2006 Submarine Ring of Fire

Hydrothermal Vent Challenge

(adapted from the 2004 Ring of Fire Expedition)

Focus
Chemistry of hydrothermal vents

Grade Level
9-12 (Chemistry)

Focus Question
What are common features of hydrothermal vent fluids, and how can these features be used to locate undiscovered hydrothermal vents?

Learning Objectives
Students will be able to define hydrothermal vents, and explain the overall processes that lead to their formation.

Students will be able to explain the origin of mineral-rich fluids associated with hydrothermal vents.

Students will be able to explain how "black smokers" and "white smokers" are formed.

Students will be able to hypothesize how properties of hydrothermal fluids might be used to locate undiscovered hydrothermal vents.

Materials
❒ Copies of "Hydrothermal Vent Challenge," one copy per student or student group

Audio/Visual Materials
❒ None

Teaching Time
One or two 45-minute class periods, plus time for internet research

Seating Arrangement
Classroom style if students are working individually, or groups of two to four students

Maximum Number of Students
30

Key Words
Ring of Fire
Mariana Arc
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate
Hydrothermal vent
Chimney
Black smoker
White smoker
Hydrothermal plume
CTD
Tow-yo
Phase separation

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.

Underwater volcanism at spreading ridges and convergent plate boundaries produces hot springs known as hydrothermal vents. Scientists first discovered hydrothermal vents in 1977 while exploring an oceanic spreading ridge near the Galapagos Islands in the submersible Alvin. In addition, the scientists also found that the hydrothermal vents were surrounded by large numbers of animals that had never been seen before. These biological communities depend upon specific chemical processes that result from the interaction of seawater and hot magma associated with underwater volcanoes.

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).

In this lesson, students will research some of these processes, their relationship to hydrothermal vent communities, and how these processes provide a means for locating undiscovered hydrothermal vents.

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 say that the focus of the 2006 Submarine Ring of Fire Expedition is interdisciplinary investigations of the hydrothermal and volcanic systems of the Mariana Arc.

3. Tell students that their assignment is to research some of the chemical interactions that take place between seawater and the volcanic magma. Distribute copies of "Hydrothermal Vent Challenge" to each student or student group. You may want to direct students to the following Web sites:
   http://www.ocean.udel.edu/deepsea/
   http://www.pmel.noaa.gov/vents/chemocean.html
   http://www.pbs.org/wnet/savageearth/hellscrust/html/sidebar2.html
   http://www.geneseo.edu/~jc99/whatarethey.html http://www.accessexcellence.com/BF/bf01/arp/

4. Lead a discussion of students' research results. The following points should emerge from this discussion:
   - Hydrothermal vents are the result of sea water percolating down through fissures in the ocean crust in the vicinity of spreading centers or subduction zones. The cold seawater is heated by hot magma, and re-emerges to form the vents.
   - As the seawater is heated, some chemicals (such as magnesium and sulfate ions) are removed, while many others (such as sulfur, copper, zinc, gold, iron, and helium) are transferred to the water from the hot crust material.
   - Seawater in hydrothermal vents may reach temperatures of over 340°C (700°F). The extremely high temperatures contribute to the solution of these materials, since the solubility of many substances increases with increasing temperature.
   - Hot seawater in hydrothermal vents does not boil because of the extreme pressure at the depths where the vents are formed.
   - Chimneys are minerals deposited from hydrothermal vent fluids when the fluids are cooled by surrounding seawater, thus lowering the solubility of many of the dissolved materials.
   - "Black smokers" are chimneys formed from deposits of iron sulfide, which is black.
   - "White smokers" are chimneys formed from deposits of barium, calcium, and silicon, which are white.
   - Hydrothermal plumes are formed by the chemically-altered seawater that emerges from hydrothermal vents. Because the heat and chemical composition of the plumes is distinctly different from the surrounding seawater, these properties can be measured and indicate the presence of hydrothermal vents. Some of these parameters (especially helium) can be detected as far as tens to hundreds of kilometers away from the vents that produced them.
   - A CTD is an instrument package that measures conductivity, temperature, and depth. The package usually includes additional instruments to measure pH, transmissivity (a measure of interference with light transmission through sea water, which can indicate the presence of suspended particles), and concentrations of certain chemicals (such as iron and sulfur that are often enriched in vent plumes).
   - To search for hydrothermal plumes, scientists tow a CTD behind a research vessel, and gradually raise and lower the instrument

package as the ship moves along. The motion of the instrument package is thus similar to a yo-yo, and this kind of exploration is called a "tow-yo" operation.

