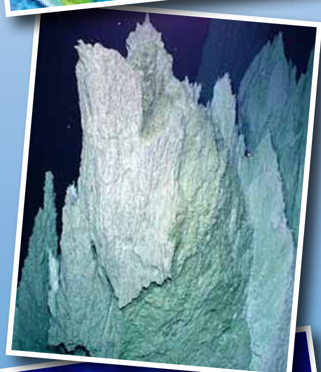
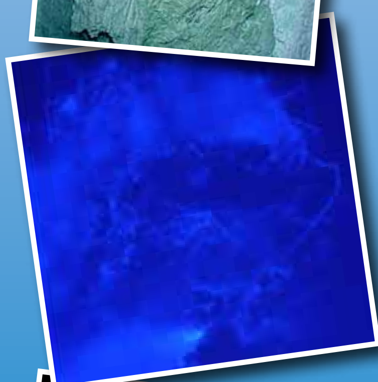
The Mid-Cayman Rise Expedition 2011

Welcome to the Ridge





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lesson plan

Focus
Chemistry of hydrothermal vent systems on mid-ocean ridges

Grade Level
9-12 (Earth Science/Chemistry/Life Science)

Focus Question
What are some differences among hydrothermal vents on mid-ocean ridges?

Learning Objectives
- Students will be able to compare and contrast hydrothermal vent systems and biological communities on different mid-ocean ridges.
- Students will be able to explain three ways in which hydrothermal vent systems on the Mid-Cayman Rise are unusual.
- Students will be able to describe and explain three types of hydrothermal vents.
- Students will be able to explain why space scientists are interested in biological communities around ultramafic hydrothermal vents.

Materials
- Copies of *Mid-Ocean Ridge Hydrothermal Vents Inquiry Guide, Technical Reading* worksheet, the *Hydrothermal Vent Plume Challenge Guided Design Portfolio Sheet* and possibly parts or all of Shank (2004) for each student; see Learning Procedure, Step 1d

Audio-Visual Materials
- 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

Maximum Number of Students
30

Key Words

Mid-Cayman Rise
Hydrothermal vent
Biogeography
Biogeographic province
Mid-ocean ridge
Ultramafic

Background Information

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.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977, deep on the ocean floor near the Galápagos Islands. Here, researchers found large numbers of animals that had never been seen before clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been found in many other locations where underwater volcanic processes are active. Hydrothermal vents are formed when seawater flows into deep cracks in the ocean floor, is heated by molten rock to temperatures that may be higher than 350° C, and then rises back to the surface to form hydrothermal vents where the superheated water erupts through the seafloor. The presence of thriving biological communities in the deep ocean was a complete surprise, because it was assumed that food energy resources would be scarce in an environment without sunlight to support photosynthesis. Researchers soon discovered that the organisms responsible for this biological abundance do not need photosynthesis, but instead are able to obtain energy from chemical reactions through processes known as chemosynthesis. Photosynthesis and chemosynthesis both require a source of energy that is transferred through a series of chemical reactions into organic molecules that living organisms may use as food. In photosynthesis, light provides this energy. In chemosynthesis, the energy comes from other chemical reactions.

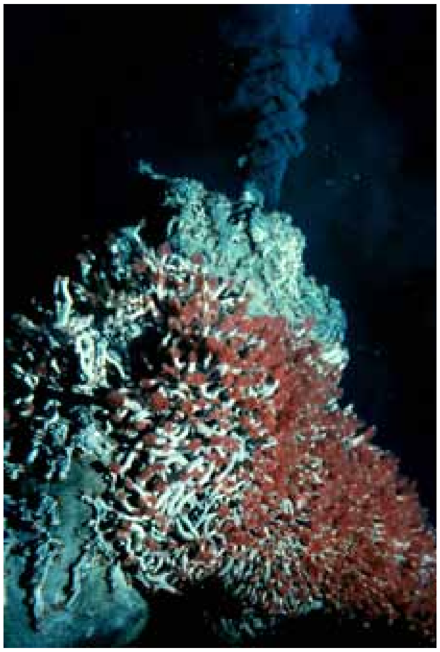
Deepwater biological communities associated with hydrothermal vents are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. These species include some of the most primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Many species are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Although much remains to be learned, new drugs and other useful products have already been discovered in hydrothermal vent organisms. At present, almost all drugs produced from natural sources come from terrestrial plants,

