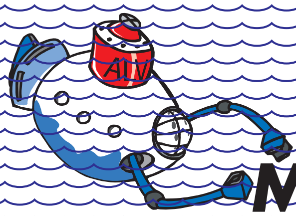

Mystery of the Megaplume

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 website (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

Background
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 coincides with the location of oceanic trenches and volcanic island arcs that result from the movement of large plates of rock that comprise the outer shell of the Earth (called the lithosphere). There are about a dozen of these plates (called tectonic plates) that 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.

Plates may slide horizontally past each other at transform plate boundaries where the motion of the plates sets up huge stresses that can cause portions of the rock to break, resulting in earthquakes. At divergent plate boundaries, magma (molten rock) rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plates boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges. At convergent plate boundaries, tectonic plates are being pushed together, and 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.

In 1977, scientists in the submersible Alvin made the first visit to an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. In the middle of deep, cold ocean waters, they found warm springs rising from area where hot magma was forming new crustal material; and around those springs they found large numbers of animals that had never been seen before.

These hot springs, called hydrothermal vents, are the result of seawater penetrating cracks in the seafloor crust near magma-containing chambers beneath a spreading ridge. 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 is 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 shimmering blue or 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 http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr7_8.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.

Exploring for new hydrothermal vents is a major objective of the 2002 Submarine Ring of Fire Ocean Expedition, which will focus on areas where new ocean crust is being formed off the coast of western North America. These areas are located at one edge of the Juan de Fuca tectonic plate. This is a comparatively small tectonic plate, and as a result has a divergent boundary (with the Pacific plate) as well as a convergent boundary (with the North American plate) relatively close together. The eruption of Mt. St. Helen in 1980 was a result of the subduction of the Juan de Fuca plate beneath the North American plate. The divergent boundary is an active spreading center that is organized along three ridges: Gorda Ridge, Juan de Fuca Ridge, and Explorer Ridge. While Gorda and Juan de Fuca Ridges have been intensively studied, Explorer Ridge is virtually unexplored and is the target of the Ring of Fire Expedition.

One of the first tasks is to prepare maps of the seafloor around Explorer Ridge to aid in identifying the most promising sites for investigation. In addition to topographic maps prepared with a multibeam sonar system (see http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/mapping7_8.pdf, scientists will also conduct tow-yo operations in hopes of locating unexplored hydrothermal vents.

Learning Procedure

In this lesson, students will analyze CTD data from a tow-yo operation on the Juan de Fuca Ridge that revealed a huge plume, suggesting a massive eruption from an uncharted hydrothermal vent.

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. 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.

2. 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.

3. Lead a discussion of the results of these data.

a. Students should recognize that the profile represents a huge plume (130 km3) 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

Evaluation

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

Have students visit http://oceanexplorer.noaa.gov to keep up to date with the real-time tow-yo operations on the Ring of Fire Expedition.

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://www.pmel.noaa.gov/vents/home.html – NOAA's hydrothermal vent web site

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML.ps_vents.html – Links to many other web sites with information about hydrothermal vents

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

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

National Science Education Standards

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understanding 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
- Structure of the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Data Sheet

CTD Data from the Juan de Fuca Ridge
(17 August 1986)

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
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
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.