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The NOAA Ship *Okeanos Explorer* Education Materials Collection

For Grades 5 – 12

Volume 2:

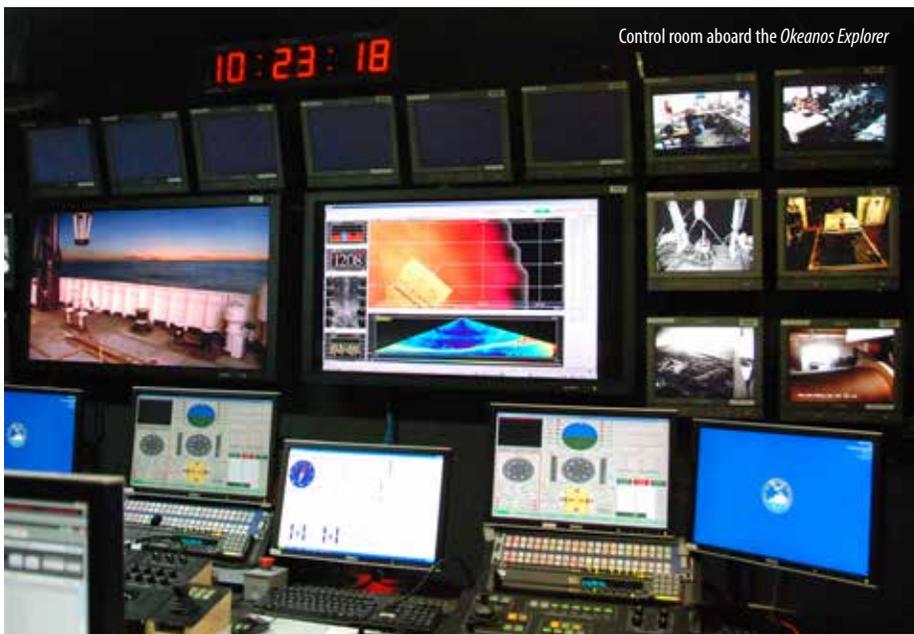
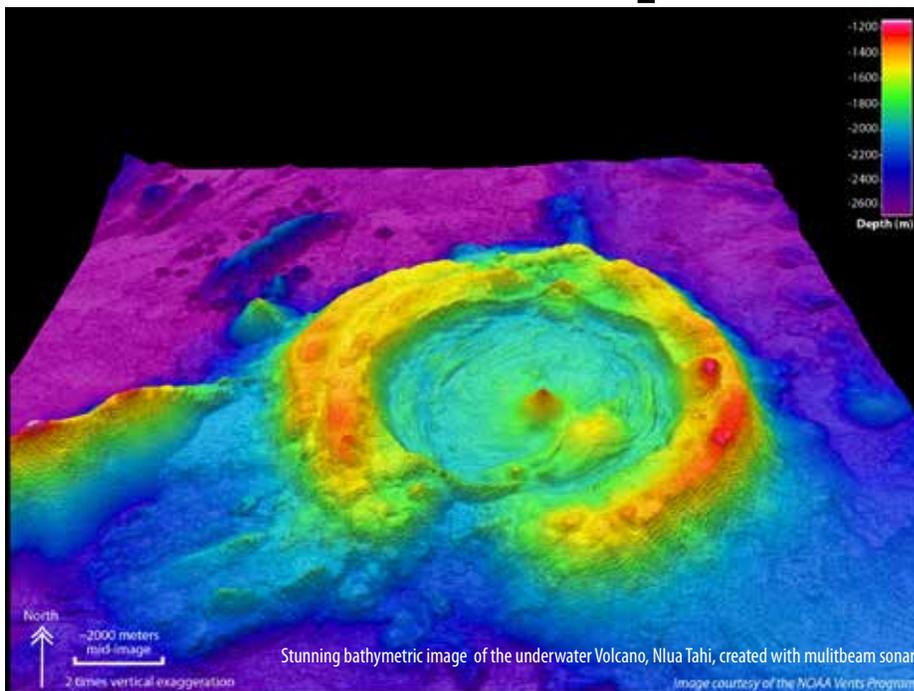
How Do We Explore?



ROV *Little Hercules*



Pink brittle stars



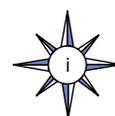


**The NOAA Ship *Okeanos Explorer*
Education Materials Collection
For Grades 5 – 12**

**Volume 2:
How Do We Explore?**



**National Oceanic and Atmospheric Administration
Office of Ocean Exploration and Research**





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Foreword

It is through exploration that we obtain our fundamental knowledge and basic understanding of things and places previously unknown to us. When it comes to ocean exploration, one must consider that the ocean is part of a much larger integrated system - neither can one separate it from the atmosphere at its surface nor the deepest parts of Earth's interior at spreading centers and subduction zones. As such, ocean exploration is, by definition, multidisciplinary.

As I write this, I am at sea with a team of scientists exploring the NE Lau Basin in the South Pacific Ocean (<http://oceanexplorer.noaa.gov/explorations/12fire/welcome.html>). We are exploring deep-sea volcanoes and their associated hydrothermal vent systems and are seeing stunning deep-sea ecosystems harboring new species with nearly every dive of the remotely operated vehicle. As one can imagine, our equipment and instrumentation is highly technical and the scientific, engineering and technical expertise is remarkable. The codependency of ocean exploration on engineering and technology and engineering and technology on the sciences employed to explore the ocean is striking. Our sciences steer advances in engineering and technology; similarly, engineering enables advancements in ocean exploration—they are inextricably intertwined.

Recognizing, among many other elements, the overlap between science and engineering and the importance of teaching the practices of both, science education has recently seen a major change in the U.S. with the release of the Next Generation Science Standards (NGSS). The precursor to the development of the NGSS, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (Framework)*, notes, "Although the intrinsic beauty of science and a fascination with how the world works have driven exploration and discovery for centuries, many of the challenges that face humanity now and in the future—related, for example to the environment, energy, and health—require social, political, and economic solutions that must be informed deeply by knowledge of the underlying science and engineering." (National Research Council, 2012).

Ocean exploration presents a unique context through which to support the NGSS. The very topic



Excitement at the 2012 USA Science & Engineering Festival held in Washington, DC. Image courtesy of NOAA.

in and of itself captures imaginations, intrigues young minds, has the potential to inspire an ocean science-literate citizenry and foster the innovative thinking that leads to engineering and technology literacy. In 2008, the National Oceanic and Atmospheric Administration (NOAA) commissioned the NOAA Ship *Okeanos Explorer*; the first Federally-dedicated ship to explore the ocean in an effort to increase the pace, efficiency and scope of ocean exploration. The *Okeanos Explorer* is equipped with advanced technological capabilities and assets which are strategically applied during ocean expeditions by a multidisciplinary exploration team. *How Do We Explore?*, Volume 2 of the NOAA Ship *Okeanos Explorer* Education Materials Collection has been designed to assist educators with teaching about these unique technological capabilities and assets and how the ocean sciences are integrated into them to explore the little-known ocean world. To emphasize the codependence of science and engineering, these lessons support the Performance Expectations and associated Science and Engineering Practices, Crosscutting Concepts and Disciplinary Core Ideas of the NGSS.

The essential importance of science education in stimulating the innovations needed to meet the challenges of ocean exploration extends far beyond scientific curiosity. The support of an educated public, informed decision-makers, and a globally-competitive workforce that understands the combined role that science, engineering and technology have in the development of innovative solutions and applications is paramount.

*Paula Keener, Marine Biologist; Director,
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NOAA Office of Ocean Exploration and Research*





NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration. Image courtesy of NOAA. <http://oceanexplorer.noaa.gov/okeanos/about.html>

About this Volume

An essential component of NOAA's Ocean Exploration and Research Program mission is to enhance understanding of ocean exploration, and build interest in careers that support ocean-related work. To help fulfill this mission, the *Okeanos Explorer Education Materials Collection* has been developed to encourage educators and students to become personally involved with the voyages and discoveries of the *Okeanos Explorer* – America's first Federal ship dedicated to Ocean Exploration. In *Volume 2* of the *Education Materials Collection*, *How Do We Explore?* we focus on the methods used by modern ocean explorers, including the overall strategy for exploration aboard the *Okeanos Explorer*, as well as four of the technologies that contribute to this strategy: telepresence, multibeam sonar, instruments for water column studies, and remotely operated vehicles (underwater robots).

Lesson plans developed for *Volume 2* are correlated with Ocean Literacy Essential Principles and Fundamental Concepts as indicated in the back of this book. Additionally, a separate *online document* illustrates individual lesson support for the Performance Expectations and three dimensions of the *Next Generation Science Standards* and associated Common Core State Standards for

Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept.

Lessons also include links to other relevant lesson plans from NOAA's Office of Ocean Exploration and Research, as well as the Ocean Explorer Web site (<http://oceanexplorer.noaa.gov/>). Educators who use the *Okeanos Explorer Education Materials Collection* should regularly check the Education page on the *Okeanos Explorer* Web site (<http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html>) for the latest information about new education materials and professional development opportunities.

Welcome aboard!





Section 1: Introduction

Introduction to Volume 2: How Do We Explore?

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as “America’s Ship for Ocean Exploration;” the only U.S. ship whose sole assignment is to systematically explore Earth’s largely unknown ocean. A key part of the vision underlying this assignment is that the *Okeanos Explorer* is a ship of discovery. Her mission is to find anomalies; things that are unusual and unexpected. When anomalies are found, explorers aboard the ship collect basic information that can guide future expeditions to investigate hypotheses based on this information. This process underscores an important distinction between exploration and research:

Exploration is about making new discoveries to expand our fundamental scientific knowledge and understanding and to lay the foundation for more detailed scientific investigations;

Research is about the attempt to understand things that have previously been discovered and leads to informed decision-making.

Exploring the unknown is a challenging assignment. Long voyages into remote areas and scientific studies both require careful planning to minimize risks, maximize the chances of obtaining useful information, and make the best use of

financial resources. Explorers must do this kind of planning without knowing exactly what they will encounter and work within a scientifically informed “strategy” for exploring the relatively unknown ocean world. As such, the exploration strategy designed for the *Okeanos Explorer* has taken years to develop and has involved many scientists, engineers, ocean experts, and visionaries from across the globe.

Historically, many expeditions of discovery have preceded the voyages of the *Okeanos Explorer*. Two of the most famous are the Lewis and Clark Expedition (1804 – 1806) and the HMS *Challenger* Expedition (1872 – 1876). There are many differences between these expeditions, but several basic questions apply to all three:

- Who looks for discoveries?
- Where do they look?
- How do they look?

Who’s Looking?

This question is important because a discovery implies finding something that hasn’t been found before. But if we see something that is new to us, how can we be reasonably sure that no one else has seen it before? The answer is that we need people who are knowledgeable about biology,

***Okeanos Explorer* Vital Statistics:**

Commissioned: August 13, 2008; Seattle, WA
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA’s Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA’s Office of Ocean Exploration and Research



NOAA Ship *Okeanos Explorer*: America’s Ship for Ocean Exploration. Image courtesy of NOAA. For more information, see the following Web site: <http://oceanexplorer.noaa.gov/okeanos/about.html>



geology, chemistry, physical science, and many other fields; in other words, we need to have experts that can participate in the process of looking.

The primary objective of the Lewis and Clark Expedition was to explore the Missouri River and its connection (if any) to the waters of the Pacific Ocean for purposes of commerce. But President Thomas Jefferson (who commissioned the expedition) was an avid citizen scientist, and wanted to find out everything possible about the natural history of the unexplored American West. Scientific observations depended primarily upon the expertise of one individual: expedition leader Meriwether Lewis, who was trained as a multidisciplinary “expert” through studies with members of the American Philosophical Society, including specialists in astronomy, mathematics, medicine, fossils, botany, and zoology. The other (approximately 45) members of the expedition were chosen for physical condition, marksmanship, or special skills (such as the ability to speak native American languages) needed by the expedition.

In contrast, the HMS *Challenger* Expedition’s primary objective was to gather information about a wide range of ocean features, such as seawater temperatures, chemistry, currents, marine life, and geology of the seafloor. The expedition was led by naturalist Charles Wyville Thompson and included five other scientists and a crew of 216.

Like HMS *Challenger*, the specific objective of the *Okeanos Explorer* is scientific: to explore Earth’s unknown ocean for the purpose of discovery and the advancement of knowledge. The ship is able to accommodate 46 people, most of whom (about 28) are ship’s crew. But while scientific experts aboard the ship are in the minority, dozens of other scientists ashore can actively participate in exploration activities. This is a fundamental difference between *Okeanos Explorer* missions and previous voyages of discovery, and is possible because of a technological capability known as telepresence. This capability uses advanced broadband satellite communication to allow people in remote locations to observe and interact with events aboard the ship. Live images can be transmitted from the seafloor to scientists ashore, classrooms, and newsrooms, opening new educational opportunities that are a major part of the *Okeanos Explorer*’s objective for advancement of knowledge. Telepresence also makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. Thanks to telepresence, many more scientists can be looking for discoveries during *Okeanos Explorer* missions than has been possible in previous voyages of discovery.

Where to Look?

The answer to this question usually depends upon the overall objectives of an expedition. The Lewis and Clark Expedition was focused primarily upon the Missouri River as a potential route for navigating to the Pacific Ocean, so the location of the River determined where they looked. . . until they reached the river’s headwaters and still saw no sign of the Pacific. After that, they continued to head west, trying to find a way past the “terrible mountains” of the Rockies.

A primary objective of the HMS *Challenger* Expedition was to “investigate the physical conditions of the deep sea in the great ocean basins (as far as the neighborhood of the Great Southern Ice Barrier) in regard to depth, temperature, circulation, specific gravity and penetration of light.” As a result of this requirement, the expedition covered 69,000 miles, entered all oceans except the Arctic, and collected data from 362 stations along its route. Because they wanted to investigate most of Earth’s ocean, expedition leaders planned to take samples at intervals that were as evenly-spaced as possible. This worked out to taking samples at 200-mile intervals.



William Clark. Image courtesy Wikipedia.
http://upload.wikimedia.org/wikipedia/commons/6/66/William_Clark-Charles_Willson_Peale.jpg



Meriwether Lewis. Image courtesy Wikipedia.
<http://media-2.web.britannica.com/eb-media/63/10263-050-BB45DC47.jpg>



The HMS Challenger.

<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.htm>



The science and ship crew of the HMS Challenger in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image courtesy of NOAA.

<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg>

Since Earth's ocean is 95% unexplored, the *Okeanos Explorer* mission also encompasses a very large geographic area. Between April 2006 and March 2008, the overall exploration strategy for the *Okeanos Explorer* was developed by a group of more than 50 scientists that represented a broad cross-section of the oceanographic community. Meetings among these scientists were facilitated by NOAA's Ocean Exploration Advisory Working Group (OEAWG). (For more information about the OEAWG, see http://www.sab.noaa.gov/Working_Groups/Working_Groups.htm).

Although the ocean is largely unexplored, we can obtain clues about where to begin looking by considering some of the exciting and scientifically-important deep-sea discoveries such as seamounts, hydrothermal vents, cold seeps, convergence zones, ocean trenches, and deep reefs. So, part of the *Okeanos Explorer* exploration strategy is to focus on areas where there is a high potential for new discoveries; but the OEAWG also emphasized the importance of including systematic exploration of unknown areas. These two strategic elements led to a concept of "boxes" and "sticks." "Boxes" are target areas of high interest where there is a reasonable likelihood that new discoveries will be made. "Sticks" are the routes that the ship will follow from one target area to the next. These routes will usually be through unknown, poorly studied regions that can be systematically investigated as the ship passes through. For more about the sticks and boxes exploration strategy, see <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/welcome.html>.

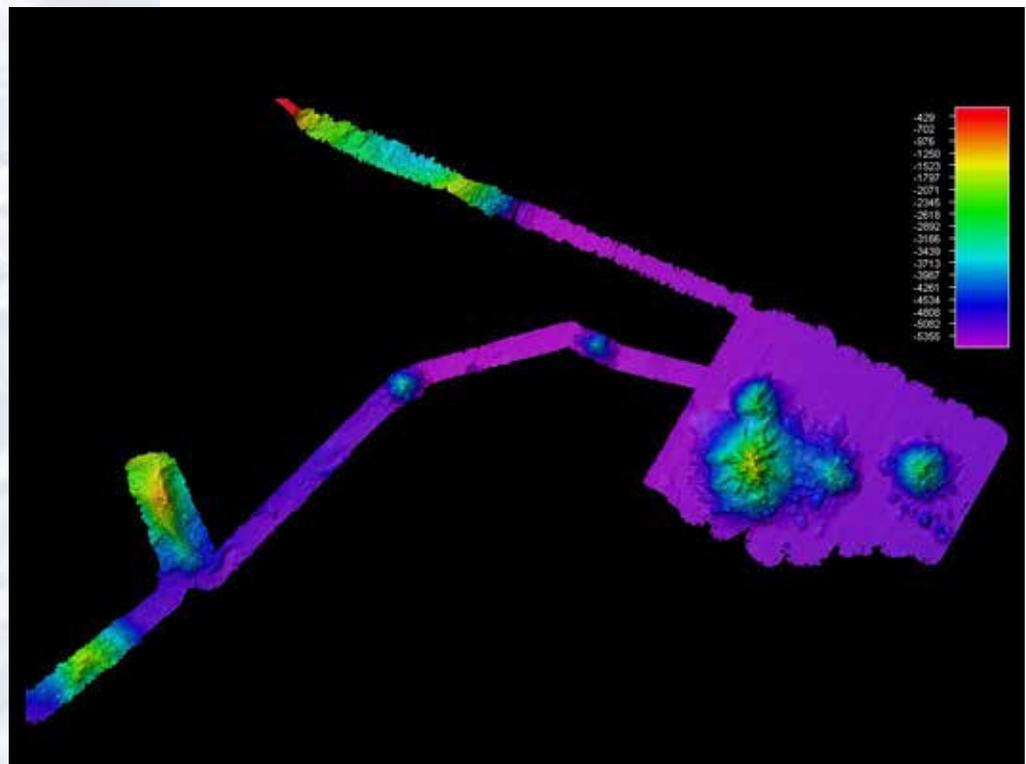
How to Look?

This question focuses on exploration technologies. The most important single instrument for any voyage of discovery is the observer that is able to recognize unusual or unique features and events, and make an accurate record of these observations. To date, only humans are able to meet these requirements. In addition to the "official" record of observations, less formal individual records have been extremely valuable to providing a complete picture of events that took place during historic voyages of discovery. While Meriwether Lewis kept meticulous records of formal observations over three years,

Image showing multibeam bathymetry collected off of Hawaii's Big Island during the NOAA Ship *Okeanos Explorer*'s 2009 field season. The long skinny lines represent "sticks" in the ship's exploration model, whereas the larger areas represent "boxes." Image created using Fledermaus version 7 using cruise EX0909 data.

Image courtesy of NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/background/hires/sticks_boxes_hires.jpg



William Clark's journal often provides more details about the daily experiences of the members of the expedition. The official record of the HMS *Challenger* Expedition fills 50 volumes and includes more than 29,000 pages; but much of what we know about events during the expedition comes from letters written by Joseph Matkin, the ship's assistant steward.

During the Lewis and Clark, HMS *Challenger*, and *Okeanos Explorer* expeditions alike, a variety of technological instruments augment human observation abilities. For Lewis and Clark, these include a mariner's compass, surveying instruments, and a portable microscope. The list for HMS *Challenger* is much larger, including weighted ropes for measuring depth; dredges and nets; specially constructed thermometers and hydrometers; water sampling bottles, and photographic cameras.

The foundation of modern ocean exploration is the integration of science, technology, engineering, and mathematics (STEM). Scientific questions drive the engineering design process, which produces technology that provides data to answer the questions. Mathematics helps translate scientific questions into engineering design problems, provides tools that help create technological solutions, and assists with interpreting and analyzing data obtained with technology to answer scientific questions.

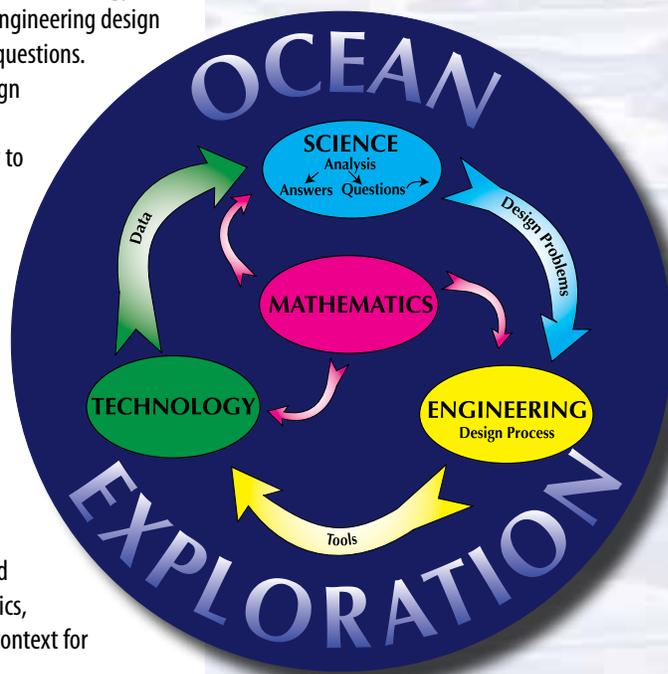
Each element provides internal feedback, as well as feedback to the other elements. Answers to one set of scientific questions often result in new questions. Engineering design is a cyclic process that progressively improves potential solutions to a given problem. Technological solutions in one field may stimulate new scientific questions, or new approaches to engineering design. Advances in mathematics can provide new ways of looking at data that result in better understanding, as well as new ways of solving problems and answering questions. NOAA's Ocean Exploration Education Program is not a STEM program; but because modern ocean exploration is based on the integration of science, technology, engineering, and mathematics, materials produced by this program can be used to create an exciting context for STEM instruction.

The *Okeanos Explorer* Exploration Strategy

The overall *Okeanos Explorer* strategy is based on finding anomalies; conditions or features that are different from the surrounding environment. This is because anomalies may point the way to new discoveries, which are part of the ship's mission. Changes in chemical properties of seawater, for example, can indicate the presence of underwater volcanic activity, hydrothermal vents, and chemosynthetic communities. Once an anomaly is detected, the exploration strategy shifts to obtaining more detailed information about the anomaly and the surrounding area. An important concept underlying this strategy is a distinction between exploration and research. As a ship of discovery, the role of *Okeanos Explorer* is to locate new features in the deep ocean, and conduct preliminary characterizations of the site that provide enough data to justify potential follow-up by future expeditions.

This strategy involves three major activities:

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



The foundation of modern ocean exploration is the integration of science, technology, engineering, and mathematics. Image courtesy of Mel and Sandy Goodwin.



The ROV Team Lead, Commanding Officer, and Science Team Lead talk about our operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

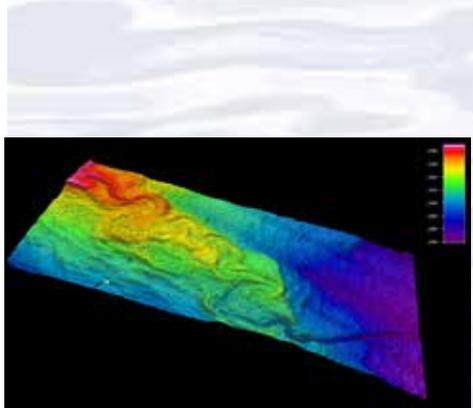


Image of an underwater river feature on the seafloor in the Northern Gulf of Mexico. Colors indicate depth. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr2-2-hires.jpg>



A gas capture device, affectionately known as the "methane bucket," was added to the front of the *Little Hercules* remotely operated vehicle for several dives. Gas from natural seafloor seeps was captured in the device at depth, where it forms a mix of hydrate (methane ice) and gas, and was then brought to shallower, warmer waters, where the hydrate dissociated, in order to estimate the volume of gas collected. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr29-1-hires.jpg>



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 other appropriate types of data.

In addition to state-of-the-art navigation and ship operation equipment, this strategy depends upon four key technologies:

- Telepresence (discussed in Lesson 2);
- Multibeam sonar mapping system (discussed in Lessons 3, 4, and 5);
- CTD (an instrument that measures conductivity, temperature, and depth) and other electronic sensors to measure chemical and physical seawater properties (discussed in Lessons 6, 7, and 8); and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery in depths as great as 4,000 meters (discussed in Lessons 9, 10, and 11).

The strategy for NOAA OER ocean exploration was the result of over five years of planning, field trials, and state-of-the-art technology that ultimately came together for the first time on one ship, the *Okeanos Explorer*, during her maiden voyage to explore the deep waters of Indonesia during the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>). This expedition was an international collaboration between scientists from the United States and Indonesia to explore the deep ocean in the Sangihe Talaud Region, located in the 'Coral Triangle', the global heart of shallow-water marine biodiversity. Questions such as "Who's Looking?", "Where To Look?" and "How To Look?" for this maiden voyage are described first hand, by Dr. Stephen H. Hammond, Acting Chief Scientist, NOAA Office of Ocean Exploration and Research, in the article starting on page 14 excerpted from *Current, The Journal of Marine Education*, Volume 28, Number 1, 2012, <http://oceanexplorer.noaa.gov/edu/oceanage/current.html>.

Ocean Exploration: Interdisciplinary Expeditions to Reveal an Unknown Ocean

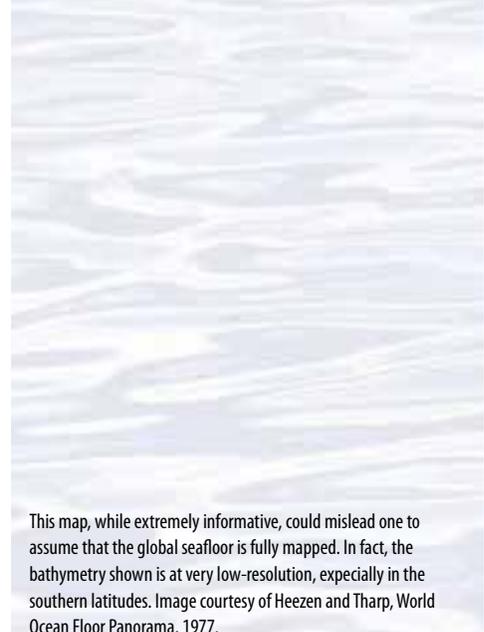


By Dr. Stephen H. Hammond

ALTHOUGH IT IS SURPRISING TO MANY, THE DISQUIETING FACT IS THAT THE EARTH'S OCEAN REMAINS VIRTUALLY unexplored. Even though one can easily find bathymetric maps of all the world's seafloors, in fact, nearly all of them present relatively low-resolution representations of seafloor topography. It is also a fact that we have much higher resolution maps of the surfaces of planets and moons in our solar system than we do of Earth.

NOAA, as the Nation's civilian ocean agency with responsibility for ocean stewardship, has a goal of understanding the effects of planetary-scale submarine volcanism on the ocean. To accomplish this, the effort must be interdisciplinary. The expertise of a geological oceanographer is required to understand the volcanological processes. Physical and chemical oceanographers provide expertise into understanding how an eruption impacts the surrounding water. Biological oceanographers understand how an eruption's physical and chemical manifestations impact existing ecosystems in the area and, interestingly, also initiate new ecosystems especially adapted to eruption-produced hydrothermal venting. It was this kind of interdisciplinary synergy that led to the discovery of chemosynthetic animal communities associated with venting at several locations along the Galápagos Rift in 1977, forever changing our understanding of life on Earth.

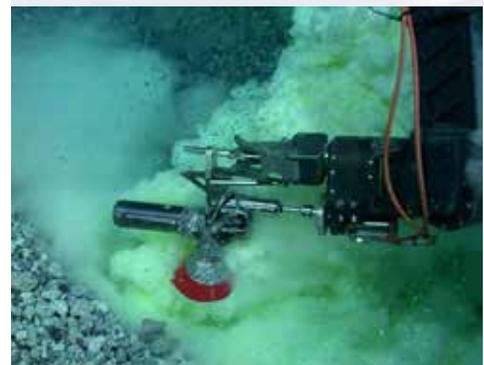
Coincidentally, very recent exploration of submarine volcanoes in the Mariana Arc revealed, for the first time, spectacular examples of volcanoes spewing immense quantities of carbon dioxide and sulfur dioxide. Both styles of venting are resulting in intense acidification of the volcanoes' regional environments. Although from a human perspective the environments around these volcanoes are highly toxic, each volcano is host to a unique ecosystem of highly adapted organisms. Recognizing that the global ocean is becoming acidified as a consequence of absorbing increasing quantities of atmospheric carbon dioxide, these discoveries raise the possibility of utilizing these volcanoes as natural ocean acidification laboratories. Again, gaining an understanding of these and other submarine volcanism sites and their environmental impacts requires an interdisciplinary oceanographic approach.



This map, while extremely informative, could mislead one to assume that the global seafloor is fully mapped. In fact, the bathymetry shown is at very low-resolution, especially in the southern latitudes. Image courtesy of Heezen and Tharp, World Ocean Floor Panorama, 1977.



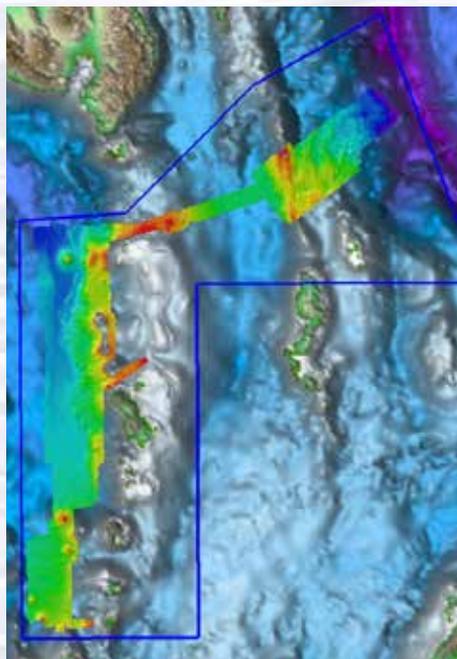
Image of a very active hydrothermal site on Kawio Barat submarine volcano taken by the ROV *Little Hercules*. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june30_update_hires.jpg



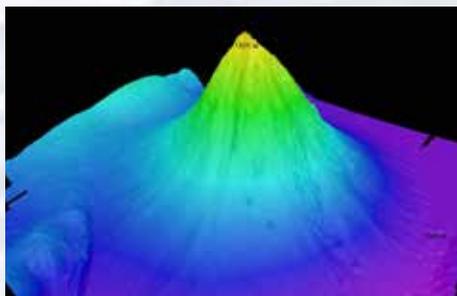
Sampling gas bubbles at a volcanically active vent on NW Rota-1 submarine volcano, Mariana Arc, in March 2010. The yellow and white material is particulate elemental sulfur produced by degassing of sulfur dioxide from erupting lava. The gases produced by volcanically or hydrothermally active submarine volcanoes often results in local to regional regions of high acidity. Image courtesy of James F. Holden, UMass Amherst.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/plumes/media/gas_bubbles_sampling.html

Map showing the Coral Triangle region—the most diverse and biologically complex marine ecosystem on the planet. The Coral Triangle covers 5.7 million square km, and matches the species richness and diversity of the Amazon rainforest. Although much of the diversity within the Coral Triangle is known, most still remains unknown and undocumented. Image courtesy of www.reefbase.org.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/coral_triangle_hires.jpg



The NOAA Ship *Okeanos Explorer* mapped an area larger than the state of Delaware during its maiden international voyage to explore Indonesia's deep seas. The new bathymetry is shown by the bright colors. Such high-resolution bathymetry is required in order to effectively explore seafloor features in more detail with ROVs. Image courtesy of NOAA *Okeanos Explorer* Program.



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor, and was found to be hydrothermally active. Images courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg

Discoveries in Indonesia's Deep Seas

In the summer of 2010, the NOAA Ship *Okeanos Explorer* embarked on its maiden voyage of exploration (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>). The expedition was the culmination of a long and complicated planning effort that involved high-level diplomatic, science, and technical leadership in the U.S. and Indonesia. Indonesia has long been recognized for the spectacular diversity of its land-based fauna. Indonesia's shallow seas likewise are rich with a diversity of marine life. What particularly intrigued the interests of both U.S. and Indonesian ocean scientists was to find out if Indonesia's deep seas, which are nearly unexplored, are just as biologically diverse.

The geological setting of the Indonesian region is incredibly complicated. Indonesia itself consists of 17,000 inhabited islands all of which lie in an area of multiple spreading centers and collision, or subduction zones. There are vast areas of relatively shallow seas punctuated by trenches and deeps that reach depths of more than 9 km. The area is subject to incessant earthquakes and is the most volcanically active region on the planet. Knowing this—and combined with the knowledge that areas of volcanically and hydrothermally active submarine volcanoes elsewhere in the world are places where spectacular biological discoveries are common—an interdisciplinary team of U.S. and Indonesian oceanographers devised a cruise plan that they believed offered a high probability of finding never-before-seen ecosystems.

The expedition planning began with highly skilled mapping technicians working closely with the scientists to create a high-resolution map of the area of interest. Utilizing this map, the interdisciplinary science team could then pick targets where active submarine volcanoes were most likely to be encountered. Once the *Okeanos Explorer* reached the exploration area, her state-of-the-art multibeam sonar mapping system was used to create more refined bathymetric maps of the target exploration areas, with the first leg of the expedition primarily devoted to creating a map of the entire exploration area.

Once the map was completed, features that were clearly volcanic in origin were identified by the science team. The second phase of exploration consisted of steaming slowly over the areas of interest while repeatedly lowering and raising a conductivity-temperature-depth (CTD) sensor package to depth. Operated by a Senior Survey Technician onboard the ship, the CTD provided real-time data that revealed whether or not there were heat and chemical plumes in the water column. The CTD survey was augmented by the ability to take water samples by triggering Niskin bottles when plumes were encountered. With input from chemical oceanographers ashore who specialize in hydrothermal vent



Scientists observe the video feed from *Little Hercules* and record their observations in the Eventlog. Image courtesy of NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/july13/media/seattle_ecc_scott_jim.html

Arrays of monitors in the ship's control room (below) and on shore (above) in Exploration Command Centers include high-resolution video streaming from the ROV as it operates on the seafloor. Images courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july27/media/control_room.html

is characterized by numerous active white smokers, massive sulfide chimneys densely colonized by what appear to be new species of animals, including dense populations of barnacles. All told, it was estimated that there were over 100 new species of vertebrates and invertebrates observed, including many new species of deep-sea corals. A high-resolution bathymetric map of an area approximately the size of Maryland was produced for an area of the seafloor never before explored.

Findings of the expedition are now being assessed and interpreted by the interdisciplinary science team. Results are being presented at professional meetings and will be published in scientific journals. Data from the U.S./ Indonesian expedition, as well as any other expedition of the *Okeanos Explorer*, are open and available to those requesting them virtually as soon as they are accessible, which is yet another important pioneering way of expediting ocean exploration. Ocean science educators are connecting classroom teachers and informal educators through lessons plans, professional development, and other offerings to the science of ocean exploration and the people who make it happen. The oceans are still almost entirely unexplored. NOAA's Ocean Exploration Program with its many partners is endeavoring to change that.

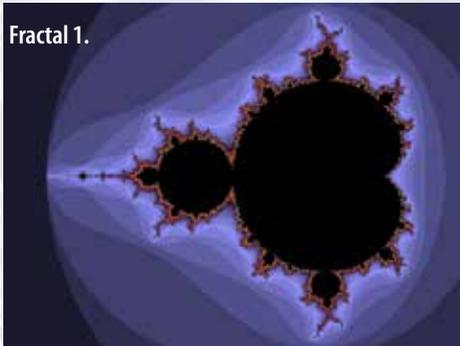
Dr. Stephen R. Hammond is the Acting Chief Scientist of the National Oceanic and Atmospheric Administration's (NOAA) Office of Ocean Exploration and Research as well as Director of the NOAA Pacific Marine Environmental Laboratory's Ocean Environment Research Division and Vents program. His is an adjunct professor in the College of Ocean and Atmospheric Studies at Oregon State University.





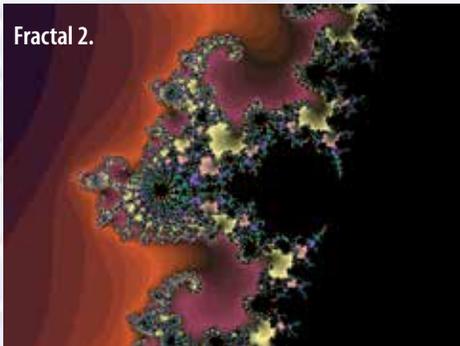
Section 1: Introduction

Lesson 1: To Explore Strange New Worlds

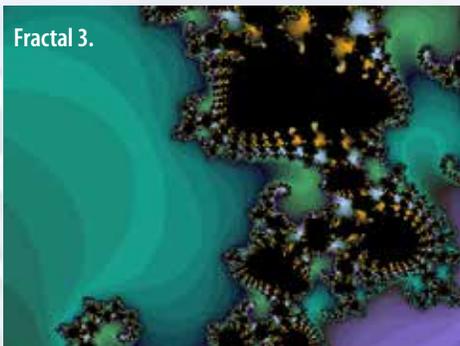


Fractal 1.

Fractal 1. The Mandelbrot set, a famous fractal.



Fractal 2.



Fractal 3.

Fractals 2 & 3: Zooming into portions of the Mandelbrot set reveals complex forms that resemble a variety of forms found in nature, including some marine animals. Images courtesy Mel Goodwin. For more information and examples, visit <http://fractalfoundation.org/>.

This lesson guides student investigations into strategies and technologies used for ocean exploration aboard the NOAA Ship *Okeanos Explorer*. Other lessons for the How Do We Explore? theme guide additional explorations into key topics of Telepresence, Multibeam Mapping, Water Column Investigations, and Underwater Robots.

Focus

Strategies for exploring unknown areas on Earth

Grade Level

Target Grade Level: 7-8; adaptations for grades 5-6 and 9-12 are provided on page 28 (Life Science/Physical Science/Earth Science)

Focus Question

What methods do scientist explorers use to investigate places that have never been seen before?

Learning Objectives

- Students will obtain and communicate information to explain how the exploration strategy used aboard the NOAA Ship *Okeanos Explorer* determines the structure and function of the ship's exploration technologies.
- Students will obtain and communicate information to explain how science, engineering and technology influenced exploration strategies of the Lewis and Clark and HMS *Challenger* Expeditions.
- Students will construct explanations for how fractal geometry can be used to model patterns in natural systems.
- Students will use fractal geometric models to explain how scale influences requirements for ocean exploration technologies.

Materials

- Copies of *Guide for Investigating Exploration Strategies*, one for each student group
- *Koch Curve Construction* scanned to a file for display on a whiteboard, or copied onto an overhead transparency
- Drawing paper
- Ruler for each student group
- Pencils
- Fractal images

Audiovisual Materials

- Interactive white board or overhead projector



Teaching Time

Two or three 45-minute class periods, plus time for student research

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Exploration Strategy
Lewis and Clark Expedition
HMS *Challenger* Expedition
Okeanos Explorer
Fractal

Background

Historically, many expeditions of discovery have preceded the voyages of the *Okeanos Explorer*. Two of the most famous are the Lewis and Clark Expedition (1804 – 1806) and the HMS *Challenger* Expedition (1872 – 1876). There are many differences between these expeditions, but several basic questions apply to all three:

- Who will look for discoveries?
- Where will they look?
- How will they look?

For additional discussion, please see the *Introduction to Volume 2: How Do We Explore?* beginning on page 9.

The question of “How to look?” also involves the critical issue of scale: Natural features and processes exist in a wide range of sizes and potential discoveries span the same range. The recent discovery of a fourth giant planet in a distant planetary system that is remarkably similar to our own solar system is an example at a scale of trillions of kilometers; while the discovery of Archaea, a fundamentally unique group of organisms, provides an example at a scale that is a billion trillion (10^{21}) times smaller.

These examples reflect an important characteristic about nature: natural features and processes generally do not become simpler with decreasing size. A useful and intriguing mathematical tool for modeling this characteristic of natural systems involves fractal geometry, which is discussed further in Part B of the Learning Procedure.

This lesson guides student investigations of exploration strategies used by the Lewis and Clark expedition, HMS *Challenger* expedition, and aboard the NOAA Ship *Okeanos Explorer* (Part A); and into fractal geometry as a tool for modeling natural systems, and how this tool might be used to plan deep-ocean explorations (Part B.).

By necessity, expeditions to explore unknown areas on Earth are based on integration of science, technology, engineering, and mathematics. Examples of this integration can be discussed in Part A, and the application of mathematical concepts to exploration of the real world is investigated in Part B.



Key Images and Video Resources

NOAA Ship *Okeanos Explorer* Slideshow Collection: http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html

NOAA Ship *Okeanos Explorer* Video Playlist: http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream_playlist.html

INDEX-SATAL 2010 Expedition Photo and Video Log: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/photolog/photolog.html>

Ocean Exploration Careers

For information about the exciting career opportunities in ocean exploration, see Appendix A starting on page 179.

The NOAA Ocean Explorer OceanAGE web page (<http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html>) is a unique online educational resource that enables users to learn more about a variety of ocean careers available to those interested in work on or in the ocean.

You may also want to check out the special issue of *Current* entitled *A Closer Look at Ocean Careers through the NOAA Ship Okeanos Explorer: A Case Study*, Volume 28, No. 1, 2012 (http://oceanexplorer.noaa.gov/edu/oceanage/current_careers.pdf).

Learning Procedure

[Note: Part A of this lesson is adapted from the *Exploring the Unknown* lesson from the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/unknown.pdf>).]

Part A. Voyages of Discovery

1. To prepare for this lesson:

(a) Review:

- Mission Plan for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/plan/plan.html>);
- “NOAA Ship *Okeanos Explorer*, ‘America’s Ship for Ocean Exploration’ ” (<http://oceanexplorer.noaa.gov/okeanos/welcome.html#>);
- “NOAA Ship *Okeanos Explorer* Maximizing Operations” (<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1006/welcome.html>);
- “Exploration or Research Science - Where Do We Draw the Line?” (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july22/july22.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 (http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf);

(c) Make copies of the *Guide for Investigating Exploration Strategies*.

(d) You may also want to review the Ocean Exploration Panel Web site (<http://oceanservice.noaa.gov/websites/retiredsites/oceanpanel.pdf>), which includes background information that was used to develop a national strategy for a new era of ocean exploration. The Ocean Exploration Panel was convened by the U.S. Department of Commerce at the direction of President Clinton in June 2000. The Panel’s final report entitled “Discovering Earth’s Final Frontier: A U.S. Strategy for Ocean Exploration” is an historic accomplishment because it is the only national strategy proposed for exploration of the global oceans by any country in the world. The executive summary of the final report is included on the Web site.

2. Briefly introduce the INDEX-SATAL 2010 Expedition. Point out that this expedition was the maiden voyage of the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth’s largely unknown ocean for the purposes of discovery and the advancement of knowledge. 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.

3. Tell students that their assignment is to investigate strategies used by other expeditions to explore unknown territories, and to invent a strategy that might guide the *Okeanos Explorer* on its voyages of discovery. Provide each student or student group with a copy of the *Guide for Investigating Exploration Strategies*. For Part A, you may want to have individual students or groups focus on only the Lewis and Clark Expedition or the HMS *Challenger* Expedition, or have them answer questions about both expeditions.

These voyages of discovery all involve aspects of science, technology, engineering, and mathematics. Have students describe how these four elements are integrated in the activities of each expedition as part of their investigations.



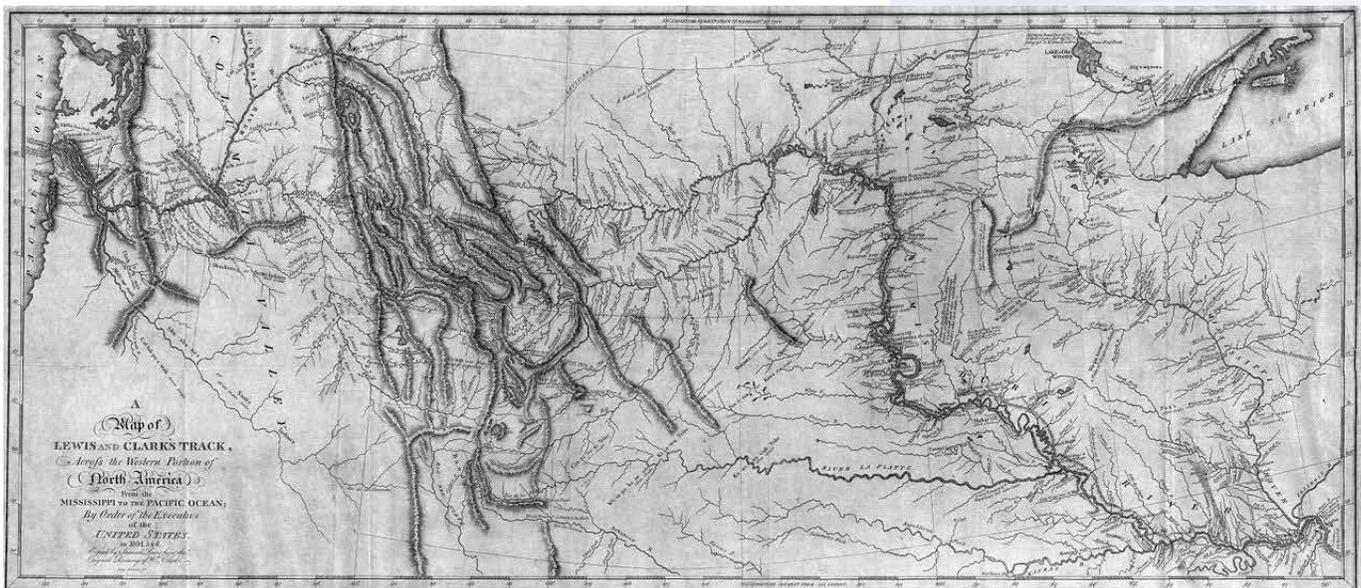
4. Lead a discussion of students' responses to questions about previous expeditions to explore the unknown. The following points should be included:

Lewis and Clark Expedition

- Thomas Jefferson's primary motivation for exploring the American West was developing commerce, specifically finding the most direct and practicable routes for water transport across the continent. Related to this mission was the requirement that the explorers should contact and develop friendly relations with native American tribes. Jefferson was also a keen citizen scientist, and his instructions for the Expedition also stated that observations should be made of soils, plants, animals, minerals, geologic formations, and climatic conditions.
- The overall plan for the Expedition's route was to follow the Missouri River upstream as far as possible, and then find a route to the Pacific Ocean. Since much of the Missouri River was unexplored, Lewis and Clark had no idea how close the headwaters of the Missouri would be to the Pacific, nor whether any route between them actually existed.
- The Expedition made extensive observations and collections in keeping with the broad instructions described above, with particular emphasis on detailed maps.
- Technical instruments included a mariner's compass and surveying instruments, portable microscope, and hydrometers. Information about natural history was collected primarily by visual observation and recorded as drawings, notes, and specimens.

