The Galápagos Rift Expedition 2011

Where Did They Come From?

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

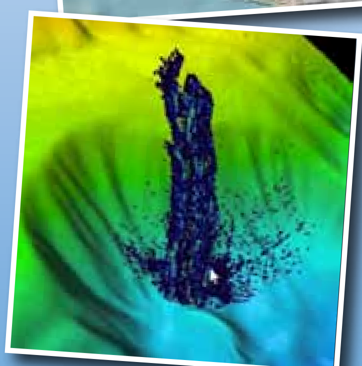


Image captions/credits on Page 2.

lesson plan

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 define and describe biogeographic provinces of hydrothermal vent communities.
- Students will identify and discuss processes that could contribute to isolation and species exchange between hydrothermal vent communities.
- Students will 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 for each student group

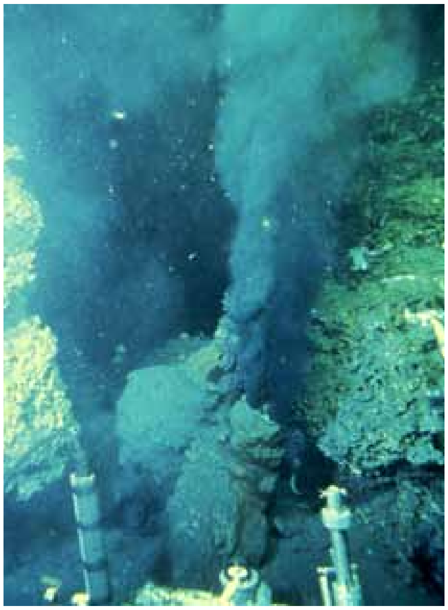
Audio-Visual Materials
- (Optional) Interactive white board or computer projection equipment; see Learning Procedure Step 1.

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Classroom style or groups of 3-4 students

Maximum Number of Students
32

Key Words
Galápagos Rift
Galápagos Spreading Center
Hydrothermal vent



The first photograph of a black smoker vent published on the cover of *Science* magazine. The blackened water is jetting out at 1-5 meters per second and is 380°C, hotter than a pizza oven. Image courtesy Spiess, Macdonald, *et al*, 1980. http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/hires/macdonald_hires.jpg

Images from Page 1 top to bottom:
An overview of the Galápagos Islands. They are produced by volcanic activity caused by magma upwelling at the Galápagos hotspot. Green to white indicates the coastline, outside this is below sea level. Image produced by Ken Macdonald using GeoMapApp courtesy of Lamont Doherty Earth Observatory.
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/hotspots/media/Galapagos_IS_Topo_600.html

Multibeam image of Mendocino Ridge Plume taken with the Kongsberg EM302 multibeam bathymetric mapping system. Image courtesy INDEX-SATAL 2010 Expedition.
http://oceanexplorer.noaa.gov/okeanos/media/movies/mendocino_ridge_plume_video.html

Close-up imagery showing a type of gooseneck barnacle, shrimp and a scaleworm on Kawio Barat submarine volcano. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/barnacle_zoom_hires.jpg

Doug Jongeward, a highly skilled IT Specialist, works in the control room of the *Okeanos Explorer* managing the enormous amounts of video and data that is collected each day on board the ship. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/8_doug_jongeward_hires.jpg

Biogeography
Biogeographic province
Mid-ocean ridge

Background Information

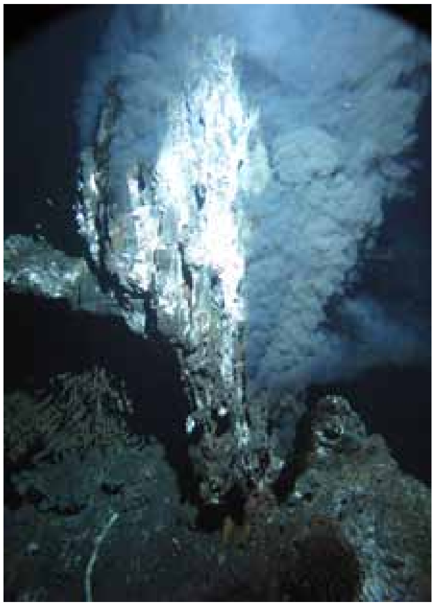
NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

On Feb. 17, 1977, scientists exploring the seafloor near the Galápagos 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, which 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. These 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). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates 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. View animations of different types of plate boundaries at: http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html.

