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2006 Submarine Ring of Fire

The Volcano Factory

(adapted from the 2004 Submarine Ring of Fire Expedition)

Focus
Volcanism on the Mariana Arc

Grade Level
5-6 (Earth Science)

Focus Question
What processes are responsible for the formation of the Mariana Arc?

Learning Objectives
Students will be able to explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench.

Students will be able to explain why the Mariana Arc is one of the most volcanically active regions on Earth.

Materials
- ❒ Foamcore or heavy cardboard; one piece approximately 20 cm x 50 cm for each student group modeling the Mariana Arc
- ❒ Modeling clay
- ❒ Additional modeling materials, depending upon techniques chosen (see Learning Procedure, Step 2.

Audio/Visual Materials
- ❒ (Optional) Overhead projector and transparencies

Teaching Time
One or two 45-minute class periods, plus time to complete models and written reports

Seating Arrangement
Groups of two to four students

Maximum Number of Students
30

Key Words
Basalt
Ring of Fire
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate
Pyroclastic
Lava flow
Mariana Arc

Background Information
The Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin and results from the motion of 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 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) that cause the tectonic plates to move several centimeters per year relative to each other.

If tectonic plates are moving apart their junction is called a divergent plate boundary; if they slide horizontally past each other they form a transform plate boundary; and if they collide more or less head-on they form a convergent plate boundary. 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 and erupting at divergent plate boundaries between the Pacific Plate and the North American and South American Plates. These eruptions form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries.

To the west, the Pacific Plate converges against the Philippine Plate. The Pacific Plate is forced beneath the Philippine Plate, creating the Marianas Trench (which includes the Challenger Deep, the deepest known area of the Earth's ocean). 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 this volcanic activity, which frequently causes earthquakes as well. The movement of the Pacific Ocean tectonic plate has been likened to a huge conveyor belt on which new crust is formed at the oceanic spreading ridges 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.

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 focussed specifically on hydrothermal systems of the Mariana Arc volcanoes, and found that these systems are very different from those found along mid-ocean ridges (visit http://oceanexplorer.noaa.gov/explorations/04fire/welcome.html for more information). The 2006 Submarine Ring of Fire Expedition is focussed on interdisciplinary investigations of the hydrothermal and volcanic processes on the submarine volcanoes of the Mariana Arc.

In this lesson, students will investigate the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench, and model one or more volcanoes in this system.

Learning Procedure

1. To prepare for this lesson, review:
   - Introductory essays for the 2006 Submarine Ring of Fire Expedition at http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html; and
   - References listed in Step 3, below.

2. Review the concepts of plate tectonics and continental drift. 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" (see Resources section). Briefly discuss the discovery of new life forms and ecosystems at hydrothermal vent systems that result from tectonic processes (you may want to use resources from NOAA's hydrothermal vent Web site (http://www.pmel.noaa.gov/vents/home.html) to supplement this discussion). Introduce the Ring of Fire,

and describe the processes that produce the Mariana Arc. Tell students that the mission of the 2006 Ring of Fire Expedition is to explore the hydrothermal systems of the Mariana Arc.

3. Have students review information about volcanoes of the Mariana Arc at http://volcano.und.nodak.edu/vwdocs/volc_images/southeast_asia/mariana/basic_geology.html. Assign each student group to prepare a three-dimensional relief map of the Marianas Arc, or a model of a typical volcano of the Marianas Islands.

   Students making relief maps should obtain a combined elevation and bathymetry image of the Marianas Arc from NOAA's National Geophysical Data Center Web page (http://www.ngdc.noaa.gov/mgg/image/2minrelief.html). Clicking on the image at http://www.ngdc.noaa.gov/mgg/image/2minsurface/45N135E.html will produce a high resolution surface relief image of the Mariana Arc. This image should be printed and enlarged to approximately 20 x 50 cm. One way to do this is to copy the image onto an overhead transparency, project the image onto a wall at the desired size, then trace the projected image onto a piece of cardboard or foamcore. The island arcs can be constructed with modeling clay. Students should identify the following locations on their models: Uracas (Farallon de Pajaros), Maug, Ascuncion, Agrihan, Pagan, Alamagan, Guguan, Sarigan, Anatahan, Medinilla, Saipan, Tinian, Aguihan, Rota, Guam, West Mariana Ridge, Backarc Basin, Forearc, Mariana Trench. The 2003 Ring of Fire Mission Plan on the Ocean Explorer Web site and information at http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm will help students locate these areas.

