Submarine Ring of Fire 2014 – Ironman Expedition

Volcanoes, Acids and Champagne!

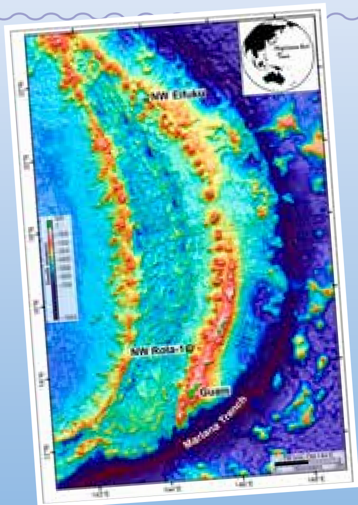


Image captions/credits on Page 2.

lesson plan

Focus

Carbon dioxide from deep-ocean volcanoes and its effect on ocean acidity

Grade Level

6-8, with adaptations for grades 9-12 (Physical Science/Life Science/ Earth Science)

Focus Question

How does carbon dioxide from deep-ocean volcanoes affect the chemistry of the surrounding seawater?

Learning Objectives

1. Students will construct an explanation based on evidence for how carbon dioxide from deep ocean volcanoes could affect acidity of the surrounding seawater.
2. Students will develop a model that uses cause and effect relationships between temperature, pressure, and states of matter to predict the state of carbon dioxide from deep ocean volcanoes.
3. Students will interpret the location of the Marianas Arc and Marianas Trench to provide evidence of the motions of tectonic plates.

Materials

For Objective 1:

- ❑ 1– Glass or plastic container, about 500 ml capacity
- ❑ 1 – Graduated cylinder or measuring cup, about 250 ml capacity
- ❑ 1 – Small pot, about 1 liter capacity
- ❑ 1 – Funnel, about 7 cm diameter
- ❑ Cheesecloth, about 30 cm (12 in) square
- ❑ 500 ml finely chopped red cabbage
- ❑ Boiling water, about 500 ml
- ❑ Baking soda
- ❑ White vinegar

For each demonstration or student group:

- ❑ 4 – Glass or plastic cups, about 250 ml capacity
- ❑ 1 – Measuring spoon, about 1 ml capacity (1/4 teaspoon)
- ❑ 1 – Measuring spoon, about 5 ml capacity (1 teaspoon)
- ❑ Safety glasses
- ❑ Drinking straw
- ❑ Tap water

For Objective 2:

- ❑ Copies of *It's a Gas! Student Worksheet*, one copy for each student group

Audio-Visual Materials

- ❑ (Optional) Interactive whiteboard

Teaching Time

Two 45-minute class periods, additional time may be needed for independent student work (see Learning Procedure, Step 6)

Seating Arrangement

Groups of three or four students

Maximum Number of Students

30

Key Words

Ring of Fire
Microbial mat
Hydrothermal vent
Underwater volcano
Eifuku
Mariana Arc
Acidification

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.

