



## The Galápagos Rift Expedition 2011

# The Oceanographic Yo-Yo

(adapted from the INSPIRE: Chile Margin 2010 Expedition)

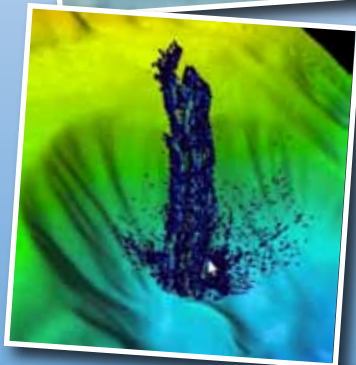


Image captions/credits on Page 2.

# lesson plan

### Focus

Ocean chemistry and hydrothermal vents

### Grade Level

7-8 (Physical Science)

### Focus Question

How do ocean explorers use chemical clues to locate hydrothermal vents in the deep ocean?

### Learning Objectives

- Students will explain the effects of hydrothermal vents on chemical and physical parameters of seawater.
- Students will explain how oceanographers can use these effects to locate hydrothermal vents.
- Students will describe some of the instruments that oceanographers use to detect chemical clues that suggest the presence of hydrothermal vents.

### Materials

- Copies of *CTD Sample Analysis Worksheet*, one for each student group
- One gallon of water, chilled in a refrigerator
- Vinegar; 1 tablespoon for each student group
- A heat source (microwave oven or hot plate)
- One eyedropper
- One tablespoon
- Two thermometers for each student group
- pH paper and a pH color indicator chart for each student group

### Audio-Visual Materials

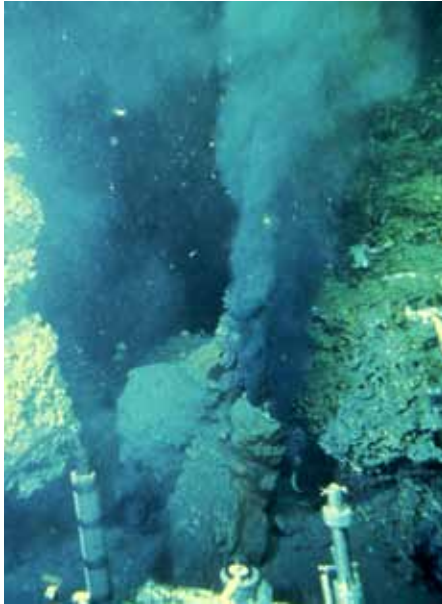
- (Optional) Interactive white board or computer projection equipment; see Learning Procedure Step 1.

### Teaching Time

Two 45-minute class periods

### Seating Arrangement

Groups of 3-4 students



The first photograph of a black smoker vent published on the cover of *Science* magazine. The blackened water is jetting out at 1–5 meters per second and is 380°C, hotter than a pizza oven. Image courtesy Spiess, Macdonald, *et al*, 1980. [http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/hires/macdonald\\_hires.jpg](http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/hires/macdonald_hires.jpg)

#### Images from Page 1 top to bottom:

An overview of the Galápagos Islands. They are produced by volcanic activity caused by magma upwelling at the Galápagos hotspot. Green to white indicates the coastline, outside this is below sea level. Image produced by Ken Macdonald using GeoMapApp courtesy of Lamont Doherty Earth Observatory.

[http://oceanexplorer.noaa.gov/explorations/05galapagos/background/hotspots/media/Galapagos\\_IS\\_Topo\\_600.html](http://oceanexplorer.noaa.gov/explorations/05galapagos/background/hotspots/media/Galapagos_IS_Topo_600.html)

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

[http://oceanexplorer.noaa.gov/oceanos/media/movies/mendocino\\_ridge\\_plume\\_video.html](http://oceanexplorer.noaa.gov/oceanos/media/movies/mendocino_ridge_plume_video.html)

Close-up imagery showing a type of gooseneck barnacle, shrimp and a scaleworm on Kawio Barat submarine volcano. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

[http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/slideshow/ex\\_july\\_highlights/gallery/hires/barnacle\\_zoom\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/barnacle_zoom_hires.jpg)

Doug Jongeward, a highly skilled IT Specialist, works in the control room of the *Okeanos Explorer* managing the enormous amounts of video and data that is collected each day on board the ship. Image courtesy of NOAA *Okeanos Explorer* Program.

[http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/8\\_doug\\_jongeward\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/8_doug_jongeward_hires.jpg)

## Maximum Number of Students

32

## Key Words

Galápagos Rift  
Galápagos Spreading Center  
Hydrothermal vent  
Magma  
Mantle  
Tectonic plate  
CTD  
Tow-yo

## 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 Feb. 17, 1977, scientists exploring the seafloor near the Galápagos Islands made one of the most significant discoveries in modern science: large numbers of animals that had never been seen before were clustered around underwater hot springs flowing from cracks in the lava seafloor. Similar hot springs, known as hydrothermal vents, have since been discovered in many other locations where underwater volcanic processes are active.

