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2005 Galapagos Spreading Center

Where Did They Come From?

Focus
Biogeography of hydrothermal vent communities

Grade Level
9-12 (Life Science)

Focus Question
Why are different hydrothermal vent communities inhabited by different species?

Learning Objectives
Students will be able to define and describe biogeographic provinces of hydrothermal vent communities.

Students will be able to identify and discuss processes that could contribute to isolation and species exchange between hydrothermal vent communities.

Students will be able to discuss characteristics that may contribute to the survival of species that inhabit hydrothermal vent communities.

Materials
Copies of "Guidance Questions for Research on the Biogeography of Hydrothermal Vents," one copy for each student or student group

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods, plus time for student research

Seating Arrangement
Classroom style or groups of 3-4 students

Maximum Number of Students
30

Key Words
Hydrothermal vent
Spreading center
Biogeography
Biogeographic province
Mid-ocean ridge
Plate tectonics

Background Information
On February 17, 1977, scientists exploring the seafloor near the Galapagos Islands made one of the most significant discoveries in modern science: large numbers of animals that had never been seen before were clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been discovered in many other locations where underwater volcanic processes are active.

These processes are often associated with movement of the tectonic plates that make up the Earth's crust. The outer shell of the Earth (called the lithosphere) consists of about a dozen large plates of rock (called tectonic plates) that move several centimeters per year relative to each other. These plates consist of a crust about 5 km thick, and the upper 60 - 75 km of the Earth's mantle. The plates that make up the lithosphere 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. Where the plates move apart, a rift is formed that allows magma (molten rock) to escape from deep within the Earth and harden into solid rock known as basalt. Areas where this happens are known as spreading centers, and are a well-known feature of mid-ocean ridges (MORs) such as the East Pacific Rise and Mid-Atlantic Ridge. Spreading centers are also called "divergent plate boundaries," because the plates are moving apart. Convergent plate boundaries, on the other hand, occur where tectonic motion causes plates to collide. When one plate descends beneath the other, the process is called subduction and high temperatures and pressures are generated that can lead to explosive volcanic eruptions (such as the Mount St. Helens eruption which resulted from subduction of the Juan de Fuca tectonic plate beneath the North American tectonic plate). Transform plate boundaries occur where plates slide horizontally past each. At these boundaries, the motion of plates rubbing against each other sets up huge stresses that can cause breaks (faults) in the rock that can result in earthquakes. A well-known example of a transform plate boundary is the San Andreas fault in California.

Volcanic activity can also occur in the middle of a tectonic plate, at areas known as hotspots, which are thought to be natural pipelines to reservoirs of magma in the upper portion of the Earth's mantle. The volcanic features at Yellowstone National Park are the result of hotspots, as are the Hawaiian Islands. As the Pacific tectonic plate moves over the Hawaiian hotspot, magma periodically erupts to form volcanoes that become islands. The oldest island is Kure at the northwestern end of the archipelago. The youngest is the Big Island of Hawaii at the southeastern end. Loihi, east of the Big Island, is the newest volcano in the chain and may eventually form another island. As the Pacific plate moves to the northwest, islands are carried farther away from the hot spot, and the crust cools and subsides. At the same time, erosion gradually shrinks the islands, and unless there is further volcanic activity (or a drop in sea level) the island eventually submerge below the ocean surface. To the northwest of Kure, the Emperor Seamounts are the submerged remains of former islands that are even older than Kure.

The tectonic setting of the Galapagos Islands is more complex. The Galapagos were also formed by a hotspot called the Galapagos mantle plume (GMP), which continues to produce active volcanoes (the Sierra Negra volcano erupted on October 22, 2005). These islands are formed on the Nazca Plate, which is moving east-southeast. On the western side of the Nazca Plate, this motion produces a divergent plate boundary with the Pacific Plate. This boundary is called the East Pacific Rise. On the northern side of the Nazca Plate, just north of the Galapagos archipelago, another divergent boundary exists with the Cocos Plate. This boundary is known as the Galapagos Spreading Center (GSC). A convergent boundary exists on the eastern side of the Nazca Plate, which is being subducted beneath the South American and Caribbean Plates. This subduction has caused some of the oldest seamounts formed by the GMP to disappear beneath the South American and Caribbean Plates, so it is not certain exactly how long the GMP has been active in its present position (for illustrations of these boundaries and plates, as well as detailed discussion of tectonic processes, see "This Dynamic Earth" available online from the U.S. Geological Survey at http://pubs.usgs.gov/publications/text/dynamic.pdf).

