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New Zealand American Submarine Ring of Fire 2007

Unexplored!

(adapted from the 2005 Submarine Ring of Fire Expedition)

Focus

Scientific exploration of deep-sea volcanoes

Grade Level

7-8 (Life Science/Physical Science/Earth Science)

Focus Question

How do scientists prepare to explore areas of the ocean that are virtually unknown?

Learning Objectives

Students will be able to compare and contrast submarine volcanoes at convergent and divergent plate boundaries.

Students will be able to infer the kinds of living organisms that may be found around hydrothermal vents.

Students will be able to describe three ways in which scientists may prepare to explore areas that are practically unknown.

Students will be able to explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Materials

- ❒ Copies of "Unexplored! Worksheet," one copy for each student or student group
- ❒ If students do not have internet access: copies of "Biological Studies 2004" (http://oceanexplorer.noaa.gov/explorations/04fire/background/biology/biology.html) and "Submarine Volcanism 2004" (http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/volcanism.html), one copy for each student or student group

Audio/Visual Materials

- ❒ Chalkboard, marker board, or overhead projector with transparencies

Teaching Time

Two or three 45-minute class periods, depending upon class time allocated for student research

Seating Arrangement

Classroom style if students are working individually, or groups of two to four students

Maximum Number of Students

30

Key Words

Ring of Fire
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate
Chemosynthetic
Volcanic arc
Hydrothermal vent
Black smoker

Background Information

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

Tectonic plates are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. The plates move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). These convection currents cause the tectonic plates to move several centimeters per year relative to each other.

The junction of two tectonic plates is called a "plate boundary." Three major types of plate boundaries are produced by tectonic plate movements. If two tectonic plates collide more or less head-on they form a convergent plate boundary. Usually, one of the converging plates will move beneath the other, which is known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. For a 3-dimensional view of a subduction zone, visit: http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html

The junction of two tectonic plates that are moving apart is called a divergent plate boundary. Magma rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. View the 3-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

The third type of plate boundary occurs where tectonic plates slide horizontally past each other, and is known as a transform plate boundary. As the plates rub against each other, huge stresses are set up that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. A well-known example of a transform plate boundary is the San Andreas Fault in California. See animations of different types of plate boundaries at: http://www.seed.slb.com/en/scictr/watch/living_planet/plate_boundaries/plate_move.htm.

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

On the western side of the Pacific Ocean, the Pacific Plate converges against the Philippine

Plate and Australian Plate. Subduction of the Pacific Plate creates the Mariana Trench (which includes the Challenger Deep, the deepest known area of the Earth's ocean) and the Kermadec Trench. As the sinking plate moves deeper into the mantle, new magma is formed as described above, and erupts along the convergent boundary to form volcanoes. The Mariana and Kermadec Islands are the result of this volcanic activity, which frequently causes earthquakes as well. The movement of the Pacific Ocean tectonic plate has been likened to a huge conveyor belt on which new crust is formed at the oceanic spreading ridges, and older crust is recycled to the lower mantle at the convergent plate boundaries of the western Pacific. For more information on plate tectonics, visit the NOAA Learning Objects Web site (http://www.learningdemo.com/noaa/). Click on the links to Lessons 1, 2 and 4 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones.

Volcanoes at convergent plate boundaries along the Kermadec and Mariana Arcs often erupt as violent explosions, and form chains of isolated cone-shaped islands. In contrast, volcanoes found near the divergent plate boundaries of oceanic spreading ridges generally do not erupt explosively and look like long, low ridges. See the satellite and sonar survey animation of the Mariana Arc Volcanic Chain at:http://oceanexplorer.noaa.gov/explorations/04fire/background/marianaarc/media/sat_em_islands_video.html.

When seawater penetrates the permeable ocean crust in the vicinity of volcanoes, increased heat and pressure cause a variety of gases, metals and other materials to dissolve into the water from the surrounding rock. This process causes many metals to be concentrated by a thousand to a million times their concentration in normal seawater. When the fluid is vented into cold ocean water, some dissolved substances precipitate out of solution, forming metal deposits, "chimneys," and "black smokers." Dissolved gases may react to form other materials. At NW Rota Volcano, for example, dissolved sulfur dioxide forms sulfuric acid and elemental sulfur. At NW Eifuku Volcano, 1,600 meters below the sea surface, the 2004 Ring of Fire Expedition found buoyant droplets of liquid carbon dioxide, probably formed from degassing of a carbon-rich magma.

