The Galápagos Rift Expedition 2011

We've Got Plumes!

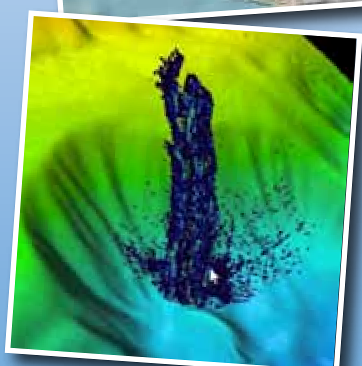


Image captions/credits on Page 2.

lesson plan

Focus
Hydrothermal vents and exploration with CTDs

Grade Level
9-12 (Earth Science/Chemistry)

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

Learning Objectives
- Students will describe hydrothermal vents.
- Students will explain how oxidation-reduction potential and light-scattering sensor data may be used to detect the presence of hydrothermal vents.
- Students will analyze CTD data collected in the vicinity of the Galápagos Spreading Center to recognize a probable plume from hydrothermal activity.

Materials
- ❑ Copies of *Galapagos CTD Data Analysis Worksheet,* one for each student group

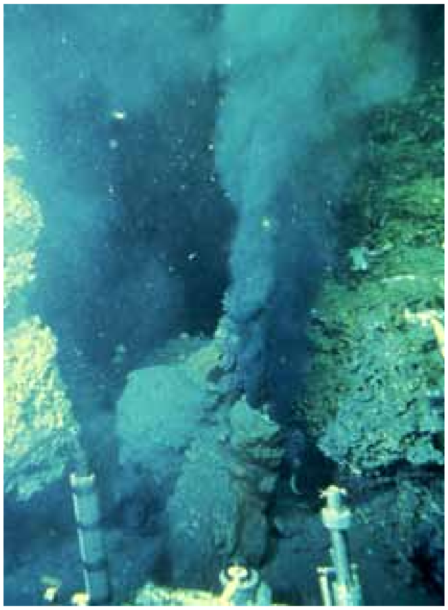
Audio-Visual Materials
- ❑ (Optional) Interactive white board or computer projection equipment; see Learning Procedure Step 1.

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of 3-4 students

Maximum Number of Students
32

Key Words
Galápagos Rift
Galápagos Spreading Center



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

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

Multibeam image of Mendocino Ridge Plume taken with the Kongsberg EM302 multibeam bathymetric mapping system. Image courtesy INDEX-SATAL 2010 Expedition.
http://oceanexplorer.noaa.gov/okeanos/media/movies/mendocino_ridge_plume_video.html

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/okeanos/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/okeanos/explorations/10index/logs/hires/8_doug_jongeward_hires.jpg

Hydrothermal vent
Plume
CTD
Tow-yo
Oxidation-reduction potential
Light scattering sensor

Background Information

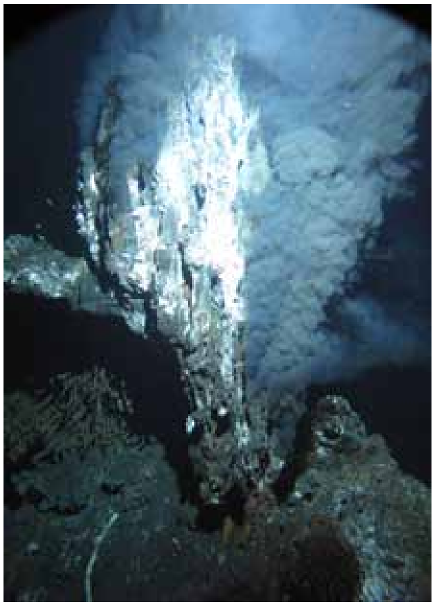
NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

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.

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.