A convergent plate boundary is formed when tectonic plates collide more or less head-on. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building (the Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process 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



A black smoker chimney named 'Boardwalk' emitting 644°F (340°C) hydrothermal fluids in the northeastern Pacific Ocean at a depth of 7,260 feet (2,200 m). Microbes grow within and on the surface of such mineral formations. Image courtesy of James F. Holden, University of Massachusetts, Amherst.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/boardwalk_black_smoker_hires.jpg

Hydrothermal vents on Kawio Barat submarine volcano spew white smoke. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/white_plumes_hires.jpg

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. View the three-dimensional structure of a subduction zone at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html.

Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, 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 three-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

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.

The Galápagos region is geologically complex (see Figure 1 on page 4). The Galápagos Islands were formed by a hotspot called the Galápagos 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 Galápagos archipelago, another divergent plate boundary exists with the Cocos Plate. This boundary is known as the Galápagos 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 additional discussion and illustrations about these processes, see "This Dynamic Earth" available online from the U.S. Geological Survey at http://pubs.usgs.gov/publications/text/dynamic.pdf).

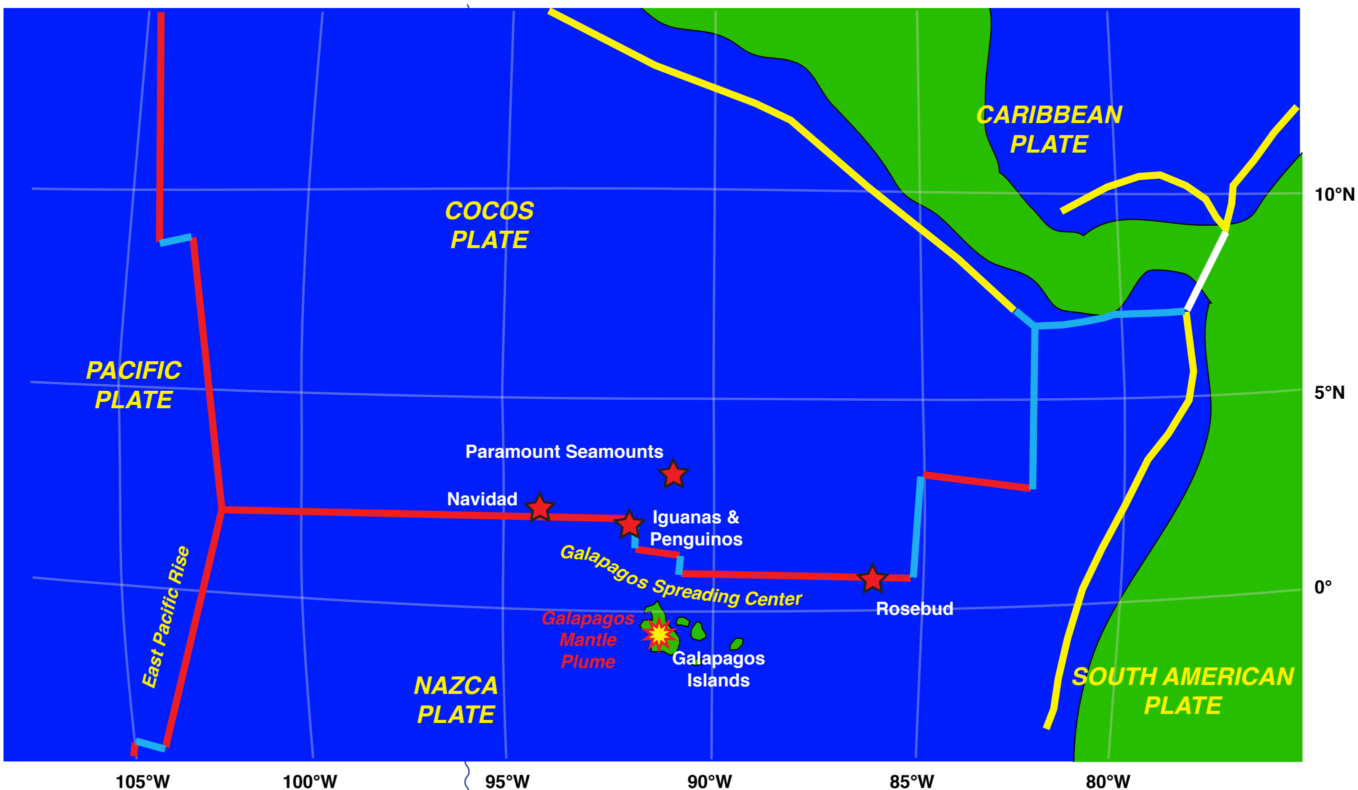


Figure 1. Galápagos Tectonic Setting. Red plate boundaries are divergent; yellow plate boundaries are convergent; blue plate boundaries are transform; white plate boundaries are undetermined. Navidad, Iguanas and Penguinos are locations where black smokers were discovered in 2005. Paramount Seamounts are an exploration target for Galápagos Rift Expedition 2011. For more information see the Galapagos Rift Expedition 2011 Expedition Education Module (http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/edu.html. Credit: UNAVCO (tectonic boundaries); NOAA (hydrothermal sites)