Images from Page 1 top to bottom:
The Mid Cayman Rise (MCR) is an undersea ridge deep in the Caribbean Sea at the tectonic boundary where the North American Plate and the Caribbean Plate are spreading apart. (Map courtesy of NOAA)
http://www.whoi.edu/oceanus/viewImage.do?id=125232&aid=86988

Typical morphology of active chimney at Lost City on the Mid Cayman Rise showing multiple, delicate pinnacles of young carbonate material. The tall, white, carbonate structures emit clear, warm fluids that form no particles in the water. The fluids coming out of these chimneys have very high pH (10-11) and maximum temperatures of less than 100°C. Image courtesy of Lost City 2003, University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/chem/media/active.html

Colonies of microbes are attached to carbonate material from within the chimney walls. There are microbes that eat methane and help to counter-balance the methane production of the methanogens (organisms that generate methane). Some colonies form filamentous strands, such as the one shown in the far right of this microphotograph. Each small dot (microbe) that makes up the strand is about 1 micron in size. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/overview/media/fig8microbe.jpg

Black smokers are formed when volcanic action emits metal sulfides. The calcium carbonate white chimneys at Lost City were formed when fluids with a very high pH and calcium content mixed with seawater. This vigorously venting black smoker, called Sully, emits jets of particle-laden fluids that create the "black smoke". The particles are predominantly very fine-grained sulfide minerals formed when the hot hydrothermal fluids mix with near freezing seawater. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/chem/media/sully2.html



Part of a 360°C black smoker chimney in the Main Endeavour hydrothermal field on the Juan de Fuca Ridge in the N.E. Pacific Ocean. Black smokers have now been found throughout the mid-ocean ridge spreading system. Since their discovery, the billowing 360°C jets of metal sulfide- and gas-laden fluids were believed to typify submarine hot spring systems. They are oases for colonies of animals such as tubeworms, giant clams, and spider crabs whose symbionts depend on volcanic gases such as carbon dioxide (CO_2) for survival. Vibrant colonies of tube worms with red gills thrive on this large edifice, which is predominantly composed of iron- and sulfur-bearing minerals. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/overview/media/fig2strawberry.jpg

but marine animals produce more 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 *Thermus thermophylus*, a microorganism that is adapted to live under extremely high temperature conditions near hydrothermal vents. One of these adaptations is a 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.

The geologic processes that produce hydrothermal vents are linked to movements of 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.

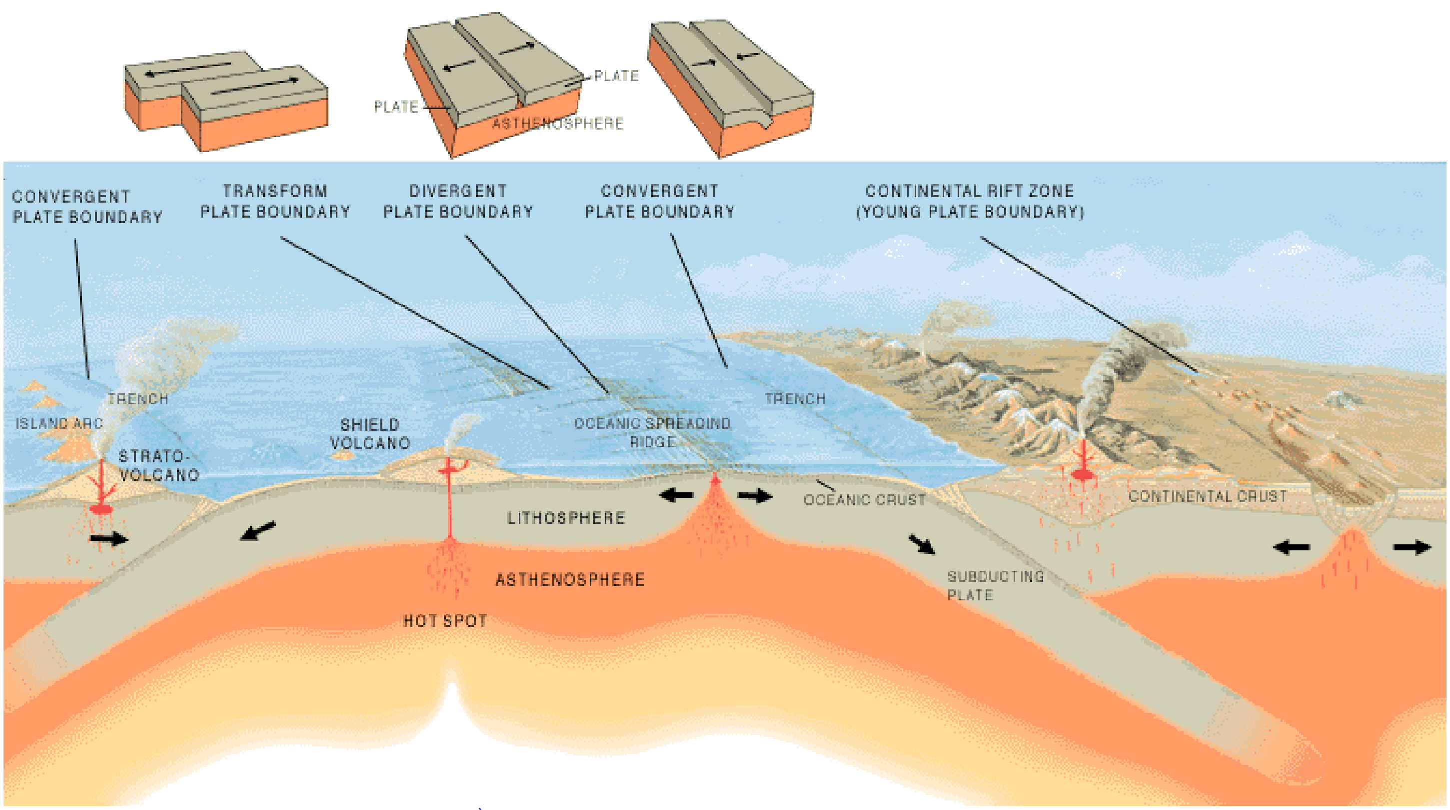
Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary; when tectonic plates collide more or less head-on, convergent plate boundary is formed; where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate 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. A rift valley is typically present along the top of the ridge. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. You can view the three-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html. For additional discussion about convergent and transform plate boundaries, see the Galapagos Rift 2011 Expedition Purpose: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/purpose.html.

