Section 1: Background Information for Volume 2: How Do We Explore?

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

Okeanos Explorer's prominent VSAT (Very small aperture terminal) dome enables satellite communications between explorers ashore and at sea and provides multiple high-definition video streams for widespread dissemination. Image credit: NOAA.

To Explore Strange New Worlds

This lesson guides student inquiries 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 inquiries into key topics of Telepresence, Multibeam Mapping, Water Column Investigations, and Underwater Robots. Activities for many of these lessons are designed to include elements of science, technology, engineering, and mathematics (STEM) to support ongoing STEM education and career initiatives.

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 12 (Life Science/Physical Science/Earth Science)

Focus Question
What methods do scientist explorers use to explore places that have never been seen before?

Learning Objectives
- Students will describe requirements for explorations of unknown areas on Earth.
- Students will discuss factors that influenced exploration strategies of the Lewis and Clark and HMS *Challenger* Expeditions.
- Students will describe the overall exploration strategy used aboard the NOAA Ship *Okeanos Explorer*.
- Students will describe how fractal geometry models natural systems, and how scale influences exploration strategies and results.

Materials
- Copies of *Exploration Strategies Inquiry Guide*, one for each student group
- Overhead transparency of *Koch Curve Construction*
- Drawing paper
- Ruler for each student group
- Pencils or markers

Audiovisual Materials
- Overhead projector

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

Highlights in this Lesson

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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 Information
NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

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 discoveries and laying the foundation for future investigations;

Research is about understanding things that are discovered.

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 or what they will need to do to achieve their objectives. The exploration strategy designed for the *Okeanos Explorer* has taken years to develop, and has involved dozens of scientists, engineers, ocean experts, and visionaries.

Years of planning, field trials, and state-of-the-art technology came together for the first time on the *Okeanos Explorer*'s maiden voyage as part of the INDEX-SATAL 2010 Expedition. This expedition was an international collaboration between scientists from the United States and Indonesia to explore the deep ocean in the Sangihe Talaud Region. This region is located in the 'Coral Triangle', which is the global heart of shallow-water marine biodiversity. A major objective of the expedition was to advance our understanding of undersea ecosystems, particularly those associated with submarine volcanoes and hydrothermal vents. Among the Expedition's many "firsts," this was the first time scientists have been able to use an underwater robot to get a first-hand look at deepwater biodiversity in the waters of the Sangihe Talaud Region. For more information about the INDEX-SATAL 2010 Expedition, please see the Diving Deeper section, page 17.

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

Okeanos Explorer Vital Statistics:
Commissioned: August 13, 2008; Seattle, Washington
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

For more information, visit *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
Follow voyages of America's ship for ocean exploration with the *Okeanos Explorer* Atlas at *http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm*

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*

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?

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

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 ability to speak native American languages) needed by the expedition.

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 credit: NOAA. *http://www.19thcenturyscience.org/HMSC/HMSC-INDEX/group.jpg*

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 about 220.

Like the HMS *Challenger* Expedition, 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 *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.

The impact of telepresence is marvelous: 10-20 scientists and thousands of public onlookers from three countries, five time zones, and distributed across thousands of miles, are able witness, discuss and document the incredible life and habitats existing at the bottom of an Indonesian Sea. Participants marvel at imagery sent from the bottom of the Indonesian sea to monitors at the Seattle ECC. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/seattle_command_center_hires.jpg*

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.

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 *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, 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 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.

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 Lessons 2, 3, and 4);
- Multibeam sonar mapping system (discussed in Lessons 5, 6, and 7);
- CTD (an instrument that measures conductivity, temperature, and depth) and other electronic sensors to measure chemical and physical seawater properties (discussed in Lessons 8, 9, and 10); and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery in depths as great as 4,000 meters (discussed in Lessons 11, 12, and 13).

For more information about these technologies, please see the Diving Deeper section.

How to Look?

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.

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 B of this lesson guides students inquiry into fractal geometry as a tool for modeling natural systems, and how this tool might be used to plan deep-ocean explorations.]

