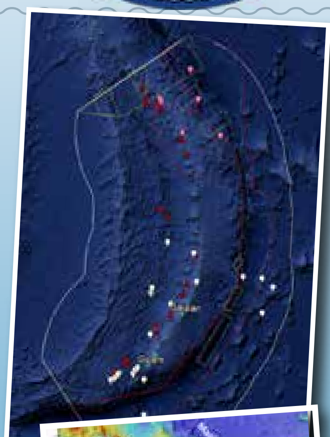
2016 Deepwater Exploration of the Marianas

Viscous Volcanoes



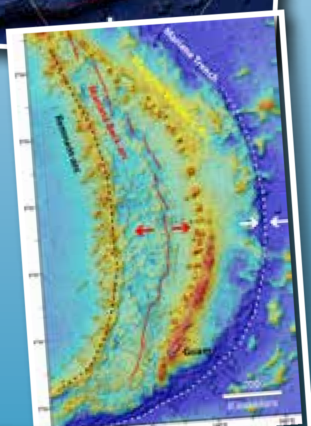


Image captions/credits on Page 2.

lesson plan

Focus

Serpentine mud volcanoes

Grade Level

6-8 (Earth Science)

Focus Question

What are serpentine mud volcanoes and how are they different from magma volcanoes?

Learning Objectives

- Students will describe mud volcanoes, contrast them with magma volcanoes, and explain how these structures, the Mariana Islands, and the Mariana Trench are related to the motion of tectonic plates.

Materials

For each serpentine mud volcano model:

- ❑ Plastic tubing, approximately 1/4” outer diameter, 1/8” inside diameter
- ❑ 2-liter plastic soda bottle
- ❑ Fast-setting epoxy glue
- ❑ Air-cure modeling clay, approximately 500 ml
- ❑ Fine sand, table salt, or finely ground coffee
- ❑ Drill and drill bit to match outside diameter of plastic tubing

For each sediment-derived mud volcano model:

- ❑ 2-liter plastic soda bottle
- ❑ Cardboard or acrylic disk, diameter slightly smaller than soda bottle diameter
- ❑ Fine sand or clay
- ❑ Drill and drill bits, 3/8” and 1/2”

For each magma volcano model:

- ❑ Modeling materials, depending upon techniques chosen (see Learning Procedure, Step 1d and Step 4.

Audio-Visual Materials

- ❑ (Optional) Interactive whiteboard

Teaching Time

Two or three 45-minute class periods

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

Key Words

Mariana Arc
Serpentine
Mud volcano
Mariana Trench
Magma volcano
Tectonic plate

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 Marina Trench is an oceanic trench in the western Pacific Ocean that is formed by the collision of two large pieces of the Earth's crust known as tectonic plates. These 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, flexible mantle layer called the asthenosphere, which is several hundred kilometers thick.

The Pacific Ocean Basin lies on top of the Pacific Plate. To the east, new crust is formed by magma rising from deep within the Earth. The magma erupts along boundaries between the Pacific Plate and the North American and South American Plates. The Pacific Plate slowly moves westward, away from the North American and South American Plates. Because the plates are moving apart, their junction is called a divergent plate boundary.