The official report of the Expedition required eight years to complete after the explorers returned, and includes two volumes totalling 992 pages.

Map of Lewis and Clark's Track, Across the Western Portion of North America. Uncolored map showing topography and rivers in the region as well as towns, native American villages, and population figures. Originally published in 1814. The map and the written account of the expedition changed American mapping of the northwest by giving the first accurate depiction of the relationship of the sources of the Missouri, the sources of the Columbia, and the Rocky Mountains. The map was copied by Samuel Lewis from William Clark's original drawing, and was engraved by Samuel Harrison.





The HMS Challenger.

<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.htm>



The science and ship crew of the HMS Challenger in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image courtesy of NOAA.

<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg>



The route of HMS Challenger. The expedition lasted 1,000 days and covered more than 68,000 nautical miles. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/media/route.html>

HMS Challenger Expedition

- The HMS *Challenger* Expedition was organized and funded to examine the deep seafloor and address specific scientific objectives:
 - To investigate depth, temperature, circulation, specific gravity and penetration of light in the deep sea;
 - To determine the chemical composition of seawater at various depths from the surface to the bottom, the organic matter in solution and the particles in suspension;
 - To ascertain the physical and chemical character of deep-sea deposits and the sources of these deposits; and
 - To investigate the distribution of organic life at different depths and on the deep seafloor.

In addition, the Expedition was instructed to obtain photographs of “native races,” and the information that was recorded about the indigenous people proved to be extremely valuable, because many island cultures changed rapidly in subsequent years.

You may also want to point out that commercial interest in the deep ocean was being stimulated by the desire to lay submarine telegraph cables, and that there was scientific controversy over whether there was any life at all in the ocean below 549 m (1800 feet).

- The Expedition’s route included the North and South Atlantic, Indian, and Pacific Oceans (<http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/media/route.html>). Along this route, 362 official stations were established at which data were collected.
- A standard set of data was collected at each of 362 stations along their route. Samples and data were carefully returned to Scotland for systematic analysis and documentation. The standard set of observations made and samples taken at each station was:
 - water depth
 - temperature at various depths
 - weather conditions
 - water conditions at surface and sometimes at depth
 - seafloor samples
 - water samples for later chemical analysis
 - samples of plant and animal life collected with dredges, trawls, and sometimes plankton nets from various depths
- Primary technical instruments were weighted ropes for measuring depth; dredges and nets; thermometers; hydrometers; and water sampling bottles.

The final reports from the HMS *Challenger* Expedition occupy 50 volumes with a total of 29,552 pages, and required 19 years to complete after the Expedition ended.

Discuss some of the ways in which science, technology, engineering, and mathematics are integrated in the activities of each expedition. For example:

- The first part of the Lewis and Clark Expedition used a custom-built keelboat designed by Thomas Jefferson and Meriwether Lewis. The initial design was extensively modified based upon experiments with prototypes during the vessel's construction in the spring and summer of 1803 (a good example of the Engineering Design Process in action. See sidebar).
- Surveying and navigation activities of all three expeditions are based on mathematical principles and methods.
- HMS *Challenger* and *Okeanos Explorer* embody many aspects of sophisticated engineering and applied mathematics. Neither vessel was originally constructed for ocean exploration, and both required an extensive retrofit to incorporate specialized exploration technologies.

5. Discuss some of the basic requirements shared by expeditions to explore unknown territories. In addition to material requirements such as appropriate transportation and technology, students should understand that modern ocean exploration depends upon many of the same human character traits that were needed by the Lewis and Clark and HMS *Challenger* Expeditions:

- Courage to face uncertainties;
- Willingness to take risks;
- Ability to face physical challenges; and
- An acceptance of the likelihood of adverse circumstances and willingness to adapt to unexpected events.

Note that “risk-taking” does not imply reckless behavior; rather, it involves a willingness to try new things, work through difficulties, and learn from failures.

Discuss similarities between human character traits needed for ocean exploration and engineering habits of mind, which include:

- systems thinking;
- creativity;
- optimism;
- collaboration;
- communication; and
- attention to ethical considerations.

In modern ocean exploration, science, technology, engineering, and mathematics are so closely integrated that it can be hard to separate one element from the others. Scientific questions drive the Engineering Design Process, which produces technology that provides data to answer the questions. Mathematics helps translate scientific questions into engineering design problems, provides tools that help create technological solutions, and assists with interpreting and analyzing data obtained with technology to answer scientific questions. Electronics are involved in every aspect of ocean exploration, including ship operations, telepresence, data acquisition, and scientific analysis. Many devices used for these activities include microcontrollers; tiny computers that are also found in home appliances, automobiles, marine engines, televisions, media players, interactive games, toys and many other products.

Engineering Design Process

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

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

These steps involve several key skills:

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

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements.

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



Lead a discussion about exploration strategies that might guide *Okeanos Explorer* missions. Have students present their ideas, then relate these to the following points from the exploration strategy discussion in the *Introduction to Volume 2: How Do We Explore?* starting on page 12:

- The overall *Okeanos Explorer* strategy is based on finding anomalies;
- This strategy involves Underway Reconnaissance, Water Column Exploration, and Site Characterization;
- Key technologies involved with this strategy include Telepresence, Multibeam Sonar Mapping, CTD and other electronic sensors, and a Remotely Operated Vehicle (ROV); and
- The *Okeanos Explorer* is a ship of discovery, focused on exploration rather than research.

Be sure students realize that the recognition of anomalies may be affected by a variety of factors, including:

- The scale at which observations are made;
- Who is making the observations; and
- How the observations are made.

For example:

- If observations of chemical and physical seawater properties are made at 10 m intervals, anomalies are more likely to be missed than if these observations are made at intervals of 1 m (which is possible with CTD equipment aboard *Okeanos Explorer*);
- The significance of a bottom feature imaged by multibeam sonar may be interpreted differently by a biologist and a geologist (this is also a good example of the importance of telepresence in the *Okeanos Explorer* exploration strategy);
- Finding anomalies in the deep ocean is highly dependent upon the technology that is available to make observations, and even with state-of-the-art technology it is likely that some anomalies will be missed because they can only be observed with instruments that are not yet available to ocean explorers.

Decisions about the scale at which observations are to be made, and which technologies will be used to make these observations are strongly influenced by our basic assumptions about natural systems. One of these assumptions, the “geometry of nature,” is explored in the following investigation.

Part B. The Fractal Geometry of Nature

- To prepare for this lesson:
 - Scan the *Koch Curve Construction* on page 32 to a file for display on a whiteboard, or copy it onto an overhead transparency.
 - Download examples of fractals in nature and “fractal forgeries of nature” from <http://classes.yale.edu/fractals/Panorama/welcome.html>. Select categories from the “Contents” menu on the left side of the page. Useful categories include “Forgeries of Nature,” “Fractal Planets, Simulated,” and “Mountains, Simulated.” There are also several hundred videos about fractals in nature available on YouTube.

2. Background

“Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line.”

~ Benoit Mandelbrot

The Fractal Geometry of Nature

Pueblo, Colorado lies just east of the Rocky Mountains. Looking west from Pueblo, you see the jagged, complex topography of the Rockies. If you drive 40 miles or so to the base of the Rockies, you no longer see as much of the overall topography, but now you can distinguish many trees and smaller rock formations; different from the view at Pueblo, but just as complex. Climb a mile up the slope of the nearest mountain, and you see details of individual trees and rocks; again, different from the previous views, but still complex. Move closer to a single tree and more details become evident, but the overall view does not become simpler. Pick a single leaf or piece of bark, chop it up, look at a single fragment under a microscope, and... you know what happens.

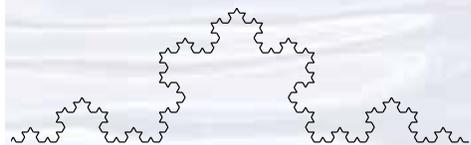
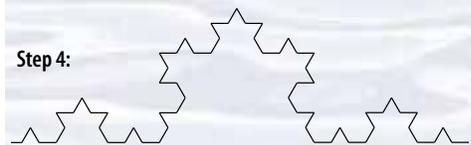
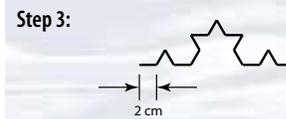
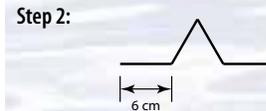
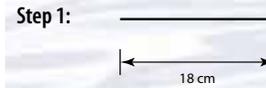
This illustrates an important characteristic about nature in general: natural features and processes generally do not become simpler with decreasing size. This characteristic has important implications for decisions about the scale of exploration observations.

Most mathematics curricula emphasize the regular geometric shapes described by Euclid (a Greek mathematician who lived around 300 B.C.). Young children (and some highly-paid “primitive” artists) use these shapes to depict nature (*e.g.*, trees as straight lines topped by circles). In fact, the artist Paul Cézanne is widely reported to have said, “Everything in nature takes its form from the sphere, the cone and the cylinder.”

Despite this emphasis, we know that nature rarely assumes the classic Euclidian forms. A basic wilderness survival strategy, for example, is that signals made with straight lines, circles, squares or triangles are easily seen by rescuers because these regular shapes are almost never found in natural landscapes.

In 1982, Benoit Mandelbrot published *The Fractal Geometry of Nature*, in which he proposed that many natural features can be modeled with geometric structures that he called fractals. The Koch Curve, named after Swedish mathematician Niels Fabian Helge von Koch, is a well-known example that provides a useful starting point for exploring fractals.

Koch Curve Construction





3. Show several simple geometric forms such as circles, square, triangles, etc., and ask students where they can find these forms in nature. Students may name various objects that are approximately circular (e.g., the moon), but should realize that if one looks closely enough there are many irregularities that prevent the objects from being exactly circular.

Use the Pueblo example described above to introduce the idea of complexity at multiple scales. Tell students that they are going to create a simple example of a structure that can be increasingly complex at an infinite number of scales.

Instruct students to begin by drawing a line measuring 18 cm (Step 1 of “Koch Curve Construction”). Next, divide the line into three equal segments (6 cm), and replace the middle segment with two sides of a triangle whose sides are 6 cm long as shown in Step 2. Now repeat this process, dividing each segment into three equal segments (2 cm), and replacing the middle segment with two sides of a triangle whose sides are 2 cm long as shown in Step 3. If you repeat this an infinite number of times, you produce the Koch Curve. Step 4 shows the results of two more repetitions. Tell students that it obviously is not possible to repeat the process infinitely, so our drawing is only an approximation of the Koch Curve; but it helps to illustrate two defining features of fractals:

- Self-similarity; and
- Fractional dimensions.

Self-similarity means that the segments of the Koch Curve are made of repeating units that look the same, regardless of how much we magnify any portion of the curve. In other words, the Koch Curve is equally complex at multiple scales.

Fractional dimension refers to the way objects occupy space. A line is a one-dimensional object. A square, triangle or other flat shape is a two-dimensional object. A cube, pyramid, sphere, or other solid is a three-dimensional object. The Koch Curve is not a one-dimensional object (a line), nor is it a two-dimensional object (square, triangle, circle, ellipse, etc). It is something in between a one- and two-dimensional object; so it has a fractional dimension. This dimension can be calculated to be approximately 1.2619 (optional: see <http://math.rice.edu/~lanius/frac/> for further discussion about how this calculation can be done).

4. Show students images downloaded in Step 1d, and discuss the idea that fractals provide useful models of nature; more accurate, in many cases, than Euclidean shapes. Point out (if students do not mention it) that the fractal characteristic of similarity at multiple scales is similar to our own experiences with nature (such as the Pueblo example). Discuss how this characteristic might be useful to explorers planning a strategy for exploring the deep ocean. Students should realize that if we observe complexity in natural features at one scale, the “fractal geometry of nature” concept suggests that we will also find similar complexity at other scales. So, if we observe deep-ocean features over a wide area (for example, with multibeam sonar), we can find areas where features seem to be relatively complex (such as seamounts, underwater volcanoes, deep reefs). We can then observe these relatively complex areas at different scales with different tools (such as video cameras on an ROV) to look for other features, organisms, or anomalies. The idea is that detecting complexity over large areas gives us a way to narrow our search to places that have a relatively high probability for anomalies.

5. *Optional*: Discuss how the fractal geometry of nature influences diversity in natural habitats. Ecologists have found that the number of species in various habitats often correlates with the physical complexity of the habitat and the variety of resources available in that habitat. They have also found that habitat complexity often exists at multiple scales. So, for example, a coral reef is complex at the scale of an entire coastline, also complex at the scale of individual fishes, similarly complex at the scale of smaller organisms that live in the space between corals and coral branches, and still complex at the scale of microorganisms that live on the surfaces of corals and other organisms on the reef. For other examples, see Wiens (1989).

See <http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/fleas.pdf> for another activity that explores the fractal nature of habitat complexity.

Adaptations for Other Grade Levels

Considerations for Grades 5-6 – Activities and information about the Lewis and Clark, HMS *Challenger*, and *Okeanos Explorer* expeditions are appropriate to all grades. Expectations for students' responses to the *Guide for Investigating Exploration Strategies* questions should be similar to expectations that would apply to other student reports at this grade level. Most students at the grade 5-6 level will not be familiar with many of the mathematical concepts involved with fractal geometry, but experience suggests that the overall idea of fractals and their potential as models of natural features and process are well within the grasp of students in these grades. Lanius (see Other Resources) provides additional discussion and ideas about how fractal concepts can be taught to elementary and middle school students.

Considerations for Grades 9-12 – Students in these grades should be expected to provide more detailed information in response to *Guide for Investigating Exploration Strategies* questions. Individual *Guide* questions may be assigned to specific student groups as topics for group reports. Mathematics knowledge among students at this level should be sufficient to allow more in-depth exploration of fractals, including calculation of fractal dimensions. Frame, Mandelbrot, and Neger (see Other Resources) offer ideas for laboratory exercises and lesson plans, as well as extensive background information and examples from many fields including fine art, architecture, and natural history.

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 click on “Maritime Heritage” for activities and links about the HMS *Challenger* and other ocean exploration expeditions.

The “Me” Connection

Have students write a brief essay discussing how they use (or might use) anomalies to explore an unfamiliar area.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Answers to *Guide for Investigating Exploration Strategies* questions and class discussions provide opportunities for assessment.



Extensions

Visit http://oceanexplorer.noaa.gov/explorations/lewis_clark01/lewis_clark01.html and <http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/challenger.html> for more information about connections between modern ocean exploration and the Lewis and Clark and HMS *Challenger* Expeditions.

Multimedia Discovery Missions

<http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html> Click on the links to Lessons 1, 3, 5, 6, and 12 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Journey to the Unknown (Grades 5-6)

(from *The NOAA Ship Okeanos Explorer Education Materials Collection Volume 1: Why Do We Explore?*)

http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_journey.pdf

Focus: Ocean Exploration (Life Science/Earth Science)

Students will experience the excitement of discovery and problem-solving to learn what organisms could live in extreme environments in the deep ocean, and will understand the importance of ocean exploration.

Come on Down! (Grades 7-8)

(from *The NOAA Ship Okeanos Explorer Education Materials Collection Volume 1: Why Do We Explore?*)

http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_comedown.pdf

Focus: Ocean Exploration (Physical Science)

Students will research the development and use of research vessels/vehicles used for deep-ocean exploration; and calculate the density of objects by determining the mass and volume.

Big Fleas Have Little Fleas (Grades 7-8)

(from the 2006 Davidson Seamount: Exploring Ancient Coral Gardens Expedition)

<http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/fleas.pdf>

Focus: Physical structure in benthic habitats (Life Science)

Students recognize that natural structures and systems often display recurrent complexity over many scales of measurement, infer the importance of structural complexity to species diversity and abundance in benthic habitats, and discuss ways that octocorals may modify seamount habitats to make these habitats more suitable for other species.

Calling All Explorers... (Grades 9-12)

(from *The NOAA Ship Okeanos Explorer Education Materials Collection Volume 1: Why Do We Explore?*)

http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_callingex.pdf

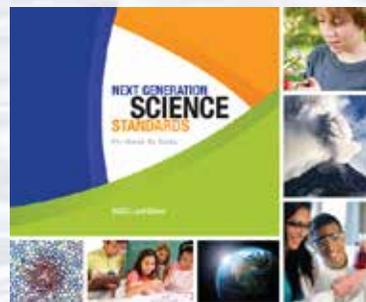
Focus: Ocean Exploration - Recent explorers of deep-sea environments and the relationship between science and history (Life Science/Earth Science)



Students learn what it means to be an explorer, both modern and historic; recognize that not all exploration occurs on land; understand the importance of curiosity, exploration, and the ability to document what one studies; gain insight into the vastness of unexplored places in the deep sea; and gain appreciation of science mentors and role models.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf



The Next Generation Science Standards

The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations and each combines Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts as described in *Next Generation Science Standards* (National Academies Press 2013). While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:
oceaneducation@noaa.gov

For More Information

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<http://oceanexplorer.noaa.gov>

Part A: Guide for Investigating Exploration Strategies

Lessons from Previous Voyages of Discovery

Two of the most famous expeditions to explore unknown territory are the Lewis and Clark Expedition and the HMS *Challenger* Expedition. Both of these expeditions are generally considered to have been successful, and produced a great deal of information that provided vital guidance for subsequent explorations and scientific studies. Exploration strategies used by these expeditions may offer some useful ideas for modern-day voyages of discovery. The following questions will help guide your investigation into these strategies.

1. Exploration strategies usually are strongly influenced by the underlying purpose of the expedition. What was the overall mission of the expedition?
2. What was the overall plan for the expedition's route?
3. What scientific measurements or observations did the expedition make?
4. What technical instruments did the expedition have available?
5. How long was the expedition?
6. How many people were involved in the expedition?
7. How much area did the expedition cover?

NOAA Ship *Okeanos Explorer*

In 2000, the President's Panel for Ocean Exploration issued its report, *Discovering Earth's Final Frontier* (available from: http://oceanservice.noaa.gov/websites/retiredsites/supp_oceanpanel.html). The report called for a new national Ocean Exploration Program, noting that 1) previous efforts to explore the ocean had "ended before a significant portion of the oceans was visited in even a cursory sense; and 2) marvelous new tools now exist that permit exploration in spatial and temporal dimensions that were unachievable 50 years ago. For these reasons, we must go where no one has ever gone before, 'see' the oceans through a new set of technological 'eyes,' and record these journeys for posterity."

In August 2008, the NOAA Ship *Okeanos Explorer* was commissioned as the only U.S. ship whose sole mission is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. List some ideas for exploration strategies that could be used to fulfill this mission. In particular, consider:

- What kind of measurements or observations should be made?
- What technologies could be used to make these measurements or observations?



The HMS *Challenger*.
<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.htm>



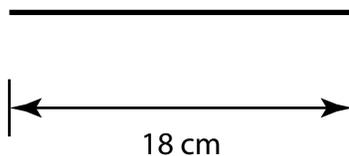
The science and ship crew of the HMS *Challenger* in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image courtesy of NOAA.
<http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg>



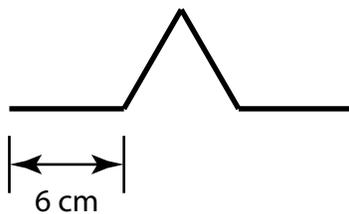
NOAA Ship *Okeanos Explorer*: America's Ship for Ocean Exploration. Image courtesy of NOAA. For more information, see the following Web site: <http://oceanexplorer.noaa.gov/okeanos/about.html>

Part B. Koch Curve Construction

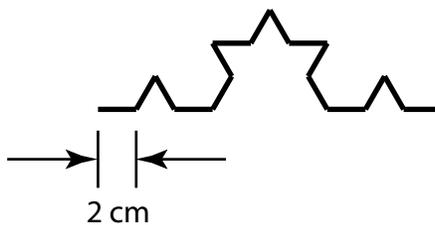
Step 1.



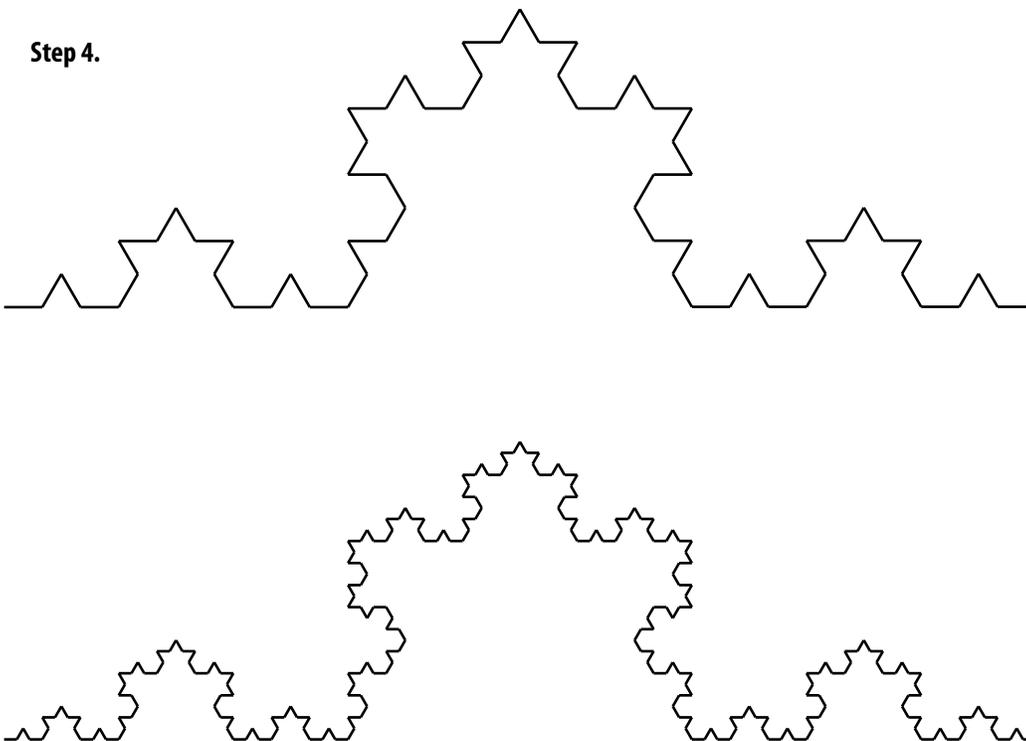
Step 2.



Step 3.



Step 4.





Section 2: Telepresence

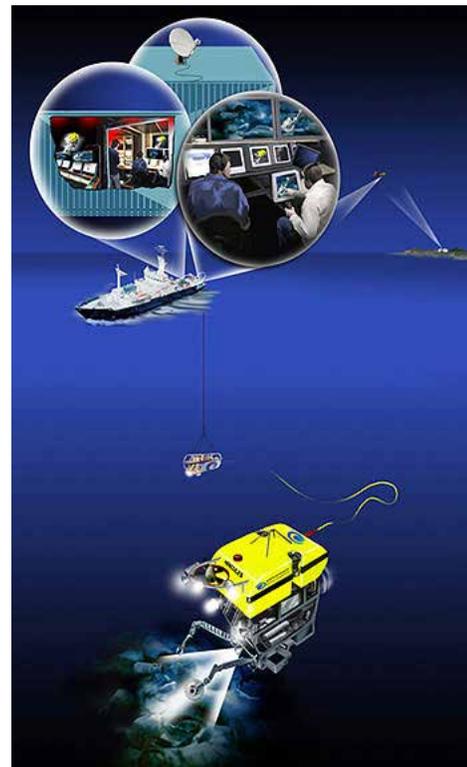
Introduction to Telepresence

Almost three decades ago, Dr. Robert Ballard envisioned the use of satellite technology to allow scientists, teachers and students on shore access to data and images from ships at sea in real-time. This concept of access in real-time is called telepresence technology. Although it continues to evolve, telepresence technology has advanced at a rapid pace in recent years, providing a virtual portal into the excitement of oceanographic discoveries and demonstrating the importance of exploring our largely unknown ocean. NOAA's Office of Ocean Exploration and Research (OER) partnered with Dr. Ballard at the Institute for Exploration (IFE) and the University of Rhode Island's (URI) Inner Space Center (ISC) to develop a new paradigm for ocean exploration that takes telepresence to a new level with the goal of increasing the pace, scope and efficiency with which we are able to explore the ocean world.

Telepresence is simply a group of technologies that enable people to observe and interact with events at remote locations. On board the NOAA Ship *Okeanos Explorer*, the foundation for telepresence is advanced broadband satellite communication. Telepresence allows video and audio in real-time and other imagery to be transmitted from a remotely operated vehicle (ROV) at sea through satellites to the ISC at URI. From the ISC, these products are transmitted through the Internet to other scientists ashore located at Exploration Command Centers (ECCs). The ECCs are remote locations outfitted with special communications equipment, including consoles with plasma screens for viewing the video, as well as an Internet-enabled intercom system. The system enables scientists and others to converse simultaneously with the explorers at sea, and/or scientists at other ECCs located anywhere in the world. Currently, ECCs are located at the URI ISC; the NOAA/University of New Hampshire (UNH) Center for Ocean and Coastal Mapping (CCOM) Joint Hydrographic Center; the NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle; at NOAA in Silver Spring, Maryland; and at the Stennis Space Center in Mississippi.

From the Ship to the Sky

The most prominent piece of communications equipment aboard the *Okeanos Explorer* is the 4.2 m diameter dome that houses the ship's 3.7-meter Very Small Aperture Terminal (VSAT) dish antenna. This antenna is the critical link between the *Okeanos Explorer* and the satellites that relay information between the ship and the ECCs, as well as the ISC. Computers and hardware included in the antenna system make constant adjustments that compensate for the ship's heave, roll and pitch to keep the antenna pointed toward the appropriate communications satellite. Radio transmitters and receivers connected to the VSAT antenna



Telepresence technology uses satellite technology and the internet to transmit data and video in real-time from remotely operated vehicles (ROVs) working at depth, to a shore-based hub at the University of Rhode Island, which then sends this data to a variety of receiving stations on shore. Image courtesy of Paul Oberlander, Woods Hole Oceanographic Institution.

<http://oceanexplorer.noaa.gov/explorations/07blacksea/background/telepresence/media/shipveh.html>



operate in the global C-band, using frequencies between 3.7 to 4.2 GHz for downlinks, and frequencies between 5.925 GHz to 6.425 GHz for uplinks (signals received from a satellite are downlinks; signals sent to a satellite are uplinks). These frequencies are in the microwave region of the electromagnetic spectrum. The satellites used by the *Okeanos Explorer's* telepresence system are 22,753.2 statute miles ("normal" miles, not nautical miles) above Earth's surface. At this altitude, the satellites' rotational speed matches the speed of Earth's rotation so they appear to remain in a fixed position when viewed from Earth's surface. For this reason, these satellites are called "geosynchronous."

Connecting ECCs to Each Other and to the *Okeanos Explorer*

Real-time voice communications among scientists onboard the ship and among the ECCs are enabled by an Internet-based intercom system, which allows all participants, regardless of location, to easily communicate with all other participants. This voice communication between the *Okeanos Explorer* and shore-side ECC's uses a technology borrowed from the broadcast industry, an IP-enabled intercom system. This system leverages the *Okeanos Explorer's* Internet connectivity to connect all of the ship-based and shore-based intercom units located at the ECCs into a single system.

The "Eventlog": Another Telepresence Communication Tool

During expeditions, real-time voice communication is supplemented by a real-time text-based tool called the "Eventlog," which allows each science observer to write his or her personal observations to a common digital, or computer-based, log. Log entries can immediately be seen by all other users. All users on the ship and at the ECCs are encouraged to participate in the Eventlog, since each individual is potentially able to provide unique observations and insight into what all are observing for the first time through the "eyes" of the ROV. Ocean exploration is, by definition, multidisciplinary and as such, scientists with differing areas of expertise must be involved in the missions so as to be able to most accurately, completely, and effectively characterize exploration targets captured in the video streams of the ROV. The Eventlog software automatically "stamps" the date, time of entry, and author of each text observation on each entry. This simplifies post-cruise data, and video searches. The Eventlog tool leverages the same technology and standards-based protocols used on the Internet for Instant Messages (IM) and chatrooms.



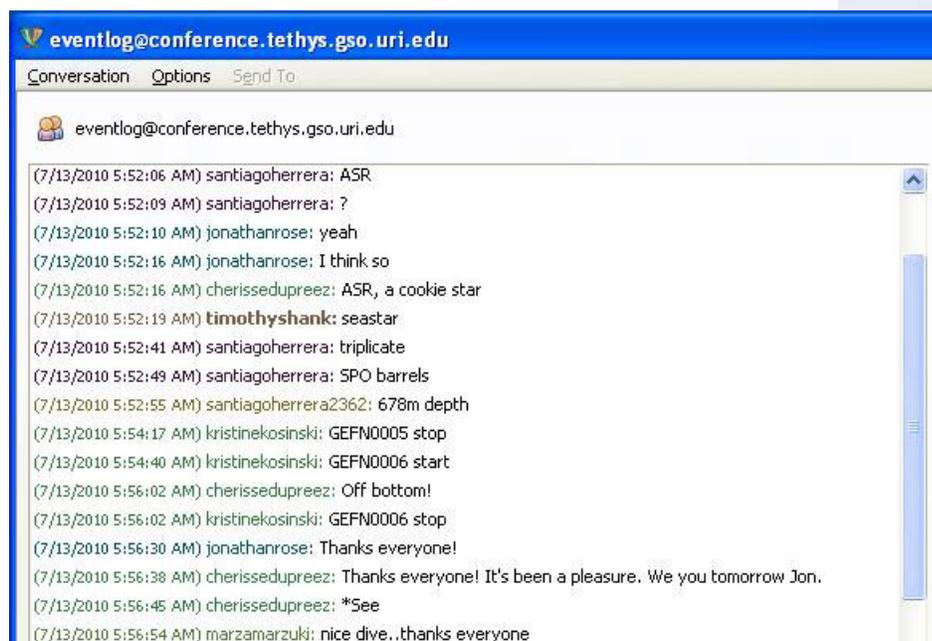
Assembly the VSAT for the *Okeanos Explorer* in the Fairhaven Ship Yard in Bellingham, WA, 2007. Image courtesy of Installation and Operation Manual for Sea Tel Model14600-75 Phase Matched C-Band TX/RX Antenna.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/apr13/media/apr13-2.html>



Technicians work on the satellite antenna in the VSAT dome. Image courtesy of NOAA *Okeanos Explorer* Program, Galapagos Rift Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/july11_update01_hires.jpg



INDEX 2010 participants used a real-time text-based collaboration tool called the "Eventlog" to communicate and make log entries about ongoing operations. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/media/ichat.html>



Voice communication between the *Okeanos Explorer* and shore-side ECCs uses an IP-enabled intercom system. Here, scientists at the Seattle ECC communicate with participants on the ship and at the Jakarta ECC. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/seattle_rts_hires.jpg



A doctoral student with the MIT-WHOI joint program, was based at the Seattle ECC during the INDEX-SATAL 2010 Expedition. Image courtesy of Woods Hole Oceanographic Institution.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/ellie_seattle_hires.jpg

Data Management through Telepresence

In addition to video collected by the *Okeanos Explorer's* ROVs, other data are also transmitted via satellite back to shore for distribution, data management and archive purposes. Data collected by the EM302 multibeam array and the EK60 echosounder used to characterize the seafloor and water column are also sent to ECCs, along with CTD data to help scientists interpret observations in real-time from the seafloor. A multitude of other data is also sent to shore for during cruise and post-cruise processing. See the article entitled *Careers Managing Scientific Information Aboard the NOAA Ship Okeanos Explorer* at http://oceanexplorer.noaa.gov/edu/oceanage/current_careers.pdf for more information on managing data onboard the *Okeanos Explorer* using telepresence.

Building Scientific Intellectual Capital with Telepresence

Through direct communication of scientists located at the various ECCs with scientists and technicians on board the *Okeanos Explorer* during expeditions, a much broader realm of scientific expertise is brought to the exploration as soon as discoveries are made, and with much less of an investment in “person-at-sea” days than during most traditional oceanographic expeditions. Since the *Okeanos Explorer's* powerful satellite dome has high-bandwidth, a large amount of data can be transmitted from the ship to the ISC and ECCs in a short span of time, including three high-definition video feeds, as well as real-time voice communication Internet connections. High definition video transmissions use broadcast industry equipment to deliver high quality video with very little time delay. Even with intensive signal processing and the delays introduced by satellite and land-based links, video travels from the ROV at depths reaching 4,000 m to the ECCs thousands of miles away in an average of six seconds.

To the ECCs and Beyond

The ability to watch the live events aboard the *Okeanos Explorer* is not limited to those with access to an ECC. Capabilities today enable users to view live feeds from the *Okeanos Explorer* via the Internet on the *Ocean Explorer* website at oceanexplorer.noaa.gov during active expeditions to bring real-time ocean exploration science and the scientists behind it into classrooms, newsrooms, and living rooms, which opens new educational opportunities that are a major part of the *Okeanos Explorer's* mission for the advancement of knowledge.

Implementing telepresence is far from simple. However, the impact of telepresence is immeasurable. During INDEX-SATAL 2010, the maiden voyage of the *Okeanos Explorer*, approximately 20 scientists gathered at the ECC at the Pacific Marine Environmental Laboratory in Washington State (PMEL) as thousands of public onlookers from three countries, five time zones, distributed across thousands of miles, were able witness, discuss and document the incredible life and habitats residing at the bottom of the Indonesian Sea. As technologies continue to evolve, so too, telepresence capabilities for ocean exploration will continue to expand, bringing with them new ways of exploring and communicating about our little known ocean world.



Section 2: Telepresence



Pen-Yuan Hsing works diligently in the ROV Control Room to maximize the scientific benefits of the dives. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr5-4-hires.jpg>



A representative group of mission personnel who were on board NOAA Ship *Okeanos Explorer* during the third and final cruise leg of the 2012 Gulf of Mexico Expedition. Image courtesy of the NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr29_update_hires.jpg



Engineers fabricate parts for the ship's infrastructure. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/engineers_hires.jpg

Lesson 2: A Day in the Life of an Ocean Explorer

Focus

Telepresence and communications for ocean exploration

Grade Level

7-8 (Physical Science) Adaptations to grades 5-6 and 9-12 can be found on page 46.

Focus Question

What strategies are used aboard the NOAA Ship *Okeanos Explorer* to investigate unknown areas in Earth's ocean and how are human communication and telepresence involved with these strategies?

Learning Objectives

- Students will discover the many methods of communication used aboard an exploration vessel and understand how telepresence technologies aboard the NOAA Ship *Okeanos Explorer* increase the pace, efficiency, and scope of ocean exploration.
- Students will explore how patterns in the basic properties of simple waves contribute to processes of obtaining, evaluating, and communicating information in ocean exploration.

Materials

- Copies of
 - "A Day in the Life of an Explorer" by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html>).
 - "Implementing Telepresence: Technology Knows No Bounds" by Webb Pinner and Kelley Elliott (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>); and
 - "Executing Telepresence: The Seattle ECC Comes Online!" by Kelley Elliott and David Butterfield (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>) or have students reference these online.
- Access to the *Ocean Explorer* video playlist http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream_playlist.html
- 1 rope, at least 3/8-inch diameter x 8 ft; braided nylon or other flexible material (preferably in a bright color for good visibility)

Audiovisual Materials

- Optional – Images of exploration technologies (see Learning Procedure, Step 1d)



Teaching Time

Three to six 45-minute class periods (see Learning Procedure, Note b)

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Telepresence
Satellite communication
Wireless communication
Electromagnetic wave
Frequency
Wavelength
Modulation

Background

Telepresence is the key to the *Okeanos Explorer*'s exploration strategy. This technology allows people to observe and interact with events at a remote location. The *Okeanos Explorer*'s telepresence capability is based on advanced broadband satellite communication through which live images can be transmitted from the seafloor to scientists ashore, classrooms, newsrooms, and living rooms, providing new educational opportunities that are a major part of *Okeanos Explorer*'s mission for advancement of knowledge.

For more information about telepresence, please see the *Introduction to Telepresence* on page 33. This lesson guides an introduction to ocean exploration aboard the *Okeanos Explorer*, and how the concept of telepresence is implemented as part of the overall exploration strategy.

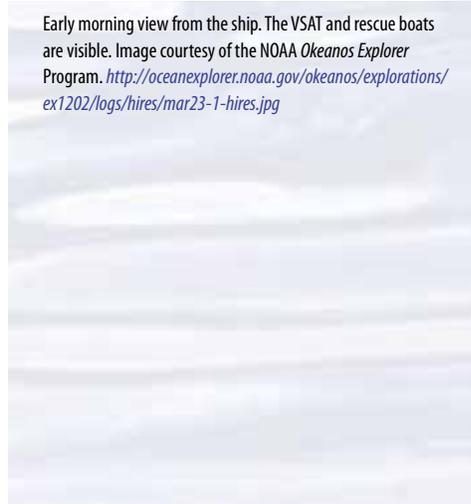
Learning Procedure

NOTES:

- This lesson provides an introduction to some of the fundamental concepts of communication, the foundation for wireless communication technology, and the interdependence of science, technology and engineering in ocean exploration. Depending upon curriculum mandates and the availability of time and resources, this introduction may be extended to include additional content and activities described under Extensions on page 47.
- This lesson includes content on the process of ocean exploration aboard the *Okeanos Explorer*, basic concepts of communication, and the technological basis for telepresence. While these topics are closely related in the context of the *Okeanos Explorer* mission, several class periods will be needed to complete the entire Learning Procedure. Educators are encouraged to adapt these topics to their own curricula, and steps in the Learning Procedure have been identified with the relevant topic to assist this process.



Early morning view from the ship. The VSAT and rescue boats are visible. Image courtesy of the NOAA *Okeanos Explorer* Program. <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/mar23-1-hires.jpg>





Senior Survey Technician Colleen Peters makes an entry in the mapping watch log book. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/mapper_hires.jpg

1. To prepare for this lesson:

a) Review:

- “A Day in the Life of an Explorer” by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html>);
- “Implementing Telepresence: Technology Knows No Bounds” by Webb Pinner and Kelley Elliott (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>); and
- “Executing Telepresence: The Seattle ECC Comes Online!” by Kelley Elliott and David Butterfield (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>).

b) Review background information about telepresence and the *Okeanos Explorer* exploration strategy and technologies.

c) Make copies of the two telepresence essays and the daily log for July 29, 2010 Colleen Peters, referenced above (or students can read these directly online).

d) If desired, download images to accompany discussions in Step 4.

2. **Basic Concepts of Communication** – Instruct students to keep a “Communication Diary” for one 12 hour day and bring it to class. In their diary, ask them to list the different communication methods they used and the reasons they chose those particular forms of communication for different situations. In class, discuss students’ results. How many different forms of communication were used? Were they surprised by their results? How might their results be different 10 or 20 years ago?

Ask students to describe the requirements for human communication. In the simplest analysis, human communication requires someone to send a message, someone to receive the message, and something that can carry the message from the sender to the receiver. Discuss some of the ways that humans send messages. In addition to verbal messages, there are many forms of nonverbal communication based on various signals. Facial expressions, gestures, and body language are well-known examples. Students should realize that signals may be passive (silence can send a powerful message under some circumstances!); and that if the sender and receiver do not attach the same meaning to a given signal, communication has still occurred. Ask students which of our senses are used for communication. With a little thought, students should realize that all five senses can be involved under some circumstances.

Point out that communication can involve different scales of time and distance. Some signals may be received long after they are sent. Pictographs created thousands of years ago can still convey messages to “receivers” who see them.

Sometimes the meaning of a particular message seems fairly clear. In other cases, the message may contain symbols whose meaning is much less obvious. Ask students if they ever use symbols to communicate. If students do not identify “emoticons,” show a few of these symbols [such as :-) or :-)]. Ask what these symbols mean, and why they are used. Students should recognize that these symbols provide a way of quickly sending a message that might otherwise require many words to express. Point out that we have inserted two more steps in the basic model of communication: an encoding step in which the sender translates a message into one or more symbols, and a decoding step in which the receiver translates the symbols back into the ideas or words they represent. Students should also recognize that a symbol is only useful if the sender and receiver

attach the same meaning to the symbol. This requirement is also useful if the sender wants to conceal a message from some receivers, and is the basis for codes and encryption.

3. **Communication Aboard a Ship** – Tell students that they are about to read about a day in the life of modern ocean explorers. Provide each student or student group with copies of the daily log for July 29, 2010 by Colleen Peters, Senior Survey Technician. Instruct students to read the log and record all obvious and probable methods of communication used in this 24-hour period aboard the *Okeanos Explorer*.

Note: There may be terms and acronyms that are unfamiliar to your students but this should not impact the lesson. However, a glossary is provided here to use as needed.

Glossary

XBT – Expendable bathythermograph; an instrument that measures the temperature of the ocean at different depths; this information is used to calculate the speed of sound in seawater, which is used to adjust the multibeam sonar mapping system

MSD book cell – A Marine Sanitation Device (MSD) is designed to keep untreated sewage out of the ocean; a book cell produces chlorine gas from the salt in seawater using electricity; chlorine gas is used to reduce the number of microorganisms in sewage

CO – Commanding Officer; the captain of the ship

VSAT – Very Small Aperture Terminal; refers to the satellite dish antenna in the large dome on the *Okeanos Explorer*'s mast

FTP – File Transfer Protocol; a type of Web site that is used to exchange very large data files (such as video)

ECC – Exploration Command Center; a location that is equipped to exchange video, voice transmissions, and other data with the *Okeanos Explorer* and other ships equipped for telepresence

Secure – On ships, this verb means to stop doing some activity or to put away equipment so that it cannot move with the motion of the ship

ROV – Remotely Operated Vehicle; an underwater robot used to obtain video images or perform other tasks; usually connected with a cable

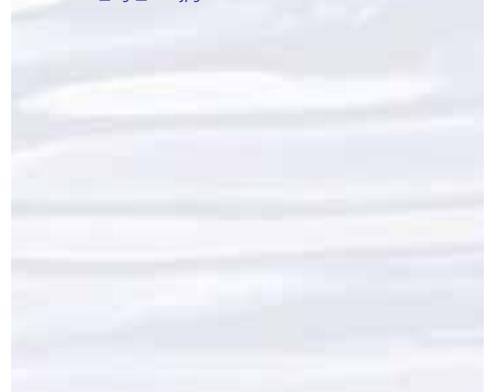
Students should realize that communications of various kinds are involved with many of the activities described in the log entry. These include hourly science updates, recording information in various logs, reviewing reports and data, meetings (safety, mapping products, and daily operations are mentioned specifically), and communication of orders. Methods of communication include face-to-face conversations, intercom, written logs, and satellite radio (including Internet). Crew members regularly use walkie-talkies as well, though these are not mentioned in the log entry.

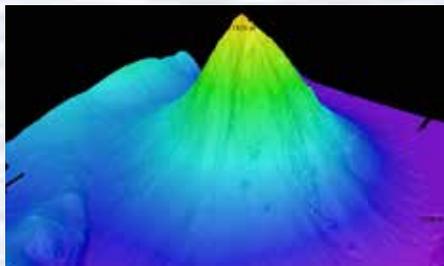
4. **Ocean Exploration Aboard the *Okeanos Explorer*** – If you have not already done so, briefly introduce the NOAA Ship *Okeanos Explorer*, the only U.S. ship whose sole assignment is ocean exploration. Say that the log entry students just read was written during the ship's maiden voyage in the summer of 2010. Briefly discuss why this kind of exploration is important (for background



A NOAA Corps officer writes in one of the many logs that the bridge officers must update during their watches. These include the Deck, VHF, GMDSS, Compass, Trash and Weather Logs. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/bloss_logs_hires.jpg





Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Students should realize that ocean exploration involves many people with many different skills. Some of these people are scientists, but operating a modern ship of exploration requires many other talents as well. (See *Appendix B: Ocean Exploration Careers*).

Highlight the overall exploration strategy used by *Okeanos Explorer*, highlighting the following points:

- a. The overall strategy is based on finding anomalies.
- b. This strategy involves three major activities:
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization.
- c. This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

5. The Technological Basis for Telepresence – Ask students how we can communicate over long distances. Point out that this almost always involves some type of technology, ranging from smoke signals to microwaves (for purposes of this discussion, we do not get into ideas about mental telepathy). Students are likely to identify various types of telecommunications (such as television, cell phones, satellites, radio, and wireless Internet) as technologies that support communication over long distances. Say that these technologies are all based on the principles of radio communication (this is explored in more detail in Step 6). Some students may consider radio to be an old-fashioned or even out-dated technology, but the basic principles of radio communication are the foundation of modern wireless communications including remote controls, cell phones, satellite television, and wireless Internet.

(a) Have students read the two essays on telepresence from the INDEX-SATAL 2010 Expedition:

- “Implementing Telepresence: Technology Knows No Bounds” by Webb Pinner and Kelley Elliott (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>); and
- “Executing Telepresence: The Seattle ECC Comes Online!” by Kelley Elliott and David Butterfield (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>).

