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2006 Submarine Ring of Fire

Where Did They Come From?

(adapted from the 2005 Galapagos: Where Ridge Meets Hotspot Expedition)

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
Ring of Fire
Mariana Arc

Background Information
The Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin and results from the motion of large pieces of the Earth's crust known as tectonic plates. These 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) that cause the tectonic plates to move several centimeters per year relative to each other.

If tectonic plates are moving apart their junction is called a divergent plate boundary; if they slide horizontally past each other they form a transform plate boundary; and if they collide more or less head-on they form a convergent plate boundary. The Pacific Ocean Basin lies on top of the Pacific Plate. To the east, new crust is formed by magma rising from deep within the Earth and erupting at divergent plate boundaries between the Pacific Plate and the North American and South American Plates. These eruptions 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.

To the west, the Pacific Plate converges against the Philippine Plate. The Pacific Plate is forced beneath the Philippine Plate, creating the Marianas Trench (which includes the Challenger Deep, the deepest known area of the Earth's ocean). 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. The Mariana 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 off the western coasts of North and South America, and older crust is recycled to the lower mantle at the convergent plate boundaries of the western Pacific.

Underwater volcanism produces hot springs in the middle of cold, deep ocean waters. These springs (known as hydrothermal vents) were first discovered in 1977 when scientists in the submersible Alvin visited an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. Here they found warm springs surrounded by large numbers of animals that had never been seen before. Since they were first discovered, sea-floor hot springs around spreading ridges have been intensively studied. In contrast, the hydrothermal systems around convergent plate boundaries are relatively unexplored.

Some of the key questions about hydrothermal systems concerns biogeography: How do new vents become populated with organisms that are uniquely adapted to the extreme conditions that are characteristic of these habitats? Since vents can appear (and disappear) relatively quickly, what reproductive strategies might be used by vent organisms to ensure that their offspring have a chance of finding a suitable habitat? Previous expeditions to the Submarine Ring of Fire, and to other active hydrothermal vent sites such as the Galapagos Rift, have provided some clues to these questions. The 2006 Submarine Ring of Fire Expedition is focussed on interdisciplinary investigations of the hydrothermal and volcanic processes on the submarine volcanoes of the Mariana Arc, and will probably provide some additional clues; as well as some additional questions. This is the nature of exploration and scientific inquiry. In this lesson, students will investigate some aspects of the biogeography of hydrothermal vent systems.

Learning Procedure

1. To prepare for this lesson, review
    - Introductory essays for the 2006 Submarine Ring of Fire Expedition at http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html;
    - NOAA Learning Object on Hydrothermal Vent Life at http://www.learningdemo.com/noaa/; and
    - 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. Introduce the Ring of Fire expeditions, and tell students that a primary focus of the 2006 Submarine Ring of Fire Expedition is interdisciplinary investigations of hydrothermal and volcanic processes on the portion of the Ring of Fire that includes the Mariana Arc.

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 "Guidance Questions for Research on the Biogeography of Hydrothermal Vents." 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.

- 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 prob-

ably 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 whale-falls 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

Assessment

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

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/06fire/welcome.html for daily logs and updates about discoveries being made by the 2006 Submarine Ring of Fire Expedition.

2. 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
   http://lasker.princeton.edu/ScienceProjects/curr.htm
   http://mae.ce.uiuc.edu/Education/Teachers/high.htm

Resources

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 the Ocean Exploration Program

The Big Balancing Act http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_balancing.pdf (9 pages, 1.3Mb) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

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

Students will be able to define and describe hydrothermal circulation systems; explain the overall sequence of chemical reactions that occur in hydrothermal circulation systems; compare and contrast "black smokers" and "white smokers;" and make inferences about the relative significance of hydrothermal circulation systems to ocean chemical balance from data on chemical enrichment that occurs in these systems.