On a global scale Earth's oceanic spreading ridges are connected and form a single mid-ocean ridge system that is part of every ocean. This mid-ocean ridge system is about 50,000 km long, and is the longest mountain range in the world. Although they are connected, the ridges that make up the global mid-ocean ridge system are not all the same.

This is because tectonic plates adjacent to different ridges may move apart at different rates. Plates that are part of fast-spreading ridge systems may move apart at rates of 20 cm/yr or more, while plates that are part of ultraslow-spreading ridge systems may move at rates of 2 cm/yr or less. In general, hydrothermal vents are most common along fast-spreading ridge systems; but about 50% of the global mid-ocean ridge system consists of slow- or ultraslow spreading ridges, and there is greater variety in the types of hydrothermal vents founds along these ridges.

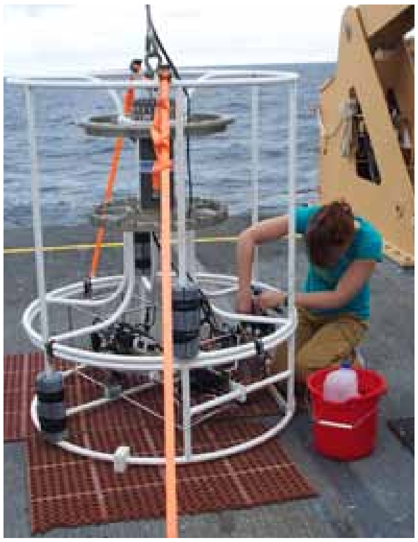
The Mid-Cayman Rise (MCR) is the world's deepest and slowest-spreading mid-ocean ridge. Exploration of the MCR was underway in the 1970's, but the discovery of the first hydrothermal vents on the Galápagos Spreading Center caused deep-sea researchers to change the focus of their investigations...until recently. In 2009, a systematic exploration along the MCR found evidence of three different types of hydrothermal vents within 100 km of each other. For more discussion about different vent types, see the Mid-Cayman Rise Expedition 2011 Exploration Purpose: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/background/edu/purpose.html.