Ask students how they think telepresence benefits ocean exploration. Students should recognize that telepresence not only enables scientists at sea to communicate with scientists ashore, but also with other interested parties as well. This means that many people can be directly involved with exploration



activities and discoveries as soon as they happen, which means that ocean exploration can happen faster, more efficiently (more people involved at less cost), and cover more area; in other words, telepresence increases the pace, efficiency, and scope of ocean exploration.

- (b) Have students watch the following short video clips from the 2012 Gulf of Mexico Expedition:

http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream_playlist.html

March 26, 2012

March 29, 2012

April 6, 2012

Tell them that the ROV dives from this expedition were streamed live through the internet so that anyone with an internet connection could see and hear about the discoveries as they were happening. As students are watching each video, have them record the communications they observe. Who do they think was communicating with whom? How were they communicating? You may have to review the possible “players” involved, such as ship crew members (the Bridge), scientists on board the ship, scientists on shore, ROV pilots/navigators, and ROV lead operators.

Discuss students’ observations. Given their new background on telepresence technology, they should have noticed communication between the ship’s bridge crew and the ROV pilot; the scientist and the ROV pilot; the scientists on the ship with scientists on shore; and one-way communication between the scientist and the public via the Internet.

Having the ability to communicate and consult at sea is one of the great benefits of telepresence. Tell students that during ROV dives, an Internet-based intercom system allows all participants, regardless of location, to easily communicate with all other participants. The real-time voice communication is supplemented by a real-time text-based collaboration tool. This text-based tool, commonly referred to as “the Eventlog”, allows ship-based and shore-based participants to write their observation to a common log. The log entries made by individuals are immediately disseminated to all other users in real-time, allowing all participants, regardless of location, to see the observations made by their peers. All users on the ship and at the ECCs are encouraged to participate in the Eventlog as all observations and insights are welcome. To help with the post-cruise analysis, each log entry includes the date and time the entry was made, the author and the text observation. The date and time matches the date and time used aboard the *Okeanos Explorer*. This simplifies post-cruise data, and video searches. The Eventlog tool leverages the same technology and standards-based protocols used on the Internet for Instant Messages (IM) and chatrooms. Table 1 lists some of the abbreviations that are used in Eventlog entries to name various organisms. Figure 1 shows a sample Eventlog.

- (c) Discuss the importance of communication to science. Students should realize that science is absolutely dependent upon communication, because the scientific process is based on the idea of testing hypotheses, then reporting the results to others who can verify those results or find additional information

Table 1. Some Eventlog abbreviations for various groups of animals

ACN	Actinaria
APH	Amphipod
ART	Arthropod
ASR	Asteroid
BAR	Barnacle
BIO	Biology (Unspecified)
BIV	Bivalve
BRY	Bryozoan
CHI	Chiton
CHN	Chondrichthyes
CNI	Cnidarian
COR	Coral
CRA	Crab
CRI	Crinoid
ECN	Echiuran
EGG	Egg case
FEC	Fecal matter
FSH	Fish
GAS	Gastropod
GRO	Gromiid
HOL	Holothurian
HYD	Hydroid
ISO	Isopod
JFH	Jellyfish
LOB	Lobster
MAT	Bacterial Mat
MOL	Mollusk
NUD	Nudibranch
OCT	Octopus
OPH	Ophiuroid
PAG	Pagurid (hermit)
PEN	Pennatulacean
POL	Polychaete
SCA	Scale worm
SHI	Shrimp
SPO	Sponge
SQA	Squat lobster
SQD	Squid
STY	Stylasterid
TUN	Tunicate
URC	Urchin
USO	Unidentified sessile object
WOD	Wood
WOR	Worm
XEN	Xenophyophoran
ZOA	Zoanthid

Figure 1. Excerpt from Eventlog for July 11, 2010

2010-07-11	01:56:29	jonathanrose	FSH
2010-07-11	01:56:57	okeanosexplorer	we'll try to get a few for him
2010-07-11	01:57:10	okeanosexplorer	depth is 48m, heading is 57
2010-07-11	01:57:16	okeanosexplorer	458m
2010-07-11	01:57:18	cherissedupreez	SQA
2010-07-11	01:57:40	davebutterfield	the light-colored material around the base of the rocks is primarily coral debris.
2010-07-11	01:58:14	okeanosexplorer	large stalked CRI
2010-07-11	01:58:23	okeanosexplorer	SQA
2010-07-11	01:58:25	okeanosexplorer	SHI
2010-07-11	01:58:30	okeanosexplorer	STY's
2010-07-11	01:58:35	okeanosexplorer	with OPH's
2010-07-11	01:58:49	okeanosexplorer	very neat SPO's
2010-07-11	01:58:58	jonathanrose	FSH
2010-07-11	01:59:00	okeanosexplorer	purple COR
2010-07-11	01:59:13	dustinschomagel	ROV Depth 452 Hdg 62 deg
2010-07-11	01:59:34	okeanosexplorer	URC

that builds on them. For this reason, the pace of scientific discovery and progress is highly dependent upon the rate at which communication can take place. In the case of the *Challenger* Expedition, for example, 19 years were required before all of the scientific results of the expedition were available; and until those results were published, there was no way for other scientists to build on the findings of the expedition. Ask students whether they think it is important for scientists to communicate with the public or if communicating with other scientists is enough. There are a number of reasons that public communication is also essential to science, including:

- Many scientists depend upon public funding to support their work, and if people do not understand why this work is important, funding may be difficult to obtain;
- Often, information from scientific investigations may be important to formulating public policies, but people need to understand this information before they can use it; and
- Non-scientists can be important to scientific investigations and discoveries as well as professional scientists (for example, Kathryn Aurora Gray, a ten-year-old Canadian student who discovered a supernova on New Year's Eve, 2010).

6. It's All About Waves – Remind students of the basic model of human communication (sender, receiver, and something to carry messages between them), and say that they are going to explore how this model applies to the way that telepresence is implemented aboard the *Okeanos Explorer*. Aboard the ship, the “sender” in our basic model is anyone who has a message or information that they wish to send to one or more “receivers” in another location including Exploration Command Centers. Telepresence, by definition, involves communicating with remote locations, and the “something to carry messages” is a modern version of radio technology.

Ask students to identify the thing that carries their message when they use a cell phone. Students should (possibly with your help) identify radio waves as the “message carrier,” and should recognize that these waves are a form of electromagnetic radiation. Other familiar forms of electromagnetic radiation include light and microwaves.

Ask students to name some different kinds of waves. Answers may include sound waves, light waves, radio waves, microwaves, ocean waves, stadium waves, earthquake waves, and slinky waves (students may think of others as well).

Ask for two volunteers, and have them hold opposite ends of a piece of rope with enough slack so that a wave will form when one end of the rope is repeatedly raised and lowered. Instruct the two students to form a wave in the rope. Have other students make a sketch of the wave.

Discuss the following questions (you may choose to have students write their answers first, or just discuss each question with the entire class):

- What moved in the rope wave?
- As the wave moved along the rope, was anything moved from one location to another location?

Students should realize that portions of the rope moved in the rope wave, but that nothing ended up in a different location. Students may be puzzled by this point, because in both cases they saw “something” moving from one place to another. Encourage students to think again about exactly what they saw, and provide sufficient hints to lead them to identify a disturbance as the “thing” that moved, and that the disturbance was caused by an input of energy that moved through the system with the wave. The energy caused portions of the rope to temporarily move from their original positions, but they returned to these positions when the energy moved to adjacent portions.

Explain to students that all waves have three features in common:

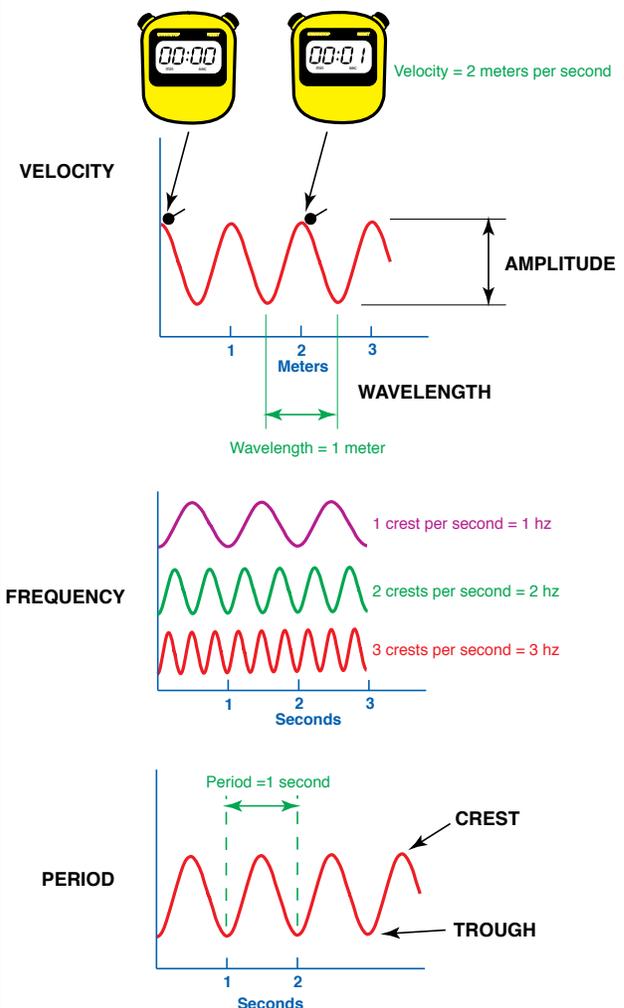
- They are energy transport phenomena. This means that they are involved in transporting energy, but do not transfer matter.
- The energy of waves moves in specific patterns.
- Waves have characteristics that include wavelength, amplitude, velocity, and sometimes frequency.

Discuss the following features of waves, and have students label them on their sketches (see Figure 2):

- Wavelength – the distance over which a wave’s shape repeats (you can also think of it as the distance between successive crests or troughs of a wave)
- Amplitude – the height of a wave
- Velocity – how fast the crest of a wave is moving from a fixed point



Figure 2





- Period – the amount of time it takes for one point on a wave to complete its full range of motion and return to its original position
- Frequency – the number of crests that pass a given point in a certain amount of time
- Crest – the highest point of a wave
- Trough – the lowest point of a wave between crests

8. **Essentially, It's All About Radio Waves** – Ask students how they think the rope wave differs from a radio wave. Students (possibly with some help) should realize that rope waves require a medium (the rope) through which they can transfer energy (this type of wave is called a mechanical wave). Radio waves, on the other hand, do not require a medium. These waves are composed of an electric field and a magnetic field that are oscillating (moving back and forth) together, and are called electromagnetic waves (these waves are sometimes described as the movement of particles called photons, which are massless packets of energy that travel at the speed of light).

Say that now we know something about the radio waves that are used to implement telepresence, and ask students how we send radio waves from one place to another. Students should identify that a device (technically called a transmitter, but students may suggest other names) is used to send radio waves, and may also identify an antenna as a necessary component of the system. Some students may have had experience with walkie-talkies, which should suggest these answers. Students may also identify satellites as a necessary component of the communications system. For telepresence as it is implemented aboard the *Okeanos Explorer*, satellites are definitely needed. Radio waves were transmitted without satellites for many years before satellites became available, and often are still transmitted this way; but satellite communications are much more reliable, particularly when the transmitting and receiving stations are thousands of miles apart. Satellites used for this kind of communication are sometimes called repeaters, because they receive signals that are transmitted to them, and then re-send these signals to receivers. So, the elements of our basic communications model have appeared again: transmitters, receivers, and things that allow messages to be exchanged between them.

Point out that we now know that radio waves transport energy, and we know something about how those waves are sent from one place to another. Ask students, “How do we use this process to send a message?” Some students may know that in the early days of radio, messages were sent by basically turning the transmitter on and off in a pattern that formed a code, and this code was used to send messages (in fact, this is also how messages were sent on radio’s predecessor: the wire telegraph). Some students also may be familiar with Morse code, which is still used to send messages this way. To send voice, music, or visual messages, though, we need an alternative approach.

This alternative involves changing the radio waves when they are sent so that the changes incorporate the desired message, then having a receiver that can “read” the changes and reproduce the message. The process of changing the radio wave is called modulation, and the process of extracting the message from a modulated radio wave is called demodulation. A device that can modulate and demodulate is called a modulator-demodulator, or modem for short. The Modulated LED activity referenced under Extensions demonstrates this process with light; which,

of course, is also an electromagnetic wave like radio waves, only with a different frequency and wavelength. Depending upon available time and resources, this activity may be done:

- by the educator as a demonstration, or
- by one or two groups of students as a demonstration, or
- by all students working in small groups with each group performing the activity independently, or
- viewed as a video demonstration (e.g., <http://www.youtube.com/watch?v=n0f7blVJIg>)

Once students have done the activity or observed a demonstration, discuss why this works, and some of the factors that influence the effectiveness of message transfer between the sender and receiver. Be sure students understand that the output from the radio or media player is an electric current that replicates a sound that originated somewhere else. This current is added to the current from the battery, and causes the light emitting diode (LED) to flicker as the current varies. The solar cell converts light energy to an electric current. When light from the LED strikes the photocell, a current is produced that varies according to the intensity of the light. The current from the photocell is converted into sound energy by the amplified speaker.

Factors that influence the effectiveness of message transfer include the distance between the sender and receiver, the amount of interference from stray light striking the solar cell, and the strength of the signal from the radio or media player. Signal strength compared to background noise is a factor that influences many other kinds of communication; consider trying to have a conversation in a noisy room, or trying to read words on a page that is cluttered with random pictures or colors. Ask students how the message transfer system might be improved. One possibility is to focus light from the LED so that it is concentrated on the solar cell. This is the idea behind using an antenna, and is why the *Okeanos Explorer* needs a large dish to send its wireless signals to the satellite that relays these signals to receivers in Exploration Command Centers.

Adaptations to Other Grade Levels

Grades 5 – 6: Use the guided imagery in the lesson *Journey to the Unknown* to help students visualize the communication techniques involved in telepresence and generate excitement about ocean exploration.

http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_journey.pdf

Omit the discussion of radio waves in Step 6.

Grades 9 – 12: Have students complete Extension activities 1 – 3. See Extension activities 4 and 5 for additional activities and content.

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 click on “Technology” for activities and links about satellite communications and other ocean exploration technologies.

The “Me” Connection

Have students write a short essay describing how telepresence could be of personal benefit.



Technicians work to repair the satellite antenna in the VSAT dome. Image courtesy of NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/dome_hires.jpg



Connections to Other Subjects

English Language Arts, Mathematics, Social Studies

Assessment

Class discussions provide opportunities for assessment.

Extensions

1. Listen to a beam of light – The Modulated LED demonstration from the Exploratorium® in San Francisco, California, shows how audio signals can be carried in visible light, similarly to the way signals can be carried in radio waves (both light and radio waves are forms of electromagnetic radiation). See www.exploratorium.edu/square_wheels/modulated_led.pdf
2. Make the simplest radio – See <http://www.midnightscience.com/oat-box-project.html>, which includes links to directions for ordering kits or a manual that explains how to make the simplest radio from parts you find yourself.
3. Mathematics - Frequency and wavelength of electromagnetic waves are related by the formula:

$$W = C \div F$$

where W is wavelength in meters, C is the velocity of the wave, and F is frequency in hertz (cycles per second). The velocity of electromagnetic waves is the velocity of light, which is 300,000,000 meters per second. Information about wavelength is used to design antennas for radio communication. From the information given in the sidebar on page 33—From the Ship to the Sky—what wavelengths correspond to the frequencies used for satellite communications on the ship?

4. Find out more about wireless communications and amateur radio: The American Radio Relay League (the national association for amateur radio) has extensive resources about wireless technology including curricula, lesson plans, free downloads, kits, and projects; see <http://www.arrl.org/etp-classroom-resources>.
5. See *Earth's Ocean is 95% Unexplored: So What?* and *Living Light* (http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf and http://oceanexplorer.noaa.gov/explorations/09bioluminescence/background/edu/media/ds_09_livinglight.pdf, respectively) for information about scientific communication using wall magazines and scientific posters.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Earth's Ocean is 95% Unexplored: So What?

(from the INDEX-SATAL 2010 Expedition)

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf

Focus: Importance of deep-ocean exploration (Grades 5-6; Life Science/Earth Science)

Students describe at least three different deep-ocean ecosystems; explain at least three reasons for exploring Earth's deep ocean; and explain at least three ways that deep-ocean ecosystems may benefit humans; and create a wall magazine to communicate scientific ideas.



Journey to the Unknown

(from the *Okeanos Explorer Educational Materials Collection*)

http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_journey.pdf

Focus: Ocean Exploration (Grades 5-6; Life Science/EarthScience)

Using guided imagery, students experience the excitement of discovery and problem-solving to learn what organisms could live in extreme environments in the deep-ocean and understand the importance of ocean exploration.

Students also posterize images and construct an ultraviolet LED poster illuminator.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book.

Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

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Section 3: Multibeam Sonar

Introduction to Multibeam Sonar

Sonar (which is short for SOund NAVigation and Ranging) systems are used to determine water depth, as well as to locate and identify underwater objects. In use, an acoustic signal or pulse of sound (often called a ping) is transmitted into the water by a sort of underwater speaker known as a transducer. The transducer may be mounted on the hull of a ship, or may be towed in a container called a towfish. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an “echo” to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Some sonar systems also measure the strength of the echo, and this information can be used to make inferences about some of the reflecting object’s characteristics. Hard objects, for example, produce stronger echoes than softer objects. This is a general description of “active sonar.” “Passive sonar” systems do not transmit sound pulses. Instead, they “listen” to sounds emitted from marine animals, ships, and other sources.

Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration. A multibeam system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The *Okeanos Explorer* is equipped with a Kongsberg Simrad EM 302 multibeam system that can produce up to 864 depth soundings in a single ping. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In some systems, the intensity of the return echo is also used to infer bottom characteristics that can be used for habitat mapping. In addition to high-resolution maps, multibeam data can be used to create three dimensional models or even “fly-through” videos that simulate a trip across the area being mapped. For a fascinating example of this, see <http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>. This 3D fly-through movie shows the seafloor in the Magic Mountain area of Explorer Ridge (near the coast of Vancouver Island) where there are active

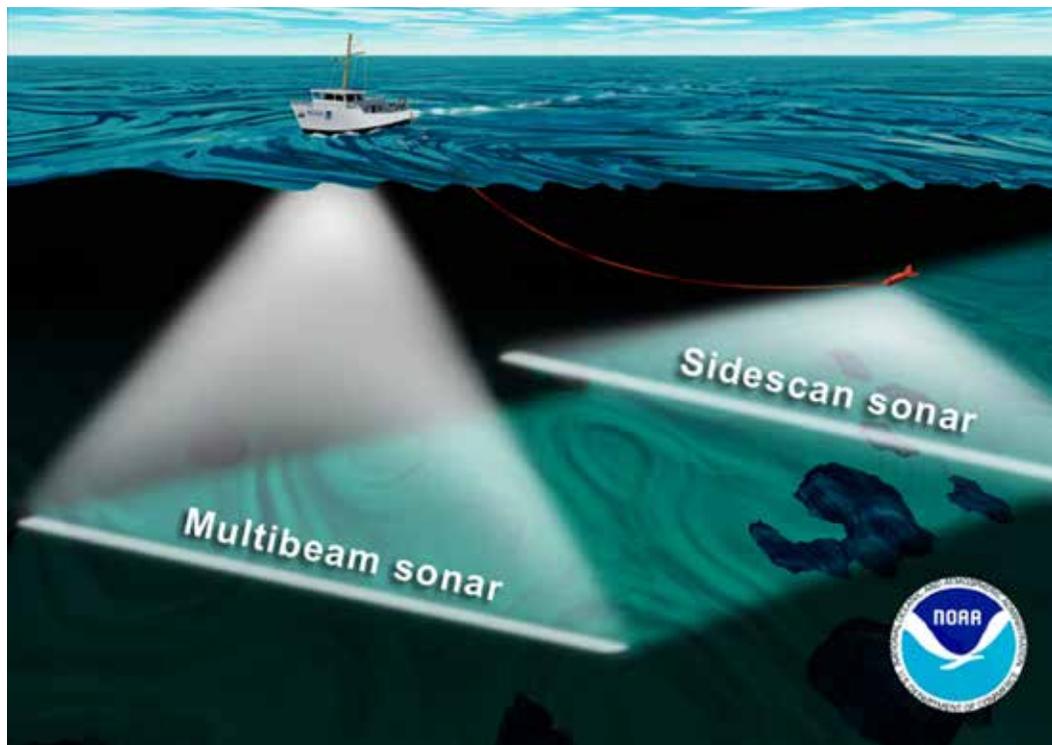


Illustration of a ship using a hull-mounted multibeam sonar while towing a side-scan sonar on a cable. Both sonars map the seafloor in a swath below the ship as it drives forward. Image courtesy of NOAA. http://oceanexplorer.noaa.gov/explorations/04fire/background/hirez/multi_sonar_hires.jpg



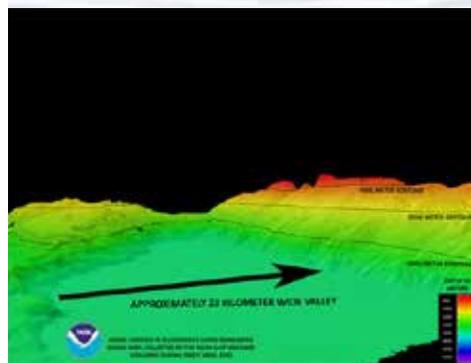
hydrothermal vents. To see what the vents look like, you can view other fly-throughs of the same area at <http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>.

Recently, a new generation of multibeam sonars has been developed that are able to map features in the water column as well as the seafloor. This ability will potentially allow multibeam sonars to map the location of fish and marine mammals, as well as a wide range of physical oceanographic processes. On May 17, 2009, the *Okeanos Explorer* was testing its multibeam sonar mapping system off the coast of California. Suddenly, the multibeam image showed a plume of what scientists believe may be methane gas rising vertically 1,000 meters from the ocean floor. No such feature had ever been reported from this area before. You can see a video simulation that shows how multibeam sonar discovered this plume, and provides a graphic overview of how multibeam works here: http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html.

An important technique for studying multibeam images uses a 3-dimensional data visualization system called Fledermaus (which is the German word for “bat,” and is pronounced “FLEE-der-mouse”). The “Watching in 3-D” lesson includes a simple analysis of multibeam data using free viewing software for multibeam imagery in the Fledermaus file format.

Note: mention of proprietary names does not imply endorsement by NOAA.

For more information about sonar systems, see <http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html>.



The EM302 gives us a high resolution “bird’s eye” view of large areas. What we see underwater is similar to what we see around us every day. In the above image, a panorama of mountains and volcanoes sit majestically near a massive river delta surrounded by a soft sand beach. Since what we see here is actually underwater, there are, of course, no rivers or river deltas, or mountains and sand bars, but seeing these features makes one wonder how an area like this was formed. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

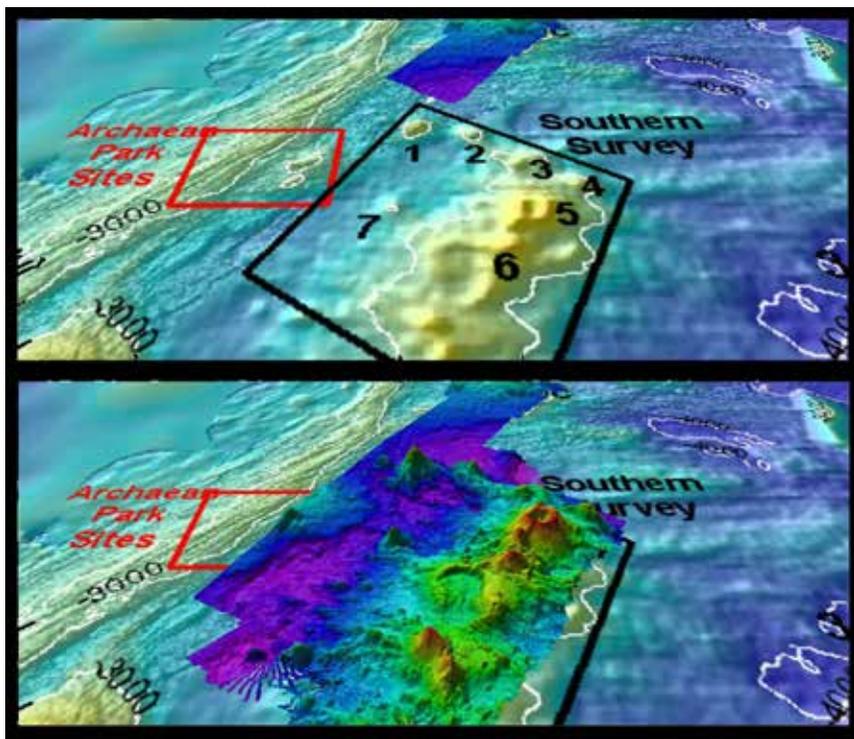
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/media/seamount_channels.html

Multibeam Sonar Systems Aboard the *Okeanos Explorer*

Okeanos Explorer carries a Kongsberg Maritime EM302 deepwater multibeam sonar system. Transducers for the system are installed on the ship’s hull in a custom-designed housing. The system can transmit up to 288 beams, can collect as many as 864 depth measurements in a single ping, and automatically compensates for movements of the ship. The EM302 operates in depths ranging between 10 m and 7,000 m. The width of the swath is about 5.5 times the depth, to a maximum of about 8 km. Depth resolution of the system is 1 cm. At a depth of 4,000 m, the system can resolve features with a dimension of approximately 50 m.

Software packages used to process data from the EM302 and to integrate these data with GPS information about geographic position and sensor data about ship movements include:

- Seafloor Information System
- CARIS
- Fledermaus
- arcGIS
- SonarWiz
- Hypack
- MapInfo



This “before and after” image provides a glimpse of *Okeanos Explorer*’s EM302 mapping system capabilities in deep water. The top image shows what we previously knew about the seafloor terrain in the southern Mariana region from satellite altimetry data. The bottom image includes an overlay of the information provided by the ship’s EM302 multibeam system. Image courtesy of NOAA Office of Ocean Exploration and Research.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg



Section 3: Multibeam Sonar

Lesson 3: Wet Maps

Focus

Bathymetric mapping

Grade Level

5-6 (Physical Science/Earth Science)

Focus Question

What kinds of maps are used for ocean exploration, and how are these maps made?

Learning Objectives

- Students will explain how multibeam sonar is an example of advances in engineering that have extended the measurement, exploration, modeling, and computational capacity of scientific investigations.
- Students will analyze data from a simulated multibeam sonar system to create a three-dimensional map that shows ocean sea floor ridges and trenches, and explain how tectonic processes produce these features.

Materials

For each student group:

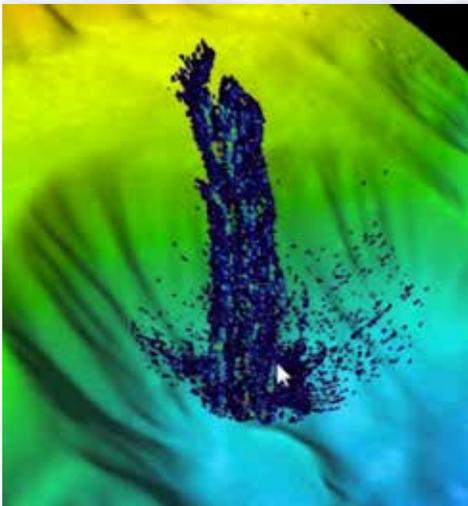
- Copies of *Multibeam Mapping Simulation Activity Guide* and *Multibeam Mapping Simulation Activity Preparation Guide* (if you decide to have the students do the preparation)
- Cardboard box with lid, approximately 10 x 10 x 6 inches (at least 6 inches deep)
- Pencils, unsharpened; or wood dowels approximately 1/4-inch diameter x 8 inches; two for each student
- Copies of Sounding Rod Scale (Figure 2); two for each student
- Clear tape
- Plaster of Paris, 1 – 2 lb, or plaster wrapcloth (from craft stores)
- Masking tape
- Colored pencils, six colors
- Ruler, one for each student group
- Graph paper

Audio Visual Materials

Optional – Images of exploration technologies and animations (see Learning Procedure, Step 1c)

Teaching Time

Three to four 45-minute class periods, depending upon the availability of resources and activities assigned for out-of-class completion



Multibeam image of Mendocino Ridge Plume taken with the Kongsberg EM302 multibeam bathymetric mapping system. Image courtesy INDEX-SATAL 2010 Expedition.

http://oceanexplorer.noaa.gov/okeanos/media/movies/mendocino_ridge_plume_video.html



Seating Arrangement

Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Bathymetric map
Multibeam sonar

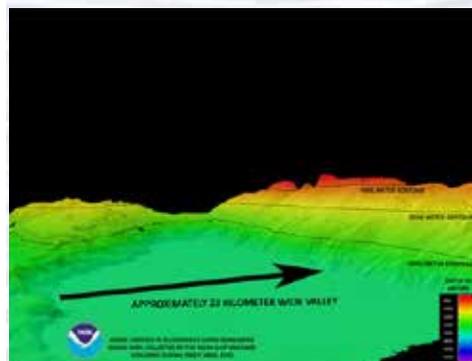
Background

Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration, and can create high-resolution maps, three dimensional models, or even “fly-through” videos that simulate a trip across the area being mapped.

For more information about how multibeam sonar is used aboard the NOAA Ship *Okeanos Explorer*, please see *Introduction to Multibeam Sonar* on page 49. In this lesson, students will learn about multibeam sonar, and use mock sonar set-ups to create a three-dimensional model of a simulated ocean floor.

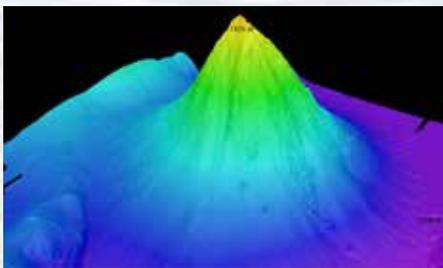
Learning Procedure

- To prepare for this lesson:
 - Review:
 - Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
 - Minding the Multibeam at Midnight by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>); and
 - State of the Art Seafloor Survey by Meme Lobecker and Elaine Stuart (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>).
 - Review background information about the *Okeanos Explorer* exploration strategy and technologies.
 - If desired, download images to accompany discussions in Step 2. You may also want to download this “before and after” image to illustrate the capabilities of multibeam sonar:
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/bires/em302_before_after_bires.jpg,
as well as one or more of the following animations to accompany discussions in Step 3:
<http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>;
http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html
 - Review *Multibeam Mapping Simulation Activity Guide* and *Multibeam Mapping Simulation Activity Preparation Guide*, and decide how much preparation will be done by students. This activity may be varied, according to time available and individual teaching and learning styles. For example, students may be divided into “Beam Teams,” each of which constructs a mystery landscape that is kept hidden from other teams. Teams then exchange boxes and perform the mapping procedure to reveal the “mystery topography.”



The EM302 gives us a high resolution “bird’s eye” view of large areas. What we see underwater is similar to what we see around us every day. In the above image, a panorama of mountains and volcanoes sit majestically near a massive river delta surrounded by a soft sand beach. Since what we see here is actually underwater, there are, of course, no rivers or river deltas, or mountains and sand bars, but seeing these features makes one wonder how an area like this was formed. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/media/seamount_channels.html



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

This can become a competition between teams if points are awarded to teams that accurately predict the topography in the shortest amount of time.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

Briefly review the mechanisms through which tectonic processes continually generate new seafloor at ridges and destroy old sea floor at trenches.

3. Ask students what they know about sonar, and provide additional information as necessary. (See *Introduction to Multibeam Sonar* on page 49). You may want to show one or more of the video clips referenced in Step 1c.

Ask students how scientists and mariners made maps of underwater features before sonar was invented. For centuries, depth measurements were made with lead lines. A lead line is a rope or line with a 10-pound lead weight attached to the end. To make a depth measurement, the line is lowered into the water until the weight reaches the bottom. Markings on the line show how much line has been let out, which is equal to the depth of the water. Depth soundings made with lead lines are accurate, but they take a lot of time and only give information about single points of the sea bottom—so many lead line measurements are needed to accurately survey a given area.

Nautical charts based on data collected with lead lines often consist of many small numbers scattered over the chart that correspond to the measured depth at the locations represented on the chart. The invention of sonar made it possible to collect many more data points, and this allowed scientists to construct bathymetric charts, which are similar to topographic maps that show the contour of landforms. Bathymetric charts, however, show the contour of the ocean floor. While they are a great improvement over charts made with lead line data, bathymetric charts are still two-dimensional representations of three-dimensional features and it takes practice to be able to accurately interpret these charts.

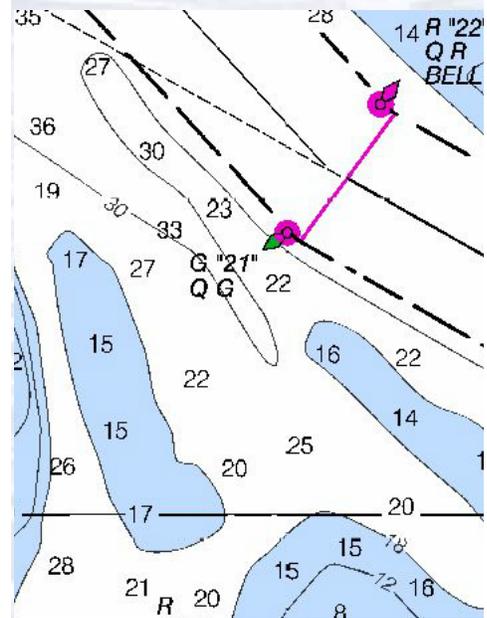
The development of multibeam sonar technology makes it possible to produce very detailed images of seafloor features, and to show the three-dimensional characteristics of these features. Point out that this is an example of how advances in engineering have extended the measurement, exploration, modeling, and computational capacity of scientific investigations.

Describe the role of multibeam sonar in ocean exploration aboard the *Okeanos Explorer*. Students should realize that this is the key technology for the “reconnaissance” component of the overall exploration strategy, and provides the “big picture” view as explorers look for anomalies. You may wish to have students read the log entry “Minding the Multibeam at Midnight” (Step 1a). This image shows how much *Okeanos Explorer*’s EM302 mapping system adds to what we know about seafloor terrain: http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg.

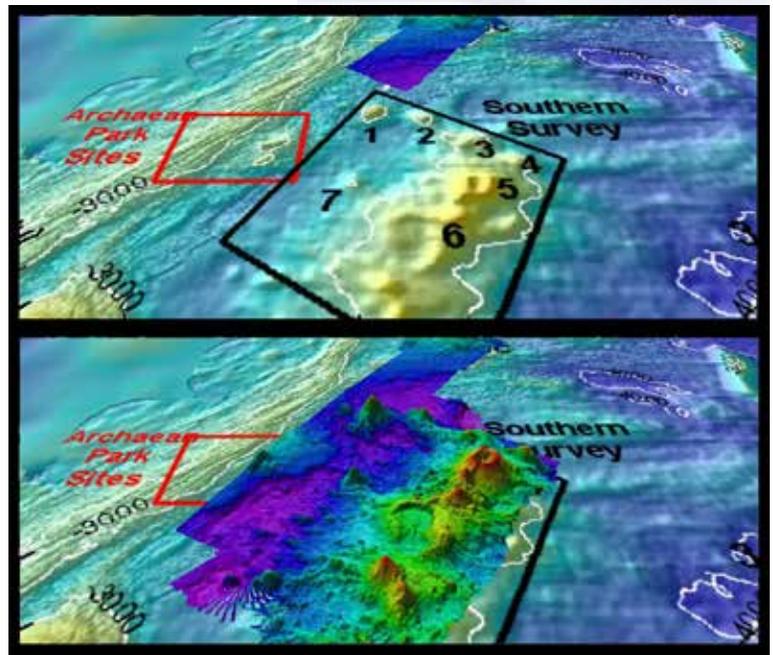
4. Tell students that their assignment is to map an unexplored and invisible landscape using methods that roughly simulate multibeam sonar technology. Divide students into “Beam Teams” of three or four students, and provide each team with a copy of the *Multibeam Mapping Simulation Activity*, and access to necessary materials. Tell students that oceanographers like to graph depth so that the greatest depths are near the bottom of the graph, because this is how we imagine a vertical slice of the ocean would appear. So, the Y-axis on the bar graphs is made so that the largest depth values will be at the bottom of the graphs. You may want to have students color the depth contours on their graphs after they are cut out using the color scheme on the Sounding Rods (or any other scheme that you choose). Coloring the cutouts will make the final model more closely resemble a multibeam sonar image.

When students have completed their 3-D bathymetry models, have each group show their models to the entire class, report their conclusions about the mystery landscape and what they infer about tectonic processes that might have produced this landscape. After each group has reported their conclusions, have them open their box, and compare the actual topography with their predictions.

5. When all groups have made their presentations, ask students how their investigations could be improved. Shortening the interval between “soundings” would improve detail in the models; but would also mean a lot more work since an additional graph cutout would have to be made for each row added to the sampling procedure. Having smaller graduations on the sounding rods would help improve the accuracy of “depth” measurements. This accuracy would also be improved by having a way to ensure that the sounding rods are exactly vertical when soundings are made.



Section of a typical nautical chart showing depth in feet. Image courtesy NOAA.



This “before and after” image provides a glimpse of *Okeanos Explorer*’s EM302 mapping system capabilities in deep water. The top image shows what we previously knew about the seafloor terrain in the southern Mariana region from satellite altimetry data. The bottom image includes an overlay of the information provided by the ship’s EM302 multibeam system. Image courtesy of NOAA Office of Ocean Exploration and Research. http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg



Students should realize that a multibeam sonar system would provide an almost continuous record of depth in a swath on either side of the ship. The *Okeanos Explorer*'s EM302 multibeam system can produce swath widths as large as five times the water depth. Students should also realize that rough topography can obscure other topographic features, so better resolution is especially important when there are boulders, reefs, or other irregular objects in a search area.

Discuss how the ability to accurately map geologic features might help forecast the locations and likelihoods of natural hazards such as volcanic eruptions and earthquakes (see <http://oceanexplorer.noaa.gov/explorations/03trench/welcome.html> for an example).

Discussion of multibeam sonar technology may also include the following components of technological literacy:

- **Scope of technology** – Development of multibeam sonar technology provides detailed images of the ocean floor that were not possible before this technology was developed.
- **Core concepts of technology** – Multibeam sonar is an example of several technological systems connected together; including sonar systems to obtain depth data, global positioning systems for geographic location, sensors to detect ship motion so that data can be corrected for pitch and roll, and computer systems to analyze raw data and convert the data to accurate depth estimates and visual images.
- **Relationships between technologies and other fields of study** – Improvements to each of the technologies listed above improves the overall capability of bathymetric information from multibeam sonar systems; and this information is useful to geologists, biologists, and many other branches of science.
- **Effects of technology on the environment** – Some scientists are concerned that marine mammals may be harmed if they are close to ships using certain types of sonar technology. *Okeanos Explorer*'s EM 302 multibeam system is equipped with a function that reduces transmission power to avoid harming mammals if they are nearby.

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 click on “Technology” for activities and links about satellite communications and other ocean exploration technologies.

The “Me” Connection

Have students write a short essay describing a situation (real or imaginary) in which the accuracy of a map was personally important.

Connections to Other Subjects

English Language Arts, Mathematics, Social Studies

Assessment

Class discussions and students’ work with the mapping simulation activity provide opportunities for assessment.

Extensions

See the *Calling All Explorers* lesson for an activity involving maps and GPS technology: http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_callingex.pdf.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Earth's Ocean is 95% Unexplored: So What?

(from the INDEX-SATAL 2010 Expedition)

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf

Focus: Importance of deep-ocean exploration (Grades 5-6; Life Science/Earth Science)

Students describe at least three different deep-ocean ecosystems; explain at least three reasons for exploring Earth's deep ocean; explain at least three ways that deep-ocean ecosystems may benefit humans; and create a wall magazine to communicate scientific ideas.

Sonar Simulation

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/sonarsim78.pdf>

Focus: Side scan sonar (Grades 7-8; Earth Science/Physical Science)

Students describe side-scan sonar; compare and contrast side-scan sonar with other methods used to search for underwater objects; and make inferences about the topography of an unknown and invisible landscape based on systematic discontinuous measurements of surface relief.

Mapping the Deep Ocean

(from the INSPIRE: Chile Margin 2010 expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/mapping.pdf>

Focus: Bathymetric Mapping (Grades 7-8; Physical Science/Earth Science)

Students create a two-dimensional topographic map from bathymetric survey data; create a three-dimensional model of seafloor topography from a two-dimensional topographic map; and interpret two- and three-dimensional topographic data.

Sound Pictures

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/soundpics912.pdf>

Focus: Sonar (Grades 9-12; Physical Science)

Students explain the concept of sonar, describe the major components of a sonar system; explain how multibeam and side-scan sonar systems are useful





to ocean explorers; and simulate sonar operation using a motion detector and a graphing calculator.

Tools of Exploration - Multibeam

(from the INDEX SATAL 2010 Expedition)

<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/multibeam.pdf>

Focus: Technology for deep ocean exploration: Multibeam Sonar (Grades 9-12; Earth Science/Physical Science)

Students describe multibeam sonar; discuss the advantages of multibeam sonar bathymetry compared to two-dimensional topographic bathymetry; and interpret three-dimensional multibeam bathymetric data.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdve_ngss.pdf

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

oceaneducation@noaa.gov

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Multibeam Mapping Simulation Activity Preparation Guide

Materials

- Each student group will need (assuming four students per group):
- 1- Cardboard box with lid, approximately 10 x 10 x 6 inches
 - 8 - Pencils, unsharpened; or wood dowels approximately 1/4-inch diameter x 8 inches; two for each student
 - 1 - Copy of Sounding Rod Scale (Figure 2); two for each student
 - Clear tape
 - Plaster of Paris, 1 – 2 lb, or plaster wrap cloth (from craft stores)
 - Masking tape
 - Colored pencils, six colors
 - Ruler
 - Graph paper, at least ten sheets
 - Awl, icepick or sharp nail

Procedure

1. If cardboard boxes of an appropriate size are not available, they can be constructed from poster board using Figure 1 as a guide. Fold along the dotted lines and tape the corners with masking tape.
2. Mark a grid of 1-inch squares on the top of the box. Make a hole at each junction point large enough so that the pencil or dowel can easily be inserted. TIP: Make a hole in the cardboard with an awl, icepick or nail; then enlarge the hole with a sharpened pencil or dowel. Label each row of holes with a number, and each column of holes with a letter (see Figure 1).
3. Cut out the Sounding Rod Scales, so that each student has two scales. If you are using the uncolored scales, color each interval with a colored pencil using the colored scales as a guide. Tape each scale onto a pencil or dowel to make two Sounding Rods for each student. The bottom of the scale should be even with one end of the pencil or dowel.
4. Prepare a “mystery landscape” in the bottom of each box that includes either an ocean ridge or trench. If students are doing this step, they should keep their work out of the sight of other groups. Mix plaster of Paris, and pour a 1 – 2 cm thick layer into the bottom of each box. You may use plaster wrap cloth instead of Plaster of Paris. You can also use crumpled newspaper or other filler to form your landscape before covering with plaster or wrap cloth. This will reduce the amount of plaster or wrap cloth needed. Do not completely cover the bottom of the box, because that will reduce the overall depth range, and we want a lot of variation in these landscapes! Allow plaster to harden. Temporarily fasten the lids to the boxes with masking tape.



