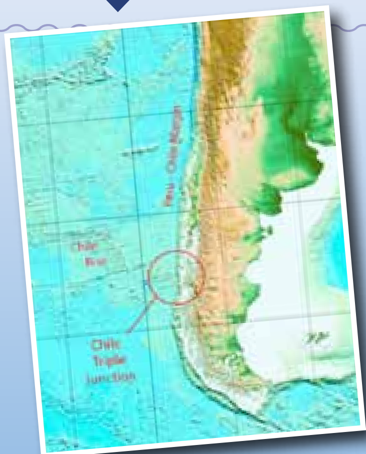
ocean explorer
www.oceanexplorer.noaa.gov



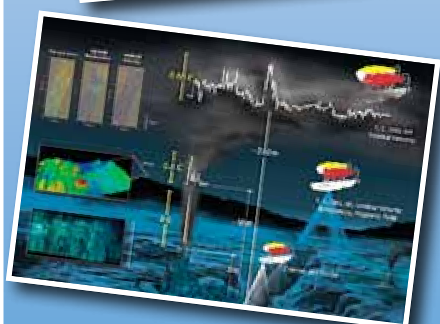


Image captions/credits on Page 2.

lesson plan

INSPIRE: Chile Margin 2010

The Chemosynthetic Cafe

Focus
Chemosynthesis in hydrothermal vent ecosystems

Grade Level
9-12 (Biology/Chemistry)

Focus Question
How is energy obtained and transferred in photosynthesis and chemosynthesis, and how are these processes similar and different?

Learning Objectives
- Students will compare and contrast photosynthesis and chemosynthesis.
- Students will define oxidation and reduction as these terms apply to electron transfer.
- Students will explain the overall process by which energy is captured and transferred during photosynthesis and chemosynthesis.

Materials
- ❑ None

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
Autotroph
Photosynthesis

Chemosynthesis
Electron transport
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 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 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

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

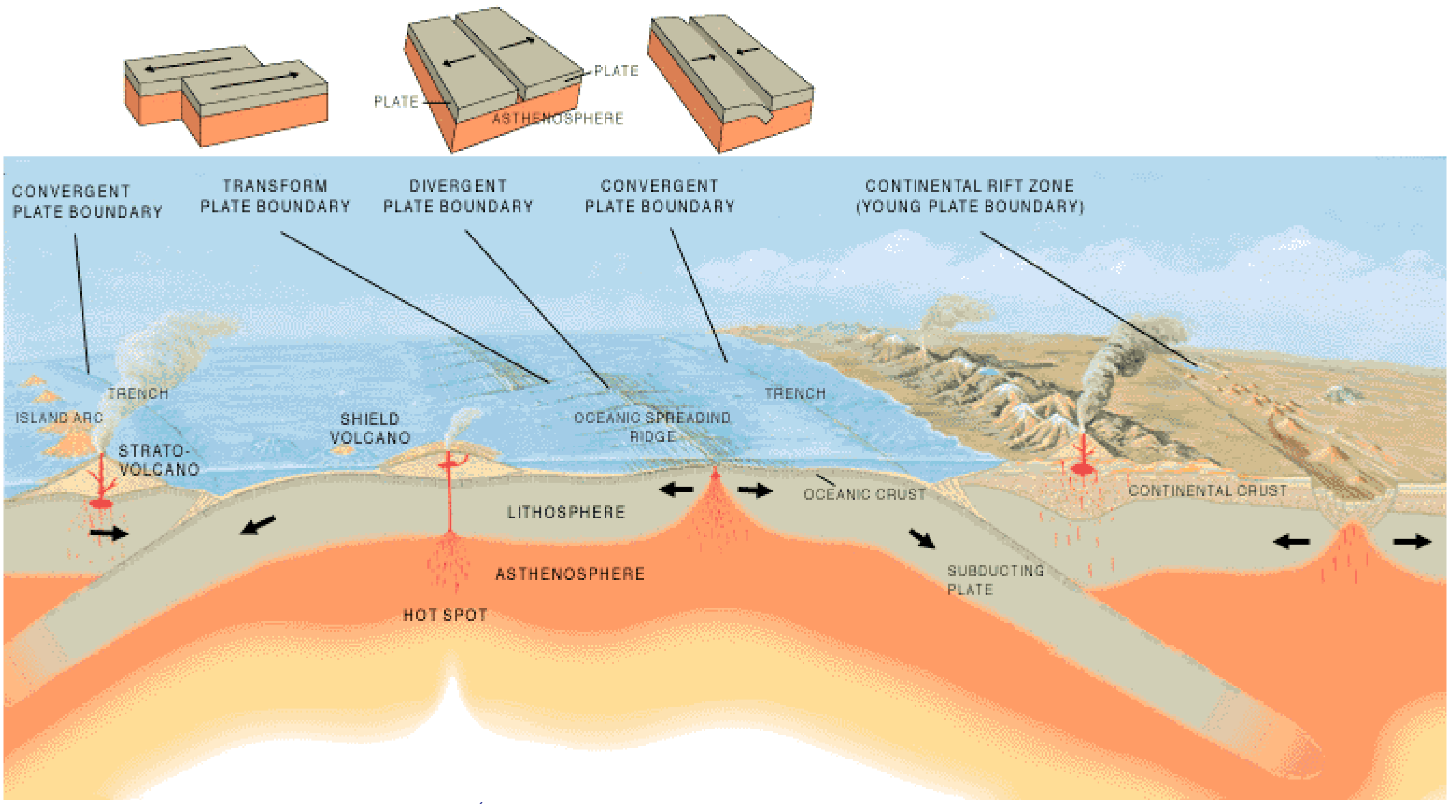
Our 3-phased approach to ocean exploration with ABE. First, guided by chemical measurements made aboard ship, we program ABE to fly around within the water column "sniffing" for where the chemical signals are strongest using specialized in situ sensors. Second, once we know where the strongest chemical 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