Types of Plate Boundaries



Artist's cross section illustrating the main types of plate boundaries. (Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.)
http://pubs.usgs.gov/gip/dynamic/Vigil.html

Hydrothermal vent communities on the MCR are interesting to biologists because they probably contain species that are new to science, some of which may provide useful bioproducts. In addition, the MCR is isolated from the rest of the global mid-ocean ridge system, though it was connected to the Galápagos Spreading Center until about 5 million years ago when the Isthmus of Panama closed the seaway connecting the Caribbean Sea and Pacific Ocean. This raises intriguing questions about MCR vent organisms: Do they resemble vent biota on other ocean ridges such as the Galápagos Spreading Center or the Mid-Atlantic Ridge? How similar are they to organisms in chemosynthetic communities of the Gulf of Mexico? Answers to these questions can provide new insights about how new hydrothermal vent systems are colonized, and whether vent organisms move between widely separated vent systems. It is also possible that some MCR hydrothermal vent systems produce organic molecules by processes that do not involve living organisms. These processes are potentially relevant to the origins of life on Earth, as well as exploration for similar systems that support living organisms in other parts of our solar system.



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.

The Mid-Cayman Rise Expedition 2011 is focused on locating new hydrothermal vent sites on the Mid-Cayman Rise, and exploring these sites with the *Little Hercules* remotely operated vehicle which will capture video images of biological and geological features of these sites.

In this lesson, students will investigate some characteristics of hydrothermal vent systems and biological communities on different mid-ocean ridges, and why some of these communities are relevant to studies concerned with the origin of life and life on other planets.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the Mid-Cayman Rise Expedition 2011 at http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/welcome.html.
   (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.
   (c) If an interactive white board or computer projection facilities are available, you may also want to bookmark one or more of the following Web pages or download some images from these sites to show your students:
      - http://www.pmel.noaa.gov/vents/about.html – Web page for the Vents Program at NOAA's Pacific Marine Environmental Laboratory
      - 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

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

hydrothermal vent in 1977
- http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, about 150 miles west of Vancouver Island, British Columbia, Canada.

(d) Review the *Mid-Ocean Ridge Hydrothermal Vents Inquiry Guide*, the *Technical Reading* worksheet adapted from German *et al*. (2010), and Shank (2004). Duplicate the *Technical Reading* sheet, and decide whether to provide the entire paper by Shank (2004) (http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf) or only the link for students to download the paper themselves.

(e) Review the *Hydrothermal Vent Plume Challenge Guided Design Portfolio Sheet*, and decide whether you will have students test their designs in the classroom, or have them do this at home and bring final models to school for class presentation and discussion.

2. Briefly introduce the Mid-Cayman Rise 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. If necessary, review the basic concept of plate tectonics and the three ways that Earth's tectonic plates may move relative to each other (these are discussed, with links to illustrations, in the Galapagos Rift 2011Expedition Purpose: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/purpose.html). Briefly describe hydrothermal vents or have students complete the activity referenced in Step 1b.

3. Provide each student group with copies of *Mid-Ocean Ridge Hydrothermal Vents Inquiry Guide*, the *Technical Reading* sheet, and Shank (2004), or the Web link for the latter paper. Tell students that answers to questions on the *Inquiry Guide* can be found in the two papers provided. Potentially unfamiliar terms listed in the first question may be discussed with the entire class, or students may be required to find definitions on their own. When students have completed this assignment, discuss their results:

(1) Definitions of the words and terms:

Host (as used in the *Technical Reading*) means that a particular type of rock or other environmental feature is the location of hydrothermal vents.

Mafic means that rocks contain high concentrations of manganese and iron.

Ultramafic means that rocks contain higher concentrations (usually greater than 90%) of manganese and iron than mafic rocks.

Serpentinization is the process of forming the mineral serpentine through a reaction between seawater and ultramafic mantle rocks known as peridotites.

Abiotic organic chemical synthesis is the formation of methane or other low-molecular weight hydrocarbons by processes that do not involve living organisms.

An **extremophile** is an organism that prefers environmental conditions that would be extreme for humans (such as high temperatures and high pressures that characterize many hydrothermal vent environments).

Ambient refers to the surroundings; ambient temperature, for example, means the temperature of the surrounding environment.

Neovolcanic refers to new volcanoes.

(2) The sentence cited in Question 2 means that the new sites may include:
- Hydrothermal vents whose vent fluids contain several different types and/or quantities of chemicals;
- Different types of chemical reactions that produce hydrocarbon molecules through processes that do not involve living organisms;
- Different organisms that are tolerant of conditions that would be extreme for humans;
- An unusual variety of living organisms; and these features occur at sites that are relatively close together.