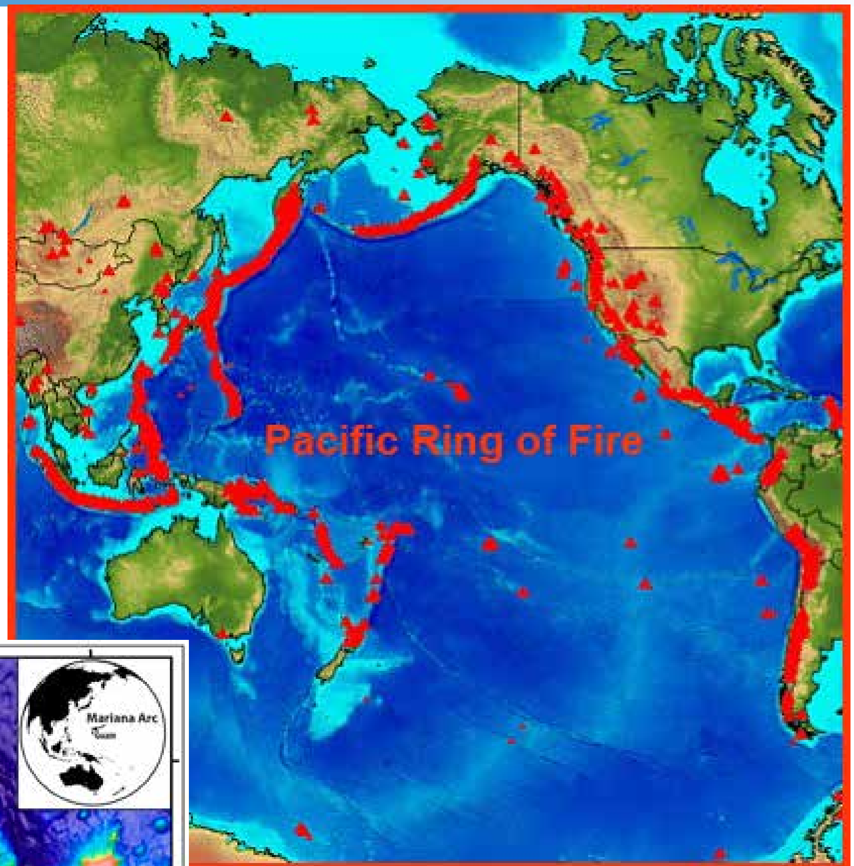
The Ring of Fire is an arc of active volcanoes and earthquake sites that partially encircles the Pacific Ocean Basin. The location of the Ring of Fire coincides with the location of oceanic trenches and volcanic island arcs that result from collisions between large pieces of Earth's crust (tectonic plates) as they move on a hot flowing layer of Earth's mantle (for more about tectonic plate boundaries, please see Appendix A). When two tectonic plates collide more or less head-on, one of the plates usually 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 molten rock (magma) rises and may erupt violently to form volcanoes that in turn may form arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. The Ring of Fire marks the location of numerous collisions between tectonic plates in the western Pacific Ocean.

Images from Page 1 top to bottom:
Bathymetric compilation map of the Mariana Arc area showing the location of the 2 focus sites on the expedition, NW Eifuku and NW Rota-1 as well as the Marianas Trench. Multibeam bathymetry (120m grid-cell size) is overlaid on satellite altimetry data. Image credit: NOAA/PMEL Submarine Ring of Fire 2014 Expedition.

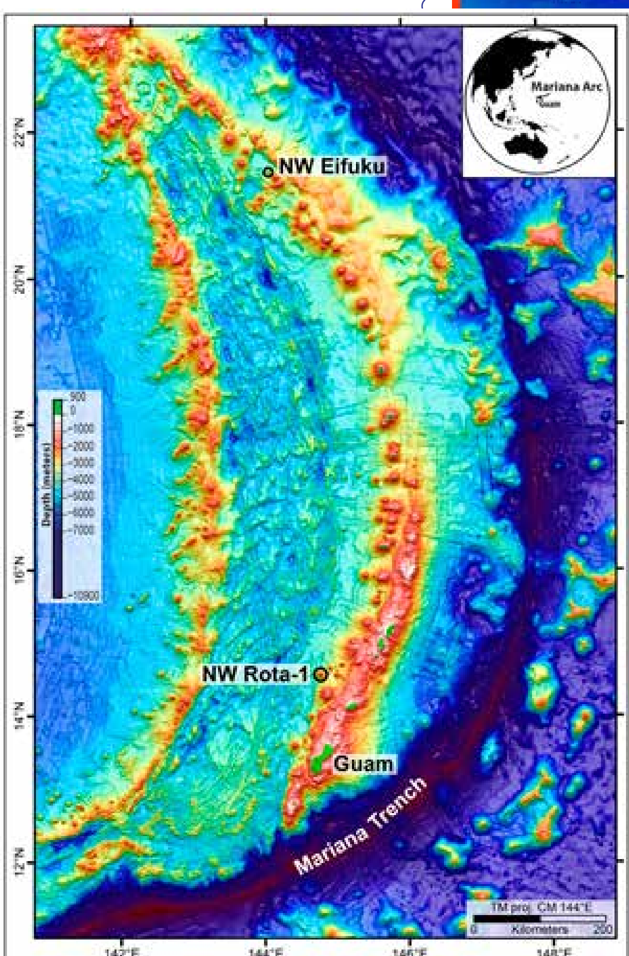
Mussel bed at NW Eifuku where pH can be as low as 5.3. Image credit: NOAA/PMEL Submarine Ring of Fire 2006 Expedition.
http://oceanexplorer.noaa.gov/explorations/06fire/logs/may8/media/mussel_water_samp.html

