

2005 Submarine Ring of Fire Expedition

Where There's Smoke, There's ...

FOCUS

Hydrothermal vent chemistry at subduction volcanoes

GRADE LEVEL

9-12 (Chemistry)

FOCUS QUESTION

How can unusual chemical phenomena near hydrothermal vents be explained in terms of melting points, boiling points, solubility, temperature, and pressure?

LEARNING OBJECTIVES

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.

MATERIALS

U Copies of "Where There's Smoke, There's... Worksheet," one copy for each student or student group

AUDIO/VISUAL MATERIALS

U (Optional) computer projection facilities to show photographs and video

TEACHING TIME

One 45-minute class period, plus time for student research

SEATING ARRANGEMENT

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

MAXIMUM NUMBER OF STUDENTS

30

KEY WORDS

Melting point
Boiling point
Solubility
Temperature
Pressure
Ring of Fire
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate

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 coincides with the location of oceanic trenches and volcanic island arcs that result from the motion of large pieces of the Earth's crust (tectonic plates). Tectonic plates consist of 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). These convection currents cause the tectonic plates to move several centimeters per year relative to each other.

The junction of two tectonic plates is known as a plate boundary. Where two plates slide horizontally past each other, the junction is known as a transform plate boundary. Movement of the plates causes huge stresses that break portions of the rock and produce 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 these 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.

If two tectonic plates collide more or less head-on, they produce a convergent plate boundary. Usually, one of the converging plates moves beneath the other in a process called subduction. Subduction produces deep trenches, and earthquakes are common. As the sinking plate moves deeper into the mantle, increasing pressure and heat release fluids from the rock causing the overlying mantle to partially melt. The new magma rises and may erupt violently to form volcanoes that often form arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. This process can be visualized as a huge conveyor belt on which new crust is formed at the oceanic spreading ridges and older crust is recycled to the lower mantle at the convergent plate boundaries. The Ring of Fire marks the location of a series of convergent plate boundaries in the western Pacific Ocean.

Underwater volcanism produces hot springs in the middle of cold, deep ocean waters. These springs (known as hydrothermal vents) were first discovered in 1977 when scientists in the submersible Alvin visited an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. Here they found warm springs surrounded by large numbers of animals that had never been seen before. Since they were first discovered, sea-floor hot springs around spreading ridges have been intensively studied. In contrast, the hydrothermal systems around convergent plate boundaries are relatively unexplored.

The Mariana Arc is part of the Ring of Fire that lies to the north of Guam in the western Pacific. Here, the fast-moving Pacific Plate is subducted beneath the slower-moving Philippine Plate, creating the Marianas Trench (which includes the Challenger Deep, the deepest known area of the Earth's oceans). The Marianas Islands are the result of volcanoes caused by this subduction, which frequently causes earthquakes as well. 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). The 2005 Submarine Ring of Fire Expedition will explore hydrothermally active volcanoes in the Kermadec Arc, an area where tectonic plates are converging more rapidly than any other subduction zone in the world.

On April 1, 2004, scientists exploring the NW Rota #1 volcano reported that the ROPOS remotely operated vehicle (ROV) had been

engulfed by balls of molten sulfur while investigating a portion of the volcano known as Brimstone Pit. The scientists also reported that plumes of hydrothermal fluids extended for several kilometers over and around the volcano's summit. These fluids were unusual, in that they contained the highest concentrations of particulate aluminum ever recorded, as well as high concentrations of sulfur, iron, and manganese. In this lesson, students will develop explanations for these and other observed phenomena based on relationships between melting points, boiling points, solubility, temperature, and pressure.

LEARNING PROCEDURE

1. To prepare for this lesson, read the Submarine Ring of Fire 2004 daily logs for March 30 and April 1 (<http://oceanexplorer.noaa.gov/explorations/04fire/logs/march30/march30.html> and <http://oceanexplorer.noaa.gov/explorations/04fire/logs/april1/april1.html>). You may also want to print copies of the photographs and/or download the video vista of Brimstone Pit.
2. Briefly review the concepts of plate tectonics and continental drift and how they are related to underwater volcanic activity and hydrothermal vent systems (you may want to use resources from NOAA's hydrothermal vent Web site (<http://www.pmel.noaa.gov/vents/home.html>) to supplement this discussion). Introduce the Ring of Fire, and describe the processes that produce the island arcs.
3. Show students photographs and videos of Brimstone Pit, or direct them to the Ocean Explorer Web site. Provide each student or student group with a copy of the "Brimstone Pit Challenge Worksheet," and have each student or student group develop explanations for observed phenomena as directed. Tell students that they are to use specific numeric information (such as solubility data) or chemical reactions where possible.
4. Lead a discussion of students' results. Students should realize that sulfur dioxide can react with water to form sulfuric acid and elemental sulfur:

$$3\text{SO}_2 + 2\text{H}_2\text{O} > 2\text{H}_2\text{SO}_4 + \text{S}$$

Sulfur melts at 113°C and boils at 444°C. Brimstone Pit is about 555 meters deep. This would correspond to a pressure of 56.5 bar:

$$1 \text{ bar (surface pressure)} + (555 \text{ meters depth} \cdot 1 \text{ bar}/10 \text{ meters depth}) = 56.5 \text{ bar}$$

The boiling point graph shows that the boiling point of seawater would be over 250°C; so seawater could easily be hot enough to melt sulfur produced by the above reaction, and create the observed molten "blobs." Sulfuric acid produced by this reaction would account for the low pH observed in the area.

Low pH values would also help explain the high concentrations of particulate aluminum, iron, and manganese in the hydrothermal fluids. These metals are dissolved into the acidic hydrothermal fluid, but precipitate as the fluid mixes with cooler seawater.

The scientists in the submersible are working at a pressure of 30 bar:

$$300 \text{ meters depth} \cdot 1 \text{ bar}/10 \text{ meters depth} = 30 \text{ bar}$$

This means that gas in the tube will expand 30 times when the pressure is reduced to one bar, assuming the temperature remains constant. So the scientists should only collect one inch of gas in the cylinder to avoid losing any gas on the way to the surface.

THE BRIDGE CONNECTION

www.vims.edu/bridge/ – Click on "Ocean Science Topics" then "Habitats," then "Deep Sea" for links to information and activities about hydrothermal vents.

THE “ME” CONNECTION

Have students write a brief essay describing how the chemical phenomena observed at Brimstone Pit might be of personal importance.

CONNECTIONS TO OTHER SUBJECTS

Earth Science

ASSESSMENT

Worksheets and class discussions provide opportunities for 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.

<http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html>
– Submarine Ring of Fire 2004 Web pages with daily logs, background essays, maps, photographs, and video

<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, volcanoes, and earthquake locations

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

- Structure and properties of matter
- Chemical reactions
- Interactions of energy and matter

Content Standard D: Earth and Space Science

- Energy in the earth system
- Geochemical cycles
- Origin and evolution of the earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Nature of scientific knowledge

FOR MORE INFORMATION

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ACKNOWLEDGEMENTS

This lesson plan was produced by Mel Goodwin, PhD, The Harmony Project, Charleston, SC for the National Oceanic and Atmospheric Administration. If reproducing this lesson, please cite NOAA as the source, and provide the following URL:

<http://oceanexplorer.noaa.gov>

Student Worksheet

On April 1, 2004, scientists exploring the NW Rota #1 volcano reported that the ROPOS remotely operated vehicle (ROV) had been engulfed by balls of molten sulfur while investigating a portion of the volcano known as Brimstone Pit. The scientists also reported that plumes of hydrothermal fluids extended for several kilometers over and around the volcano's summit. These fluids were unusual, in that they contained the highest concentrations of particulate aluminum ever recorded, as well as high concentrations of sulfur, iron, and manganese.

