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Aegean and Black Sea 2006 Expedition

The Volcano Factory

(adapted from the 2004 Submarine Ring of Fire Expedition)

Focus
Volcanism

Grade Level
5-6 (Earth Science)

Focus Question
What processes are responsible for the formation of Thera and its neighboring islands?

Learning Objectives
Students will be able to explain the tectonic processes that result in the formation of volcanoes and island arcs.

Students will be able to explain volcanic processes that account for the present configuration of Thera and its neighboring islands.

Materials
- ❒ Foamcore or heavy cardboard; one piece approximately 20 cm x 50 cm for each student group
- ❒ 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
Thera
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Tectonic plate
Pyroclastic
Lava flow

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. 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.

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 its 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.

In this lesson, students will prepare models of the Theran volcano and discuss processes that account for the current configuration of Thera and its neighboring islands.

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/. If students will not have access to the internet for research, you will also need to download suitable materials, or confirm that such materials are available in libraries to which students have access.

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).

3. Introduce the Aegean and Black Sea 2006 Expedition, emphasizing the Bronze Age eruption of the Theran volcano. Tell students that their assignment is to create a model of this volcano. Their first task is to review information about the volcano at http://oceanexplorer.noaa.gov/explorations/06blacksea and http://www.immersionpresents.org/content. You may also want to have them research other information about the Theran Islands (the internet has numerous resources about this area). Next, they 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 assign-

ment. 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 Thera and its neighboring islands. Be sure students explain the terms caldera and pyroclastic flow, and describe processes that account for the present arrangement of the islands.

3. After each student group has presented their models, lead a discussion about Thera and its neighboring islands. Students should realize that the processes that formed these islands are ongoing, and that the volcano may erupt again at any time. Point out that not all eruptions are as violent as the Bronze Age event, but that there is evidence that the volcano's caldera has repeatedly refilled, only to collapse again in a subsequent eruption. Prior to the Bronze Age eruption, the islands formed an almost continuous chain around the rim of the volcano's caldera. The violence of that eruption, though, destroyed part of this chain and created several new passages between the islands.

   Have students use their models to discuss discoveries made by the Aegean and Black Sea 2006 Expedition (http://oceanexplorer.noaa.gov/explorations/06blacksea/).

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 Thera or one of its neighbors. Have each student write a short essay describing life on the island, and how they feel about living near an active volcano that may erupt at any time.

Connections to Other Subjects

English/Language Arts, Geography, Mathematics, Life Science

Assessment

Models and written reports provide opportunities for assessment.

Extensions

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

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

Looking for Clues

http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Clues.pdf
(8 pages, 556k) (from the Titanic 2004 Expedition)

Focus: Marine archaeology of the Titanic

In this activity, students will be able to draw inferences about a shipwreck given information on the location and characteristics of artifacts from the wreck, and will list three processes that contribute to the Titanic's deterioration.

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.

In this activity, 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.

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

http://volcano.und.nodak.edu/vw.html – 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

- 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 resources
- Risks and benefits

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 d*. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.

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 a*. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

- *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.

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