   Explain to students that they will have to exaggerate the vertical scale of their models to adequately show the topography. If the Mariana Arc is about 1200 km long, fitting this area onto a surface that is 50 cm long means that each cm on the model will be equal to 24 km. At this scale, the maximum depth of the Marianas Trench (a little less than 11 km) would only be less than 5 mm. A vertical scale of 1 cm = 1,000 m will allow students to model the vertical relief reasonably well.

   Modelling at this scale will produce an Arc system that will show the relief referenced to sea level (so Mt. Everest, for example, would fit in the Mariana Trench). The Mariana Arc volcanoes students produce at this scale, however, will be quite small; all will be less than one centimeter in height. If you want students to model only the volcanoes, a larger scale, such as 1 cm = 100 m, would be better.

   Students who are assigned to make volcano models should visit http://volcano.und.nodak.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.und.nodak.edu/vwdocs/volc_models/models.html. The Play Dough, Paper and Cardboard, Three-dimensional 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. Be sure students explain the terms stratovolcano, pyroclastic, and lava flow. You may want to direct them to http://volcano.und.nodak.edu/vwdocs/vwlessons/volcano_types/strato.htm and http://volcano.und.nodak.edu/vwdocs/Submarine/plates/converg/ for additional background information.

4. After each student group has presented their models, lead a discussion about the Mariana Arc. 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. Point out that soon after the 2003 Ring of Fire Expedition, there was a major eruption of the Anatahan volcano. Be sure students also realize that the visible volcanoes that form the Marianas 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. Have students use their models to discuss discoveries made by the 2004 Ring of Fire Expedition (http://oceanexplorer.noaa.gov).

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" then "Marine Geology." Enter http://www.vims.edu/bridge/archive0799.html for directions for preparing a three-dimensional plot of any part of the Earth's surface.

The "Me" Connection

Have students imagine that they live on one of the Mariana 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, Geography, Mathematics, Life Science

Assessment

Models and written reports provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html for daily logs and updates about discoveries being made by the 2006 Submarine Ring of Fire 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 Mariana Islands listed, including wildlife, ecosystems, and economic importance.

Resources

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 1, 2, 4, and 5 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, and Chemosynthesis and Hydrothermal Vent Life.

Other Relevant Lesson Plans from the Ocean Exploration Program

The Biggest Plates on Earth http://www.oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_big_plates_5_6.pdf (7 pages, 192k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Plate tectonics – movement of plates, results of plate movement, and magnetic anomalies at spreading centers.

Students will be able to describe the motion of tectonic plates and differentiate between three typical boundary types that occur between tectonic plates, infer what type of boundary exists between two tectonic plates, understand how magnetic anomalies provide a record of geologic history around spreading centers, infer the direction of motion between two tectonic plates given information on magnetic anomalies surrounding the spreading ridge between the plates, and describe plate boundaries and tectonic activity in the vicinity of the Juan de Fuca plate.

Unexplored! http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf (7 pages, 724k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Scientific exploration of deep-sea volcanoes (Life Science/Physical Science/Earth Science)

Students will be able to compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Island, Reefs, and a Hotspot http://www.oceanexplorer.noaa.gov/explorations/02hawaii/background/education/media/nwhi_hot.pdf (8 pages, 484kb) (from the 2002 Northwestern Hawaiian Islands Expedition)

Focus: Formation of the Hawaiian archipelago (Earth Science)

Students will be able to describe eight stages in the formation of islands in the Hawaiian archipelago and will be able to describe the movement of tectonic plates in the Hawaiian archipelago region. Students will also be able to describe how a combination of hotspot activity and tectonic plate movement could produce the arrangement of seamounts observed in the Hawaiian archipelago.

