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2006 Submarine Ring of Fire

Mystery of the Megaplume

(adapted from the 2002 Submarine Ring of Fire Expedition)

Focus
Hydrothermal vent chemistry

Grade Level
9-12 (Chemistry)

Focus Question
How does water chemistry provide clues to the location of hydrothermal vents?

Learning Objectives
Students will be able to describe hydrothermal vents, and characterize vent plumes in terms of physical and chemical properties.

Students will be able to describe tow-yo operations, and how data from these operations can provide clues to the location of hydrothermal vents.

Students will be able to interpret temperature anomaly data to recognize a probable plume from a hydrothermal vent.

Materials
- ❒ Copies of "CTD Data from the Juan de Fuca Ridge," 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, depending upon the amount of time spent on plate tectonics and/or supplemental materials on hydrothermal vents

Seating Arrangement
Classroom-style or groups of two to four students

Maximum Number of Students
30

Key Words
Hydrothermal vent
Vent plume
CTD
Tow-yo operation
Anomaly
Anhydrite
Mariana Arc
Ring of Fire

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.

Hydrothermal vents are extremely interesting to scientists for a variety of reasons. Many new species have been found in vent communities, and many biologists suspect that the chemosynthetic vent bacteria may resemble the first forms of life on Earth. Precipitates from vent plumes include precious and semiprecious minerals, and vent chimneys may provide new sources of these materials. The flux of heat and minerals from vents also influences the chemistry of the entire ocean, which has direct implications to weather patterns and climate variations.

But before new vents can be explored, they must first be found. While the general location of vents is fairly well-known (they occur around oceanic spreading ridges) the number of vents that has been precisely located is relatively small. To locate new vents, scientists first look for clues in the water column over potential sites. Because a vent plume tends to spread out, it can be much larger than the vent itself, so there is a better chance of locating traces of the plume that can then be followed back to the source vent. To search for these traces, scientists tow a package of electronic instruments 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 (see "Yo-Yos, Tow-Yos and pH, Oh My!" http://oceanexplorer.noaa.gov/explorations/02galapagos/

background/education/media/gal_gr7_8_l2.pdf for additional discussion and activities about tow-yos).

The instrument package used in tow-yo operations is commonly referred to as a CTD (which stands for conductivity (to measure sea water salinity), temperature, and depth), but 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). The overall idea is to watch for sudden changes ("anomalies") in one or more of the properties being measured, that may signal an unusual occurrence, such as an active hydrothermal vent. Some anomalies may seem rather small, but still provide significant clues to the presence of vent plumes. Temperature anomalies, for example, may be less than 0.1° C; but if there is a consistent pattern to the anomaly (for example, if the change in temperature only occurs in a certain section of the water column) this may be enough to lead scientists to a new vent.

The 2006 Submarine Ring of Fire Expedition is focussed on interdisciplinary investigations of the hydrothermal and volcanic processes on the submarine volcanoes of the Mariana Arc. CTD observations will be an important part of these investigations. In this lesson, students will analyze CTD data from a tow-yo operation on the Juan de Fuca Ridge (also part of the Ring of Fire that was the subject of the 2002 Submarine Ring of Fire Expedition) that revealed a huge plume, suggesting a massive eruption from an uncharted hydrothermal vent.

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 how these boundaries are related to the "Submarine Ring of Fire." Describe hydrothermal vents, and the types of materials that are typically released in vent plumes. You may want to use materials from NOAA's hydrothermal vent Web site (http://www.pmel.noaa.gov/vents/home.html)and/or "This Dynamic Earth" (see Resources section) to supplement this discussion. Describe tow-yo operations, and how anomalies can provide clues about the presence of vents on the ocean floor. Say that anomalies are often less than 0.1° C. Be sure students understand that the instrument package is raised and lowered through the water column as the ship steams on a known course, so that a profile of water chemistry conditions can be generated. Introduce the Submarine Rine of Fire expeditions, and tell students that a key aspect of the 2006 Submarine Ring of Fire Expedition is investigations that use data collected with CTDs.

3. Distribute copies of "CTD Data from the Juan de Fuca Ridge" to each student or student group. Have each group plot temperature anomaly data against depth (on the y-axis) and distance along ship's track (on the x-axis). Students should label the temperature anomaly at each point. Next, have the students connect points with the same temperature anomaly to form contour lines. The result should be a series of concentric, rough ovals, with the lowest anomalies on the outside oval, and the highest anomalies on the innermost oval.

