INDEX/SATAL 2010

Tools of Exploration: ROV

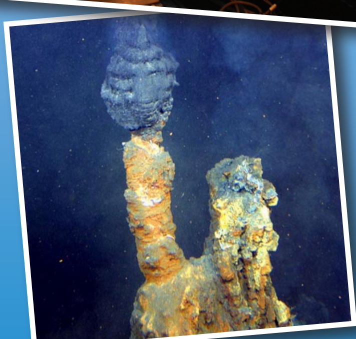

Image captions/credits on Page 2.

lesson plan

Focus
Remotely operated vehicles (ROVs) for deep ocean exploration

Grade Level
9-12 (Earth Science/Physical Science/Technology)

Focus Question
How do scientist use a remotely operated vehicle to help explore Earth's deep ocean?

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

Materials
- None

Audio-Visual Materials
- (Optional) Video projector or other equipment for displaying video images (see Learning Procedure Step 1d)

Teaching Time
One 45-minute class period

Seating Arrangement
Groups of 4-6 students

Maximum Number of Students
30

Key Words
Remotely operated vehicle (ROV)
Underwater video

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

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

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

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

Images from Page 1 top to bottom:
The ROV Hercules being lowered into the water from the NOAA Ship *Okeanos Explorer*. Image credit: NOAA OER.

NOAA scientists examining live video feed from the ROV Hercules. Image credit: NOAA OER.

Mussels, shrimp, limpets, and crabs cover the slope of an underwater volcano near a hydrothermal vent. Image credit NOAA
http://www.photolib.noaa.gov/bigs/expl0071.jpg

Black smokers on the Kermadec Arc. Image courtesy of New Zealand American Submarine Ring of Fire 2007 Exploration, NOAA Vents Program, the Institute of Geological & Nuclear Sciences and NOAA-OE.
http://oceanexplorer.noaa.gov/explorations/07fire/logs/july31/media/brothers_blacksmoker_600.jpg

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.

During the summer of 2010, scientists from Indonesia and the United States will work together on an expedition to explore the deep ocean surrounding Indonesia. This mission is called INDEX/SATAL 2010, since the expedition is focussed on INDonesia, EXploration, and the Sangihe Talaud (SATAL) region. Working from the Indonesian Research Vessel *Baruna Jaya IV* and the NOAA Ship *Okeanos Explorer*, these ocean explorers expect to find new deep-sea ecosystems, undiscovered geological features, and living organisms that have never been seen before. New discoveries are always exciting to scientists; but information from ocean exploration is important to everyone, because:

- Biodiversity in deep-sea ecosystems includes new species that can provide important drugs and other useful products;
- Some deep-sea ecosystems include organisms that can be used for human food;
- Information from deep ocean exploration can help predict earthquakes and tsunamis; and
- Human benefits from deep ocean systems are being affected by changes in Earth's climate and atmosphere.

A major objective of the INDEX/SATAL 2010 expedition is to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts associated with active geologic processes in Indonesia's deep sea. The primary strategy used aboard the *Okeanos Explorer* to find these kinds of features involves searching for anomalies; conditions that are different from the surrounding environment. Changes in chemical properties of seawater, for example, can indicate the presence of underwater volcanic activity, hydrothermal vents, and chemosynthetic communities. This strategy involves three major activities:

- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties "from top to bottom" while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration

Indonesia's Research Vessel
Baruna Jaya IV

Port of Registry - Jakarta, Indonesia
Purpose - Oceanography, Fishery
Launched - 1995
Length - 60.4 m
Width - 12.10 m
Draft - 4.15 m
Draft mean - 4.15m
Cruising speed - 10 kts
BPPT Indonesia - owner
17 crew, 33 scientists, and engineers

Deck Gear:
6 ton A-Frame
3 ton Crane
2 - Gilson Winches
2 - Otter Trawl Winches
Hydrographic Winch

Oceanographic Equipment:
Seabeam ELAXC1050D Multibeam
Seabeam ELAC 1190 Multibeam
ELAC 4700
Acoustic Doppler Current Profiler RDI Broadband
Sea Bird SBE-911 CTD with Rosette
Aanderaa, MORS, RDI current meters
Gravity Core Sediment Sampler
Oretech 3000 Subbottom Profiler
Edge Tech 4200-MP Sidescan Sonar

Fishery Equipment:
Mid- and Deep-water Fisheries Trawl
Koden Fish Finder
Simrad EK 500
Plankton Net

of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

Site characterization activities depend heavily upon remotely operated vehicles (ROVs), which are unoccupied robots linked to an operator by a group of cables. Underwater ROVs are usually controlled by an operator aboard a surface ship. Most are equipped with one or more video cameras and lights, and may also carry other equipment such as a manipulator or cutting arm, water samplers, and measuring instruments to expand the vehicle's capabilities. For the INDEX/SATAL 2010 expedition, NOAA Ship *Okeanos Explorer* will carry Little Hercules, an ROV whose primary purpose is to gather high quality video imagery. Little Hercules has four thrusters and can operate as deep as 4000 meters.

For more information about other ROVs, visit http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html.

This lesson is intended to introduce students to remotely operated vehicles and video imagery as they are used in the exploration strategy of the *Okeanos Explorer*. In the future, students will have access to additional video imagery collected by ROVs as the *Okeanos Explorer* continues its voyages of discovery in Earth's deep ocean.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the INDEX/SATAL 2010 Expedition at http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html
   (b) Review information about the importance of deep ocean exploration in the Background section of the *Earth's Ocean is 95% Unexplored: So What?* lesson;
   (c) Download the data file Loph08_video_1.mov from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/loph08_video_1.mov, and install it on computers that students will be using to complete the activity. Alternatively, you may have students download this file onto their own computer systems.
   (d) Download one or more photographs of the Little Hercules ROV from (http://www.moc.noaa.gov/oe/visitor/photos/photos-e.html), and images of several other ROVs from http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html. You may also want to download a compilation of video clips collected by Little Hercules during a shakedown cruise off Kona, Hawaii, from http://www.channels.com/episodes/show/10098569/NOAA-Ship-Okeanos-Explorer-Highlight-video-offshore-Kona-Hawaii.

2. Briefly introduce the INDEX/SATAL 2010 Expedition, and point out that this expedition is the maiden voyage of the *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Ask students for their ideas about why this kind of exploration might be important, and highlight some of the reasons referenced in Step 1b. Be sure students understand that discoveries of deep sea chemosynthetic communities during the last 30 years are major scientific events that have changed many assumptions about life in the ocean and have opened up many new fields of scientific investigation.

   Review the overall exploration strategy used by the *Okeanos Explorer*, highlighting the concept of finding anomalies, and that this strategy involves three major activities:
   - Underway reconnaissance;
   - Water column exploration; and
   - Site characterization.

   Underway reconnaissance involves mapping the ocean floor and water column while the ship is underway, and using other sensors to measure chemical and physical properties of seawater. Water column exploration involves making measurements of chemical and physical properties "from top to bottom" while the ship is stopped. In some cases these measurements may be made routinely at pre-selected locations, while in other cases they may be made to decide whether an area with suspected anomalies should be more thoroughly investigated. Site characterization involves more detailed exploration of a specific region, including obtaining high quality imagery, making measurements of chemical and physical seawater properties, and obtaining appropriate samples.

   Key technologies involved with this strategy include:
   - Multibeam sonar mapping system;
   - CTD and other electronic sensors to measure chemical and physical seawater properties; and
   - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery in depths as great as 4,000 meters.

   A fourth technological capability that is essential to the *Okeanos Explorer* exploration strategy is advanced broadband satellite communication. This capability provides the foundation for "telepresence;" technologies that allow people to observe and interact with events at a remote location. Telepresence allows live images to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities that are a major part of the *Okeanos Explorer*'s mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

3. Show students images of several ROVs, and briefly describe their capabilities. Conclude with one or more images of the Little Hercules ROV, and explain that the primary purpose of this underwater robot is to gather high quality video images as part of site characterization activities. At this point you may want to show the video clip compilation referenced in Step 1d. Lead a discussion of how ocean explorers might use these images. Students should realize that in many cases, these images provide the only indication of living organisms in sites being characterized. In addition, these images can provide data about geological formations and other environmental conditions that cannot be obtained with other data gathering instruments. Students should also realize that video imagery also has limitations, including:
   - coverage is limited to a relatively small area;
   - mobile organisms may avoid the moving ROV and/or lights used for video imaging; and
   - many organisms cannot be accurately identified from photographs alone.

4. Tell students that their assignment is to study a set of four video clips that were collected by the SeaEye Falcon ROV during the 2008 *Lophelia* Expedition in the Gulf of Mexico, and prepare a report describing their observations. Say that they should pay particular attention to living organisms, and identify these as fully as possible. They should also be alert for any signs of geologic activity such as venting gas, plumes of precipitated material, or other unusual observations. Their report should reference their observations by clip number, as well as elapsed playing time (the first clip begins at 10 sec, and the last clip ends at 4 min, 8 sec). You can make this a contest by offering an appropriate prize for the group that observes the largest number of different organisms. Students may protest that they have never seen most of the things in the video clips; and this is exactly the point! Deep ocean explorers often encounter organisms that no one has seen before. All they can do is obtain good descriptions (which is why images are so valuable) and consult with experts who are familiar with organisms that appear similar. Having the ability to make these consultations at sea in one of the great benefits of telepresence.

5. Have each group present a summary of their findings. A dynamic way to do this is to play the video clips and have student groups say, “Stop!” when they have something to report. You may want to include the following observations, either along with student

presentations or separately. It is likely that students will make many observations that are not part of this list.

Clip 1

0′ 11″ - fine sediments, periodically stirred up by ROV; lots of particles in water
0′ 20″ - bubbles, possibly from a gas seep
0′ 28″ - more bubbles
0′ 34″ - more bubbles
0′ 48″ - steady stream of bubbles, probable gas seep

Clip 2

1′ 00″ - coarse rubble on bottom; uneven topography, ledges
1′ 03″ - lots of particles in water; snowy grouper (*Epinephelus niveatus*)
1′ 10“ - possible soft corals or crinoid
1′ 45″ - crinoid confirmed

Clip 3

1′ 58″ - soft bottom
1′ 59″ - coral (*Lophelia*?); soft corals; tubeworm tubes
2′ 09″ - sea urchin (lower right)
2′ 19″ - particles in water
2′ 27″ - more tubeworms and soft corals
2′ 34″ - 3 crabs, at least 2 different species
2′ 47″ - another crab (upper right), aggressive posture; feathery object (lower center) moving in the current
2′ 58″ - feather duster worms (center right), retract into tubes as ROV approaches
3′ 13″ - more corals; ledge

Clip 4

3′ 20″ - broken rubble over bottom, plate-like pieces
3′ 23″ - redeye gaper (*Chaunax stigmaeus*, toadfish, anglerfish)

Discuss how the observed organisms could be more completely identified. Ideally, specimens would be collected for identification by experts. This is particularly important when previously-unknown species are encountered. Some ROVs are capable of collecting sessile and slow-moving organisms, but organisms such as crabs and fishes usually escape. In some cases (such as the redeye gaper) it is possible to identify the species from the video alone.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Human Activities,” then “Technology” for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

The "Me" Connection

The video clips used in this activity were made in the deep Gulf of Mexico. Many similar habitats have been exposed to oil and dispersants from the Deepwater Horizon well disaster. Have students write a brief essay on how oil spill impacts on deepwater ecosystems might affect them personally.

Connections to Other Subjects

English/Language Arts

Assessment

Analysis of video clips and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html for the latest activities and discoveries by the INDEX/SATAL 2010 Expedition.

2. Visit the *Okeanos Explorer* Digital Atlas (http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm) and Web page (http://oceanexplorer.noaa.gov/okeanos/welcome.html) for reports, images, and other products from *Okeanos Explorer* cruises.

3. Visit http://www.marinetech.org/rov_competition/rov_video_2007.php for a video from the the Marine Technology Society's student ROV competition, and links to other sites about underwater robots.

4. For ideas about building your own underwater robots, see Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pages; and Bohm, H. 1997. Build Your Own Underwater Robot and Other Wet Projects. Westcoast Words. 148 pages.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

My Wet Robot
(PDF, 300 kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf
Focus: Underwater Robotic Vehicles

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

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.

Where's My 'Bot?
(PDF, 492 kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf

Focus: Marine Navigation (Earth Science/Mathematics)

In this activity, students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

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 Big Burp: Where's the Proof?
(PDF, 364 kb) (from the Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf

Focus: Potential role of methane hydrates in global warming (Earth Science)

In this activity, students will be able to describe the overall events that occurred during the Cambrian explosion and Paleocene extinction events and will be able to define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also be able to describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian explosion and Paleocene extinction events.

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 Roving Robotic Chemist
(PDF, 440 kb) (from the PHAEDRA 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf

Focus: Mass Spectrometry

In this lesson, students will be able to explain the basic principles underlying mass spectrometry, discuss the advantages of in-situ mass spectrometry, explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle, and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

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.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html – Web site for the INDEX/SATAL 2010 Expedition, with links to lesson plans, career connections, and other resources

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

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

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

Yoerger, D., A. Bradley, M. Jakuba, M. Tivey, C. German, T. Shank, and R. Embley. 2007. Mid-ocean ridge exploration with an autonomous underwater vehicle. Oceanography 20(4):52-61(available online at http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/20_4/20.4_yoerger_et_al.pdf)

German, C., D. Yoerger, M. Jakuba, T. Shank, C. Langmuir, and K. Nakamura. 2008. Hydrothermal exploration with the Autonomous Benthic Explorer. Deep-Sea Research I 55:203-219

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
- Motions and forces

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

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science
- Science as a human endeavor

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

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept 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 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:
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For More Information

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