(3) Type 1 vents have high vent fluid temperatures (up to 407° C), and are associated with mafic rocks. Type 2 vents also have high vent fluid temperatures, but these vents are the serpentinization of ultramafic rocks. Type 3 vents also involve serpentinization, but have much lower vent fluid temperatures (around 40° to 90° C).

(4) Hydrothermal vent systems on the Mid-Cayman Rise are unusual because:
- All three types of hydrothermal vents are found on the MCR;
- The deepest vent presently known is on the MCR; and
- The MCR is geographically and tectonically isolated from the rest of the global ridge system.

(5) A biogeographic province is a region of the seafloor that has a distinct group of animal species.

(6) 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);

Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:

- Define the problem.
- Gather relevant information.
- Brainstorm possible solutions.
- Analyze possible solutions and select the most promising.
- Test the solution by building a prototype.
- Revise and improve the solution.
- Repeat previous steps until results are acceptable.
- Report the design process and results.

These steps involve several key skills:

- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

Shallow Atlantic (or Azorean) (Menez Gwen and Lucky Strike systems); and
Central Indian (Kairei and Edmond systems)

(7) 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

(8) Space scientists are interested in biological communities around ultramafic hydrothermal vents because the chemical environment around these vents is favorable to production of organic molecules by processes that do not involve living organisms. Such processes may give clues about the origins of life on Earth, as well as on other planets where similar conditions may be found (such as Jupiter's moon, Europa, which is composed of rocks similar to those found on Earth and is covered by a deep ocean under a shell of ice).

(9) Hydrothermal vent plumes are masses of seawater that have been changed by mixing with the fluid from hydrothermal vents.

(10) Hydrothermal vent plumes may be detected by ocean explorers because they are enriched with dissolved chemicals, mineral particles, and microbes when compared to the ambient water column.

4. Discuss students' solutions for the *Hydrothermal Vent Plume Challenge*. While many solutions are possible, ideally they will demonstrate (a) formation of a neutrally buoyant "plume," due to (b) changes in density caused by temperature.

   Layering could be produced in a clear cylinder with three fluids having high (Fluid A), intermediate (Fluid B) and low (Fluid C) specific gravities. Fluid C would be carefully layered on top of Fluid A in the container, then Fluid B injected through a plastic tube near the bottom of the cylinder. Adding a dye to Fluid B would make the layer more visible. Although this procedure would produce a layer, it would not demonstrate the influence of temperature in attaining neutral buoyancy.

   A better solution would be to prepare about three gallons of ice-cold water, then transfer this to a glass carboy or similar container. Next, about two gallons of water with a temperature of about 26° C is layered on top of the cold water by gently pouring the warmer water down the inside of the carboy using a funnel. To demonstrate formation of a neutrally buoyant plume, about 10 ml of dyed water with a temperature of around 180° C is injected near the bottom of the carboy. The dyed mass of water will rise until it becomes chilled by the surrounding water, then stops rising and slowly diffuses in a horizontal direction. Through repeated trials, the designers will discover a number of refinements, including:

- The desirability of adding a small weight to the open end of the plastic tubing so it can be easily positioned at the bottom of the carboy;
- The importance of a high temperature for the injected water, since the much larger mass of cold water will quickly chill the dyed water and unless the dyed water is hot it will not have time to rise very much before it becomes neutrally buoyant;
- The importance of injecting the entire mass of dyed water all at once, rather than gradually; and
- The importance of not having ice in the carboy, since it will float and lower the temperature of the upper layer of warm water.

Class discussions of student groups' solutions should highlight the importance of Steps 1 and 2; understanding the design problem, and identifying the processes that are to be modeled. You may want to require groups to submit their selected design solution (Step 4) before proceeding with testing so that you can suggest alternatives to designs that have not adequately considered the first two steps.

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then select "Geology" or "Habitats" for activities and links about hydrothermal vent formation and ecology.

The "Me" Connection

Have students write a short essay describing how knowledge about Earth's tectonic plates could be of personal benefit.

Connections to Other Subjects

English/Language Arts (Text-dependent analysis)

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/welcome.html for the latest activities and discoveries by the Mid-Cayman Rise Expedition 2011.
2. Visit the education sections of Web sites provided in Step 1 for additional activities about hydrothermal vents.
3. 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.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

We've Got Plumes!
(from the Galápagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_gotplumes.pdf

Focus: Hydrothermal Vent Chemistry (Earth Science/Chemistry)

Students describe hydrothermal vents; explain how oxidation reduction potential and light-scattering sensor data may be used to detect the presence of hydrothermal vents; and analyze CTD data collected in the vicinity of the Galápagos Spreading Center to recognize a probable plume from hydrothermal activity.