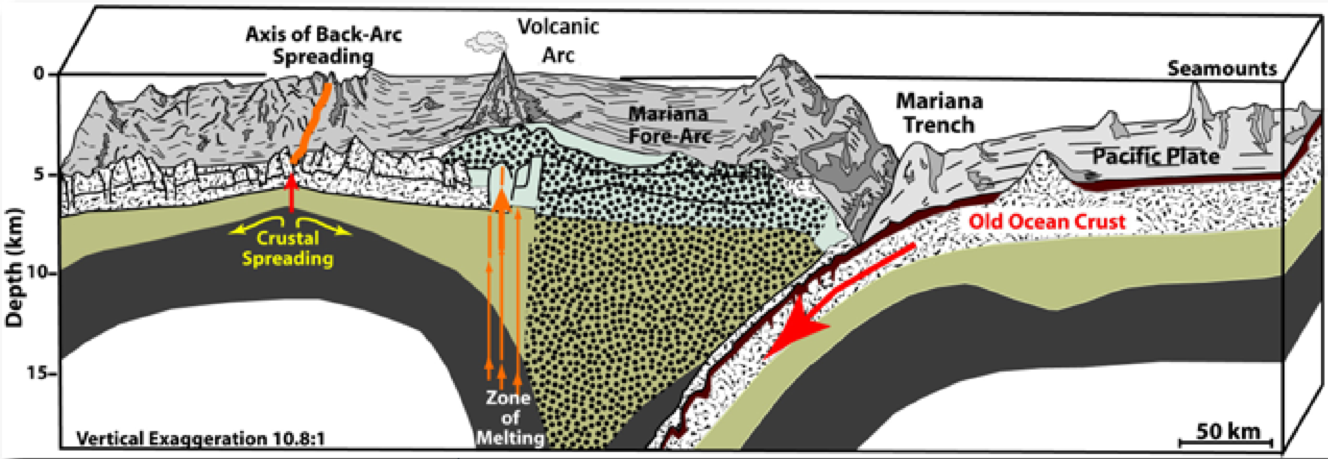
At the Mariana Trench, the west-moving Pacific Plate converges against the Phillipine Plate (this type of plate junction is called a convergent plate boundary). The Pacific Plate is forced beneath the Phillipine Plate, and as the sinking plate moves deeper into the mantle, fluids are released from the 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. The Mariana Islands are the result of

Images from Page 1 top to bottom:
This Google Earth map shows the operating area of the 2016 Deepwater Exploration of the Marianas Expedition. Image courtesy of the NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/plan/media/map.html

Map showing the locations of the Mariana Trench (white dashed line), Volcanic Arc (yellow dashed line), and back-arc spreading center (red line) and remnant arc (black dashed line). Image courtesy of Bill Chadwick.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/geology/media/fig2.html

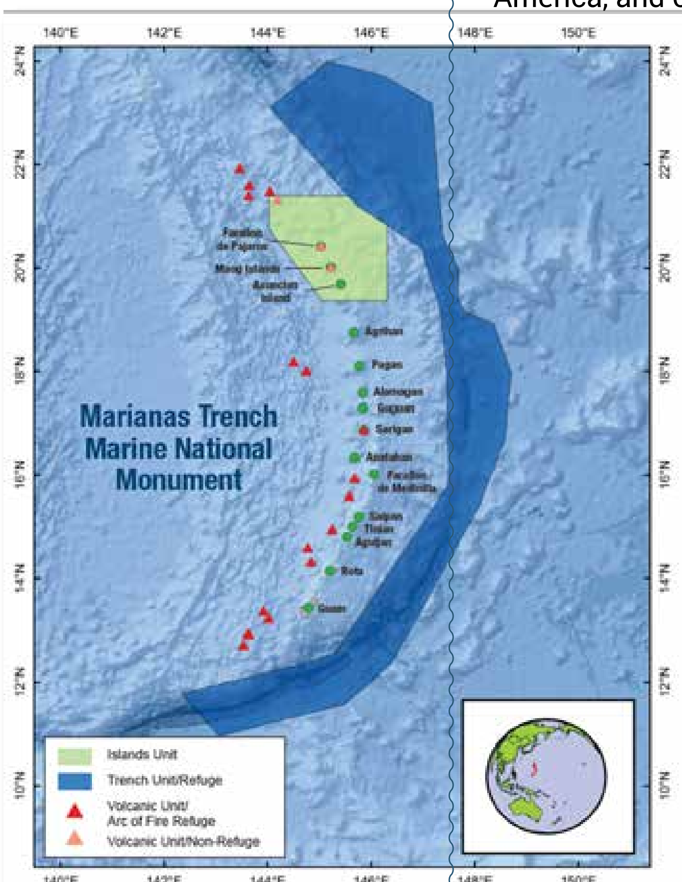
ROV *Deep Discoverer* (D2) will be used to conduct daily dives from 250 to 6,000 meters. Image courtesy of the NOAA Office of Ocean Exploration and Research.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/plan/media/d2.html

