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2005 Submarine Ring of Fire Expedition

It's a Gas! Or Is It?

Focus
Effects of temperature and pressure on solubility and phase state

Grade Level
7-8 (Physical Science/Earth Science)

Focus Question
How do principles of solubility and phase state help explain chemical phenomena observed around deep-sea volcanoes?

Learning Objectives
Students will be able to describe the effect of temperature and pressure on solubility of gases and solid materials.

Students will be able to describe the effect of temperature and pressure on the phase state of gases.

Students will be able to infer explanations for observed chemical phenomena around deep-sea volcanoes that are consistent with principles of solubility and phase state.

Materials
- ❒ Copies of "It's a Gas! Worksheet," one copy for each student or student group

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods

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
Phase state
Solubility

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. Along the Mariana Arc to the north of Guam, 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.

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.

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 Submarine Ring of Fire 2004 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.

The intense heat of volcanic activity combined with high pressure of deep ocean environments produces fascinating chemical phenomena. Scientists exploring hydrothermal vents often see vertical structures called "chimneys" that appear to be emitting plumes of white or black "smoke." During the Submarine Ring of Fire 2004 Expedition, scientists exploring the NW Eifuku volcano observed bubbles of a cloudy white fluid rising from the sediment around some chimneys. These bubbles were unusual because they did not tend to fuse into larger bubbles the way most gas bubbles do. In this activity, students will use their knowledge of solubility principles to develop possible explanations for these observations.

Learning Procedure

1. To prepare for this lesson, read the Submarine Ring of Fire 2004 daily logs for April 6 and April 10 (http://oceanexplorer.noaa.gov/explorations/04fire/logs/april06/april06.html and http://oceanexplorer.noaa.gov/explorations/04fire/logs/april10/april10.html). You may also want to print copies of the photographs or download videos of black smokers and "champagne" bubbles.

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 Mariana Arc.

3. You may want to review some basic principles of solubility with your students, or allow them to use the "It's a Gas!" worksheet to work through these principles on their own. Alternatively, if time permits you may want to demonstrate the "thought experiments" described on the worksheet. Some students may need help with "thought experiment" 3e if they are unfamiliar with the behavior of liquids in a vacuum.

   The key points are:
   - Solubility is the extent to which one substance (the solute) dissolves in another substance (the solvent).
   - Solubility is affected by temperature and pressure.
   - The solubility of most solids increases as temperature and pressure increase.
   - The solubility of most gases decreases as temperature increases.
   - The solubility of most gases increases as pressure increases.
   - As temperature increases, the phase of a substance changes from solid to liquid to gas.
   - Decreasing pressure favors change from liquid to gas phase; conversely, increasing pressure favors change from gas to liquid phase.

   Be sure students realize that while the solubility of most materials increases with increasing temperature, there are substances whose solubility declines as temperature increases.

4. Provide each student or student group with a copy of the "It's A Gas! Worksheet." Have students complete the review questions and develop explanations for the observation problems.

5. Discuss students' proposed explanations for the observations described on the worksheet.

   Knowing that solubility of most substances increases with increasing temperature, students may hypothesize that the hot fluids escaping from the East Diamante volcano contained dissolved metals, and that these precipitated when the fluid cooled to form chimneys. Similarly, precipitated metal particles could be expected to cause the fluid to appear dark and resemble black smoke.

   High pressure could cause substances that we normally think of as gases to change to a liquid phase. The sticky bubbles at the Eifuku volcano were actually liquid carbon dioxide. Since pressure also increases the solubility of gases, the fluids sampled from the white chimneys at Eifuku could have contained high concentrations of dissolved gases, even though they were very hot.

It is reasonable for students to hypothesize that as the fluid cooled in the plastic tube, the high pressure could have caused some of the gases to enter a solid phase, producing the fluffy white material. However, scientists believe that this material was actually a carbon dioxide hydrate: a substance composed of carbon dioxide and water, and belonging to a class of substances known as clathrates. These substances, which only exist at high pressures, are formed when the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (carbon dioxide) without actually forming chemical bonds between the two materials (see http://198.99.247.24/scng/hydrate/about-hydrates/about_hydrates.htm, as well as the Ocean Exploration Blake Ridge expedition for more information).