Where Did They Come From?
(from the Galápagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_wherefrom.pdf

Focus: Species variation in hydrothermal vent communities (Life Science)

Students define and describe biogeographic provinces of hydrothermal vent communities, identify and discuss processes contributing to isolation and species exchange between hydrothermal vent communities, and discuss characteristics which may contribute to the survival of species inhabiting hydrothermal vent communities.

Hot Maps
(from the Galápagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_hotmaps.pdf

Focus: Multibeam sonar exploration for hydrothermal vent systems (Earth Science/Physical Science)

Students describe multibeam sonar, discuss the advantages of multibeam sonar bathymetry compared to two-dimensional topographic bathymetry, and interpret three-dimensional multibeam bathymetric data from the vicinity of the Galápagos Spreading Center.

Inside *Okeanos Explorer*: Doppler Velocity Log
(from the Galápagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_doppler.pdf

Focus: Doppler effect and velocity estimation (Physical Science/Physics)

Students explain the Doppler effect, describe how a Doppler velocity log is used to estimate the *Okeanos Explorer's* speed while underway, and compare velocity log estimates with velocity calculated from geographic positions reported on the *Okeanos Explorer* Atlas.

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

Focus: Technology for deep ocean exploration: CTD (Chemistry/Earth Science)

Students describe typical effects of hydrothermal vents, volcanoes, and cold seeps on chemical and physical parameters of seawater; explain how oceanographers can use CTD data to locate these geologic features; and analyze data from CTD casts for the presence of anomalies.

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.

Wow, That Hertz!
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_hertz.pdf

Focus: Communications physics (Physical Science/Physics)

Students explain the concept of energy transfer though wave propagation, and how this process is used to support telepresence and scientific communications aboard the *Okeanos Explorer*; define an electric current, and describe the relationship between current, voltage and resistance using Ohm's Law; identify resistors, capacitors, and inductors, and explain how each of these influences the flow of electric current; and identify and describe the function of the five basic electronic building blocks that make radios work.

Watching in 3-D
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_3d.pdf

Focus: Multibeam sonar (Physical Science/Earth Science)

Students describe multibeam sonar and explain why the velocity of sound in water must be measured before maps can be created with the *Okeanos Explorer's* multibeam sonar system; and interpret three-dimensional multibeam data of underwater features mapped by the *Okeanos Explorer*.

A Quest for Anomalies
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_anomalies.pdf

Focus: Use of CTD data in ocean exploration (Earth Science/Physical Science/Technology)

Students describe and explain redox potential and optical backscatter, and how these parameters are related to deep-sea ecosystems and geologic features; and analyze data from CTD casts aboard the *Okeanos Explorer* for the presence of anomalies.

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.

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/ex1104/welcome.html – Web site for the Mid-Cayman Rise Expedition 2011 Expedition

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

http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm – Web site for the *Okeanos Explorer* Atlas, which provides a map-based link to information about current and previous ocean exploration expeditions conducted aboard the NOAA Ship *Okeanos Explorer*

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://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.

http://explore.noaa.gov/special-projects/indonesia-u-s-scientific-and-technical-cooperation-in-ocean-exploration/files/Okeanos_Explorer_for_WOC_-_FINAL.pdf – NOAA Fact Sheet about the *Okeanos Explorer*

German, C. R., A. Bowen, M. L. Coleman, D. L. Honig, J. A. Huber, M. V. Jakuba, J. C. Kinsey, M. D. Kurz, S. Leroy, J. M. McDermott, B. Mercier de Lépinay, K. Nakamura, J. S. Seewald, J. L. Smith, S. P. Sylva, C. L. Van Dover, L. L. Whitcomb, and D. R. Yoerger. 2010. Diverse styles of submarine venting on the ultraslow spreading Mid-Cayman Rise. Proceedings of the National Academy of Sciences 107(32):14020–14025. www.pnas.org/content/early/2010/07/13/1009205107.full.pdf

Shank, T. M. 2004. The Evolutionary Puzzle of Seafloor Life. *Oceanus* 42:78-85; available from: http://www.whoi.edu/cms/files/dfino/2005/4/v42n2-shank_2276.pdf

Correlations

Framework for K-12 Science Education

A. Scientific and Engineering Practices

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

B. Crosscutting Concepts

2. Cause and effect: Mechanism and explanation
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
7. Stability and change