Photograph of iron-oxide-encrusted microbial mat collected using ROV (remotely operated vehicle) at Yellow Top Vent, Northwest Eifuku.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/april12/media/yellow_cone.html

NW Rota-1 seamount has been observed erupting explosively on previous visits. Image credit: Submarine Ring of Fire 2006 Exploration, NOAA/PMEL.
http://oceanexplorer.noaa.gov/explorations/06fire/logs/april29/media/lavabombs.html



Map of all of the volcanoes around the Pacific (red triangles), making up the Ring of Fire. Image credit: NOAA/PMEL Submarine Ring of Fire 2014 Expedition.



Bathymetric compilation map of the Mariana Arc area showing the location of the 2 focus sites on the expedition, NW Eifuku and NW Rota-1 as well as the Marianas Trench. Multibeam bathymetry (120m grid-cell size) is overlaid on satellite altimetry data. Image credit: NOAA/PMEL Submarine Ring of Fire 2014 Expedition.

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 ocean). 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. The 2004 Submarine Ring of Fire Expedition focused specifically on hydrothermal systems of the Mariana Arc volcanoes, and found that these systems are very different from those found along mid-ocean ridges. In 2006, the third Submarine Ring of Fire Expedition visited multiple volcanoes, including the actively erupting NW Rota-1 and Daikoku, which featured a pond of molten sulfur (visit http://oceanexplorer.noaa.gov/explorations/03fire/welcome.html, http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html , and http://oceanexplorer.noaa.gov/explorations/06fire/logs/summary/summary.html for more information on these discoveries).

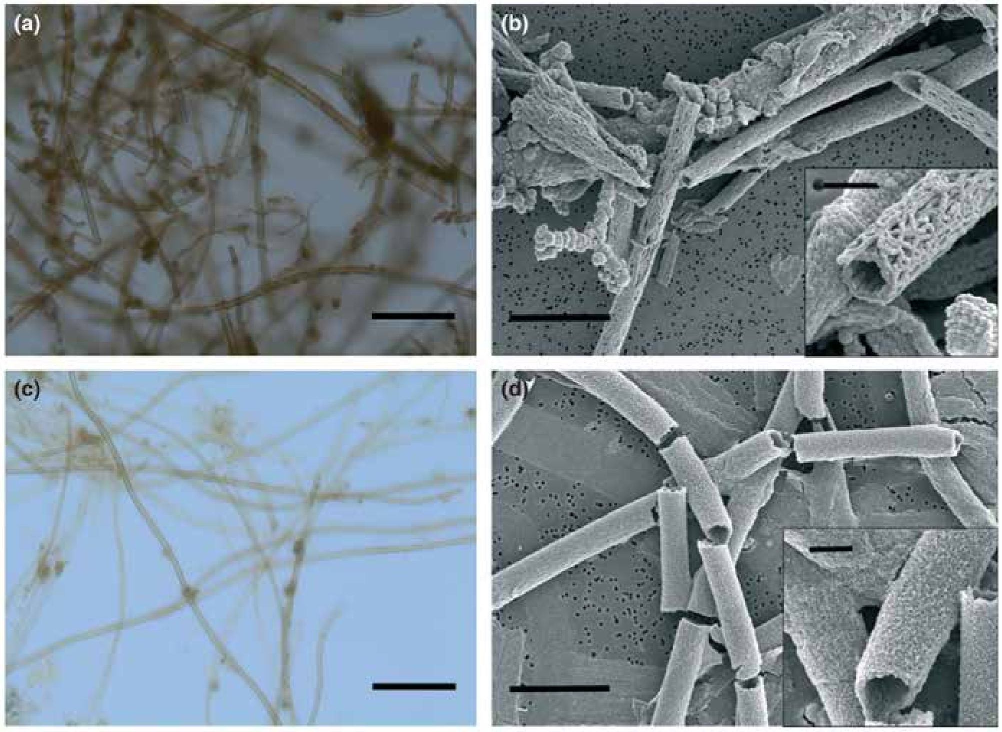
On April 10, 2004, scientists exploring the NW Eifuku Seamount in the northern Mariana Arc saw small white chimneys emitting a cloudy white fluid near the volcano's summit, as well as masses of bubbles rising from the sediment around the chimneys. The bubbles were composed of some type of fluid, and were so abundant that the scientists named the site "Champagne." Further investigation revealed that the fluid was saturated with carbon dioxide, and that the bubbles were liquid carbon dioxide. The concentration of carbon dioxide in the vent fluid was an order of magnitude higher than in previously studied hydrothermal vents.

Droplets of liquid CO_2 are emitted from the seafloor around white-smoker vents at the Champagne hydrothermal vent field on NW Eifuku Seamount. This is a close-up of some droplets at the Champagne vent site. Image credit: NOAA Submarine Ring of Fire 2004 Expedition.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/hirez/bubbles_hirez.jpg

In addition, ocean explorers found dense populations of mussels, crustaceans, and other organisms associated with the hydrothermal vents. Particularly important are microbes that are able to use chemicals in vent fluids as a source of energy, and are the basis for complex food webs. Zetaproteobacteria are a class of microbes that are able to use iron as an energy source, and form dense mats in some areas of the NW Eifuku Seamount. These food webs are based on chemosynthesis, and are fundamentally different from food webs that are based on energy from sunlight captured through photosynthesis. Chemosynthetic organisms may have been the first life forms on Earth, and may give important clues about life on other planets.

Mussel bed at NW Eifuku where pH can be as low as 5.3. NOAA Submarine Ring of Fire 2006 Expedition.
http://oceanexplorer.noaa.gov/explorations/06fire/logs/may8/media/mussel_water_samp.html

The purpose of the 2014 Submarine Ring of Fire – Ironman Expedition is to investigate the ecology of Zetaproteobacteria mat ecosystems, as well as to explore the NW Eifuku and MW Rota-1 Seamounts in greater detail. The exploration will include investigation of hydrothermal vent fluids, the effect of vented carbon dioxide on the pH of surrounding waters, the chemical environment of microbial mats in the vicinity of vents, the effects of acidic conditions on mussels and other benthic organisms, and detailed mapping of the summit of NW Eifuku.



Micrographs showing the overall similarity between representative samples of marine and freshwater sheaths inside microbial mats. The top panels show, (a) a light micrograph of a sample taken from a hydrothermal vent with a syringe sampler (J2-481-BS4), and (b) an SEM image of this sample that shows the fine structure of the sheaths. The lower panels show a sample taken from a local freshwater iron-seep in Maine morphologically dominated by *Leptothrix ochracea*; (c), a light micrograph; (d) an SEM image showing fine structure of the sheaths. Scale bars for a and c are 15 µm, b and d 5 µm with panels insets 1 µm. From Fleming *et al.*, 2013.

Acidification caused by carbon dioxide vented from deep-ocean volcanoes is a natural process, but Earth's ocean is also becoming more acidic due to human activities. Since the Industrial Revolution, widespread burning of fossil fuels has increased the concentration of carbon dioxide in Earth's atmosphere. The ocean absorbs about a quarter of the carbon dioxide humans release into the atmosphere every year. This oceanic uptake of CO_2 causes changes in ocean chemistry including decreases in pH and carbonate ion concentrations, collectively known as global ocean acidification. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution. While ocean acidification has happened at other times in Earth's history, the present increase is happening 100 times faster than any other acidification event in at least 20 million years.

Deep-sea hydrothermal vents are dynamic and extremely productive biological ecosystems supported by chemosynthetic microbial primary production. In the absence of photosynthesis, these microorganisms derive energy via the oxidation of reduced chemicals emitted in hydrothermal fluids. In contrast to other strategies for microbial chemosynthesis at hydrothermal vents, iron oxidation has only recently been studied. These white chimneys at Champagne vent site, NW Eifuku volcano are ~20 cm (8 in) across and ~50 cm (20 in) high, venting fluids at 103°C (217°F). Notice the droplets in the upper left portion of the image. Image credit: NOAA Submarine Ring of Fire 2004 Expedition.
http://oceanexplorer.noaa.gov/explorations/04fire/logs/april10/media/chimneys.html

Rapid change in the ocean's chemistry may pose serious threats to the health of Earth's ocean and its ecosystems. A more acidic environment has a dramatic effect on some species that build calcium carbonate (limestone) shells, such as oysters. When shelled organisms are at risk, the entire food web also is at risk. For example, pteropods are an important food source for salmon. According to some research reports, a 10 percent drop in pteropod production could result in a 20 percent drop in the mature body weight of pink salmon. Measurements of volcanic CO_2 during the 2014 Submarine Ring of Fire – Ironman Expedition will help scientists understand how Earth's natural contribution to ocean acidification compares to acidification caused by human activities.

In this lesson, students will demonstrate how increased carbon dioxide makes oceans more acidic, investigate the effects of temperature and pressure on solubility and phase state, and investigate the tectonic processes responsible for the formation of the Mariana Arc, Marianas Trench, and intense volcanic activity in this region.

Learning Procedure

Note: The three Learning Objectives for this lesson may be addressed individually or in combination, depending upon time available and the specific curriculum structure for which the educator is responsible. To facilitate this decision, the relevant objective for each of the following steps is indicated.

1. To prepare for this lesson:
   a. (***All Objectives***) Review background information about the 2014 Submarine Ring of Fire – Ironman Expedition (http://oceanexplorer.noaa.gov/explorations/14fire/welcome.html). Read the Submarine Ring of Fire 2004 daily log for April 10 (http://oceanexplorer.noaa.gov/explorations/04fire/logs/april10/april10.html). You may also want to download some images or videos to help introduce the expedition to students.

   b. (***Objective 1***, Carbon dioxide and ocean acidification) Prepare a pH indicator solution by boiling the chopped red cabbage in a small pot with about 500 ml of water for 20 minutes. Let the mixture rest for about 30 minutes. Cover the opening of the funnel with at least four layers of cheesecloth, and strain the cabbage mixture through the cheesecloth into glass jars or plastic cups. The activity described in Step 3 may be done as a class demonstration, or as an individual activity for groups of 2-3 students.

2. (***All Objectives***) 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/eoi/nemo/explorer/concepts/hydrothermal.html) to supplement this discussion). Introduce the Ring of Fire, and describe the processes that produce the Mariana Arc. Tell students about the 2004 discovery of strange fluid droplets at the NW Eifuku Seamount. If you plan to complete the activity described in Step 4, do not tell students that the fluid droplets were liquid carbon dioxide at this point.

3. (***Objective 1***, Carbon dioxide and ocean acidification)
   a. If students are not already familiar with the concept of acids and bases, briefly discuss this concept and that a measurement called pH is used to describe how acidic or basic a solution is. A pH of 7 is considered neutral. Acidic solutions, such as vinegar or lemon juice, have a pH less than 7. The more acidic a solution is, the lower the pH number. Basic solutions, such as milk or baking soda dissolved in water, have a pH greater than 7.

   b. Tell students that red cabbage contains chemicals that change color depending upon pH. These types of chemicals are called pH indicators. In basic solutions, these chemicals from red cabbage are light blue, but they change to pink-purple in acidic solutions.

   c. Pour about 50 ml of tap water into a glass jar or plastic cup. Add 5 ml of the red cabbage indicator solution to the jar. The solution should have a pale blue color. The pH of tap water varies from place to place, so if the solution is not pale blue, add a pinch of baking soda, and gently swirl the container so that the baking soda dissolves. Repeat if necessary until the solution has a pale blue color.

   d. Pour about 50 ml of tap water into a second glass jar or plastic cup. Add 5 ml of the red cabbage solution to the jar, then add 5 ml of white vinegar. The solution should have a pink-purple color.

   e. Put about 1 ml (1/4 tsp) of baking soda into a third glass jar or plastic cup, fill the container with tap water, and gently swirl the container so that the baking soda dissolves.

   f. Pour about 50 ml of tap water into the fourth glass jar or plastic cup. Add 1 ml of the baking soda solution from the preceding step to the jar, then add 5 ml of the red cabbage solution to the jar. The solution should have a pale blue color. Put on a pair of safety glasses, and blow gently through a straw into the solution. Keep blowing for several minutes, until the color of the solution changes from pale blue to pink-purple.

g. Ask students to interpret these results, either in a whole-class discussion, reflection in small groups, or as an individual written assignment (the small group approach followed by a whole-class discussion is usually most effective). Students should infer from Steps 3c and 3d that the cabbage indicator solution is blue in basic solutions and pink-purple in acidic solutions. Ensure students realize that when they exhale, the air from their lungs contains more carbon dioxide than the air in the atmosphere. Knowing this, students should infer that blowing through a straw into the baking soda solution bubbles carbon dioxide through the liquid, and some of this carbon dioxide dissolves into the water to form a weak acid. When this happens, the red cabbage indicator changes to a pink-purple color, showing that the pH has changed and the liquid has become more acidic. Conclude the discussion by asking students how carbon dioxide from deep ocean volcanoes might affect the acidity of surrounding seawater, and how increased acidity might affect marine organisms. If time permits, you may want to pose the latter question as a topic for group research. At a minimum, students should be aware that many shelled organisms are threatened by increased ocean acidity, and these organisms are an important part of marine food webs.

4. (***Objective 2***, Phase states of carbon dioxide from deep ocean volcanoes)
   a. If necessary review basic principles of solubility, or allow students to use the *It's a Gas! Student Worksheet* to work through these principles on their own. 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.

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

   b. Provide each student group with a copy of the *It's A Gas! Student Worksheet*. Have students collaborate to complete the review questions and develop models (which may include drawings and diagrams) that support explanations for the observation problems.

c. Discuss student groups' proposed explanations for the observations described on the worksheet. Student constructed models should be used to reinforce these explanations.

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 Seamount 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://serc.carleton.edu/earthandmind/posts/just_phase_were.html, as well as the Ocean Exploration Windows to the Deep Expedition http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html for more information).

As the remotely operated vehicle (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.

5. (***Objective 3***, the Mariana Arc and tectonic processes)
   a. Be sure students understand the idea of convergent, divergent, and transform boundaries, as well as the overall type of earthquake and volcanic activity associated with each type of boundary (strong earthquakes and explosive volcanoes at convergent boundaries; slow-flowing volcanoes, weaker earthquakes at divergent boundaries; strong earthquakes, rare volcanoes at transform

boundaries). You may want to use materials from "This Dynamic Earth" and/or "This Dynamic Planet" (http://pubs.usgs.gov/gip/dynamic/dynamic.html#anchor19309449).

b. Assign each student group to prepare a model that illustrates tectonic plate movements in the vicinity of the Mariana Arc and Marianas Trench. The model should include the names of major tectonic plates in the region, and illustrate how the location of the Mariana Arc and Marianas Trench provides evidence of the motions of these plates. There are numerous websites (such as http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm) that provide adequate information on which to base the models.

c. Lead a class discussion in which students use their models to describe how the location of the Mariana Arc and Marianas Trench provides evidence that supports hypotheses about the motions of tectonic plates, and why these processes lead to the formation of numerous volcanoes and hydrothermal vents.

d. (Optional) Have student groups construct a model of a volcanic island in the Mariana Arc. Resources at http://volcano.oregonstate.edu/ and http://volcano.oregonstate.edu/volcano-models will provide adequate information. Depending upon available time and your tolerance for chaos, you may decide to allow students to include eruptions in their models.

The BRIDGE Connection

www.vims.edu/bridge/ – In the menu on the left, scroll over "Ocean Science Topics," click on "Geology" and scroll down to resources about the NeMO program for activities based on scientific investigations of active volcanoes on the deep ocean floor.

The "Me" Connection

Have students imagine that they live on one of the Marianas Islands. Have each student write a short essay describing life on the island, and how they feel about living over one of the most volcanically active places on Earth.

Connections to Other Subjects

English Language Arts

Assessment

Group assignments and class discussions provide opportunities for assessment.

Adaptations to Other Grade Levels

Grades 9-12: Refer to the lessons, **Off Base** (http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_offbase.pdf) and **It Looks Like Champagne** (http://oceanexplorer.noaa.gov/explorations/07fire/background/edu/media/champagne.pdf). Have students summarize computational models that describe the effects of ocean acidification on marine organisms.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/14fire/welcome.html for more information and resources related to the Submarine Ring of Fire 2014 – Ironman Expedition.

2. Have students visit http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm and prepare a brief report on one of the 15 Marianas Islands listed, including wildlife, ecosystems, and economic importance.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to lessons 1, 4, and 5 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Subduction Zones and Chemosynthesis and Hydrothermal Vent Life.

Other Relevant Lessons from NOAA's Ocean Exploration Program

What's a CTD?
(from the NOAA Ship *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-WCCTD56.pdf

Focus: Measuring physical properties of seawater for ocean exploration

Students explain how a CTD is used aboard the *Okeanos Explorer* to reveal patterns that help ocean explorers answer questions about the natural world; and analyze and interpret data from the *Okeanos Explorer* to make inferences about relationships between density, salinity, temperature, and pressure of seawater.

It Looks Like Champagne
(from the New Zealand American Submarine Ring of Fire 2005 expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_champagne.pdf

Focus: Deep ocean carbon dioxide and global climate change (Chemistry/Earth Science)

Students will be able to interpret phase diagrams, explain the meaning of "critical point" and "triple point", define "supercritical fluid," describe two practical uses of supercritical carbon dioxide, and discuss the concept of carbon dioxide sequestration.

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

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://www.pmel.noaa.gov/co2/files/noaa_oa_factsheet.pdf – NOAA Ocean Acidification Fact Sheet

http://www.pmel.noaa.gov/eoi/nemo/education.html – Underwater volcano education curriculum from NOAA's Pacific Marine Laboratory

http://www.ucar.edu/news/releases/2006/report.shtml – Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers

Next Generation Science Standards

HS-ESS3 Earth and Human Activity (Objective 1)

Performance Expectation HS-ESS3-6.

Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

[Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]

Science and Engineering Practices

Using Mathematics and Computational Thinking

- Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere.

ESS3.D: Global Climate Change

- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

Crosscutting Concepts

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

MS-PS1 Matter and Its Interactions (Objective 2)

Performance Expectation MS-PS1-4.

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. [Clarification Statement: Emphasis is on qualitative molecular-level models of solids, liquids, and gases to show that adding or removing thermal energy increases or decreases kinetic energy of the particles until a change of state occurs. Examples of models could include drawings and diagrams. Examples of particles could include molecules or inert atoms. Examples of pure substances could include water, carbon dioxide, and helium.]

Science and Engineering Practices

Developing and Using Models

- Develop a model to predict and/or describe phenomena.

Disciplinary Core Ideas

PS1.A: Structure and Properties of Matter

- 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.

PS3.A: Definitions of Energy

- The term "heat" as used in everyday language refers both to thermal motion (the motion of atoms or molecules within a substance) and radiation (particularly infrared and light). In science, heat is used only for this second meaning; it refers to energy transferred when two objects or systems are at different temperatures.
- Temperature is not a measure of energy; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

Crosscutting Concepts

Cause and Effect

- Cause and effect relationships may be used to predict phenomena in natural or designed systems.

MS-ESS2 Earth's Systems (Objective 3)

Performance Expectation MS-ESS2-3.

Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions. [Clarification Statement: Examples of data include similarities of rock and fossil types on different continents, the shapes of the continents (including continental shelves), and the locations of ocean structures (such as ridges, fracture zones, and trenches).] [Assessment Boundary: Paleomagnetic anomalies in oceanic and continental crust are not assessed.]

Science and Engineering Practices

Analyzing and Interpreting Data

- Analyze and interpret data to provide evidence for phenomena.

Disciplinary Core Ideas

ESS1.C: The History of Planet Earth

- Tectonic processes continually generate new ocean sea floor at ridges and destroy old sea floor at trenches.

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

- Maps of ancient land and water patterns, based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart.

Crosscutting Concepts

Patterns

- Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.

Ocean Literacy Essential Principles and Fundamental Concepts

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

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 3.
The ocean is a major influence on weather and climate.

Fundamental Concept f. . The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

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 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

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 e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems.

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.