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/okeanos/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 *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/slideshow/ex_july_highlights/gallery/hires/white_plumes_hires.jpg

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 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

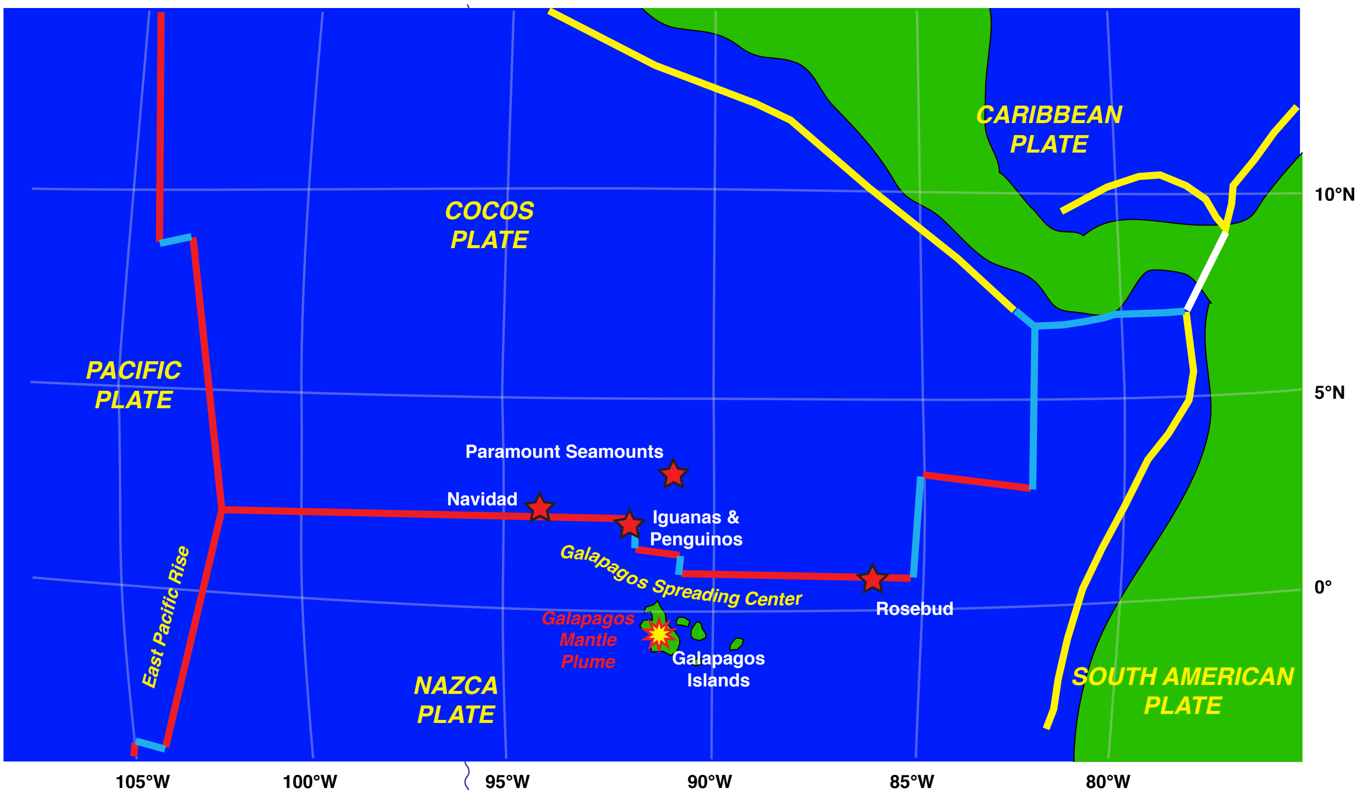


Figure 1. Galápagos Tectonic Setting. Red plate boundaries are divergent; yellow plate boundaries are convergent; blue plate boundaries are transform; white plate boundaries are undetermined. Navidad, Iguanas and Penguinos are locations where black smokers were discovered in 2005. Paramount Seamounts 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/okeanos/explorations/ex1103/background/edu/edu.html. Credit: UNAVCO (tectonic boundaries); NOAA (hydrothermal sites)

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.