C. Disciplinary Core Ideas

Physical Sciences

Core Idea PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter

PS1.B: Chemical Reactions

Core Idea PS2: Motion and Stability: Forces and Interactions

PS2.A: Forces and Motion

PS2.B: Types of Interactions

PS2.C: Stability and Instability in Physical Systems

Life Sciences

Core Idea LS2: Ecosystems: Interactions, Energy, and Dynamics

LS2.C: Ecosystems Dynamics, Functioning, and Resilience

Core Idea LS4: Biological Evolution: Unity and Diversity

LS4.C: Adaptation

Earth and Space Sciences

Core Idea ESS2: Earth's Systems

ESS2.B: Plate Tectonics and Large-Scale System Interactions

Engineering, Technology, and the Applications of Science

Core Idea ETS1: Engineering Design

ETS1.A: Defining and Delimiting an Engineering Problem

ETS1.B: Developing Possible Solutions

ETS1.C: Optimizing the Design Solution

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.

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.

Common Core State Standards for Mathematics

Grade 5

Geometric measurement: understand concepts of volume and relate volume to multiplication and to addition.

Grade 6

Solve real-world and mathematical problems involving area, surface area, and volume.

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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Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, Science and Technology Consultant to OER's Education Team.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit

If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

Welcome to the Ridge
Technical Reading

(adapted from German, C. R., A. Bowen, M. L. Coleman, D. L. Honig, J. A. Huber, M. V. Jakuba, J. C. Kinsey, M. D. Kurz, S. Leroy, J. M. McDermott, B. Mercier de Lépinay, K. Nakamura, J. S. Seewald, J. L. Smith, S. P. Sylva, C. L. Van Dover, L. L. Whitcomb, and D. R. Yoerger. 2010. Diverse styles of submarine venting on the ultraslow spreading Mid-Cayman Rise. Proceedings of the National Academy of Sciences 107(32):14020–14025; www.pnas.org/content/early/2010/07/13/1009205107.full.pdf)

Abstract

Thirty years after the first discovery of high-temperature submarine venting, the vast majority of the global mid-ocean ridge remains unexplored for hydrothermal activity. Of particular interest are the world's ultraslow spreading ridges that were the last to be demonstrated to host high-temperature venting but may host systems particularly relevant to prebiotic chemistry and the origins of life. Here we report evidence for previously unknown, diverse, and very deep hydrothermal vents along the approximately 110 km long, ultraslow spreading Mid-Cayman Rise (MCR). Our data indicate that the MCR hosts at least three discrete hydrothermal sites, each representing a different type of water-rock interaction, including both mafic and ultramafic systems and, at about 5,000 m, the deepest known hydrothermal vent. Although hydrothermal activity occurs on all mid-ocean ridges, the diversity of vent types identified here and their relative geographic isolation make the MCR unique in the oceans. These new sites offer prospects for an expanded range of vent-fluid compositions, varieties of abiotic organic chemical synthesis and extremophile microorganisms, and unparalleled faunal biodiversity—all in close proximity.

The approximately 50,000 km global ridge system, comprising both Mid-ocean ridges and back-arc spreading centers, is an integral component of Earth's plate tectonic system. These ridges define the diverging margins of tectonic plates that separate at rates that range from "very fast" (>20 cm/yr) to "ultraslow" (<2 cm/yr). But the distribution of slow or fast-spreading ridge systems is not uniform throughout the globe: slow and ultraslow ridges dominate the Arctic, Atlantic, and southwest Indian oceans, while fast spreading ridges are only found in the Southern and Pacific oceans. To date, only about 10% of the global ridge system has been explored systematically for hydrothermal activity, and it has only recently been recognized that the world's slowest-spreading ridges can host hydrothermal activity. In general, there are more hydrothermal vents on fast-spreading ridge systems. Slow and ultraslow spreading ridges make up about 50% of the total global ridge length, however, and a greater diversity of styles of hydrothermal venting has been found along these slower ridges. Some hydrothermal vents on these ridges are produced by the interaction of seawater with ultramafic rocks. Ultramafic-hosted sites such as Rainbow or Lost City create chemical environments that strongly favor reducing reactions. These conditions are favorable to abiotic organic synthesis, which is relevant to studies of prebiotic chemistry and the origins of life.