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

Figure 1: Types of Plate Boundaries

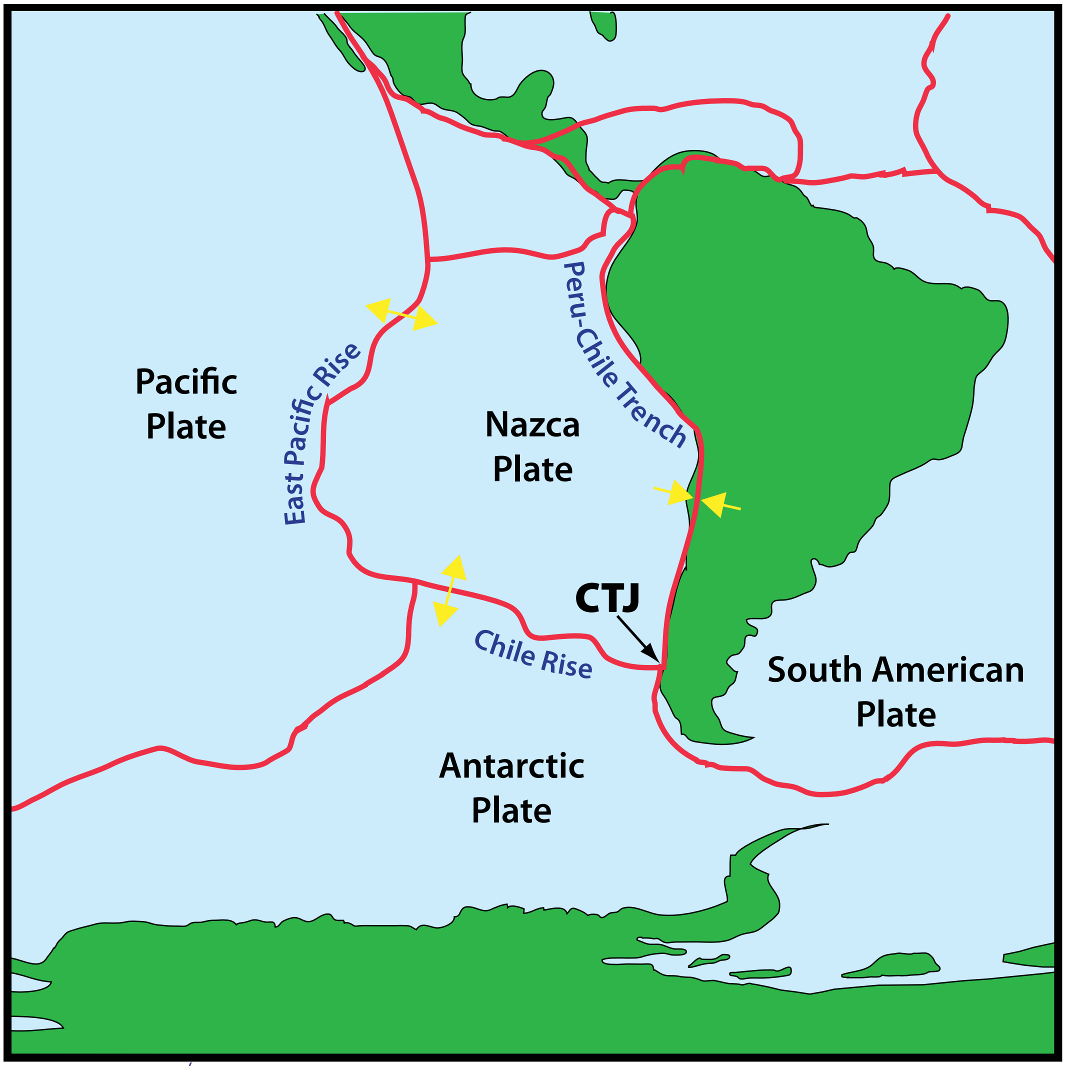


Artist's cross section illustrating the main types of plate boundaries. (*Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.*)
http://pubs.usgs.gov/gip/dynamic/Vigil.html

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

Figure 2: Chile Triple Junction



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.