This tectonic setting means hydrothermal systems along the GSC may receive magma from the GMP as well as from rifts associated with the spreading center itself. One of the key questions about hydrothermal systems is how variations in the supply of magma affect hydrothermal vent systems and their biogeography. Because the Galapagos mantle plume is known to provide an increased supply of magma to nearby hydrothermal vent systems, the GSC is an ideal "natural experiment" to study this question. Ironically, despite the importance of hydrothermal vents, the Galapagos Spreading Center (GSC) where they were first discovered has received very little exploration. This is the primary purpose of the 2005 Galapagos Spreading Center Expedition.

In this lesson, students will investigate some aspects of the biogeography of hydrothermal vent systems.

Learning Procedure

1. To prepare for this lesson, review background essays for the 2005 Galapagos Spreading Center Expedition, the 2005 Galapagos Rift Expedition, and the 2002 Ocean Exploration Galapagos Rift Expedition (http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html; http://oceanexplorer.noaa.gov/explorations/05galapagosrift/welcome.html; and http://oceanexplorer.noaa.gov/explorations/02galapagos/galapagos.html, respectively) as well as articles on biogeography of hydrothermal vents by Cindy Lee Van Dover and Timothy Shank (http://www.divediscover.whoi.edu/hottopics/biogeo.html and http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf, respectively).

   You may also want to visit the Dive and Discover presentation on the 25th anniversary of the discovery of hydrothermal vents (http://www.divediscover.whoi.edu/ventcd/vent_discovery), and obtain the CD-ROM or download selected images to enhance group discussions in Step 4.

2. Briefly review the concepts of plate tectonics, being sure that students understand the processes that take place at convergent and divergent boundaries, and why these boundaries are often the site of volcanic activity.

3. Tell students that their assignment is to research some basic questions and theories about the biogeography of hydrothermal vent systems, and prepare a report that includes answers to the questions on the "Guidance Questions for Research on the Biogeography of Hydrothermal Vents" worksheet. Information needed to answer questions on the worksheet can be found on the Web sites referenced in Step 1, as well as many other sources. You may want to provide these references to your students, or allow them to discover them (and others) on their own.

4. Lead a discussion of students' reports. The following points should be included:

- A spreading center (mid-ocean ridge) is formed where tectonic plates move apart (divergent plate boundaries). This movement causes a rift to form that allows magma (molten rock) to escape from deep within the Earth and become new crust material. Hotspots are thought to be formed by natural pipelines to reservoirs of magma in the upper portion of the Earth's mantle, and are believed be relatively stationary compared to tectonic plates. The combination of comparatively stationary hotspots and plates that are in constant motion produces "chains" of islands and seamounts formed from hotspot lava as a plate moves over a hotspot location.

- Determining the combined effects of the Galapagos Mantle Plume (GMP) and Galapagos Spreading Center (GSC) is one of the primary objectives of the 2005 Galapagos Spreading Center Expedition. One possibility is that enhanced magma supply from the GMP weakens the crust and causes increased volcanic activity in the vicinity of the GSC, leading to more abundant hydrothermal systems. On the other hand, it is also possible that magma from the GMP causes the crust to thicken. This might suppress hydrothermal venting, or might cause hydrothermal vents to be confined to areas where faulting creates cracks in the thickened crust that allow vents to form.

- Hydrothermal vent biogeographic provinces include the Northeast Pacific (Gorda, Juan de Fuca, and Explorer Ridge systems); Eastern Pacific (East Pacific Rise and Galapagos spreading center systems); Western Pacific (Mariana, Lau, Fiji, and Manus systems); Deep Atlantic (or Mid-Atlantic) (Trans-Atlantic Geotraverse (TAG), Snake Pit, and Broken Spur systems); Shallow Atlantic (or Azorean) (Menez Gwen and Lucky Strike systems); and Central Indian (Kairei and Edmond systems).

- Species that characterize the biogeographic provinces of hydrothermal vent systems are:
  - *tubeworms, clams, and limpets* (eastern Pacific and northeast Pacific; different species of each group in each province);
  - *shrimp and mussels* (Deep Atlantic and Shallow Atlantic; different species of each group in each province); and
  - *barnacles, mussels, and snails* (western Pacific; different species than those found in the eastern Pacific or Atlantic).

  The Indian Ocean province is dominated by shrimp similar to those found in the Atlantic, as well as snails and barnacles similar to those in the western Pacific province.

- Processes that can contribute to migrations between hydrothermal vent communities include:
  - *whalefalls* – decomposition of whale carcasses that fall to the seafloor creates conditions that are somewhat similar to those found at hydrothermal vent sites, so these carcasses may provide "stepping stones" for the migration of species between vent sites;
  - *woodfalls* – decomposing wrecks of wooden ships may create conditions similar to those described for whale carcasses;
  - *larval dispersal* – motile larvae are probably one of the primary means of species dispersal;
  - *deep-sea currents* – that can carry adult organisms or larvae are probably are major factor in the dispersal of many species; and
  - *"stepping stones"* – in addition to whalefalls and woodfalls, other "stepping stones" include seamounts and underwater volcanoes.