Key Images and Video Resources

NOAA Ship *Okeanos Explorer* 2008-2010 Slideshow Collection: *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html*

NOAA Ship *Okeanos Explorer* 2008-2010 Video Playlist: *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/video_playlist.html*

INDEX-SATAL 2010 Expedition Slideshows: *http://oceanexplorer.noaa.gov/okeanos/media/slideshow/flash_slideshow.html*

Photo and Video Log: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/photolog/photolog.html*

Okeanos Explorer Digital Atlas

The *Okeanos Explorer* Digital Atlas is a map-based tool that allows users to view information from *Okeanos Explorer* missions, including the ship's track, meteorological and oceanographic observations, bathymetric data, information from ROV dives, and other data products: *http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm*

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_what.pdf*);
   (c) Make copies of the *Exploration Strategies Inquiry Guide*.
   (d) 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."

2. Briefly introduce the INDEX-SATAL 2010 Expedition. Point out that this expedition is 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 *Okeanos Explorer* on its voyages of discovery. Provide each student or student group with a copy of the *Exploration Strategies Inquiry Guide*. 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.

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.

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 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 360 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 of the 360 stations were:
  - water depth
  - temperature at various depths
  - weather conditions
  - water conditions at surface and sometimes at depth

Careers in Ocean Exploration

Modern ocean explorers typically have skills that include Science, Technology, Engineering, and Mathematics. The log essay from July 29, 2010 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html*) gives a glimpse of the range of activities involved in a typical day aboard the *Okeanos Explorer*, and essays from July 7 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html*) and August 12 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug02/aug02.html*) provide more information about the ROV Team and NOAA Corps Officers aboard the ship.

You can watch video interviews with many modern ocean explorers on the Ocean Explorer OceanAGE Web page (*http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*). For more information, and links, see Discovering Careers in Ocean Exploration in the Diving Deeper section, page 22.

ROV team members Karl McLetchie, Tom Kok, and Joel De Mello in front of *Little Hercules*. Even with the ROV secure on deck, work continues with routine checks and maintenance. Image courtesy of C. Verplanck, NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/rov_deck_hires.jpg

- 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.

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.

   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 "Background" section (above):
   - 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 100 ft 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 inquiry.

Part B. The Fractal Geometry of Nature

1. 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 is a well-known example that provides a useful starting point for exploring fractals.

2. 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

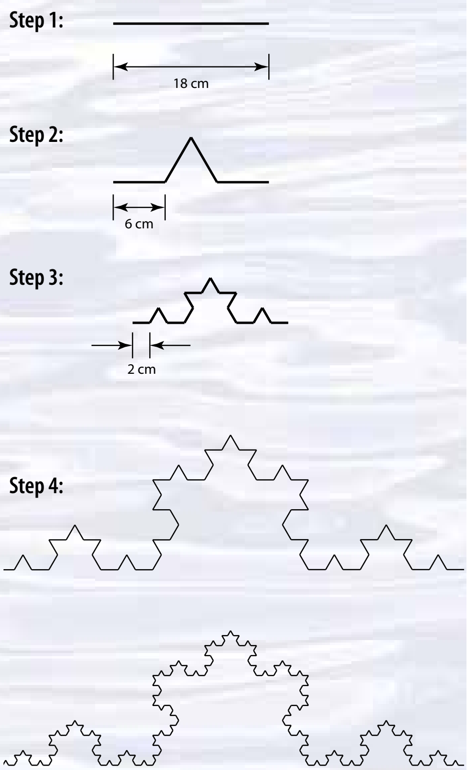
various objects that are approximately circular (*e.g.*, the moon), but should realize that if one looks closely enough there are many irregularities that prevent the objects from being exactly circular.

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.

Koch Curve Construction



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).

3. 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.

4. 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 *Inquiry Guide* 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 *Inquiry Guide* questions. Individual *Inquiry 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 *Inquiry Guide* questions and class discussions provide opportunities for assessment.