What's the Difference? http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_difference.pdf (7 pages, 720k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Volcanic processes at convergent and divergent tectonic plate boundaries (Earth Science)

Students will be able to compare and contrast volcanoes at convergent and divergent plate boundaries; identify three geologic features that are associated with most volcanoes on Earth; and explain why some volcanoes erupt explosively while others do not.

Where There's Smoke, There's . . . http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_smoke.pdf (6 pages, 680k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry)

Students will be able to use fundamental relationships between melting points, boiling points, solubility, temperature, and pressure to develop plausible explanations for observed chemical phenomena in the vicinity of subduction volcanoes.

It Looks Like Champagne http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_champagne.pdf (7 pages, 736k) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Deep ocean carbon dioxide and global climate change (Chemistry/Earth Science)

Students will be able to interpret phase diagrams, and explain the meaning of "critical point" and "triple point;" define "supercritical fluid," and will be able to describe two practical uses of supercritical carbon dioxide; and discuss the concept of carbon dioxide sequestration.

The Galapagos Spreading Center http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l2.pdf (8 pages, 480k) (from the 2002 Galapagos Rift Expedition)

Focus: Mid-Ocean Ridges (Earth Science)

Students will be able to describe the processes involved in creating new seafloor at a mid-ocean ridge; students will investigate the Galapagos Spreading Center system; students will understand the different types of plate motion associated with ridge segments and transform faults.

Thar She Blows! http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l3.pdf (5 pages, 456k) (from the 2002 Galapagos Rift Expedition)

Focus: Hydrothermal vents

Students will demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor; students will demonstrate an understanding of how the transfer of energy effects solids and liquids.

Chemosynthesis for the Classroom http://www.oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_chemo_gr912.pdf (6 pages, 464k) (from the 2002 Gulf of Mexico Expedition)

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Other Links and Resources

http://www.oceanexplorer.noaa.gov/explorations/04fire/background/marianaarc/marianaarc.html – Virtual fly-throughs and panoramas of eight sites in the Mariana Arc

http://www.oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Magic Mountain Virtual Web site, featuring animations and videos of the Magic Mountain hydrothermal field

http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html and http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html – Animations of the 3-dimensional structure of a mid-ocean ridge and subduction zone

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.pmel.noaa.gov/vents/nemo/education.html – Web site for the New Millennium Observatory Project, a long-term study of the interactions between geology, chemistry, and biology on Axial Seamount, an active volcano on the Juan de Fuca Ridge that is part of the mid-ocean ridge system

http://vulcan.wr.usgs.gov/ – USGS Cascades Volcano Observatory, with extensive educational and technical resources

http://volcano.und.edu/ – Volcano World Web site at the University of North Dakota

http://nationalzoo.si.edu/publications/zoogoer/1996/3/lifewithoutlight.cfm – "Life without Light: Discoveries from the Abyss," by Robin Meadows; Smithsonian National Zoological Park, Zoogoer Magazine, May/June 1996

http://www.ngdc.noaa.gov/mgg/image/2minrelief.html – Index page for NOAA's National Geophysical Data Center combined global elevation and bathymetry images (http://www.ngdc.noaa.gov/mgg/image/2minsurface/45N135E.html includes the Mariana Arc)

http://www.guam.net/pub/sshs/depart/science/mancuso/marianas/intromar.htm – Web site with background information on 15 of the Mariana Islands.

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

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

http://www.extremescience.com/DeepestOcean.htm – Extreme Science Web page on the Challenger Deep

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

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

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

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.

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

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

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

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.

The ocean and life in the ocean shape the features of the Earth.

- *Fundamental Concept e.* Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Priniciple 5.

The ocean supports a great diversity of life and ecosystems.

- *Fundamental Concept a.* Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.
- *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 c.* Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
- *Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
- *Fundamental Concept e.* The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
- *Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.
- *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.

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

3. What species characterize these provinces?

4. 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?

5. 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?

6. 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?

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

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

9. 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?