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2004 Ring of Fire Expedition

Hydrothermal Vent Challenge

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 45-minute class period, 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
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 Ring of Fire is an arc of active volcanoes and earthquake sites that partially encircles the Pacific Ocean Basin. The location of the Ring of Fire coin-

cides with the location of oceanic trenches and volcanic island arcs that result from the motion of the large plates (tectonic plates) that make up the outer shell of the Earth (the lithosphere). These plates consist of a crust about 5 km thick, and the upper 60 - 75 km of the Earth's mantle. The plates that make up the lithosphere 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). These convection currents cause the 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.

Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma (molten rock) 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.

A convergent plate boundary is formed when tectonic plates collide more or less head-on. Usually one of the converging plates moves beneath the other (a process called 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 rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches.

The 2004 Ring of Fire Expedition continues exploration of the convergent plate boundary that forms the Mariana Arc, part of the Ring of Fire that lies to the north of Guam in the western Pacific. Here, the fast-moving Pacific Plate converges against the slower-moving Philippine Plate. The Pacific Plate is subducted beneath the Philippine Plate, creating the Mariana Trench (which includes the Challenger Deep, the deepest known area of the Earth's oceans). The Mariana Islands are the result of volcanoes caused by this subduction, 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 along the underwater volcanoes and island arcs of the western Pacific. While many volcanoes in the Mariana Arc have been mapped and sampled in recent years, the Ring of Fire Expeditions are the first explorations focused specifically on submarine hydrothermal systems of the Arc.

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 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.

Refer to the 2002 Ring of Fire Expedition for lesson plans developed for Grades 9-12 (http://oceanexplorer.noaa.gov).

Learning Procedure

1. 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. Tell students that their assignment is to research some of the chemical interactions that take place between seawater and the volcanic magma.

2. 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/

3. 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

Evaluation

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

Extensions

Have students visit http://oceanexplorer.noaa.gov to keep up to date with the latest Ring of Fire Expedition discoveries.

Resources

http://oceanexplorer.noaa.gov – Follow the Ring of Fire Expedition daily as documentaries and discoveries are posted each day for your classroom use. A wealth of information can also be found at both of these sites.

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

http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction_vr.html – 3-dimensional "subduction zone" plate boundary video

http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – 3-dimensional structure of a "mid-ocean ridge," where two of the Earth's tectonic plates are spreading apart

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

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?