AdVENTurous Findings on the Deep Sea Floor http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l2.pdf (5 pages, 536k) (from the 2002 Galapagos Rift Expedition)

Focus: Vent development along the Galapagos Rift

Students will conduct investigations to observe the formation of precipitates; students will create a model of a developing hydrothermal vent; students will generate comparisons between the created hydrothermal vent model and the actual hydrothermal vents developing along the Galapagos Rift.

Other Links and Resources

http://www.oceanexplorer.noaa.gov/explorations/04fire/background/marianaarc/marianaarc.html – Virtual fly-throughs and panoramas of eight sites in the Mariana Arc

http://www.oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Magic Mountain Virtual Web site, featuring animations and videos of the Magic Mountain hydrothermal field

http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html and http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – Animations of the 3-dimensional structure of a mid-ocean ridge and subduction zone

http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 – On-line version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience

http://pubs.usgs.gov/pdf/planet.html – "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

http://www.pmel.noaa.gov/vents/nemo/education.html – Web site for the New Millennium Observatory Project, a long-term study of the interactions between geology, chemistry, and biology on Axial Seamount, an active volcano on

the Juan de Fuca Ridge that is part of the mid-ocean ridge system

http://vulcan.wr.usgs.gov/ – USGS Cascades Volcano Observatory, with extensive educational and technical resources

http://volcano.und.edu/ – Volcano World Web site at the University of North Dakota

http://nationalzoo.si.edu/publications/zoogoer/1996/3/lifewithout-light.cfm – "Life without Light: Discoveries from the Abyss," by Robin Meadows; Smithsonian National Zoological Park, Zoogoer Magazine, May/June 1996

http://www.ngdc.noaa.gov/mgg/image/2minrelief.html – Index page for NOAA's National Geophysical Data Center combined global elevation and bathymetry images (http://www.ngdc.noaa.gov/mgg/image/2minsurface/45N135E.html includes the Mariana Arc)

http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm – Web site with background information on 15 of the Mariana Islands.

http://volcano.und.nodak.edu/vwdocs/volc_models/models.html – U of N. Dakota volcano Web site, directions for making various volcano models

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

http://www.extremescience.com/DeepestOcean.htm – Extreme Science Web page on the Challenger Deep

http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html – Web page for the 2005 Galapagos Spreading Center Expedition

http://www.divediscover.whoi.edu/ventcd/vent_discovery – Dive and Discover presentation on the 25th anniversary of the discovery of hydrothermal vents

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ps_vents.html – Article, "Creatures of the Thermal Vents" by Dawn Stover

http://www.oceansonline.com/hydrothe.htm – "Black Smokers and Giant Worms," article on hydrothermal vent organisms

Corliss, J. B., J. Dymond, L.I. Gordon, J.M. Edmond, R.P. von Herzen, R.D. Ballard, K. Green, D. Williams, A. Bainbridge, K. Crane, and T. H. Andel, 1979. Submarine thermal springs on the Galapagos Rift. Science 203:1073-1083. – Scientific journal article describing the first submersible visit to a hydrothermal vent community

Shank, T. M. 2004. The evolutionary puzzle of seafloor life. Oceanus 42(2):1-8; available online at http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf.

Tunnicliffe, V., 1992. Hydrothermal-vent communities of the deep sea. American Scientist 80:336-349.

Van Dover, C. L. Hot Topics: Biogeography of deep-sea hydrothermal vent faunas; available online at http://www.divediscover.whoi.edu/hottopics/biogeo.html

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Transfer of energy

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

Content Standard F: Science in Personal and Social Perspectives
- Natural hazards
- Risks and benefits

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
- *Fundamental Concept e.* Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
- *Fundamental Concept f.* Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

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 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.

For More Information

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