When the movement of tectonic plates causes deep cracks to form in the ocean floor, seawater can flow into these cracks. As the seawater moves deeper into the crust, it is heated by molten rock. As the temperature increases, sulfur and metals such as copper, zinc, and iron dissolve from the surrounding rock into the hot fluid. Eventually, the mineral-rich fluid rises again and erupts from openings in the seafloor. The temperature of the erupting fluid may be as high as 400°C, and contains hydrogen sulfide, which is toxic to many species. When the hot hydrothermal fluid meets cold (nearly freezing) seawater, minerals in the fluid precipitate. The precipitated mineral particles give the fluid a smoke-like appearance, so these vents are often called black smokers or white smokers, depending upon the types of minerals in the fluid. Precipitated minerals may also form chimneys that can be several meters high.

Hydrothermal vent communities and other deepwater chemosynthetic ecosystems are fundamentally different from other biological systems on Earth, and there are plenty of unanswered questions about the individual species and interactions between species found in these communities. Many of these species are new to science, and include primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Although much remains to be learned, useful products have already been discovered in hydrothermal vent organisms. At present, almost all drugs produced from natural sources come from terrestrial plants, but marine animals produce more

Port view of the *Okeanos Explorer*.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/port_view_hires.jpg

The NOAA Ship *Okeanos Explorer*
Formerly: USNS *Capable*
Launched: October 28, 1988
Transferred to NOAA: September 10, 2004
Commissioned: August 13, 2008
Class: T-AGOS
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46 (19 Mission/science)
Speed: 10 knots
Range: 9600 nm
Endurance: 40 days

Systems and Instrumentation:
Kongsberg EM302 Multibeam rated to 7,000 m
SBE 911plus CTD
ROVs -
Little Hercules - 4,000 m depth rating; USBL tracking; depth, altitude, attitude/heading sensors; Seabird SBE 49 FastCat CTD; HD camera and HMI lights
Camera platform with depth/altitude/heading sensors, HD camera and HMI lights.
Telepresence

Operations:
Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations; Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

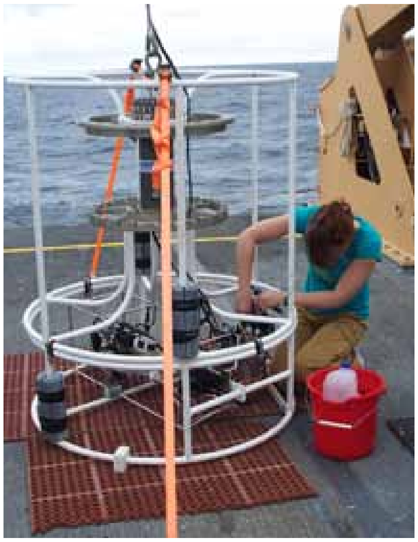
Aft view of the *Okeanos Explorer*.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/aft_view_hires.jpg

drug-like substances than any group of organisms that live on land. Some chemicals from microorganisms found around hydrothermal vents (the exopolysaccharide HE 800 from *Vibrio diabolicus*) are promising for the treatment of bone injuries and diseases, while similar chemicals may be useful for treating cardiovascular disease. Other examples of useful products include a protein from *Thermus thermophylus,* which is a microorganism that is adapted to live under extremely high temperature conditions near hydrothermal vents. One of these adaptations is the protein Tth DNA polymerase that can be used to make billions of copies of DNA for scientific studies and crime scene investigations. Another microorganism (genus *Thermococcus*) produces a type of protein (an enzyme called pullulanase) that can be used to make sweeteners for food additives.