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

Port view of the *Okeanos Explorer*.
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 Instumentation:
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

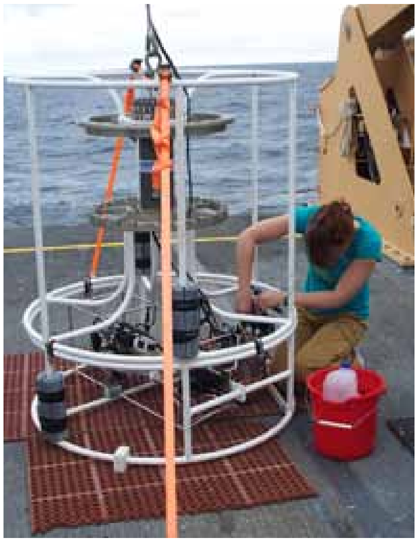
For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.

Aft view of the *Okeanos Explorer*.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/aft_view_hires.jpg

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 thermophylus,* 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!

These discoveries set the stage for the Galápagos Rift Expedition 2011, which will use the state-of-the-art exploration capabilities of 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 this Expedition is to survey and map known hydrothermal vent sites, and to search



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/ex1103l1/news-articles/update-for-june-25-2011/image/image_view_fullscreen

A CTD with water sampling bottles attached to the rosette frame. Image courtesy of NOAA *Okeanos Explorer* Program.

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.

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 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 and http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html.

Okeanos Explorer is equipped with a Sea Bird SBE 911plus CTD. Besides measuring conductivity, temperature, and water pressure (which is used to calculate depth), up to eight additional sensors can be added to measure other physical and chemical characteristics. For the Galapagos Rift Expedition 2011, *Okeanos Explorer's* CTD will also carry an altimeter (to measure distance from the seafloor, which is essential for tow-yo operations), 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 (particles that are formed as precipitates when hot, mineral-laden vent fluids enter the much colder water near the seafloor). Oxidation-

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

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.

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

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.

This lesson focuses on physical and chemical measurements that may signal the presence of hydrothermal vents and introduces students to simple analysis of CTD data.

Learning Procedure

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 hydrothermal vent communities, you may want to have students complete the background portion of the *Hydrothermal Vent Plume Inquiry Guide* (http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf) which guide student inquiries about hydrothermal vents and plumes.
   (c) Review background information on CTD technology at http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html.
   (d) Review questions on the *Galápagos CTD Data Analysis Worksheet*.
   (e) Download the CTD data file from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/galapagosctd_11_6_24.xls, and install it on computers that students will be using to complete the *Worksheet* activity. Alternatively, you may have students download this file onto their own computer systems.

2. Briefly introduce the Galápagos Rift Expedition 2011, and the NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole

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

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.

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 the advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers (ECCs). 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.

Briefly discuss hydrothermal vent communities, or have students complete the activity referenced in Step 1b. Say that a primary purpose of the Galápagos Rift Expedition 2011 is to search for new hydrothermal vents in unexplored regions of the Galápagos Rift. Tell students 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 previously undiscovered vents.

3. Introduce the CTD as an instrument that ocean explorers use to gather physical and chemical data about the water column between the sea surface and ocean floor, and ask students why oceanographers would want to measure conductivity, temperature, and depth. Be sure students understand the relationship between conductivity and salinity, and that while "CTD" stands for conductivity, temperature, and depth, the actual instrument usually carries sensors that can measure several other parameters as well. You may want to use information and/or images from http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html. Discuss how concentration of particulates and oxidation-reduction potential may be affected by hydrothermal vent activity.

   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) is lowered to the bottom to gather video images of the area, and hopefully provide the first look at a newly discovered vent!

4. Tell students that their assignment is to look for anomalies in CTD data collected aboard the *Okeanos Explorer* in tow-yo operations near the Galápagos Rift on June 24, 2011. Provide each student group with a copy of the *Galápagos CTD Data Analysis Worksheet*, and ensure that students have access to the file referenced in Step 1e. Explain that this activity is intended to familiarize them with CTD data and how they can be analyzed to find anomalies that may indicate the presence of undiscovered features on the ocean floor. You may also want to mention that this skill will allow them to investigate additional data that will be available from future *Okeanos Explorer* missions.