NOAA Ship *Okeanos Explorer* uses telepresence technology to transmit data in real time to a shore-based hub where the video is then transmitted to a number of Exploration Command Centers located around the country as well as to any Internet-enabled device. Access to the video combined with a suite of Internet-based collaboration tools allow scientists on shore to join the operation in real-time, and allows the general public to follow the expedition online. Image courtesy of the NOAA Office of Ocean Exploration and Research.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/plan/media/telepresence.html



Cross-section of the Mariana subduction zone, showing the relationship between the Trench, Forearc, Volcanic Arc, and Back-Arc. Image adapted from Hussong and Fryer, 1981.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/geology/media/fig1-hires.jpg

this volcanic activity. The subduction processes that produce volcanoes can also cause major earthquakes. 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 off the western coasts of North and South America, and older crust is recycled to the lower mantle at the convergent plate boundaries of the western Pacific. The Mariana Trench includes the Challenger Deep, the deepest known area of Earth's ocean (10,916 meters; 35,814 feet deep).

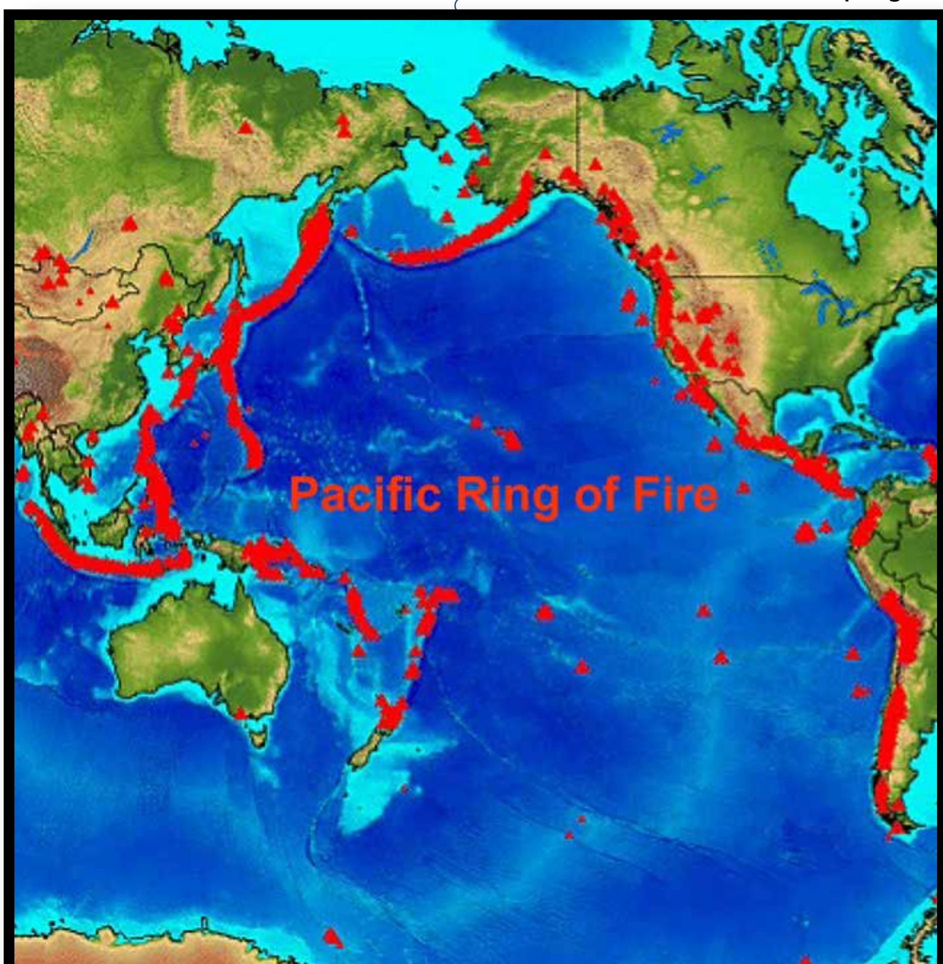


Management designations within the Marianas Trench Marine National Monument. The green points denote islands. Image courtesy of the Marianas Trench Marine National Monument.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/mtmnm/media/map.html

