. If students are not familiar with the concept of plate tectonics, complete part or all of the *When Plates Collide* lesson. Briefly introduce the INSPIRE: Chile Margin 2010 Expedition. Emphasize that the subduction of a spreading ridge beneath a continental tectonic plate is unique (as far as we know), and that very little is known about the geologic features and ecosystems that exist in this area. Point out that this area is also part of the same tectonic plate system that produced the strong 2010 earthquake in Chile, as well as the largest earthquake ever recorded. If possible, show some images of hydrothermal vents, and say that hydrothermal vents are often found at the junction between two of Earth's tectonic plates. Tell students that their assignment is to investigate how hydrothermal vents are formed, and how they are related to the motion of tectonic plates.

3. Provide each student with a copy of the *Hydrothermal Vents Inquiry Guide*, and selected Web addresses or downloaded reference materials. When students have answered questions on the *Inquiry Guide*, lead a discussion of their results. The following points should be included:
   - Hydrothermal vents are underwater hot springs that form when seawater flows into cracks in the ocean floor and is heated by hot magma beneath Earth's crust.
   - The temperature of hydrothermal vent fluid is often between 300°C and 400°C.
   - Hot hydrothermal vent fluid is capable of dissolving elements and minerals from rock beneath the ocean floor, so this fluid often contains large amounts of substances such as sulfur, copper, zinc, gold, and iron, and is very acidic.
   - Seawater in hydrothermal vents does not boil because of the high pressure in the deep ocean.
   - Vent chimneys are chimney-like structures formed by minerals that precipitate when hydrothermal vent fluids are cooled by surrounding seawater, because the solubility of many dissolved materials is reduced when temperature decreases.
   - "Black smokers" are vent chimneys formed from deposits of iron sulfide, which is black.
   - "White smokers" are vent chimneys formed from deposits of barium, calcium, and silicon, which are white.
   - Hydrothermal vents, volcanoes, and earthquakes often happen at the junction of two of Earth's tectonic plates because movement of the plates causes cracks that allow molten rock to rise through Earth's crust, and allow seawater to flow through heated rock beneath the ocean floor.

4. (Optional) Several activities have been described to model the dispersion of hot hydrothermal fluid in cold seawater. Two to try are:
   Cold Water, Hot Water and Super-heated Water!
   (http://www.ridge2000.org/SEAS/downloads/curriculum/seas_unit3_activity1.pdf; from the Student Experiments At Sea program of the Ridge 2000 initiative); and

   AdVENTurous Findings on the Deep Sea Floor
   (http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l2.pdf; from the Ocean Explorer 2002 Galapagos Rift Expedition)

Both activities involve placing a container of hot colored water in a larger container of cold water and observing the dispersal of the colored fluid. *AdVENTurous Findings on the Deep Sea Floor* also includes an activity to demonstrate the formation of precipitates. These activities are written as student activities, but may also be done as demonstrations if this is more appropriate to available time and facilities.

5. (Optional) Have students create a poster or three-dimensional model of a hydrothermal vent. Key features that should be included are:
   - Ocean floor
   - Cracks in the ocean floor
   - Rock in Earth's crust
   - Seawater
   - Magma
   - Superheated water
   - Precipitating minerals ("smoke")
   - Vent chimney

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then select "Geology" or "Habitats" for activities and links about hydrothermal vent formation and ecology.

The "Me" Connection

Have students write a brief essay discussing how hydrothermal vents might be useful to humans.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html for the latest activities and discoveries by the INSPIRE: Chile Margin 2010 Expedition.
2. Visit the education sections of Web sites provided in Step 1 for additional activities about hydrothermal vents.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

And Now for Something Completely Different...
(PDF, 172 kb) (from the 2005 GalAPAGos: Where Ridge Meets Hotspot expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf

Focus - Biological communities at hydrothermal vents (Life Science)

In this activity, students will identify and describe organisms typical of hydrothermal vent communities near the Galapagos Spreading Center, explain why hydrothermal vent communities tend to be short-lived, and identify and discuss lines of evidence which suggested the existence of hydrothermal vents before they were actually discovered.

InVENT a Deep-Sea Invertebrate
(PDF, 460 kb) (from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l3.pdf

Focus - Galapagos Rift Ecosystem: Structure and Function in Living Systems (Life Science)

In this activity, students will design an invertebrate capable of living near deep-sea hydrothermal vents, and in doing so, will learn about the unique adaptations that organisms must have in order to survive in the extreme environments of the deep sea.

Let's Make a Tubeworm!
(PDF, 464 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

Focus: Symbiotic relationships in cold-seep communities (Life Science)

In this activity, students will be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. Students will also be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Living With the Heat
(PDF, 88 kb) (from the Submarine Ring of Fire 2002 Expedition)
http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_living_heat_5_6.pdf

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents. (Life Science/Physical Science)

In this activity, students will be able to describe how hydrothermal vents are formed and characterize the physical conditions at these sites, explain what chemosynthesis is and contrast this process with photosynthesis, identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities, and describe common food pathways between organisms typically found in hydrothermal vent communities.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html – Web site for the INSPIRE: Chile Margin 2010 Expedition

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates

http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, "We're in Hot Water Now: Hydrothermal Vents"; includes links to National Geographic magazine articles and video with an emphasis on geography and geographic skills

http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents: includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977

Tunnicliffe, V., S. Juniper, M. Sibuet. 1999. Reducing Environments of the Deep-Sea Floor. In: P. Warneck (ed) Chemistry of the natural atmosphere. Academic Press. San Diego. 927 pp (available online at http://cmbc.ucsd.edu/Students/Current_Students/SIO277/ch4%20reducing%20env.pdf)

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Content Standard D: Earth and Space Science
- Structure of the Earth system
- Earth's history

Content Standard F: Science in Personal and Social Perspectives
- Natural hazards

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 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 a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

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

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
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A Hydrothermal AdVENTure

Hydrothermal Vents Inquiry Guide

Visit the Web sites or other materials provided by your teacher, and answer the following questions:

1. What are hydrothermal vents and how are they formed?

2. How hot is hydrothermal vent fluid?

3. How does the temperature affect the chemical composition of hydrothermal vent fluid?

4. Does seawater boil in hydrothermal vents? Why?

5. What are vent chimneys, and how are they formed?

6. What are "black smokers," and why are they black?

7. What are "white smokers," and why are they white?

8. Hydrothermal vents, volcanoes, and earthquakes often happen at the junction of two of Earth's tectonic plates. Why?