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New Zealand American Submarine Ring of Fire 2007

What's The Difference?

Focus
Volcanic processes at convergent and divergent tectonic plate boundaries

Grade Level
9-12 (Earth Science)

Focus Question
How do volcanic processes differ at convergent and divergent tectonic plate boundaries?

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

Students will be able to identify three geologic features that are associated with most volcanoes on Earth.

Students will be able to explain why some volcanoes erupt explosively while others do not.

Materials
❒ Copies of "Submarine Volcanism Worksheet," one copy for each student or student group

Audio/Visual Materials
❒ (Optional) Computer projection equipment to show downloaded video materials

Teaching Time
One or two 45-minute class periods, plus time 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
Volcano
Caldera
Hot spot
Ring of Fire
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate

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 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 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. 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.

Beginning in 2002, Ocean Exploration expeditions have undertaken systematic mapping and study in previously-unexplored areas of the Submarine Ring of Fire. Visit

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

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 the characteristics of volcanoes at mid-ocean ridges and convergent plate boundaries, and make inferences to account for observed differences between volcanoes at these locations.

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 Submarine Ring of Fire 2004 background essay, "Submarine Volcanism 2004" (http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/volcanism.html). If students do not have internet access, you will also need to download diagrams of the structure of mid-ocean ridges and subduction zones (http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html and http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html), as well as reference materials cited on the "Submarine Volcanism Worksheet." You may also want to visit the Magic Mountain Web pages (http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html) to see the "landscape" around an active hydrothermal site, and/or view first-ever footage of a submarine volcano in the act of erupting live red lava: http://www.oceanexplorer.noaa.gov/explorations/06fire/logs/april29/april29.html.

2. Briefly review the concepts of plate tectonics and continental drift, and introduce the New Zealand American Submarine Ring of Fire 2007 Expedition. Be sure students understand the distinction between mid-ocean ridges and subduction zones. You may want to show students the streaming video lessons available in Lessons #1, 2, and 4 on the following NOAA Learning Object site: http://www.learningdemo.com/noaa/.

3. Provide each student or student group with a copy of the "Submarine Volcanism Worksheet," and have students answer the worksheet questions.

4. Lead a discussion of students' responses to questions on the worksheet. The correct responses are:

   (1) What are three geologic features that account for most volcanoes on Earth?
   Oceanic spreading centers at divergent plate boundaries (e.g, the Atlantic mid-ocean ridge), subduction zones at convergent plate boundaries (e.g., Pacific Ring of Fire), and

"hot spots" which are believed to be relatively small regions in the Earth's mantle that are especially hot (e.g., volcanoes of the Hawaiian Islands and Yellowstone Park); you may want to point out that more than half of the world's volcanoes are located on the Pacific Ring of Fire, but that more than three-fourths of all lava produced on Earth comes from mid-ocean ridges. For an example of hot spot-produced volcanoes, see the 2002 NOAA Ocean Exploration expedition, "Exploring Alaska's Seamounts" at http://www.oceanexplorer.noaa.gov/explorations/02alaska/welcome.html.

(2) How is the shape of volcanoes at mid-ocean ridges different from the shape of volcanoes at subduction zones?
Mid-ocean ridge volcanoes tend to be linear and look like long, low ridges, while volcanoes at subduction zones tend to be cone-shaped and isolated.

(3) What causes a volcano to erupt explosively?
Stiff, viscous magma that traps gases and allows pressure to build up until an explosive eruption occurs.

(4) What are two primary factors that affect the viscosity of magma?
Silica (SiO_2) content and temperature of the magma

(5) What is the difference between sheet lavas and pillow lavas?
Sheet lavas resemble broad blankets and are formed by lava that is very fluid and flows quickly (high effusion rate), while pillow lavas are bulbous mounds formed by slow-flowing lava (low effusion rate).

(6) Do volcanoes at mid-ocean ridges and subduction zones erupt explosively?
Volcanoes at subduction zones often erupt explosively; volcanoes at mid-ocean ridges usually do not.

(7) What is a caldera?
A large depression on the summit of a volcano caused by the downward collapse of the summit when large amounts of magma are suddenly removed from the magma chamber beneath the summit; this removal is often the result of a large explosive eruption.

(8) Are calderas more likely to occur at mid-ocean ridges or subduction zones? Why?
Calderas are more likely to occur at subduction zones, because subduction zone volcanoes are more likely to erupt explosively.