In 2009, the Marianas Trench Marine National Monument was established to protect biological and geological resources associated with volcanoes, islands, and deepwater habitats in the vicinity of the Mariana Trench. These resources include subduction systems in the trench; submerged volcanoes; hydrothermal vents; coral reef, chemosynthetic, and hydrothermal ecosystems; and deep-sea coral and sponge communities.

NOAA's Ocean Explorer program has a long history of explorations in the vicinity of the Mariana Trench. In 2003, the Ocean Exploration Ring of Fire Expedition surveyed more than 50 volcanoes along the Mariana Arc, and discovered that ten of these had active hydrothermal systems (visit *http://oceanexplorer.noaa.gov/explorations/03fire/welcome.html* for more information on these discoveries). The 2004 Submarine Ring of Fire Expedition 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 (visit *http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html* for more information). The 2006 Submarine Ring of Fire Expedition focused on interdisciplinary investigations of the hydrothermal and volcanic processes on the submarine volcanoes of the Mariana Arc. In 2007, 2012, and 2014, Ocean Explorer expeditions visited other areas of the Submarine Ring of Fire. In 2015, NOAA and other partners began a multi-year science effort named CAPSTONE (Campaign to Address Pacific monument Science, Technology, and Ocean Needs) focused on deepwater areas of U.S. marine protected areas in the central and western Pacific Ocean.

The 2016 Deepwater Exploration of the Marianas Expedition continues the CAPSTONE program, focusing specifically on deepwater habitats in and around the Marianas Trench Marine National Monument (MTMNM) and the Commonwealth of the Northern Mariana Islands (CNMI). The purpose of the expedition is to provide information about these unexplored and poorly known habitats. This information is essential to understanding and managing deepwater resources associated with Earth's deepest oceanic trench.



Map of the all the volcanoes around the Pacific (red triangles) making up the Ring of Fire. Image courtesy of Submarine Ring of Fire 2014 - Ironman, NOAA/PMEL, NSF.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/history/media/fig1.html

The Marianas Trench Marine National Monument is part of a larger region known as the Submarine Ring of Fire, named for the numerous volcanoes that result from the movements of tectonic plates in the region. While the best-known volcanoes are those that involve eruptions of molten rock (magma volcanoes), the MTMNM also includes mud volcanoes. Mud volcanoes are found around the world, and are commonly produced when a viscous mixture of water and sediment (that we commonly call "mud") beneath the land or seafloor surface becomes pressurized and erupts to the surface to form a pool that often is surrounded by a cone similar to the cone we associate with magma volcanoes.

Mud volcanoes in the Mariana region, however, are formed by a different process. The mud volcanoes here form only in the zone between the trench and the active volcanic arc. This area is called the "forearc" region. Here, movement of tectonic plates brings mantle rocks into contact with seawater. When this happens, numerous chemical reactions occur between fluids driven off of the subducting Pacific Ocean plate and minerals in the mantle rock (a process called serpentinization, producing a new type of rock called serpentinite). Serpentine is less dense than the surrounding mantle rock, and it is very soft so is easily crushed. There are many faults in the forearc area and fluids from the subducting plate tend to find their way to sea floor springs along the fault planes. When earthquakes occur, the rocks on either side of a moving fault plane grind up the soft serpentinized rock, thus rising fluids mix with the ground-up rock to form serpentinite mud. When the serpentinite muds ooze out of the fault up to the seafloor they can build large mounds that may be up to 50 km in diameter and 2.6 km high. Mud volcanoes produce new habitats for living organisms, but have not been well-explored, so we know very little about mud volcano ecosystems.

In this lesson, students will investigate mud volcanoes and their relationship to the motion of tectonic plates.