Learning Procedure

The purpose of this lesson is to compare and contrast photosynthesis and chemosynthesis, and to reinforce students' understanding of the role of oxidation and reduction reactions in transferring energy in both processes. The activity described in Step 3 was suggested by a lesson plan on glycolysis, Krebs cycle, and electron transport chains by Regina Lamendella (http://www.eng.uc.edu/STEP/step_Lessons/gina_lamednella/Leslie%20Hadaway%20Respiration%20Lesson/Lamendella_R_08_Major2_LessonPlan.doc).

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 concepts and procedures in Steps 2 and 3. Because curricula vary widely in the amount of detail students are expected to master concerning topics of photosynthesis and metabolism, some modification may be needed to the information presented and discussed in these steps.

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 students are not familiar with hydrothermal vents, provide a brief overview, emphasizing that vents are associated with unique ecosystems whose food webs are based on energy from chemical reactions, in contrast to more familiar ecosystems whose food webs are based on energy from the sun. You may want to show images or video of vents from http://www.pmel.noaa.gov/vents/multimedia.html. Tell students that a primary objective of the INSPIRE: Chile Margin 2010 Expedition is to locate previously undiscovered hydrothermal vent ecosystems in the vicinity of the Chile Triple Junction.

   If necessary, review the basic concepts of photosynthesis, chemosynthesis, autotroph and heterotroph. Display definitions of photosynthesis and chemosynthesis so they are visible to all students. If your curriculum does not prescribe specific definitions for these processes, the following may be used:

   - "Photosynthesis is the process by which plants convert carbon dioxide into organic compounds, using energy from sunlight."
   - "Chemosynthesis is the process by which organisms convert carbon molecules (usually carbon dioxide or methane) into organic compounds using energy from the oxidation of other molecules."

   Ask students how photosynthesis and chemosynthesis are similar, and how they are different. Students should realize that both process involve the conversion of carbon compounds into organic molecules (especially carbohydrates), and both require a source of energy. Differences include the fact that photosynthesis is carried out only by plants, while a variety of organisms are capable of chemosynthesis; and the source of energy for photosynthesis is light, while the energy for chemosynthesis comes from other chemical reactions.

   Ask students why photosynthesis and chemosynthesis are important in ecosystems? Students should identify the primary importance of both as providing a source of energy for life processes among organisms that make up ecosystems.

Show students the following equations that are often used to summarize photosynthesis and chemosynthesis:

- Photosynthesis:

$$6\ CO_2 + 6\ H_2O > C_6H_{12}O_6 + 6\ O_2$$

Carbon dioxide and water react to form glucose (sugar) and oxygen.

- Chemosynthesis:

$$6\ CO_2 + 6\ H_2S > C_6H_{12}O_6 + 6\ S$$

Carbon dioxide and hydrogen sulfide react to form glucose and sulfur.

Note that other equations may be used as examples of chemosynthesis, since this process can involve a variety of different reactants.

Ask students what these equations explain about energy production by photosynthesis and chemosynthesis. Students should realize that there is no term in these equations that represents energy. Better versions would be:

$$6\ CO_2 + 6\ H_2O + \text{energy} > C_6H_{12}O_6 + 6\ O_2$$

Carbon dioxide and water, plus light energy, react to form glucose (sugar) and oxygen.

and

$$6\ CO_2 + 6\ H_2S + \text{energy} > C_6H_{12}O_6 + 6\ S$$

Carbon dioxide and hydrogen sulfide, plus chemical energy, react to form glucose and sulfur.

But these versions really don't explain where the energy comes from or how it is transferred. At the high school level, students should understand that:

- Photosynthesis and chemosynthesis involve many chemical reactions, and many other compounds in addition to those identified in the summary equations; and
- Energy is transferred between molecules through the exchange of electrons.

Be sure students understand the concepts of reduction and oxidation as they apply to the exchange of electrons between molecules. When a molecule gains an electron it is said to be reduced; when a molecule loses an electron, it is said to be oxidized. Two mnemonics that help recall these definitions are:

"LEO (the astrological lion) says GER"
(Lose Electron = Oxidized; Gain Electron = Reduced)

and

"OIL RIG"
(Oxidize Is Losing; Reduce is Gaining)

Discuss the overall processes of energy transfer in photosynthesis and chemosynthesis:

In general, when a molecule gains an electron, it gains energy. Photosynthesis includes two sets of reactions called Photosystem I and Photosystem II. Both begin when a photon of radiant energy from the sun strikes a molecule of chlorophyll or other photosynthetic pigment. This energy causes the photosynthetic pigment molecule to release an electron that is captured by another organic molecule. In Photosystem I, the energy of electron transfer forms NADPH, a high-energy molecule that can provide energy needed for other reactions to occur that produce a variety of organic molecules.