These processes are often associated with movement of the tectonic plates, which are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. These plates move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary. As the plates rub against each other, huge stresses are set up that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. A well-known example of a transform plate boundary is the San Andreas Fault in California. View animations of different types of plate boundaries at:

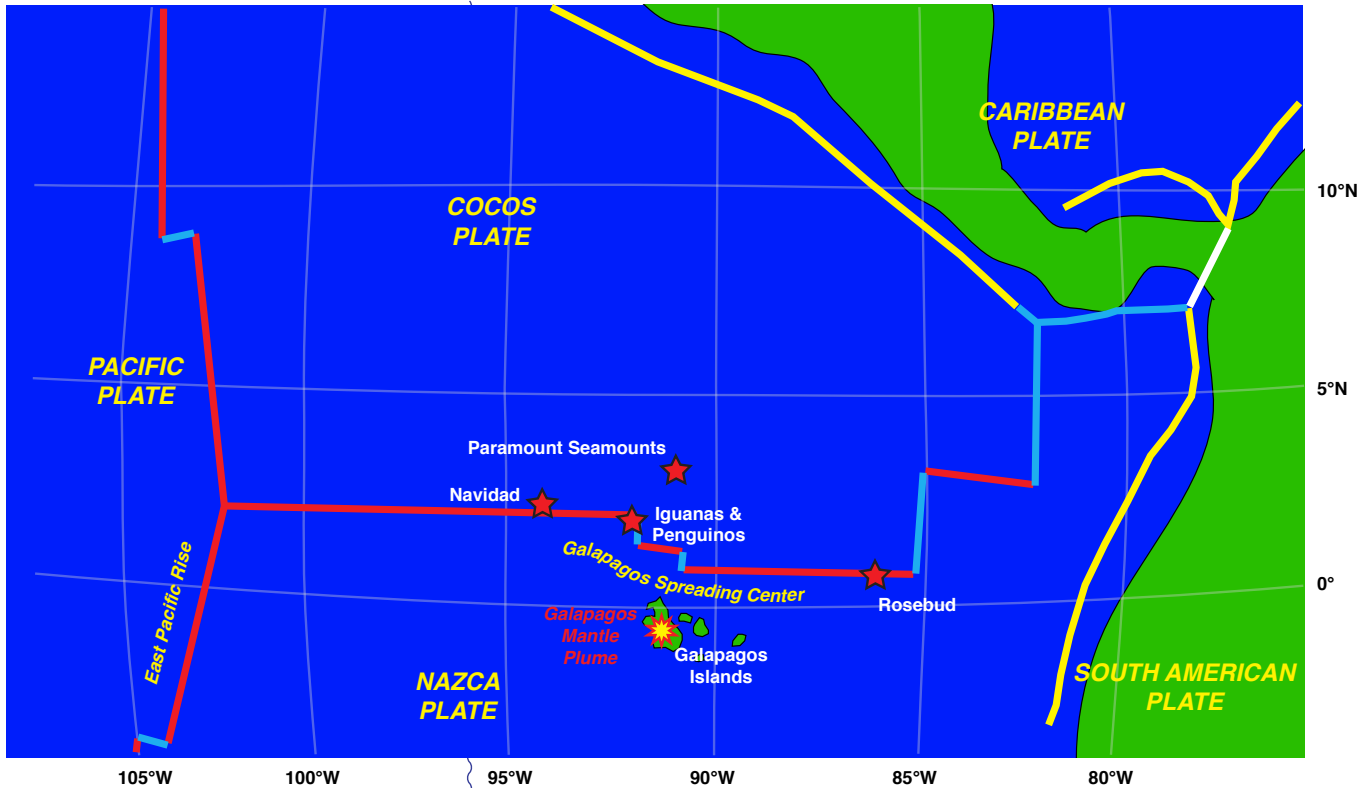
[http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate\\_boundaries/en/index.html](http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html).

A convergent plate boundary is formed when tectonic plates collide more or less head-on. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building (the Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. View the three-dimensional structure of a subduction zone at: <http://oceanexplorer.noaa.gov/explorations/03fire/logs/subduction.html>.

Where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma rises from deep within the Earth and erupts to form new crust on the lithosphere. Most divergent plate boundaries are underwater (Iceland is an exception), and form submarine mountain ranges called oceanic spreading ridges. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. View the three-dimensional structure of a mid-ocean ridge at: <http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html>.

Volcanic activity can also occur in the middle of a tectonic plate, at areas known as hotspots, which are thought to be natural pipelines to reservoirs of magma in the upper portion of the Earth's mantle. The volcanic features at Yellowstone National Park are the result of hotspots, as are the Hawaiian Islands. As the Pacific tectonic plate moves over the Hawaiian hotspot, magma periodically erupts to form volcanoes that become islands. The oldest island is Kure at the northwestern end of the archipelago. The youngest is the Big Island of Hawaii at the southeastern end. Loihi, east of the Big Island, is the newest volcano in the chain and may eventually form another island.

