OCEAN EXPLORATION & RESEARCH

Submarine Ring of Fire 2012: NE Lau Basin Expedition

Boiling Hot

Image captions/credits on Page 2.

lesson plan

Focus
Effects of temperature and pressure on solubility and phase state

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

Focus Question
How do temperature and pressure affect solubility and phase state?

Learning Objectives
- Students will use conceptual models of matter to explain the effect of temperature and pressure on solubility and phase state.
- Students will construct explanations for observed chemical phenomena around deep-sea volcanoes that are consistent with principles of solubility and phase state.

Materials
- Copies of *Boiling Hot Worksheet*, one for each student group

Audio-Visual Materials
- (Optional) Interactive whiteboard

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of two to three students

Maximum Number of Students
30

Key Words
Ring of Fire
Lau Basin
Solubility
Phase state

Images from Page 1 top to bottom:
Tectonic features of the Lau Basin overlaid on satellite altimetry data, modified from Martinez and Taylor Geophysical Monograph 166, 2006.See page 3 for larger image and more information. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/tectonic_features.html

A closeup of a Conductivity, Temperature, Depth profiler (CTD), the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD. The bottles are closed on command from the ship, usually when a scientist monitoring the sensors sees strong evidence of a plume. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plumes/media/ctd_closeup.html

An eruption near the summit of the West Mata volcano. The blast (top left) is intense, and broken rock can be seen in the plume. Three glowing bands of superheated "pillow" lava (seen below the blast) are flowing down the volcano's slope. Image courtesy of NSF and NOAA.
http://oceanexplorer.noaa.gov/explorations/09laubasin/logs/hires/eruptive_blast_hires.jpg

The Quest 4000 remotely operated vehicle will be utilized on the SRoF'12 – NE Lau expedition, providing high-definition video and seafloor sampling capabilities. Image courtesy of MARUM.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/quest4000.html

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

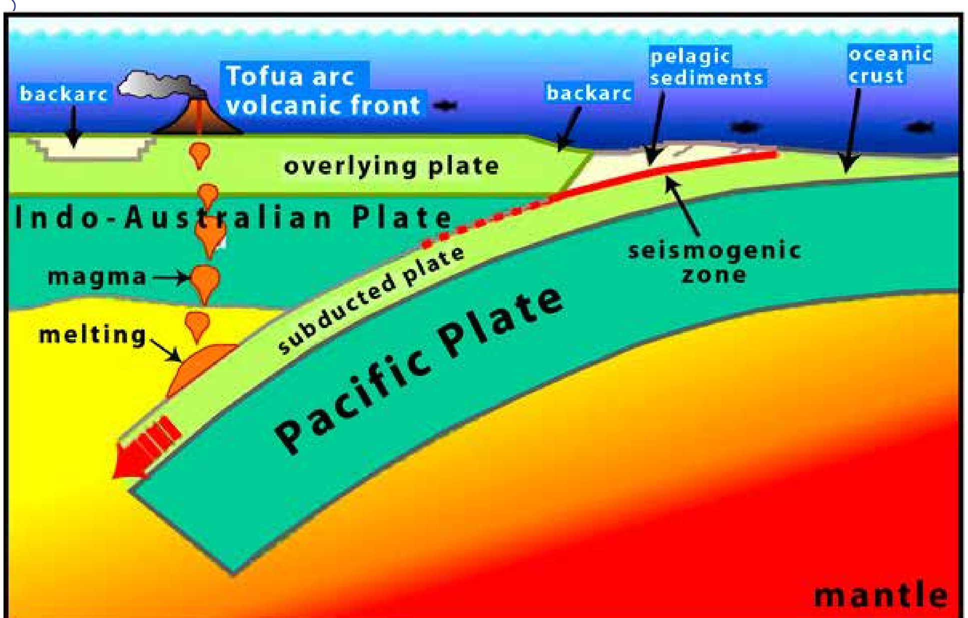
The Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin, including the Lau Basin, Kermadec and Mariana Islands in the western Pacific, the Aleutian Islands between the Pacific and Bering Sea, the Cascade Mountains in western North America, and numerous 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. Along mid-ocean ridges (also called spreading centers), tectonic plates are moving apart. Molten rock rises from Earth's mantle into the gap between the separating plates and produces extensive lava flows. Along oceanic trenches, tectonic plates are colliding so that one plate is descending below another plate. This process is called subduction. The subducting plate is heated as it descends into Earth's mantle, causing gases and water to be released from the heated rock. These gases and water lower the melting temperature of the hot mantle rocks, so that magma (molten rock) is produced. The magma rises and accumulates in areas called magma chambers, and then erupts to form volcanoes.