In 2002 and 2005, NOAA's Office of Ocean Exploration and Research sponsored expeditions to the Galápagos Rift (see http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html and http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html for more information about these expeditions). A major objective of the 2002 expedition was to revisit a hydrothermal vent site named Rose Garden to investigate changes that might have occurred in the community of living organisms around the vent since it was discovered in 1977. Scientists found that significant changes had indeed taken place: Rose Garden had completely disappeared! In its place was a fresh sheet of lava that had apparently buried the vent and all of the surrounding organisms. About 300 meters away, a new vent field (which the scientists named Rosebud) was discovered with typical hydrothermal vent species beginning to colonize cracks in recently-formed lava. These discoveries underscored a growing awareness that the deep ocean environment can change much more quickly than was previously believed. The 2005 expedition focused on a portion of the GSC that had never been explored for hydrothermal vents. Scientists hoped that they would find black smokers, because at that time high temperature (several hundred degrees C) vents had not been found in the Galápagos region; only vents whose temperatures were less than 50°C. Using chemical and physical clues, explorers eventually made the first discovery of black smokers on the Galápagos Rift!

These discoveries set the stage for the Galápagos Rift Expedition 2011, which will use the state-of-the-art exploration capabilities of the NOAA Ship *Okeanos Explorer* to obtain detailed information about the biology and geology of Galápagos hydrothermal ecosystems, and determine whether different ecosystems are found at different vent fields within the Galápagos region.

A major objective of the Expedition is to compare species composition between vent sites on the Galapagos Rift and East Pacific Rise to assess whether these sites are separated by an evolutionary barrier.



Senior Survey Technician Elaine Stuart works on the CTD while the altimeter battery recharges. Water sampling bottles, which are often attached to the rosette frame, have been removed for tow-yo operations. Sensors are mounted in the lower part of the frame where SST Stuart is working. Image courtesy of NOAA *Okeanos Explorer* Program.
http://tethys.gso.uri.edu/OkeanosExplorerPortal/ex1103l1/news-articles/update-for-june-25-2011/image/image_view_fullscreen

A CTD with water sampling bottles attached to the rosette frame. Image courtesy of NOAA *Okeanos Explorer* Program.

This objective is based on questions about how populations of living organisms develop and evolve in hydrothermal vent communities. Despite the vast distances separating hydrothermal vents and the rapidly changing vent environment, there are striking similarities in vent communities separated by thousands of miles. At the same time, there are distinctly different animal populations associated with hydrothermal vents in different regions of Earth's ocean.

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

Learning Procedure

1. To prepare for this lesson:
   (a) Review:
   - Introductory essays for the Galápagos Rift Expedition 2011 at http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html
   - *Biogeography of deep-sea hydrothermal vent faunas* by Cindy Lee Van Dover (http://www.divediscover.whoi.edu/hottopics/biogeo.html);
   - *The Evolutionary Puzzle of Seafloor Life* by Timothy Shank (http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf); and
   - *Hunting for Hydrothermal Vents* by Rachel Haymon *et al.* (http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/20_4/20.4_haymon_et_al.pdf)

   You may also want to review background essays for the 2002 and 2005 Ocean Explorer Galápagos Expeditions (http://oceanexplorer.noaa.gov/explorations/02galapagos/galapagos.html, and http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html, respectively).

   (b) If students are not familiar with hydrothermal vent communities, you may want to have students complete the background portion of the *Hydrothermal Vent Plume Inquiry Guide* (http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf) which guide student inquiries about hydrothermal vents and plumes.

2. Briefly introduce the Galápagos Rift Expedition 2011, and the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Be sure students understand that discoveries of deep-sea chemosynthetic communities during the last 30 years are major scientific events that have changed many assumptions about life in the ocean and have opened up many new fields of scientific investigation. Briefly discuss hydrothermal vent communities, or have students complete the activity referenced in Step 1b. Be sure

Okeanos Explorer crew launch the ROV *Little Hercules*. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/media/launch.html

students understand the processes that take place at convergent and divergent boundaries, and why these boundaries are often the site of volcanic activity.

3. Point out that a primary purpose of the Galápagos Rift Expedition 2011 is to compare species composition between vent sites on the Galapagos Rift and East Pacific Rise to assess whether these sites are separated by an evolutionary barrier. 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.

   • How the combination of hotspots (such as the GMP) and spreading centers (such as the GSC) affects hydrothermal vent communities has been a major question, with some scientists predicting that the presence of hotspots is likely to increase the numbers of hydrothermal vents and vent organisms, while others have predicted the opposite. During the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition, scientists discovered that there were significantly fewer active high-temperature vents than expected at the GSC. A possible explanation is that hotspots cause cycles of volcanic and hydrothermal activity at mid-ocean ridges alternating with periods in which such activity is absent.

   If this hypothesis is correct, then larvae from hydrothermal vent animals should be more easily dispersed during periods when there are many active vents, than when vents are few and far between. During periods of volcanic inactivity, animal communities around the few active vents will be more isolated from each other, and may develop different genetic patterns.