The Galápagos region is geologically complex (see Figure 1 on page 4). The Galápagos Islands were formed by a hotspot called the Galápagos Mantle Plume (GMP), which continues to produce active volcanoes (the Sierra Negra volcano erupted on October 22, 2005). These islands are formed on the Nazca Plate, which is moving east-southeast. On the western side of the Nazca Plate, this motion produces a divergent plate boundary with the Pacific Plate. This boundary is called the East Pacific Rise. On the northern side of the Nazca Plate, just north of the Galápagos archipelago, another divergent plate boundary

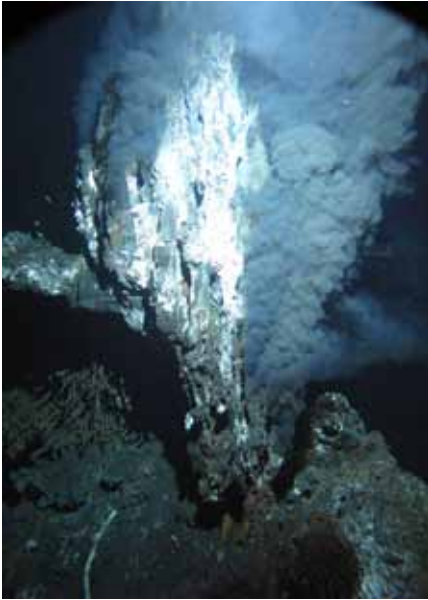


**Figure 1. Galápagos Tectonic Setting.**

Red plate boundaries are divergent; yellow plate boundaries are convergent; blue plate boundaries are transform; white plate boundaries are undetermined. Navidad, Iguanas and Pinguinos are locations where black smokers were discovered in 2005. Paramount Seamounts are an exploration target for Galápagos Rift Expedition 2011. For more information see the Galapagos Rift Expedition 2011 Expedition Education Module (<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1103/background/edu/edu.html>). Credit: UNAVCO (tectonic boundaries); NOAA (hydrothermal sites)

exists with the Cocos Plate. This boundary is known as the Galápagos Spreading Center (GSC). A convergent boundary exists on the eastern side of the Nazca Plate, which is being subducted beneath the South American and Caribbean Plates. This subduction has caused some of the oldest seamounts formed by the GMP to disappear beneath the South American and Caribbean Plates, so it is not certain exactly how long the GMP has been active in its present position (for additional discussion and illustrations about these processes, see “This Dynamic Earth” available online from the U.S. Geological Survey at <http://pubs.usgs.gov/publications/text/dynamic.pdf>).

When the movement of tectonic plates causes deep cracks to form in the ocean floor, seawater can flow into these cracks. As the seawater moves deeper into the crust, it is heated by molten rock. As the temperature increases, sulfur and metals such as copper, zinc, and iron dissolve from the surrounding rock into the hot fluid. Eventually, the mineral-rich fluid rises again and erupts from openings in the seafloor. The temperature of the erupting fluid may be as high as 400°C, and contains hydrogen sulfide, which is toxic to many species. When the hot hydrothermal fluid meets cold (nearly freezing) seawater, minerals in the fluid precipitate. The precipitated mineral particles give the fluid a smoke-like appearance, so these vents are often called black smokers or white smokers, depending upon the types of minerals in the fluid. Precipitated minerals may also form chimneys that can be several meters high.



A black smoker chimney named 'Boardwalk' emitting 644°F (340°C) hydrothermal fluids in the northeastern Pacific Ocean at a depth of 7,260 feet (2,200 m). Microbes grow within and on the surface of such mineral formations. Image courtesy of James F. Holden, University of Massachusetts, Amherst.

[http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/hires/boardwalk\\_black\\_smoker\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/hires/boardwalk_black_smoker_hires.jpg)



Hydrothermal vents on Kawio Barat submarine volcano spew white smoke. Image captured more than 1,850 meters deep by the *Little Hercules* ROV on August 3, 2010. Image courtesy of NOAA *Ocean Explorer* Program, INDEX-SATAL 2010.

[http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/slideshow/ex\\_july\\_highlights/gallery/hires/white\\_plumes\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/white_plumes_hires.jpg)

Hydrothermal vent communities and other deepwater chemosynthetic ecosystems are fundamentally different from other biological systems on Earth, and there are plenty of unanswered questions about the individual species and interactions between species found in these communities. Many of these species are new to science, and include primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Although much remains to be learned, useful products have already been discovered in hydrothermal vent organisms. At present, almost all drugs produced from natural sources come from terrestrial plants, but marine animals produce more drug-like substances than any group of organisms that live on land. Some chemicals from microorganisms found around hydrothermal vents (the exopolysaccharide HE 800 from *Vibrio diabolicus*) are promising for the treatment of bone injuries and diseases, while similar chemicals may be useful for treating cardiovascular disease. Other examples of useful products include a protein from *Thermus thermophilus*, which is a microorganism that is adapted to live under extremely high temperature conditions near hydrothermal vents. One of these adaptations is the protein Tth DNA polymerase that can be used to make billions of copies of DNA for scientific studies and crime scene investigations. Another microorganism (genus *Thermococcus*) produces a type of protein (an enzyme called pullulanase) that can be used to make sweeteners for food additives.