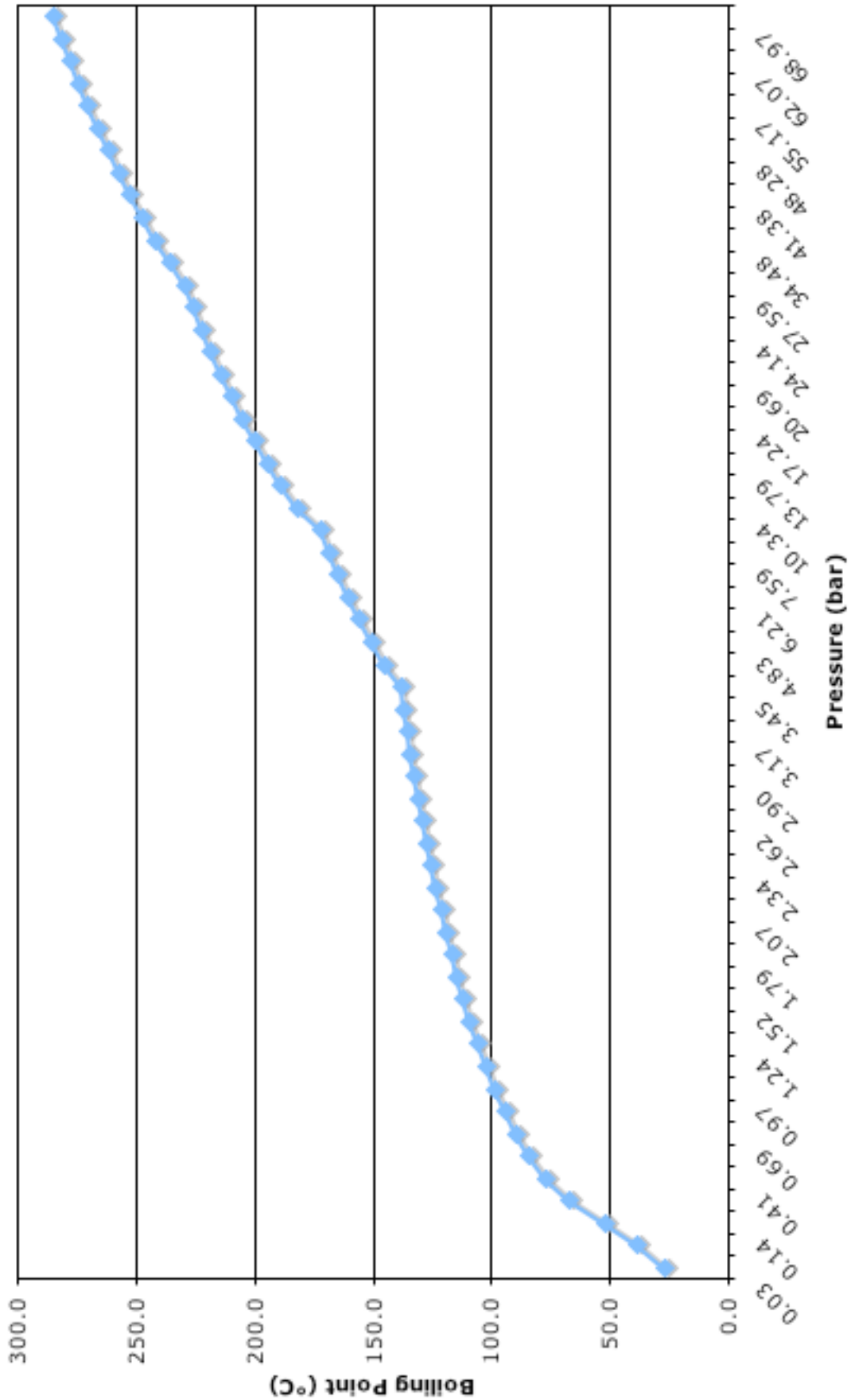
Your challenge is to use information about simple chemical reactions, melting points, boiling points, solubility, temperature, and pressure to provide reasonable explanations for

1. The blobs of molten sulfur that splattered over the ROPOS
2. The low pH (about 2) observed in water samples collected from Brimstone Pit
3. The high concentrations of particulate aluminum, iron, and manganese in hydrothermal fluid plume over NW Rota #1 volcano

Hints and other useful information:

- Sulfur dioxide is a common volcanic gas released from magma.
- The solubility of many metals, including aluminum, iron, and manganese increases at low pH values.
- Here is a boiling point curve for seawater. (See next page.) The graph shows that the temperature at which seawater boils increases as the pressure increases. The critical point is the point at which the properties of the gas phase and liquid phase become identical.
- You can find information about the depth of Brimstone Pit at <http://oceanexplorer.noaa.gov/explorations/04fire/logs/march30/march30.html>.
- The pressure at the surface of the ocean is one atmosphere (one bar in the metric system).
- Pressure in the ocean increases by one atmosphere (one bar) with every 10 meter increase in depth.

Boiling Point at Various Pressures



Student Handout

Extra Challenge:

Scientists inside a manned submersible at 300 m depth on a submarine volcano north of New Zealand observe gas bubbles coming out of a vent. The only thing they have available to collect the gas bubbles is a plastic cylinder that is open on one end and capped on the other end. They intend to collect bubbles by holding the cylinder with over the gas bubbles with the open end downward. The plastic cylinder is 30" long. The scientists know that the gas bubbles will expand as the submarine rises. What is the maximum amount of gas (in inches) that the scientists can collect in their cylinder without losing any gas as the submarine rises to the sea surface (assume the temperature in the cylinder remains constant)?

[provided by John Lupton, a NOAA scientist]