How Do We Explore? Lessons

Telepresence

A Day in the Life of an Ocean Explorer (Grades 5-6)

Focus: Telepresence and communications for ocean exploration

Students identify the basic requirements for human communication; describe at least three ways in which humans communicate; discuss the importance of scientific communication; and explain the concept of telepresence, how it is implemented aboard NOAA Ship *Okeanos Explorer*, and how it is used to increase the pace, efficiency, and scope of ocean exploration.

Please Pass the Remote (Grades 7-8)

Focus: Wireless communication for ocean exploration

Students identify and discuss at least five ways in which they use wireless technology; discuss the importance of communication to science, and describe some of the factors that contribute to the complexity of human communication; discuss factors that influence the effectiveness of human communication; identify the major components of a wireless communications station, and how these are used to implement telepresence aboard the *Okeanos Explorer*.

Wow, That Hertz! (Grades 9-12)

Focus: Communications physics

Students explain the concept of energy transfer though wave propagation, and how this process is used to support telepresence and scientific communications aboard the *Okeanos Explorer*; define an electric current, and describe the relationship between current, voltage and resistance using Ohm's Law; and identify and describe the function of the five basic electronic building blocks that make radios work.

Multibeam Mapping

Wet Maps (Grades 5-6)

Focus: Bathymetric mapping

Students describe three types of bathymetric maps, and discuss how each type may be used by ocean explorers; compare and contrast bathymetric mapping technologies; explain why multibeam mapping is used aboard the *Okeanos Explorer*; and simulate a multibeam sonar system to create a three-dimensional map of a model seafloor.

Mapping the Deep-Ocean Floor (Grades 7-8)

Focus: Bathymetric mapping

Students explain the advantages of 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.

Watching in 3-D (Grades 9-12)

Focus: Multibeam sonar

Students describe multibeam sonar and explain why the velocity of sound in water must be measured before maps can be created with the *Okeanos Explorer*'s multibeam sonar system; and interpret three-dimensional multibeam data of underwater features mapped by the *Okeanos Explorer*.

Water Column Investigations

What's a CTD? (Grades 5-6)

Focus: Measuring physical properties of seawater for ocean exploration

Students define "CTD" and explain how this instrument is used aboard the *Okeanos Explorer*; define salinity and density; explain how relationships between temperature, salinity, and density in seawater are useful to ocean explorers; and use data from the *Okeanos Explorer* to create and interpret graphs of temperature, salinity, and depth.

The Oceanographic Yo-yo (Grades 7-8)

Focus: Ocean chemistry and hydrothermal vents

Students explain the effects of hydrothermal vents on chemical and physical parameters of seawater; describe instruments aboard the *Okeanos Explorer* that detect these effects; and analyze data from the *Okeanos Explorer* to find chemical clues that suggest the presence of hydrothermal vents.

A Quest for Anomalies (Grades 9-12)

Focus: Use of CTD data in ocean exploration

Students describe and explain redox potential and optical backscatter, and how these parameters are related to deep-sea ecosystems and geologic features; and analyze data from CTD casts aboard the *Okeanos Explorer* for the presence of anomalies.

Underwater Robots

Invent a Robot! (Grades 5-6)

Focus: Engineering Design

Students discuss advantages and disadvantages of using underwater robots in scientific explorations, and how underwater robots are used aboard the *Okeanos Explorer*; use the process of engineering design to develop potential solutions for an ocean exploration problem; and explain the principle of hydraulic power transfer systems, and construct a robotic arm that demonstrates this principle.

What *Little Herc* Saw (Grades 7-8)

Focus: Use of robotics for ocean exploration

Students discuss the importance of robotic vehicle technology to the ocean exploration strategy used aboard the *Okeanos Explorer*; discuss how information from underwater robots about biological and geological features is relevant to the concept of biodiversity; and demonstrate a process for analyzing video data from the *Okeanos Explorer*'s underwater robot.

Through Robot Eyes (Grades 9-12)

Focus: Image analysis

Students describe typical applications and limitations of imagery obtained with remotely operated vehicles (ROVs); demonstrate how lasers may be used to calibrate images for size and distance measurements; and analyze ROV imagery from the *Okeanos Explorer* to make inferences about deep-ocean habitats.