In 2002 and 2005, NOAA's Office of Ocean Exploration and Research sponsored expeditions to the Galápagos Rift (see <http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html> and <http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html> for more information about these expeditions). A major objective of the 2002 expedition was to revisit a hydrothermal vent site named Rose Garden to investigate changes that might have occurred in the community of living organisms around the vent since it was discovered in 1977. Scientists found that significant changes had indeed taken place: Rose Garden had completely disappeared! In its place was a fresh sheet of lava that had apparently buried the vent and all of the surrounding organisms. About 300 meters away, a new vent field (which the scientists named Rosebud) was discovered with typical hydrothermal vent species beginning to colonize cracks in recently-formed lava. These discoveries underscored a growing awareness that the deep ocean environment can change much more quickly than was previously believed. The 2005 expedition focused on a portion of the GSC that had never been explored for hydrothermal vents. Scientists hoped that they would find black smokers, because at that time high temperature (several hundred degrees C) vents had not been found in the Galápagos region; only vents whose temperatures were less than 50°C. Using chemical and physical clues, explorers eventually made the first discovery of black smokers on the Galápagos Rift!



Port view of the *Okeanos Explorer*.

[http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/port\\_view\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/port_view_hires.jpg)

### The NOAA Ship *Okeanos Explorer*

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

### Systems and Instrumentation:

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

### Operations:

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

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



Aft view of the *Okeanos Explorer*.

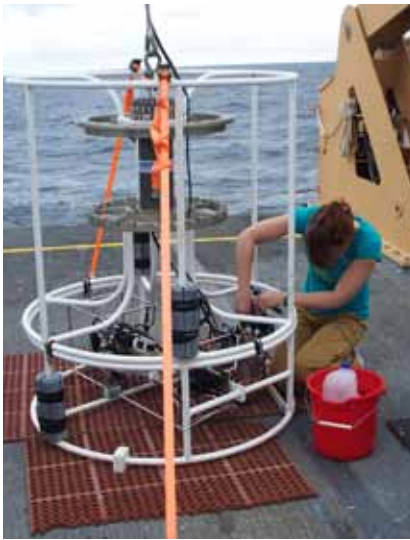
[http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/aft\\_view\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/aft_view_hires.jpg)

These discoveries set the stage for the Galápagos Rift Expedition 2011, which will use the state-of-the-art exploration capabilities of the NOAA Ship *Okeanos Explorer* to obtain detailed information about the biology and geology of Galápagos hydrothermal ecosystems, and determine whether different ecosystems are found at different vent fields within the Galápagos region. A major objective of the Expedition is to survey and map known hydrothermal vent sites, and to search for new hydrothermal vents in unexplored regions of the Galápagos Rift. Because hydrothermal vents cause changes to the chemistry and physical characteristics of surrounding seawater, these vents are often surrounded by masses of seawater that are distinctly different from normal seawater. These water masses are called plumes, and provide ocean explorers with clues about the location of hydrothermal vents.

To search for these clues, expedition scientists will use an instrument called a CTD, which stands for conductivity, temperature, and depth. This instrument is a package of electronic devices that measure several chemical and physical 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.

In addition to sensors for measuring conductivity, temperature, and water pressure (which is used to calculate depth), for the Galápagos Rift Expedition 2011, the *Okeanos Explorer's* CTD will also carry an altimeter (to measure distance from the seafloor), a light scattering sensor (LSS), oxidation-reduction potential (ORP) sensor, and a dissolved oxygen sensor. A LSS measures the concentration of hydrothermal particles in the water. Oxidation-reduction (also called redox) potential is a measure of the tendency of a substance to gain or lose electrons. ORP 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 ORP 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. Plumes (masses of changed seawater) are usually found within a few



Senior Survey Technician Elaine Stuart works on the CTD while the altimeter battery recharges. Water sampling bottles, which are often attached to the rosette frame, have been removed for tow-yo operations. Sensors are mounted in the lower part of the frame where SST Stuart is working. Image courtesy of NOAA *Okeanos Explorer* Program.

[http://tethys.gso.uri.edu/OkeanosExplorerPortal/ex110311/news-articles/update-for-june-25-2011/image/image\\_view\\_fullscreen](http://tethys.gso.uri.edu/OkeanosExplorerPortal/ex110311/news-articles/update-for-june-25-2011/image/image_view_fullscreen)

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. For more information, see [http://oceanexplorer.noaa.gov/technology/tools/sonde\\_ctd/sondectd.html](http://oceanexplorer.noaa.gov/technology/tools/sonde_ctd/sondectd.html) and <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html>.

When CTD data show evidence of a possible plume from a hydrothermal vent, scientists use sonar to look for bubbles and particles in the water column, and to prepare high resolution maps of the seafloor in the surrounding area. Final confirmation of the presence of a hydrothermal vent comes from close-up examination of the area with an underwater robot (remotely operated vehicle, ROV) that sends video images to the ship as well as to scientists participating in the Expedition from Exploration Command Centers ashore. For more information about the *Okeanos Explorer* exploration strategy, see the lesson, **To Explore Strange New Worlds** ([http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe\\_78\\_toexplore.pdf](http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_78_toexplore.pdf)).

This lesson focuses on physical and chemical measurements that may signal the presence of hydrothermal vents and some of the technologies used to make these measurements.