- Factors that could contribute to geographic isolation include topographic features, such as deep rift valleys like those found along the Atlantic mid-ocean ridge, or massive transform faults that are roughly perpendicular to mid-ocean ridges; tectonic movements that close pathways between regions (see below); and deep-sea currents (see below).

- A proposed explanation for the similarities and differences among the vent fauna of the Juan de Fuca Ridge and East Pacific Rise is that, at one time, the East Pacific Rise was probably continuous along the western Pacific through the Juan de Fuca Ridge. When the North American tectonic plate overrode the Pacific plate, the East Pacific Rise was subducted beneath the North American plate where we now recognize the San Andreas fault. The result was to isolate the Juan de Fuca Ridge from the East Pacific Rise.

- Some factors that may have tended to isolate hydrothermal vent habitats in the North Atlantic from sites in the Pacific include:
  - *The North Atlantic Ocean basin* formed about 180 million years ago, but the South American and African continents did not separate until 110 million years ago, so the North Atlantic and South Atlantic Oceans were separated for 70 million years after the North Atlantic basin was formed;
  - *The Drake Passage* connecting the Pacific and Atlantic Oceans did not exist until 21 million years ago; and
  - *The Romanche and Chain Fracture Zones* near the equator and a strong deep-sea current in the same area could act as barriers to the

migration of animals from the South Atlantic to North Atlantic.

- The presence of clams at the Logatchev vent site may be the result of the fact that the isthmus of Panama (which is now a barrier to species exchange between the Atlantic and Pacific Oceans) was under water until 5 million years ago, so larvae of vent clams could have migrated from Pacific hydrothermal sites to Atlantic sites prior to this time.

- The key to a species' success in a precarious environment is that the benefits of living in such an environment must outweigh the risks. Being able to thrive under the thermal and chemical conditions typical of hydrothermal vents is an obvious requirement. In addition, rapid growth to maturity is important so that the species has a chance to reproduce before the next volcano erupts. If a volcano does not erupt, there is an increased chance that other species may successfully compete with tubeworms for nutritional or space resources. There is some suggestion that this occurred at the site of the famous Rose Garden vent; tubeworms were abundant when the vent was discovered in 1977, but were greatly reduced compared to mussels when the site was re-visited in 1985.

The Bridge Connection

www.vims.edu/bridge – Select Ocean Science Topics, then select Ecology, then Deep Sea

The "Me" Connection

Many human communities on Earth have become much less geographically isolated in the last two hundred years. Have students write a short essay in which they explore the advantages and disadvantages of reduced geographic isolation to their own community and themselves.

Connections to Other Subjects

English/Language Arts; Physical Science; Geography; Earth Science

Evaluation

Reports and discussions in Step 3 and 4 provide opportunities for assessment.

Extensions

Visit these sites for many more activities and links related to plate tectonics, earthquakes and seismology:
http://www.ldeo.columbia.edu/~mwest/WS4instructors/primer.html

Resources

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

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.

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

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

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

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

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Biological evolution
- Interdependence of organisms
- Behavior of organisms

Content Standard D: Earth and Space Science

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

Content Standard E: Science and Technology

- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Natural and human-induced hazards

For More Information

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Student Handout

Guidance Questions for Research on the Biogeography of Hydrothermal Vents

1. Compare and contrast: spreading center (mid-ocean ridge) and hotspot.

2. How might the interaction between the Galapagos Spreading Center and the Galapagos Mantle Plume affect the occurrence and distribution of hydrothermal vent habitats?

3. What are the six biogeographic provinces of hydrothermal vent communities?

4. What species characterize these provinces?

5. When the same species are found in different hydrothermal vent communities, this suggests that these species are able to move between these communities. But some of these sites are tens to hundreds of miles apart. What are some processes that could contribute to migrations between these communities?

6. The existence of different biogeographic provinces suggests that these geographic areas have been isolated from each other in some way (if they were not isolated, fauna would be expected to mix across all of the sites so the same animals would be found everywhere). What are some factors that could contribute to this isolation?

7. The hydrothermal vent fauna of the Juan de Fuca Ridge (Northeast Pacific province) has many similarities with the fauna of the East Pacific Rise (Eastern Pacific province), yet is different enough to be considered a separate biogeographic province. What tectonic events provide a possible explanation for these observations?

8. What are some factors that may have tended to isolate hydrothermal vent habitats in the North Atlantic from sites in the Pacific?

9. What barrier may help explain the presence of clams at the Logatchev vent site?

10. Animals such as the vent tubeworm that live near tectonically active sites are, in a sense, living on borrowed time since there is a strong possibility of volcanic eruptions that could bury living organisms under a blanket of hot lava. What characteristics might help such species avoid extinction? What may happen to such species if a volcano does not erupt?