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/lessonplans/media/10journeyunknown.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/lessonplans/media/10comeondown.pdf

Focus: Ocean Exploration (Physical Science)

Students will research the development and use of research vessels/vehicles used for deep-ocean exploration; calculate the density of objects by determining the mass and volume; and construct a device that exhibits neutral buoyancy.

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/lessonplans/media/10callingallexplorers.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.

Other Resources

Anonymous. 2010. Web site for the INDEX-SATAL 2010 Expedition [Internet]. Office of Ocean Exploration and Research, NOAA [cited January 7, 2011]. Available from *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html* – includes links to lesson plans, career connections, and other resources

Anonymous. Ocean Explorer [Internet]. NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. Available from: *http://oceanexplorer.noaa.gov*.

Anonymous. Web site based on the "History of Oceanography: HMS *Challenger*" exhibit at the Birch Aquarium [Internet]. Scripps Institution of Oceanography [cited Dec 30, 2010]. Available from *http://www.aquarium.ucsd.edu/Education/Learning_Resources/Challenger/introduction.php*.

Anonymous. Online version of the 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*.

Anonymous. 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

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

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

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.

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.

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]

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard C: Life Science

- Populations and ecosystems
- Diversity and adaptations of organisms

Content Standard D: Earth and Space Science

- Structure of the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

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

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Nature of science
- History of science

Ocean Literacy Essential Principles and Fundamental Concepts

Because most Fundamental Concepts are broad in scope, some aspects of some Concepts may not be explicitly addressed in this lesson. Such aspects, however, can be easily included at the discretion of the individual educator.

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept 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.

Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

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

Fundamental Concept a. Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.

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

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

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

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

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

Essential Principle 7.
The ocean is largely unexplored.

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

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

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

Fundamental Concept 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.

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

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
oceanexeducation@noaa.gov

For More Information

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Diving Deeper: Additional Information about Key Topics

This section provides additional details and discussion of selected topics mentioned in "Background Information."

The INDEX-SATAL 2010 Expedition

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

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

http://oceanexplorer.noaa.gov/okeanos/media/hires/ex_bow_starboard_side_hires.jpg

During the INDEX-SATAL 2010 Expedition, U.S. and Indonesian scientists worked side-by-side on two ships, the *Okeanos Explorer* (above) and the Indonesian research vessel *Baruna Jaya IV* (below), and at Exploration Command Centers (ECCs) ashore. Image courtesy of NOAA Office of Ocean Exploration and Research.

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

Indonesia is well-known as one of Earth's major centers of biodiversity (which means the variety of all forms of life). Although Indonesia covers only 1.3 percent of Earth's land surface, it includes:

- 10 percent of the world's flowering plant species;
- 12 percent of the world's mammal species;
- 16 percent of all reptile and amphibian species;
- 17 percent of the world's bird species;
- 15 percent of the world's coral reefs;
- the highest number of coral species in the world (more than 450 identified species); and
- more than 2000 species of near shore fishes.

Very little is known about Indonesia's deep ocean, but scientists expect that biodiversity may be high there as well, along with new ecosystems and many species that have never been seen before.

Scientists in the Exploration Command Center at NOAA's Pacific Marine Environmental Laboratory in Seattle view live video from the *Okeanos Explorer's* ROV. Image courtesy NOAA
http://www.pmel.noaa.gov/images/headlines/ecc.jpg

Key questions for the expedition included:

- Where are active geologic processes producing submarine volcanoes and hydrothermal vents?
- What ecosystems are associated with seamounts, spreading centers, and trenches in Indonesia's deep sea?
- What is the role of deep-sea volcanically-derived gasses such as carbon dioxide in ocean acidification processes, and climate variability?
- How does biodiversity in Indonesia vary spatially across the region?
- Do extremely high biodiversity patterns of Indonesian shallow water coral reef ecosystems extend to other depths and habitats?