As the ROV rose to the surface and pressure decreased, the clathrate would separate into carbon dioxide gas and water, and dissolved gases would come out of solution, causing the observed bubbles and disappearance of the white material.

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 information gained from exploring deep sea volcanoes could be of personal importance.

Connections to Other Subjects

English/Language Arts, Geography

Assessment

Worksheets and class discussions offer 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. A wealth of information can also be found at both of these sites.

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://www.pbs.org/wgbh/nova/teachers/activities/2609_abyss.html – Nova Teachers Web site, Volcanoes of the Deep Classroom Activity to research and classify symbiotic relationships between individual organisms of different species.

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
- Properties and changes of properties in matter

Content Standard D: Earth and Space Science
- Structure of the Earth system

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in society

Content Standard G: History and Nature of Science
- Nature of science

For More Information

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Student Worksheet

Substances may exist as solids, liquids, or gases. These are called "phases," and the phase of a specific substance is affected by temperature and pressure.

A solution is a mixture in which the molecules of one substance are evenly distributed among the molecules of another substance. Often, a solution forms when one substance (called the solute) dissolves in another substance (the solvent). So, in a sugar solution the sugar is the solute and water is the solvent. Solutions may be solids, liquids, or gases.

Solubility is the extent to which a solute dissolves in a solvent, and is also affected by temperature and pressure.

A. Here are some "thought experiments" based on your own experience that may help you figure out how temperature and pressure affect solubility and phase.

1. Solubility of gases

a. What happens when you remove the cap from a bottle of soda?

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b. Is the pressure in the bottle higher or lower after you remove the cap?

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c. What do you think happens to the solubility of a gas when the pressure increases?

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d. If you removed the caps from a bottle of ice-cold soda and a bottle of soda at room temperature, what differences would you expect?

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e. What do you think happens to the solubility of a gas when temperature increases?

____

2. Solubility of solids

a. Suppose you pour salt into a glass of water until no more will dissolve (this is called a saturated solution). What could you do to get even more salt dissolved in the solution?

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b. If you have a saturated solution, what do you expect to happen if the solution is cooled in a refrigerator?

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c. What do you think happens to the solubility of most solids when the temperature increases?

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3. Phases

a. What is the phase of water at room temperature?

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b. What happens if you raise the temperature of water above 100°C?

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c. What happens if you lower the temperature of water below 0°C?

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d. If a substance is in a solid phase at room temperature, what do you think happens to the phase of the substance as temperature increases?

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e. If you put a glass of water into an air-tight container and then pump all of the air out of the container, what will happen to the water?

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What does this suggest about the effect of reduced pressure on the phase of a substance?

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What does this suggest about the effect of increased pressure on the phase of a substance?

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B. Use these principles to develop explanations for the following observations made by scientists exploring deep-sea volcanoes on the Ring of Fire Expeditions:

1. Using a remotely operated vehicle (ROV) carrying a video camera, scientists found hot fluids escaping from the side of the East Diamante volcano. Often, the fluids were escaping from vertical formations that resemble chimneys. Chemical examination showed that one of these chimneys was composed of iron, zinc, and minerals of barium and copper. How do the principles of solubility help explain how these chimneys are formed?

2. Scientists exploring the East Diamante volcano also observed that many of the chimneys appeared to be emitting black smoke. How do the principles of solubility help explain something that looks like black smoke?

3. During their first dive at Eifuku volcano, Ring of Fire scientists saw cloudy bubbles rising from the sediment around small white chimneys. The bubbles were sticky, and did not tend to fuse together to form bigger bubbles the way most gas bubbles do. How does the effect of pressure on phase help explain these bubbles?

4. Some of the white chimneys at Eifuku were emitting a cloudy white fluid whose temperature was 103°C, even though the temperature of the surrounding seawater was 2°C. Scientists used the ROV to collect samples of the fluid in a plastic tube for analysis. While the ROV was still on the sea floor (at a depth of 1,650 m), some fluffy white material formed inside the plastic tube. As the ROV rose toward the surface, the fluid in the tube began to bubble vigorously. By the time the ROV had reached a depth of 50 m, all of the solid white material was gone and the plastic tube contained only clear gas and seawater. How do the effects of temperature and pressure on solubility and phase help explain these observations?