



Section 3: Multibeam Mapping 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.

Watching in 3D

Focus

Multibeam sonar

Grade Level

9-12 (Physical Science/Earth Science)

Focus Question

How does multibeam sonar help explore Earth's deep ocean?

Learning Objectives

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

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 videos (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



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. The strategy for accomplishing this mission is to use state-of-the-art technologies to search the ocean for anomalies; things that are unusual and unexpected. When an anomaly is found, the exploration strategy shifts to obtaining more detailed information about the anomaly and the surrounding area. An important concept underlying this strategy is the 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 investigations that provide enough data to justify follow-up by future expeditions.

The *Okeanos Explorer* strategy involves three major activities:

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

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

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

- Telepresence;
- Multibeam sonar mapping;
- CTD (an instrument that measures conductivity, temperature, and depth) 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.

In many ways, 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, and newsrooms, and opens new educational opportunities that are a major part of *Okeanos Explorer*’s mission for advancement of knowledge.



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

In the summer of 2010, years of planning, field trials, and state-of-the-art technology came together for the first time on the ship'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, see <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>.

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 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 swath. 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. 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 also provides a graphic overview of how multibeam works here: (http://ccom.unh.edu/NOAA_oceanexploration/PlumePoints2.mov). For more information about sonar systems, see <http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html>.

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 technology and simple analysis of multibeam data using free viewing software for multibeam imagery in the Fledermaus file format. In the future, students will have the opportunity to apply their analytic skills to investigate new multibeam images as the *Okeanos Explorer* continues its voyages of discovery in Earth’s deep ocean.

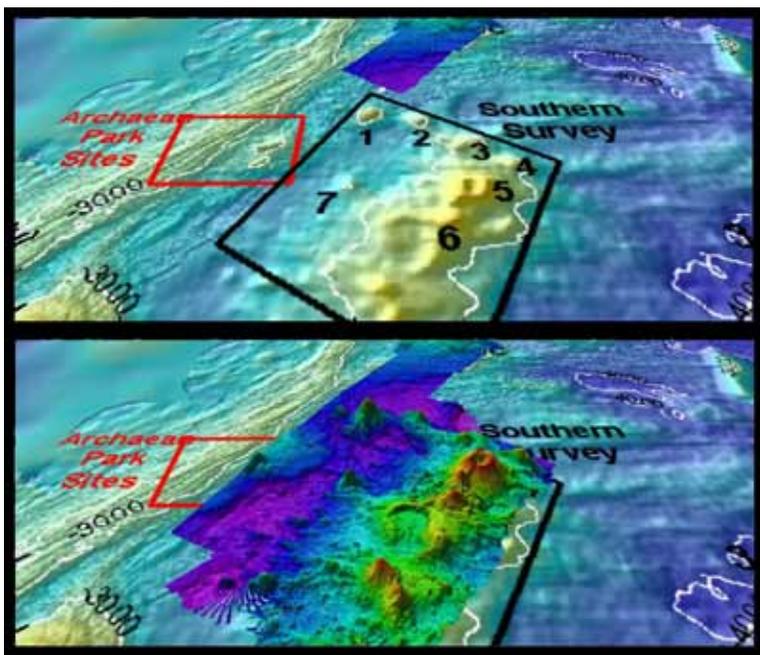
Note: mention of proprietary names does not imply endorsement by NOAA.

Multibeam Mapping 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 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.

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 to compensate for pitch and roll 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

STEM Connections

Ocean exploration aboard the *Okeanos Explorer* is a real-world example of STEM concepts in action:

Science provides the overall objective – to better understand Earth’s ocean – as well as a methodology for systematically acquiring this understanding;

Technology includes the tools, systems and processes that have been made to make deep-ocean exploration possible;

Engineering designs the technologies that can function in the deep-ocean environment;

Mathematics provides the basis for measurements, data analysis, and engineering design.

With increasing attention to developing integrated approaches to STEM education and technological literacy, the *How Do We Explore?* theme offers an exciting context for educators who wish to bring more STEM content to their classrooms.

To assist with such efforts, most lessons developed for the *How Do We Explore?* theme identify opportunities to include specific benchmarks and standards for technological literacy that have been developed by the International Technology and Engineering Education Association (ITEA, 2007). While these standards have not been widely adopted, they provide useful guidance for efforts to enhance STEM content in advance of its inclusion in formal curricula.

In addition, the *How Do We Explore?* suite of lessons includes activities that are intended to provide opportunities to apply design processes, build technological devices, and develop some of the hands-on abilities that are an integral part of most concepts about STEM education. These activities are directly tied to the technologies and scientific methodologies used for ocean exploration aboard the *Okeanos Explorer*.