4. Lead a discussion of the results of these data.
   a. Students should recognize that the profile represents a huge plume (130 km^3) with unusually high temperature anomaly. Students should infer that the origin of this plume must have been a massive hydrothermal vent.

b. Discuss the significance of Notes 2 and 3. Water samples taken from the center of the plume contained large grains of anhydrite, a mineral that is common in hydrothermal vents. Because these grains were settling at a rate of 70 – 200 meters per day, the plume could not have been more than a few days old when the grains were collected (otherwise, the grains would already have settled out of the water column). The fact that no trace of the plume was found eight weeks later suggests that the event causing the plume was brief and did not re-occur between the observation times.

c. Ask the students to speculate on what sort of event could have produced this plume. "A major volcanic eruption" is likely to be one of the first suggestions, but such an eruption would probably have blown the plume into a much more dispersed form. Moreover, you can tell the students that rock fragments typical of volcanic activity ("pyroclastic fragments") were not found in the water samples. This additional data should lead to the idea of a sudden encounter between a very large volume of seawater and a very large volume of very hot rock. Scientists investigating the megaplume concluded that the total output of hydrothermal fluid was equal to the annual output of between 200 and 2,000 high-temperature chimneys.

The Bridge Connection

www.vims.edu/bridge/geology.html

The "Me" Connection

Have students write an article describing the pros and cons of first-hand exploration of an oceanic spreading center in a deep-diving submersible compared to exploration using remotely operated vehicle (ROV).

Connections to Other Subjects

English/Language Arts, Geography, Earth Science

Assessment

Individual data plots prepared by each student or student group may be collected to assess the thoroughness of their work. Additionally, students may be asked to define key words and/or address discussion points 3a, b, and c in writing before participating in a group discussion.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html for daily logs, updates about discoveries, and real-time CTD operations on 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

Baker, E.T., G.J. Massoth, and R.A. Feely, 1987. Cataclysmic hydrothermal venting on the Juan de Fuca Ridge. Nature 329:149-151. – Scientific journal article on which this activity is based

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.

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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
- Conservation of energy and the increase in disorder
- Interactions of energy and matter

Content Standard D: Earth and Space Science
- Energy in the Earth system

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 Principle 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
CTD Data from the Juan de Fuca Ridge

Distance on Ship's Track (km)	Depth (m)	Temperature Anomaly (°C)
0.25	2000	0.00
0.5	1800	0.00
0.75	1600	0.00
1.00	1400	0.00
1.25	1200	0.00
1.50	1400	0.00
1.75	1600	0.00
2.00	1800	0.04
2.25	2000	0.00
2.50	1800	0.04
2.75	1600	0.04
3.00	1400	0.04
3.25	1200	0.00
3.50	1400	0.04
3.75	1600	0.12
4.00	1800	0.08
4.25	2000	0.00
4.50	1800	0.08
4.75	1600	0.12
5.00	1400	0.08
5.25	1200	0.04
5.50	1400	0.12
5.75	1600	0.20
6.00	1800	0.12
6.25	2000	0.00
6.50	1800	0.16
6.75	1600	0.24
7.00	1400	0.16
7.25	1200	0.06
7.50	1400	0.16
7.75	1600	0.26
8.00	1800	0.20
8.25	2000	0.00
8.50	1800	0.20
8.75	1600	0.28
9.00	1400	0.16

Distance on Ship's Track (km)	Depth (m)	Temperature Anomaly (°C)
9.25	1200	0.05
9.50	1400	0.24
9.75	1600	0.28
10.00	1800	0.20
10.25	2000	0.04
10.50	1800	0.22
10.75	1600	0.28
11.00	1400	0.24
11.25	1200	0.04
11.50	1400	0.20
11.75	1600	0.28
12.00	1800	0.22
12.25	2000	0.04
12.50	1800	0.20
12.75	1600	0.28
13.00	1400	0.20
13.25	1200	0.04
13.50	1400	0.20
13.75	1600	0.28
14.00	1800	0.22
14.25	2000	0.04
14.50	1800	0.22
14.75	1600	0.28
15.00	1400	0.20
15.25	1200	0.00
15.50	1400	0.20
15.75	1600	0.26
16.00	1800	0.22
16.25	2000	0.00
16.50	1800	0.20
16.75	1600	0.26
17.00	1400	0.16
17.25	1200	0.00
17.50	1400	0.16
17.75	1600	0.24
18.00	1800	0.20
18.25	2000	0.00
18.50	1800	0.20

Distance on Ship's Track (km)	Depth (m)	Temperature Anomaly (°C)
18.75	1600	0.22
19.00	1400	0.12
19.25	1200	0.00
19.50	1400	0.08
19.75	1600	0.16
20.00	1800	0.16
20.25	2000	0.00
20.50	1800	0.12
20.75	1600	0.12
21.00	1400	0.04
21.25	1200	0.00
21.50	1400	0.04
21.75	1600	0.04

Notes:

1. Ship's course was due south during this tow. Repeated tows to the east and west of this position showed that the plume was nearly symmetrical.

2. Water samples taken at the center of the plume contained large grains of the hydrothermal mineral anhydrite, which had settling rates of 70 – 200 meters/day.

3. Tows in the same area eight weeks later revealed no evidence of this plume.