New submarine volcanoes, a large hydrothermal field with a thriving exotic animal ecosystem and areas rich with deep-sea ocean animals were some of the discoveries made during the expedition. For more information, including video and still images, see *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html*. Benefits from deep-ocean exploration in Indonesia are discussed further in "INDEX-SATAL 2010 Expedition Purpose," *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/purpose.html*.

Telepresence

[Note: The following discussion is adapted, in part, from the July 9, 2010 mission log by Webb Pinner and Kelley Elliott; *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july09/july09.html*]

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

The *Okeanos Explorer*'s powerful satellite dome enables explorers aboard the ship to have high-bandwidth communication with remote parts of the world. "High-bandwidth" means that a large amount of data can be transmitted from the ship 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 as deep as 4000 m to the Exploration Command Centers (ECCs) thousands of miles away in an average of 6 seconds.

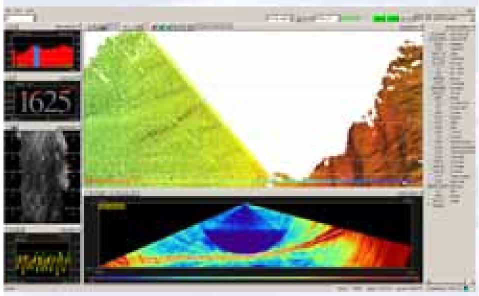
All communications with the shore are made possible by the *Okeanos Explorer*'s powerful satellite dome, which enables the ship to establish high-bandwidth connectivity with Exploration Command Centers throughout the world. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/okeanos_vsat_hires.jpg*

Voice communications use an Internet-based intercom system which 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. 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. The Eventlog software automatically records the date, time of entry, and author of each text observation.

The ability to watch the live events aboard the *Okeanos Explorer* is not limited to those with access to an ECC. Video streams from the ship are distributed over advanced computer network called Internet2 that allows users in academic institutions around the globe to simultaneously view the live video. At the beginning of the INDEX-SATAL Expedition, only computers connected to this advanced network were able to view video streams but as the excitement built up around the *Okeanos Explorer* and the Expedition, participants began using increasingly creative solutions for developing ad-hoc viewing stations and in some cases mini-ECCs utilizing the standard Internet. These solutions extended telepresence capabilities to smaller academic institutions, public venues, hotel rooms, the cafeteria at the U.S. Embassy in Jakarta, and even at one scientist's private residence.

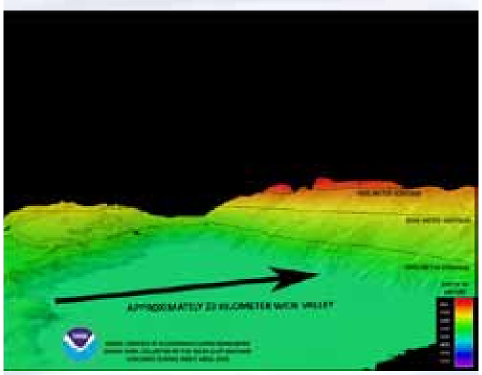
Multibeam Sonar

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 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 that 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.



This is a screen grab from the multibeam acquisition computer during a typical mapping watch. The center area shows the coverage, on the left is the sonar signal strength, depth, backscatter and ship motion data. The bottom window is the water column display, where the sonar can also detect features such as plumes. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/multibeam_acq_hires.jpg*

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 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 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.



The EM302 gives us a high resolution "birds 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 you 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 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 432 depth measurements in a single swath, 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.

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

CTD

CTD stands for conductivity, temperature, and depth, and refers to 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 instruments that can measure additional physical or chemical properties.

Two commonly used supplemental sensors measure optical backscatter and redox potential. Optical backscatter is important because the oxidation of methane from cold-seeps causes precipitates of carbonate material to form. These precipitates cause the normally clear deep-ocean water to become cloudy so that light shining through the water is scattered and reflected back toward the light source.

Redox potential is a measure of the tendency of a substance to gain or lose electrons. Redox potential 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 redox potential may signal the presence of chemosynthetic communities nearby.

Ocean explorers often use CTD measurements to detect evidence of volcanoes, hydrothermal vents, and other deep-sea features that cause changes to the physical and chemical properties of seawater. Masses of changed seawater 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 usually 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.