Learning Procedure

1. To prepare for this lesson:
   a. Review background information about the 2016 Deepwater Exploration of the Marianas expedition. [*http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/welcome.html*]

   b. Review "The Geology of the Mariana Convergent Plate Region" by Bill Chadwick and Patty Fryer [*http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/geology/welcome.html*].

   c. Review the Multimedia Discovery Mission, Plate Tectonics (Lesson 1) [*http://oceanexplorer.noaa.gov/edu/learning/welcome.html#lesson1*]. Decide whether your students will be able to understand this presentation on their own, or whether you want to use the slides with your own narration and explanations.

d. Review information about basic geology of the Mariana Islands (*http://volcano.oregonstate.edu/vwdocs/volc_images/southeast_asia/mariana/basic_geology.html*), strato volcanoes (*http://volcano.oregonstate.edu/stratovolcanoes*) and ideas for volcano models (*http://volcano.oregonstate.edu/book/export/html/208*).

e. You may also want to review "Mud Volcanoes of the Marianas" (see Resources section on page 11).

2. Briefly introduce:
- The NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge;
- The Marianas Trench region and the Submarine Ring of Fire;
- Marine national monuments, and the variety of biological, geological, and cultural resources found in the MTMNM; and
- The 2016 Deepwater Exploration of the Marianas Expedition.

3. If necessary, review the concept of tectonic plate movements. You may want to show video from the Multimedia Discovery Mission about Plate Tectonics (Lesson 1), or your own presentation about this topic. Make sure students understand the distinction between convergent and divergent plate junctions, and why there are so many active volcanoes along the Submarine Ring of Fire.

4. Describe the features of typical strato volcanoes, sediment-based mud volcanoes, and serpentine mud volcanoes. Emphasize that submarine eruptions of various kinds often produce new habitats for living organisms, and these habitats and organisms make ecosystems that are very different than those found elsewhere on Earth. Hydrothermal vent systems are a familiar example, but hydrothermal systems associated with volcanic activity host living communities that are different from those found at hydrothermal systems associated with serpentinization (for more information, see the lesson, Animals of the Lost City, *http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_animals.pdf*).

Please note that while serpentinization is a key geologic process at both the Lost City and Mariana mud volcano sites, there are important differences that make direct comparison of these sites inappropriate. In particular, (a) the Mariana mud volcano processes involve fluids from the subducting plate (which are NOT seawater); (b) Lost city serpentinization is happening on the seafloor, not in the underlying mantle as is the situation at the Mariana mud volcanoes; and (c) while both sites have chemoautotrophic communities, the organisms are different between these sites.

Assign each student group to prepare a model of a typical magma volcano of the Mariana Islands, a model of a serpentine mud volcano or a model of a sediment-derived mud volcano.

Students who are assigned to make magma volcano models should visit *http://volcano.oregonstate.edu/vwdocs/volc_images/southeast_asia/mariana/basic_geology.html*, and model one of the volcanic islands described (Agrigan, Alamagan, Anatahan, Asuncion, Farallon de Pajaros, Guguan, Maug, Pagan, or Sarigan). Once they have selected a volcano, students should select one of the modeling techniques described at *http://volcano.oregonstate.edu/book/export/html/208*. The play dough, paper and cardboard, topographic cardboard, and simple clay techniques are most appropriate for this assignment. Depending upon available time and your tolerance for chaos, you may decide to allow students to include eruptions in their models. Each student group should prepare a brief written report describing the volcanic processes that formed the Mariana Arc.