Hydrothermal fluids also provide an energy source for a variety of chemosynthetic microbes that in turn are the basis for unique food webs associated with hydrothermal vents. Many of these microbes have specific adaptations to extreme conditions; scientists found evidence for microbes living in hot spring fluids on NW Rota with a pH of 2.0 or less. Other new and unique microbes are expected to be found in association with extreme vent fluids as other sites are identified and explored along the Kermadec Arc.

Since they were discovered in 1977, hydrothermal vent communities associated with divergent plate boundaries have been extensively studied. In contrast, much less is known about hydrothermal systems near convergent plate boundaries like those of the Mariana and Kermadec Arcs. Beginning in 2002, Ocean Exploration expeditions have undertaken systematic mapping and study of hydrothermal systems in previously-unexplored areas of the Submarine Ring of Fire. Visit

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

for more information about the many discoveries, as well as still and video imagery, from these expeditions. The New Zealand American Submarine Ring of Fire 2007 Expedition is focused on detailed exploration of hydrothermal systems at Brothers Volcano in the Kermadec Arc,

an area where tectonic plates are converging more rapidly than any other subduction zone in the world.

In this lesson, students will investigate ways in which scientists may prepare to explore submarine volcanoes and hydrothermal systems in areas that are practically unknown.

Learning Procedure

1. To prepare for this lesson, review the introductory essays for the New Zealand American Submarine Ring of Fire 2007 Expedition at http://oceanexplorer.noaa.gov/explorations/07fire/welcome.html, and the background essays by Verena Tunnicliffe ("Biological Studies 2004;" http://oceanexplorer.noaa.gov/explorations/04fire/background/biology/biology.html) and Kim Juniper ("Ecothoughts: Figuring Out Vent Ecosystems on the Fly;" http://oceanexplorer.noaa.gov/explorations/04fire/logs/april08/april08.html).

2. Briefly 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/index.html) to supplement this discussion). Be sure students understand the concept of primary production, and the distinction between chemosynthetic primary production and photosynthetic primary production (see the "Lesson" portion of Lesson 5 at http://www.learningdemo.com/noaa/ for a comparison of photosynthesis and chemosynthesis). Introduce the Ring of Fire, and describe the processes that produce the Mariana Arc.

   Tell students that the 2004 and 2005 Submarine Ring of Fire Expeditions explored hydrothermal systems of the Mariana and Kermadec Arcs, and that the mission of the New Zealand American Submarine Ring of Fire 2007 Expedition is to conduct a detailed exploration of hydrothermal systems at Brothers Volcano in the Kermadec Arc, an area where tectonic plates are converging more rapidly than any other subduction zone in the world. Point out that these expeditions are studying places that have been explored very little or not at all. Lead a brief discussion of students' ideas about how they might prepare for this type of expedition, and record their ideas on a marker board or overhead projector transparency.

3. Provide each student or student group with a copy of "Unexplored! Worksheet" (and copies of "Biological Studies 2004" by Verena Tunnicliffe and "Submarine Volcanism 2004" by Bill Chadwick if students do not have access to the internet). Have students study the background materials and answer the questions on the worksheet.

4. Review students' answers to the worksheet questions. The correct answers are:

   (1) What processes form submarine volcanoes at mid-ocean ridges and along the Pacific Ring of Fire?
   At mid-ocean ridges, tectonic plates are moving apart and magma rises to fill the gap between the spreading plates. Along the Pacific Ring of Fire, tectonic plates are colliding, with one plate forced under the other causing the lower plate to move into the Earth where it is melted and recycled. This process also causes melting above the

collision zone, and the molten rock rises back to the surface creating chains of volcanoes.

(2) How are the volcanoes produced at mid-ocean ridges different from the volcanoes along the Pacific Ring of Fire?
Volcanoes at mid-ocean ridges look like long ridges and are usually nonexplosive, while volcanoes along the Pacific Ring of Fire are cone-shaped and often erupt explosively.

(3) What are hydrothermal vents?
Hydrothermal vents are hot springs on the ocean floor.

(4) What produces "black smokers?"
"Black smokers" are produced by hydrothermal vent fluid which contains high concentrations of dissolved minerals. When the fluid enters the cold water of the deep ocean, some of these minerals precipitate giving the appearance of black smoke.

