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Thunder Bay Sinkholes 2008

Entering the Twilight Zone
(adapted from the 2002 Gulf of Mexico Expedition)

Focus
Deep water habitats

Grade Level
5-6 (Life Science)

Focus Question
What organisms are typical of deep water habitats, and how do they interact?

Learning Objectives
Students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities.

Students will be able to infer probable trophic relationships within and between major deep-sea habitats.

Students will be able to describe the process of chemosynthesis in general terms, and will be able to contrast chemosynthesis and photosynthesis.

Students will be able to describe major deep-sea habitats and list at least three organisms typical of each habitat.

Materials
- ❒ 5 x 7 index cards
- ❒ Drawing materials
- ❒ Corkboard, flip chart, or large poster board

Audiovisual Materials
- ❒ None

Teaching Time
Two 45-minute class periods, plus time for individual group research

Seating Arrangement
Groups of four students

Maximum Number of Students
32

Key Words
Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Trophic level
Pelagic zone
Epipelagic zone
Mesopelagic zone
Bathypelagic zone
Hadopelagic zone
Benthic zone
Intertidal zone
Subtidal zone
Bathyal zone
Abyssal zone
Hadal zone
Hydrothermal vent

Background Information
In June, 2001, the Ocean Explorer Thunder Bay ECHO Expedition was searching for shipwrecks in the deep waters of the Thunder Bay National Marine Sanctuary and Underwater Preserve in Lake Huron. But the explorers discovered more

than shipwrecks: dozens of underwater sinkholes in the limestone bedrock, some of which were several hundred meters across and 20 meters deep. The following year, an expedition to survey the sinkholes found that some of them were releasing fluids that produced a visible cloudy layer above the lake bottom, and the lake floor near some of the sinkholes was covered by conspicuous green, purple, white, and brown mats.

Preliminary studies of the mats have found that where water is shallow ($\leq$ 1.0 m) the mats are composed of green algae. In deeper (about 18 m) waters, mats are formed by filamentous purple cyanobacteria. Mats near the deepest (93 m) sinkholes are white or brown, but their composition is presently unknown. The appearance of mats near the deepest sinkholes is very similar to mats observed in the vicinity of cold seeps and hydrothermal vents in the deep ocean, which are often formed by chemosynthetic bacteria. These bacteria are able to obtain energy from inorganic chemicals, and are a food source for a variety of other organisms that inhabit cold seep and vent communities. Biological communities whose primary energy source comes from chemosynthesis are distinctly different from more familiar biological communities in shallow water and on land where photosynthetic organisms convert the energy of sunlight to food that can be used by other species. Hydrothermal vent and cold seep communities are home to many species of organisms that have not been found anywhere else on Earth, and the existence of chemosynthetic communities in the deep ocean is one of the major scientific discoveries of the last 100 years.

Scientists hypothesize that the source of the fluids venting from the Lake Huron sinkholes is the Silurian-Devonian aquifer beneath the lake's sediments. Aquifers are rocks and sediments that contain large amounts of water. Between 350 and 430 million years ago, during the Paleozoic era, shallow seas covered what is now the border between Canada and the United States between Minnesota and New York. Over thousands of years, sand, minerals, and sediments accumulated on the seafloor, and were gradually compressed to form sandstone, limestone and shale. About 1.8 million years ago, the Great Ice Age of the Pleistocene epoch began and continued until about 10,000 years ago. During this time, four major periods of glaciation occurred, separated by three interglacial periods. As the final glacial period came to a close, retreating glaciers along the U.S.-Canadian border revealed five huge lakes that we now know as the Laurentian Great Lakes. In the Great Lakes region, aquifers are found in deposits of sand and gravel left by glaciers, as well as in porous bedrocks (limestone and sandstone) that were formed much earlier in geologic time. Five major aquifers are recognized in this region: one near the land or lake floor surface (the surficial aquifer) and the others in deeper bedrock named for the geologic time periods when they were formed (the Cambrian-Ordovician, Silurian-Devonian, Mississippian, and Pennsylvanian aquifers). The bedrock that forms the Silurian-Devonian aquifer is primarily limestone and mineral formations from evaporating seawater. Both fresh and saline water are found in the Silurian-Devonian aquifer.

Sinkholes are common features where limestone is abundant, because limestone rocks are soluble in acid. Atmospheric carbon dioxide often dissolves in rainwater to form a weak acid (carbonic acid). Rainwater flowing over land surfaces may also pick up organic acids produced by decaying leaves and other once-living material. The resulting weak acid can slowly dissolve limestone rocks to form caves, springs, and sinkholes. Sinkholes on land are known recharge areas for the Silurian-Devonian aquifer (areas where water flows into the aquifer). But very little is known about the chemistry, geology, and biology of submerged sinkholes that may serve as vents for groundwater in the aquifer. Water samples collected near these sinkholes is very different from the surrounding lake, with much higher concentrations of sulfate, phosphorus, and particulate organic matter, as well as ten times more bacteria compared to nearby lake water. These observations suggest that submerged sinkholes may be biogeochemical "hot spots" inhabited by unusual and possibly unknown life forms. At the same time, water flow through submerged sinkholes depends upon recharge from land. This means that sinkhole ecosystems are likely to be very sensitive to changes in rainfall patterns that may accompany climate change, as well as human alterations of these landscapes surrounding recharge areas. These factors make understanding sensitive sinkhole ecosystems an urgent necessity.

Because little is presently known about these systems, information from chemosynthetic communities in the deep ocean may provide a useful starting point for exploration of sinkhole ecosystems. This activity focuses on major ocean habitats, organisms typically found in these habitats, and the interactions that take place within and among these habitats.

Learning Procedure

1. To prepare for this lesson, visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community, http://www.bio.psu.edu/hotvents for a virtual tour of a hydrothermal vent community, and introductory essays for the Thunder Bay Sinkholes Expedition at http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html. You may also want to watch video clips linked from http://www.glerl.noaa.gov/res/Task_rpts/2006/eosruberg06-1.html.

2. Briefly introduce the Thunder Bay Sinkholes Expedition, highlighting the discovery of fluids emerging from sinkholes on the lake floor, and the variety of mats found in the vicinity of these sinkholes. Be sure students understand the concept of an aquifer, and that the mats are likely to be living organisms (algae and/or bacteria) that can serve as food for many other organisms. Point out that very little is known about the mats in Lake Huron or the biological communities they may support; but since their appearance is very similar to mats found in some deep ocean habitats, these habitats may provide clues for explorations of the Thunder Bay sinkholes.

   Lead a discussion of the major categories of ocean habitats, and introduce deep-sea chemosynthetic communities (hydrothermal vents and cold seeps).

   Ocean habitats are usually categorized into zones:

   I. Pelagic zones are found in the water column above the bottom. Organisms that inhabit pelagic zones are divided into plankton that drift with the ocean currents and nekton that can swim and control their motion in the water (at least to some extent).
      A. The epipelagic zone includes surface waters where light is adequate for photosynthesis (about 200 m, maximum). Phytoplankton are the dominant primary producers in this zone.
      B. The mesopelagic zone (about 200 m - 1,000 m) is the twilight zone. Because there is not enough light for photosynthesis, much less energy is available to support animal life. Bacteria and detritus (pieces of dead plants and animals that slowly settle to the bottom) are the primary sources of food for animals like jellyfishes that are confined to this zone. Other animals, including squids, fishes, and shrimps can move up and down through the water column, and have a wider range of food available to them.
      C. The bathypelagic zone (sometimes divided further into an additional abyssopelagic zone) has no light at all. Deep-sea organisms are dependent upon production in other zones. The base of bathypelagic food webs may be primary production in shallower water (obtained by feeding on detritus or on other animals

feeding in shallower water) or chemosynthetic communities like hydrothermal vents or cold-seeps.

D. The hadopelagic zone is sometimes used to include the water column in the deepest ocean trenches (about 11,000 m).

II. Benthic zones are areas on or in the ocean bottom. Animals that swim near the bottom are called "benthopelagic."

A. The intertidal zone is on the shore between the level of high and low tide.
B. The subtidal zone includes the ocean bottom on continental shelves down to about 300 m. Green plants are the base of food webs in shallower waters, but bacteria and detritus are the primary energy source below about 200 m.
C. The bathyal zone includes the rest of the continental shelf (between about 300 m and 3,000 m).
D. The abyssal zone is the ocean bottom between 3,000 m and 6,000 m. The bottom is primarily muddy and flat in most places (hence the common term "abyssal plain"). This is the largest benthic zone and covers about half of the Earth's surface.
E. The hadal zone is sometimes used to describe the very deep ocean bottom between 6,000 m and 11,000 m.
F. Vents and seeps are unusual deep-water habitats that support communities of living organisms whose food webs are based on chemosynthetic bacteria, rather than photosynthetic activity near the surface.

Hydrothermal vents are volcanic hot springs that usually occur along ridges separating the Earth's tectonic plates. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food web. Other deep-sea chemosynthetic communities are found in areas where hydrocarbon gases (often methane and hydrogen sulfide) and oil seep out of sediments. These areas, known as cold seeps, are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water, called methane hydrate ice, that is 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 bacteria may form thick bacterial mats, or may live in close association with other organisms. One of the most conspicuous associations exists between chemosynthetic bacteria and large tubeworms that belong to the group Vestimentifera (formerly classified within the phylum Pogonophora; recently Pogonophora and Vestimentifera have been included in the phylum Annelida). Pogonophora means "beard bearing," and refers to the fact that many species in this phylum have one or more tentacles at their anterior end. Tentacles of vestimentiferans are bright red because they contain hemoglobin (like our own red blood cells). Vestimentiferans can grow to more than 10 feet long, sometimes in clusters of millions of individuals, and are believed to live for more than 100 years. They do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome, that contains chemosynthetic bacteria. Hemoglobin in the tubeworm's blood absorbs hydrogen sulfide and oxygen from the water around the tentacles, and then transports these raw materials to bacteria living in the trophosome. The bacteria produce organic molecules that provide nutrition to the tubeworm. Similar relationships are found in clams and mussels that have chemosynthetic bacteria living in their gills. Other organisms found in these communities (snails, eels, sea stars, crabs, isopods, sea cucumbers, and fishes) probably use tubeworms, mussels, and bacterial mats as sources of food, but specific relationships between these organisms have not been well-studied. Deep-sea chemosynthetic communities are surrounded by a much larger ocean environment. Very little is known about interactions between these communities and organisms in other ocean habitats.

Emphasize the contrast between communities that depend upon chemosynthesis with those dependent upon photosynthesis. You may want to point out that in both processes, organisms build organic molecules (e.g., sugars) from inorganic molecules (e.g., carbon dioxide and water). This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Review the concepts of food chains and food webs, including the concept of trophic levels (primary producer, primary consumer, secondary consumer, and tertiary consumer). Be sure students understand that food webs in most of the habitats are largely based upon photosynthetic production, either directly (primary consumers obtain energy from photosynthetic plants) or indirectly (primary consumers obtain energy from detritus). This situation is fundamentally different in deep-sea chemosynthetic communities, which may also provide an alternative basis for food webs in habitats that are adjacent to these communities.

3. Assign each student group one or more of the following deep ocean habitats to research:
    - Mesopelagic zone
    - Bathypelagic zone
    - Hadopelagic zone
    - Bathyal zone
    - Abyssal zone
    - Hadal zone
    - Hydrothermal vents
    - Cold seeps

    In addition to written reference materials (encyclopedia, periodicals, and books on the deep-sea), the following Web sites contain useful information:
    - http://www.bio.psu.edu/cold_seeps
    - http://people.whitman.edu/~yancey/deepsea.html
    - http://oceanlink.island.net/
    - http://www.pbs.org/wgbh/nova/abyss/life/bestiary.html
    - http://biodidac.bio.uottawa.ca/
    - http://www.fishbase.org/search.cfm

    Each student group should identify six organisms typical of their assigned habitat, and determine the energy (food) source(s) of each of these organisms. It may not be possible to precisely determine specific foods in all cases, but students should be able to draw reasonable inferences from information about related organisms and anatomical features that may give clues about what the animals eat. Students should prepare a 5 x 7 index card for each organism with an illustration of the organism (photocopies from reference material, downloaded Internet pictures, or their own sketches), notes on where the organism is found, approximate size of the organism, and its trophic level (whether it is a primary producer, primary consumer, secondary consumer, or tertiary consumer).

4. Have each student group orally present their research results to the entire class. On a corkboard, flip chart, or piece of poster board, draw a general profile of ocean habitats (see "Generalized Ocean Habitats" diagram), and arrange the cards to show representative organisms in each habitat. When all cards have been attached to the base material, draw lines to indicate trophic (feeding) relationships between and among these organisms.

5. Lead a discussion of the food web the students have created. What is the source of primary production in each habitat? What would the students infer about the relative abundance

of each trophic level? In the simplest analysis, organisms at lower trophic levels (primary producers and primary consumers) must be more abundant than those on higher trophic levels. If this does not appear to be true, then there must be additional energy sources for the higher trophic levels (for example, some secondary or tertiary predators may feed in more than one habitat). What similarities and differences might exist between these food webs and those that are associated with sinkholes in Lake Huron? Students should realize that the depth range of Great Lakes habitats is much less than the depth range of ocean habitats, but also that sunlight is essentially absent in the deepest portions of the lakes. Nutrient-rich fluids venting into these areas could conceivably provide conditions favorable to the development of chemosynthetic communities.

Discuss the importance of exploring habitats such as the Thunder Bay sinkholes. Students should realize that unique or unusual habitats are likely to be inhabited by species that are also unique or unusual. Such species may be directly important to humans (e.g., as sources of drugs to combat human diseases), as well as to other ecosystems (such as those that support Great Lakes fisheries). Point out that the abyssal plain covers about half of Earth's surface, but is largely unexplored. While the term "plain" may suggest that this region is largely featureless and homogenous, recent discoveries of hydrothermal vents, cold seeps, and Thunder Bay sinkholes are good examples of why this assumption is probably wrong.

The Bridge Connection

www.vims.edu/BRIDGE/ – Click on "Ocean Science Topics", "Biology", "Plankton," in the navigation menu on the left for resources on ocean food webs. Click on "Ocean Science Topics", "Habitats", "Deep Sea" for resources on deep sea communities.

The "Me" Connection

Have students write a short essay describing their personal position in a food web, and how they could adapt if their source of primary production were no longer available.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Results and presentation of the research component of this activity provide a basis for group assessment. In addition, individual written interpretations of the pooled results may be required prior to Step 5 to provide a means of individual assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html to keep up to date with the latest Thunder Bay Sinkholes Expedition discoveries, and to find out what researchers are learning about these ecosystems.

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ Click on the links to Lessons 3, 5, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Journey to the Unknown & Why Do We Explore

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l1.pdf
(10 pages, 596k) (from the 2002 Galapagos Rift Expedition)

Focus: Ocean Exploration

In this activity, students will experience the excitement of discovery and problem-solving to learn about organisms that live in extreme environments in the deep ocean and come to understand the importance of ocean exploration.

AdVENTurous Findings on the Deep Sea Floor

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l2.pdf
(5 pages, 536k) (from the 2002 Galapagos Rift Expedition)

Focus: Vent development along the Galapagos Rift (Earth Science)

In this activity, students will conduct investigations to observe the formation of precipitates, create a model of a developing hydrothermal vent and generate comparisons between the created hydrothermal vent model and the actual hydrothermal vents developing along the Galapagos Rift.

Living With the Heat

http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_living_heat_5_6.pdf
(6 pages, 88k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Earth Science, Life Science)

In this activity, students will be able to describe how hydrothermal vents are formed and characterize the physical conditions at these sites, explain what chemosynthesis is and contrast this process with photosynthesis, identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities, and describe common food pathways between organisms typically found in hydrothermal vent communities.

Let's Make a Tubeworm!

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf
(6 pages, 464k) (from the 2002 Gulf of Mexico Expedition)

Focus: Symbiotic relationships in cold-seep communities (Life Science)

In this activity, students will be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. Students will also be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

And Now for Something Completely Different...

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf
(10 pages, 172k) (from the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition)

Focus: Biological communities at hydrothermal vents (Life Science)

Students will identify and describe organisms typical of hydrothermal vent communities near the Galapagos Spreading Center, explain why hydrothermal vent communities tend to be short-lived, and identify and discuss lines of evidence which suggested the existence of hydrothermal vents before they were actually discovered.

What's That?

http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_whatsthat.pdf
(7 pages, 356k) (from the The Lost City 2005 Expedition)

Focus - Investigating Lost City hydrothermal field ecosystems by remotely operated vehicles (Life Science/Physical Science)

In this activity, students will be able to describe a sampling strategy for investigating an unknown area, and will be able to explain why this strategy is appropriate for such an investigation; identify and discuss some of the limitations faced by scientists investigating unexplored areas of the deep ocean, and discuss how an autonomous underwater vehicle such as the Autonomous Benthic Explorer (ABE) can contribute to discoveries such as the Lost City Hydrothermal Field.

Chemists with No Backbones

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_ChemNoBackbones.pdf
(4 pages, 356k) (from the 2003 Medicines from the Deep Sea Expedition)

Focus: Benthic invertebrates that produce pharmacologically-active substances (Life Science)

Students will be able to identify at least three groups of benthic invertebrates that are known to produce pharmacologically-active compounds and will describe why pharmacologically-active compounds derived from benthic invertebrates may be important in treating human diseases. Students will also be able to infer why sessile marine invertebrates appear to be promising sources of new drugs.

Microfriends

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_microfriends.pdf
(6 pages, 420k) (from the 2003 Medicines from the Deep Sea Expedition)

Focus: Beneficial microorganisms (Life Science)

Students will be able to describe at least three ways in which microorganisms benefit people, describe aseptic procedures, and obtain and culture a bacterial sample on a nutrient medium.

Animals of the Fire Ice

http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_fireice.pdf
(5 pages, 364k) (from the 2003 Windows to the Deep Expedition)

Focus: Methane hydrate ice worms and hydrate shrimp (Life Science)

In this activity, students will be able to define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

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/08thunderbay/welcome.html – Follow the Thunder Bay Sinkholes 2008 Expedition daily as documentaries and discoveries are posted each day for your classroom use

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 focussing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/projects/thunderbay01/thunderbay01.html – Web site for the 2001 Ocean Explorer Expedition to survey "Shipwreck Alley" in Thunder Bay, Lake Huron

http://gvsu.edu/wri/envbio/biddanda/sinkhole.htm – 1 minute ROV video clip of conspicuous white benthic mats interspersed with the brownish mats

characterizing the lake floor in the vicinity of the sinkhole, and a dark cloudy nepheloid-like plume layer prevailing just over the site of submarine groundwater seepage

ftp://ftp.glerl.noaa.gov/eos/El_Cajon_Boils_Short.wmv – Underwater video of El Cajon "boils"

ftp://ftp.glerl.noaa.gov/eos/Purple_Mats_40_sec.wmv – Underwater video of the purple benthic mats from the Middle Island Sinkhole

Biddanda, B. A., D. F. Coleman, T. H. Johengen, S. A. Ruberg, G. A. Meadows, H. W. VanSumeren, R. R. Rediske, and S. T. Kendall. 2006. Exploration of a submerged sinkhole ecosystem in Lake Michigan. Ecosystems 9:828-842. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2006/20060020.pdf

Ruberg, S.A., D.F. Coleman, T.H. Johengen, G.A. Meadows, H.W. VanSumeren, G.A. LANG, and B.A. Biddanda. 2005. Groundwater plume mapping in a submerged sinkhole in Lake Huron. Marine Technology Society Journal 39(2):65-69. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2005/20050038.pdf

http://www.pmel.noaa.gov/vents – "Vents Program" Web page from NOAA's Pacific Marine Environmental Laboratory

http://www.divediscover.whoi.edu/vents/index.html for more information and activities on hydrothermal vent communities.

http://www.rps.psu.edu/deep/ – Notes from an expedition exploring deep-sea communities

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. Science 226:965-967 – Early report on cold seep communities.

http://www.sdnhm.org/exhibits/mystery/fg_timeline.html – Geologic timeline on the "Fossil Mysteries" Web page from the San Diego Natural History Museum

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Transfer of energy

Content Standard C: Life Science

- Structure and function in living systems
- Populations and ecosystems

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments
- Science and technology in society

Content Standard G: History and Nature of Science

- Nature of science

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

Fundamental Concept b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.

Essential Principle 4.
The ocean makes Earth habitable.

Fundamental Concept a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.

Fundamental Concept b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

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

Fundamental Concept b. Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

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

Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
oceanexeducation@noaa.gov

For More Information

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Student Handout

Generalized Ocean Habitats