### Learning Procedure

*[NOTE: The water sample analysis activity described in Step 5 is adapted from the 2002 Galapagos Rift Expedition lesson, “Yo-Yos, Tow-Yos and pH, Oh My!” by Stacia Fletcher, South Carolina Aquarium, Charleston, SC.]*

1. To prepare for this lesson:
  - (a) Review introductory essays for the Galápagos Rift Expedition 2011 at <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html>
  - (b) If students are not familiar with deep-sea chemosynthetic communities you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (<http://oceanexplorer.noaa.gov/edu/learning/welcome.html>), and/or information from <http://www.pmel.noaa.gov/vents/nemo/explorer.html>.
  - (c) Review procedures for the simulated analysis of CTD samples (Step 4) and prepare materials for this activity:
    - Chill one gallon of water overnight in a refrigerator.
    - For each group of four students, fill five 100ml beakers with chilled water and label each with an A, B, C, D or E.

- Heat the water in all beakers labeled D for 60 seconds in the microwave oven shortly before the start of class.
- Add 3 drops of vinegar to all beakers labeled C and E and stir.
- Add one tablespoon of vinegar to all beakers labeled D and stir.

2. If students are not familiar with deep-sea chemosynthetic communities, briefly describe the concept of chemosynthesis, and contrast it with photosynthesis. Tell students that chemosynthetic ecosystems in the deep ocean are found where a source of chemical energy is emerging from the ocean floor. If you have decided to use materials referenced in Step 1b, present these now.

3. Briefly introduce the Galápagos Rift Expedition 2011, and 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. 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.

Mention the overall exploration strategy used by the *Okeanos Explorer*, which involves three major activities:

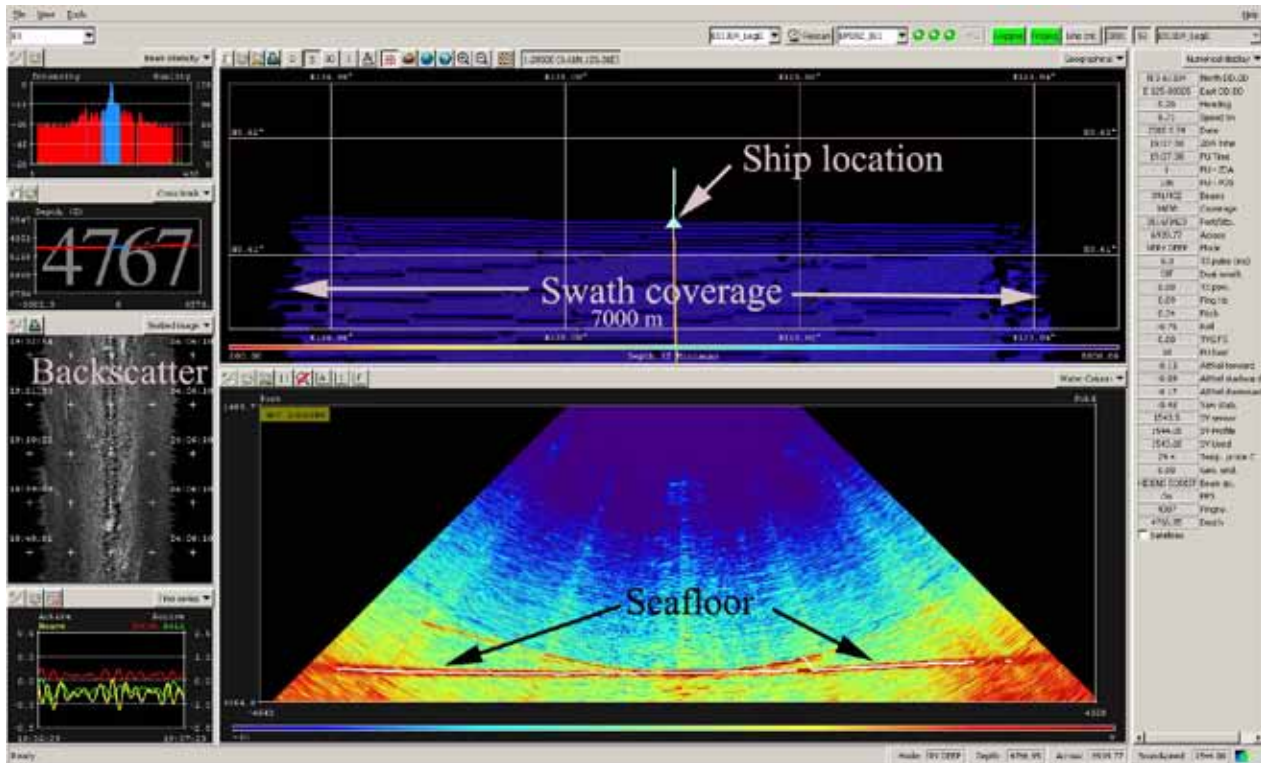
- Underway reconnaissance;
- Water column exploration; and
- Site characterization.

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

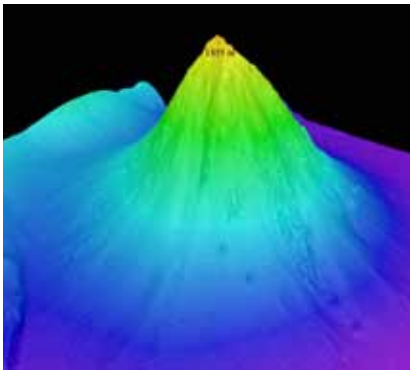
Key technologies involved with this strategy include:

- Multibeam sonar mapping system;
- CTD and other electronic sensors to measure chemical and physical seawater properties; and
- A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters.