For more information, see: http://www.iteaconnect.org/TAA/Publications/TAA_Publications.html

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/bires/em302_before_after_bires.jpg,

as well as one or more of the animations referenced above 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://ccom.unb.edu/NOAA_oceanexploration/PlumePoints2.mov.

(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* for each student, and copies of *Introduction to Multibeam Imagery Worksheet* for each student group.

(e) Download the iView4D software from <http://www.ivs3d.com/products/iview4d/>, and Download the data file **INDEX2010_mb_1.sd** from

http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/INDEX2010_mb_1.sd

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.

(f) Review *Hands-On Activity Guide Multibeam Mapping: PING)))*™ *Sonar Simulation* included with the *Mapping the Ocean Floor* lesson, and decide whether you wish to include the activity as part of this lesson.

2. Provide each student with a copy of the *Sonar Background Review Worksheet* as homework in preparation for the remainder of this lesson.

3. 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.

4. Review students' answers to questions on the *Sonar Background Review Worksheet*. The following points should be included:

- Sound waves in water move as compression waves, while electromagnetic waves are transverse waves.
- 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.
- The physical distance between two consecutive pressure fronts in a sound wave is wavelength.
- The number of pressure fronts that pass a stationary point in a certain amount of time is the frequency of the wave.
- The mathematical relationship between wavelength and frequency is:

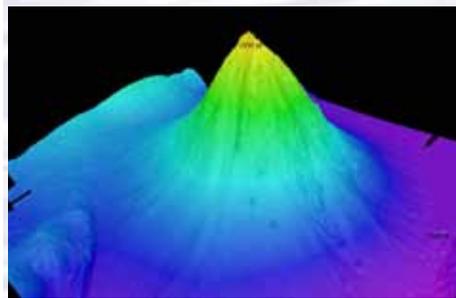
$$\text{speed of sound} = \text{frequency} \times \text{wavelength}$$

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.

- When a sound wave moving through water encounters a change in temperature, the local speed of sound and wavelength change, but frequency remains constant.
- When a sound wave moves through the water, energy is the thing that actually moves.
- If one sound wave induces a greater pressure change than another sound wave, the first sound wave contains more energy.
- 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.



The ROV Little Hercules descends through deep water to an undersea volcano in the Celebes Sea to search for hydrothermal vents and associated ecosystems. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/1june29_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



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>



Senior Survey Technician Elaine Stuart holds onto the CTD as it comes aboard the *Okeanos Explorer*. Image courtesy NOAA
<http://www.moc.noaa.gov/oe/visitor/photos/photospage-b/CAP%20015.jpg>



- When a sound wave moves through water, it gradually loses some of its energy, so its amplitude is reduced.
- Sound waves with higher frequencies lose energy more rapidly than lower frequency sound.
- 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.

5. Ask students what they know about sonar, and provide additional information as necessary. Be sure students understand that sonar (which stands for SOUND Navigation and Ranging) uses an acoustic signal or pulse of sound that is transmitted into the water by a sort of underwater speaker known as a transducer. Transducers 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. 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 video clips referenced in Step 1c.

Describe the role of multibeam sonar in ocean exploration aboard *Okeanos Explorer*. The image (see pg 4) http://oceanexplorer.noaa.gov/okeanos/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/okeanos/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”



Physical Scientist Meme Lobecker teaches Indonesian scientist Cecep Sujana how to conduct an XBT cast. The XBT measures temperature through the water column. The XBT software calculates sound velocity, which is applied to the multibeam data for accurate measure of bathymetry. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/bires/xbt_cast_bires.jpg

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 questions on the *Worksheet*, lead a discussion of their results. This discussion should include:

- The northern and southern latitude boundaries for the image are about $4^{\circ} 44' 49''$ N latitude and about $4^{\circ} 36' 10''$ 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 placing the cursor near the edges of the image and reading the latitude and longitude coordinates from the window on the lower left.
- The eastern and western longitude boundaries for this image are about $125^{\circ} 9' 39''$ E longitude and about $125^{\circ} 01' 02''$ E longitude, respectively.
- The deepest parts of the image are approximately 5,400 meters deep (near the northwestern edge of the image).
- 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 $4^{\circ} 44' 21''$ N, and the southern latitude boundary is about $4^{\circ} 36' 16''$ 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

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

- 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

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





The slope of the volcano is the angle between the side of the triangle and its base. The tangent of this angle 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° 40' 24" N, 125° 5' 11" E and 4° 39' 38" N, 125° 4' 44" E appears to have relatively steep topography and would be an interesting place to look for biological organisms.
8. Discussion of multibeam sonar technology may also 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.
 - **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.
9. If desired, have students complete the *PING)))™ Sonar Simulation Activity* (Step 1f). This activity addresses additional components of technological literacy, including:
- Attributes of design;
 - Understanding of engineering design;
 - Problem-solving approaches;
 - Abilities to apply design processes; and
 - 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 “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

Assessment

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



Extensions

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

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.