Okeanos Explorer carries a Seabird Electronics Model 9/11+ CTD system mounted on a SBE 32 rosette frame. This rosette includes 24 sampling bottles that can be individually triggered to collect samples at various depths. 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.

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

Remotely Operated Vehicles

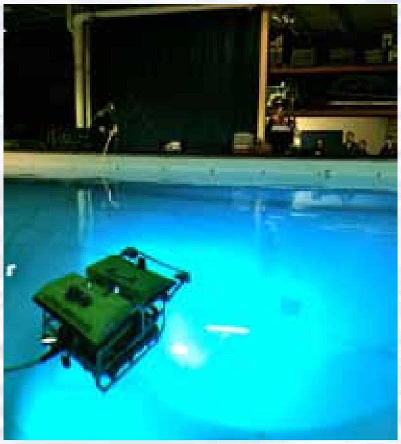
Remotely operated vehicles (ROVs) are unoccupied robots linked to an operator by a group of cables. Underwater ROVs are usually controlled by an operator aboard a surface ship. These robots typically include five basic systems:

- Power system;
- Propulsion system;
- Communication system;
- Buoyancy control system; and
- Information gathering system(s).

In addition, some ROVs are equipped with other tools such as a manipulator or cutting arm, water samplers, and measuring instruments to expand the vehicle's capabilities.

A CTD
http://terra.gso.uri.edu/NOAAShipOkeanosExplorer/ship-info/2009/ex-operations-photos/CAP%20028.jpg/image_view_fullscreen

John Sherrin and Elaine Stuart collect water samples from the CTD/rosette on Kawio Barat. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june27_update_hires.jpg



The *Little Hercules* ROV at the University of New Hampshire during tank testing. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/media/test_tank.html

The *Little Hercules* remotely-operated vehicle (ROV) is a dual-body system capable of operating to depths of 4,000m. It is deployed from the *Okeanos Explorer* and attached to it by a tether. One vehicle is suspended above the other and serves to illuminate and image the surroundings. Image courtesy of NOAA Office of Ocean Exploration and Research.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/little_herc_rov_hires.jpg

Little Hercules during one of its first dives in Indonesia. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/underwater_hires.jpg

For the INDEX-SATAL 2010 Expedition, 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 (URI) 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 to *Seirios* by a 30-m tether, while the camera platform is attached to the *Okeanos Explorer*'s traction winch by a 17 mm electromechanical cable. Following a four-month overhaul, *Little Herc*'s systems included:

- Power – Primary power is from the *Okeanos Explorer*, supplied to the ROV by wires in the tether cable that connects *Little Herc* to the ship. A transformer inside a watertight container, called a power bottle, converts the ship's current to voltages needed by the thrusters and other equipment aboard the ROV.
- Propulsion – *Little Herc* has four motors called thrusters. Two of these are oriented horizontally to provide forward, backward, and rotational motion. The other two thrusters are mounted so that they form a V when viewed from the front. This is called a vertran configuration, and allows the ROV to move up, down, and laterally. The thrusters are controlled by electronic motor controllers that regulate the speed and direction of the motors' rotation.
- Communication – Video and sensor data from *Little Herc* are sent to the *Okeanos Explorer*'s Control Room on fiber optic cables included in the tether that connects the ROV to the ship. Inputs from the sensors are routed through a multiplexer that makes it possible to send many separate signals through a small number of cables.
- Buoyancy control – The yellow floatation package on *Little Herc* is filled with syntactic foam made from tiny hollow glass balls that will not collapse under the pressure of the deep-ocean environment.
- Information gathering – *Little Herc* carries a variety of sensors used for navigation as well as to collect scientific data. 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 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.

Overall specifications for *Little Hercules* are:

- Overall Length: Five feet
- Overall Width: Three feet
- Overall Height: Three feet
- Weight: 1,000 lbs
- Depth Rating: 4,000 m

For a compilation of video clips collected by *Little Hercules* during a shakedown cruise off Kona, Hawaii, visit *http://www.channels.com/episodes/show/10098569/NOAA-Ship-Okeanos-Explorer-Highlight-video-offshore-Kona-Hawaii*.