Figure 1. Box Preparation

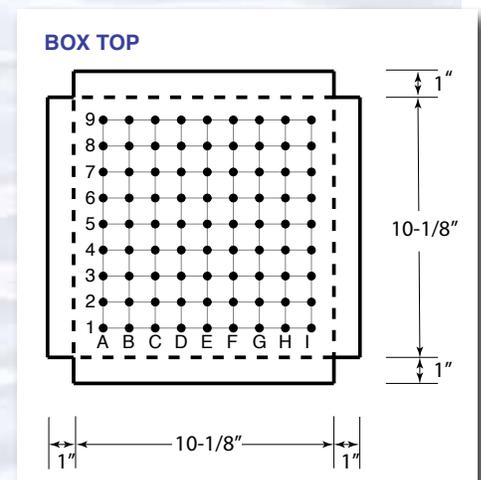
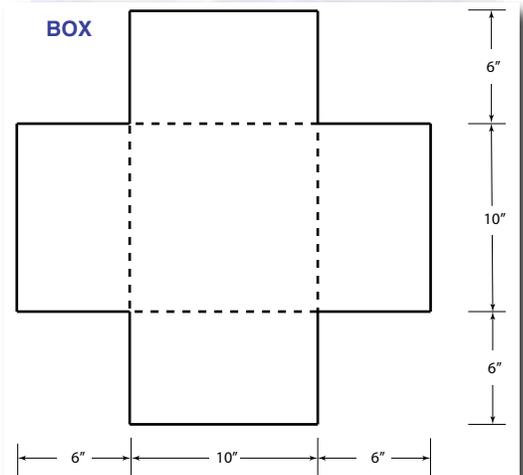
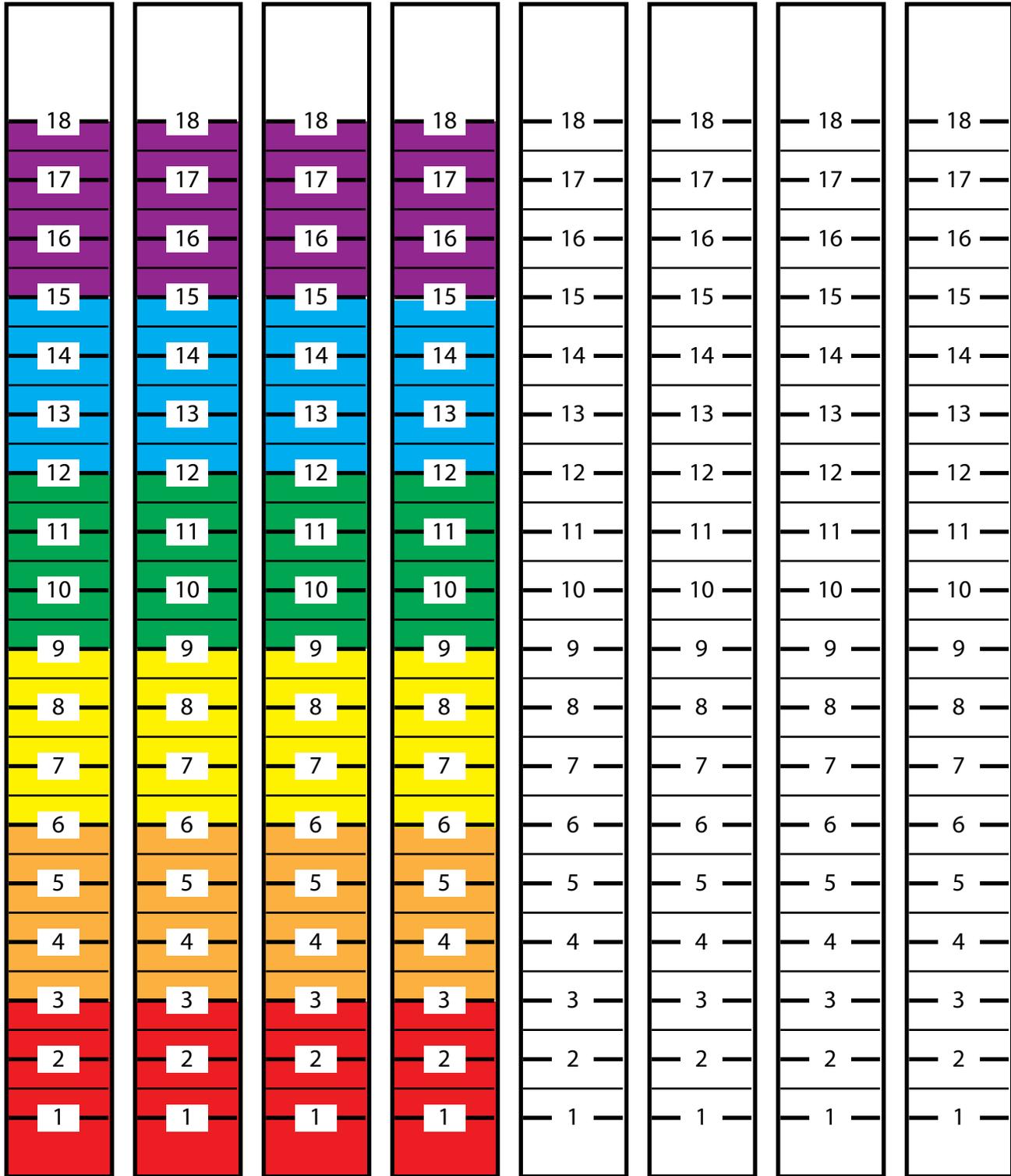


Figure 2. Sounding Rod Scale





Multibeam Mapping Simulation Activity Guide

1. Your Beam Team should include three or four students, and each student should have two Sounding Rods. You will use these Rods to measure the depth under each of the holes in the lid of your box, then you will plot these depths to create a three-dimensional model of the landscape hidden inside the box. Each student will be responsible for measuring the depth of two or three of the holes in each row. Do one row at a time, simulating a swath. If you stand in a circle (or part of a circle) around the box, you should all be able to make your measurements at the same time.
2. When your teacher tells you to begin, each member of your team should measure the depth in their assigned holes in the first row using a Sounding Rod. Leave the Rods in place until you have recorded your measurements on the Data Sheet. It will probably be easiest if one team member does the recording while the other members call out the depth measurements.
3. When you have finished measuring the depths in the first row, use the same procedure to measure depths of the remaining holes, recording the data from your measurements one row at a time.
4. When you have measured all of the depths, and entered all the values, plot the results for each row on a bar graph as directed by your teacher. Figure 3 shows an example of the graph that resulted from plotting one row of depth data. It will probably be quickest if each team member is responsible for plotting specific rows of data.
5. When your graphs are completed, cut them out as shown in Figure 3. Be sure to leave the border at the bottom of each graph! Fold as shown, and tape each graph onto the top of the box so that the folded edge of each graph lies on its corresponding row on the box top. Stand the graphs up so that they are perpendicular to the top of the box (additional tape may be needed to keep the graphs upright).

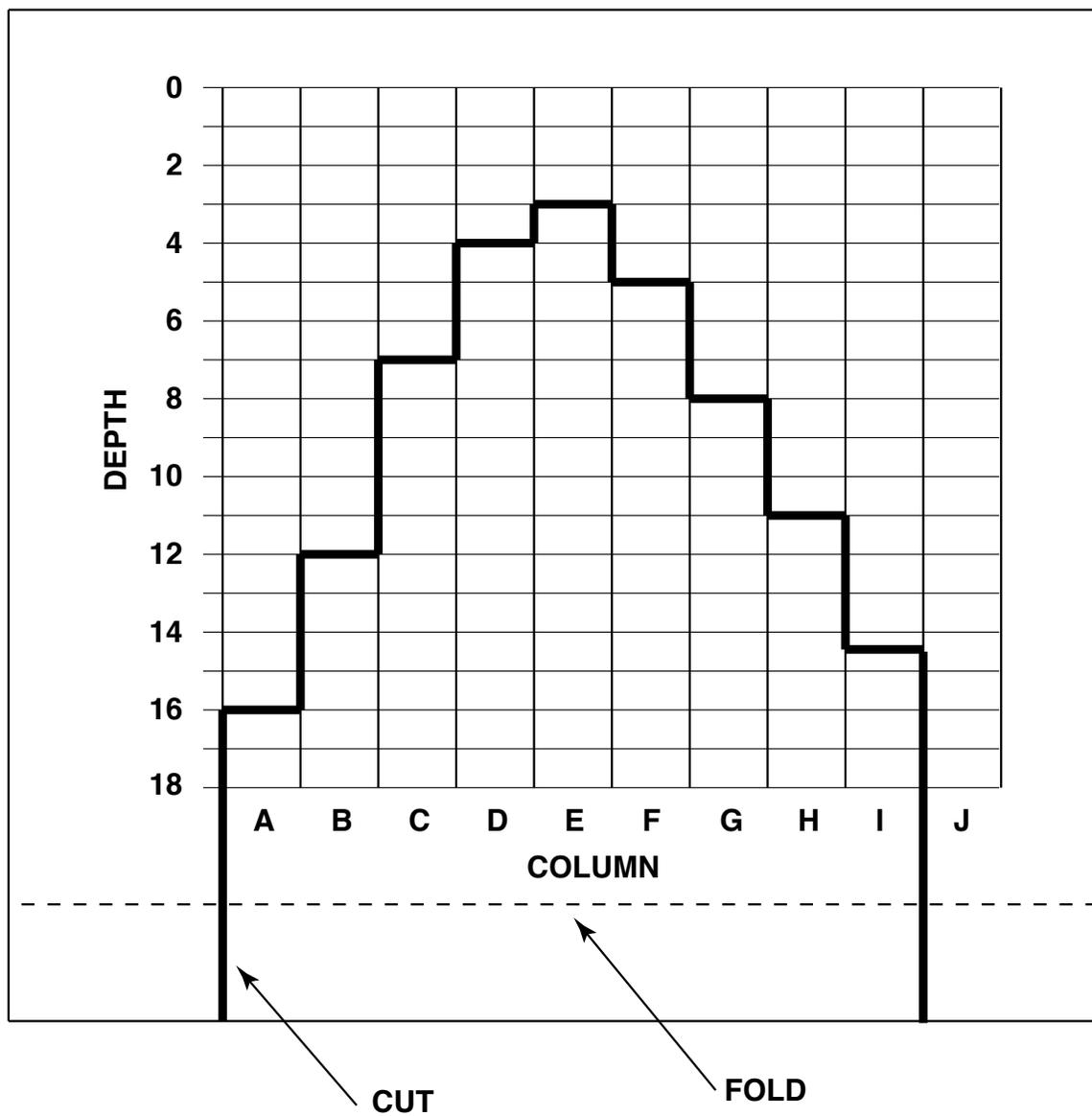
Now you should have a three-dimensional model of the mystery landscape inside the box. Wait for further instructions from your teacher.

Multibeam Mapping Simulation Data Sheet

		COLUMNS									
		A	B	C	D	E	F	G	H	I	J
ROWS	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
	10										

Figure 3. Example of graph of data from Row 1.

DATA		COLUMNS									
		A	B	C	D	E	F	G	H	I	J
ROWS	1	16	12	7	4	3	5	8	11	14.5	



DATA

COLUMNS

	A	B	C	D	E	F	G	H	I	J
ROWS										

DEPTH										
	0									
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
	A	B	C	D	E	F	G	H	I	J

COLUMN

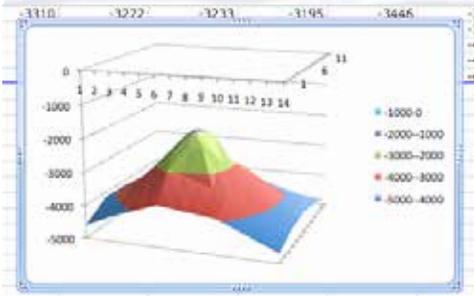
Fold → -----





Section 3: Multibeam Sonar

Lesson 4: Mapping the Deep-ocean Floor



3-Dimensional surface plot made using bathymetric survey data from Kawio Barat Volcano collected by the *Okeanos Explorer* during the INDEX-SATAL 2010 Expedition.

Focus

Bathymetric mapping

Grade Level

7-8 (Physical Science/Earth Science)

Focus Question

What is multibeam sonar, and what are its advantages for ocean exploration?

Learning Objectives

- Students will analyze and interpret data from the *Okeanos Explorer* to explain how multibeam sonar is used to identify patterns of ocean floor structures, and how multibeam sonar technology extends the measurement and exploration capacity of modern ocean exploration.

Materials

- Copies of *Making Three-Dimensional Surface Charts using Microsoft Excel™* and *Table 1: Bathymetric Survey Data from Kawio Barat Volcano*; one copy for each student group

Audio Visual Materials

- (Optional) Images of exploration technologies and animations (see Learning Procedure, Step 1c)

Teaching Time

Two or three 45-minute class periods

Seating Arrangement

Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Bathymetric map
Multibeam sonar



Background

Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration, and can create high-resolution maps, three dimensional models, or even “fly-through” videos that simulate a trip across the area being mapped.

For more information about how multibeam sonar is used aboard the NOAA Ship *Okeanos Explorer*, please see *Introduction to Multibeam Sonar* on page 49. In this lesson, students will learn about multibeam sonar and its role in the exploration strategy used aboard the *Okeanos Explorer*; and use data from the *Okeanos Explorer* to create a bathymetric map.

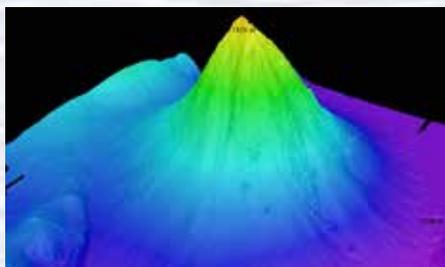
Learning Procedure

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions provided on the student worksheet.

1. To prepare for this lesson:
 - (a) Review:
 - Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
 - Minding the Multibeam at Midnight by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>); and
 - State of the Art Seafloor Survey by Meme Lobecker and Elaine Stuart (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>).
 - (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
 - (c) If desired, download images to accompany discussions in Step 2. You may also want to download this “before and after” image to illustrate the capabilities of multibeam sonar:
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/bires/em302_before_after_bires.jpg,
as well as one or more of the following animations to accompany discussions in Step 3:
<http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>;

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>; and
http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html.
 - (d) Review *Making Three-Dimensional Surface Charts using Microsoft Excel™*.
 - (e) (Optional) Review procedures for viewing multibeam imagery in the Fledermaus file format explained in the *Watching in 3D* lesson, and decide whether to demonstrate this imagery as part of class discussions.
 - (f) Ensure that students will have access to Microsoft Excel™ on the computers they will use to complete the chart activity (Step 5) and download the file **KawioBaratReduced.xlsx** (<http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/KawioBaratReduced.xlsx>); OR **KawioBaratReduced.xls** (<http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/KawioBaratReduced.xls>) depending upon which version of Microsoft Excel™ students will be using.





Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by the *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

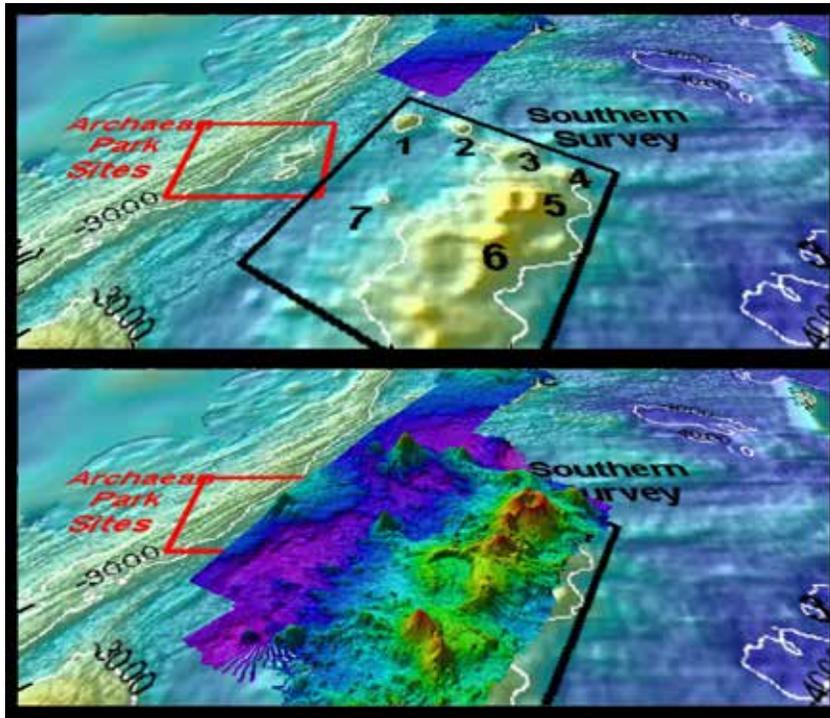
3. Ask students what they know about sonar, and provide additional information as necessary. (See *Introduction to Multibeam Sonar* on page 49). You may want to show one or more of the video clips referenced in Step 1c.

Describe the role of multibeam sonar in ocean exploration aboard the *Okeanos Explorer*. Students should realize that this is the key technology for the “reconnaissance” component of the overall exploration strategy, and provides the “big picture” view as explorers look for anomalies. Another important point is that, thanks to telepresence, images from mapping results can be shared in real-time with scientists in Exploration Command Centers, so that these scientists can have input into selecting sites where water column studies and underwater robot dives are to take place.

Briefly discuss other types of bathymetric maps, and how they were made. Before the invention of sonar, water depths were determined by dropping a weighted line over the side of a ship and measuring the amount of line needed to reach the bottom. These measurement (called soundings) were recorded on nautical charts.

Many nautical charts still in use today are covered with tiny numbers that represent individual soundings, some of which were made many years ago. Sonar made it possible to collect many more depth readings, but until recently these could only be recorded directly beneath a ship. Improvements in electronics and modern computer technologies led to the development of multibeam sonar, which provides three-dimensional images of the seafloor, in much greater detail than older methods. Maps generated by multibeam sonar systems are particularly useful for ocean exploration, since they allow scientists to focus on areas that are geologically interesting or have a high probability of being inhabited by unusual organisms. This image: http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg.

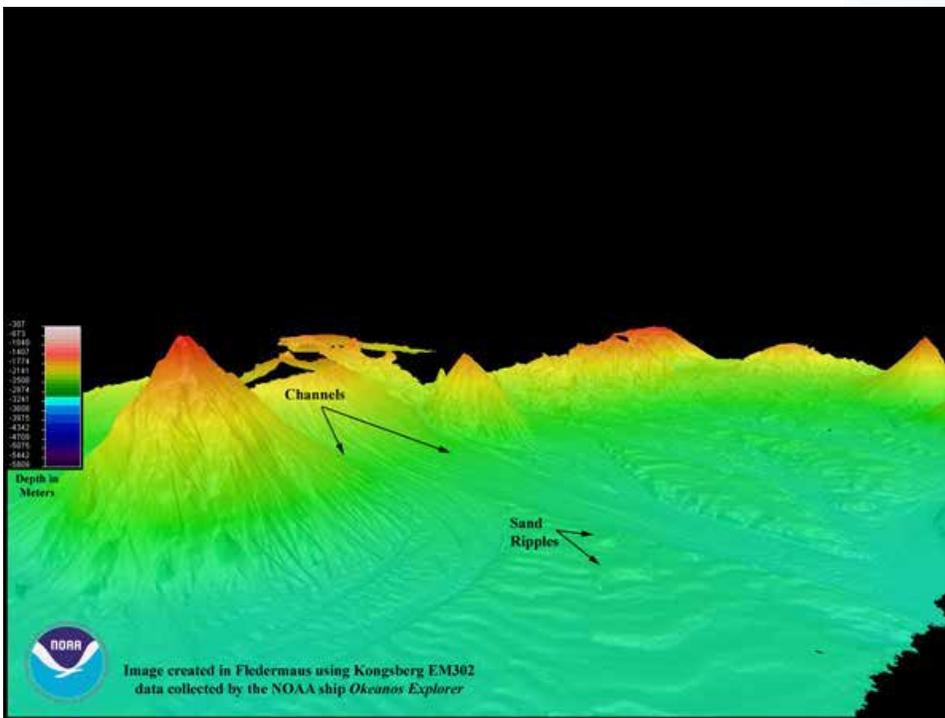




This “before and after” image provides a glimpse of *Okeanos Explorer*’s EM302 mapping system capabilities in deep water. The top image shows what we previously knew about the seafloor terrain in the southern Mariana region from satellite altimetry data. The bottom image includes an overlay of the information provided by the ship’s EM302 multibeam system. Image courtesy of NOAA Office of Ocean Exploration and Research.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg

shows how much *Okeanos Explorer*’s EM302 mapping system adds to what we know about seafloor terrain.

4. Tell students that one of the priorities for the INDEX-SATAL 2010 Expedition was to explore a submarine volcano named Kawio Barat. Say that their assignment is to create a three-dimensional graph called a surface plot using depth data from the Kawio Barat area. Provide each student group with a copy of *Making Three-Dimensional Surface Charts using Microsoft Excel™* as well as *Table 1: Bathymetric Survey Data from Kawio Barat Volcano*. Tell students that these data were collected by the *Okeanos Explorer*’s multibeam sonar mapping



The EM302 gives us a high resolution “bird’s eye” view of large areas. What we see underwater is similar to what we see around us every day. In the above image, a panorama of mountains and volcanoes sit majestically near a massive river delta surrounded by a soft sand beach. Since what we see here is actually underwater, there are of course no rivers or river deltas, or mountains and sand bars, but seeing these features makes one wonder how an area like this was formed. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/media/seamount_channels.html



system during the INDEX-SATAL 2010 Expedition. Be sure students understand that each data point represents the depth of water at the location described by the geographic coordinates. Note that for the purposes of this exercise, we are only using a small sample of all the data collected, which for this site amounts to hundreds of thousands of data points.

When students have completed their surface plots, lead a discussion of their results. Figure 1 shows a typical plot of the data, and the results of several rotations as described on the worksheet. Call students' attention to, and ask them to explain how these data demonstrate how technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations. Students should recognize that the data were produced from multibeam sonar technology that greatly extends the capabilities for ocean exploration compared to the capabilities that existed before this technology was available.

Students should also realize that the large number of data points is very difficult to interpret simply by inspecting the table of numbers. In fact, Table 1 only includes 182 data points, while the actual multibeam data file for the Kawio Barat volcano contains thousands of data points. Mathematical analysis technology makes it possible to understand relationships in a large data set, and to have a clear visual image of the geographic structure that the data represents. In this case, the mathematical analysis technology is provided by Microsoft Excel™. Analysis of full datasets produced by multibeam sonar uses an analysis tool called Fledermaus (which is the German word for “bat,” and is pronounced “FLEE-der-mouse”) that provides three-dimensional visualizations from multibeam data. The *Watching in 3-D* lesson includes a simple analysis of multibeam data using free viewing software for multibeam imagery in the Fledermaus file format.

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 click on “Technology” for activities and links about ocean exploration technologies.

The “Me” Connection

Have students write a first-hand account of their experiences on an exploratory mission to the Kawio Barat volcano, including topographic features revealed by multibeam sonar surveys.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Class discussions and students' work with the charting activity provide opportunities for assessment.

Extensions

See the *Calling All Explorers* lesson for an activity involving maps and GPS technology: http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_callingex.pdf.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Earth's Ocean is 95% Unexplored: So What?

(from the INDEX-SATAL 2010 Expedition)

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf

Focus: Importance of deep-ocean exploration (Grades 5-6; Life Science/Earth Science)

Students describe at least three different deep-ocean ecosystems; explain at least three reasons for exploring Earth's deep ocean; explain at least three ways that deep-ocean ecosystems may benefit humans; and create a wall magazine to communicate scientific ideas.

Sonar Simulation

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/sonarsim78.pdf>

Focus: Side-scan sonar (Grades 7-8; Earth Science/Physical Science)

Students describe side-scan sonar; compare and contrast side-scan sonar with other methods used to search for underwater objects; and make inferences about the topography of an unknown and invisible landscape based on systematic discontinuous measurements of surface relief.

Mapping the Deep Ocean

(from the INSPIRE: Chile Margin 2010 expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/mapping.pdf>

Focus: Bathymetric Mapping (Grades 7-8; Physical Science/Earth Science)

Students create a two-dimensional topographic map from bathymetric survey data; create a three-dimensional model of seafloor topography from a two-dimensional topographic map; and interpret two- and three-dimensional topographic data.

How Does Your Magma Grow?

(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_magma.pdf

Focus: Hot spots and mid-ocean ridges (Grades 7-8; Physical Science)

Students identify types of plate boundaries associated with movement of the Earth's tectonic plates; compare and contrast volcanic activity associated with spreading centers and hot spots; describe processes which resulted in the formation of the Galapagos Islands; and describe processes that produce hydrothermal vents.





Sound Pictures

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/soundpics912.pdf>

Focus: Sonar (Grades 9-12; Physical Science)

Students explain the concept of sonar, describe the major components of a sonar system; explain how multibeam and side-scan sonar systems are useful to ocean explorers; and simulate sonar operation using a motion detector and a graphing calculator.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

oceaneducation@noaa.gov

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Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: 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>



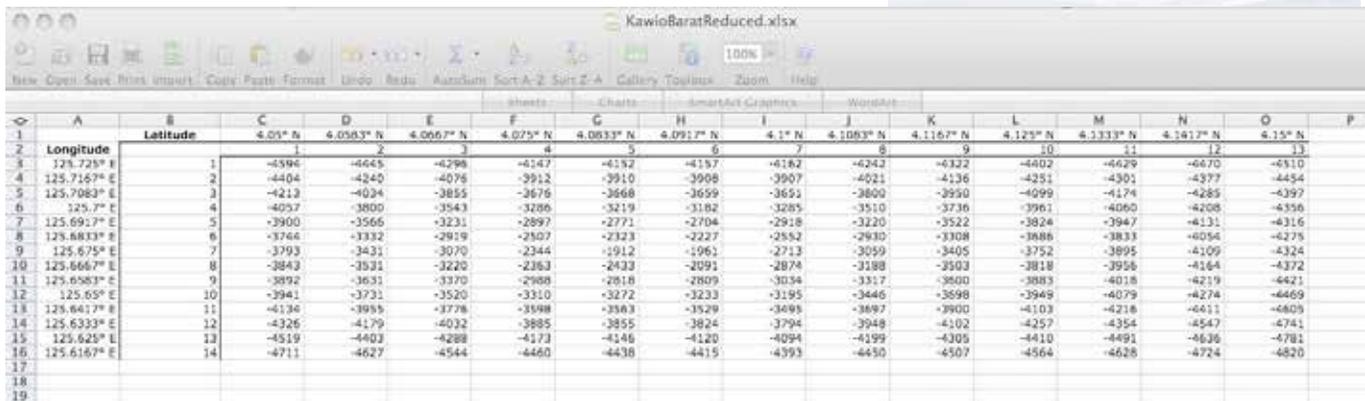
Making Three-Dimensional Surface Charts using Microsoft Excel™

NOTE: The following instructions are written for Microsoft Excel™ version 12.2.0. Other versions may require modifications to these instructions. If you are using Office 2003 or an older version of Office, you may need to use the Office Compatibility Pack, which can be downloaded from: <http://www.microsoft.com/download/en/details.aspx?displaylang=en&id=3>.

Table 1 lists 182 data points from a bathymetric survey in the vicinity of the Kawio Barat volcano. Each depth measurement is listed with a corresponding geographic location described by latitude and longitude. Your assignment is to analyze these data points in a way that gives a sense of the topography in the survey area. To do this, you can make a surface plot using Microsoft Excel™. We just have to rearrange the data somewhat so that Excel™ will give us what we want.

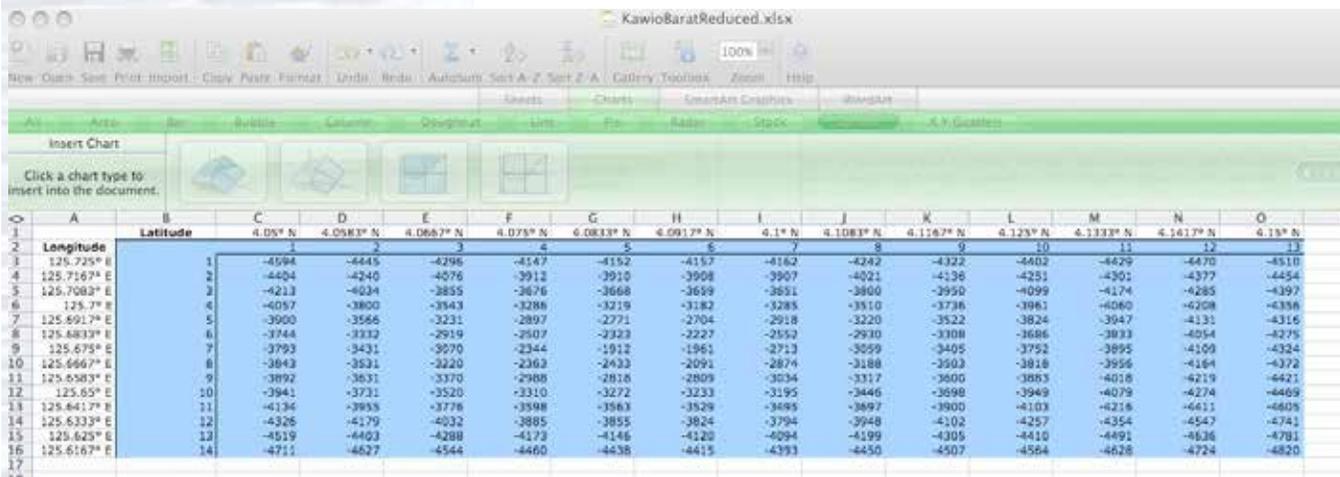
1. Open Microsoft Excel™, then open the file “KawioBaratReduced.xls” or “KawioBaratReduced.xls”. Your screen should resemble Figure 1. Notice that latitude values are across the top of the page as columns, and the longitude values are on the left side of the page in rows. The depth measurements are in the middle of the page, in grid cells that correspond to the latitude and longitude of the location where each measurement was made. You can also see that a row and a column have been added that have numbers from 1 to 14 corresponding to the longitude values, and numbers from 1 to 13 corresponding to the latitude values. This will cause Excel™ to use a simple linear scale when it plots the data.

Figure 1.



2. To make a surface plot, click on the “Charts” tab at the top of the spreadsheet or select “Chart” from the “Insert” menu. A chart menu will open at the top of the spreadsheet.
3. Click and hold in the blank cell just below the “Latitude” label (cell B2) and drag down and to the right to select all of the depth measurements as well as the row and column numbers in column B and Row 2. Now your screen should resemble Figure 2.
4. If you see a button in the Chart menu labeled “Surface”, click this button and then click on the icon for “3D Surface” (be sure the cells are still highlighted). If you do not see the “Surface” button, click on the icon labeled “Other” and select the “3D Surface” option. Now you should see a 3D surface plot that looks a lot

Figure 2.



like the Kawio Barat volcano! (Figure 3). You can try the other surface plotting options to see how they change the way the data are presented.

5. You can even rotate it to see what the other side looks like: Under the “Chart” menu, select “3D Rotation.” A “Format Chart Area” window will open. Select 3D Rotation from the choices on the left, then experiment with the X and Y settings to view your chart from various positions. When you find a view you like, print the image.

Figure 3.

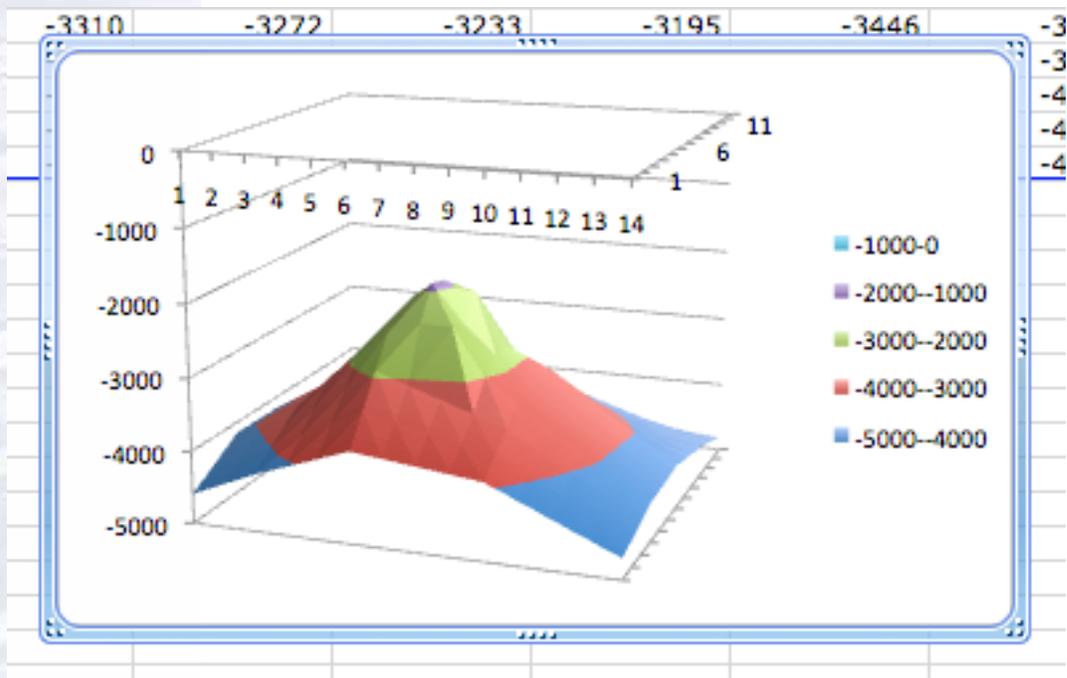


Table 1
Bathymetric Survey Data from Kawio Barat Volcano
***Okeanos Explorer* INDEX-SATAL 2010 Expedition**

North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)
4.050	125.725	-4594	4.075	125.725	-4147	4.100	125.725	-4162
4.050	125.717	-4404	4.075	125.717	-3912	4.100	125.717	-3907
4.050	125.708	-4213	4.075	125.708	-3676	4.100	125.708	-3651
4.050	125.700	-4057	4.075	125.700	-3286	4.100	125.700	-3285
4.050	125.692	-3900	4.075	125.692	-2897	4.100	125.692	-2918
4.050	125.683	-3744	4.075	125.683	-2507	4.100	125.683	-2552
4.050	125.675	-3793	4.075	125.675	-2344	4.100	125.675	-2713
4.050	125.667	-3843	4.075	125.667	-2363	4.100	125.667	-2874
4.050	125.658	-3892	4.075	125.658	-2988	4.100	125.658	-3034
4.050	125.650	-3941	4.075	125.650	-3310	4.100	125.650	-3195
4.050	125.642	-4134	4.075	125.642	-3598	4.100	125.642	-3495
4.050	125.633	-4326	4.075	125.633	-3885	4.100	125.633	-3794
4.050	125.625	-4519	4.075	125.625	-4173	4.100	125.625	-4094
4.050	125.617	-4711	4.075	125.617	-4460	4.100	125.617	-4393
4.058	125.725	-4445	4.083	125.725	-4152	4.108	125.725	-4242
4.058	125.717	-4240	4.083	125.717	-3910	4.108	125.717	-4021
4.058	125.708	-4034	4.083	125.708	-3668	4.108	125.708	-3800
4.058	125.700	-3800	4.083	125.700	-3219	4.108	125.700	-3510
4.058	125.692	-3566	4.083	125.692	-2771	4.108	125.692	-3220
4.058	125.683	-3332	4.083	125.683	-2323	4.108	125.683	-2930
4.058	125.675	-3431	4.083	125.675	-1912	4.108	125.675	-3059
4.058	125.667	-3531	4.083	125.667	-2433	4.108	125.667	-3188
4.058	125.658	-3631	4.083	125.658	-2818	4.108	125.658	-3317
4.058	125.650	-3731	4.083	125.650	-3272	4.108	125.650	-3446
4.058	125.642	-3955	4.083	125.642	-3563	4.108	125.642	-3697
4.058	125.633	-4179	4.083	125.633	-3855	4.108	125.633	-3948
4.058	125.625	-4403	4.083	125.625	-4146	4.108	125.625	-4199
4.058	125.617	-4627	4.083	125.617	-4438	4.108	125.617	-4450
4.067	125.725	-4296	4.092	125.725	-4157	4.117	125.725	-4322
4.067	125.717	-4076	4.092	125.717	-3908	4.117	125.717	-4136
4.067	125.708	-3855	4.092	125.708	-3659	4.117	125.708	-3950
4.067	125.700	-3543	4.092	125.700	-3182	4.117	125.700	-3736
4.067	125.692	-3231	4.092	125.692	-2704	4.117	125.692	-3522
4.067	125.683	-2919	4.092	125.683	-2227	4.117	125.683	-3308
4.067	125.675	-3070	4.092	125.675	-1961	4.117	125.675	-3405
4.067	125.667	-3220	4.092	125.667	-2091	4.117	125.667	-3503
4.067	125.658	-3370	4.092	125.658	-2809	4.117	125.658	-3600
4.067	125.650	-3520	4.092	125.650	-3233	4.117	125.650	-3698
4.067	125.642	-3776	4.092	125.642	-3529	4.117	125.642	-3900
4.067	125.633	-4032	4.092	125.633	-3824	4.117	125.633	-4102
4.067	125.625	-4288	4.092	125.625	-4120	4.117	125.625	-4305
4.067	125.617	-4544	4.092	125.617	-4415	4.117	125.617	-4507

Table 1 (continued)
Bathymetric Survey Data from Kawio Barat Volcano
Okeanos Explorer INDEX-SATAL 2010 Expedition

North Latitude	East Longitude	Depth (m)	North Latitude	East Longitude	Depth (m)
4.125	125.725	-4402	4.142	125.725	-4470
4.125	125.717	-4251	4.142	125.717	-4377
4.125	125.708	-4099	4.142	125.708	-4285
4.125	125.700	-3961	4.142	125.700	-4208
4.125	125.692	-3824	4.142	125.692	-4131
4.125	125.683	-3686	4.142	125.683	-4054
4.125	125.675	-3752	4.142	125.675	-4109
4.125	125.667	-3818	4.142	125.667	-4164
4.125	125.658	-3883	4.142	125.658	-4219
4.125	125.650	-3949	4.142	125.650	-4274
4.125	125.642	-4103	4.142	125.642	-4411
4.125	125.633	-4257	4.142	125.633	-4547
4.125	125.625	-4410	4.142	125.625	-4636
4.125	125.617	-4564	4.142	125.617	-4724
4.133	125.725	-4429	4.150	125.725	-4510
4.133	125.717	-4301	4.150	125.717	-4454
4.133	125.708	-4174	4.150	125.708	-4397
4.133	125.700	-4060	4.150	125.700	-4356
4.133	125.692	-3947	4.150	125.692	-4316
4.133	125.683	-3833	4.150	125.683	-4275
4.133	125.675	-3895	4.150	125.675	-4324
4.133	125.667	-3956	4.150	125.667	-4372
4.133	125.658	-4018	4.150	125.658	-4421
4.133	125.650	-4079	4.150	125.650	-4469
4.133	125.642	-4216	4.150	125.642	-4605
4.133	125.633	-4354	4.150	125.633	-4741
4.133	125.625	-4491	4.150	125.625	-4781
4.133	125.617	-4628	4.150	125.617	-4820





Section 3: Multibeam Sonar

Lesson 5: Watching in 3D

Focus

Multibeam sonar

Grade Level

9-12 (Physical Science/Earth Science)

Focus Question

How is multibeam sonar used to explore Earth's deep ocean?

Learning Objectives

- Students will explain how multibeam sonar uses the properties of sound waves in water for scientific research about topography of the ocean floor.
- Students will analyze and interpret multibeam sonar data to identify patterns in the distribution of seafloor features that contribute to scientific research about large-scale interactions in Earth's systems.

Materials

- Copies of the *Sonar Background Review Worksheet*, one copy for each student
- Copies of the *Introduction to Multibeam Imagery Worksheet*, one copy for each student group

Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 3)

Teaching Time

Two or three 45-minute class periods

Seating Arrangement

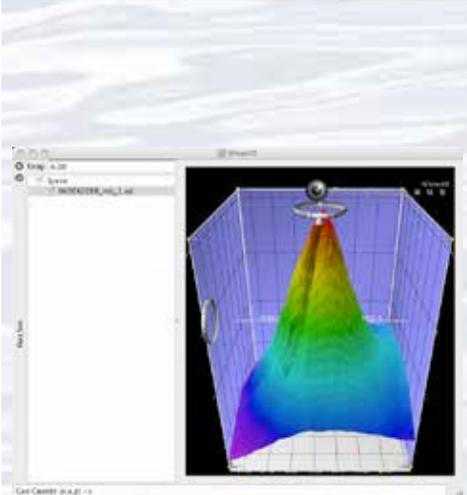
Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Bathymetric map
Multibeam sonar



A multibeam sonar image of the Kawio Barat submarine volcano as viewed in iView4D software and using data collected during the INDEX-SATAL 2010 Expedition.



Background

Multibeam sonar is one of the most powerful tools available for modern deep-sea exploration, and can create high-resolution maps, three dimensional models, or even “fly-through” videos that simulate a trip across the area being mapped. For more information about how multibeam sonar is used aboard the NOAA Ship *Okeanos Explorer*, please see the *Introduction to Multibeam Sonar* on page 49.

An important technique for studying multibeam images uses a three-dimensional data visualization system called Fledermaus (which is the German word for “bat,” and is pronounced “FLEE-der-mouse”). This lesson introduces students to multibeam sonar technology and simple analysis of multibeam data using free viewing software for multibeam imagery in the Fledermaus file format. As the *Okeanos Explorer* continues its voyages of discovery in Earth’s deep ocean, students have additional opportunities to apply their analytic skills to investigate new multibeam images (see, for example, *Okeanos Explorer* Multibeam Sonar Supplemental Datasheet #1 for Cruise 12.02; http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdmultibeam1.pdf). Note: mention of proprietary names does not imply endorsement by NOAA.

Learning Procedure

1. To prepare for this lesson:

a) Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
- Minding the Multibeam at Midnight by Colleen Peters (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>); and
- State of the Art Seafloor Survey by Meme Lobecker and Elaine Stuart (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>).

(b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.

(c) If desired, download images to accompany discussions in Step 2. You may also want to download this “before and after” image to illustrate the capabilities of multibeam sonar:

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/em302_before_after_hires.jpg,

as well as one or more of the following animations to accompany discussions in Step 3:

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul08/media/sm2k.html>;

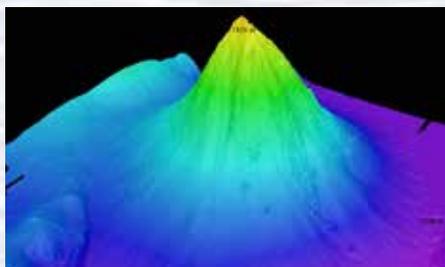
<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>; and

http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html

(d) Review background information on multibeam sonar technology and questions on the *Sonar Background Review* and *Introduction to Multibeam Imagery Worksheets* and make copies of *Sonar Background Review Worksheet* for each student, and copies of *Introduction to Multibeam Imagery Worksheet* for each student group.

(e) Download the iView4D software from <http://www.qps.nl/display/main/download>, and download the data file **INDEX2010_mb_1.sd** from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/INDEX2010_mb_1.sd





Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

and install these on computers that students will be using to complete the *Worksheet* activity. Alternatively, you may have students download these resources onto their own computers.

- Provide each student with a copy of the *Sonar Background Review Worksheet* as homework in preparation for the remainder of this lesson.
- Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
 - The overall strategy is based on finding anomalies;
 - This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
 - This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

- Review students' answers to questions on the *Sonar Background Review Worksheet*. These may be compared with the answers provided.
- Ask students what they know about sonar, and provide additional information as necessary. Be sure students understand that sonar uses an acoustic signal or pulse of sound that is transmitted into the water by a sort of underwater speaker known as a transducer. If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an "echo" to the sonar transducer. The time elapsed between the emission of the sound pulse and the reception of the echo is used to calculate the distance of the object. Since the time between transmission of a pulse and the return of its echo is the time it takes the sound to travel to the bottom and back, if we know this time and the local speed of sound we can calculate the distance to the bottom (this distance is called range). The time measured between pulse transmission and echo return is the "round trip" time, so the pulse has travelled twice the range during this time. For this reason, the general formula for range is:

$$\text{range} = (1/2) (\text{local speed of sound}) (\text{echo time})$$

A multibeam sonar system uses multiple transducers pointing at different angles on either side of a ship to create a swath of signals. The time interval between signal transmission and return echo arrival is used to estimate depth over the area of the swath. In addition to high-resolution maps, multibeam data can





be used to create three-dimensional models or even “fly-through” videos that simulate a trip across the area being mapped. You may want to show one or more of the images or video clips referenced in Step 1c.

Describe the role of multibeam sonar in ocean exploration aboard *Okeanos Explorer*. The image on page 50 http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/bires/em302_before_after_bires.jpg shows how much *Okeanos Explorer*'s EM302 mapping system adds to what we know about seafloor terrain. Students should realize that this is the key technology for the “reconnaissance” component of the overall exploration strategy, and provides the “big picture” view as explorers look for anomalies.

Show this image http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/bires/xbt_cast_bires.jpg in which two scientists are conducting an XBT cast during the INDEX-SATAL 2010 Expedition. Be sure students understand that an XBT is an “expendable bathythermograph” which measures temperature through the water column. Ask students why this information is important to accurate multibeam operations. Students should realize that temperature affects the local speed of sound, which we have to know in order to calculate range as described above.

6. Provide each student group with a copy of the *Introduction to Multibeam Imagery Worksheet*, and ensure that students have access to the software and file referenced in Step 1e. Tell students that this activity is intended to familiarize them with multibeam imagery and how it can be manipulated to answer basic questions about features on the ocean floor. You may also want to mention that this skill will enable them to investigate additional images that will be available from future *Okeanos Explorer* missions.
7. When students have answered the questions on the *Introduction to Multibeam Imagery Worksheet*, lead a discussion of their results. Students' answers may be compared with the answers provided. The discussion may include the following components of technological literacy (ITEA, 2007):
 - **Scope of technology:** Development of multibeam sonar technology is the result of specific, goal-directed research.
 - **Relationships between technologies and other fields of study:** Progress in the development of multibeam sonar technology is closely linked to advancements in science and mathematics.

Ocean researchers conduct an XBT cast during the INDEX-SATAL 2010 Expedition. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/aug05/media/xbt_cast.html

Latitude and Longitude

If students are not familiar with the concepts of latitude and longitude, see *The Robot Archaeologist* (<http://oceanexplorer.noaa.gov/explorations/09newworld/background/edu/media/robot.pdf>), page 11.

Degrees, Minutes, Seconds or Decimal Degrees?

The iView4D software provides longitude and latitude (x and y “Geo Coords” on the bottom left of the viewer window) in degrees, minutes, and seconds; but the *Okeanos Atlas* uses the decimal degree format.

To convert degrees/minutes/seconds to decimal degrees:

1. Convert seconds to minutes, and add to minutes.
2. Convert minutes to degrees, and add to degrees.

For example, to convert $4^{\circ} 44' 49''$ to decimal degrees:

1. Divide $49''$ by 60 seconds/minute = 0.81667; add to $44' = 44.81667'$
2. Divide $44.81667'$ by 60 minutes/degree = 0.74694°; add to $4^{\circ} = 4.74694^{\circ}$

To convert decimal degrees to degrees/minutes/seconds:

1. Multiply the decimal portion of the number by 60. The whole number portion of the result is minutes.
2. Multiply the decimal portion of the result by 60 to find the number of seconds.

For example, to convert 4.74694° to degrees/minutes/seconds:

1. Multiply 0.74694 by 60 = 44.8164. The number of minutes is 44.
2. Multiply 0.8164 by 60 = 48.984. The number of seconds is 49.

So, $4.74694^{\circ} = 4^{\circ} 44' 49''$

- **Effects of technology on the environment:** Multibeam sonar technology provides a new way to monitor various aspects of the environment to provide information for decision-making.

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 “Habitats” then select “Deep Ocean” for activities and links about deep ocean ecosystems.

The “Me” Connection

Have students write a brief essay describing a backpacking trip across a landscape having the topography shown in the multibeam image used for the *Worksheet* activity.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Students’ answers to *Worksheet* questions and class discussions provide opportunities for assessment.