5. When students have answered questions on the *Worksheet*, lead a discussion of their results. This discussion should include:
   - One second elapses between each set of readings recorded in the data file. The total time covered by the data in this file is 30 minutes.
   - The maximum depth reached by the CTD during the two raising-lowering cycles shown on the graph was 1884.697 m. The minimum depth during these two cycles was 1594.885 m. At its maximum depth, the CTD was 20.81 m above the bottom. About 16 minutes were required to complete one raising and lowering cycle.
   - The data from LSS-1 show distinct anomalies that occurred when the CTD was near the deepest portion of the raising and lowering cycle, with maximum anomalies observed at depths between 1,850 and 1,900 m.
   - A plot of LSS-2 shows anomalies similar to those observed for LSS-1. Plots of salinity, temperature, and ORP do not show anomalies that might signal the presence of hydrothermal plumes. Salinity increases with increasing depth by about 0.02 psu. Temperature decreases with increasing depth by about 0.4C. ORP increases over the period of the tow, but does not show a consistent relationship to depth. See Figures 3, 4, 5, and 6. Note that "Upoly" means user-defined polynomial, which in this case is a sensor that measures ORP. The polynomial part refers to information about the sensor that technicians provide to the software that processes data from the CTD.

Figure 3

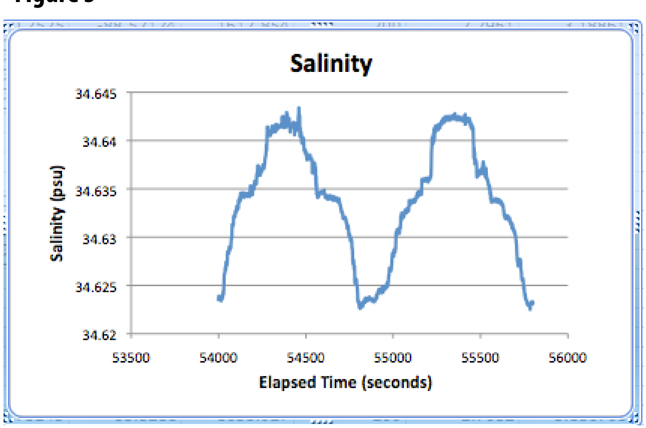
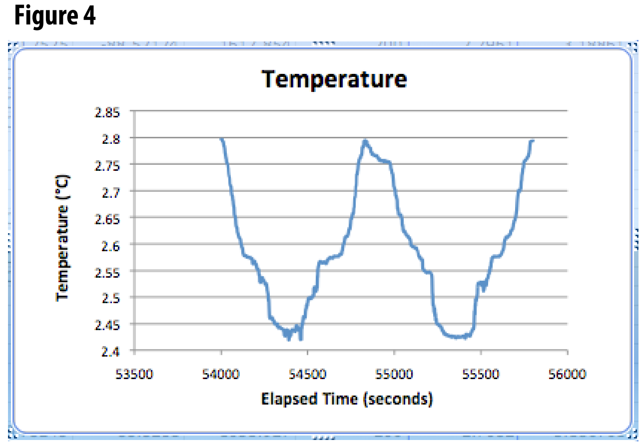


Figure 4



- Data from LSS-2 include much higher voltages than data from LSS-1, which makes it reasonable to infer that LSS-2 is more sensitive.