Students who are assigned to make serpentine mud volcano models should visit *http://volcano.oregonstate.edu/book/export/html/208*, and review ideas for air pressure volcano models. A simpler version than the ones described on this Web page can be made inside a 2-liter soda bottle as illustrated in Figure 1. Students may use fine sand, ground coffee, or table salt to simulate serpentine muds. The size of the volcano cone will depend on the amount of “mud” in the “fault.” Students may experiment with different size faults to increase the amount of “mud” available, or try the T-connector and funnel system shown in the diagram “Model for Tephra eruptions” on the Web page. Students may also try adding water to the container, but this will significantly increase the potential for messiness, and eliminate salt and coffee (or any other soluble material) for simulating serpentine mud. Each student group should

**Figure 1:
Making an Air Pressure
Mud Volcano**

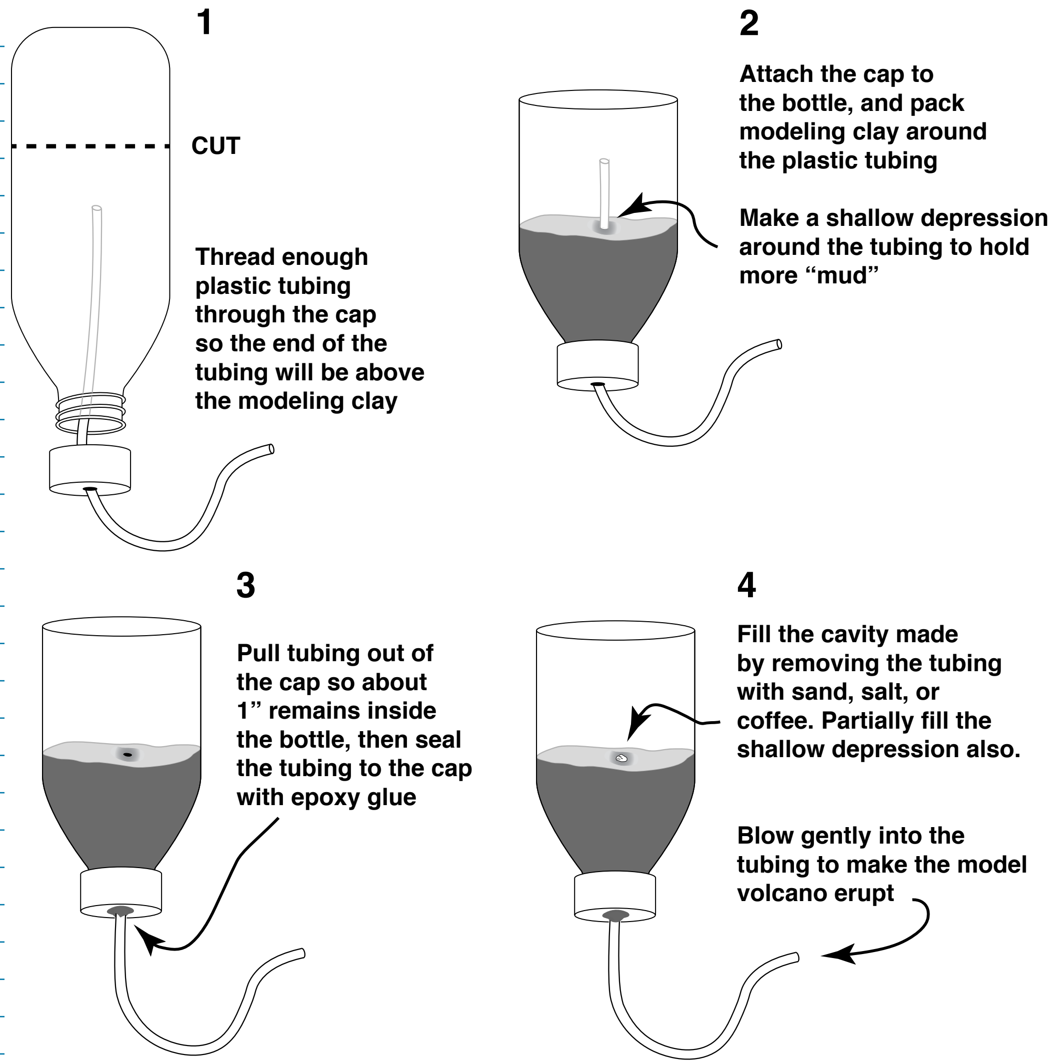
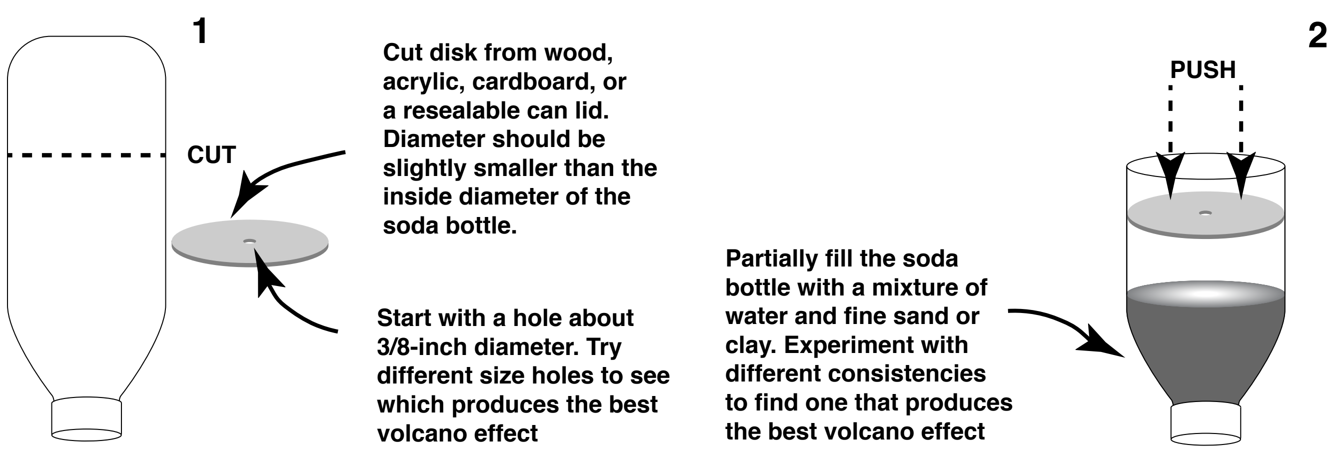