Extensions

Visit the Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 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

The Ridge Exploring Robot

(from the INSPIRE: Chile Margin 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/robot.pdf>

Focus: Autonomous Underwater Vehicles/Marine Navigation (Grades 9-12; Earth Science/Mathematics)

Students explain a three-phase strategy that uses an Autonomous Underwater Vehicle (AUV) to locate, map, and photograph previously undiscovered hydrothermal vents; design a survey program to provide a photomosaic of a hypothetical hydrothermal vent field; and calculate the expected position of the AUV based on speed and direction of travel.

Sound Pictures

(from the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10sanandreas/background/edu/media/soundpics912.pdf>

Focus: Sonar (Grades 9-12; Physical Science)

Students explain the concept of sonar, describe the major components of a sonar system, explain how multibeam and sidescan sonar systems are useful to



ocean explorers, and simulate sonar operation using a motion detector and a graphing calculator.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

oceanexeducation@noaa.gov

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Sonar Background Review Worksheet

1. How are sound waves in water different from electromagnetic waves such as light or radio waves?
2. What are some conditions that affect the speed of sound waves travelling in water?
3. Sound waves may be thought of as a sequence of moving pressure fronts. What is the term for the physical distance between two consecutive pressure fronts?
4. What is the term for the number of pressure fronts that pass a stationary point in a certain amount of time?
5. What is the mathematical relationship between the properties described in Questions 3 and 4?
6. When a sound wave moving through water encounters a change in temperature, what happens to the properties described in Questions 3 and 4?
7. When a sound wave moves through the water, what is it that is actually moving?
8. Instruments called hydrophones measure the changes in pressure caused by the pressure fronts of a sound wave. If one sound wave is found to cause greater pressure changes than another sound wave, what does this indicate about the two waves?
9. The pressure caused by a sound wave is directly related to a third property of waves. What is this property?
10. What happens to the property identified in Question 9 as a sound wave moves through water?
11. How is the effect identified in Question 10 related to the property identified in Question 4?
12. When a sound wave moving through water encounters another medium, such as rock or sand, what are three things that happen to the quantity identified in Question 7?

Sonar Background Review Worksheet Answers

1. Sound waves in water move as compression waves, while electromagnetic waves are transverse waves.
2. The speed of sound waves travelling in water is affected by conditions of the water such as salinity, pressure, and temperature; the speed of sound waves under a particular set of these conditions is called the local speed of sound. In the ocean, the speed of sound is about 1,500 meters per second.
3. The physical distance between two consecutive pressure fronts in a sound wave is wavelength.
4. The number of pressure fronts that pass a stationary point in a certain amount of time is the frequency of the wave.
5. The mathematical relationship between wavelength and frequency is:

$$\text{speed of sound} = \text{frequency} \times \text{wavelength}$$

Typically, wavelength is measured in meters (m), and frequency is measured in cycles per second (Hz), so units for the speed of sound are meters per second.

6. When a sound wave moving through water encounters a change in temperature, the local speed of sound and wavelength change, but frequency remains constant.
7. When a sound wave moves through the water, energy is the thing that actually moves.
8. If one sound wave induces a greater pressure change than another sound wave, the first sound wave contains more energy.
9. The pressure caused by a sound wave is directly related to the amplitude of the wave, which is related to the acoustic energy of the wave; higher amplitude waves contain more energy.
10. When a sound wave moves through water, it gradually loses some of its energy, so its amplitude is reduced.
11. Sound waves with higher frequencies lose energy more rapidly than those with lower frequencies.
12. When a sound wave moving through water encounters another medium, some of its energy is transferred into the new medium, some of it is reflected off the surface of the medium, and the rest is scattered in all directions. How much energy is reflected and how much is scattered depends on the characteristics of the medium and the angle at which the wave strikes the medium (angle of incidence). The energy that is reflected maintains the frequency characteristics of the original sound wave.

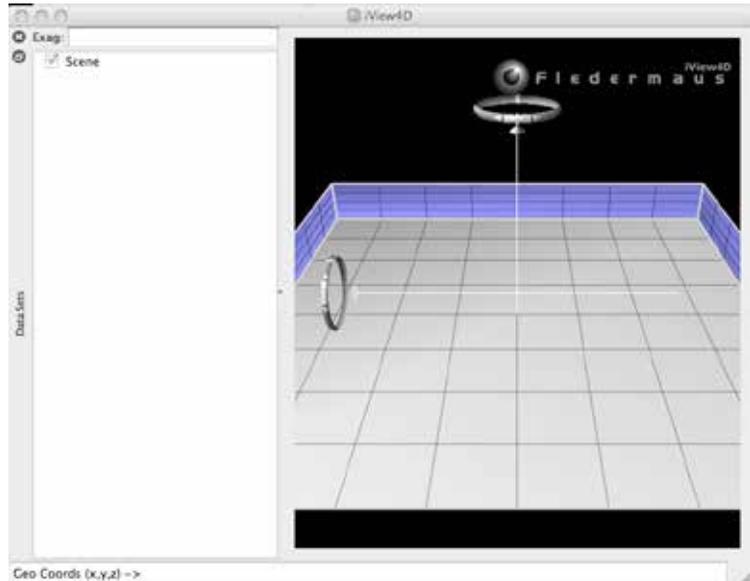




Introduction to Multibeam Imagery Worksheet

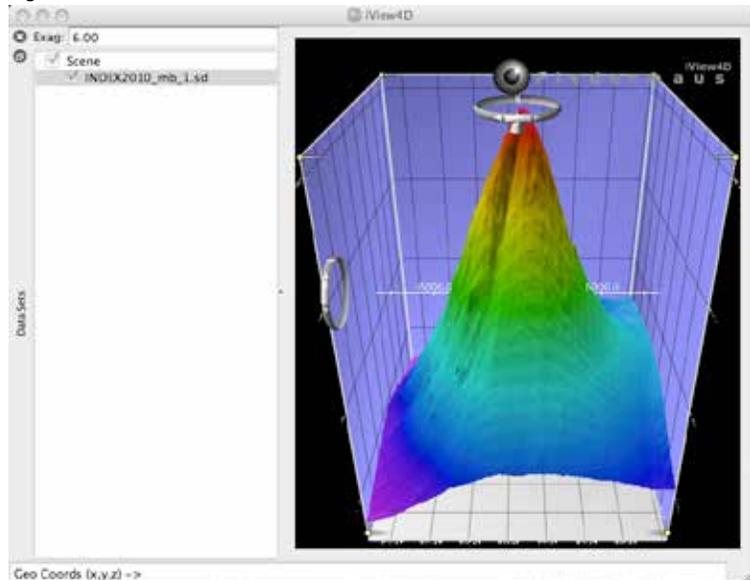
1. Launch the iView4D software. Your screen should resemble Figure 1. Note the Rotation Control Rings near the top center and mid-left side of the screen. If your screen doesn't look like Figure 1, be sure "Bounds" is checked under the "View" drop-down menu.

Figure 1.



2. Open the file, **INDEX2010_mb_1.sd**. Now your screen should resemble Figure 2. This is a multibeam sonar image of the Kawio Barat submarine volcano which was identified as a priority for exploration during the INDEX-SATAL 2010 Expedition.

Figure 2.



The ocean floor is shown as a three-dimensional image. The x-axis represents longitude, the y-axis represents latitude, and the z-axis represents depth. When

you move the cursor over the image, the window near the bottom of the screen shows the geo coordinates (x, y, and z) for the location beneath the cursor.

The Rotation Control Ring near the top allows you to rotate the image around the vertical axis, and the Rotation Control Ring on the left allows you to rotate the image around the horizontal axis. Alternatively, you can left-click (simple click on a Macintosh platform) and drag up or down to rotate the image around the horizontal axis, or left-click and drag left or right to rotate the image around the vertical axis.

You can zoom the image by right-clicking (or control-clicking on a Macintosh platform) in the middle of the image, then dragging to zoom in or out.

Some images use “vertical exaggeration” to show features more clearly. This means that the vertical scale is larger than the horizontal scale so vertical features are magnified. You can control the amount of vertical exaggeration by clicking and dragging the cone-shaped object on the vertical scale line near the middle of the image. Numbers on the scale lines show the relative horizontal and vertical scales.

Experiment with these controls to find out how they allow you to manipulate the image, then answer the following questions:

3. What are the northern and southern latitude boundaries for this image? (Hint: The Rotation Control Ring on the left allows you to rotate the image so that you are looking straight down.)
4. What are the eastern and western longitude boundaries for this image?
5. The deepest parts of the image are approximately how deep?
6. How deep is the shallowest part of this volcano? (Hint: Increasing the vertical exaggeration will make it easier to spot the shallowest portion.)
7. What is the approximate diameter of the volcano at its base? (Hint: One minute of latitude is equal to one nautical mile, which is equal to 1.852 km; but note that the squares on the Fledermaus image are not necessarily equal to one minute.)
8. What is the approximate slope of the volcano? (Hint: Think of the volcano as a right triangle whose base is one-half the volcano’s diameter.)
9. Often, areas where local topography is steep or very changeable will also be areas that have a variety of biological organisms. What is the approximate location of an area on the volcano that seems to have this kind of topography? (Hint: This is easier to see without vertical exaggeration.)





Answers for Multibeam Imagery Worksheet

- The northern and southern latitude boundaries for the image are about $4^{\circ} 44' 49''$ (4.7469°) N latitude and about $4^{\circ} 36' 10''$ (4.6028°) N latitude respectively. Reading the numbers on the latitude and longitude scales can be difficult; an easier way to find this information is to rotate the image so that we are directly overhead, then place the cursor near the edges of the image and read the latitude and longitude coordinates from the window on the lower left.
- The eastern and western longitude boundaries for this image are about $125^{\circ} 9' 39''$ (125.1608°) E longitude and about $125^{\circ} 01' 02''$ (125.0172°) E longitude, respectively.
- The deepest parts of the image are approximately 5,400 meters deep (near the northwestern edge of the image).

6. The shallowest part of this volcano is about 1,870 meters deep.

- We can estimate the diameter of the volcano by finding the north and south latitude boundaries of the base. If we use the edge of the light blue shading as the base (the actual base is deeper than this, but is not completely shown in the image; students may select a different outer boundary, in which case the following calculations will need to be adjusted, but the calculation technique is the same), the northern latitude boundary is about $4^{\circ} 44' 21''$ (4.73917°) N, and the southern latitude boundary is about $4^{\circ} 36' 16''$ (4.60444°) N. The difference between these numbers is $8' 5''$. Since one minute of arc is equal to 60 seconds of arc, 5 seconds is equal to

$$5 \div 60 = 0.083 \text{ minute}$$

So the diameter is approximately 8.083 minutes, which is equal to 8.083 nautical miles, which is equivalent to

$$8.083 \text{ nm} \cdot 1.852 \text{ km} = 14.97 \text{ km}$$

- To calculate the approximate slope of the volcano using the triangle hint, we need to know the diameter and height of the volcano. If we continue to use the edge of the light blue shading as the base, the depth at this point is about 4,539 m. Since the shallowest part of the volcano is about 1,870 m, its height is approximately 2,669 m. If the base of the triangle is one-half the volcano's diameter, this is equal to

$$0.5 \cdot 14.97 \text{ km} = 7.485 \text{ km} = 7,485 \text{ m}$$

The slope of the volcano is the angle between the side of the triangle and its base. The tangent of this angle is equal to the height divided by the base:

$$\tan \text{ slope} = 2,669 \text{ m} \div 7,485 \text{ m} = 0.357$$

The arctangent of 0.357 is the angle of the slope, which is equal to 19.6 degrees. If we set the vertical exaggeration in the upper left window to 1.0 (no exaggeration), this estimation looks reasonable.

- The deep valley on the southwestern side of the volcano, running roughly between $4^{\circ} 40' 24''$ (4.6733°) N, $125^{\circ} 5' 11''$ (125.0864°) E and $4^{\circ} 39' 38''$ (4.6606°) N, $125^{\circ} 4' 44''$ (125.0789°) E appears to have relatively steep topography and would be an interesting place to look for biological organisms.





Section 4: Water Column Investigations

Introduction to Water Column Investigations

Measurements of conductivity, temperature, and depth are a key component of the exploration strategy used aboard the NOAA Ship *Okeanos Explorer*. This is because underwater volcanoes, hydrothermal vents, chemosynthetic communities, and other features of the deep ocean are often associated with changes in the chemical properties of seawater. A CTD is a package of electronic instruments that measure these properties. Conductivity is a measure of how well a solution conducts electricity and is directly related to salinity, which is the concentration of salt and other inorganic compounds in seawater. Salinity is one of the most basic measurements used by ocean scientists. Salinity measurements can be combined with temperature data to determine seawater density, which is a primary driving force for major ocean currents. Often, CTDs are attached to a much larger metal frame called a rosette, which may hold water sampling bottles that are used to collect water at different depths, as well as other sensors that can measure additional physical or chemical properties.



A closeup of a CTD, the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD, which is housed in the steel container in the center of the rosette. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>

Temperature measurements from CTD sensors can be used to detect changes in water temperature that may indicate the presence of volcanoes or hydrothermal vents. Masses of seawater with unusual characteristics are called plumes, and are usually found within a few hundred meters of the ocean floor. Since underwater volcanoes and hydrothermal vents may be several thousand meters deep, ocean explorers often raise and lower a CTD rosette through several hundred meters near the bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD may resemble the movement of a yo-yo; a resemblance that has led to the nickname "tow-yo" for this type of CTD sampling. See <http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html> and <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html> for more information.

CTD Systems Aboard *Okeanos Explorer*

The *Okeanos Explorer* is equipped with a Seabird Electronics Model 9/11+ CTD system mounted on an SBE 32 rosette frame. This rosette includes 24 sampling bottles that can be individually triggered to collect samples at various depths. On many CTD casts, additional sensors to measure oxidation-reduction potential and optical backscatter are added to the instrument package, because these parameters can also signal the presence of hydrothermal vents and reducing communities.

The SBE 9+ CTD unit has a depth rating of 6,800 meters. The ship also carries an expendable bathythermograph (XBT) that is used to measure the velocity of sound in the ocean at various depths. This information is needed by the multibeam sonar system to collect accurate bathymetric data.

Note: Mention of proprietary names does not imply endorsement by NOAA.





Section 4: Water Column Investigations

Lesson 6: What's a CTD?

Focus

Measuring physical properties of seawater for ocean exploration

Grade Level

5-6 (Physical Science)

Focus Question

What is the relationship between temperature, salinity, pressure, and density of seawater, and why is this important to ocean exploration aboard the *Okeanos Explorer*?

Learning Objectives

- Students will explain how a CTD is used aboard the *Okeanos Explorer* to reveal patterns that help ocean explorers answer questions about the natural world.
- Students will analyze and interpret data from the *Okeanos Explorer* to make inferences about relationships between density, salinity, temperature, and pressure of seawater.

Materials

- Copies of *CTD Data Collected on Okeanos Explorer Cruise EX1004, Leg 3 Worksheet*; one copy for each student or student group
- Graph paper

Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 2)

Teaching Time

One or two 45-minute class periods

Seating Arrangement

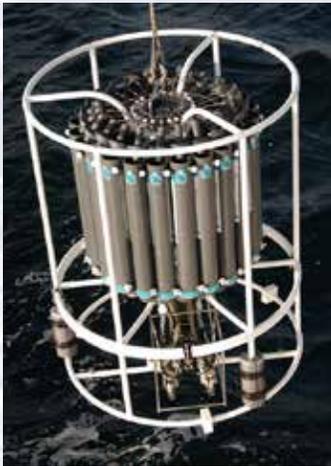
Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
CTD
Salinity
Density



A CTD rosette with water sampling bottles attached is lowered to measure the salinity, temperature, depth and concentration of particles in the water column. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june27/media/ex_ctd.html



Background

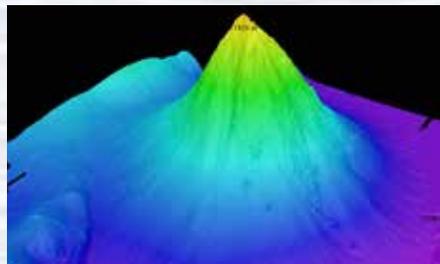
For discussion about the exploration strategy used aboard the *Okeanos Explorer*, please see the introductory section beginning on page 9. For background information about CTD instruments, please see the *Introduction to Water Column Investigations* on page 87.

This lesson introduces students to simple analysis of CTD data, how these data are related to seawater density, and how they may be used to search for hydrothermal vents.

Learning Procedure

- To prepare for this lesson:
 - Review:
 - Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
 - Background information on CTD technology at <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html>
 - Review background information about the *Okeanos Explorer* exploration strategy and technologies.
 - If students are not familiar with deep-sea chemosynthetic communities, you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (<http://oceanexplorer.noaa.gov/edu/learning/welcome.html>), and/or information from <http://www.pmel.noaa.gov/vents/nemo/explorer.html>.
 - Review procedures on the *CTD Data Collected on Okeanos Explorer Cruise EX1004, Leg 3 Worksheet*.
 - If desired, download images referenced in Step 2.
- Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
 - The overall strategy is based on finding anomalies;
 - This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
 - This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg



A closeup of a CTD, the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD, which is housed in the steel container in the center of the rosette. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.

http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_closeup_hires.jpg

3. If students are familiar with the concepts of seawater density, briefly review:
 - The definition of density;
 - The relationships between temperature, salinity, pressure, and density in seawater; and
 - The meaning of conductivity and its relationship to salinity.When this review is complete, proceed to Step 4.

If students are not familiar with these concepts, perform the following demonstrations:

- (a) While students watch, dissolve 2 tablespoons of table salt in approximately 250 ml of hot tap water. Add three drops of liquid food coloring, and stir to mix. Wait at least three minutes. Pour approximately 400 ml of hot tap water into a clear 500 ml beaker. Hold the beaker so that the water is visible to students, and slowly pour the colored salt water down along the inside wall of the beaker. A shimmering pool of colored water should form on the bottom of the beaker, below the uncolored tap water. Have students record their observations in writing.
- (b) While students watch, place approximately 100 ml of ice into a container with approximately 150 ml cool tap water. Add three drops of liquid food coloring. Pour approximately 400 ml of hot tap water into a clear 500 ml beaker. Tell students to watch closely as you hold the beaker so that the water is visible to students, and slowly pour the colored ice water down along the inside wall of the beaker. The colored water will flow to the bottom of the beaker and form a layer beneath the warmer water, but will soon disperse into the larger volume of water. Have students record their observations in writing, being sure to include what happened when the colored ice water first flowed into the warmer water.

Remind students that the density of a substance is related to an object's mass (how much material it contains) and volume (the object's physical size). A handful of styrofoam, for example, weighs much less than a handful of rocks because the density of the styrofoam is less than the density of the rocks. Density is usually defined as "mass per unit volume," and the density of an object or substance is stated in "grams per cubic centimeter."

Have students record their inferences about the effect of dissolved salt on the density of water, and the effect of temperature on the density of water. When students have finished writing, lead a discussion of their inferences. Students should understand that dissolved salt increases the density of water, and that the density of water also increases as temperature decreases. Tell students that in the ocean, density is also affected by water pressure. Since water pressure increases with increasing depth, the density of seawater also increases as depth increases.

4. Show an image of a CTD, and explain that this is actually a collection of several electronic instruments that measure properties of seawater. The basic instruments measure temperature, depth, and conductivity. Tell students that conductivity measures how easily electric currents pass through a liquid, and that electric current passes much more easily through water containing salt than through fresh water. Also say that CTDs actually measure water pressure as a way to measure depth.



Most of the device seen in the image in the sidebar is a water sampling device called a rosette or carousel, that contains water sampling bottles that are used to collect water at different depths. Before the rosette is lowered into the ocean, the bottles are opened so that water flows freely through them. As the rosette travels through the water column, scientists can monitor readings from the CTD sensors. If something unusual appears in the measurements, the scientists can send a signal through the CTD cable that closes one or more of the bottles to collect a water sample from the location where the unusual measurements appeared.

5. Give each student or student group a copy of the *CTD Data Collected on Okeanos Explorer Cruise EX1004, Leg 3 Worksheet*. Be sure students understand that CTD graphs are constructed with depth on the y-axis with zero at the top of the axis because this is the way we imagine depth when we think of a cross-section of the ocean. You may also need to point out that the vertical and horizontal scales of graphs do not have to begin at zero, and explain that adjusting these scales to the minimum and maximum values of the data has the advantage of making the relationships between the variables much more clear.

When students have completed the worksheet assignment, lead a discussion of their results. Students' graphs should resemble Figures 1, 2, and 3.

The discussion should include the following points:

- Density changed most rapidly near the surface.
- In general, density increases as depth increases.
- As depth increases, temperature and salinity tend to level out, while density continues to increase because pressure continues to increase with increasing depth.
- If an underwater robot is neutrally buoyant, the robot will sink if it enters a water mass that has a lower density.
- If the water mass has a greater density, the robot will rise until it encounters a water mass with density equaling that of the robot.

CTD monitoring crew. Image courtesy of NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/ctd_cast_hires.jpg



Figure 1.

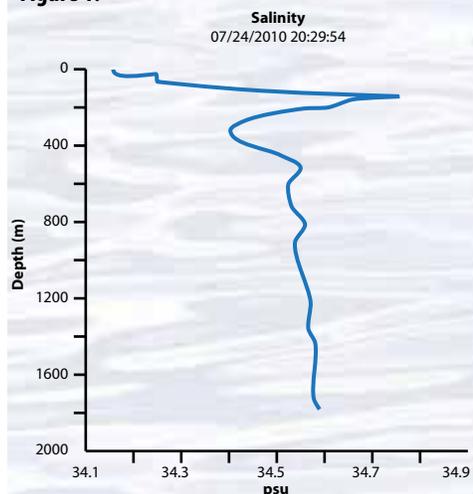


Figure 2.

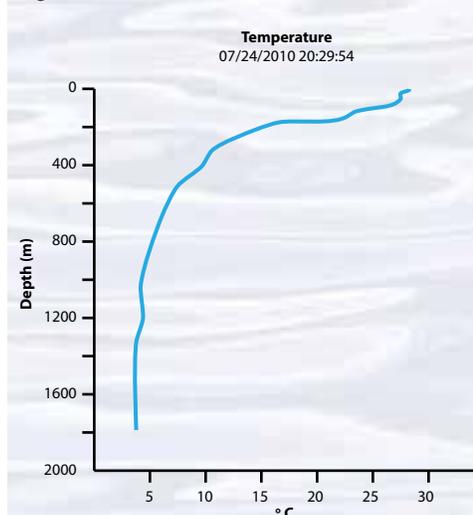
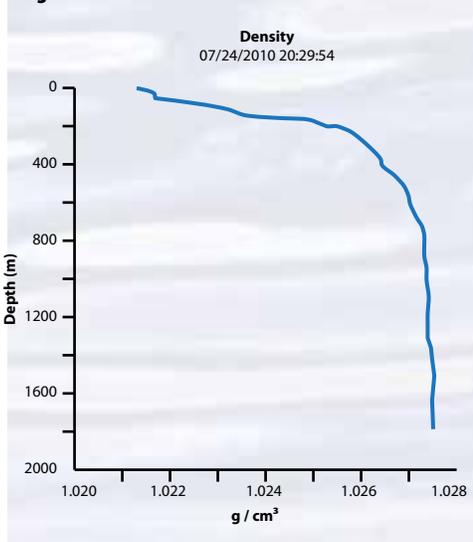


Figure 3.



If students are not familiar with deep-sea chemosynthetic communities, briefly describe the concept of chemosynthesis, and contrast it with photosynthesis. Tell students that chemosynthetic ecosystems in the deep ocean are found where a source of chemical energy is emerging from the ocean floor. If you have decided to use materials referenced in Step 1c, present these now. Tell students that a major objective of the INDEX-SATAL 2010 Expedition was to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts associated with active geologic processes in Indonesia's deep sea.

Ask what kinds of clues might be found in CTD data that could reveal the presence of hydrothermal vents or volcanoes. Increased temperature is fairly obvious, since heat from Earth's core is the energy source that causes vents to form. Temperatures of hydrothermal fluids may be more than 300°C, since the high pressure of deep-sea environments prevents water from boiling. Other clues (not discussed in this lesson) may come from instruments that measure acidity (fluids from hydrothermal vents are often highly acidic), and from chemical analyses of seawater samples (hydrogen sulfide, for example, is often found in hydrothermal vent fluids, but is not normally found in seawater).

In late June, during the INDEX-SATAL 2010 Expedition, CTD data showed temperature anomalies that suggested the possible presence of hydrothermal vents nearby. On June 30, 2010, *Okeanos Explorer's* ROV *Little Hercules* visited the site and found an active hydrothermal vent "surrounded by yellow and black molten sulfur, multiple species of hot-vent shrimp, a 10 cm scale worm, and a small patch of stalked barnacles. After departing from the vent, the ROV ascended the summit ridge and encountered fields of sulfide chimneys with vast aggregations of stalked barnacles at their base. The chimneys varied in terms of age and venting characteristics. Some chimneys were fairly oxidized and others covered in white sulfide. Some chimneys were venting clear fluid while others were venting black smoke." You can read more about the site, and see images from *Little Hercules* here: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html>.

- Discussion of CTD technology may also include the following components of technological literacy (ITEA, 2007):
 - **Scope of technology** – Development of CTD instrumentation allows many chemical and physical characteristics to be measured in the ocean, some of which could not be measured in deep water before this technology was created.
 - **Core concepts of technology** – A CTD is an example of several technological systems connected together; including different systems to measure various chemical and physical characteristics of seawater, and equipment for collecting water samples from very deep areas in Earth's ocean.
 - **Relationships between technologies and other fields of study** – Improvements to each of the technologies listed above improves the overall capability of water column investigations; and this information is useful to geologists, biologists, and many other branches of science.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the menu on the left side of the page, then "Habitats," then select "Deep Sea" for activities and links about deep-ocean ecosystems.

The “Me” Connection

Have students write a brief essay describing how the density of fluids on Earth affects their own lives. Students may struggle with this initially, depending upon their understanding of what can be included in the term “fluids.” You may need to suggest that this term includes gases as well as liquids, which may help students think in terms of atmospheric fluids (air) and issues concerning the density of these fluids (barometric pressure, which affects weather patterns, storms, etc.).

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Students’ answers to *Worksheet* questions and class discussions provide opportunities for assessment.

Extensions

Visit the Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 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

And Now for Something Completely Different...

(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf

Focus: Biological communities at hydrothermal vents (Grades 5-6; Life Science)

Students 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.

A Hydrothermal AdVENTure

(from the INSPIRE: Chile Margin 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/aydrothermal.pdf>

Focus: Hydrothermal vents (Grades 5-6; Earth Science)

Students explain the overall structure of hydrothermal vents and how they are related to the motion of tectonic plates, and create a model of a hydrothermal vent.

The Volcano Factory

(from the 2004 Submarine Ring of Fire Expedition)

<http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.volcanism.pdf>

Focus: Volcanism on the Mariana Arc (Grades 5-6; Earth Science)

Students explain the tectonic processes that result in the formation of the

Notes About Density Calculations

The density of seawater depends on temperature, salinity, and pressure. The mathematical relationship between these factors is somewhat complicated, and is known as the “equation of state” of seawater. There are several online calculators, though, that compute density of seawater from input values of temperature, salinity, and pressure (e.g., <http://www.es.flinders.edu.au/~mattom/Utilities/density.html>). These calculators use several units that may be unfamiliar:

σ_T – The density of seawater is always greater than 1.000 g/cm³ and less than 2.000 g/cm³, so oceanographers often express density as sigma T (σ_T), which is [(Sea water density - 1) x 1000]. This way, oceanographers do not have to write 1 or the decimal places every time they want to record a density measurement.

units of density – Oceanographers often use density units of kg/m³, instead of the more familiar g/cm³. The relationship between these is 1 kg/m³ = 1000 g/cm³.

units of pressure – Oceanographers often use units of decibars (0.1 bar), which is approximately equal to the depth in meters. Pressure may also be stated in units of kilopascals (kPa). The relationship between these is

1 decibar = 10 kilopascals.





Mariana Arc and the Mariana Trench, and explain why the Mariana Arc is one of the most volcanically active regions on Earth.

Unexplored!

(from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf

Focus: Scientific exploration of deep-sea volcanoes (Grades 5-6; Life Science/Physical Science/Earth Science)

Students compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Living With the Heat

(from the Submarine Ring of Fire 2006 Expedition)
<http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf>

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Grades 5-6; Life Science/Earth Science)

Students 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 among organisms typically found in hydrothermal vent communities.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:
oceaneducation@noaa.gov

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Student Worksheet CTD Data Collected on *Okeanos Explorer* Cruise EX1004, Leg 3

The data in the chart on page 98 are from a CTD cast made aboard the *Okeanos Explorer* on July 24, 2010, as part of the INDEX-SATAL 2010 Expedition.

1. Make a graph of salinity and depth. Put depth on the y-axis of each graph, and put zero at the TOP of the y-axis. Oceanographers like to plot CTD data with depth on the y-axis and the greatest depths at the bottom of the plot, since that is the way we usually think about a profile of the water column.
2. Make a graph of temperature and depth, with depth on the y-axis as in Step 1.
3. Make a graph of density and depth, with depth on the y-axis as in Step 1.
4. Where did density change most rapidly?
5. In general, what happens to density as depth increases?
6. How do changes in density with increasing depth differ from changes in temperature and salinity with increasing depth?
7. If an underwater robot is neutrally buoyant (that is, it does not rise or sink in the water column) at a certain depth, what will happen if the robot enters a water mass that has a lower density?
8. What will happen if the water mass has a greater density?



CTD Data Collected on *Okeanos Explorer* Cruise EX1004, Leg 3

Depth (m)	Temperature (°C)	Salinity (psu)*	Density (g/cm ³)
20	29.5	34.15	1.0213
40	28.5	34.24	1.0217
60	28.5	34.25	1.0217
80	27	34.35	1.0223
100	25.5	34.45	1.0228
125	24	34.6	1.0233
150	23.5	34.76	1.0236
175	18	34.65	1.025
200	16.5	34.6	1.0253
220	15	34.54	1.0256
320	11.5	34.4	1.0262
420	10	34.46	1.0265
520	8	34.55	1.0269
620	7	34.52	1.027
720	6	34.53	1.0272
820	5.5	34.56	1.0273
920	5	34.54	1.0273
1050	4.5	34.55	1.0274
1150	4.5	34.56	1.0274
1250	4.5	34.57	1.0274
1350	4	34.57	1.0274
1450	4	34.58	1.0275
1550	4	34.58	1.0275
1650	4	34.58	1.0275
1750	4	34.58	1.0275
1800	4	34.59	1.0275

* Salinity is measured by conductivity (how easily electricity flows through a seawater sample). The software used to process conductivity data from the *Okeanos Explorer*'s CTD converts the conductivity measurement to salinity values in practical salinity units (psu). Before psu was adopted as a standard unit, salinity was measured in parts-per-thousand (abbreviated ppt or o/oo), and you still may see references to these units, which are almost the same as psu.





Section 4: Water Column Investigations

Lesson 7: The Oceanographic Yo-yo



A conductivity/temperature/depth (CTD) sensor package. Image courtesy of NOAA Okeanos Explorer Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/july16/media/ctd.html>

Focus

CTD (conductivity, temperature, depth profiler), ocean chemistry and hydrothermal vents

Grade Level

7-8 (Physical Science)

Focus Question

How do ocean explorers aboard the *Okeanos Explorer* use chemical clues to locate hydrothermal vents in the deep ocean?

Learning Objectives

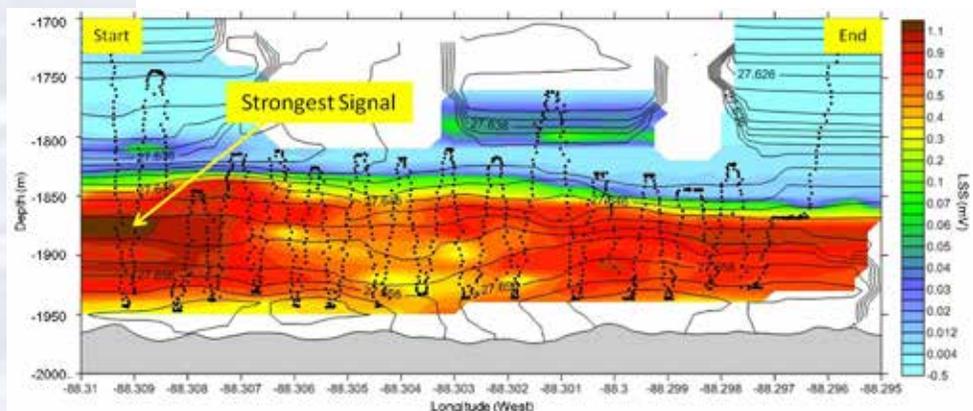
- Students will analyze and interpret data from the *Okeanos Explorer* to make inferences about the possible presence of hydrothermal vents.
- Students will explain how interaction with hydrothermal vents affects chemical and physical properties of seawater.

Materials

- One gallon of water, chilled in a refrigerator
- Vinegar; 1 tablespoon for each student group
- A heat source (microwave oven or hot plate)
- One eyedropper
- One tablespoon
- For each student group:
 - Copy of *CTD Sample Analysis Worksheet*
 - Two thermometers
 - 5 strips wide range (approximate pH 2-9) pH paper with color chart
 - Five 100ml beakers or plastic cups labeled A, B, C, D, and E

This is a plot of the data from a CTD tow. The x axis displays the longitude of the tow, the vertical axis is depth, and the shading along the tow is the Light Scattering Sensor data. The dark patch on the left (beginning of tow) is the strongest plume signal. Image courtesy of NOAA Okeanos Explorer Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow01_results_diagram_hires.jpg



Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 2)

Teaching Time

Two 45-minute class periods

Seating Arrangement

Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration

Okeanos Explorer

CTD

Conductivity

pH

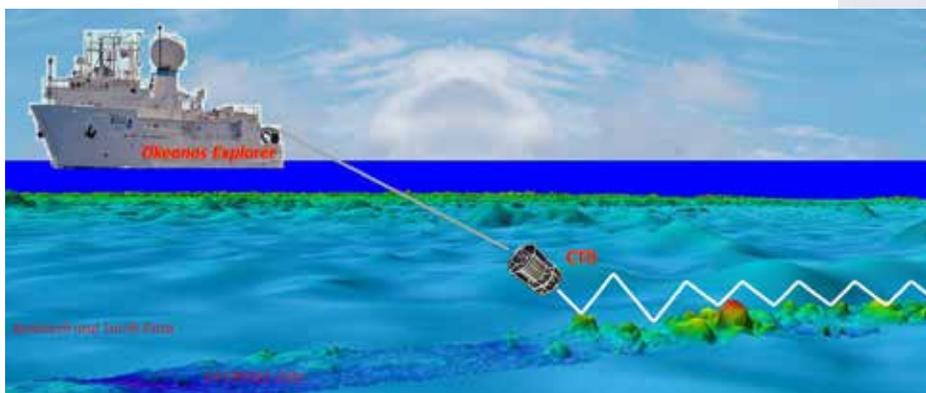
Hydrothermal vent

Plume

Background

For discussion about the exploration strategy used aboard the *Okeanos Explorer*, please see the *Introduction to Volume 2: Why Do We Explore* beginning on page 9. For background about CTD instruments, please see the *Introduction to Water Quality Investigations* on page 87.

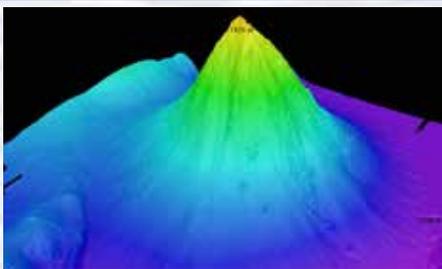
Temperature measurements from CTD sensors can be used to detect changes in water temperature that may indicate the presence of volcanoes or hydrothermal vents. Masses of seawater with unusual characteristics are called plumes, and are usually found within a few hundred meters of the ocean floor. Since underwater volcanoes and hydrothermal vents may be several thousand meters deep, ocean explorers often raise and lower a CTD rosette through several hundred meters near the bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD may resemble the movement of a yo-yo; a resemblance that has led to the nickname “tow-yo” for this type of CTD sampling.



This image demonstrates the concept of a CTD Tow-Yo. The CTD is lowered to within 20 meters of the seafloor, and then is cycled between near-bottom and 300 meters above the seafloor (like a yo-yo) as it is towed behind the ship. Sensor data is recorded and monitored continuously to look for signs that plumes from hydrothermal vents are present. Image courtesy of NOAA *Okeanos Explorer* Program.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow_yo_diagram_hires.jpg

This lesson introduces students to simple analysis of CTD data as a method for finding underwater volcanoes and hydrothermal vents.



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

Learning Procedure

1. To prepare for this lesson:

a) Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
- Background information on CTD technology at <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html>

(b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.

(c) If students are not familiar with deep-sea chemosynthetic communities, you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (<http://oceanexplorer.noaa.gov/edu/learning/welcome.html>), and/or information from <http://www.pmel.noaa.gov/vents/nemo/explorer.html>.

(d) Review procedures for the simulated analysis of CTD samples (Step 4).

Prepare materials for this activity:

- 1) Chill one gallon of water overnight in a refrigerator.
- 2) For each group of four students, fill five 100ml beakers with chilled water and label each with an A, B, C, D and E.
- 3) Heat the water in all beakers labeled D for 60 seconds in the microwave oven about 15 minutes before the start of class. The water should be above 50°C, but not boiling.
- 4) Add 3 drops of vinegar to all beakers labeled C and E and stir.
- 5) Add one tablespoon of vinegar to all beakers labeled D and stir.

(e) If desired, download images referenced in Step 2.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

Show an image of a CTD, and explain that this is actually a collection of several electronic instruments that measure various things about seawater. The basic instruments measure temperature, depth, and conductivity. Most of the device

seen in the image is a water sampling device called a rosette or carousel, that contains water sampling bottles that are used to collect water at different depths. Before the rosette is lowered into the ocean, the bottles are opened so that water flows freely through them. As the rosette travels through the water column, scientists can monitor readings from the CTD sensors. If something unusual appears in the measurements, the scientists can send a signal through the CTD cable that closes one or more of the bottles to collect a water sample from the location where the unusual measurements appeared.

If students are not familiar with deep-sea chemosynthetic communities, briefly describe the concept of chemosynthesis, and contrast it with photosynthesis. Tell students that chemosynthetic ecosystems in the deep ocean are found where a source of chemical energy is emerging from the ocean floor. If you have decided to use materials referenced in Step 1c, present these now. Tell students that a major objective of the INDEX-SATAL 2010 Expedition was to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts associated with active geologic processes in Indonesia's deep sea.

3. Discuss some of the clues that might result from the interaction of hydrothermal vents with seawater. Increased temperature is fairly obvious, since heat from Earth's core is the energy source that causes vents to form. Temperatures of hydrothermal fluids may be more than 300°C, since the high pressure of deep-sea environments prevents water from boiling. Fluids from hydrothermal vents are often highly acidic, in contrast to normal seawater which is slightly basic; so pH is another potential clue. You may need to explain that pH is a measure of the concentration of hydrogen ions. For a more detailed discussion about pH, please see the lesson, *Why Do We Explore?* (<http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09whydoweexplore.pdf>). Hydrogen sulfide is often found in hydrothermal vent fluids, but is not normally found in seawater. So a chemical analysis that indicates its presence in a seawater sample would be another clue that signals vents may be nearby.
4. The following activity simulates an analysis of water samples collected by a CTD. Tell students that their assignment is to analyze several samples collected by a CTD to determine whether any of the samples suggest that they might have been collected from a location near a hydrothermal vent. Demonstrate the correct way to measure pH with a pH strip if students are not already familiar with this procedure.

Provide each student group with two thermometers, 5 strips of pH paper, a pH color indicator chart, a *CTD Sample Analysis Worksheet*, and samples A, B, C, D and E. Tell students to make measurements needed to complete the worksheet on page 108 and to plot the CTD data on the graphs provided on pages 109-110.

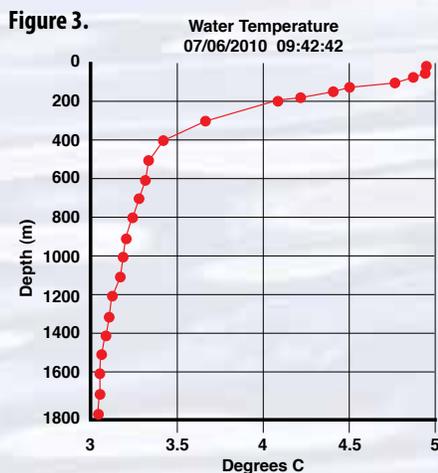
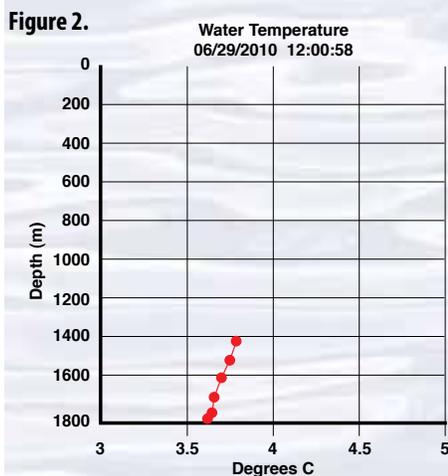
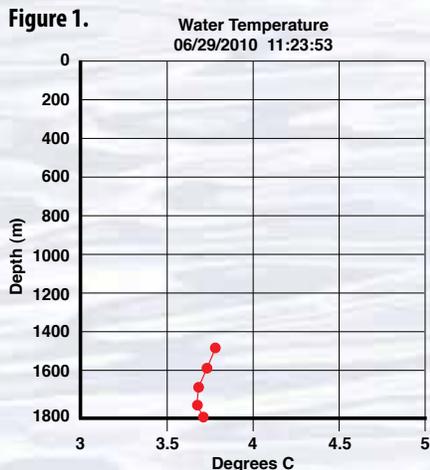
Be sure students understand that the grids provided for their graphs have zero at the TOP of the y-axis. This is because oceanographers like to plot CTD data with depth on the y-axis and the greatest depths at the bottom of the plot, since that is the way we usually think about a profile of the water column.

5. Discuss students' results. Students should infer that sample D may have been collected in the vicinity of a hydrothermal vent, since its temperature is noticeably higher than that of the other samples, and its pH is noticeably lower. Ask students



A closeup of a CTD, the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD, which is housed in the steel container in the center of the rosette. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.

http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_closeup_hires.jpg



Note: Graphs of temperature and other CTD data collected during *Okeanos Explorer* cruises in 2010.

what other measurements might be made to support this inference. These might include chemical analysis to detect the presence of substances associated with hydrothermal vents, such as hydrogen sulfide.

Students' graphs of CTD data should resemble Figures 1, 2, and 3. Students should recognize that Figure 1 is different from the others, in that water temperature increases near the bottom (even a small increase is significant). Since this is not what would ordinarily be expected, it is an anomaly! In fact, this CTD cast was made in the vicinity of an active hydrothermal vent. The next day, *Okeanos Explorer's* ROV *Little Hercules* visited the site and found an active hydrothermal vent "surrounded by yellow and black molten sulfur, multiple species of hot-vent shrimp, a 10 cm scale worm, and a small patch of stalked barnacles. After departing from the vent, the ROV ascended the summit ridge and encountered fields of sulfide chimneys with vast aggregations of stalked barnacles at their base. The chimneys varied in terms of age and venting characteristics. Some chimneys were fairly oxidized and others covered in white sulfide. Some chimneys were venting clear fluid while others were venting black smoke." You can read more about the site, and see images from *Little Hercules* here: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html>.

Point out that this is an excellent example of the interdependence of science, engineering, and technology. The instrument technologies produced by engineering made it possible to make measurements that detected an anomaly. Other technologies made it possible to investigate the anomaly and provide scientific data from a new hydrothermal vent site.

- Discussion of CTD technology may also include the following components of technological literacy (ITEA, 2007):
 - **Scope of technology** – Development of CTD instrumentation allows many chemical and physical characteristics to be measured in the ocean, some of which could not be measured in deep water before this technology was created.
 - **Core concepts of technology** – A CTD is an example of several technological systems connected together; including different systems to measure various chemical and physical characteristics of seawater, and equipment for collecting water samples from very deep areas in Earth's ocean.
 - **Relationships between technologies and other fields of study** – Improvements to each of the technologies listed above improves the overall capability of water column investigations; and this information is useful to geologists, biologists, and many other branches of science.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics" in the menu on the left side of the page, then "Habitats" then select "Deep Sea" for activities and links about deep-ocean ecosystems.

The "Me" Connection

Have students read the daily log entry for July 29, 2010 from the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html>), and write a brief essay discussing whose job they would like to have if they were personally aboard the ship.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Class discussions and students' work with the charting activity provide opportunities for assessment.

Extensions

Visit the Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 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

And Now for Something Completely Different...

(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf

Focus: Biological communities at hydrothermal vents (Grades 5-6; Life Science)

Students 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.

A Hydrothermal AdVENTure

(from the INSPIRE: Chile Margin 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/ahydrothermal.pdf>

Focus: Hydrothermal vents (Grades 5-6; Earth Science)

Students explain the overall structure of hydrothermal vents and how they are related to the motion of tectonic plates, and create a model of a hydrothermal vent.

The Volcano Factory

(from the 2004 Submarine Ring of Fire expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF_volcanism.pdf

Focus: Volcanism on the Mariana Arc (Grades 5-6; Earth Science)

Students explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench, and explain why the Mariana Arc is one of the most volcanically active regions on Earth.



Unexplored!