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), the Kermadec Trench, and the Tonga Trench, among others. 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 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.

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 Northeastern Lau Basin is very unusual, because in addition to volcanic activity associated with the subduction of the Pacific Plate beneath the Indo-Australian Plate, there are also areas in which the Indo-Australian Plate seems to be pulling apart; and these areas are also rich in volcanic and hydrothermal activity. Preliminary surveys of the area between 2008 and 2011 have shown that the Northeastern Lau Basin is one of the most concentrated areas of active submarine volcanism and hot springs anywhere on Earth. For additional discussion, please see the Expedition Education Module for the Submarine Ring of Fire 2012: NE Lau Basin Expedition at http://oceanexplorer.noaa.gov/explorations/12fire/background/edu/edu.html.



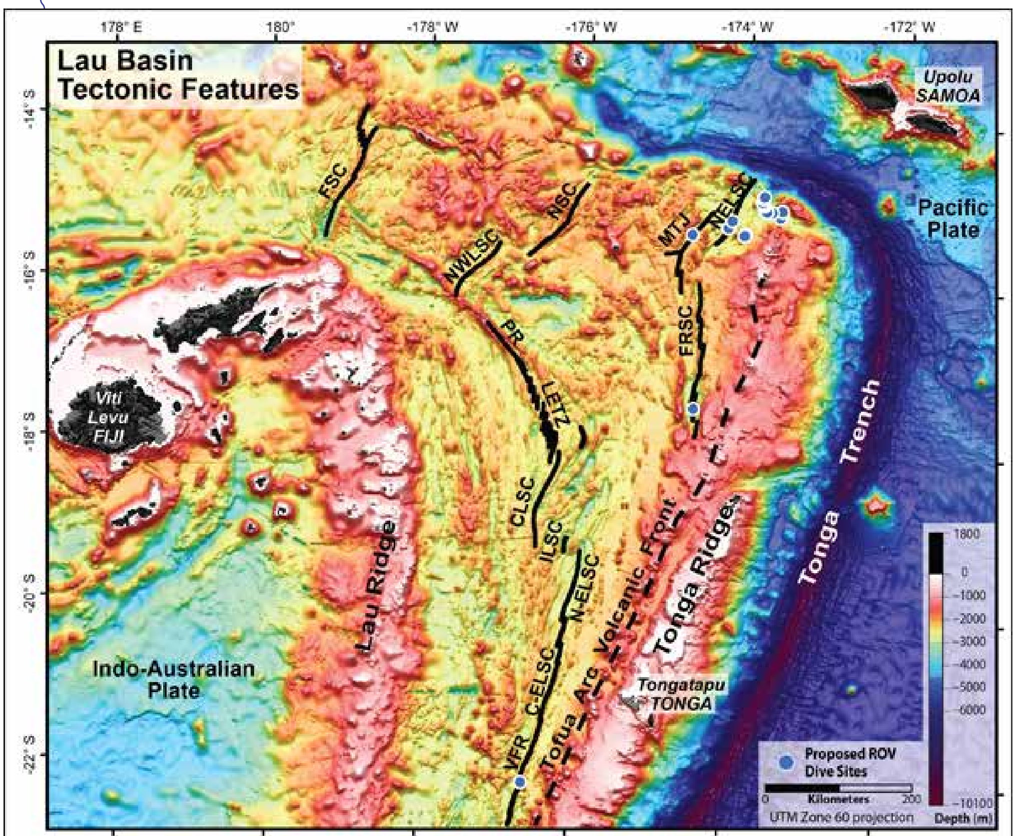
This illustration shows the Pacific plate in the east colliding with the Indo-Australian plate in the west. A consequence of this collision is subduction with the down going slab comprised of oceanic crust, or lithosphere, and a thin veneer of pelagic sediment. This causes extension behind the subduction zone, which is represented by backarc basins forming behind the arc front. At certain depths, usually around 200 kilometers (~100 nautical miles), there is melting of the subducted materials. The melting produces magmas that rise buoyantly to pond in the overlying mantle wedge and periodically erupt on Earth's surface as lavas, forming arc volcanoes. Image courtesy of GNS Science.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/pacific_plate.html

Beginning in 2002, NOAA 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
- http://oceanexplorer.noaa.gov/explorations/07fire/welcome.html

for more information about the many discoveries, as well as still and video imagery, from these expeditions. The primary objective of the Submarine Ring of Fire 2012: NE Lau Basin Expedition is to explore and characterize the unique ecosystems in the NE Lau Basin through examination of their geology, chemistry, and macro- and microbiology.



Tectonic features of the Lau Basin overlaid on satellite altimetry data, modified from Martinez and Taylor Geophysical Monograph 166, 2006. The Spreading centers and ridges are shown with black solid lines: Valu Fa Ridge (VFR), Central Eastern Lau Spreading Center (C-ELSC), Intermediate Lau Spreading Center (ILSC), Central Lau Spreading Center (CLSC), Lau Extensional Transform Zone (LETZ), Peggy Ridge (PR), North-West Lau Spreading Center (NWLSC), Niuafo'ou Spreading Center (NSC), Futuna Spreading Center (FSC), Mangatolu Triple Junction (MTJ), Fonualei Rift and Spreading Center (FRSC), North-East Lau Spreading Center (NELSC). Tonga Trench, ridges and tectonic plates are also noted. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/tectonic_features.html

In this lesson, students will investigate the effect of temperature and pressure on solubility and phase state and construct explanations for observed chemical phenomena around deep-sea volcanos that are consistent with the principles of solubility and phase state.

Learning Procedure

Note: Portions of this activity are adapted from the *It's a Gas! Or Is It?* lesson from the New Zealand American Submarine Ring of F ire 2007 Expedition.

1. To prepare for this lesson, read the mission plan and Volcanology background essay for the Submarine Ring of Fire 2012: NE Lau Basin Expedition at http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html. You may also want to review 3D imagery and video fly-throughs, also linked from this page. 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).

2. Briefly introduce the Submarine Ring of Fire 2012: NE Lau Basin Expedition. If necessary, review the concepts of plate tectonics. Be sure students understand the distinction between mid-ocean ridges and subduction zones. You may want to show some of the imagery referenced in Step 1. If students are not familiar with plate tectonics and time permits, you may wish to use some or all of Multimedia Discovery Missions Lessons 1, 2 and 4, which include interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones [http://oceanexplorer.noaa.gov/edu/learning/welcome.html].

3. There are at least three ways that you may use the thought experiments (Part A) on the *Boiling Hot 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 in Part A of 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 *Boiling Hot Worksheet*, and have them develop explanations for the observation problems (Part B).

5. Discuss students' proposed explanations for the observations described in Part B of the *Worksheet*. Key concepts to reinforce during this discussion include:
   - Gases and liquids are made of molecules or inert atoms that are moving about relative to each other;
   - In a liquid, the molecules are constantly in contact with others;
   - In a gas, they are widely spaced except when they happen to collide;
   - In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations;
   - The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter.

