



Section 3: Multibeam Sonar

Lesson 5: Watching in 3D

Focus

Multibeam sonar

Grade Level

9-12 (Physical Science/Earth Science)

Focus Question

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

Learning Objectives

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

Materials

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

Audio Visual Materials

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

Teaching Time

Two or three 45-minute class periods

Seating Arrangement

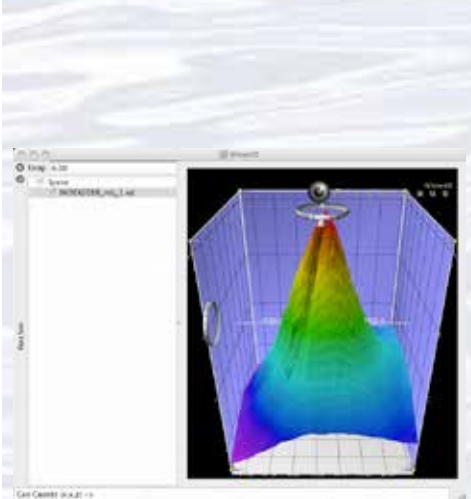
Groups of three to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
Bathymetric map
Multibeam sonar



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



Background

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

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

Learning Procedure

1. To prepare for this lesson:

a) Review:

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

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

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

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

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

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

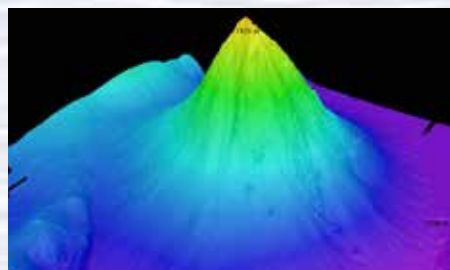
<http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain>; and

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

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

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





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

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



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

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



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

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



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

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

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

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

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

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

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

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





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

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

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

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

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

Latitude and Longitude

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

Degrees, Minutes, Seconds or Decimal Degrees?

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

To convert degrees/minutes/seconds to decimal degrees:

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

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

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

To convert decimal degrees to degrees/minutes/seconds:

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

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

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

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

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

The BRIDGE Connection

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

The “Me” Connection

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

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

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

Extensions

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

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA’s Ocean Exploration Program

The Ridge Exploring Robot

(from the INSPIRE: Chile Margin 2010 Expedition)

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

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

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

Sound Pictures

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

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

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

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



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

Next Generation Science Standards

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



Send Us Your Feedback

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

Please send your comments to:

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Sonar Background Review Worksheet

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

Sonar Background Review Worksheet Answers

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

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

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

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

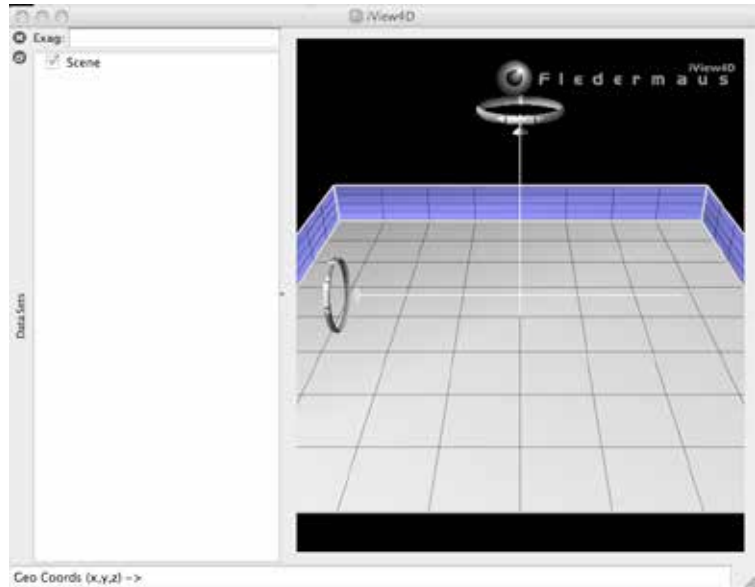




Introduction to Multibeam Imagery Worksheet

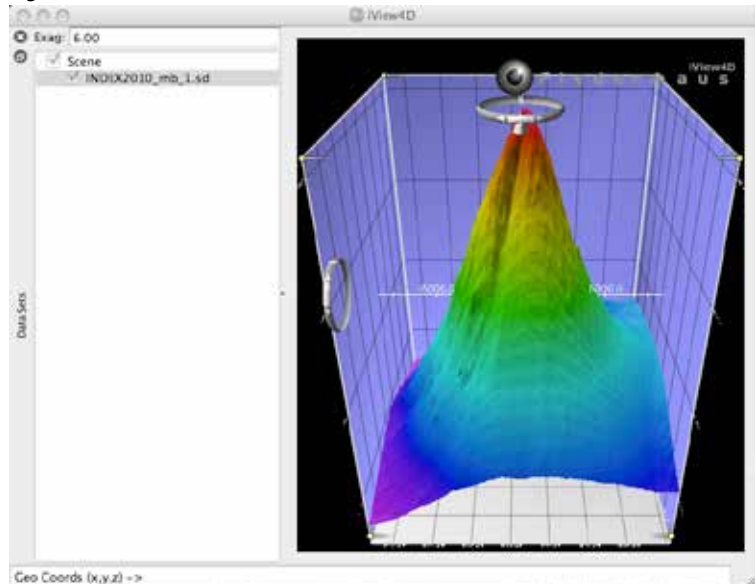
1. Launch the iView4D software. Your screen should resemble Figure 1. Note the Rotation Control Rings near the top center and mid-left side of the screen. If your screen doesn't look like Figure 1, be sure "Bounds" is checked under the "View" drop-down menu.

Figure 1.



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

Figure 2.



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

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

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

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

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

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

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





Answers for Multibeam Imagery Worksheet

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

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

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

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

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

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

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

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

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

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

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

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