**Data acquisition screen:** There is a lot of information to keep track of when standing watch at the multibeam acquisition station. Each piece of information provides unique and valuable details about the seafloor, which are used in the exploration decision-making process: swath coverage is used to determine the spacing of consecutive passes of the ship over an area being surveyed to ensure that the area is completely mapped; the water column allows us to visualize the detected seafloor and water mass above it in order to identify features on the seafloor or above; and the backscatter imagery shows the relative hardness or softness of the seafloor, which helps identify targets such as shipwrecks and deep water coral reefs. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. [http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/june26fig3\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/june26fig3_hires.jpg)



This is a perspective view of the Kawio Barat (West Kawio) seamount looking from the northwest acquired with multibeam sonar. The underwater volcano rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010. [http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/june26fig1\\_hires.jpg](http://oceanexplorer.noaa.gov/oceanos/explorations/10index/logs/hires/june26fig1_hires.jpg)

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

Tell students that a primary purpose of the Galápagos Rift Expedition 2011 is to search for new hydrothermal vents in unexplored regions of the Galapagos Rift. Explain that ocean explorers searching for hydrothermal vents make use of the fact that these vents cause changes in the chemical and physical properties of seawater. These changes can be measured and used as clues to find the location of previously undiscovered vents.



Scientists and spectators located at the Seattle ECC watch as a thriving hydrothermal ecosystem unfolds before them in video footage streaming live from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

[http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/seattle\\_command\\_center\\_hires.jpg](http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/seattle_command_center_hires.jpg)

Discuss some of the clues from changes that hydrothermal vents might cause in seawater. Increased temperature is fairly obvious, since heat from Earth's core is the energy source that causes vents to form. Temperatures of hydrothermal fluids may be more than 300°C, since the high pressure of deep-sea environments prevents water from boiling. Fluids from hydrothermal vents are often highly acidic, in contrast to normal seawater which is slightly basic; so pH is another potential clue. You may need to explain that pH is a measure of the concentration of hydrogen ions (which actually exist as hydronium ions, H<sub>3</sub>O<sup>+</sup>). For a more detailed discussion about pH, please see page 20 of the lesson, *Why Do We Explore?* (<http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09whydoweexplore.pdf>).

Hydrogen sulfide is often found in hydrothermal vent fluids, but is not normally found in seawater; so a chemical analysis that indicates its presence in a seawater sample would be another clue that signals vents may be nearby. Particles of precipitated minerals from hydrothermal vent fluids offer another potential clue.

Chemicals that provide energy for chemosynthetic communities may provide yet another clue. This energy comes from a series of reactions called an electron transport chain, and is based on chemicals that can provide electrons to start these reactions. These chemicals are called reducing substances, because they cause other substances to become reduced, which means that the latter substances gain electrons. Common reducing substances in chemosynthetic environments are methane and hydrogen sulfide. The tendency of a substance to gain or lose electrons can be measured as redox potential. Redox potential increases directly with the tendency of a substance to gain electrons and become reduced. So the presence of chemicals that tend to lose electrons (such as hydrogen sulfide) causes the redox potential of the surrounding water to be lower than the redox potential of normal seawater. See the Galápagos Rift Expedition 2011 Expedition Education Module for more discussion about chemosynthesis and reducing habitats. Briefly introduce the CTD as an instrument that ocean explorers use to gather physical and



Okeanos Explorer crew launch the ROV Little Hercules. Image courtesy of NOAA Okeanos Explorer Program, INDEX-SATAL 2010.

<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/media/launch.html>

chemical data about the water column between the sea surface and ocean floor. Be sure students understand that while “CTD” stands for conductivity, temperature, and depth, the actual instrument usually carries sensors that can measure several other parameters as well.

4. Explain the strategy that the Galápagos Rift Expedition 2011 uses to search for hydrothermal vents:

First, scientists raise and lower a CTD through several hundred meters near the ocean bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD resembles the movement of a yo-yo, so this process is called tow-yo operations. During tow-yo operations, scientists may also make maps of the seafloor using multibeam sonar. Next, when CTD data show evidence of a possible plume from a hydrothermal vent, scientists use another type of sonar to look for bubbles and particles in the water column. Finally, when scientists feel they have strong evidence that a hydrothermal vent is in the area, the *Okeanos Explorer’s* remotely operated vehicle (ROV), *Little Hercules*, is lowered to the bottom to gather video images of the area, and hopefully provide the first look at a newly discovered vent!

5. The following activity simulates an analysis of water samples collected by a CTD to identify samples that may have been collected near a hydrothermal vent site. Tell students that their assignment is to analyze several samples collected by a CTD to determine whether any of the samples suggest that they might have been collected from a location near a hydrothermal vent. Demonstrate the correct way to measure pH with a pH strip if students are not already familiar with this procedure.

Provide each student group with two thermometers, 20 strips of pH paper, a pH color indicator chart, a *CTD Sample Analysis Worksheet*, and samples A, B, C, D and E. Tell students to make measurements needed to complete the worksheet.

