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New Zealand American Submarine Ring of Fire 2007

It's a Gas! Or Is It?

(adapted from the 2005 Submarine Ring of Fire Expedition)

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 Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin, including the Kermadec and Mariana Islands in the western Pacific, the Aleutian Islands between the Pacific and Bering Sea, the Cascade Mountains in western North America, and numerous volcanoes on the western coasts of Central America and South America. These volcanoes result from the motion of large pieces of the Earth's crust known as tectonic plates.

Tectonic 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). These convection currents cause the tectonic plates to move several centimeters per year relative to each other.

The junction of two tectonic plates is called a "plate boundary." Three major types of plate boundaries are produced by tectonic plate movements. If two tectonic plates collide more or less head-on they form a convergent plate boundary. Usually, one of the converging plates will move beneath the other, which is known as 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 (molten rock) 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. For a 3-dimensional view of a subduction zone, visit: http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html.

The junction of two tectonic plates that are moving apart is called a divergent plate boundary. Magma 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. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. View the 3-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

The third type of plate boundary occurs where tectonic plates slide horizontally past each other, and 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. See animations of different types of plate boundaries at: http://www.seed.slb.com/en/scictr/watch/living_planet/plate_boundaries/plate_move.htm.

The volcanoes of the Submarine Ring of Fire result from the motion of several major tectonic plates. The Pacific Ocean Basin lies on top of the Pacific Plate. To the east, along the East Pacific Rise, new crust is formed at the oceanic spreading center between the Pacific Plate and the western side of the Nazca Plate. Farther to the east, the eastern side of the Nazca Plate is being subducted beneath the South American Plate, giving rise to active volcanoes in the Andes. Similarly, convergence of the Cocos and Caribbean Plates produces active volcanoes on the western coast of Central America, and convergence of the North American and Juan de Fuca Plates causes the volcanoes of the Cascades in the Pacific Northwest.

On the western side of the Pacific Ocean, the Pacific Plate converges against the Philippine Plate and Australian Plate. Subduction of the Pacific Plate creates the Mariana Trench (which includes the Challenger Deep, the deepest known area of the Earth's ocean) and the Kermadec Trench. As the sinking plate moves deeper into the mantle, new magma is formed as described above, and erupts along the convergent boundary to form volcanoes. The Mariana and Kermadec 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, and older crust is recycled to the lower mantle at the convergent plate boundaries of the western Pacific. For more information on plate tectonics, visit the NOAA Learning Objects Web site (http://www.learningdemo.com/noaa/). Click on the links to Lessons 1, 2 and 4 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones. See the satellite and sonar survey animation of the Mariana Arc Volcanic Chain at: http://oceanexplorer.noaa.gov/explorations/04fire/background/marianaarc/media/sat_em_islands_video.html

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.

Beginning in 2002, Ocean Exploration expeditions have undertaken systematic mapping and study in previously unexplored areas of the Submarine Ring of Fire. Visit

- http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/;
- http://www.oceanexplorer.noaa.gov/explorations/03fire/;
- http://www.oceanexplorer.noaa.gov/explorations/04fire/;
- http://www.oceanexplorer.noaa.gov/explorations/05fire/; and
- http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html

for more information about the many discoveries, as well as still and video imagery, from these expeditions. The New Zealand American Submarine Ring of Fire 2007 Expedition is focused on detailed exploration of hydrothermal systems at Brothers Volcano 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:
   - 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);
   - Submarine Ring of Fire 2006 daily log for April 25 log (http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/april25/april25.html); and
   - "Vent Chemistry" essay (http://www.oceanexplorer.noaa.gov/explorations/06fire/background/chemistry/chemistry.html)

   You may also want to print copies of the photographs or download videos of "champagne" bubbles (http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/summary/media/nwrota1_sulfur_bubbles.html; http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/april25/media/image1_combo.html) and/or video images of gases erupting from Submarine Ring of Fire '06 April 24 log (http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/april24/media/nwrota_brimstone3.html; http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/april25/media/nwrota_brimstone7.html).