(from the New Zealand American Submarine Ring of Fire 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf

Focus: Scientific exploration of deep-sea volcanoes (Grades 5-6; Life Science/Physical Science/Earth Science)

Students compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Living With the Heat

(from the Submarine Ring of Fire 2006 Expedition)

<http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf>

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Grades 5-6; Life Science/Earth Science)

Students 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 among organisms typically found in hydrothermal vent communities.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

oceaneducation@noaa.gov

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CTD Sample Analysis Worksheet

Group Name: _____

Sample	Temperature	pH
A	_____	_____
B	_____	_____
C	_____	_____
D	_____	_____
E	_____	_____

1. Do the data in the table above suggest that any of these samples might have been collected near a hydrothermal vent?

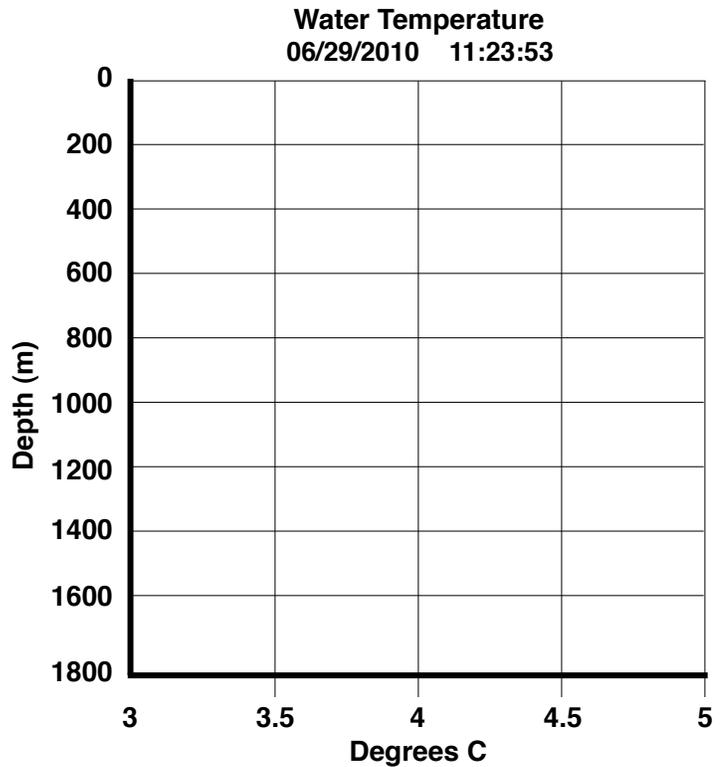
2. How do your data support this inference?



3. Here are some data from CTD casts made aboard the *Okeanos Explorer* during the INDEX-SATAL 2010 Expedition (these are just a few of the data points provided by the CTD instruments; the complete data sets contain thousands of points!). Plot these points on the grids. Do any of your graphs show any possible anomalies?

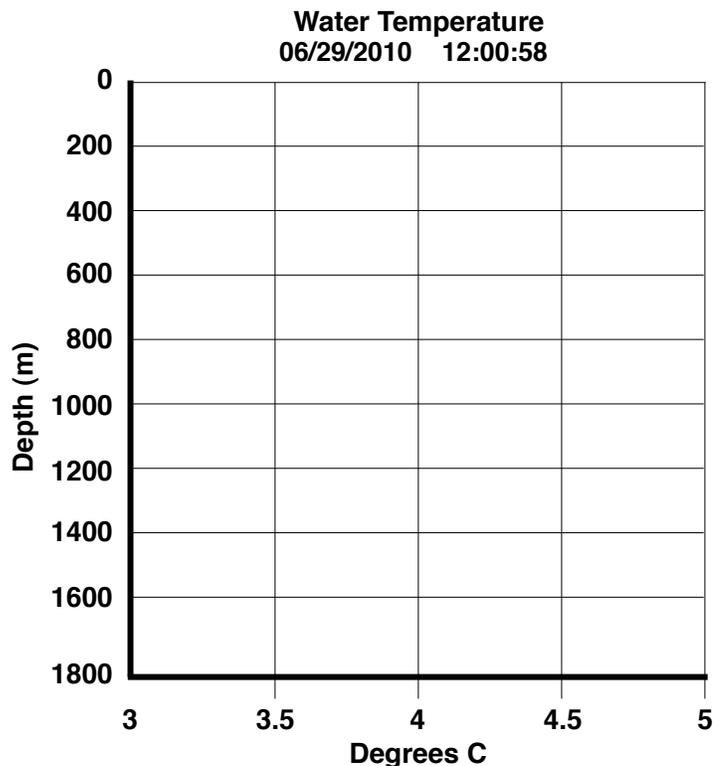
CTD Cast 06/29/2010 11:23:53

Depth (m)	Water Temperature (°C)
1450	3.8
1600	3.75
1680	3.6
1750	3.6
1800	3.7



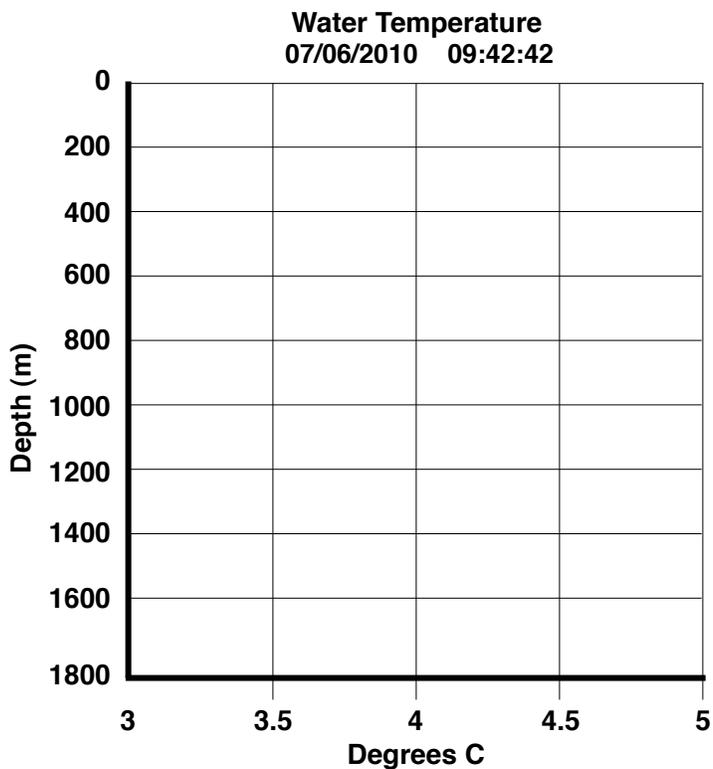
CTD Cast 06/29/2010 12:00:58

Depth (m)	Water Temperature (°C)
1400	3.8
1500	3.75
1600	3.7
1700	3.67
1750	3.65
1800	3.6



CTD Cast 07/06/2010 09:42:42

Depth (m)	Water Temperature (°C)
10	4.95
50	4.9
80	4.85
100	4.8
150	4.5
175	4.4
190	4.2
200	4.1
300	3.7
400	3.4
500	3.35
600	3.32
700	3.30
800	3.25
900	3.20
1000	3.175
1100	3.16
1200	3.15
1300	3.12
1400	3.10
1500	3.08
1600	3.07
1700	3.06
1800	3.05





Section 4: Water Column Investigations

Lesson 8: A Quest for Anomalies

Focus

CTD (conductivity, temperature, depth profiler)

Grade Level

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

Focus Question

How is a CTD used aboard the *Okeanos Explorer* to help explore Earth's deep ocean?

Learning Objectives

- Students will explain how properties of redox potential and optical backscatter are related to deep-sea ecosystems and geologic features.
- Students will analyze and interpret data from the *Okeanos Explorer* to detect potential anomalies.

Materials

- Copies of *Introduction to CTD Data Worksheet*; one copy for each student or student group

Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 2)

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

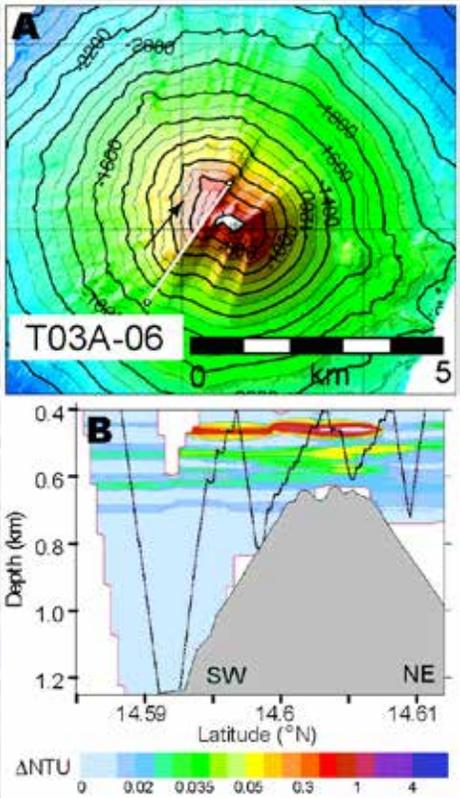
Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
 CTD
 Oxidation-reduction potential (ORP)
 Optical backscatter (OBS)
 Plume



These images represent aspects of a towed hydrocast (tow-yo) at NW Rota-1 submarine volcano, located at 14° 36' N. The tow-yo was performed February 12, 2003. A) The bathymetric map shows (in white) the tow line of the hydrocast. B) The hydrothermal plume above the volcano shown as delineated by optical backscatter. The black saw-tooth pattern is the track of the CTD-rosette package as it passed over the volcano. The stair-step features in the track are the locations where samples were taken. ΔNTU= nepelometric turbidity units above ambient seawater.
http://oceanexplorer.noaa.gov/explorations/06fire/background/hirez/nwrota1_tow_hires.jpg



Background

For discussion about the exploration strategy used aboard the *Okeanos Explorer*, please see the *Introduction to Volume 2: How Do We Explore?* beginning on page 9. For background about CTD instruments, please see the *Introduction to Water Column Investigations* on page 87.

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. The presence of thriving biological communities in the deep ocean was a complete surprise, because it had been assumed that food energy resources would be scarce in an environment without sunlight to support photosynthesis. Researchers soon discovered that the organisms responsible for this biological abundance do not need photosynthesis, but instead are able to obtain energy from chemical reactions through processes known as chemosynthesis. Photosynthesis and chemosynthesis both require a source of energy that is transferred through a series of chemical reactions into organic molecules that living organisms may use as food. In photosynthesis, light provides this energy. In chemosynthesis, the energy comes from other chemical reactions. Energy for chemosynthesis in the vicinity of hydrothermal vents often comes from hydrogen sulfide.



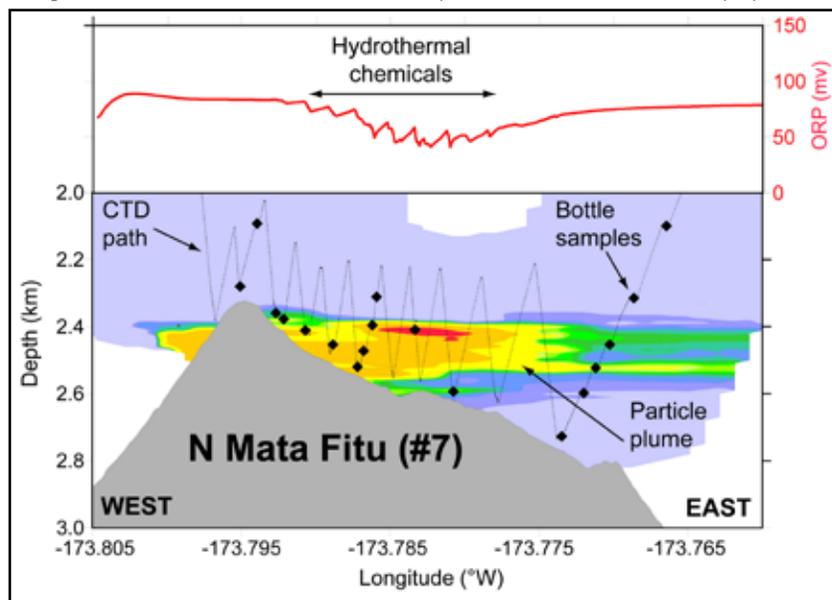
Image of hydrothermal vents found during the second ROV dive on the Kawio Barat volcano. The yellow deposits are molten sulfur. Multiple species of hot-vent shrimp are also visible. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june30_update_hires.jpg

In chemosynthesis, energy from chemical reactions is captured and stored in other molecules. This energy moves from one molecule to another when electrons are transferred between the molecules. These transfers take place in a series of reactions called an electron transport chain. The electron transport chain begins with the loss of an electron from a substance such as hydrogen sulfide or methane. This electron is captured by an organic molecule, which releases an electron to a second organic molecule, and the process continues through several other molecules. Each time an electron is transferred, the molecule that gains the electron also gains energy; and the molecule that loses the electron loses energy. The last molecule in the chain keeps the electron, and has a higher energy content than before it received the electron. Some energy is lost each time an electron moves from one molecule to another. The energy captured by the electron transport chain is used by chemosynthetic organisms to convert carbon dioxide into molecules that can serve as energy sources (food) for living organisms.

When an atom or molecule loses an electron it is said to be oxidized, and when an atom or molecule gains an electron it is said to be reduced. A reducing substance is a substance that causes another substance to be reduced; in other words, a reducing substance donates electrons. Similarly, an oxidizing substance is a substance that causes another substance to be oxidized; that is, an oxidizing substance receives electrons. A reaction in which one or more electrons are transferred between two molecules is called a redox reaction. Note that the terms oxidation, reduction, and redox may also be used in slightly different ways for some types of chemistry, but these distinctions are not important for this discussion. Chemosynthesis depends upon the availability of reducing substances such as hydrogen sulfide or methane that can donate electrons. Habitats in which these substances occur are called reducing habitats.

Hydrothermal vents and chemosynthetic communities are often associated with changes in the chemical properties of seawater. To look for these changes, ocean explorers use an instrument known as a CTD, which stands for conductivity, temperature, and depth. A CTD is a package of electronic instruments that measure these properties. Conductivity is a measure of how well a solution conducts electricity and is directly related to salinity, which is the concentration of salt and other inorganic compounds in seawater. Salinity is one of the most basic measurements used by ocean scientists. When combined with temperature data, salinity measurements can be used to determine seawater density, which is a primary driving force for major ocean currents. Often, CTDs are attached to a much larger metal frame called a rosette, which may hold water sampling bottles that are used to collect water at different depths, as well as other sensors that can measure additional physical or chemical properties.

CTD measurements provide evidence of volcanoes, hydrothermal vents, and other deep-sea features that cause changes to the physical and chemical properties of seawater. Masses of seawater with unusual characteristics are called plumes, and are usually found within a few hundred meters of the ocean floor. Since underwater volcanoes and hydrothermal vents may be several thousand meters deep, ocean explorers often raise and lower a CTD rosette through several hundred meters near the bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD may resemble the movement of a yo-yo; a



Results from a CTD tow-yo over Mata Fitu in 2010. The bottom panel shows the CTD path over the volcano profile. Light-scattering values define the plume; red colors are the highest particle concentrations, blue colors are the lowest concentrations. The top panel shows the change in oxidation-reduction potential (ORP) values during the tow. Higher chemical concentrations are denoted by negative deflections in the ORP value. Image courtesy of NOAA Vents Program.

http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_results_hires.jpg

resemblance that has led to the nickname “tow-yo” for this type of CTD sampling.

See http://oceanexplorer.noaa.gov/technology/tools/sonde_ctd/sondectd.html and <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html> for more information.

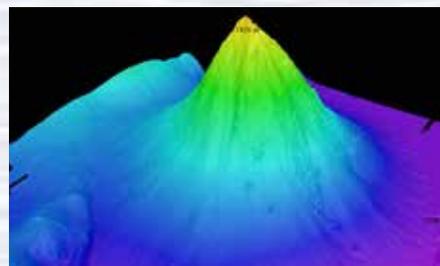
Temperature measurements from CTD sensors can be used to detect water temperature anomalies that may indicate the presence of volcanoes or hydrothermal vents. Two other sensors are also important to the search for these deep-ocean features. Optical backscatter (OBS) sensors detect the presence of suspended particles that may come from hydrothermal vents or from the oxidation of methane, which causes precipitates of carbonate material to form. Oxidation-reduction potential (ORP) sensors measure the tendency of a substance to gain or lose electrons. ORP is measured in volts, and increases directly with the tendency of a substance to gain electrons and become reduced. Because chemosynthetic communities are based on chemical substances that can donate electrons, these chemical substances have a tendency to lose electrons. So a drop in ORP may signal the presence of chemosynthetic communities nearby.

This lesson introduces students to simple analysis of CTD data. In the future, students will have the opportunity to apply their analytic skills to investigate additional information from CTDs as the *Okeanos Explorer* continues its voyages of discovery in Earth’s deep ocean.

Learning Procedure

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions on the student worksheet.

1. To prepare for this lesson:
 - a) Review:
 - Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
 - Background information on CTD technology at <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html>
 - (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
 - (c) Review questions on the *Introduction to CTD Data Worksheet*.
 - (d) Download the data file **EX0904_ctd_1.xls** from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/ex0904_ctd_1.xls, and install it on computers that students will be using to complete the *Worksheet* activity. Alternatively, you may have students download this file onto their own computer systems. Students will also need access to Microsoft Excel™ to complete this activity.
 - (e) If desired, download images referenced in Step 2.
2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth’s Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
 - The overall strategy is based on finding anomalies;



Okeanos Explorer’s EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI’s Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg



- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the sidebar on page 112 to accompany this review.

Plot showing light scattering (dNTU) sensor and oxygen reduction potential (ORP) data, versus time, acquired by the CTD/rosette as it passed through a plume over the top of Kawio Barat volcano. There was an intense particle anomaly and ORP decrease in the bottom 30 meters of the water column when the plume was encountered. A drop in the ORP, like you see here, means that there are more electron donor compounds in the water produced by enrichment of seawater in dissolved metals and chemicals billowing out of hydrothermal vents. The ORP values begin to increase again, recovering slowly, when the CTD leaves the plume. Image courtesy of Sharon Walker, PMEL.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/kawio_barat_hires.jpg

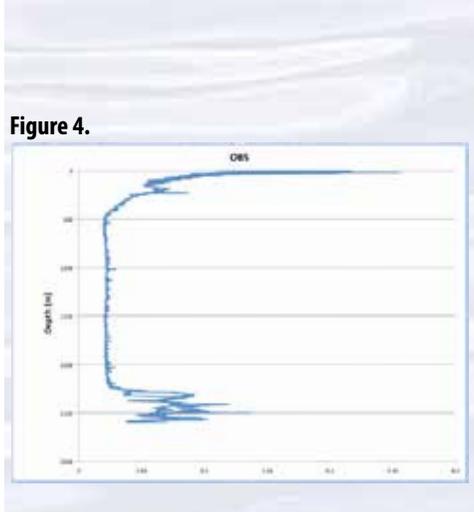
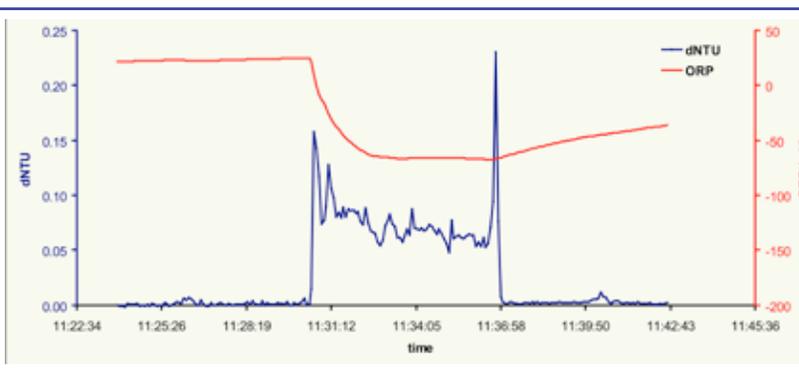


Figure 4.

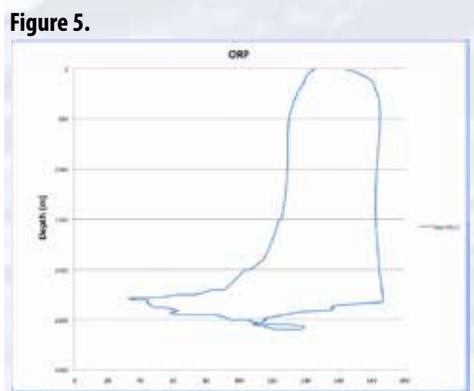


Figure 5.

3. Ask students why oceanographers would want to measure conductivity, temperature, and depth. Be sure students understand the relationship between conductivity and salinity. Briefly describe a CTD, emphasizing that these devices are often capable of measuring many other parameters in addition to conductivity, temperature, and depth. You may want to use information and/or images from the site referenced in Step 1a. Discuss how OBS and ORP may be affected by hydrothermal vent activity.
4. Tell students that their assignment is to look for anomalies in CTD data collected aboard the *Okeanos Explorer* in 2009. Provide each student group with a copy of the *Introduction to CTD Data Worksheet*, and ensure that students have access to the file referenced in Step 1d. Tell students that this activity is intended to familiarize them with CTD data and how they can be analyzed to find anomalies that may indicate the presence of undiscovered features on the ocean floor. You may also want to mention that this skill will enable them to investigate additional data that will be available from future *Okeanos Explorer* missions.
5. When students have answered questions on the *Worksheet*, lead a discussion of their results. This discussion should include:
 - The time required to complete the entire CTD cast was 7,160 seconds; just under two hours.
 - The maximum depth recorded by the CTD was 2601.255 meters.
 - Students should notice that the maximum depth occurred about half-way through the cast; this is because data were recorded during the CTD's ascent (the "up cast"), as well as during its descent (the "down cast").
 - Students' plots of OBS and ORP should resemble Figures 4 and 5 respectively.

- Plots of OBS and ORP both show anomalies between depths of 2,000 and 2,500 meters; increased OBS due to precipitates or particulate material and a reduction in ORP are both indicative of plumes from hydrothermal vents.
- Two lines on the ORP plot represent data collected during the downcast and upcast; the numbers are different, in part, because the sensor that measures ORP continues to be affected by reducing substances for a period of time after it leaves the plume.
- OBS and ORP sensors are technologies produced by engineering that, in this case, made it possible to detect anomalies that led to the scientific discovery of a new hydrothermal vent site.

During the INDEX-SATAL 2010 Expedition, CTD data collected in late June showed anomalies that suggested the possible presence of hydrothermal vents nearby. On June 30, 2010, *Okeanos Explorer's* ROV *Little Hercules* visited the site and found an active hydrothermal vent “surrounded by yellow and black molten sulfur, multiple species of hot-vent shrimp, a 10 cm scale worm, and a small patch of stalked barnacles. After departing from the vent, the ROV ascended the summit ridge and encountered fields of sulfide chimneys with vast aggregations of stalked barnacles at their base. The chimneys varied in terms of age and venting characteristics. Some chimneys were fairly oxidized and others covered in white sulfide. Some chimneys were venting clear fluid while others were venting black smoke.” You can read more about the site, and see images from *Little Hercules* here: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html>.

6. Discussion of CTD technology may also include the following components of technological literacy (ITEA, 2007):
- **Scope of technology** – Development of CTD technology is the result of specific, goal-directed research.
 - **Relationships between technologies and other fields of study**– Progress in the development of CTD technology is closely linked to advancements in science and mathematics.
 - **Effects of technology on the environment** – CTD sonar technology provides an effective way to monitor and explore the deep-ocean environment to provide information for decision-making.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Habitats” then select “Deep Sea” for activities and links about deep-ocean ecosystems.

The “Me” Connection

Have students write a short essay discussing how discovering a deep-ocean anomaly might turn out to be of personal benefit.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Students’ answers to *Worksheet* questions and class discussions provide opportunities for assessment.





Extensions

Visit the Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 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

Chemosynthesis in the Classroom

(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 (Grades 9-12; Chemistry/Biology)

Students observe the development of chemosynthetic bacterial communities; recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive; and explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Hydrothermal Vent Challenge

(from the Submarine Ring of Fire 2004 Expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF_ventball.pdf

Focus: Chemistry of hydrothermal vents (Grades 9-12; Chemistry)

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

Thar She Blows!

(from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_13.pdf

Focus: Hydrothermal vents (Grades 9-12; Chemistry/Biology)

Students demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor, and demonstrate an understanding of how the transfer of energy effects solids and liquids.

This Life Stinks

(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 (Grades 9-12; Chemistry/Biology)

Students define the process of chemosynthesis; contrast this process with photosynthesis; explain the process of methane-based chemosynthesis; and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.



The Tell-Tale Plume

(from the INSPIRE: Chile Margin 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf>

Focus: Hydrothermal Vent Chemistry (Grades 9-12; Chemistry/Biology)

Students describe hydrothermal vents; identify changes that they cause to the physical and chemical properties of seawater; and use oceanographic data to recognize a probable plume from hydrothermal activity.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

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Acknowledgments

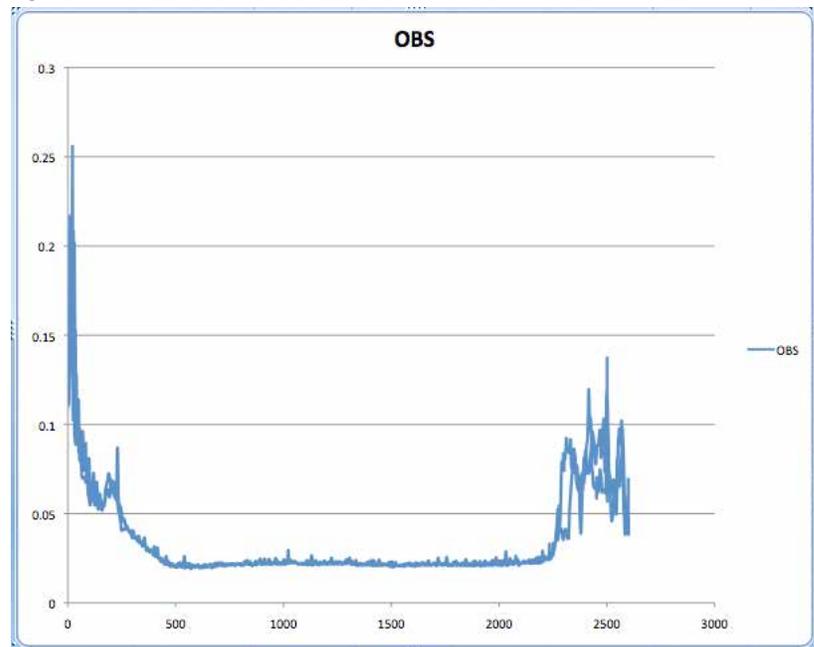
Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov>

Introduction to CTD Data Worksheet

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions on the student worksheet.

1. Open the **ex0904_ctd_1.xls** file in Microsoft Excel®. These data were collected during a CTD cast aboard the *Okeanos Explorer*. The first row shows the contents of each column: Date and time; Latitude in decimal degrees; Longitude in decimal degrees; Elapsed time since the start of the cast in seconds; Depth in meters; Temperature in °C; Conductivity in Siemens per meter; Salinity in Practical Salinity Units; Optical Backscatter (OBS); and Oxidation-Reduction Potential (ORP). The units of OBS and ORP aren't really important, because we are only concerned with finding readings that are distinctly different from other readings near the same depth (anomalies).
2. How much time was needed to complete the entire CTD cast?
3. What was the maximum depth recorded by the CTD?
4. Plot OBS as a function of Depth:
 - a. Select the Depth and OBS columns.
 - b. Under the "Insert" menu select "Chart..." A pop-up menu will appear.
 - c. In the popup menu, click on the "XY (Scatter)" tab.
 - d. Click on the "Smoothed Line Scatter" button. Now you should have a graph that resembles Figure 1.

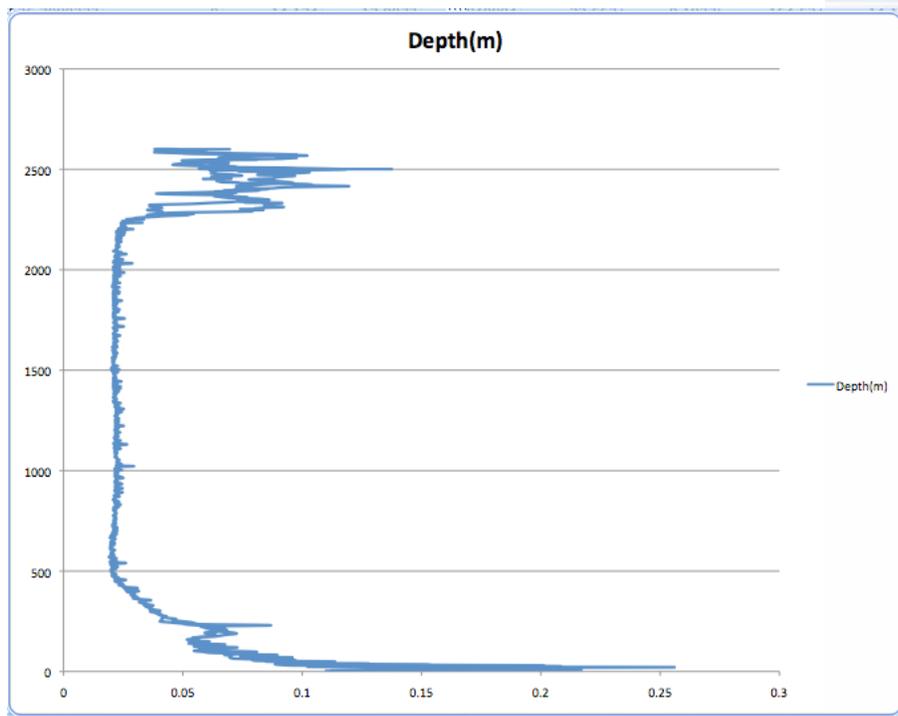
Figure 1.



5. Oceanographers like to plot CTD data with depth on the y-axis and the greatest depths at the bottom of the plot, since that is the way we usually think about a profile of the water column. For an x-y plot, Excel plots the first column on the x-axis. So, to make an "oceanographer's plot" we need to re-arrange the data so that temperature values come before depth values.
 - a. Select the OBS column and the Depth column to the RIGHT of the Temperature column.

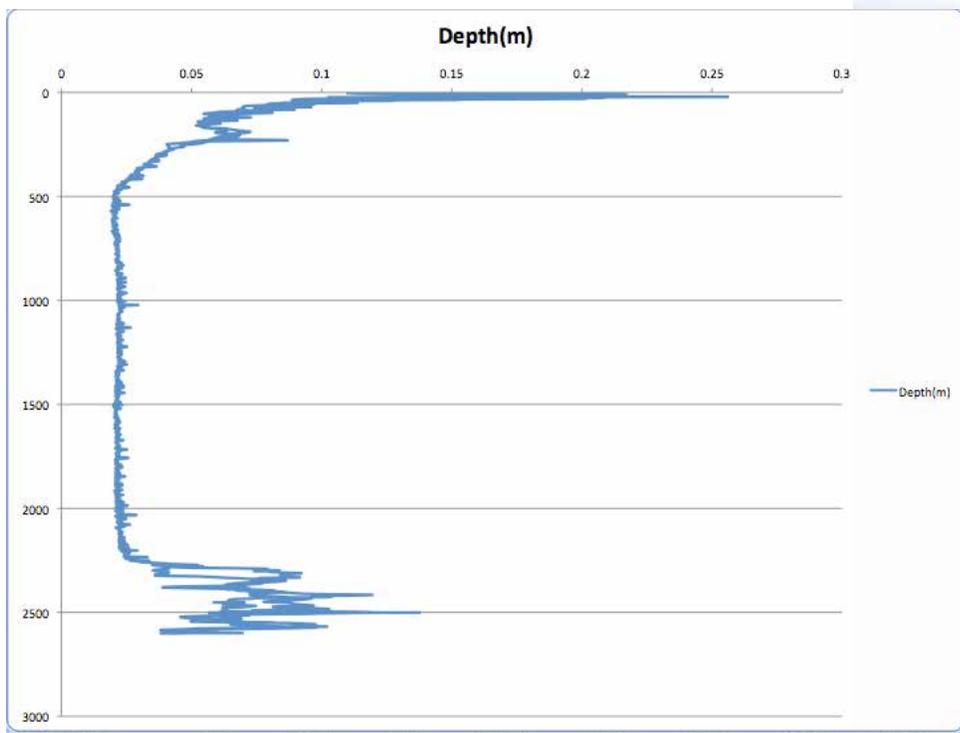
b. Click on the “Smoothed Line Scatter” button (the “XY (Scatter)” tab should still be selected). Now you should have a graph that resembles Figure 2.

Figure 2.



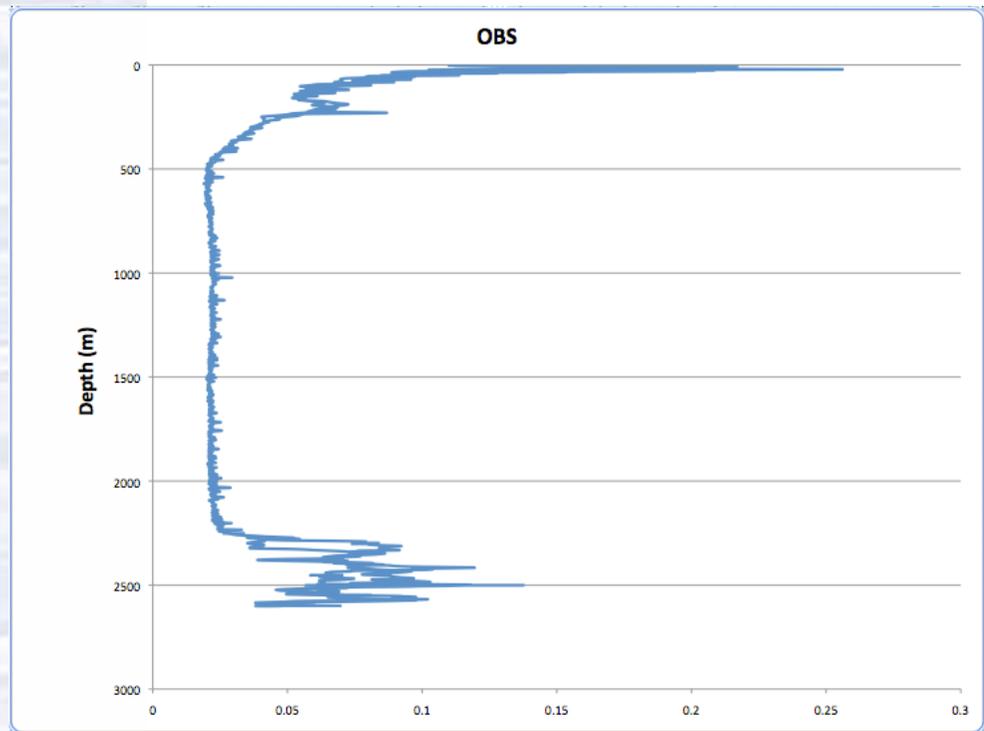
c. To make the greatest depths appear at the bottom of the plot, double click on the y-axis. The “Format Axis” window will appear. Click the “Scale” button on the left side of the window, then check the “Values in Reverse Order” box, then click “OK.” Now your graph should resemble Figure 3.

Figure 3.



- d. We need to make four more changes. First, the x-axis is now at the top of the plot. To fix that, double click the y-axis again and check the “Horizontal (category) axis crosses at maximum value” box. Then click “OK.” Next, the title of the graph needs changing: Click on the title, then highlight the text. Type in “OBS.” Now remove the legend on the right side of the graph by clicking on the legend and hitting the “Delete” key. Finally, let’s add a label to the y-axis: Click inside the plot area, then drag one of the handles on the left side of the plot toward the center to make space for a label. Make the “Drawing” toolbar visible (select from “Toolbars” in the “View” menu), and select the text tool. Click on the left side of the plot and type “Depth (m).” Format the text with tools in the Formatting toolbar (select from “Toolbars” in the “View” menu), then drag the green handle on the text box to rotate the text 90 degrees. Right-click (control click on a Macintosh platform) and drag the text box to the desired location. Now your graph should resemble Figure 4.

Figure 4.



6. Repeat the procedures in Steps 4 and 5 to make an “oceanographer’s plot” of ORP as a function of Depth.
7. Do either of your plots show any anomalies? Why does the ORP plot appear to have two lines?
8. What is the relationship between OBS, ORP, and hydrothermal vents?



Section 5: Underwater Robots

Introduction to Underwater Robots

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see Lesson 1, *To Explore Strange New Worlds*). These are unoccupied robots usually linked to a surface ship by a group of cables. Most ROVs 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, equipment for collecting samples, and measuring instruments to expand the vehicle's capabilities for gathering data about the deep-ocean environment.

For her maiden voyage during the INDEX-SATAL 2010 Expedition, the NOAA Ship *Okeanos Explorer* carried *Little Hercules*, an ROV originally developed by a team of engineers at Dr. Robert Ballard's Institute for Exploration (IFE) at the University of Rhode Island for the primary purpose of gathering high quality video imagery. Nicknamed "*Little Herc*," the ROV proved to be well-suited to this purpose on

a variety of successful missions for IFE, including providing the first and only images of John Kennedy's PT Boat, *PT-109*. Eventually, a much larger ROV named "*Hercules*" took over these tasks, and *Little Herc* became part of an exhibit at the Mystic Aquarium. This shore duty came to an end, however, when it became clear that *Okeanos Explorer*'s primary ROV would not be ready in time for the INDEX-SATAL 2010 Expedition. Through a collaboration between IFE and NOAA's Office of Ocean Exploration and Research, *Little Herc* was brought out of retirement and refitted specifically to meet the expedition's needs.

Little Herc is operated in tandem with a camera platform that carries 2,400 watts of lighting provided by HMI (hydrargyrum medium-arc iodide) arc lamps. This lighting illuminates the total darkness of the deep ocean, helps guide *Little Hercules*, and provides lighting for the high-definition video images of the ROV at work. The camera platform is named *Seirios*, after the name of the brightest star in the night sky (also called the Dog Star, sometimes spelled "*Sirius*"). *Little Herc* is attached

Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

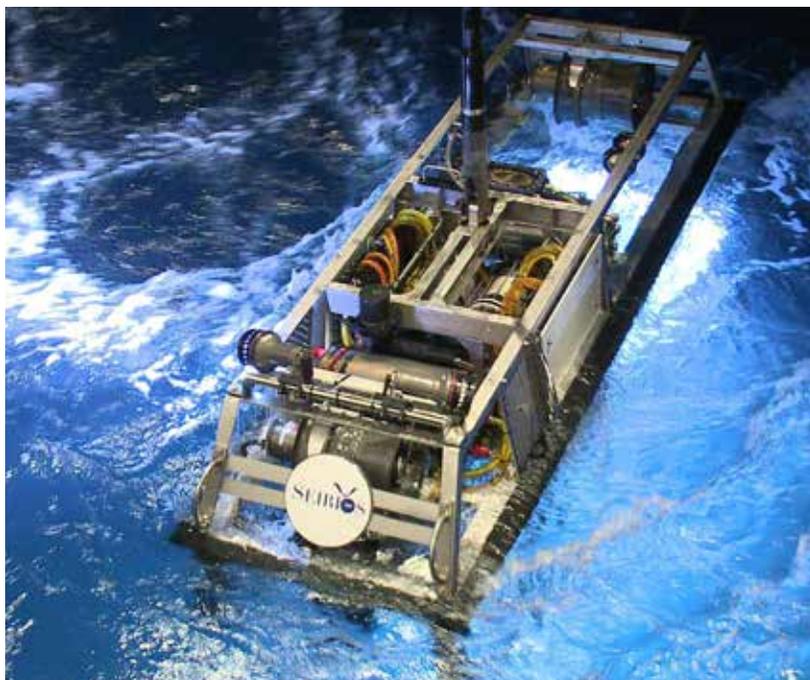
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



to *Seirios* by a 30-m cable called the Remotely Operated Vehicle Tether, while the camera platform is attached to the *Okeanos Explorer's* traction winch by a 17 mm Oceanographic Instrumentation and Control Cable which has an armored outer jacket with 3 power conductors and 3 optical fibers for transmitting data and control signals.

A variety of sensors are aboard the ROV for navigation and data collection. These include depth and altitude sensors, an Ultra Short Baseline Tracking System, full color imaging sonar, and a Seabird SBE 49 FastCAT CTD. Video equipment includes two Insite Pacific single CCD (charge-coupled device) high-resolution miniature color video cameras, one Insite Pacific triple CCD high-definition Zeus Plus video camera, two Deep Sea Power and Light 250-watt LED matrix lights, and two Deep Sea Power and Light 400-watt HMI arc lamps. For additional details about *Little Herc*, see the sidebar, The *Little Hercules* Remotely Operated Vehicle. For more information about other ROVs, visit <http://oceanexplorer.noaa.gov/technology/subs/subs.html>.

Lessons in this section introduce students to remotely operated vehicles and video imagery as they are used for ocean exploration aboard the *Okeanos Explorer*. Additional video imagery from other *Okeanos Explorer* voyages of discovery can be accessed from the *Okeanos Explorer* Web site (http://oceanexplorer.noaa.gov/okeanos/media/exstream/exstream_playlist.html).



The *Seirios* camera sled returns to the surface following a great day of work. Image courtesy of NOAA *Okeanos Explorer* Program, Galapagos Rift Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/july22_update3_hires.jpg

The *Little Hercules* Remotely Operated Vehicle

Little Hercules was developed by a team of engineers at Dr. Robert Ballard's Institute for Exploration (IFE) at the University of Rhode Island. Its primary purpose is to gather high quality video imagery in support of scientific research and ocean exploration. Major systems include:

- **Power** – 2,800 volts (AC) supplied from the surface; stepped down to 120 VAC by a transformer aboard *Little Herc*
- **Propulsion** – Four Technadyne 1020 electric thrusters; two oriented horizontally to provide forward, backward, and rotational motion, and two mounted to form a V when viewed from the front which provides up, down, and lateral movement
- **Onboard Control** – PC104 computer
- **Imaging** – Main Camera: One Insite Pacific triple CCD high-definition Zeus Plus HDTV camera with zoom and macro; Utility Cameras: Two Insite Pacific single CCD high-resolution miniature color video cameras
- **Lighting** – Two Deep Sea Power and Light 250-watt-equivalent LED matrix lights; Two Deep Sea Power and Light 400-watt HMI arc lamps
- **Navigation** – Ultrashort Baseline acoustic transponder (works in concert with ship-based system that calculates the ROV's underwater position)
- **Sensors** – Paroscientific 8B7000 pressure/depth sensor; Seabird SBE 49 FastCAT CTD; Trittech PA500 altimeter; Trittech Super Seaking scanning sonar

These components are integrated within an aluminum frame that is supported in water by a flotation package of syntactic foam, which provides slightly positive buoyancy that is trimmed to neutral by the ROV's vertical thrusters. Most electronics are contained in a 10-inch diameter titanium pressure housing. The ROV is rated to a depth of 4,000 meters, and in air weighs 1,200 pounds.

Little Hercules is operated in tandem with a camera platform named *Seirios* that is equipped with a HD video camera identical to that on the ROV, as well as six HMI (hydrargyrum medium-arc iodide) arc lamps that provide a total of 2,400 watts of lighting. *Seirios* has no buoyancy module, and is intentionally much heavier than water to provide a buffer between the ROV and surface motion of the ship. *Little Hercules* is attached to *Seirios* by a 30-m cable called the Remotely Operated Vehicle Tether. *Seirios* is attached to the *Okeanos Explorer's* traction winch by a 17 mm Oceanographic Instrumentation and Control Cable which has an armored outer jacket with 3 power conductors and 3 optical fibers for transmitting data and control signals. A traction winch has large diameter grooved drums that are designed to protect cables from excessive friction and bending under heavy load conditions.

Prior to every dive, the ROV crew reviews multibeam sonar maps of the proposed dive area, and develops a track-line that is the initial path that the ROV will follow. During a dive, the ROV pilots may modify the track-line as they receive requests from scientists aboard the ship and in Exploration Command Centers to obtain video images of certain features and organisms that the ROV encounters during its exploration.



Section 5: Underwater Robots

Lesson 9: Invent a Robot!



The Team tested the *Little Hercules* marker release mechanism in the ROV Hanger. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr4-3-hires.jpg>

Focus

Engineering design

Grade Level

5-6 (Physical Science/Technology)

Focus Question

How can scientists design and build robotic arms that are capable of specific movements?

Learning Objectives

- Students will explain how underwater robots are used in scientific exploration to gather data and help answer questions about the natural world.
- Students will design and optimize potential solutions for an ocean exploration problem.

Materials

For each student group:

- Copy of *Student Worksheet*
- Five pieces of cardboard or heavy poster board, each approximately 12" x 12" (the stiffer the better)
- Duct tape, approximately 2" x 80'
- 10 - Machine screws with nuts, #8 x 1"
- 4 - Machine screws with nuts, #8 x 3"
- 21 - Flat washers, #8 hole
- 4 - Oral syringes
- Two pieces of plastic tubing, approximately 3/16" inside diameter; each approximately 12" long (should fit snugly over the end of the syringes)
- Water
- Small container, such as a 9-oz drinking cup

Tools (may be shared by several student groups)

- Heavy scissors to cut cardboard ("bandage scissors" are inexpensive and work well)
- Nail or Phillips screwdriver to punch holes in cardboard
- Screwdriver to fit machine screw

Audio Visual Materials

- (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1d)



Teaching Time

Two or three 45-minute class periods, plus time for students to construct their robotic arm

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Robot
Remotely operated vehicle
Engineering design

Background

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see *Lesson 1: To Explore Strange New Worlds*). These are unoccupied robots usually linked to a surface ship by a group of cables. Most ROVs 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, equipment for collecting samples, and measuring instruments to expand the vehicle's capabilities for gathering data about the deep-ocean environment. For additional information about ROVs used aboard the *Okeanos Explorer*, please see the *Introduction to Underwater Robots* on page 123.

This lesson introduces students to the process used to design remotely operated vehicles.

Learning Procedure

1. To prepare for this lesson:

a) Review:

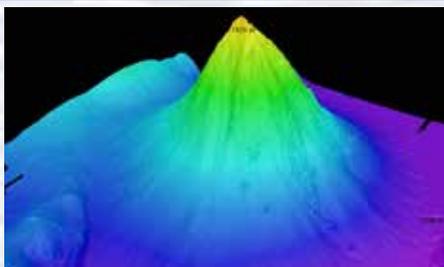
- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>); including *Little Hercules* ROV (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html>);
- Daily log entries for
July 7 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html>);
July 24 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/july24.html>); and
August 6 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug06/aug06.html>).