The Mid-Cayman Rise (MCR) is a deep (4,500 – 6,500 m) and ultraslow (<2 cm/yr) spreading ridge that is about 110 km long. The MCR is tectonically and geographically isolated from all other components of the global ridge system due to its location at the deepwater gateway that used to exist between the eastern Pacific and equatorial Atlantic oceans prior to the closure of the Isthmus of Panama about 3.1 million years ago.

While hydrothermal vent sites only typically occupy small areas on the sea floor (about 100 m across), the plumes formed when hot, acidic vent fluids mix turbulently with cold deep-ocean seawater can rise hundreds of meters through the water column. As the plume rises, cold seawater is mixed into the plume, and this causes the plume to become neutrally buoyant at some depth. These plumes can then be detected for kilometers or more away from their source, as they disperse, due to their enrichment in dissolved chemicals, mineral particulates, and microbes when compared to the ambient water column. To date, three vent types have been identified at Mid-ocean ridges. Type 1, the most commonly reported, is a mafic-hosted, high-temperature (up to 407°C) system that can occur because of neovolcanic or tectonic activity, and has low concentrations of dissolved methane in the vent plume. Type 2 is a distinct form of high-temperature venting associated with serpentinization of ultramafic rocks with high concentrations of dissolved hydrogen, methane, and iron in the vent fluids. Type 3 is the most recently identified, from the Lost City site, and also involves serpentinization of ultramafic rock but vent fluids exiting the sea floor have much lower temperatures (about 40 – 90° C). Remarkably, our results provide evidence that one example of all three of these distinct vent types are currently active on the MCR, all within a distance of less than 100 km along the ridge axis.

Welcome to the Ridge

Mid-ocean Ridge Hydrothemal Vent Inquiry Guide

1. Be sure you understand the meaning of the following words and terms:
   - Host (as this word is used in the second sentence of the *Technical Reading* Abstract)
   - Mafic
   - Ultramafic
   - Serpentinization
   - Abiotic organic chemical synthesis
   - Extremophile
   - Ambient
   - Neovolcanic

   Use information contained in the *Technical Reading* and the article by Shank (2004) to answer the following questions.

2. Explain the meaning of the following sentence:
   "These new sites offer prospects for an expanded range of vent-fluid compositions, varieties of abiotic organic chemical synthesis and extremophile microorganisms, and unparalleled faunal biodiversity—all in close proximity."

3. The technical reading describes three types of hydrothermal vents. What are the differences between these types?

4. In what ways are hydrothermal vent systems on the Mid-Cayman Rise unusual?

5. What is a "biogeographic province?"

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

7. What species characterize these provinces?

8. Why are space scientists interested in biological communities around ultramafic hydrothermal vents?

9. What are hydrothermal vent plumes?

10. What characteristics of hydrothermal vent plumes allow them to be detected by ocean explorers?

Welcome to the Ridge

Hydrothemal Vent Plume Challenge
Guided Design Portfolio Sheet

According to the Technical Reading,

"While hydrothermal vent sites only typically occupy small areas on the sea floor (about 100 m across), the plumes formed when hot, acidic vent fluids mix turbulently with cold deep-ocean seawater can rise hundreds of meters through the water column before attaining neutral buoyancy. These plumes can then be detected for kilometers or more away from their source, as they disperse."

Your challenge is to design a model that shows a plume rising through a water column, then forming a neutrally buoyant layer somewhere between the bottom and surface of the water column. Your model should demonstrate the processes that are involved in forming a hydrothermal vent plume from the time the hydrothermal fluid enters the cold deep-ocean seawater until the neutrally buoyant plume is formed.

Use the Engineering Design Process (see Box on page 21) and fill in each of the Guided Design steps below.

1. Define the problem.

State the problem in your own words:

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Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:

- Define the problem
- Gather relevant information
- Brainstorm possible solutions
- Analyze possible solutions and select the most promising
- Test the solution by building a prototype
- Revise and improve the solution
- Repeat previous steps until results are acceptable
- Report the design process and results

These steps involve several key skills:

- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

2. Gather relevant information.

List the processes you need to demonstrate with your model:

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3. Brainstorm possible solutions.

Use words or sketches to describe some possible solutions. Remember that your design is constrained by the requirements that it must be practical to actually do the demonstration in an average classroom, and not require any specialized or expensive equipment.

4. Analyze possible solutions and select the most promising.

State which of the possible solutions is most promising and why:

5. Test the solution by building a prototype.
Provide details of your test, and the results:

6. Revise and improve the solution.
Describe modifications that you think might improve your design:

7. Report the design process and results.

Summarize your conclusions: