INSPIRE: Chile Margin 2010

Reduced Fare

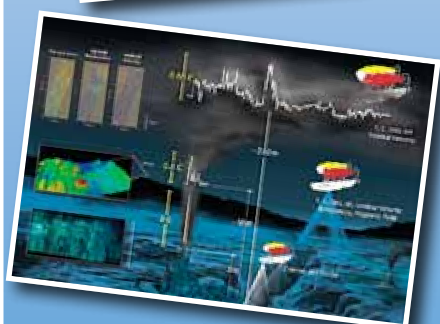


Image captions/credits on Page 2.

lesson plan

Focus

Deep-sea reducing environments

Grade Level

9-12 (Biology/Chemistry)

Focus Question

What are reducing environments, and where do they occur in the deep ocean?

Learning Objectives

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

Materials

- Copies of *Reducing Environments Inquiry Guide*, one copy for each student group
- Copies of Tunnicliffe *et al.*, 1999 (see Resources); one copy for each student group
- Materials for demonstrating an electric current produced by a redox reaction:

  For each student group:
  - 2 Tablespoons salt
  - 2 Tablespoons warm water
  - Dish for mixing salt and water
  - Cellulose sponge, approximately 2" square
  - Aluminum foil, approximately 4" square
  - Paper plate
  - Inexpensive multimeter (Radio Shack Part Number 22-810 or or equivalent)
  - 2 Jumper cables (Radio Shack Part Number 278-1157 or equivalent)
  - 2" length of graphite from a carpenter's pencil

Audio-Visual Materials

- (Optional) video or computer projection equipment to show images from the INSPIRE: Chile Margin 2010 Web page (http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html)

Teaching Time

Two 45-minute class periods, plus time for student assignments

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

Hydrothermal vent
Reducing environment
Cold seep
Whale fall
Reduction
Oxidation
Redox
Chile Triple Junction

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.

Earthquakes and volcanoes are among Earth's most spectacular and terrifying geological events. The Mount St. Helens eruption of 1980 (5.1 magnitude) and the Haiti (7.0 magnitude) and Chile (8.8 magnitude) earthquakes of 2010 are recent and memorable examples of the extreme power that often accompanies these events. The Indian Ocean tsunami of 2004 was caused by an underwater earthquake that is estimated to have released the energy of 23,000 Hiroshima-type atomic bombs, and caused the deaths of more than 150,000 people.

Volcanoes and earthquakes are both 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

Images from Page 1 top to bottom:
Map of the Southeast Pacific Ocean and South American continent showing the Chile Rise spreading center, the Peru-Chile Margin, and the location of the Chile Triple Junction. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/geology/media/geology1.html

Our 3-phased approach to ocean exploration with ABE. First, guided by chemical measurements made aboard ship, we program ABE to fly around within the water column "sniffing" for where the chemical signals are strongest using specialized in situ sensors. Second, once we know where the strongest chemical signals from a hydrothermal vent are, we program ABE to fly closer to the seafloor, making detailed maps of the seabed and, ideally, also intercepting the stems of hot buoyant hydrothermal plumes of water rising up above the seafloor. Third, and finally, we program ABE up once more to descend to right above the seabed and drive to and fro, very carefully – using obstacle avoidance techniques to stop it from crashing into the rough rocky terrain it finds – while taking photographs of whatever it is we have found: hydrothermal vents, cold seeps, and whatever new and unique animals they might host. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html

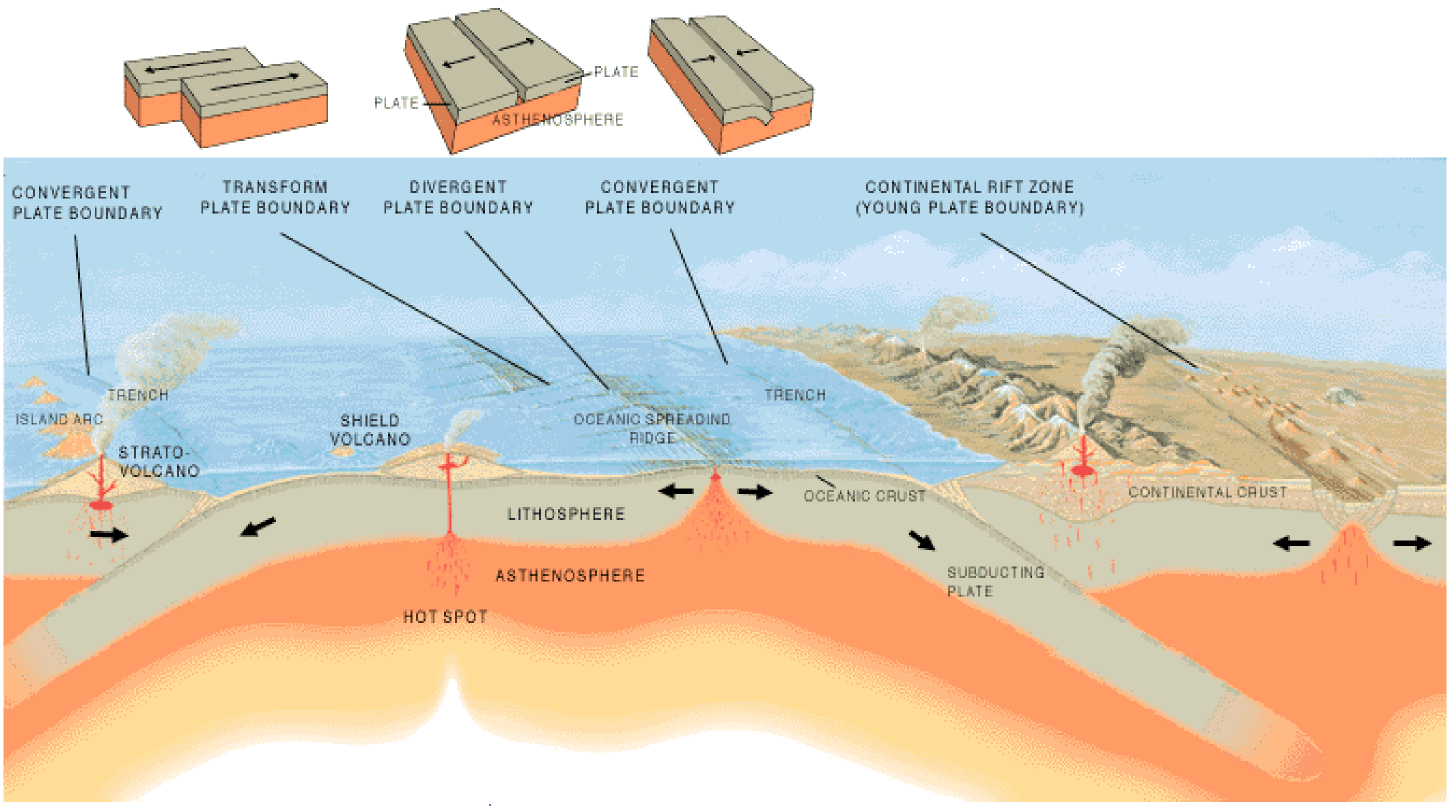
The ABE (Autonomous Benthic Explorer) autonomous underwater vehicle (free-swimming robot) about to be set loose to explore the bottom of the SW Indian Ocean from aboard the Chinese research ship RV Da Yang Yi Hao in Spring 2007. Over the past 5 years, ABE has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/plan/media/missionplan3.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

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.

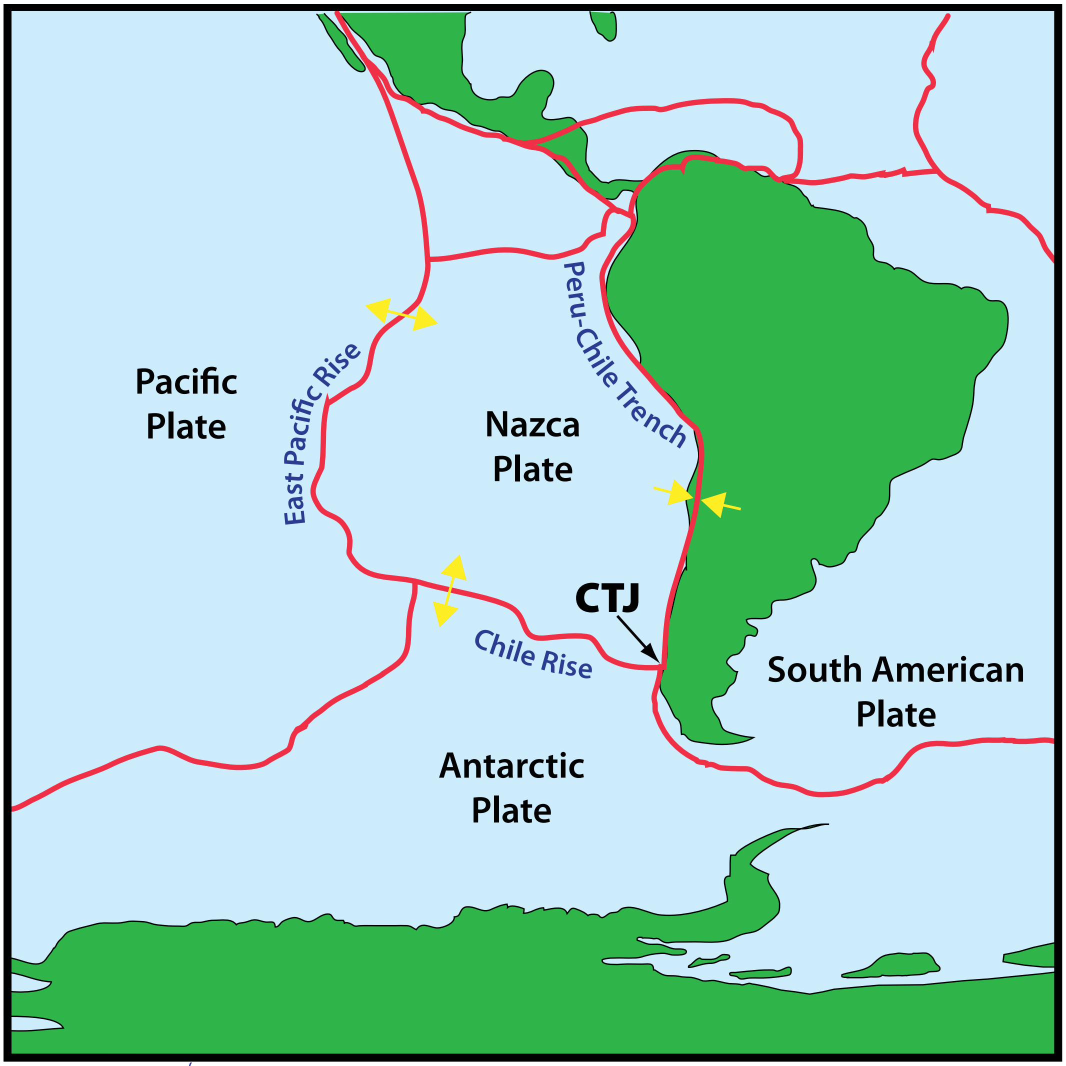
Figure 1: Types of Plate Boundaries



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

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 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

Figure 2: Chile Triple Junction



of the neighboring trenches. View the 3-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 3-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

Along the western coast of Chile, three of Earth's tectonic plates intersect in a way that does not occur anywhere else on the planet (see

Figure 2). Chile, and the other countries of South America, lie on top of the South American tectonic plate. To the west of Chile, the Nazca Plate extends beneath the Pacific Ocean and meets the Pacific Plate along a divergent plate boundary called the East Pacific Rise. The southern edge of the Nazca Plate adjoins the Antarctic Plate along another divergent plate boundary called the Chile Rise. The eastern edge of the Chile Rise is being subducted beneath the South American plate at the Chile Triple Junction (CTJ), which is unique because it consists of a mid-oceanic ridge being subducted under a continental tectonic plate. The eastern portion of the Nazca Plate is also being subducted along the Peru-Chile Trench, and the Andes mountains are one consequence of this process. Not surprisingly, complex movements of three tectonic plates at the CTJ result in numerous earthquakes. In fact, the largest earthquake ever recorded (magnitude 9.5) occurred along the Peru-Chile Trench in 1960. While earthquakes and volcanoes are often associated with massive destruction and loss of human life, the same processes that cause these events are also responsible for producing unique habitats for very different life forms.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977 at a divergent plate boundary near the Galapagos 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 the movement of tectonic plates causes deep cracks to form in the ocean floor. Seawater flows into these cracks, is heated by magma, and then rises back to the surface of the seafloor. The water does not boil because of the high pressure in the deep ocean, but may reach temperatures higher than 350° C. This superheated water dissolves minerals in Earth's crust. Hydrothermal vents are locations where the superheated water erupts through the seafloor. The temperature of the surrounding water is near-freezing, which causes some of the dissolved minerals to precipitate from the solution. This makes the hot water plume look like black smoke, and in some cases the precipitated minerals form chimneys or towers.

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 a process 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. Energy for chemosynthesis in the vicinity of hydrothermal vents often comes from hydrogen sulfide.

In chemosynthetic communities where hydrogen sulfide is present, large tubeworms known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. Vestimentifera have been regarded previously as a distinct phylum or a group within the phylum Pogonophora. Recent molecular evidence suggests that Vestimentifera and Pogonophora should be considered part of the polychaete family Siboglinidae within the phylum Annelida. These unusual animals do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Vestimentiferans have tentacles that extend into the water. The tentacles are bright red due to the presence of hemoglobin which can absorb hydrogen sulfide and oxygen and transport these chemicals to bacteria in the trophosome. The bacteria produce organic molecules that provide nutrition to the tube worm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills. Bacteria are also found living independently from other organisms in large bacterial mats. A variety of other organisms are also found in cold seep communities, and probably use tubeworms, mussels, and bacterial mats as sources of food. These include snails, eels, sea stars, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships among these organisms have not been well-studied. Visit http://www.pmel.noaa.gov/vents/about.html for more information and activities on hydrothermal vent communities.

Ocean explorers have also discovered chemosynthetic communities that use other forms of chemical energy. Cold seeps are areas where hydrocarbon gases (such as methane) or oil seep out of sediments commonly found along continental margins. Like hydrothermal vents, cold seeps are home to many species of organisms that have not been found anywhere else on Earth. Typical features of cold seep communities include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Chemosynthetic communities also are found in other deep ocean habitats. In some parts of the ocean, dissolved oxygen concentration is very low, usually because oxygen has been depleted by large amounts of decaying organic matter. Under these conditions, hydrogen sulfide builds up and can support communities of organisms similar to those found near hydrothermal vents and cold seeps. These communities are also found around dead whales (called whale falls) and large masses of dead kelp or trees. Deepwater chemosynthetic communities 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.

Chemosynthesis depends upon the availability of reducing substances such as hydrogen sulfide or methane that can donate electrons. Habitats in which these substances occur are called reducing habitats. In this lesson, students will investigate some of the characteristics of reducing habitats in the deep ocean.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the INSPIRE: Chile Margin 2010 Expedition at http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html
   (b) Review the *Reducing Environments Inquiry Guide*, and key points in Step 4.
   (c) Review the procedure for demonstrating an electric current flow from a redox reaction (Step 6). This may be done by individual student groups or as a class demonstration, depending upon time and available materials. Many variations on this procedure may be found on the internet, often described as "lemon battery," "potato battery," etc., though the electric current is not produced by the vegetable but rather by dissimilar metals inserted into the vegetable. The vegetable itself provides an electrolyte that allows electrons to flow from the metal being oxidized to the metal being reduced.

2. Introduce the the INSPIRE: Chile Margin 2010 Expedition, and briefly review the geologic conditions that are associated with the presence of hydrothermal vents. If necessary, review the concept of chemosynthesis, and contrast this process with photosynthesis.

3. Be sure students understand the concepts of oxidation, reduction, oxidizing agent, and reducing agent. You may want to suggest one of the following mnemonics that help recall definitions for these terms:

"LEO (the astrological lion) says GER"
(Lose Electron = Oxidized; Gain Electron = Reduced)
or
"OIL RIG"
(Oxidize Is Losing; Reduce is Gaining)

Tell students that their assignment is to investigate deep-sea reducing environments (such as may occur at the CTJ) using an article published in a technical journal. Say that some terms in scientific articles may be unfamiliar, because authors try to make precise statements that sometimes involve a specialized vocabulary. Definitions for most terms can be found easily with keyword searches. In some cases, it is helpful to separate a difficult sentence into smaller parts. You may want to briefly discuss these examples:

Geothermal processes supply reduced chemical species which, through microbial mediation, provide chemical energy for production of organic carbon.
"Geo" refers to earth and "thermal" refers to heat; "chemical species" means chemical compounds or molecules; "microbial mediation" refers to processes that involve micro-organisms such as bacteria; "organic carbon" refers to chemical substances that contain carbon and are produced by living organisms. So this sentence says that heat from the Earth produceds molecules that have gained one or more electrons, and these molecules are used by micro-organisms to produce various chemicals found in living organisms.

Organic carbon in sediments is oxidized to methane by biogenic or thermogenic processes.
"Organic carbon" refers to chemical substances that contain carbon and are produced by living organisms; "biogenic" means produced by living organisms; "thermogenic" means produced by heat. So this sentence says that in sediments, living organisms or heat can cause carbon-containing substances to lose electrons, resulting in the formation of methane.

Epilithic and epizoic growth have been little studied at cold seeps.
"Epilithic" means on rock; epizoic means on animals. So the sentence says that organisms growing on rocks or animals in cold seep habitat haven't been studied very much.

4. Provide each student group with a copy of the *Reducing Environments Inquiry Guide* and the article by Tunnicliffe *et al.* (1999). You may want to have students answer questions on the *Guide* in written reports, or prepare notes for oral presentations.

5. Lead a discussion of students' results. The following points should be included:
   - A "reducing environment" is a habitat in which there are chemicals (such as hydrogen sulfide or methane that can donate electrons to other compounds.

- Oxygen is usually low in a reducing environment because oxygen reacts with reducing substances to form other compounds.

- Reducing environments found in the deep ocean include hydrothermal vents, cold seeps, organic remains, dysaerobic basins, and anoxic sediments and crustal rocks.

- Reduced chemicals that are typically abundant in these reducing environments include hydrogen sulfide (hydrothermal vents); methane, petroleum, and/or other hydrocarbon gases (cold seeps); organic compounds such as lipids from whale carcasses, and materials that produce hydrogen sulfide when they decay (organic remains); chemicals produced by anaerobic decay of organic material (dysaerobic basins); and fossil organic material that can be used by anaerobic micro-organisms (anoxic sediments and crustal rocks); note that some of these micro-organisms are capable of producing methane which provides energy to cold-seep environments.

- "Salt tectonics" refers to eruptions of ancient salt deposits that are lighter than overlying sediments and tend to push upward, causing deep cracks that provide conduits for underlying methane and petroleum to move upward through the sediment.

- The decaying bodies of large marine reptiles of the Jurassic and Triassic Periods may have provided the first habitats for organisms found in modern reducing environments of the deep ocean.

- Substrates found in deep ocean reducing environments include structures produced by precipitated minerals from hydrothermal fluids, such as sulfide chimneys and towers; bones; sediments; rock from volcanic eruptions; external surfaces of animals such as tube worms and mussel shells; carbonate structures formed by oxidation of methane (the oxidation reaction forms bicarbonate, which subsequently reacts with calcium in seawater to form solid structures; and methane hydrate deposits.

- The range of temperatures reported from black smoker vents is about 2°C to 350–400°C.

- Most animals are found in habitats whose temperature is less than 30°C.

- Hydrogen sulfide is present in most seafloor reducing habitats that are colonized by animals and/or microorganisms.

- Hydrothermal fluids are the most chemically complex reducing solutions found in the marine environment.

- At hydrothermal vents, the fundamental energy source is heat from Earth's mantle that forms hydrothermal fluids containing sulfide and other reduced chemicals. At cold seeps, the fundamental energy source is degradation of organic matter in sediments which produces methane and other hydrocarbons. Since much of this organic matter comes from the remains of plants and animals from ecosystems in overlying ocean, it is reasonable to argue that the fundamental energy source is the sun that fuels production of organic material in these ecosystem.

- Chemolithoautotrophy is the production of organic carbon compounds using chemical energy obtained from the reduction or oxidation of non-organic compounds. Sulfide oxidation is probably the most important energy source for chemolithoautotrophy in seafloor hydrothermal systems. Methane oxidation is probably the most important energy source for chemolithoautotrophy in cold-seep ecosystem along continental margins.

- In addition to chemosynthesis, heterotrophic metabolism may be important to nutrient cycling and energy flow in reducing environments.

- Vestimentifera have a specialized organ known as the trophosome that contains symbiotic bacteria. Chemicals for chemosynthesis are taken up from the surrounding water by the tubeworm's branchial plume (a sort of gill) and transported to the trophosome by the tubeworm's blood. Vestimentifera have no mouth or digestive system, and obtain all of their nutrition from symbiotic bacteria. Vesicomyid clams have symbiotic bacteria in their gills, which also take up oxygen and carbon dioxide. Hydrogen sulfide is taken up through the clam's foot, which is inserted into sulfide-rich sediments and transported to the gills by the clam's blood. Vesicomyid clams have a digestive system and are capable of filter-feeding, but the digestive system is greatly reduced and the clams cannot live without their symbionts (in this case, "reduced" means that the digestive system is very small). Bathymodiolid mussels also have bacterial symbionts in their gills, but they have a functional digestive system and obtain at least some of their nutrition from filter-feeding.

- "Endemic to vent environments" means that the organisms aren't found anywhere else. Whale carcasses and other reducing environments might be important to the development of living communities in vent environments by providing "stepping stones" for the dispersal of animals between these environments.

- Species diversity in reducing environments is generally lower than in other deep-sea environments, because reducing environments are often less stable due to geologic processes.

6. Have students demonstrate an electric current produced by a redox reaction. A simple procedure for doing this is:
   (a) Prepare an electrolyte solution by mixing 2 tablespoons salt with 2 tablespoons warm water.
   (b) Soak a 2" x 2" piece of cellulose sponge in the electrolyte solution. The sponge should be moist but not dripping.
   (c) Place a 4" x 4" square of aluminum foil on a paper plate, and attach one end of a jumper cable to the edge of the foil. Connect the other end of the jumper cable to the negative lead of a multimeter set to measure volts (if you can adjust the range of the meter, it should be set to a maximum of 2 volts).
   (d) Place the electrolyte-soaked sponge on top of the aluminum foil. Take care that the sponge does not touch the jumper cable.
   (e) Connect one end of a second jumper cable to a 2" piece of graphite from a pencil. Connect the other end of the jumper cable to the positive lead of the multimeter. Touch the other end of the graphite to the top of the sponge and read the voltage on the multimeter.

7. Discuss the redox reaction that produced the voltage in Step 6. Aluminum metal reacts with oxygen in air and water in the electrolyte to form aluminum hydroxide. The aluminum loses electrons (so it is oxidized) and oxygen gains electrons (so it is reduced). The reactions are:

$$Al + 3\ OH^- > Al(OH_3) + 3\ e^-$$

$$O_2 + 2\ H_2O + 4\ e^- > 4\ OH^-$$

The overall reaction is:

$$4\ Al + 3\ O_2 + 6\ H_2O > 4\ Al(OH_3)$$

Electrons flow from the aluminum, through the multimeter, through the graphite electrode, and through the electrolyte solution to the junction of the electrolyte solution and the aluminum foil where the reaction with oxygen takes place. The purpose of the salt is to provide ions that allow electrons to flow.

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

Considering that humans could not survive in most reducing environments without special life support equipment, have students write a short essay discussing at least one reducing environment that is personally beneficial or important.

Connections to Other Subjects

English/Language Arts

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html for the latest activities and discoveries by the INSPIRE: Chile Margin 2010 Expedition.
2. Visit http://oceanexplorer.noaa.gov/edu/learning/welcome.html for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, and Chemosynthesis and Hydrothermal Vent Life. Click on links to Lessons 1, 2, 4, and 5 respectively.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Chemosynthesis for the Classroom

(PDF, 274 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_chemo_gr912.pdf

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

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

Hydrothermal Vent Challenge

(PDF, 412 kb) (from the Submarine Ring of Fire 2004 Expedition)
http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.ventchall.pdf

Focus: Chemistry of hydrothermal vents (Chemistry)

Students will be able to define hydrothermal vents and explain the overall processes that lead to their formation. Students will be able to explain the origin of mineral-rich fluids associated with hydrothermal vents. Students will be able to explain how black smokers and white smokers are formed. Students will be able to hypothesize how properties of hydrothermal fluids might be used to locate undiscovered hydrothermal vents.

Where There's Smoke, There's ...
(PDF, 248 kb) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_smoke.pdf

Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry)

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

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

Focus: Hydrothermal vents (Physical Science)

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

The Census of Marine Life
(PDF, 300 kb) (from the 2007: Exploring the Inner Space of the Celebes Sea Expedition]
http://oceanexplorer.noaa.gov/explorations/07philippines/background/edu/media/census.pdf

Focus: The Census of Marine Life (Biology)

In this activity, students will be able to describe the Census of Marine Life (CoML) and explain in general terms the CoML strategy for assessing and explaining the changing diversity, distribution and abundance of marine species from the past to the present, and for projecting the future of marine life. Students will also be able to use the Ocean Biogeographic Information System to retrieve information about ocean species from specific geographic areas.

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

Focus: Mid-Ocean Ridges (Earth Science)

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

This Life Stinks
(PDF, 276 kb) (from the 2003 Windows to the Deep Expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_lifestinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

In this activity, students will be able to define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

This Old Tubeworm
PDF, 484 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_oldtube.pdf

Focus: Growth rate and age of species in cold-seep communities (Life Science)

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals of the same species. Students will also be able to estimate the age of an individual of a specific size, given information on age-specific growth in individuals of the same species.

Where Did They Come From?
(PDF, 296 kb) (from the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition)
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_biogeography.pdf

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

In this activity, students will 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.

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/explorations/10chile/welcome.html – Web site for the INSPIRE: Chile Margin 2010 Expedition

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

Tunnicliffe, V., S. Juniper, M. Sibuet. 1999. Reducing Environments of the Deep-Sea Floor. In: P. Warneck (ed) Chemistry of the natural atmosphere. Academic Press. San Diego. 927 pp (available online at http://cmbc.ucsd.edu/Students/Current_Students/SIO277/ch4%20reducing%20env.pdf)

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Chemical reactions

Content Standard C: Life Science
- The cell
- Interdependence of organisms
- Matter, energy, and organization in living systems

Content Standard D: Earth and Space Science
- Energy in the earth system
- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives
- Natural resources

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
Fundamental Concept 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.

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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Layout and design by Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov/

Reduced Fare

Reducing Environments Inquiry Guide

1. What is a "reducing environment?"

2. Why is oxygen usually low in a reducing environment?

3. List at least three different reducing environments that are found in the deep ocean.

4. Name the reduced chemicals that are typically abundant in each of the reducing environments listed.

5. What are "salt tectonics?"

6. How may the large marine reptiles of the Jurassic and Triassic Periods have influenced modern reducing environments in the deep ocean?

7. What types of substrates (habitats for animals) are found in deep ocean reducing environments?

8. What is the range of temperatures reported from black smoker vents?

9. Most animals are found in habitats whose temperature is less than ____________

10. What chemical is present in most seafloor reducing habitats that are colonized by animals and/or microorganisms?

11. What are the most chemically-complex reducing solutions found in the marine environment?

12. Compare and contrast the energy source for hydrothermal vent and cold seep ecosystem.

13. What is chemolithoautotrophy? What is the most important energy source for chemolithoautotrophy in seafloor hydrothermal systems? What is the most important energy source for chemolithoautotrophy in cold-seep ecosystem along continental margins?

14. In addition to chemosynthesis, what other form of energy metabolism may be important to nutrient cycling and energy flow in reducing environments?

15. Compare and contrast symbiotic associations in vestimentiferan tube worms, vesicomyid clams, and bathymodiolid mussels.

16. "Many animals in vent environments are endemic." What does this mean? How might whale carcasses be important to living communities in vent environments?

17. Is species diversity in reducing environments generally higher or lower than in other deep-sea environments?