You may want to assign one or more of these essays as background reading prior to beginning the rest of the lesson.

- (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
- (c) Copy the *Student Worksheet*, one copy for each student group.
- (d) Download images referenced in Step 2. You may also want to download



The Institute for Exploration's *Little Hercules* remotely operated vehicle is deployed from NOAA Ship *Okeanos Explorer*. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr5_update_hires.jpg



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

examples of imagery from underwater robots (http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html).

- Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition, and discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Telepresence technologies that allow people to observe and interact with events at a remote location;
 - 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 and samples in depths as great as 4,000 meters.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

- Explain that building complicated ROVs such as *Little Hercules* involves a process called Engineering Design. If students are not already familiar with this concept, explain that Engineering Design is a process that engineers use to create solutions to problems. There are many versions of the process, but the basic steps are:

- Define the problem;
- Gather relevant information;
- Brainstorm possible solutions;
- Analyze possible solutions and select the most promising; and
- Test the solution.

Defining the problem includes identifying constraints such as available materials and resources. Emphasize that research on a problem should be carried out before beginning to design a solution. This may involve Internet searches, market research, field observations, or consulting with others who have experience with the defined problem. Often, a productive way to generate ideas is for people to work together to brainstorm, test, and refine possible solutions. Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success and how well each takes the constraints into account.

Testing the solution often involves building models of simplified designs to be sure an idea will work before investing a lot of time and money to construct something more elaborate. This step is sometimes called prototyping or “proof of concept.” If the prototype works, the designers will continue to develop their solution with the same materials and techniques. If the prototype does not work,

then designers must go back to a previous step and consider solutions that use other materials and techniques. This entire process may be repeated several times to improve the solution until results are satisfactory. For complex projects, these steps may be done by teams that work on different parts of the problem. An ROV such as *Little Herc* might have a design team working on the video system, another team working on propulsion, and another responsible for electronics.

You may also want to point out that explorers often encounter unexpected problems or challenges during an expedition. A famous example is the Apollo 13 mission during which engineers on Earth had to design a “scrubber” that would remove carbon dioxide from the air that the astronauts had to breathe, using only materials that were already aboard the spacecraft. To find solutions for these kinds of challenges, explorers often turn to Engineering Design.

Remind students that *Little Hercules* is designed to obtain high quality video images in ocean environments as deep as 4,000 meters. It can also carry electronic instruments to measure environmental features such as temperature, but has no way to bring anything back to the ship except images. Tell students that their task is to use the methods of Engineering Design to develop a robotic arm that is able to pick up objects that are about the size of a soda can.

Say that other teams working on this problem have decided that a hydraulic control system may be part of the solution to the robotic arm design task. So to begin their design process, students need to review some basic concepts of hydraulics and simple mechanics.

4. Be sure students are familiar with the following concepts related to simple machines:

- The exact number of “simple machines” depends to some extent upon your perspective, but the list typically includes levers, pulleys, wheel-and-axles, inclined planes, wedges, and screws. In some ways, through pulleys and wheel-and-axles are variations of the lever; and the wedge and screw are alternative forms of the inclined plane.
- Levers are divided into three classes, depending upon the positions of the input lever arm, the fulcrum, and the output arm (or load). In a Class I lever the fulcrum is between the input arm and the output arm (such as a crowbar). In a Class II lever, the output force is between the input force and the fulcrum (as in a wheelbarrow). In a Class III lever, the input force is between the output force and the fulcrum (as in a human arm).
- Mechanical advantage is the ratio of force output to force input. One of the big advantages of many simple machines is that they have high mechanical advantages, such as a crowbar, that essentially multiplies the force applied by a human by a factor of 2, 3, or more. But in some machines the mechanical advantage is less than 1, because the machine’s purpose is not to increase the input force but rather to change the direction or distance over which the force operates.



5. Provide each student group with a copy of the *Student Worksheet*, and the materials listed in Part B of the *Worksheet*. Have each group complete Parts A and B of the *Worksheet*. Then lead a discussion of students' results. Students should understand that

- Hydraulic refers to the use of confined liquid to transmit power, multiply force, or produce motion;
- Hydraulic systems use a liquid while pneumatic systems use air or other gases; and
- An actuator is a mechanical device that converts energy into some kind of motion.
- The energy that operates the actuators they built in Part B is mechanical energy from their own muscles, that is transferred to the moving arm by the hydraulic system of the actuator.

Provide Additional Materials listed in Part C of the *Worksheet*, and any additional instructions or advice that may be needed. Encourage students to consider several possible solutions, and point out that optimization of designs involves testing different solutions to determine which of them best solves the problem, given the criteria and the constraints. You may want to require each group to present the concept for their model before they actually begin construction; if this is a requirement, you may want to provide the additional materials after the concept has been approved.

6. When students have completed Part C of the *Worksheet*, have each group present their model and explain its operation to the rest of the class. Ask students to describe the criteria and constraints that influenced their design, how they developed their solutions, and how they optimized their chosen solution. There are many ways to construct a model that meets the design requirements. The essential points are:

- Design requirements are clearly identified. For instance, the model must be able to grasp an object, such as an empty plastic cup, and lift the object at least one inch.
- Several options are considered.
- The selected option fulfills the design requirements.
- If the model does not fulfill the design requirements, students should identify necessary modifications.

When all groups have presented their results, lead a class discussion about the next steps in designing a robotic arm that would be able to retrieve objects from the ocean floor, and what additional design decisions would be needed. The list of decisions includes:

- Materials for constructing the arm, considering environmental conditions in the deep ocean;
- Number of movements needed (this is called “degrees of freedom;” the actuator in Part B of the *Worksheet* has one degree of freedom; the human arm has more than 26 degrees of freedom);
- How the arm will be powered (are hydraulics the best solution; what are some other options);
- How the arm will be controlled from the surface; and
- What other sensors might be needed (such as a video camera mounted on the arm to show what is being lifted, or a pressure sensor on the gripper to know how much an object is being squeezed).

Be sure students realize that in a real hydraulic system, their hand muscles would be replaced by a pump to move hydraulic fluid in and out of actuators.

7. (Optional) **Some Math Connections** – Have students calculate the volume of hydraulic fluid (water in this case) needed to fill the system in their design. This will involve measuring the length and diameter of the syringes and tubing, and calculating volume as

$$V = \pi \cdot r^2 \cdot L$$

where V is volume, r is the radius of the tubing or syringe, and L is its length.

You may also have students verify their calculations by measuring the volume of water actually contained in their system.

8. These activities and discussions may also address the following components of technological literacy (ITEA, 2007):
- Usefulness of technology
 - Development of technology
 - Process of inventions and innovations
 - Attributes of design
 - Understanding of engineering design and the design process
 - Problem-solving approaches
 - Abilities to apply design processes
 - Abilities to use and maintain technological products

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

Have students write a brief essay describing how they might personally use the process of Engineering Design.

Connections to Other Subjects

English/Language Arts, Life Science, Mathematics, Physics

Assessment

Students’ models and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.
2. Visit <http://www.marinetech.org/rov-competition-2/> for a video from the most recent Marine Technology Society’s student ROV competition, and links to other sites about underwater robots.
3. For ideas about building your own underwater robots, see Bohm and Jensen (1998), Bohm (1997), and the Sea Perch Program (see Other Resources).



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

What's That? (from the The Lost City 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_whatstbat.pdf

Focus - Investigating Lost City hydrothermal field ecosystems by remotely operated vehicles (Grades 5-6; Life Science/Physical Science)

Students describe a sampling strategy for investigating an unknown area, and 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.

Call to Arms

(from the Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems Education Materials Collection)

<http://oceanexplorer.noaa.gov/edu/guide/media/gomdse11calltoarms56.pdf>

Focus - Robotic analogues for human structures (Grades 5-6; Life Science/Physical Science)

Students describe the types of motion found in the human arm; design and construct a model of a mechanical arm that mimics some or all of the motion capabilities of the human arm; describe combinations of simple machines that are used in their mechanical arm models; define mechanical advantage, and discuss the importance of mechanical advantage in robotic arm designs; and describe four common robotic arm designs that mimic motion capabilities of the human arm.

The Robot Ranger

(from the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks Expedition)

<http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09ranger.pdf>

Focus - Robotic Analogues for Human Structures (Vision, Distance Estimation) (Grades 5-6; Life Science/Physical Science)

Students describe how humans are able to estimate the distance to visible objects, and describe a robotic system with a similar capability.

Big Enough?

(from the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks Expedition)

<http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09bigenough.pdf>

Focus - Buoyancy (Grades 5-6; Physical Science)

Students define buoyancy, mass, volume, and density, and explain the relationships between these properties. Given the mass and volume of an object, students calculate the minimum buoyancy required to keep the object afloat in



seawater. Students also explain why objects in seawater are more buoyant than the same objects in fresh water.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/bdwe_ngss.pdf



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

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Student Worksheet

Your group is one of several teams working to design a robotic arm that is able to pick up objects that are about the size of a soda can from the ocean floor. One of the other design teams has suggested that hydraulic actuators may be part of the final design. Your team's task is to build a model that demonstrates how this could be done.

A. Review of Background Information

1. What does "hydraulic" mean?
2. What is the difference between "hydraulic" and "pneumatic"?
3. What is an actuator?

B. Build a Simple Hydraulic Actuator

Materials

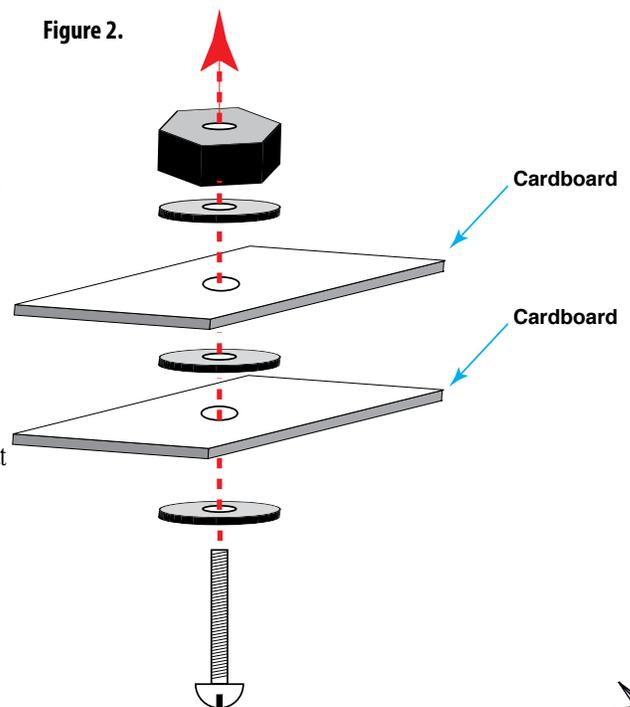
- One piece of cardboard or heavy poster board, approximately 12" x 12" (the stiffer the better)
- Duct tape, approximately 2" x 60"
- Machine screw with nut, #8 x 1"
- 3 - Flat washers, #8 hole
- 2 - Oral syringes
- Plastic tubing, approximately 3/16" inside diameter x 12" (should fit snugly over the end of the syringes)
- Water
- Small container, such as a 9-oz drinking cup

Tools

- Heavy scissors to cut cardboard ("bandage scissors" are inexpensive and work well)
- Nail or Phillips screwdriver to punch holes in cardboard
- Screwdriver to fit machine screw
- Tape measure

Procedure

1. Cut two pieces of cardboard using the pattern on page 136 (Figure 1).
2. Reinforce the cardboard pieces: Put a piece of duct tape on one side, then cut off the excess tape around the edges. Put a second piece of duct tape on the other side, and trim the edges. Repeat this process, if necessary, until the pieces are very stiff.
3. Punch a hole in each of the pieces as shown on the pattern. The hole should be large enough for the #8 machine screw, but not much larger.
4. Attach the two pieces with a #8 machine screw, three flat washers, and a #8 nut as shown in Figure 2. You may need a screwdriver to twist the machine screw through the holes. Do not tighten the machine screw assembly too much; the pieces need to be able to move freely around the machine screw. You may find that an extra washer or nut between the two cardboard pieces allows for more motion.



5. Take a piece of duct tape 6" long, and tear it in half lengthwise, and then tear one of these pieces in half lengthwise again. These narrower pieces of duct tape will be useful for attaching a syringe to the shorter piece of cardboard.

6. Attach the plunger of one syringe to the shorter piece of cardboard as indicated on the pattern. Tear one of the narrower pieces of duct tape in half, and wrap it around the plunger and cardboard as shown in Figure 3. Now wrap a second narrow piece of duct tape around the plunger at right angles to the first piece of tape. Add more tape if necessary, but you do not want the joint between the plunger and cardboard to be too tight.



Figure 3.

7. Tape the syringe onto the larger piece of cardboard as shown in Figure 4. Be sure the plunger is fully inserted into the barrel of the syringe.



Figure 4.

8. Press one end of the plastic tubing onto the end of the other syringe so it is firmly attached. Place the other end of the plastic tubing into a small

container of water, and pull the plunger back so that water is drawn into the tubing and syringe. Fill the syringe as full as possible, then hold the end of the plastic tubing so that it is higher than the end of the syringe, and slowly push on the plunger until the syringe is about half-full, and there is no air in the syringe or plastic tubing. You may have to refill the syringe with more water and repeat this procedure a few times to get rid of all the air.

9. Attach the open end of the plastic tubing to the syringe that is taped to the cardboard assembly. Slowly press the plunger on the unattached syringe, and you should see the small arm on the cardboard assembly rotate around the machine screw. Pull out slowly on the plunger to reverse this motion. Your hydraulic actuator is completed!

C. Design and Build a Hydraulic Mechanism for a Robotic Arm

Remember that your team's task is to build a model that demonstrates how hydraulic actuators could be used for a robotic arm that is able to pick up objects that are about the size of a soda can from the ocean floor. This model does NOT have to have all of the features that will be needed in the final robotic arm. You only need to show that a design using hydraulic actuators could produce the movements that would be needed to accomplish the purpose of the robotic arm. Your model needs to be able to do two things:

- Grasp an object (such as an empty plastic cup); and
- Lift the object at least one inch.

So that other teams can learn from your experience, it is very important to document how you apply the process of Engineering Design. In addition to creating a model that meets the two requirements, your team should produce a report that:

1. Defines the problem;
2. Describes your solution, including a drawing of your model;
3. Explains your construction procedure; and
4. Reports the results of your tests of the model.

If your model cannot meet the design requirements, describe the modifications that you think are necessary to make it work.

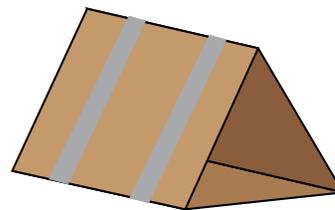
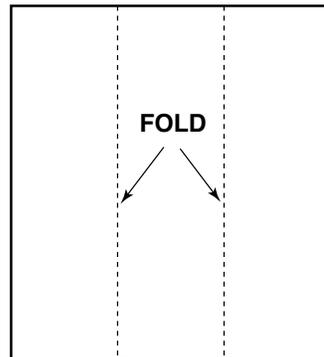
Additional Materials

- Four pieces of cardboard or heavy poster board, each approximately 12" x 12"
- Duct tape, approximately 2" x 20'
- 9 - Machine screws with nuts, #8 x 1"
- 4 - Machine screws with nuts, #8 x 3"
- 17 - Flat washers, #8 hole
- 2 - Oral syringes
- Plastic tubing, approximately 3/16" inside diameter x 12"

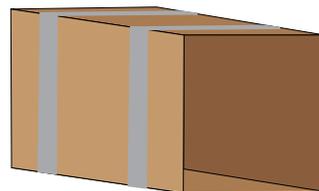
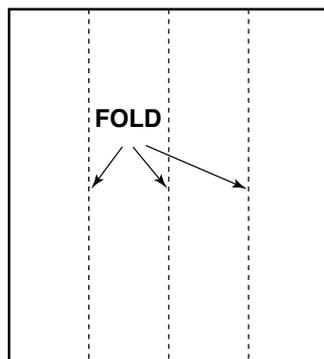
Note: These materials are sufficient to construct many models that will meet the design requirements, but your model may not need all of them.

Tip: Cardboard arms and supports are much stronger if they are folded and taped to form beams with square or triangular cross-sections (see Figure 5).

Figure 5.

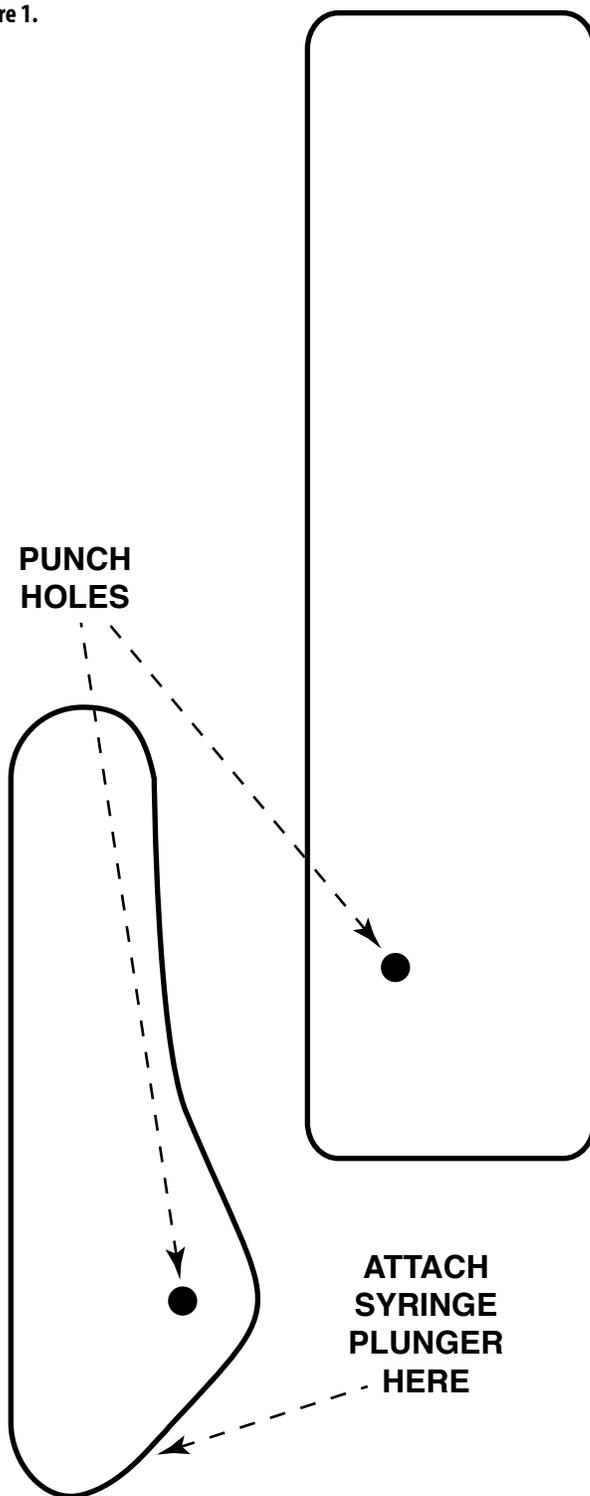


TRIANGULAR
SECTION
BEAM



SQUARE
SECTION
BEAM

Figure 1.





Section 5: Underwater Robots

Lesson 10: What *Little Herc* Saw



A video engineer adjusts the images from the HD camera on the remotely operated vehicle, *Little Hercules*. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr17-3-hires.jpg>

Focus

Use of robotics for ocean exploration

Grade Level

7-8 (Physical Science/Technology)

Focus Question

How are remotely operated vehicles used aboard *Okeanos Explorer* to help explore Earth's deep ocean?

Learning Objectives

- Students will explain how robotic vehicle technology is used to extend the exploration capacity of scientific investigations aboard the *Okeanos Explorer*.
- Students will discuss how information from underwater robots about the variety of biological and geological conditions in marine ecosystems is relevant to the concept of biodiversity.
- Students will analyze and interpret video data from the *Okeanos Explorer*'s underwater robot to make inferences about environmental interactions of organisms in deep-sea ecosystems.

Materials

- Copies of *Some Things Little Herc Saw*; one for each student group
- Digital or print copies of still imagery (see Learning Procedure Step 1e)

Audio Visual Materials

- (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1e)

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30



Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Robot
Imagery
Video

Background

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see *Lesson 1: To Explore Strange New Worlds*). For additional information about ROVs used aboard the *Okeanos Explorer*, please see the *Introduction to Underwater Robots* on page 123.

This lesson introduces students to remotely operated vehicles and video imagery as they are used for ocean exploration aboard the *Okeanos Explorer*. The techniques presented in this lesson may be used to complete *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

Learning Procedure

1. To prepare for this lesson:

a) Review:

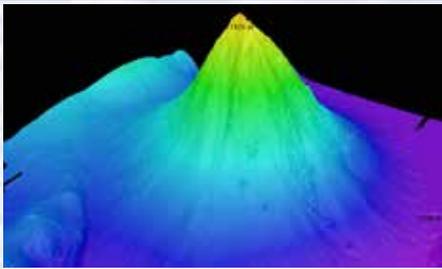
- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>); including *Little Hercules* ROV (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html>);
- Daily log entries for
July 7 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html>);
July 24 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/july24.html>); and
August 6 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug06/aug06.html>).

You may want to assign one or more of these essays as background reading prior to beginning the rest of the lesson.

- (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
- (c) Review procedures for analyzing ROV imagery beginning with Step 4. Depending upon available time, you may decide to have individual student groups analyze fewer images, then pool their results.
- (d) Make copies of *Some Things Little Herc Saw*; one copy for each student group.
- (e) Download the following image and video files from the INDEX-SATAL 2010 Expedition by going to: http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/movies/0711_site_k_transit_video.html:

20100711_01h56m25s04_ROVHD_TRANSIT.jpg
20100711_01h56m44s04_ROVHD_TRANSIT.jpg
20100711_01h57m05s04_ROVHD_TRANSIT.jpg
20100711_01h57m25s04_ROVHD_TRANSIT.jpg
20100711_01h57m49s04_ROVHD_TRANSIT.jpg
20100711_01h58m11s04_ROVHD_TRANSIT.jpg
20100711_01h58m30s04_ROVHD_TRANSIT.jpg





Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

20100711_01h58m39s04_ROVHD_TRANSIT.jpg

20100711_01h56m16s04_ROVHD_TRANSIT-300kb.mov

You may want to print the still images, but if possible it is preferable to have students work with these on classroom computers or their own computers. If students will not be using classroom computers, ensure that they will have access to the still image (.jpg) files.

- (f) (Optional) You may also want to download images referenced in Steps 2 and 3, and/or additional examples of imagery from underwater robots (http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html).

- Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition, and discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_wbat.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Telepresence technologies that allow people to observe and interact with events at a remote location;
 - 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 and samples in depths as great as 4,000 meters.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

- Briefly describe the capabilities of typical ROVs (you may want to show some images from <http://oceanexplorer.noaa.gov/technology/subs/subs.html>). Conclude with the *Little Hercules* ROV, and explain that the primary purpose of this underwater robot is to gather high quality video imagery as part of site characterization activities. At this point you may want to show the video clip compilation referenced in Step 1f. Lead a discussion of how ocean explorers might use this imagery. Students should realize that in many cases this imagery provides the only indication of living organisms in sites being characterized. In addition, this imagery 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.

Show one of the still images downloaded in Step 1e, call students' attention to the



red dots near the center of the image and ask for ideas about why these dots are present. Students should realize (possibly with your help) that these dots provide a scale that makes it possible to estimate the size of objects in the image. Explain that *Little Hercules'* video system has two lasers whose beams are parallel and are 10 cm apart. This places two bright dots on each image that establish the scale of the image.

4. Show students the video clip **20100711_01h56m16s04_ROVHD_TRANSIT-300kb.mov**. Say that this video was made by the ROV *Little Hercules* on July 11, 2010, during a dive to a volcanic cone-shaped seamount that turned out to be one of the most diverse sites visited by the INDEX-SATAL 2010 Expedition.

Tell students that their assignment is to analyze eight still frames from this video, and estimate the number of different organisms in each frame, and the abundance of each organism. Provide each student group with one or more frames (either printed or on a computer), and a copy of *Some Things Little Herc Saw*. You may want to review the general biology of some of the organisms depicted on the handout, or assign each student group to provide this background for one or more organisms.

Provide each student group with one or more of the images downloaded in Step 1e. It is easiest to examine these images on a computer since zoom functions are available, but printed copies may be used if adequate computer resources are not available.

Instruct students to identify organisms as completely as possible. Students may protest that they have never seen most of the things in the video clip; 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 is one of the great benefits of telepresence. Tell students that during ROV dives, an Internet-based intercom system allows all participants, regardless of location, to easily communicate with all other participants. This real-time voice communication is supplemented by a real-time text-based tool called “the Eventlog,” which allows each participant to write their personal observations to a common log. Log entries made by individuals can immediately be seen by all other users in real-time. The Eventlog software automatically records the date, time of entry, and author of each text observation.

Figure 1 shows the Eventlog entries during the time that the video clip was made. Table 1 lists some of the abbreviations that are used in Eventlog entries to name various organisms.

5. Have each student group present the results of their analyses. There is considerable variety of organisms in the video clip, and among the eight still frames. Briefly discuss the concept of biodiversity. This concept is usually understood to include variety at several levels:
 - **variety of ecosystems:** high biodiversity suggests many different ecosystems in a given area;

So many images, so little time!

During the INDEX-SATAL 2010 Expedition, the *Okeanos Explorer's* ROV team saved about 3,400 high-resolution still images. To make the images useful for later analyses (including the analyses done in this lesson), each image must be accompanied by certain information, including the geographic location and depth.

Each video file has a unique name that includes the date and time of the first frame as well as the camera source and a brief description. Individual frames from video files are selected by the ROV video team and saved as high-resolution JPEG images. The image filenames match the original video filename, but the date and time portions of the filenames are corrected to correspond with the actual time that the individual video frame was recorded.

Knowing the time that a specific frame was recorded makes it possible to retrieve information from other data files, including geographic location and depth. This information is included with each JPEG image, similar to the way that date and time are included with images from most digital cameras. For more details, see Pinner (2010).

Table 1. Some Eventlog abbreviations for various groups of animals

ACN	Actinaria
APH	Amphipod
ART	Arthropod
ASR	Asteroid
BAR	Barnacle
BIO	Biology (Unspecified)
BIV	Bivalve
BRY	Bryozoan
CHI	Chiton
CHN	Chondrichthyes
CNI	Cnidarian
COR	Coral
CRA	Crab
CRI	Crinoid
ECN	Echiuran
EGG	Egg case
FEC	Fecal matter
FSH	Fish
GAS	Gastropod
GRO	Gromiid
HOL	Holothurian
HYD	Hydroid
ISO	Isopod
JFH	Jellyfish
LOB	Lobster
MAT	Bacterial Mat
MOL	Mollusk
NUD	Nudibranch
OCT	Octopus
OPH	Ophiuroid
PAG	Pagurid (hermit)
PEN	Pennatulacean
POL	Polychaete
SCA	Scale worm
SHI	Shrimp
SPO	Sponge
SQA	Squat lobster
SQD	Squid
STY	Stylasterid
TUN	Tunicate
URC	Urchin
USO	Unidentified sessile object
WOD	Wood
WOR	Worm
XEN	Xenophyophoran
ZOA	Zoanthid

Figure 1. Excerpt from Eventlog for July 11, 2010

2010-07-11	01:56:29	jonathanrose	FSH
2010-07-11	01:56:57	okeanosexplorer	we'll try to get a few for him
2010-07-11	01:57:10	okeanosexplorer	depth is 48m, heading is 57
2010-07-11	01:57:16	okeanosexplorer	458m
2010-07-11	01:57:18	cherissedupreez	SQA
2010-07-11	01:57:40	davebutterfield	the light-colored material around the base of the rocks is primarily coral debris.
2010-07-11	01:58:14	okeanosexplorer	large stalked CRI
2010-07-11	01:58:23	okeanosexplorer	SQA
2010-07-11	01:58:25	okeanosexplorer	SHI
2010-07-11	01:58:30	okeanosexplorer	STY's
2010-07-11	01:58:35	okeanosexplorer	with OPH's
2010-07-11	01:58:49	okeanosexplorer	very neat SPO's
2010-07-11	01:58:58	jonathanrose	FSH
2010-07-11	01:59:00	okeanosexplorer	purple COR
2010-07-11	01:59:13	dustinschomagel	ROV Depth 452 Hdg 62 deg
2010-07-11	01:59:34	okeanosexplorer	URC

- **variety of species:** high biodiversity suggests many different species in a given area;
- **variety of interactions between species;** and
- **variety within species (genetic diversity):** high biodiversity suggests a relatively high level of genetic variety among individuals of the same species.

The concept of biodiversity generally combines two measurements:

- the number of species in a given area; and
- how evenly individuals are distributed among these species.

Evenness is greatest when species are equally abundant. The simplest measure of species diversity is the number of species present in an environment. This is called species richness. But there is more to diversity than just the number of species in an environment. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species.

Discuss these measurements as they apply to students' analyses of the eight still frames. There are many different species represented among the eight frames, but only a few are abundant in all of the frames. Many are only represented by one or two individuals in all eight frames. This is typical of biological communities that have relatively high biodiversity. If we did similar analyses of frames from video clips made in other locations, we could compare numbers of species and number of individuals within each species to get an idea about the relative diversity between the various locations.

Lead a discussion on the significance of biodiversity. The fact that diversity often decreases in stressed environments suggests that high diversity may be "good." On the other hand, it is important to realize that diversity can also be increased by changed or variable conditions (such as those at the boundary of two different types of habitat) or following a major change in a mature ecosystem (such as a forest fire). Encourage pro and con discussions of these questions, but be sure to challenge students to defend their positions. At some point in this discussion,

ask students whether “unknown” is the same as “unimportant.” You may want to cite examples in which obscure species proved to be directly important to humans, such as the Madagascar periwinkle that now provides a powerful cancer treatment; or the *Forcepsia* sponges from deep-ocean habitats that have similar anti-cancer properties (for more information, see <http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html>).

6. **Some Math Connections** – When scientists discuss biodiversity and populations of organisms, they often like to estimate the abundance of various species. One way to do this with video data is to navigate an underwater robot along a series of transects (a transect is a path along which data are collected) while recording video from a forward-looking camera. When the transects are completed, the video recording is reviewed and imaged organisms are identified and counted. The total counts for each species are divided by the total area of the transect to obtain an estimate of the density of each species. For example, if 50 corals belonging to a single species were counted in a video transect that covered 100 square meters, the density of that species would be
- $$50 \text{ corals} / 100 \text{ square meters} = 0.5 \text{ coral/square meter.}$$

Ask students how we might estimate the area covered during the video clip. Students should realize that we need to know the width of the area covered by each frame, and the total length of the transect. The width of the frames can be estimated using the laser dots (which are 10 cm apart). The spacing of these dots is similar on each of the eight still frames, and the width of the area covered is about 3.6 m.

To find the length of the transect, we first need to know whether the ROV was headed in a straight line (more or less) during the time of the video clip. Checking the heading recorded for each of the eight frames, we find that the ROV's heading varied between 48.5 and 80.0 degrees. This is not exactly a straight line, but is okay for an approximation. Since we know the geographic location of each frame, we can find the distance between the location of the first frame (2° 50.84217' N, 125° 3.47277' E) and the location of the last frame (2° 50.84815' N, 125° 3.48355' E) using an online calculator (such as <http://www.movable-type.co.uk/scripts/latlong.html>) which gives a distance between the locations of the first and last frame equal to 0.02282 km.

So, our estimate of the area covered during the video clip is

$$3.6 \text{ m} \cdot 22.8 \text{ m} = 82.1 \text{ m}^2$$

To calculate the density of the various types of organisms seen in the video clip, we would need to analyze the entire clip, counting each individual of each organism, then dividing the totals by the area of the video transect.

7. Discussion of underwater robots and image technology may also include the following components of technological literacy (ITEA, 2007):
- **Core concepts of technology:** Underwater robots are composed of closely inter-related systems designed to meet specific requirements and constraints, which often involve trade-offs.
 - **Relationships between technologies and other fields of study:** Underwater robotics technology is closely linked to advancements in science and mathematics, and specific information requirements in these fields drive further innovation and invention.



- **Effects of technology on the environment:** Underwater robotics technology provides new ways to monitor various aspects of the environment to provide information for decision-making.

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

Have students write a brief essay about how the ability to use robotic imagery to compare biological communities could be personally beneficial.

Connections to Other Subjects

English Language Arts, Life Science, Mathematics, Physics

Assessment

Students’ analyses of video images and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.
2. For additional techniques for analyzing video images, see the *Through Robot Eyes* lesson.
3. Visit <http://www.marinetech.org/rov-competition-2/> for a video from the Marine Technology Society’s most recent student ROV competition, and links to other sites about underwater robots.
4. For ideas about building your own underwater robots, see Bohm and Jensen (1998), Bohm (1997), and the Sea Perch Program (see Other Resources).
5. For additional work with ROV video imagery, see *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

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

I, Robot, Can Do That!

(from the Lost City 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater robotic vehicles for scientific exploration (Physical Science/ Life Science)

Students will describe and contrast at least three types of underwater robots used for scientific explorations; discuss the advantages and disadvantages of

using underwater robots in scientific explorations; and identify robotic vehicles best suited to carry out certain tasks.

Let's Hit the Slopes!

(from the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition)

http://oceanexplorer.noaa.gov/explorations/10lophelia/background/edu/media/lopb10_hitslopes78.pdf

Focus: Benthic communities on continental slopes in the Gulf of Mexico (Grades 7-8; Life Science)

Students describe benthic communities found at selected sites on continental slopes in the Gulf of Mexico; explain the possible ecological role of at least three species that are characteristic of these communities; and calculate an index of similarity between two biological communities given species occurrence data.

Next Generation Science Standards

Lesson plans developed for Volume 2 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/hdwe_ngss.pdf



Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:
oceaneducation@noaa.gov

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<http://oceanexplorer.noaa.gov>

Some Things *Little Herc* Saw



Anglerfish. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



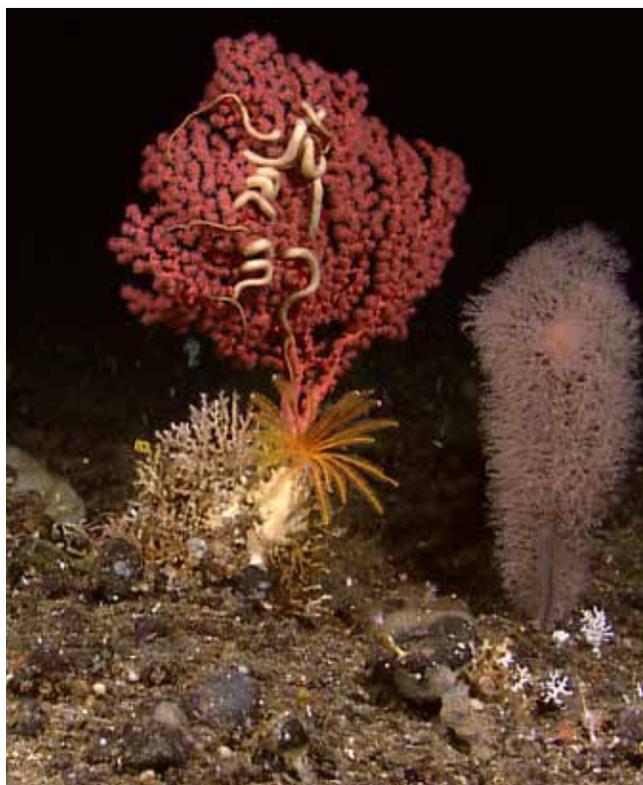
An anemone (Phylum Cnidaria) on the branches of a bamboo coral. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Unidentified Cnidarian. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea anemone (Phylum Cnidaria); white stylasterid coral in background. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Brittle star (Phylum Echinodermata; Class Ophiuroidea) on reddish bubblegum coral (Phylum Cnidaria); yellow sea lily (Phylum Echinodermata; Class Crinoidea) at base of coral; another soft coral (Phylum Cnidaria) to the right. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Cnidarian; brittle star (Phylum Echinodermata; Class Ophiuroidea) on white stylasterid coral to the right. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Yellow sea lily (Phylum Echinodermata; Class Crinoidea); bubblegum coral (Phylum Cnidaria) in background. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Cup coral (Phylum Cnidaria). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Gray-brown encrusting sponge (Phylum Porifera) on rock; white soft corals (Cnidaria) to the left. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Flatfish. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Gastropod snail. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea cucumber (Genus *Holothuria*). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Hermit crab (Phylum Arthropoda). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Bamboo coral (Phylum Cnidaria; Family Isididae). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Octopus (Phylum Mollusca; Class Cephalopoda). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



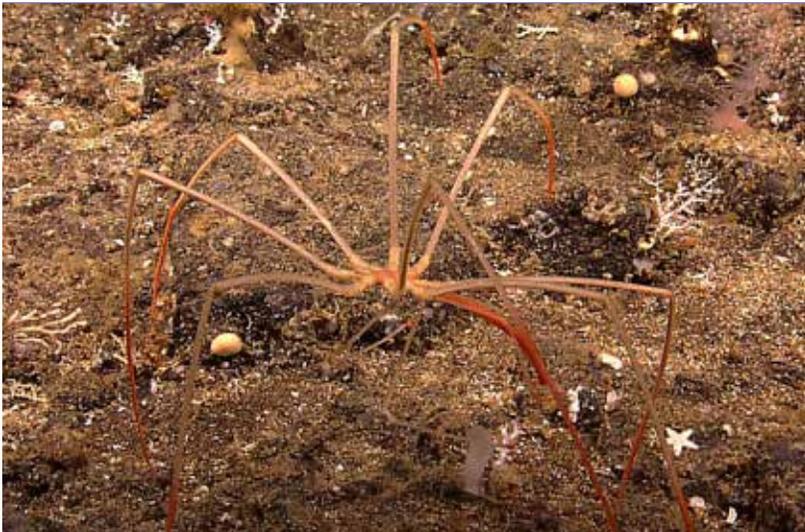
Purple soft coral (Phylum Cnidaria) with brittle star (Phylum Echinodermata; Class Ophiuroidea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Brittle star (Phylum Echinodermata; Class Ophiuroidea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Purple sponge (Phylum Porifera). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Sea spider (Class Pycnogonida). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Soft coral (Phylum Cnidaria). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Soft coral (Phylum Cnidaria) and sponges (Phyla Porifera); squat lobsters (Phylum Arthropoda) in right foreground. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Stalked sea lily (Phylum Echinodermata; Class Crinoidea), left; sea urchin (Phylum Echinodermata; Class Echinodea). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Yellow encrusting sponge (Phylum Porifera). Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.



Section 5: Underwater Robots

Lesson 11: Through Robot Eyes

Focus

Image analysis

Grade Level

9-12 (Physical Science/Technology)

Focus Question

How can images obtained by underwater robots be used to assist ocean exploration aboard the *Okeanos Explorer*?

Learning Objectives

- Students will explain how robotic vehicle technology is used to extend the exploration capacity of scientific investigations aboard the *Okeanos Explorer*.
- Students will use mathematics and computational thinking to show how lasers may be used in scientific investigations to calibrate images for size and distance measurements.
- Students will analyze and interpret video data from the *Okeanos Explorer*'s underwater robot to make inferences about environmental interactions of organisms in deep-sea ecosystems.

Materials

- Copies of the *Robot Imagery Investigation Guide*, one for each student group
- Copies of *ImageJ Basics*, one for each student group; see Learning Procedure, Step 1c
- Ruler, one for each student group

Audio Visual Materials

- (Optional) Video projector or other equipment to display downloaded images (see Learning Procedure, Step 1d)

Teaching Time

One or two 45-minute class periods, plus time for students to complete the *Investigation Guide*

Seating Arrangement

Groups of two to four students

Maximum Number of Students

30



The combination of the *Little Hercules* ROV (above) and the *Seirios* camera sled (below)—equipped with high definition cameras and powerful lighting systems are capable of diving to 4,000 m depth. When deployed, they will be our “eyes in the sea,” providing the expedition team and audiences on shore with spectacular first looks at the deep-sea habitats. Images courtesy of NOAA *Okeanos Explorer* Program, 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/background/hires/plan_little_herc_hires.jpg



Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Robot
Imagery
Video
ImageJ

Background Information

The site characterization component of the *Okeanos Explorer* exploration strategy depends heavily upon remotely operated vehicles (ROVs; for more information about the *Okeanos Explorer* exploration strategy, please see *Lesson 1: To Explore Strange New Worlds*). For additional information about ROVs used aboard the *Okeanos Explorer*, please see the *Introduction to Underwater Robots* on page 123.

This lesson introduces students to remotely operated vehicles and video imagery as they are used for ocean exploration aboard the *Okeanos Explorer*. The techniques presented in this lesson may be used to complete *Okeanos Explorer* Video Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

Learning Procedure

1. To prepare for this lesson:

a) Review:

- Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>); including *Little Hercules* ROV (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html>);
- Daily log entries for
July 7 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html>);
July 24 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/july24.html>); and
August 6 (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug06/aug06.html>).

You may want to assign one or more of these essays as background reading prior to beginning the rest of the lesson.

- (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
- (c) Review procedures on the *Robot Imagery Investigation Guide*. If students will be using classroom computers, download ImageJ and the *ImageJ Basics* handout from <http://rsbweb.nib.gov/ij/download.html> and <http://rsbweb.nib.gov/ij/docs/pdfs/ImageJ.pdf>, respectively.

Also, download the image files **EX2010.07.12_ROV_01.jpg** and **EX2010.07.12_ROV_02.jpg** from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_01.jpg and http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_02.jpg, respectively.



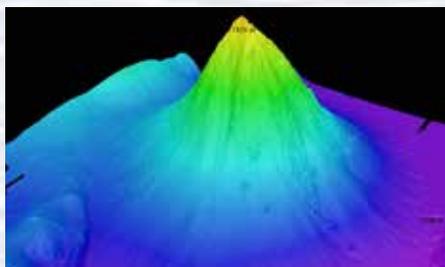
Video technology plays a big role in the exploration conducted on the *Okeanos Explorer*. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july24/media/andy_at_controls.html



A video engineer adjusts the images from the HD camera on the remotely operated vehicle, *Little Hercules*. Image courtesy of the NOAA *Okeanos Explorer* Program.

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/hires/apr17-3-hires.jpg>



Okeanos Explorer's EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.

<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI's Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg

If students will not be using classroom computers, ensure that they will have access to the file oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_01.jpg.

(d) Download images referenced in Step 2 and 3. You may also want to download examples of imagery from underwater robots from http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html.

2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition, and discuss why this kind of exploration is important (for background information, please see the lesson, *Earth's Ocean is 95% Unexplored. So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:

- The overall strategy is based on finding anomalies;
- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Telepresence technologies that allow people to observe and interact with events at a remote location;
 - 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 and samples in depths as great as 4,000 meters.

You may want to show some or all of the images in the adjacent sidebar to accompany this review.

3. Show students images of several ROVs (see <http://oceanexplorer.noaa.gov/technology/subs/subs.html>), 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 or videos alone.

Show the image **EX2010.07.12_ROV_02.jpg**. Call students' attention to the red dots near the center of the image, and ask for ideas about why these dots are present. Students should realize (possibly with your help) that these dots provide a scale that makes it possible to estimate the size of objects in the image.

Tell students that their assignment is to learn about some of the ways scientists use imagery from underwater robots to investigate deep-sea ecosystems. Provide each student group with:

- A copy of the *Robot Imagery Investigation Guide*;
- The image file oceanexplorer.noaa.gov/okeanos/edu/resources/media/EX2010.07.12_ROV_01.jpg;
- The ImageJ Basics handout; and
- Any additional instructions about operating the ImageJ software on classroom computer systems.

Point out that the primary purpose of the *Investigation Guide* exercises is to become familiar with techniques that can be used for a wide variety of investigations and projects that use digital imagery.

4. When students have answered all questions on the *Investigation Guide*, lead a discussion of their results. The answer sheet can be found on page 161.
5. Discussion of underwater robots and image technology may also include the following components of technological literacy (ITEA, 2007):
 - **Core concepts of technology:** Underwater robots are composed of closely inter-related systems designed to meet specific requirements and constraints, which often involve trade-offs.
 - **Relationships between technologies and other fields of study:** Underwater robotics technology is closely linked to advancements in science and mathematics, and specific information requirements in these fields drive further innovation and invention.
 - **Effects of technology on the environment:** Underwater robotics technology provides new ways to monitor various aspects of the environment to provide information for decision-making.

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

Have students write a brief essay about how robotic imagery might be of personal benefit.

Connections to Other Subjects

English Language Arts, Life Science, Mathematics, Physics

Assessment

Students’ answers to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit the *Okeanos Explorer* Web page (<http://oceanexplorer.noaa.gov/okeanos/welcome.html>) for reports, images, and other products from *Okeanos Explorer* cruises.
2. Visit <http://www.marinetech.org/rov-competition-2/> for a video from the Marine Technology Society’s student ROV competition, and links to other sites about underwater robots.



3. For ideas about building your own underwater robots, see Bohm and Jensen (1998), Bohm (1997), and the Sea Perch Program (see Other Resources).
4. For additional work with ROV video imagery, see *Okeanos Explorer* ROV Imagery Supplemental Datasheets for selected *Okeanos Explorer* cruises (e.g., http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/background/edu/media/ex1202_sdrov1.pdf).

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

Where's My 'Bot?

(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 (Grades 9-12; Earth Science/Mathematics)

Students 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.

Hydrothermal Vent Challenge

(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 (Grades 9-12; Chemistry)

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

Thar She Blows!

(from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_13.pdf

Focus: Hydrothermal vents (Grades 9-12; Chemistry/Biology)

Students demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor, and demonstrate an understanding of how the transfer of energy affects solids and liquids.