- Phase Separation is the separation of a substance into two or more phases (vapor, liquid, or solid). Under the high temperature and pressure conditions of hydrothermal vents, a vapor phase may separate and move away from a higher-salinity liquid phase. Each phase contains a distinctly different combination of dissolved materials.

- The primary producers in hydrothermal vent communities are a wide variety of bacteria and archaea that utilize sulfur, hydrogen, methane and other compounds released by the reactions between seawater and magma.

The Bridge Connection

www.vims.edu/bridge – Click on "Ocean Science Topics" then "Marine Geology."

The "Me" Connection

Have students write a brief essay describing why processes at hydrothermal vent communities are (or are not) relevant to their own lives.

Connections to Other Subjects

English/Language Arts, Geography, Biology, Earth Science

Assessment

Written answers to the "Hydrothermal Vent Challenge" collected prior to group discussion provide a means of assessment.

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.

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 Big Balancing Act http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_balancing.pdf (9 pages, 1.3Mb) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry/Earth Science) Students will be able to define and describe hydrothermal circulation systems; explain the overall sequence of chemical reactions that occur in hydrothermal circulation systems; compare and contrast "black smokers" and "white smokers;" and make inferences about the relative significance of hydrothermal circulation systems to ocean chemical balance from data on chemical enrichment that occurs in these systems.

What's the Difference? http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_difference.pdf (7 pages, 720k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Volcanic processes at convergent and divergent tectonic plate boundaries (Earth Science)

Students will be able to compare and contrast volcanoes at convergent and divergent plate boundaries; identify three geologic features that are associated with most volcanoes on Earth; and explain why some volcanoes erupt explosively while others do not.

Where There's Smoke, There's . . . http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_smoke.pdf (6 pages, 680k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry)

Students will be able to use fundamental relationships between melting points, boiling points, solubility, temperature, and pressure to develop plausible explanations for observed chemical phenomena in the vicinity of subduction volcanoes.

It Looks Like Champagne http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_champagne.pdf (7 pages, 736k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Deep ocean carbon dioxide and global climate change (Chemistry/Earth Science)

Students will be able to interpret phase diagrams, and explain the meaning of "critical point" and "triple point;" define "supercritical fluid," and will be able to describe two practical uses of supercritical carbon dioxide; and discuss the concept of carbon dioxide sequestration.

The Galapagos Spreading Center http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l2.pdf (8 pages, 480k) (from the 2002 Galapagos Rift Expedition)

Focus: Mid-Ocean Ridges (Earth Science)

Students will be able to describe the processes involved in creating new seafloor at a mid-ocean ridge; students will investigate the Galapagos Spreading Center system; students will understand the different types of plate motion associated with ridge segments and transform faults.

Thar She Blows! http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l3.pdf (5 pages, 456k) (from the 2002 Galapagos Rift Expedition)

Focus: Hydrothermal vents

Students will demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor; students will demonstrate an understanding of how the transfer of energy effects solids and liquids.

Chemosynthesis for the Classroom http://www.oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_chemo_gr912.pdf (6 pages, 464k) (from the 2002 Gulf of Mexico Expedition)

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

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/lifewithoutlight.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.

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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

- Chemical reactions
- Interactions of energy and matter

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems

Content Standard D: Earth and Space Science

- Energy in the Earth system
- Geochemical cycles

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

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

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 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 Challenge

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

2. How is the chemical composition of hydrothermal vent fluid different from surrounding seawater?

3. What temperatures are typical of hydrothermal vent fluids? How does this affect the chemical composition of the fluid?

4. Why doesn't seawater boil in hydrothermal vents?

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. What are hydrothermal plumes? How can they be used to locate undiscovered hydrothermal vents?

9. What is a CTD?

10. What is a "tow-yo" operation?

11. What is phase separation, and how does it affect the composition of hydrothermal vent fluid?

12. What are the primary producers in hydrothermal vent communities, and what is their source of energy?