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Aegean and Black Sea 2006 Expedition

What's the Difference?

(adapted from the 2005 New Zealand American Submarine Ring of Fire Expedition)

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 45-minute class period, 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
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate

Background Information
The geographic region surrounding the Aegean and Black Seas has been the stage for many spectacular performances in Earth's geologic and human history. Human activities on the region's stage began during Paleolithic times; artifacts discovered near Istanbul are believed to be at least 100,000 years old. Well-known Aegean cultures include the Minoans (ca 2,600 – 1,450 BC), Mycenaeans (ca 1,600 – 1,100 BC), Ancient Greeks (776 – 323 BC), and Hellenistic Greeks (323 – 146 BC). Istanbul—"the only city that spans two continents"—has been a crossroads of travel and trade for more than 26 centuries. Mariners have traveled the Aegean and Black

Seas since Neolithic ("Stone Age" times; 6,500 – 3,200 BC), probably for a combination of purposes, including trading, exploration, and warfare.

Interactions between these cultures and many others were often violent and destructive. So, too, were interactions with geological processes. Some of these processes are directly related to the same forces that are believed to have caused the breakup of Pangaea (see "Volcanoes, below). One of the most dramatic and destructive events was the eruption of a volcano near a small Aegean island called Thera (also known as Santorini), sometime between 1,650 and 1,450 BC. Estimated to be four times more powerful than the Krakatoa volcano of 1883, the eruption left a crater 18 miles in diameter, spewed volcanic ash throughout the Eastern Mediterranean, and may have resulted in global climactic impacts. Accompanied by earthquakes and a tsunami, the volcano destroyed human settlements, fleets of ships, and may have contributed to the collapse of the Minoan civilization on the island of Crete, 110 km to the south. On Thera, the largest of the islands near the volcano, the ancient city of Akrotiri was completely buried beneath the ash. Excavation of the city began in 1967, and is ongoing. The Bronze Age eruption of the Theran volcano was by no means its last. In fact, the volcano erupted at least 12 times between 197 BC and 1950 and most geologists agree that a violent eruption will happen again.

Many volcanoes, including the one near Thera, are caused by movement of tectonic plates. These plates are portions of Earth's outer crust (lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. Tectonic 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.

The junction of two tectonic plates is known as a plate boundary. Where two plates slide horizontally past each other, the junction is known as a transform plate boundary. Movement of the plates causes huge stresses, breaks portions of the rock, and produces earthquakes. Places where these breaks occur are called faults. A well-known example of a transform plate boundary is the San Andreas Fault in California.

Where tectonic plates are moving apart, they form a divergent plate boundary. At these boundaries, magma (molten rock) rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges.

If two tectonic plates collide more or less head-on, they produce a convergent plate boundary. Usually, one of the converging plates moves beneath the other in a process called subduction. Subduction produces deep trenches, and earthquakes are common. As the sinking plate moves deeper into the mantle, increasing pressure and heat release fluids from the rock, causing the overlying mantle to partially melt. The new magma rises and may erupt violently to form volcanoes that often form arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. This process can be visualized as a huge conveyor belt on which new crust is formed at the oceanic spreading ridges and older crust is recycled to the lower mantle at the convergent plate boundaries.

The tectonic setting of the Aegean/Black/Mediterranean Sea area is complex, and includes two major plates (the Eurasian and African Plates) as well as several minor ones (including the Hellenic, Turkish, Arabian, and Van Plates). Boundaries between these plates are not always clear, but motion at plate boundaries is undoubtedly responsible for earthquakes and volcanoes throughout the region. This is not considered a highly volcanic area, but even one Thera-type volcano can do plenty of damage!

Thera and its neighboring islands are the most active volcanic center in the Aegean Arc, and are part of a single volcano that has erupted many times. At one time, there were fewer than the five islands visible today. In fact, one of it older names is "Strongyle," which means circular or rounded, suggesting that the overall appearance was different in the past. During some of its eruptions, the floor of the volcano's crater collapsed into the magma chamber below, forming a caldera. Over time, the caldera was partially re-filled by other volcanic activity. Before the eruption during Minoan times, the rim of the caldera was an almost-continuous ring, with only a single entrance. The floor of the caldera collapsed again during the Minoan eruption, destroying part of the above-water ring, thereby creating two new channels.

Studies of volcanic ash deposits suggest that the Minoan eruption happened in at least five stages. The first was a series of precursory volcanic events that took place over several months and may have provided the inhabitants with a warning of things to follow, perhaps accounting for the absence of human remains at Akrotiri. The next stage should have left no doubt about what was coming: An eruption column 36 km high was ejected into the atmosphere, blanketing the Eastern Mediterranean with hot pumice and ash. Then came an even more violent stage. Cracks in the crater floor allowed seawater to contact hot magma, producing explosions of steam that hurled large blocks of rock and clouds of steam and ash over the islands and adjacent ocean. These explosions were followed by a classic "pyroclastic flow;" a river of ash, pumice, gases, and possibly mud that flowed down the sides of the volcano at speeds of 60 miles per hour or more. In the final and most violent stage of all, the pyroclastic flow reached the coast with temperatures approaching 400°C. Visit http://www.immersionpresents.org/content/ for more information about the Minoan eruption, including photographs of other volcanoes in similar eruptive stages.

Exploring the history of the Theran volcano is one of the primary goals of the Aegean and Black Sea 2006 Expedition. In this lesson, students will investigate the characteristics of volcanoes at divergent 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 background essays for the Aegean and Black Sea 2006 Expedition at http://oceanexplorer.noaa.gov/explorations/06blacksea/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."

2. Introduce the Aegean and Black Sea 2006 Expedition, emphasizing the Bronze Age eruption of the Theran volcano. Briefly review the concepts of plate tectonics and continental drift. Be sure students understand the distinction between mid-ocean ridges and subduction zones.

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.

(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 (SiO2) 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 moe 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

Have students visit http://oceanexplorer.noaa.gov/explorations/06blacksea to keep up to date with the latest Aegean and Black Sea 2006 Expedition discoveries.

Resources

NOAA Learning Objects

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.

Other Relevant Lessons from the Ocean Exploration Program

What's Eating Titanic?

http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Rusticles.pdf
(5 pages, 408k) (from the Titanic 2004 Expedition)

Focus: Biodeterioration processes (Physical Science/Biological Science)

In this activity, students will be able to describe three processes that contribute to the deterioration of the Titanic, and define and describe rusticles, explaining their contribution to biodeterioration. Students will also be able to explain how processes that oxidize iron in Titanic's hull differ from iron oxidation processes in shallow water.

Designing Tools for Ocean Exploration

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l1.pdf
(13 pages, 496k) (from the 2002 Galapagos Rift Expedition)

Focus: Ocean Exploration

Students will understand the complexity of ocean exploration; learn about the technological applications and capabilities required for ocean exploration; discover the importance of teamwork in scientific research projects; and develop the abilities necessary for scientific inquiry.

Submersible Designer

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9-12_l4.pdf
(4 pages, 452k) (from the 2002 Galapagos Rift Expedition)

Focus: Deep Sea Submersibles

Students will understand that the physical features of water can be restrictive to movement; understand the importance of design in underwater vehicles by designing their own submersible; and understand how submersibles such as ALVIN and ABE, use energy, buoyancy, and gravity to enable them to move through the water.

Mapping the Canyon

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/dehslessons2.pdf
(10 pages, 72k) (from the 2001 Deep East Expedition)

Focus: Hudson Canyon Bathymetry (Earth Science)

In this activity, students will be able to compare and contrast a topographic map to a bathymetric map; investigate the various ways in which bathymetric maps are made; and learn how to interpret a bathymetric map.

Finding the Way

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/dehslessons4.pdf
(10 pages, 628k) (from the 2001 Deep East Expedition)

Focus: Underwater Navigation (Physical Science)

In this activity, students will describe how the compass, Global Positioning System (GPS), and sonar are used in underwater explorations; and understand how navigational tools can be used to determine positions and navigate in the underwater environment.

Other Resources and Links

http://oceanexplorer.noaa.gov/explorations/06blacksea – Web site for the Aegean and Black Sea 2006 Expedition

http://www.immersionpresents.org/ – Immersion Presents Web site; click on "Ancient Eruptions!" for more information about the Aegean and Black Sea 2006 Expedition, images, and educational activities

http://www.ngdc.noaa.gov/paleo/ctl/clihis10k.html –Timeline for last 10,000 years from NOAA's Paleoclimatology Web site

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://disc.gsfc.nasa.gov/oceancolor/scifocus/oceanColor/dead_zones.shtml – Web page from NASA about "Creeping Dead Zones," including SeaWIFS satellite imagery

http://news.nationalgeographic.com/news/2000/12/122800blacksea.html – National Geographic Web site, "Ballard Finds Traces of Ancient Habitation Beneath Black Sea"

http://blacksea.orlyonok.ru/blacksea.shtml – Web site of the Living Black Sea Marine Environmental Education Program in the Russian Federal Children Center Orlyonok

Friedrich, W. L.. 2000. Fire in the Sea. The Santorini Volcano: Natural History and the Legend of Atlantis. Translated by Alexander R. McBirney. Cambridge University Press. 258 pp.

Ryan, W. and W. Pitman. 1999. Noah's Flood: The New Scientific Discoveries About the Event That Changed History. Simon and Schuster. New York.

Yanko-Hombach, V. 2003. "Noah's Flood" and the late quaternary history of the Black Sea and its adjacent basins: A critical overview of the flood hypotheses. Paper presented at the Geological Society of America Annual Meeting, November 2–5, 2003, Seattle, WA (abstract available online at http://gsa.confex.com/gsa/2003AM/finalprogram/abstract_58733.htm).

http://ina.tamu.edu/ub_main.htm – Web site with information about the excavation of a Bronze Age shipwreck at Uluburun, Turkey

http://projectsx.dartmouth.edu/history/bronze_age/ – Dartmouth University Web site, "Prehistoric Archaeology of the Aegean," with texts, links to other online resources, and numerous bibliographic references

http://oceanexplorer.noaa.gov/explorations/04fire/background/volcanism/volcanism.html – Ocean Explorer Ring of Fire 2004 expedition essay on volcanism

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

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

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding 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 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.
- *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 the Earth.
- *Fundamental Concept b.* Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.
- *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 b.* From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
- *Fundamental Concept c.* The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.
- *Fundamental Concept f.* Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).
- *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 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

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 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?

10. How quickly do biological organisms colonize newly-erupted lava?