The Tell-Tale Plume

(from the INSPIRE: Chile Margin 2010 Expedition)

<http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf>

Focus: Hydrothermal Vent Chemistry (Grades 9-12; Chemistry/Biology)

Students describe hydrothermal vents; identify changes that they cause to the physical and chemical properties of seawater; and use oceanographic data to recognize a probable plume from hydrothermal activity.



The Roving Robotic Chemist

(from the PHAEDRA 2006 Expedition)

http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf

Focus: Mass Spectrometry

Students 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.

Next Generation Science Standards

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Robot Imagery Investigation Guide

Underwater robots are our eyes into Earth's deep ocean. As digital imaging technology continues to improve, views through these robot eyes are beautiful and fascinating (see, for example, http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html and http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html). Site characterization is a key element of the *Okeanos Explorer's* strategy for making discoveries, and this characterization depends heavily upon the ability of underwater robots to obtain images that can be used to identify living organisms and geological features. The following activities are designed to acquaint you with some techniques for analyzing images obtained with underwater robots. Once you are familiar with these techniques, you will be able to use them for a wide variety of investigations about ocean organisms and ecosystems.

Many underwater robots carry digital cameras that can look ahead of the robot as well as directly below it. Often, the forward-looking camera records video while the downward-looking camera may record still or video imagery depending upon specific mission needs. For some surveys, a series of overlapping still images is obtained from the downward-looking camera. These images are spliced together to produce a mosaic image that can provide complete coverage of a large area. The essay by Liz Podowski (<http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug30/aug30.html>) provides more details about this technique.

One problem with most images from underwater robots is that they are two-dimensional, so it can be very difficult to accurately judge the size of organisms and ecosystem features. To overcome this problem, underwater photography systems use a system of lasers. Downward-looking cameras typically have two lasers whose beams are parallel and a known distance apart. This places two bright dots on each image that establish the scale of the image. In Figures 1 and 2, the dots on the image are 10 cm apart. Using this information, estimate:

Figure 1.





1. The approximate height of the portion of the large branching soft coral that is visible in Figure 1:

2. The span of the two brittle star arms that are closest to horizontal, not including the portions that are twisted around the coral in Figure 1:

3. The approximate length of the shrimp in the lower left of Figure 2:

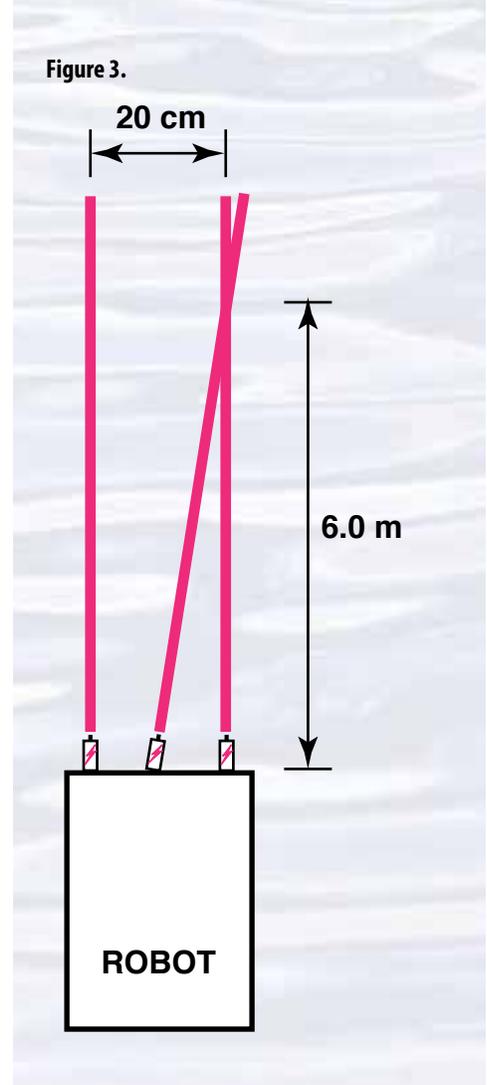
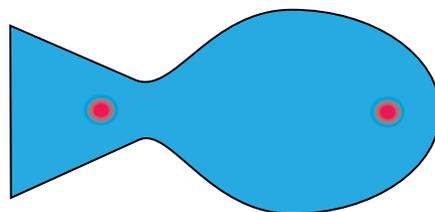
4. The approximate length of the violet sea cucumber in the upper center of Figure 2:

Note: the sea cucumber may be somewhat larger than this, since it is farther away than the substrate where the laser dots are located.

A similar system can be used in forward-looking video, but it is often important to be able to estimate distance as well. To provide this capability, a third laser is added to the system, in between the two parallel lasers. This additional laser is angled so that it converges with one of the parallel laser beams at a known distance in front of the robot (see Figure 3).

Suppose a video system using the lasers diagrammed in Figure 3 shows the image in Figure 4:

Figure 4.



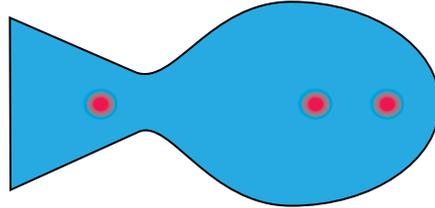


5. How far away is the fish?

6. What is the total length of the fish?

Now suppose the same video system shows the image in Figure 5:

Figure 5.

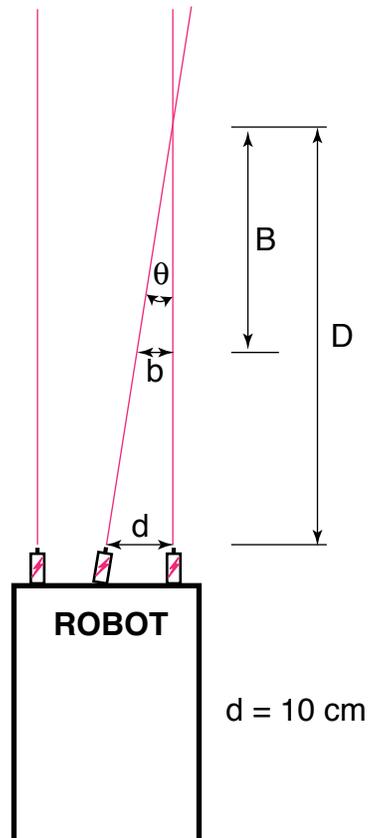


7. How far away is the fish?

8. What is the total length of the fish?

HINT:

Figure 6.



Fishes are a conspicuous part of many marine ecosystems, and ocean explorers often have questions about what kinds of fish inhabit certain areas, and how many fishes are there. Koenig (2001) describes a way to obtain this information that involves navigating an underwater robot along a series of transects (a transect is a path along which data are collected) while recording video from a forward-looking camera. When the transects are completed, the video recording is reviewed and imaged fishes are identified and counted. The total counts for each species are divided by the total area of the transect to obtain an estimate of the density of each species. For example, if 50 fish belonging to a single species were counted in a video transect that covered 100 square meters, the density of that species would be $50 \text{ fish} / 100 \text{ square meters} = 0.5 \text{ fish/square meter}$.

9. What might be some errors involved with surveying fishes in this way?

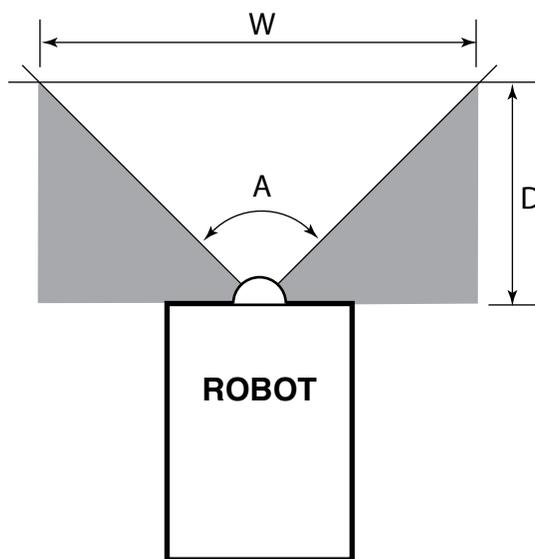
To find the area of a transect, we need to know the width (W) and length (L) of the transect (Figure 7). The width of the transect can be calculated from:

- The effective distance for identifying fish species (D); and
- The video camera's horizontal angle of view (A)

The effective distance for identifying fish species (D) is the limit at which the fish can be identified with a high degree of certainty. Koenig (2001) used a distance of 5 m. The horizontal angle of view (A) depends on the camera used and the position of the zoom.

10. Suppose we have a camera whose horizontal angle of view is 90 degrees. Using 5 m as the effective distance, what is the width (W) of a video transect?

Figure 7.



The length of a transect (L) can be calculated from the geographic coordinates of the robot at the beginning and end points of the transect. The distance between two points whose latitude and longitude are known can be calculated using the spherical law of cosines formula:

$$d = \text{acos}(\sin(\text{lat1}) \cdot \sin(\text{lat2}) + \cos(\text{lat1}) \cdot \cos(\text{lat2}) \cdot \cos(\text{long2} - \text{long1})) \cdot R$$

where lat1, long1, lat2, and long2 are the latitude and longitude of points 1 and 2, respectively in radians, d is the distance between the points in km, and R is Earth's mean radius (6,371 km); latitude and longitude measurements in degrees may be converted to radians by dividing by 180.

11. If our transect began at 2.523456° North latitude, 125.069212° East longitude, and ended at 2.525255 North latitude, 125.069146° East longitude, what was the length (L) of the transect (Hint: 1. Be sure to use a calculator or spreadsheet program accurate to at least six decimal places.)
-

12. Now that you know the width (W) and length (L) of the transect, how much area did the transect include? (Hint: be sure to allow for the space that is outside the camera's horizontal field of view.)
-

Basic analyses of video and single-frame images can be done by identifying and counting individual organisms, and by using laser scale dots to estimate the area covered by the image. Much more sophisticated analyses can be done using image analysis software. ImageJ is a very powerful image analysis program developed by the National Institutes of Health, and is free to the public. Links for downloading, tutorials, and full documentation are available at: <http://rsbweb.nih.gov/ij/index.html>.

Launch the ImageJ program, and open the file provided by your teacher. Review the *ImageJ Basics* handout, then try the following:

- Draw a line between the two laser dots, and set the measurement scale as described in the handout (remember the dots are 10 cm apart).

13. A decapod crustacean is clearly visible near the bottom center of the image. Measure the distance between the eyes, and the length of the longest segment in the first right cheliped (the leg with a claw near the front of the crab), and record your results. (Hint: Use the magnifying glass to enlarge the image for greater accuracy.)
-

14. What is the approximate area occupied by the large white sponge in the lower left of the image?
-

15. Notice the branching coral in the upper right of the image. What is the approximate area of this coral? (Outline the entire coral shape, not the individual branches.)
-

Robot Imagery Investigation Guide Answer Sheet

1. The approximate height of the portion of the soft coral visible in Figure 1 is 25.4 cm.
2. The span of the two brittle star arms that are closest to horizontal is about 10 cm.
3. The approximate length of the shrimp in the lower left of Figure 2 is 9.2 cm.
4. The approximate length of the violet sea cucumber in the upper center of Figure 2 is 10.9 cm; the sea cucumber may be somewhat larger than this, since it is farther away than the substrate where the laser dots are located.
5. The fish in Figure 4 is 6 meters from the robot, since the beam from the third laser converges with the beam from the parallel laser on the right, giving the appearance of only two dots on the fish.
6. The total length of the fish in Figure 4 is approximately 30 cm.
7. The fish in Figure 5 is 3 meters from the robot, since the beam from the third laser forms a dot that is 5.0 cm from the dot formed by the parallel laser on the right. The hint in Figure 6 is that that the angle θ is constant, so the tangent of θ is constant and equal to d / D , and also equal to b / B .
8. The total length of the fish in Figure 5 is approximately 30 cm.
9. Errors involved with video fish surveys include avoidance of the robot by some fish species, attraction to the robot by other species which may also circle the robot and be counted more than once, and the exclusion of cryptic species that hide in crevices that are out of the camera's view. In some cases, particularly when areas are being explored for the first time, it may not be possible to accurately identify every fish seen. This problem may arise when the characteristics used for identification require close inspection (such as the number of rays in a fin). Accurate identification also depends upon the experience of scientists watching the video; but occasionally, no one can identify a strange organism because it is a species new to science and has never been seen before!
10. The width (W) of a video transect made with a camera whose horizontal angle of view (A) is 90 degrees and an effective distance (D) of 5 m is:
$$W = 2 \cdot (\tan (0.5 \cdot A)) \cdot D = 2 \cdot (\tan 45) \cdot 5 = 2 \cdot 1 \cdot 5 = 10 \text{ m}$$
11. The length of a transect that begins at 2.523456° North latitude, 125.069212° East longitude, and ends at 2.525255 North latitude, 125.069146 East longitude is 0.2002 km.
12. Using values from questions 8 and 9, the area of the transect is

$$10 \text{ m} \cdot 200.2 \text{ m} = 2002 \text{ square meters}$$





To correct for the space that is outside the camera's field of view, it is necessary to subtract

$$0.5 \cdot (W \cdot D) = 25 \text{ square meters}$$

which is the shaded area shown in Figure 6.

13. The distance between the eyes of the crustacean is about 2.15 cm; the length of the longest segment in the first right cheliped is about 7.80 cm.

14. The area occupied by the large white sponge in the lower left of the image is about 353 cm².

15. The area of the branching coral in the upper right of the image is about 253 cm².

Note that students' results will vary depending upon how precisely they outline objects whose areas are to be estimated.



Resources

General

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. All links were checked on November 6, 2014.

- Goodwin, M. 2006. *Discover Your World with NOAA: An Activity Book* [Internet]. NOAA [cited November 16, 2010]. Available from: <http://celebrating200years.noaa.gov/edufun/book/welcome.html#book>. — A free printable book for home or school introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of activities focusing on the exploration, understanding, and protection of Earth as a whole system
- Gopnik, A., A.N. Meltzoff, and P.K. Kuhl. 2001. *The Scientist in the Crib. What Early Learning Tells Us About the Mind*. Harper Collins, 279 pp.
- International Technology Education Association. 2007. *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA. 260 pp.
- National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press, 2012
- Next Generation Science Standards, National Academies Press 2013. <http://www.nap.edu/NGSS/>
- NOAA Office of Ocean Exploration and Research [cited January 24, 2011]. *Okeanos Explorer* America's Ship For Ocean Exploration [Internet]. Available from: <http://oceanexplorer.noaa.gov/okeanos/about.html>; NOAA Fact Sheet about *Okeanos Explorer*
- NOAA Office of Ocean Exploration and Research [cited November 16, 2010]. Ocean Explorer Web site. Web site of NOAA's Ocean Explorer Program. Available from: <http://oceanexplorer.noaa.gov>
- NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. *Okeanos Explorer* Education Materials Collection [Internet]. Available from: <http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html>
- The President's Panel on Ocean Exploration. 2000. *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration*. 61p. Available from: <http://oceanpanel.nos.noaa.gov>

Introduction

- Connors, M. A. Exploring Fractals [Internet]. Department of Mathematics and Statistics, University of Massachusetts Amherst [cited January 4, 2011]. Available from <http://www.math.umass.edu/~mconnors/fractal/fractal.html>
- Frame, M., B. Mandelbrot, and N. Neger. Fractal Geometry [Internet]. Yale University [cited January 4, 2011]. Available from <http://classes.yale.edu/fractals/> — a collection of Web pages “to support a first course in fractal geometry for students without especially strong mathematical preparation, or any particular interest in science;” includes Laboratory Exercises, Lesson Plans, and Software
- Halley, J. M., S. Hartley, A. S. Kallimanis, W. E. Kunin, J. J. Lennon, and S. P. Sgardelis. 2004. Uses and abuses of fractal methodology in ecology. *Ecology Letters* 7: 254–271. <http://www.uvm.edu/~pdodds/teaching/courses/2009-08UVM-300/docs/others/2004/halley2004.pdf>
- Lanius, C. Fractals - A Fractals Unit for Elementary and Middle School Students [Internet]. Rice University [cited January 4, 2011]. Available from <http://math.rice.edu/~lanius/frac/>



- Mandelbrot, B. 1977. *The Fractal Geometry of Nature*. W. H. Freeman and Company. New York
- Report of the Scientific Results of the Voyage of the HMS *Challenger* During the Years 1873-76 [cited December 30, 2010]. Available from <http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/index-linked.htm>
- Scripps Institution of Oceanography [cited Dec 30, 2010]. Web site based on the “History of Oceanography: HMS *Challenger*” exhibit at the Birch Aquarium [Internet]. Available from http://www.aquarium.ucsd.edu/Education/Learning_Resources/Challenger/introduction.php
- Sea Perch Program [Internet]. Massachusetts Institute of Technology Sea Grant Program. [cited January 12, 2011]. Available from <http://seaperch.mit.edu/> – Includes detailed instructions for building a simple remotely operated underwater vehicle; based on designs from “Build Your Own Under Water Robot and Other Wet Projects” by Harry Bohm and Vickie Jensen
- Wiens, J. A. 1989. Spatial Scaling in Ecology. *Functional Ecology* 3(4): 385-397; available online at <http://www.jstor.org/pss/2389612> [cited January 4, 2011]

Telepresence

- American Radio Relay League. [cited January 7, 2011]. ARRL Education and Technology Program Curriculum Guide [Internet]. Available from <http://www.arrl.org/curriculum-guide>
- American Radio Relay League. [cited January 7, 2011]. Radio Lab Handbook [Internet]. Available from <http://www.arrl.org/radio-lab-handbook>
- Briggs, C. and A. Maverick, 1858. *The Story of the Telegraph and a History of the Great Atlantic Cable*. Rudd and Carleton. New York. 255 pp. Available from Google Books, <http://books.google.com/>.
- DeVito, J. A. 2007. *Essentials of Human Communication* (6th Edition). Allyn & Bacon. Boston. 388 pp.
- Elliott, K. and D. Butterfield 2010. Executing Telepresence: The Seattle ECC Comes Online! [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june29/june29.html>
- NOAA Office of Ocean Exploration and Research, NOAA [cited January 7, 2011]. Web site for the INDEX-SATAL 2010 Expedition [Internet]. Available from <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html> – includes links to lesson plans, career connections, and other resources
- Peters, C. 2010. A Day in the Life of an Explorer [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html>
- Pinner, W. and K. Elliott. 2010. Implementing Telepresence: Technology Knows No Bounds [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html>
- Prof. Bunsen Science [cited January 10, 2011]. Light Modulation [Internet]. Available from: <http://www.profbunsen.com.au/files/lightmodulation.pdf>
- Purwoadi, M. A. 2010. Introducing the Jakarta ECC [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june25/june25.html>
- Rathjen, D. and P. Doherty. Modulated LED [Internet]. Exploratorium® [cited January 10, 2011]. Available from: www.exploratorium.edu/square_wheels/modulated_led.pdf – Part of the “Square Wheels ...and Other Easy-To-Build, Hands-On Science Activities” collection (http://www.exploratorium.edu/square_wheels/index.html)
- Satellite Radio Frequencies [Internet]. [cited January 14, 2011]. Available from <http://www.zarya.info/Frequencies/FrequenciesISS.php>; Web site listing frequencies of radio transmissions from the International Space Station



The Radio Amateur Satellite Corporation [Internet]. [cited January 14, 2011]. Documents for New Satellite Users. Available from <http://www.amsat.org/amsat-new/information/faqs>; collection of articles introducing amateur satellites and related topics from AMSAT.org

Multibeam Sonar

Doucet M., C. Ware, R. Arsenault, T. Weber, M. Malik, L. Mayer, and L. Gee. Advanced Mid-Water Tools for 4D Marine Data Fusion and Analysis. Paper presented at OCEANS 2009, Biloxi, Mississippi, October 26-29, 2009; available online at http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5422282&url=http%3A%2F%2Fieeexplore.ieee.org%2Fexpl%2Fabs_all.jsp%3Farnumber%3D5422282

Gardner, J. V., M. A. Malik, and S. Walker 2009. Plume 1400 Meters High Discovered at the Seafloor off the Northern California Margin. EOS Transactions, American Geophysical Union, 90(32): 275 - 275

L-3 Communications SeaBeam Instruments [cited January 24, 2011]. Multibeam Sonar Theory of Operation [Internet]. Available from: <http://www.ldeo.columbia.edu/res/pi/MB-System/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf>

Lobecker, M. and E. Stuart. 2010. State of the Art Seafloor Survey [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july31/july31.html>

Malik, M. E. Lobecker, E. Stuart, C. Peters, and N. Verplanck. 2010 NOAA Ship *Okeanos Explorer* Maps Kawio Barat [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june26/june26.html>

NOAA Office of Ocean Exploration and Research [Internet]. NOAA Ocean Explorer [cited January 17, 2011]. Sonar. Available from: <http://www.oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html>

NOAA Office of Ocean Exploration and Research [cited January 14, 2011]. 2002. Magic Mountain Virtual site [Internet]. Available from: <http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html>; Links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes

Peters, C. 2010. Minding the Multibeam at Midnight [Internet]. NOAA Ocean Explorer [cited January 10, 2011]. Available from: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug05/aug05.html>

University of New Hampshire [cited January 14, 2011]. [Internet]. Available from: http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html; Video simulations of *Okeanos Explorer* discovering a midwater plume on May 17, 2009 using multibeam sonar; video formats are provided for PC users and Macintosh users

Water Column Investigations

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

NOAA Pacific Marine Environmental Laboratory [cited January 4, 2011]. [Internet]. CTD and Tow Methods Available from: <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html>

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/archive/20-4_yoerger.pdf

Underwater Robots

Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pp.

Bohm, H. 1997. Build Your Own Underwater Robot and Other Wet Projects. Westcoast Words. 148 pp.

Pinner, W. 2010. Bulk Geo-Tagging of Images Using SCS Timestamped NMEA GGA, HDT and ROV Data [Internet]. OceanDataRat.org. [cited February 2, 2011]. Available from <http://www.oceandatarat.org/?p=124>

Sea Perch Program [Internet]. Massachusetts Institute of Technology Sea Grant Program. [cited January 12, 2011]. Available from <http://seaperch.mit.edu/> – Includes detailed instructions for building a simple remotely operated underwater vehicle; based on designs from “Build Your Own Under Water Robot and Other Wet Projects” by Harry Bohm and Vickie Jensen

Key Images and Video Links

Telepresence

Images:

Control room aboard the NOAA Ship *Okeanos Explorer*.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug03/media/ex_UTC.html

The Inner Space Center (ISC) at the University of Rhode Island.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/aug7/media/isc_video.html

The science team at the University of Rhode Island’s Exploration Command Center (ECC) participate in the Mid-Cayman Rise 2011 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/bires/7_ecc_bires.jpg

A doctoral student with the MIT-WHOI joint program, based at the Seattle ECC during the INDEX-SATAL 2010 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/bires/ellie_seattle_bires.jpg

The team aboard the *Okeanos Explorer* communicates with participants at Exploration Command Centers on shore during the Mid-Cayman Rise 2011 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/dailyupdates/media/aug9_update_1.html

Video:

A series of live webcasts with San Francisco’s Exploratorium® from the NOAA Ship *Okeanos Explorer* during her maiden voyage to Indonesia in 2010. These webcasts are archived on the explo.tv site.

<http://www.exploratorium.edu/tv/index.php?project=94&program=1095>

Video footage captured by the *Little Hercules* remotely operated vehicle (ROV) and camera platform during the April 26 ROV dive from NOAA Ship *Okeanos Explorer* during the Gulf of Mexico 2012 Expedition. The dive was conducted at site 15577 – a recently mapped but never-before seen shipwreck in the western Gulf of Mexico.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/dailyupdates/media/movies/highlights0426_video.html

Multibeam Sonar Mapping

Images:

A Senior Survey Technician makes an entry in the mapping watch log book during the INDEX-SATAL 2010 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/bires/mapper_bires.jpg

Slideshow of 3D bathymetric images from the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/media/slideshow/flash_slideshow.html



Flat-topped Bear Seamount off the coast of Massachusetts rises approximately 2000 meters from the surrounding ocean floor to a depth of 1100 meters from the Mountains in the Sea 2003 Expedition.

<http://oceanexplorer.noaa.gov/explorations/03mountains/logs/summary/media/seamounts.html>

Videos:

Mendocino Ridge gas plume discovery off the California coast.

http://oceanexplorer.noaa.gov/okeanos/media/movies/ex_podcast_video.html

Magic Mountain Chimney Fields in the Northeast Pacific Ocean - an interactive map which links to computer animations of the seafloor.

<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html>

3D fly-throughs of volcanoes during the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

<http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html>

3D fly throughs of the volcanoes mapped on the New Zealand American Submarine Ring of Fire 2005 Expedition.

<http://oceanexplorer.noaa.gov/explorations/05fire/background/kermadecarc/kermadecarc.html>

Water Column Investigations

Images:

A scientist extracts water from one of the sample bottles in the CTD rosette during the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

<http://oceanexplorer.noaa.gov/explorations/12fire/logs/sept20/media/scientistctd.html>

Illustration of a CTD “tow-yo”.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/bires/tow_yo_diagram_bires.jpg

Scientists examine multibeam and CTD data in preparation for a dive during the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

<http://oceanexplorer.noaa.gov/explorations/12fire/logs/sept20/media/scientistslab.html>

CTD data from a “tow-yo” in the Western Pacific.

http://oceanexplorer.noaa.gov/explorations/12fire/background/plumes/media/ctd_results.html

Underwater Robots

Images:

The ROV *Little Hercules* aboard the *Okeanos Explorer*.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/background/bires/plan_little_herc_bires.jpg

The ROV sled *Seirios* being deployed from the *Okeanos Explorer*.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/background/plan/media/plan_seirios_launching.html

The Quest 4000 remotely operated vehicle during the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

<http://oceanexplorer.noaa.gov/explorations/12fire/logs/sept19/media/quest4000.html>

The Quest 4000 remotely operated vehicle collecting geological samples with the manipulator claw during the Submarine Ring of Fire 2012: Northeast Lau Basin Expedition.

<http://oceanexplorer.noaa.gov/explorations/12fire/logs/sept19/media/claw.html>

The Autonomous Benthic Explorer (ABE), a free-swimming robot.

<http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration1.html>

NOAA Ocean Explorer Web page on submersible technology; includes many images of underwater vehicles.

<http://oceanexplorer.noaa.gov/technology/subs/subs.html>

Video:

Geologists and biologists explore the sea floor during the March 23 ROV dive from the NOAA Ship *Okeanos Explorer* during the Gulf of Mexico 2012 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/mar23/media/movies/highlights0323_wm640.wmv

A gas capture device is assembled and installed on the *Little Hercules* ROV, then deployed by the team on the *Okeanos Explorer* during the Gulf of Mexico 2012 Expedition.

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/apr18/media/movies/highlights0415_video.html



Ocean Literacy Essential Principles and Fundamental Concepts

Grades 5-8

	1. To Explore Strange New Worlds	2. A Day in the Life of an Ocean Explorer	3. Wet Maps	4. Mapping the Deep Ocean Floor	6. What's a CTD?	7. The Oceanographic Yo-yo	9. Invent a Robot	10. What Little Herc Saw
EP 1. The Earth has one big ocean with many features.								
FC a. The ocean is the dominant physical feature on our planet Earth— covering approximately 70% of the planet’s surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.	•							
FC b. Ocean basins are composed of the seafloor and all of its geological features (such as islands, trenches, mid-ocean ridges and rift valleys) and vary in size, shape and features due to the movement of Earth’s crust (lithosphere). Earth’s highest peaks, deepest valleys and flattest vast plains are all in the ocean.	•			•	•	•	•	•
FC c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth’s rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation. This ‘global ocean conveyor belt’ moves water throughout all of the ocean’s basins, transporting energy (heat), matter, and organisms around the ocean. Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.								
FC d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.								
FC e. Most of Earth’s water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. The salt in seawater comes from eroding land, volcanic emissions, reactions at the seafloor, and atmospheric deposition.								
FC f. The ocean is an integral part of the water cycle and is connected to all of the earth’s water reservoirs via evaporation and precipitation processes.								
FC g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.								
FC h. Although the ocean is large, it is finite and resources are limited.								
EP 2. The ocean and life in the ocean shape the features of the Earth.								
FC 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.								
FC b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.								
FC c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials— occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.								
FC d. Sand consists of tiny bits of animals, plants, rocks and minerals. Most beach sand is eroded from land sources and carried to the coast by rivers, but sand is also eroded from coastal sources by surf. Sand is redistributed by waves and coastal currents seasonally.								
FC e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.								



Ocean Literacy Essential Principles and Fundamental Concepts Grades 5-8 (continued)

	1. To Explore Strange New Worlds	2. A Day in the Life of an Ocean Explorer	3. Wet Maps	4. Mapping the Deep Ocean Floor	6. What's a CTD?	7. The Oceanographic Yo-yo	9. Invent a Robot	10. What Little Herc Saw
EP 3. The ocean is a major influence on weather and climate.								
FC a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.								
FC b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.								
FC c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.								
FC d. Most rain that falls on land originally evaporated from the tropical ocean.								
FC e. The ocean dominates the Earth's carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.								
FC f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.								
FC g. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.								
EP 4. The ocean makes Earth habitable.								
FC a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.								
FC b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.								
EP 5. The ocean supports a great diversity of life and ecosystems.								
FC a. Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.	•							
FC 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.								
FC 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.	•							
FC 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.	•	•						
FC 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.	•	•	•	•	•	•	•	•
FC 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.	•	•						
FC 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.	•	•	•	•	•	•	•	•

Ocean Literacy Essential Principles and Fundamental Concepts

Grades 5-8 (continued)

	1. To Explore Strange New Worlds	2. A Day in the Life of an Ocean Explorer	3. Wet Maps	4. Mapping the Deep Ocean Floor	6. What's a CTD?	7. The Oceanographic Yo-yo	9. Invent a Robot	10. What Little Herc Saw
FC h. Tides, waves and predation cause vertical zonation patterns along the shore, influencing the distribution and diversity of organisms.								
FC i. Estuaries provide important and productive nursery areas for many marine and aquatic species.								
EP 6. The ocean and humans are inextricably interconnected.								
FC 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.	•	•						
FC b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.	•	•	•	•	•	•	•	•
FC c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.								
FC d. Much of the world's population lives in coastal areas.								
FC e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.	•							
FC f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).								
FC g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.	•		•	•	•	•	•	•
EP 7. The ocean is largely unexplored.								
FC 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.	•	•	•	•	•	•	•	•
FC b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.	•	•	•	•	•	•	•	•
FC c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.			•	•	•	•	•	•
FC 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.	•	•	•	•	•	•	•	•
FC e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems.	•							
FC 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.	•	•	•	•	•	•	•	•



Ocean Literacy Essential Principles and Fundamental Concepts

Grades 9-12

	5. Watching in 3D	8. A Quest for Anomalies	11. Through Robot Eyes
EP 1. The Earth has one big ocean with many features.			
FC a. The ocean is the dominant physical feature on our planet Earth—covering approximately 70% of the planet’s surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian, Southern and Arctic.			
FC b. Ocean basins are composed of the seafloor and all of its geological features (such as islands, trenches, mid-ocean ridges and rift valleys) and vary in size, shape and features due to the movement of Earth’s crust (lithosphere). Earth’s highest peaks, deepest valleys and flattest vast plains are all in the ocean.	•	•	•
FC c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth’s rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation. This ‘global ocean conveyor belt’ moves water throughout all of the ocean’s basins, transporting energy (heat), matter, and organisms around the ocean. Changes in ocean circulation have a large impact on the climate and cause changes in ecosystems.			
FC d. Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.			
FC e. Most of Earth’s water (97%) is in the ocean. Seawater has unique properties: it is saline, its freezing point is slightly lower than fresh water, its density is slightly higher, its electrical conductivity is much higher, and it is slightly basic. The salt in seawater comes from eroding land, volcanic emissions, reactions at the seafloor, and atmospheric deposition.			
FC f. The ocean is an integral part of the water cycle and is connected to all of the earth’s water reservoirs via evaporation and precipitation processes.			
FC g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.			
FC h. Although the ocean is large, it is finite and resources are limited.	•		
EP 2. The ocean and life in the ocean shape the features of the Earth.			
FC 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.			
FC b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.			
FC c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials—occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.			
FC d. Sand consists of tiny bits of animals, plants, rocks and minerals. Most beach sand is eroded from land sources and carried to the coast by rivers, but sand is also eroded from coastal sources by surf. Sand is redistributed by waves and coastal currents seasonally.			
FC e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.			

Ocean Literacy Essential Principles and Fundamental Concepts

Grades 9-12 (continued)

	5. Watching in 3D	8. A Quest for Anomalies	11. Through Robot Eyes
EP 3. The ocean is a major influence on weather and climate.			
FC a. The ocean controls weather and climate by dominating the Earth’s energy, water and carbon systems.			
FC b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.			
FC c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.			
FC d. Most rain that falls on land originally evaporated from the tropical ocean.			
FC e. The ocean dominates the Earth’s carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.			
FC f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.			
FC g. Changes in the ocean’s circulation have produced large, abrupt changes in climate during the last 50,000 years.			
EP 4. The ocean makes Earth habitable.			
FC a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.			
FC b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.			
EP 5. The ocean supports a great diversity of life and ecosystems.			
FC a. Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.			
FC 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.			
FC 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.			
FC 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.			
FC 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.	•	•	•
FC 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.			
FC 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.	•	•	•

Ocean Literacy Essential Principles and Fundamental Concepts Grades 9-12 (continued)

	5. Watching in 3D	8. A Quest for Anomalies	11. Through Robot Eyes
FC h. Tides, waves and predation cause vertical zonation patterns along the shore, influencing the distribution and diversity of organisms.			
FC i. Estuaries provide important and productive nursery areas for many marine and aquatic species.			
EP 6. The ocean and humans are inextricably interconnected.			
FC 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.			
FC b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.	•	•	•
FC c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.			
FC d. Much of the world's population lives in coastal areas.			
FC e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.			
FC f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).			
FC g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.	•	•	•
EP 7. The ocean is largely unexplored.			
FC 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.	•	•	•
FC b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.	•	•	•
FC c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.	•	•	•
FC 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.	•	•	•
FC e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems.			
FC 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.	•		•



Appendix A: Ocean Exploration Careers

OceanAGE (Another Generation of Explorers) Web site

The NOAA Ocean Explorer OceanAGE web presence (<http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html>) is a unique online educational resource that enables users to learn more about a variety of ocean careers available to those interested in work on or in the ocean. The site is populated with a diversity of talented people who explore our ocean planet, and range from explorers, graduate students, submersible pilots, and vessel crew to NOAA Corps Officers. The target audience for this interesting mini-database of scientific and technical careers is students of any age, and any others interested in learning more about the diversity of career options for scientific and technical work that supports ocean exploration and research careers at sea.



A page from the OceanAge Web site featuring Catalina Martinez, one of NOAA's ocean explorers.

<http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html>

Components of the OceanAGE site consist of video profile interviews presenting a multitude of ocean-oriented careers. These are supplemented with imagery, biographies, and other related content and resources. The OceanAGE online video profiles offer a storyline of each featured career, including an introduction about the person being featured, his/her background, education, type of research or job currently involved/employed in, and personal rewards/obstacles encountered along the way. A career timeline is also presented, from youth to adult professional accomplishments. Other career opportunities they might be qualified for, as well as hobbies, are also featured. Through the video web interfaces, visitors to the site can hear from explorers and scientists such as *Titanic* discoverer Dr. Robert Ballard, who details his background and his job as an oceanographer (<http://oceanexplorer.noaa.gov/edu/oceanage/05ballard/welcome.html>), and Dr. Shirley A. Pomponi, who has dedicated her life to researching the ocean for marine natural products (<http://oceanexplorer.noaa.gov/edu/oceanage/03pomponi/pomponi.html>).

OceanAGE videos are filmed at sea during an expedition, or in the workplace or laboratory where the featured presenters continue their exploration work. Appealing imagery highlights the most interesting achievements for each specific career. Depending on the individual background, additional resources are provided, including research papers, articles, and other relevant content.



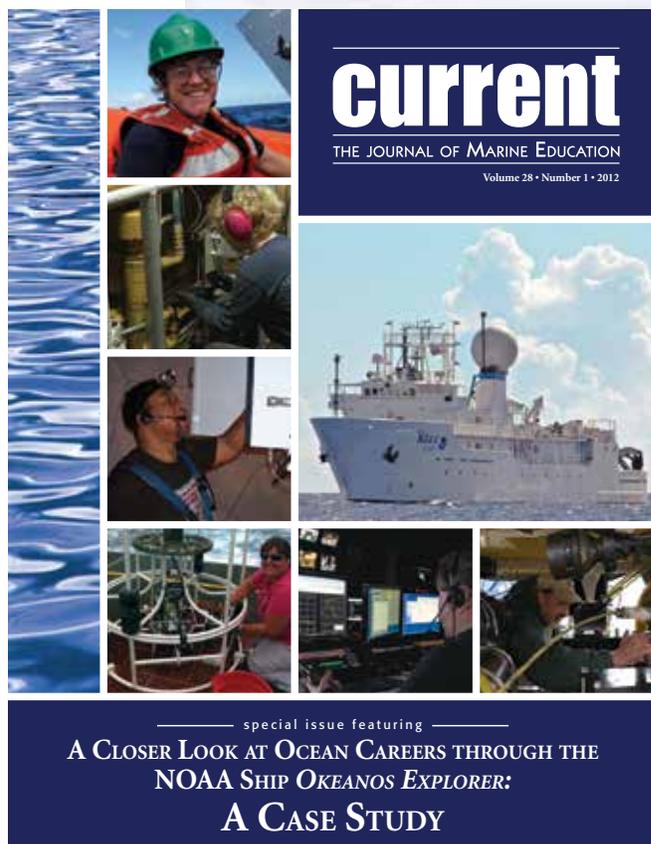
Many of those featured on OceanAGE travel worldwide through their work. Students interested in careers that would enable them to travel while working on or in the ocean hear firsthand about these experiences. OceanAGE can also open many doors for learning about ocean technologies, and personal life experiences. OceanAGE online video profiles have also been used in higher education as material for introducing careers such as that of a submersible pilot, an archaeologist, a fish ecologist and a mammal biologist.

OceanAGE continues to be populated with those involved in exploration efforts in partnership with NOAA's Office of Ocean Exploration and Research (OER), so that Web site visitors will be able to more effectively learn from personal stories about the fascinating people who explore our little-known ocean world. OER encourages educators to use the OceanAGE site with their students in an effort to potentially inspire their career choices and build a more robust, competitive science and engineering workforce to help meet the needs of the future ocean sciences community. Visit us at: <http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html>.

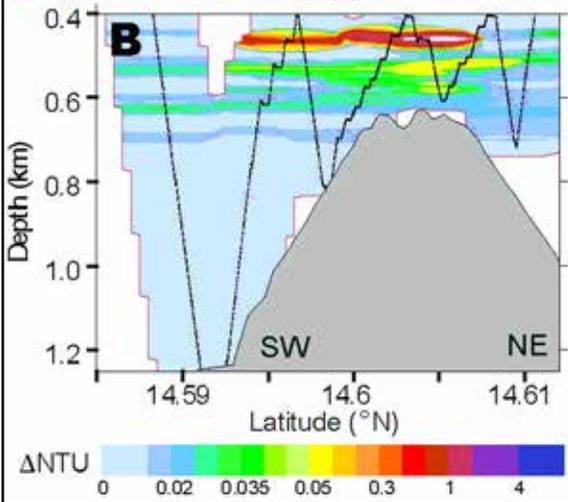
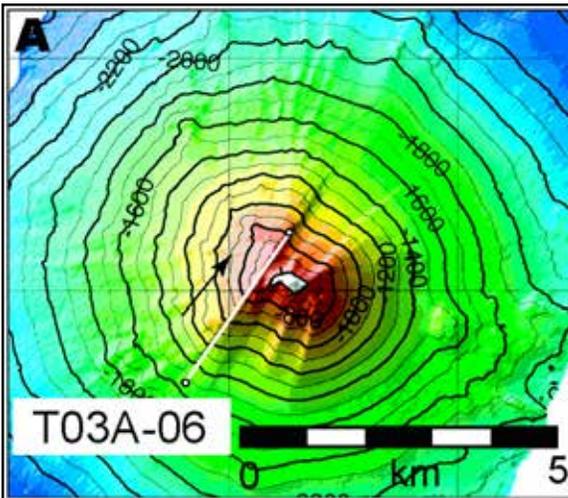
A Closer Look at Ocean Careers through the NOAA Ship *Okeanos Explorer*: "A Case Study"

In the late summer of 1998, just after the NOAA Ship *Okeanos Explorer* was commissioned in Seattle, Washington, an *Okeanos Explorer* Education Forum was held for two days during which participants made recommendations for developing an education program based on the ship's unique capabilities and assets. The participants discussed at length the importance of making the *Okeanos Explorer* "come alive" by capturing the enthusiasm of the ship's officers, crew and explorers as they live and work onboard the Nation's first dedicated ship for ocean exploration. At the Forum, the participants recommended that a Special Issue of *Current: The Journal of Marine Education* be produced, featuring the lives and work of the men and women on board the *Okeanos Explorer*.

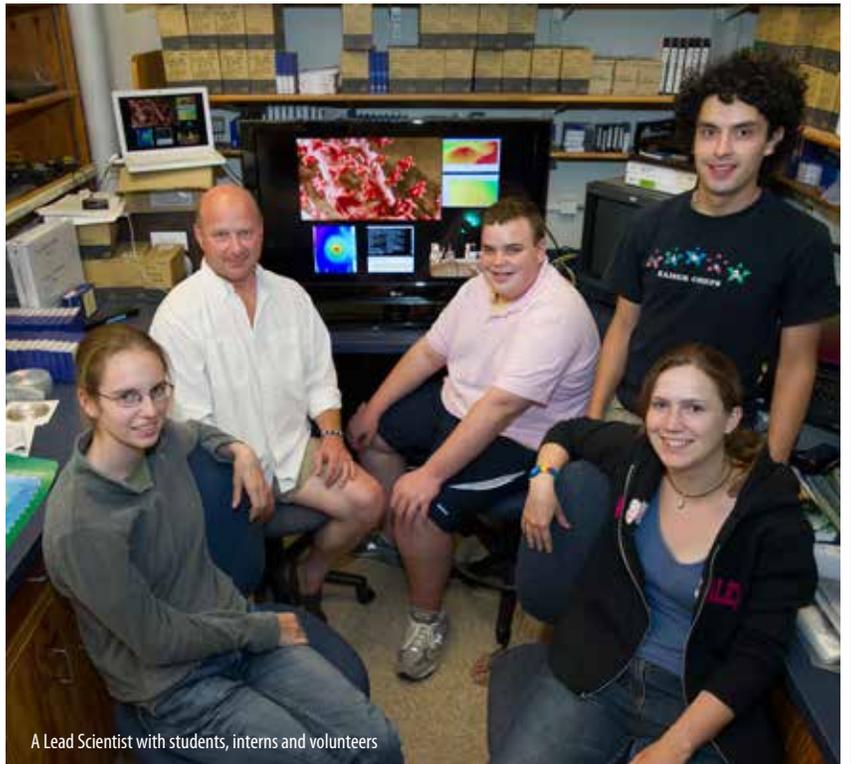
Those on board the *Okeanos Explorer* are, of course, not the only officers, crew and explorers in the world and the instrumentation is not unique to the *Okeanos Explorer*, however, the combination of personnel and instrumentation on a single U.S. vessel dedicated to ocean exploration is unique and is presented in a Special Issue of *Current* entitled *A Closer Look at Ocean Careers through the NOAA Ship Okeanos Explorer: A Case Study*, Volume 28, No. 1, 2012 (http://oceanexplorer.noaa.gov/edu/oceanage/current_careers.pdf). It is written for educators and students wishing to know more about the paths traveled and daily goings-on of those who dedicate their lives to understanding more about our little-known ocean world. Who knows? Perhaps one educator can tell a little different "career" story to one student as a result of reading an interesting article in this issue, and together, they can make a difference. . . just like the differences that are being made by those represented in the "stories" told in this special issue of *Current*.



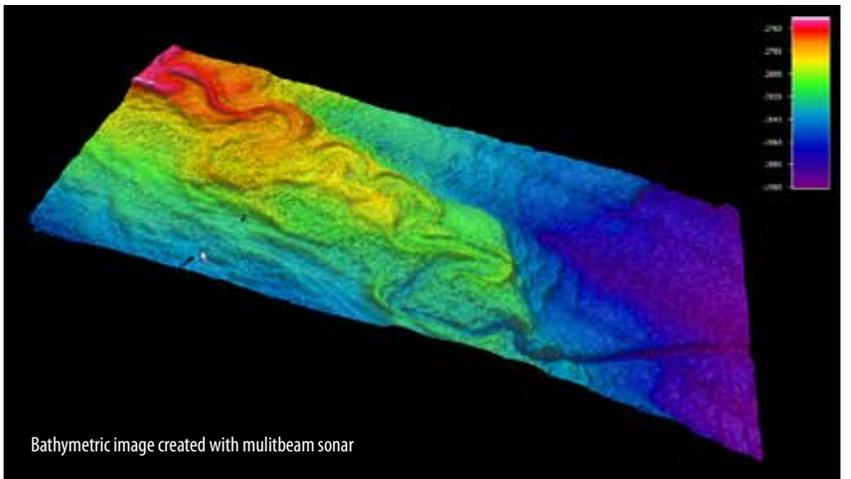
The cover of the Special Issue of *Current: A Closer Look at Ocean Careers through the NOAA Ship Okeanos Explorer: A Case Study*, Volume 28, No. 1, 2012.
http://oceanexplorer.noaa.gov/edu/oceanage/current_careers.pdf



Plotted results of towed hydrocast over an underwater volcano



A Lead Scientist with students, interns and volunteers



Bathymetric image created with multibeam sonar



Early morning view of back deck and VSAT on board the *Okeanos Explorer*



A Lead Scientist discusses complex ocean bottom topography with the ROV Team Lead