**Figure 2:
Making a Sediment-derived
Mud Volcano**



prepare a brief written report describing the processes that form serpentine mud volcanoes.

Students who are assigned to make sediment-derived mud volcano models may also use a 2-liter soda bottle as illustrated in Figure 2. The diameter of the disk should be close to the diameter of the soda bottle to minimize leakage around the side of the disk. Students may experiment with different-sized holes in the disk and different "mud" mixtures to find a combination size that gives the best results. Each student group should prepare a brief written report describing the processes that form sediment-derived mud volcanoes.

5. After each student group has presented their models, lead a discussion on magma volcanoes and serpentine mud volcanoes around the Mariana Arc. Students should understand that both types of volcanoes are the result of subduction of the Pacific Plate, which produces magma as well as fluids distilled from the descending plate. Erupting magma produces magma volcanoes. Faulting in the vicinity of the convergent plate junction can bring mantle rock into contact with fluids driven off of the subducting Pacific Ocean plate. When this happens, chemical reactions take place that change the mantle rock to serpentine. Serpentine tends to rise along fault lines, and fluids distilled from the descending plate can carry ground up pieces of serpentine out of the fault to form mud volcanoes.

   Sediment-derived mud volcanoes are not typical of the Mariana Arc, but are found in many other places around the world. They are included in this lesson to emphasize that there are two distinctly different types of mud volcanoes, produced by very different processes. Sediment-derived mud volcanoes are formed when subterranean water is heated by geological processes, rises through faults, and mixes with sediments to produce mud. The mud is often pressurized by gases, and erupts at Earth's surface to form "volcanoes." When students press on the disk to produce a model eruption, they are simulating this pressurization.

   Students should realize that the processes that formed these islands and volcanoes are ongoing, and that new (and existing) volcanoes may erupt at any time. Be sure students also realize that the visible volcanoes that form the Mariana Islands are only a small fraction of the volcanoes that have been produced by subduction along the island arc. Because of the extreme depths of the Mariana Trench, there are almost certainly many volcanoes that have not been discovered, and most have not been studied in any detail.