Figure 5

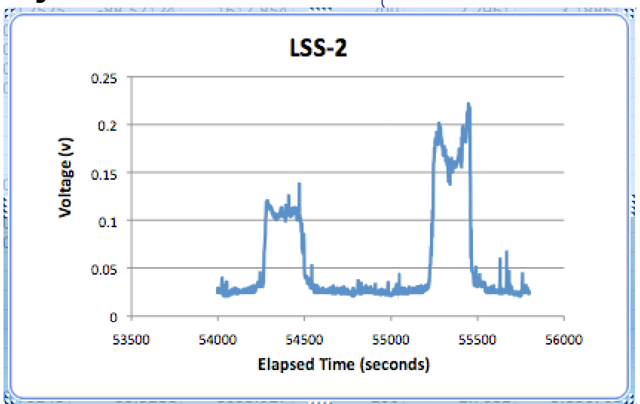
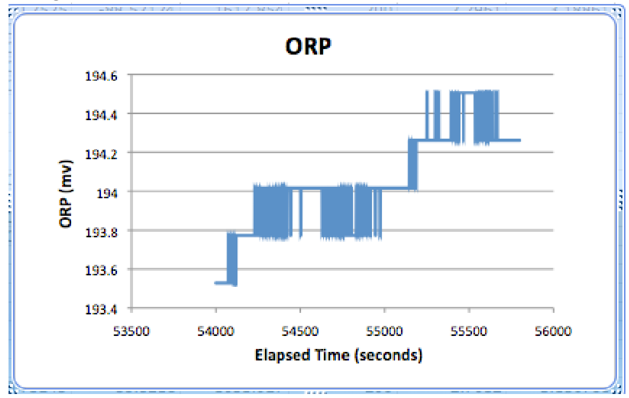
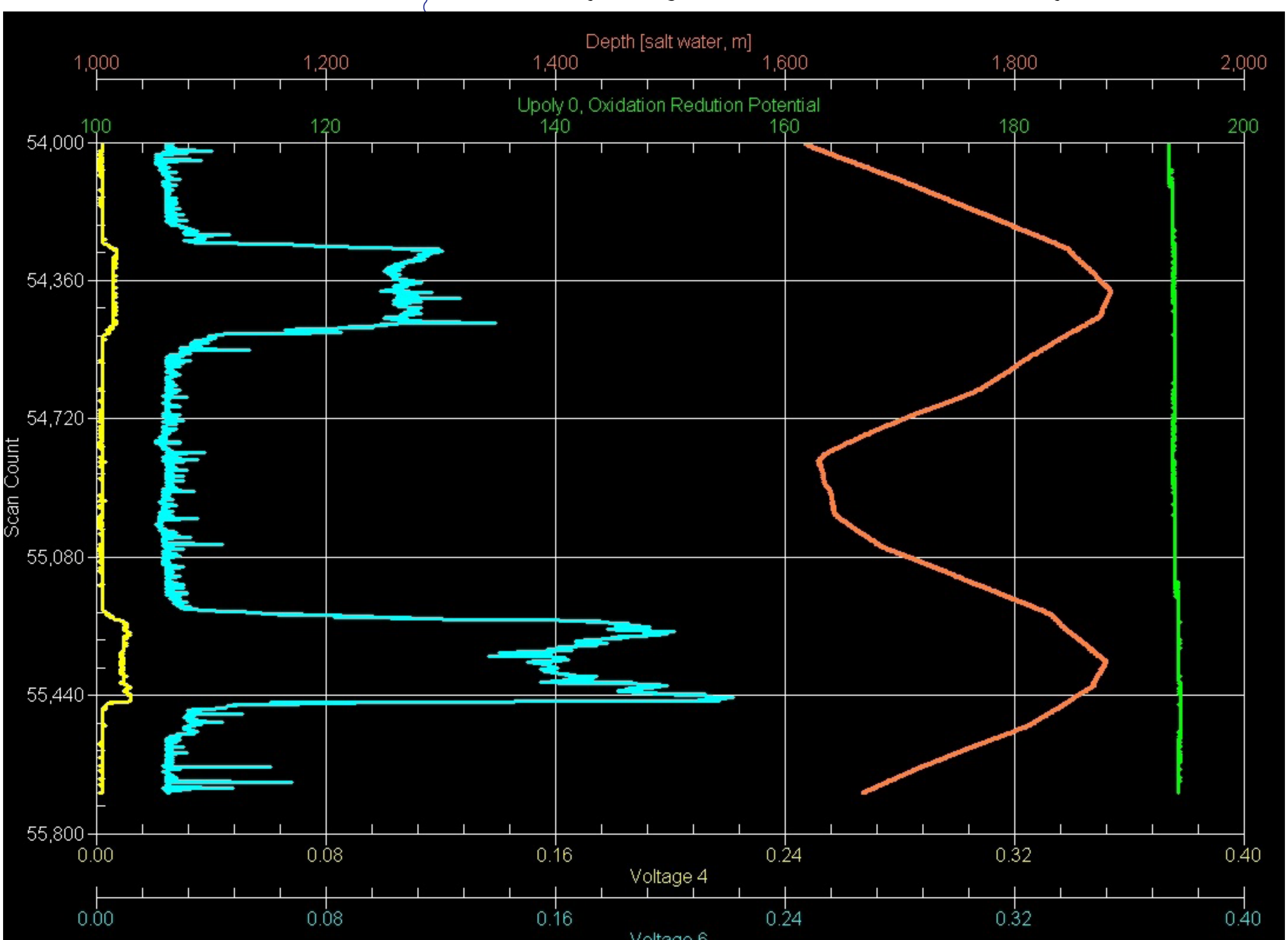