- 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)
  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 a major factor in the dispersal of many species
  “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/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then "Habitats" then select "Deep Ocean" for activities and links about deep ocean ecosystems.

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, Social Studies (Geography), Physical Science, Earth Science

Assessment

Students answers to *Worksheet* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Digital Atlas (http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm) and Web page (http://oceanexplorer.noaa.gov/okeanos/welcome.html) for reports, images, and other products from *Okeanos Explorer* cruises.
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://www.eas.purdue.edu/external_relations/seismology_resources.html
   - http://mae.cee.uiuc.edu/K-12/index.html

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html – Click on the links to Lessons 1, 5, and 6 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Tools of Exploration – Remotely Operated Vehicles
(from the INDEX-SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/multibeam.pdf

Focus: Technology for deep ocean exploration: Remotely Operated Vehicles (Earth Science/Physical Science)

Students describe systems and capabilities of science-class remotely operated vehicles, typical applications and limitations of imagery obtained with ROVs, and use ROV imagery to make inferences about deep ocean habitats.

To Explore Strange New Worlds
(Grades 7-8; adaptations for Grades 5-6 & 9-12) (from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_toexplore.pdf

Focus: Strategies for exploring unknown areas on Earth (Life Science/Physical Science/Earth Science)

Students describe requirements for explorations of unknown areas on Earth; discuss factors that influenced exploration strategies of the Lewis and Clark and *Challenger* Expeditions; describe the overall exploration strategy used aboard the NOAA Ship *Okeanos Explorer*; and describe how fractal geometry models natural systems, and how scale influences exploration strategy and results.

Through Robot Eyes
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_roboteyes.pdf

Focus: Image analysis (Physical Science/Technology)

Students describe typical applications and limitations of imagery obtained with remotely operated vehicles (ROVs); demonstrate how lasers may be used to calibrate images for size and distance measurements; and analyze ROV imagery from the *Okeanos Explorer* to make inferences about deep ocean habitats.

The Ridge Exploring Robot
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/robot.pdf

Focus: Autonomous Underwater Vehicles/Marine Navigation (Earth Science/Mathematics)

Students explain a three-phase strategy that uses an autonomous underwater vehicle (AUV) to locate, map, and photograph previously undiscovered hydrothermal vents, design a survey program to provide a photomosaic of a hypothetical hydrothermal vent field, and calculate the expected position of the AUV based on speed and direction of travel.

Reduced Fare
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/reducedfare.pdf

Focus: Deep-Sea Reducing Environments (Life Science)

Students describe oxidation and reduction; explain the meaning of "reducing environment;" give at least three examples of deep-sea reducing environments; and demonstrate a flow of electric current produced by a redox reaction.

The Chemosynthetic Cafe
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/cafe.pdf

Focus: Biochemistry of hydrothermal vents (Life Science)

Students compare and contrast food web energy sources in hydrothermal vent and aerobic environments, and use models to explain the overall chemistry of autotrophic nutrition.

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

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

Students 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 these systems to ocean chemical balance compared to terrestrial runoff from data on chemical enrichment in hydrothermal circulation systems.

Hydrothermal Vent Challenge
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VentChallenge.pdf

Focus: Chemistry of hydrothermal vents (Chemistry)

Students 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.

Survivors on the Ocean Ridge
(from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l5.pdf

Focus: Inheritance of genetic traits and the effect of environmental pressures on the expressed traits (Life Science)

Students investigate the history of explorations of the hydrothermal vent systems; design a new shrimp species based on the introduction of a new gene form from migrating shrimp populations along the rift systems; assess the viability of the new shrimp species; and develop a model for the establishment of a population of a new species of shrimp.

Other 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.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html – Web site for Galápagos Rift Expedition 2011, with links to lesson plans, career connections, and other resources

http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html – Web page for the NOAA Ship *Okeanos Explorer* Education Materials Collection

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html – Web site for the 2002 Galápagos Rift Expedition

http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html – Web site for the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition

http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates

http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, *We're in Hot Water Now: Hydrothermal Vents*, includes links to *National Geographic* magazine articles and video with an emphasis on geography and geographic skills

http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977.

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.courseworld.com/ocean/smokers.html – *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

Haymon, R. M., E. T. Baker, J. A. Resing, S. M. White, K. C. Macdonald, and the GalAPAGoS Team. 2007. Hunting for Hydrothermal Vents Along the Galápagos Spreading Center. *Oceanography* 20(4):100-107. http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/20_4/20.4_haymon_et_al.pdf

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 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.

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.

Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

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

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

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

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

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Credit

Where Did They Come From?

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?