(9) Would you expect to find more primitive lava composition at mid-ocean ridges or subduction zones? Why?
More primitive lava would be expected at mid-ocean ridges, because this lava is produced by magma directly from the Earth's interior, in contrast to the magma at subduction zone volcanoes which includes material from the surface of the subducted plate.

(10) How quickly do biological organisms colonize newly-erupted lava?
Biological colonization occurs rapidly, often within a few months of the lava's eruption.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" then "Marine Geology" for links to resources about plate tectonics and volcanoes.

The "Me" Connection

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

Connections to Other Subjects

English/Language Arts, Chemistry

Assessment

Worksheets and class discussions provide opportunities for assessment.

Extensions

1. 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.

2. Lieu, 1996 (see "Resources") has directions for a simple demonstration of phase changes of carbon dioxide.

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

Where Did They Come From? [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.WhereFrom.pdf] (10 pages; 296 k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Species variation in hydrothermal vent communities (Life Science)

In this activity, students will define and describe biogeographic provinces of hydrothermal vent communities, identify and discuss processes contributing to isolation and species exchange between hydrothermal vent communities, and discuss characteristics which may contribute to the survival of species inhabiting hydrothermal vent communities.

Hydrothermal Vent Challenge [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VentChallenge.pdf] (9 pages; 288 k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Chemistry of hydrothermal vents (Chemistry)

Students will be able to define hydrothermal vents and explain the overall processes that lead to their formation; explain the origin of mineral-rich fluids associated with hydrothermal vents; explain how "black smokers" and "white smokers" are formed; and hypothesize how properties of hydrothermal fluids might be used to locate undiscovered hydrothermal vents.

Roots of the Mariana Arc [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.Roots.pdf] (11 pages; 312 k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Seismology and geological origins of the Mariana Arc (Earth Science)

In this activity, students will be able to explain the processes of plate tectonics and volcanism that resulted in the formation of the Mariana Arc and will be able to describe, compare, and contrast S waves and P waves. Students will also be able to explain how seismic data recorded at different locations can be used to determine the epicenter of an earthquake and will infer a probable explanation for the existence of ultra-low velocity zones.

Mystery of the Megaplume [http://www.oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.Megaplume.pdf] (11 pages; 324 k) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Hydrothermal vent chemistry (Chemistry, Earth Science, Physical Science)

In this activity, students will be able to describe hydrothermal vents and characterize vent plumes in terms of physical and chemical properties, describe tow-yo operations and how data from these operations can provide clues to the location of hydrothermal vents, and interpret temperature anomaly data to recognize a probable plume from a hydrothermal vent.

The Big Balancing Act [http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_balancing.pdf] (9 pages, 383Kb) (from the Submarine Ring of Fire 2006 Expedition)

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry/Earth Science)

In this activity, students will be able to define and describe hydrothermal circulation systems; explain the overall sequence of chemical reactions that occur in hydrothermal circulation systems; and compare and contrast "black smokers" and "white smokers." Given data on chemical enrichment that occurs in hydrothermal circulation systems, students will be able to make inferences about the relative significance of these systems to ocean chemical balance compared to terrestrial runoff.

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

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.

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
- Interactions of energy and matter

Content Standard D: Earth and Space Science

- Energy in the Earth system
- Geochemical cycles
- Origin and evolution of the Earth system

Content Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

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:
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Student Handout

Submarine Volcanism Worksheet

The following Web sites provide extensive information on volcanoes and processes that produce them, including all the information you will need to answer these questions.

- Ocean Explorer Submarine Ring of Fire Expedition essay on volcanism – http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/volcanism.html
- Volcano World Web site – http://volcano.und.nodak.edu/
- New Millennium Observatory (NeMO) Web site – http://pmel.noaa.gov/vents/nemo/explorer/concepts/mor.html

1. What are three geologic features that account for most volcanoes on Earth?

2. How is the shape of volcanoes at mid-ocean ridges different from the shape of volcanoes at subduction zones?

3. What causes a volcano to erupt explosively?

4. What are two primary factors that affect the viscosity of magma?

5. What is the difference between sheet lavas and pillow lavas?

6. Do volcanoes at mid-ocean ridges and subduction zones erupt explosively?

7. What is a caldera?

8. Are calderas more likely to occur at mid-ocean ridges or subduction zones? Why?

9. Would you expect to find more primitive lava composition at mid-ocean ridges or subduction zones? Why?

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