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/index.html) to supplement this discussion). Introduce the Ring of Fire, and describe the processes that produce the Mariana Arc.

3. There are at least three ways that you may use the thought experiments (Part A) on the "It's a Gas!" worksheet. Which one you choose depends primarily upon time available for this activity. The quickest approach is to use thought experiments as a guide to key topics, and simply review basic principles of solubility in a lecture or discussion format.

   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.

   Another approach is to demonstrate the thought experiments as a group activity as 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.

   Alternatively, you can have students work through the thought experiments on their own, individually or in small groups, using library or internet resources as needed. Appropriate answers are:

1. Solubility of gases

a. What happens when you remove the cap from a bottle of soda?
   [bubbles form in the liquid]

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

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

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?
   [more bubbles would form in the warmer soda]

e. What do you think happens to the solubility of a gas when temperature increases?
   [solubility of gases decreases with increasing temperature]

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?
   [heat the solution]

b. If you have a saturated solution, what do you expect to happen if the solution is cooled in a refrigerator?
   [some of the dissolved substance will "come out of solution" (precipitate)]

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

3. Phases

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

b. What happens if you raise the temperature of water above 100°C?
[the phase changes from liquid to gas]
c. What happens if you lower the temperature of water below 0°C?
[the phase changes from liquid to solid]
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?
[it probably changes to a liquid and then to a gas if temperature is high enough]
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?
[the water will change from liquid to gas phase (evaporate)]
f. What does this suggest about the effect of reduced pressure on the phase of a substance?
[reduced pressure tends to favor formation of gas phases]
g. What does this suggest about the effect of increased pressure on the phase of a substance?
[increased pressure tends to favor formation of solid phases]

Be sure students realize that, in general, if a material is solid at room temperature, its solubility will probably increase as the temperature of the solvent increases, but there are some substances (such as lithium sulfate) whose solubility declines as temperature increases.

4. Provide each student or student group with a copy of the "It's A Gas! Worksheet," and have them develop explanations for the observation problems (Part B).

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 (for more information about black smokers see http://divediscover.whoi.edu/vents/vent-info-mod.html).

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://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/about-hydrates/about_hydrates.htm, as well as the Ocean Exploration Windows to the Deep expedition (http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html) 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/explorations/07fire/welcome.html to keep up to date with the latest New Zealand American Submarine Ring of Fire 2007 Expedition discoveries, and find out what scientists are learning about hydrothermal systems in the vicinity of Brothers Volcano.

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 NOAA's Ocean Exploration Program

It's Going to Blow Up! [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.BlowUp.pdf] (15 pages; 332k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Volcanism on the Pacific Ring of Fire (Earth Science)

Students will be able to describe the processes that produce the Submarine Ring of Fire; explain the factors that contribute to explosive volcanic eruptions; identify at least three benefits that humans derive from volcanism; describe the primary risks posed by volcanic activity in the United States; and identify the volcano within the continental U.S. that is considered most dangerous.

What's for Dinner? [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.Dinner.pdf] (8 pages; 288k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Sources of nutrition for biological communities associated with volcanoes of the Mariana Arc (Life Science)

Students will be able to compare and contrast photosynthesis and chemosynthesis as sources of primary production for biological communities; give at least three examples of organisms that live near hydrothermal vent systems; and describe two sources of primary production observed in biological communities associated with volcanoes of the Mariana Arc.

Other Links and Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

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

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.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.

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

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

http://www.pmel.noaa.gov/vents/nemo/explorer/bio_gallery/biogallery1.html – NeMO Explorer animal gallery

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

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept a. The ocean is the dominant physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

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 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.

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Student Handout

It's A Gas! 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?

____

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

____

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

____

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?

____

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?

____

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

____

Student Handout

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

3. Phases

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

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

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

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?

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?

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

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

Student Handout

B. Use these principles to develop explanations for the following observations made by scientists exploring deep-sea volcanoes on the Submarine 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 resembled 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, Submarine 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?