In Photosystem II, the electron released by the photosynthetic pigment is passed along an "electron transport chain" that involves pheophytin, plastoquinone, cytochrome b6f complex, and plastocyanin. Each time an electron is transferred, the molecule that gains the electron also gains energy; and the molecule that loses the electron loses energy. Some of the energy released in the electron transport chain drives the formation of ATP, another high-energy molecule that can provide energy to a variety of reactions that synthesize other compounds. The photosynthetic pigment regains its lost electron from a water molecule through a series of reactions called photolysis that release oxygen gas as a by-product. Collectively, these steps are called the light-dependent reactions of photosynthesis. [Notes: (1) Small amounts of ATP are also formed in Photosystem I, but most ATP synthesis involves Photosystem II; (2) ATP synthesis takes place through a process known as chemiosmosis which is not a redox reaction, but the energy for chemiosmosis originates from redox reactions in the electron transport chain.]

Point out that carbon dioxide and carbohydrate synthesis are not involved in these reactions; at this stage, it's all about capturing energy. Subsequently, photosynthetic organisms use this energy in a series of light-independent reactions (also called the Calvin-Benson cycle) to convert carbon dioxide into organic molecules (e.g., sugars, amino acids, lipids) that can serve as sources of energy and substances needed by other organisms.

In chemosynthesis, the energy transfer process begins with the loss of an electron from a substance such as hydrogen sulfide or methane. Chemosynthesis can involve a variety of chemicals that can serve as electron donors, as well as a variety of reaction pathways. Details of chemosynthetic reactions in deep-sea ecosystems are not yet fully understood. At least some of these systems involve electron transport chains that provide energy for the synthesis of ATP. As in the light-independent reactions of photosynthesis, this energy is used to convert carbon dioxide into molecules that can serve as sources of energy and substances needed by living organisms. Known chemosynthetic organisms from deep-sea environments are bacteria or Archaea, and these microbes often are the basis of complex food webs.

If students are not familiar with the concept of electron transport chains, you may want to show the animation: http://www.truveo.com/Electron-Transport-Chain-Animation-Overview/id/3589599027. This illustrates electron transport associated with glycolysis, but the overall concept is similar for other electron transport chains.

3. Tell students that their assignment is to explain energy transfer in photosynthesis and chemosynthesis by creating a short skit that illustrates the major energy transfer steps involved in one of these processes. To complete this assignment, students will have to identify these steps, the chemical compounds involved, and decide how to “act out” the energy transfer steps. The steps for photosynthesis are easily identified as outlined above. As noted, the steps for chemosynthesis are not as well-known, particularly for deep-sea organisms. If students have difficulty finding suitable information, suggest that they use an electron transport chain that consists of flavin, cytochrome c, and cytochrome d, which has been documented for the sulfide-oxidizing bacterium, *Thiobacillus denitrificans* (Aminuddin and Nicholas, 1974).

   One of the simplest approaches to acting out the energy transfer steps would be to write the names of the compounds on separate sheets of paper, then have students assume the role of one or more compounds and pass a tennis ball (or other object representing electrons) from one student to another in the appropriate sequence. At each transfer, students should identify which compound is oxidized and which compound is reduced. ATP production will not involve a specific electron transfer step, but can be an event that occurs during the transfer of electrons through electron transport chains.

4. Have each student group present their skit to the other students. Be sure students are arranged so that everyone can see the action (e.g., in a round-table format).

5. Discuss and reinforce the following concepts:
   - Source of energy for photosynthesis and chemosynthesis
   - Mechanism of energy transfer in photosynthesis and chemosynthesis
   - The role of carbon dioxide, water, and oxygen
   - The role of ATP and NADPH in energy transfer

   Be sure students realize that oxygen is a vital part of chemosynthetic food webs, even though it is not a product of chemosynthetic reactions (in contrast to photosynthesis). Like most metazoans, animals in chemosynthetic ecosystems preferentially obtain metabolic energy from aerobic respiration in which oxygen is the final electron acceptor in a series of electron transfers.

The BRIDGE Connection

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

The "Me" Connection

Have students write a short essay discussing the personal importance of photosynthetic and chemosynthetic autotrophs.

Connections to Other Subjects

English/Language Arts

Assessment

Student presentations 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.
3. Student skits may also be used to model other biochemical processes, such as aerobic and anaerobic respiration, Calvin-Benson cycle, Krebs cycle, etc.

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

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

In this activity, 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 f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature,

oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

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For More Information

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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/