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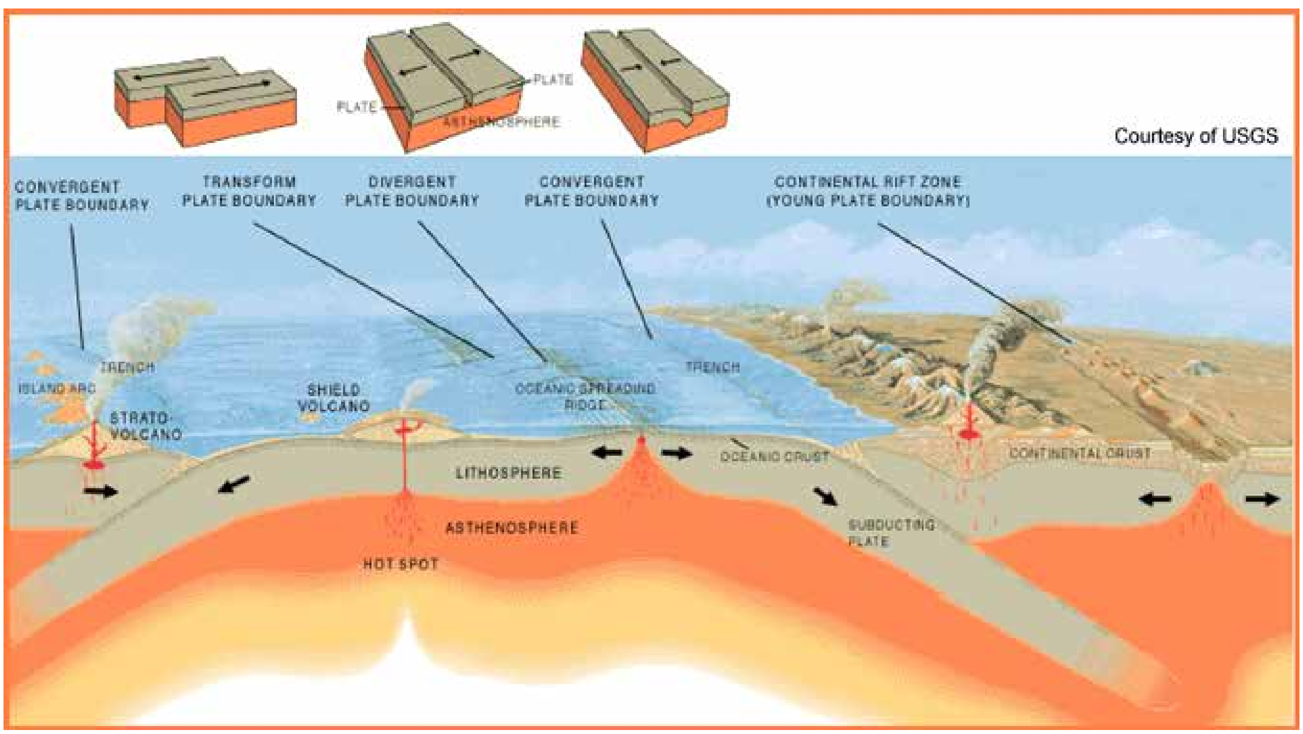
Appendix A
More About Tectonic Plate Boundaries

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



Most submarine volcanoes occur where tectonic plates are either moving apart or colliding. This image shows the many types of plate boundaries: convergent, transform, divergent, and continental rift zone. The Explorer Ridge is a divergent plate boundary at an ocean spreading ridge in the eastern Pacific, where new oceanic crust is formed. The Mariana Arc, on the other end of the conveyor belt in the western Pacific, was formed by the melting of the subducting Pacific Plate. (Image courtesy of USGS website. Cross section by Jose F. Vigil from This Dynamic Planet.) http://oceanexplorer.noaa.gov/explorations/02fire/background/plan/media/plate.html 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.

A global view of the Pacific Ring of Fire, showing Mid-Ocean Ridge and Island Arc/Trench Systems. Explorer Ridge and the Marianas Volcanic Arc are shown, as well as the East Pacific Rise. Image courtesy of Submarine Ring of Fire 2002, NOAA/OER.

http://oceanexplorer.noaa.gov/explorations/02fire/background/plan/media/globe.html

It's a Gas!
Student Worksheet

Substances may exist as solids, liquids, or gases. These are called "phases" or "states," and the phase or state of a specific substance is affected by temperature and pressure. Consider how the addition or removal of thermal energy affects the state of a substance, and develop a drawing or diagram that describes and predicts this relationship.

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?

   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?

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 Seamount. 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?

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2. Scientists exploring the East Diamante Seamount 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?

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3. During their first dive at Eifuku Seamount, 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?

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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?

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Answer Sheet

1a – bubbles
1b – lower
1c – solubility increases
1d – less bubbles from cold soda
1e – solubility decreases

2a – heat the solution
2b – something will precipitate out of the solution
2c – solubility increases

3a – liquid
3b – the phase changes to a gas
3c – the phase changes to a solid
3d – the phase will change to either a liquid or a gas
3e – the water will change to a gas (evaporate)
3f – reduced pressure tends to move the phase state toward a liquid or a gas
3g – increased pressure tends to move the phase state toward a liquid or a solid

See Learning Procedure 4c for explanations to part B of the worksheet.