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

Discovering Careers in Ocean Exploration

Ocean exploration aboard the *Okeanos Explorer* requires many different skills to operate underwater robots, obtain high-quality video imagery, and provide maps that chart deep ocean features in greater detail than has ever been seen before. The log essay from July 7, 2010 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july07/july07.html*), provides brief biographies of 13 members of the ROV team, and underscores the importance of Science, Technology, Engineeering, and Mathematics to modern ocean exploration.

Although *Okeanos Explorer*'s accommodations limit the number of explorers who can be aboard the ship, telepresence means that exploration activities include many other individuals; many more, in fact, than could possibly fit aboard a single exploration vessel. You can watch video interviews with many modern ocean explorers on the Ocean Explorer OceanAGE Web page (*http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*). These include:

- Deep-Sea Biologists Amy Baco-Taylor and Tim Shank;
- Marine Ecologist Peter Etnoyer;
- Geophysicist Bob Embley;
- Marine Mammal Biologist Kristin Laidre;
- Oceanographer Bob Ballard;
- NOAA Corps Officer Shannon Ristau;
- NOAA Scientist/Educator Catalina Martinez;

and many others.

Meet some of ocean exploration's next generation among members of the INSPIRE: Chile Margin 2010 Expedition; an expedition that was spearheaded by a team of graduate students! See *http://oceanexplorer.noaa.gov/explorations/10chile/background/explorers/explorers.html*.

Operating a modern ship of exploration requires a highly skilled crew. During the INDEX-SATAL 2010 Expedition, *Okeanos Explorer*'s 26 crew members included:

1 - Commanding Officer
5 - Deck Officers
2 - Engineering Officers
6 - Deck Crew
3 - Engineers
2 - Survey Technicians
4 - Electronics Technicians
3 - Stewards

The log essay from July 29, 2010 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/july29/july29.html*) gives a glimpse of the range of activities involved in a typical day aboard the *Okeanos Explorer*. Read more about the ship's NOAA Corps Officers in the log essay from August 12, 2010 (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/aug02/aug02.html*), and find out more about the ship's crew here: *http://www.moc.noaa.gov/oe/*.


Dave Lovalvo, ROV Operations Coordinator


Robin Sawyer, Medical Officer


Richard Conway, Electrical Engineer


Webb Pinner, Computer Engineer


Randy Prickett, Pilot/USN Diver 1st Class


Colleen Peters, Senior Survey Technician

Exploration Strategies Inquiry Guide

Part 1 – Lesson 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 inquiry 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?

Part 2 – NOAA Ship *Okeanos Explorer*

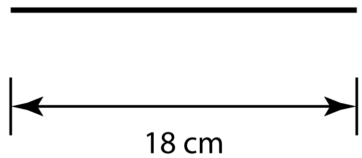
In 2000, the President's Panel for Ocean Exploration issued its report, *Discovering Earth's Final Frontier*. The report called for a new national Ocean Exploration Program, noting that previous efforts to explore the ocean had "ended before a significant portion of the oceans was visited in even a cursory 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, 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:

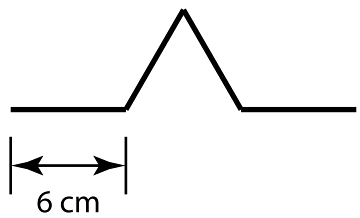
- What kind of measurements or observations should be made?
- What technologies could be used to make these measurements or observations?

Koch Curve Construction

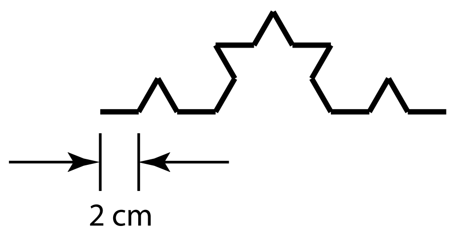
Step 1.



Step 2.



Step 3.



Step 4.