6. Discuss students’ results. Students should infer that sample D may have been collected in the vicinity of a hydrothermal vent, since its temperature is noticeably higher than that of the other samples, and its pH is noticeably lower. Ask students what other measurements might be made to support this inference. Suggested measurements might include redox potential, and chemical analysis to detect the presence of reducing substances.

7. (Optional) Have students read *Reality Check: When the CTD Stops Working*, by Colleen Peters. This essay describes the first-hand experience of a Senior Survey Technician aboard the *Okeanos Explorer*, and provides students with some insight to some of the realities of ocean exploration. When students have completed the

reading, use the following questions as springboards for discussion:

- *How often do you think problems arise during an ocean exploration mission?*

**Comments:** The *Okeanos Explorer* is a technological orchestra: many different instruments have to work together to achieve the desired results. Many of these instruments are complex, and must function under harsh conditions. Problems are not unusual, and often happen at inconvenient times.

- *Couldn't repairs to the CTD wait until Colleen had a little more sleep?*

**Comments:** Ocean exploration cruises operate on a tight schedule, and there is usually no time to waste. So, when things need fixing they need to be fixed immediately, not when it's more convenient. In this case, about 12 hours after the repair the LSS found plume spikes that may indicate an undiscovered hydrothermal vent; and that discovery might have been missed if the repair was delayed!

- *How did Colleen approach the repair problem?*

**Comments:** She started by focusing on the most likely source of trouble – a cable that had already been problematic. She also thought through what she was going to do, so she had a plan. In addition, she was aware that she was tired, so she made a point of not rushing the repair.

- *How hard was it to fix the CTD problem?*

**Comments:** The repair involved relatively simple technology; some grease, wire cutters, zip ties, and electrical tape. Similarly, the problem itself was fairly simple; just a cable. But simple things can create big problems; the near-disaster aboard Apollo 13 was caused by a malfunctioning switch that cost a few dollars.

### The BRIDGE Connection

[www.vims.edu/bridge/](http://www.vims.edu/bridge/) – Click on “Ocean Science Topics” in the menu on the left side of the page, then select “Geology” or “Habitats” for activities and links about chemosynthetic ecosystems.

### The “Me” Connection

Have students review information about the explorers participating in the Galápagos Rift Expedition 2011 (<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html>), and write a brief essay discussing whose job they would like to have if they were personally taking part in the expedition.

### Connections to Other Subjects

English/Language Arts, Earth Science

### Assessment

Written reports and class discussions provide opportunities for assessment.

**Extensions**

Visit <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1103/welcome.html> for the latest activities and discoveries by the Galápagos Rift Expedition 2011.

**Multimedia Discovery Missions**

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> – Click on the links to Lessons 1, 2, 4, 5, 6, and 12 on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, 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**

**How Does Your Magma Grow?**

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

[http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos\\_magma.pdf](http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_magma.pdf)

Focus: Hotspots and mid-ocean ridges (Physical Science)

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

**One Tough Worm**

(from the 2002 Gulf of Mexico Expedition)

[http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom\\_toughworm.pdf](http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_toughworm.pdf)

Focus: Physiological adaptations to toxic and hypoxic environments (Life Science)

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism’s ability to extract oxygen from its environment. Students will also be able to describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

**The Tectonic Challenge**

(from the INDEX-SATAL 2010 Expedition)

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

Focus: Plate tectonics (Earth Science)

Students describe the motion of tectonic plates; differentiate between three typical boundary types that occur between tectonic plates; infer the type of boundary that exists between two tectonic plates given information on earthquakes and volcanism in the vicinity of the boundary; and explain the relationship between tectonic plate movements and earthquakes, volcanoes, and tsunamis.

**To Explore Strange New Worlds**

(Grades 7-8; adaptations for Grades 5-6 & 9-12)

(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)

[http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/hdwe\\_78\\_toexplore.pdf](http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/hdwe_78_toexplore.pdf)

Focus: Strategies for exploring unknown areas on Earth  
(Life Science/Physical Science/Earth Science)

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

**Mapping the Deep Ocean Floor**

(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)

[http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/hdwe\\_78\\_oceanfloor.pdf](http://oceanexplorer.noaa.gov/oceanos/edu/lessonplans/media/hdwe_78_oceanfloor.pdf)

Focus: Bathymetric mapping (Physical Science/Earth Science)

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.

### Who Promised You a Rose Garden?

(from the 2002 Galapagos Rift Expedition)

[http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal\\_gr7\\_8\\_l3.pdf](http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr7_8_l3.pdf)

Focus: Biological communities associated with hydrothermal vents along the Galapagos Rift and mapping (Life Science/Earth Science)

Students conduct independent research to discover what types of organisms can survive near hydrothermal vents; learn how organisms living along hydrothermal vents can survive in the absence of sunlight and photosynthesis; and use mapping skills to learn more about the Rose Garden at the Galapagos Rift.

### Other Resources

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

<http://oceanexplorer.noaa.gov/oceanos/explorations/ex1103/welcome.html> – Web site for Galápagos Rift Expedition 2011, with links to lesson plans, career connections, and other resources

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

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

<http://oceanexplorer.noaa.gov/explorations/02galapagos/welcome.html> – Web site for the 2002 Galápagos Rift Expedition

<http://oceanexplorer.noaa.gov/explorations/05galapagos/welcome.html> – Web site for the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition

<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

<http://www.pmel.noaa.gov/vents/nemo/index.html> – Web site for NOAA’s New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates

<http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html> – National Geographic Xpeditions lesson plan, *We’re in Hot Water Now: Hydrothermal Vents*, includes links to *National Geographic* magazine articles and video with an emphasis on geography and geographic skills

<http://www.divediscover.whoi.edu/vents/index.html> – Woods Hole Oceanographic Institution’s Dive and Discover Web site about hydrothermal vents includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977

### National Science Education Standards

#### Content Standard A: Science As Inquiry

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

#### Content Standard B: Physical Science

- Transfer of energy

#### 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

- Understandings about science and technology

#### Content Standard F: Science in Personal and Social Perspectives

- Personal health
- Populations, resources, and environments

### Ocean Literacy Essential Principles and Fundamental Concepts

#### Essential Principle 2.

**The ocean and life in the ocean shape the features of the Earth.**

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



### **Essential Principle 5.**

#### **The ocean supports a great diversity of life and ecosystems.**

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

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

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

### **Essential Principle 7.**

#### **The ocean is largely unexplored.**

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

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

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

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

### Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: [oceaneducation@noaa.gov](mailto:oceaneducation@noaa.gov).

### For More Information

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### Acknowledgements

This lesson was developed and written for NOAA’s Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, Science and Technology Consultant to OER’s Education Team.

The water sample analysis activity described in Step 5 is adapted from the 2002 Galapagos Rift Expedition lesson, “Yo-Yos, Tow-Yos and pH, Oh My!” by Stacia Fletcher, South Carolina Aquarium, Charleston, SC.

Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

### Credit

If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov>

## The Oceanographic Yo-yo CTD Sample Analysis Worksheet

Group Name: \_\_\_\_\_

Sample	Temperature	pH
A		
B		
C		
D		
E		

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

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How do your data support this inference?

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## Reality Check: When the CTD Stops Working

Colleen Peters, Senior Survey Technician, NOAA Ship *Okeanos Explorer*



I was in a deep post-watch slumber, when I dreamt that someone was calling my name. A hand reached around the curtain of my rack to lightly tap my arm. “Colleen.... The CTD is on deck, there’s a problem with the LSS”. It was Megan [Lieutenant Megan Nadeau, the *Okeanos Explorer’s* Operations Officer]. If anyone needs to be woken up in the middle of the night, I highly recommend that Megan be the one to do it.

I got up in the darkness, and still groggy, tried not to wake up my roommate while I blindly searched for yesterday’s clothes and shoes. I got dressed, pulled back my hair and headed into the bright passageway and made my way to the control room to see what had happened.

It was 4 AM (I had only been asleep for two hours) and the tow-yos had only begun 16 hours prior. The night watch had experienced a problem with one of the sensors, the Light Scattering Sensor (LSS) was spiking in such a way that it was not collecting real data. We have two for redundancy, but one of the sensors had stopped working properly shortly after the CTD was in the water—but we had continued with the tow because we had the second LSS. When the second sensor stopped working, it was time to troubleshoot, because the LSS is our primary plume-detecting sensor. At the request of shore-side scientists, the CTD was pulled back to the surface and brought on deck to be investigated.

I grabbed some tools on my way out the door. A new cable, silicone grease, a cotton swab, some electrical tape, a pair of dykes [diagonal side-cutters], some zip ties, and a rubber mat. When I arrived on deck, I placed the mat near the top end of the CTD where all the auxiliary cables connect. The deck is coated with heavy duty nonskid that can rip a pair of jeans, never mind your skin. I disconnected both of the LSS cables from the CTD. I inspected the cables for signs of leakage. All clear.

I then disconnected both the sensors from their cables. The one that was working but had just started spiking I simply cleaned out the cables and connectors and with a little bit of grease to help keep water out, and reconnected the cable. The LSS that was not working was likely due to a cable issue—we did not have the correct cables on board (they were not sensitive enough) and so we used modified ones. I replaced the modified cable with one of the original ones. This way, we can still collect valuable data, make a comparison between the sensitivities, and have the modified cable repaired in time for the next tow-yo.

Since I was still sleepy, trying to remember how things were configured, I took my time to make sure I got everything right. It costs the ship a lot of extra time to have to pull the CTD on deck, so it was better to not have to do it twice. Once the cables were all connected, I had to button them up—lash them to the frame with electrical tape so that nothing would come loose during the tow and adversely affect the data or the equipment. Once that was complete, I assisted the deck department in deploying the CTD.

Once the CTD was in the water, I returned to the lab to start the cast. Being the resident technician, I took the lead, and had the watch leader observe. We started the data, and made sure that everything looked right before proceeding down. I stayed to watch the CTD descend to around 1000 meters, (about half way down) before turning things over, because I needed to make the call of whether or not the troubleshooting was successful. The data looked good. The LSS’s were mimicking each other—the signals were of the same pattern, but because of the difference in sensitivities of the two cables, they were simply on two different scales. As far as I was concerned, it was a success. I turned it back over to the watch leader, and he proceeded with the tow... and I proceeded back to bed.