Other Resources

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

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. 2011. *Okeanos Explorer* Education Materials Collection [Internet]. NOAA Office of Ocean Exploration and Research [cited January 4, 2011]. Available from: <http://oceanexplorer.noaa.gov>





Anonymous. 2009. [Internet]. University of New Hampshire [cited January 14, 2011]. Available from: http://ccom.unh.edu/NOAA_oceanexploration/; 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

Anonymous. 2002. Magic Mountain Virtual site [Internet]. NOAA Office of Ocean Exploration and Research [cited January 14, 2011]. 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

Anonymous. 2000. Multibeam Sonar Theory of Operation [Internet]. L-3 Communications SeaBeam Instruments [cited January 24, 2011]. Available from: <http://www.ldeo.columbia.edu/res/pi/MB-System/sonarfunction/SeaBeamMultibeamTheoryOperation.pdf>

Anonymous. *Okeanos Explorer* America's Ship For Ocean Exploration [Internet]. NOAA Office of Ocean Exploration and Research [cited January 24, 2011]. Available from: http://explore.noaa.gov/special-projects/indonesia-u-s-scientific-and-technical-cooperation-in-ocean-exploration/files/Okeanos_Explorer_for_WOC_-_FINAL.pdf; NOAA Fact Sheet about *Okeanos Explorer*

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://www.ivs3d.com/news/PID985675.pdf>

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.

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

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Nature of scientific knowledge

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

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept 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.

Fundamental Concept 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.

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 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.

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

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

Send Us Your Feedback

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

Please send your comments to:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC for NOAA. 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>



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.

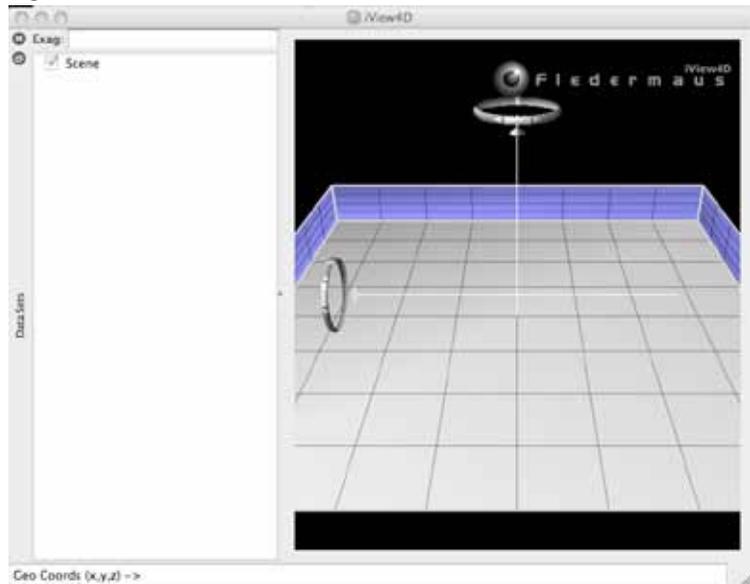




Introduction to Multibeam Imagery Worksheet

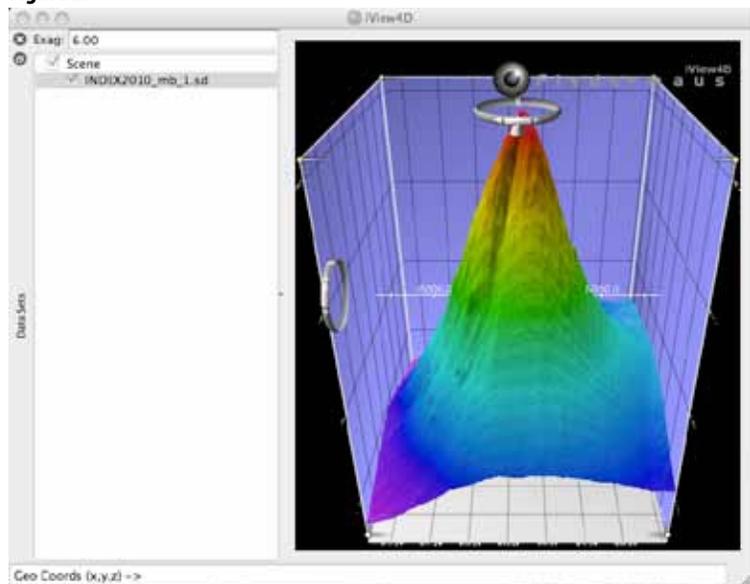
1. Launch the iView4D software. Your screen should resemble Figure 1. Note the Rotation Control Rings near the top center and mid-left side of the screen. If your screen doesn't look like Figure 1, be sure "Bounds" is checked under the "View" drop-down menu.

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-dimension 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.)
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.)