The BRIDGE Connection

www.vims.edu/bridge/ – Enter “Mariana” in the search bar to access resources about the Mariana Arc and other volcanic regions.

The “Me” Connection

Have students write a brief essay discussing why exploration of remote ocean regions such as the Mariana Trench might be of personal significance.

Connections to Other Subjects

English/Language Arts, Social Studies

Assessment

Participation in class discussions and group models provide opportunities for assessment.

Extensions

Visit *http://oceanexplorer.noaa.gov/okeanos/explorations/explorations.html* for links to individual voyages of discovery by NOAA Ship *Okeanos Explorer*.

Other Relevant Lessons from NOAA’s Ocean Exploration Program

The Volcano Factory (Grades 5-6)
from the 2006 Submarine Ring of Fire Expedition
[*http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VolFactory.pdf*]

Focus: Volcanism on the Mariana Arc (Earth Science)

Students explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench; and explain why the Mariana Arc is one of the most volcanically active regions on Earth.

It’s Going to Blow Up! (Grades 7-8)
from the 2006 Submarine Ring of Fire 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.

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/okeanos/edu/welcome.html – Web page for the NOAA Ship *Okeanos Explorer* Education Materials Collection

http://oceanexplorer.noaa.gov/edu/learning/welcome.html – Multimedia Discovery Missions, a series of 14 interactive multimedia presentations and learning activities that address topics ranging from Chemosynthesis and Hydrothermal Vent Life and Deep-sea Benthos to Food, Water and Medicine from the Sea

Fryer, P. 1992. Mud Volcanoes of the Marianas. *Scientific American* 266(2):46-52

http://schmidtocean.org/cruise/hydrothermal-hunt-at-mariana/ – "Hydrothermal Hunt at Mariana;" web page from Schmidt Ocean Institute

http://hvo.wr.usgs.gov/volcanowatch/archive/2005/05_10_13.html – "The Dirty Truth About Mud Volcanoes;" web page from U.S. Geological Survey Hawaii Volcano Observatory

http://egsc.usgs.gov/isb//pubs/teachers-packets/volcanoes/ – links to an interdisciplinary set of materials for grades 4-8 with activities that incorporate earth science, other sciences, social studies, language arts, and mathematics; contents include: a two-sided color poster, teaching guide (with glossary and bibliography), six lesson plans with timed activities (activity sheets in PDF format), and an evaluation sheet

Next Generation Science Standards

MS-ESS2 Earth's Systems

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

Connections to Nature of Science

Scientific Knowledge is Open to Revision in Light of New Evidence

- Science findings are frequently revised and/or reinterpreted based on new evidence.

Disciplinary Core Ideas

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 systems.

Common Core State Standards Connections:

ELA/Literacy –

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

RST.6-8.9 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Mathematics –

MP.2 Reason abstractly and quantitatively.

6.EE.B.6 Use variables to represent numbers and write expressions when solving a real-world or mathematical problem; understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.

7.EE.B.4 Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Ocean Literacy Essential Principles and Fundamental Concepts

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

Fundamental Concept h. Although the ocean is large, it is finite, and resources are limited.

Essential Principle 2.
The ocean and life in the ocean shape the features of Earth.

Fundamental Concept e. Tectonic activity, sea level changes, and the force of waves influence the physical structure and landforms of the coast.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept b. The ocean provides food, medicines, and mineral and energy resources. It supports jobs and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept d. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (point source, nonpoint source, and noise pollution), changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

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 b. Understanding the ocean is more than a matter of curiosity. Exploration, experimentation, and discovery are required to better understand ocean systems and processes. Our very survival hinges upon it.

Fundamental Concept c. Over the last 50 years, use of ocean resources has increased significantly; the future sustainability of ocean resources depends on our understanding of those resources and their potential.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, physicists, animators, and illustrators. And these interactions foster new ideas and new perspectives for inquiries.

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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Credit