(1) The boiling point of liquids increases as pressure increases. For each 10 m of depth, pressure increases by about one atmosphere. So, the pressure at a depth of 1,525 m is about 153 atmospheres. There are numerous Web sites that calculate boiling points at various pressures. The Dive and Discover Web site from Woods Hole Oceanographic Institution (http://www.divediscover.whoi.edu/vents/boiling.html) shows that the boiling point at a depth of 1,000 m is 310° C, and the boiling point at a depth of 2,000 m is 370° C. At a depth of 1,525 m, the estimated boiling point would be roughly halfway between these temperatures; well above the observed temperature of 315° C. Note that at this grade level, predictions about changes of state are expected to be qualitative, not quantitative.

(2, 3) 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-infomod.html).

(4) 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.

(5) 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 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/ – In the menu on the left, scroll over “Ocean Science Topics,” then ““Geology,” for links to resources about plate tectonics and volcanoes.

The “Me” Connection

Have students write a brief essay describing how exploration of deep-sea volcanoes could be of personal importance.

Connections to Other Subjects

English Language Arts

Assessment

Students’ responses to *Worksheet* questions and class discussions provide opportunities for assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html. for more information and resources related to the Submarine Ring of Fire 2012: NE Lau Basin Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Lessons 1, 2, and 4 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-ocean Ridges, and Subduction Zones.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Volcano Friends
(from the New Zealand America Submarine Ring of Fire 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07fire/background/edu/media/volcano.pdf

Focus: Ecological impacts of volcanism in the Mariana Islands (Life Science/Earth Science)

Students describe at least three beneficial impacts of volcanic activity on marine ecosystems, and explain the overall tectonic processes that cause volcanic activity along the Kermadec Arc.

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

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

Students 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?
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.Dinner.pdf

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

Students 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.

Friendly Volcanoes
(from the Submarine Ring of Fire 2004 Expedition)
http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.friendlyvol.pdf

Focus: Ecological impacts of volcanism in the Mariana Islands (Life Science/Earth Science)

Students describe at least three beneficial impacts of volcanic activity on marine ecosystems and explain the overall tectonic processes that cause volcanic activity along the Mariana Arc.

Other 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.

http://oceanexplorer.noaa.gov - Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html - Web page for the Submarine Ring of Fire 2012: NE Lau Basin Expedition

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

http://pubs.usgs.gov/gip/dynamic/dynamic.html - Online version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience

http://www.volcano.si.edu/tdpmap/ - "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction_vr.html - 3-dimensional "subduction zone" plate boundary video

http://volcano.oregonstate.edu/ - Volcano World Web site from Oregon State University

Relationship to A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

The objectives of this lesson integrate the following Practices, Crosscutting Concepts, and Core Ideas:

Objective: Students use conceptual models of matter to explain the effect of temperature and pressure on solubility and phase state.

Practices:

2. Developing and using models
6. Constructing explanations

Crosscutting Concepts:

6. Structure and function

Core Ideas:

PS1.A: Structure and Properties of Matter

Objective: Students construct explanations for observed chemical phenomena around deep-sea volcanoes that are consistent with principles of solubility and phase state.

Practices:

6. Constructing explanations

Crosscutting Concepts

2. Cause and effect

Core Ideas:

ESS2.B: Plate Tectonics and Large-Scale System Interactions

Correlations to Common Core State Standards for English Language Arts

RI.4 – 4. Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings; analyze the impact of a specific word choice on meaning and tone.

W.1 – Write arguments to support claims with clear reasons and relevant evidence.

SL.1 – Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 7 and 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.

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.

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

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Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

Boiling Hot Worksheet

Substances may exist as solids, liquids, or gases. These are called "phase states," 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.

Part 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?
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?

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

1. On May 9, 2009 during the Northeast Lau Response Cruise, the remotely operated vehicle (ROV) *Jason II* collected samples of hydrothermal vent fluid from a sulfide chimney at the Maka Volcano, at a depth of 1,525 m. The temperature of this fluid was 315° C. How can this fluid be liquid when water boils at about 100° C?

2. Using a 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?

3. 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?

4. 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?

5. 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?