(5) How do hydrothermal vent fluids influence the kinds of living organisms are found around hydrothermal vents?
Some of the chemicals dissolved in the hydrothermal vent fluid provide an energy source for microorganisms that are not dependent on sunlight.

(6) To plan biological explorations in areas that are practically unknown, biologists build their study plans around what three pieces of information?
- *Prior biological work in similar areas*
- *Known geological and chemical conditions*
- *Experience with similar systems elsewhere in the world*

(7) What kinds of animals might be expected around hydrothermal vents in the Mariana Arc?
Shrimps, crabs, anemones, snails, barnacles, mussels, vestimentiferans (tubeworms)

(8) What are two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc?
Chemosynthetic bacteria and photosynthetic plankton

(9) Filamentous bacterial mats are an example of what type of primary production?
Chemosynthesis

(10) Scientists exploring the slope of a volcano named East Diamante found that the surface of the slope in deep water was covered with dense mats formed by chemosynthetic bacteria, but as the slope rose toward the sea surface encrusting red algae appeared and the bacterial mats gradually disappeared. What does the appearance of encrusting red algae on the slope of volcano signify?
Transition from chemosynthetic primary production to photosynthetic primary production

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" then "Habitats," then "Deep Sea" for links to information and activities about hydrothermal vents.

The "Me" Connection

Identify a geographic area that is completely unfamiliar to your students. Have students write a brief essay describing how they would prepare to learn as much as they could about this area in a specified period of time (one day or less).

Connections to Other Subjects

English/Language Arts, Geography

Assessment

Worksheets and class discussions provide opportunities for assessment.

Extensions

Have students visit http://oceanexplorer.noaa.gov/explorations/07fire/welcome.html to keep up to date with the latest New Zealand American Submarine Ring of Fire 2007 Expedition discoveries, and find out what scientists are learning about hydrothermal systems in the vicinity of Brothers Volcano.

Multimedia Learning Objects

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

The Volcano Factory [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VolFactory.pdf] (7 pages; 273 k)

Focus: Volcanism on the Mariana Arc (Earth Science)

Students will be able to 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.

Living With the Heat [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf] (9 pages; 289 k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Physical Science/Earth Science/Biology)

In this activity, students will be able to describe how hydrothermal vents are formed and characterize the physical conditions at these sites, explain what chemosynthesis is and contrast this process with photosynthesis, identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities, and describe common food pathways between organisms typically found in hydrothermal vent communities.

Other Links and Resources

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

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

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

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

http://www.pbs.org/wgbh/nova/teachers/activities/2609_abyss.html – Nova Teachers Web site, Volcanoes of the Deep Classroom Activity to research and classify symbiotic relationships between individual organisms of different species.

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

http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – 3-dimensional structure of a "mid-ocean ridge," where two of the Earth's tectonic plates are spreading apart

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

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

- Motions and forces
- Transfer of energy

Content Standard C: Life Science

- Populations and ecosystems
- Diversity and adaptations of organisms

Content Standard D: Earth and Space Science

- Structure of the Earth system

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in society

Content Standard G: History and Nature of Science

- Nature of science

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

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

Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept b. Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson. Please send your comments to: oceanexeducation@noaa.gov

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Student Handout

Unexplored! Worksheet

Read the background essays by Verena Tunnicliffe ("Biological Studies 2004;" http://oceanexplorer.noaa.gov/explorations/04fire/background/biology/biology.html) and Bill Chadwick ("Submarine Volcanism 2004;" http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/volcanism.html).

1. What processes form submarine volcanoes at mid-ocean ridges and along the Pacific Ring of Fire?

2. How are the volcanoes produced at mid-ocean ridges different from the volcanoes along the Pacific Ring of Fire?

3. What are hydrothermal vents?

4. What produces "black smokers?"

5. How do hydrothermal vent fluids influence the kinds of living organisms found around hydrothermal vents?

6. To plan biological explorations in areas that are practically unknown, biologists build their study plans around what three pieces of information?

7. What kinds of animals might be expected around hydrothermal vents in the Mariana Arc?

8. What are two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc?

9. Filamentous bacterial mats are an example of what type of primary production?

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10. Scientists exploring the slope of a volcano named East Diamante found that the surface of the slope in deep water was covered with dense mats formed by chemosynthetic bacteria, but as the slope rose toward the sea surface encrusting red algae appeared and the bacterial mats gradually disappeared. What does the appearance of encrusting red algae on the slope of volcano signify?

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