Figure 6



You may want to show Figure 7, which is a screen grab of the actual CTD sensor readings captured during the segment of the June 24, 2011 tow-yo that generated the data used in this activity.

Figure 7



Note that oceanographers often like to plot CTD data with depth on the y-axis and the greatest depths at the bottom of the plot, since that is the way we usually think about a profile of the water column. We have not done this in the *Worksheet* activity, since the software used to process tow-yo data aboard *Okeanos Explorer* generated plots similar to that shown in Figure 7, which has maximum depth values farthest from the x-axis. If students rotate their graphs 90 degrees clockwise, their plots should resemble the screen grab shown in Figure 7.

The BRIDGE Connection

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

The "Me" Connection

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

Connections to Other Subjects

English/Language Arts, Social Studies

Assessment

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

Extensions

1. Visit http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/welcome.html for more information about the expedition and to check out the Daily Updates.
2. 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

Tools of Exploration – Remotely Operated Vehicles
(from the INDEX-SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/multibeam.pdf

Focus: Technology for deep ocean exploration: Remotely Operated Vehicles (Earth Science/Physical Science)

Students describe systems and capabilities of science-class remotely operated vehicles, typical applications and limitations of imagery obtained with ROVs, and use ROV imagery to make inferences about deep ocean habitats.

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/okeanos/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*; describe how fractal geometry models natural systems, and how scale influences exploration strategy and results.

Wow, That Hertz!
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_hertz.pdf

Focus: Wireless communications physics (Physical Science/Physics)

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

Watching in 3-D
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_3d.pdf

Focus: Multibeam sonar (Physical Science/Earth Science)

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

Through Robot Eyes
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_912_roboteyes.pdf

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

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 (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.

Reduced Fare
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/reducedfare.pdf

Focus: Deep-Sea Reducing Environments (Life Science)

Students describe oxidation and reduction; explain the meaning of "reducing environment;" give at least three examples of deep-sea reducing environments; and demonstrate a flow of electric current produced by a redox reaction.

The Chemosynthetic Cafe
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/cafe.pdf

Focus: Biochemistry of hydrothermal vents (Life Science)

Students compare and contrast food web energy sources in hydrothermal vent and aerobic environments, and use models to explain the overall chemistry of autotrophic nutrition.

The Big Balancing Act
(from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_balancing.pdf
Focus: Hydrothermal vent chemistry at subduction volcanoes (Chemistry/Earth Science)

Students define and describe hydrothermal circulation systems; explain the overall sequence of chemical reactions that occur in hydrothermal circulation systems; compare and contrast "black smokers" and "white smokers;" and make inferences about the relative significance of these systems to ocean chemical balance compared to terrestrial runoff from data on chemical enrichment in hydrothermal circulation systems.

Hydrothermal Vent Challenge
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VentChallenge.pdf

Focus: Chemistry of hydrothermal vents (Chemistry)

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

Survivors on the Ocean Ridge
(from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l5.pdf

Focus: Inheritance of genetic traits and the effect of environmental pressures on the expressed traits (Life Science)

Students investigate the history of explorations of the hydrothermal vent systems; design a new shrimp species based on the introduction of a new gene form from migrating shrimp populations along the rift systems; assess the viability of the new shrimp species; and develop a model for the establishment of a population of a new species of shrimp.

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/okeanos/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/okeanos/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

- Chemical reactions
- Motions and forces

Content Standard D: Earth and Space Science

- Energy in the Earth system
- Geochemical cycles

Content Standard E: Science and Technology

- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives

- Natural resources

Content Standard G: History and Nature of Science

- Nature of scientific knowledge

Ocean Literacy Essential Principles and Fundamental Concepts

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 2.
The ocean and life in the ocean shape the features of the Earth.

Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

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 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: oceanexeducation@noaa.gov.

For More Information

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Credit

We've Got Plumes!

Galápagos CTD Data Analysis Worksheet

NOTE: The following instructions are for Microsoft Excel®2008. Other versions of Excel or other spreadsheets will require slightly different procedures. See user documentation for how to import text files and make graphs from these files. If you have difficulty opening the file referenced in Step 1 and are using an older version of Excel®, you may need the Office Compatibility Pack. This can be downloaded from: http://www.microsoft.com/download/en/details.aspx?displaylang=en&id=3. If you would like to open the file in a newer version of Excel, be sure that you have turned on "Compatibility Mode". If you only want to look at Excel® files, you may want to try the Excel® Viewer (http://www.microsoft.com/download/en/details.aspx?id=10), but this will not allow you to graph or edit the data.

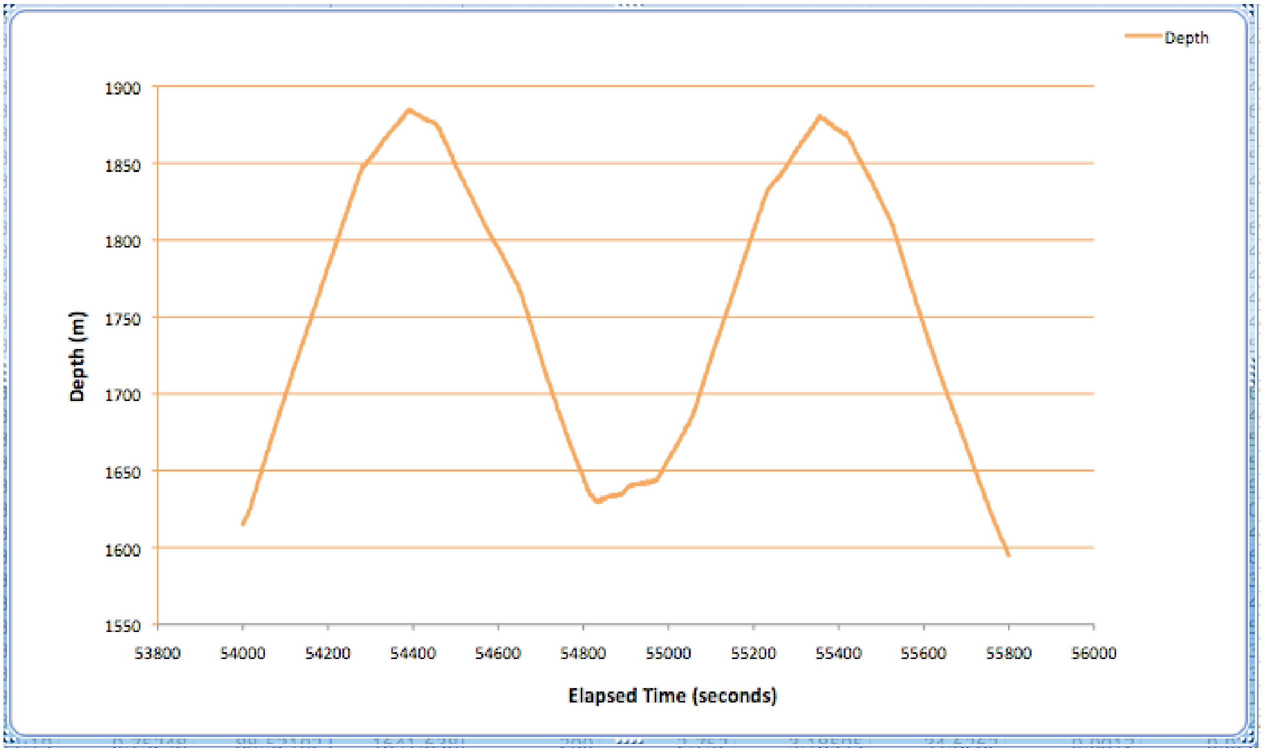
1. Open the "GalápagosCTD.11.6.24.xlsx" file in Microsoft Excel®. These data were collected during a tow-yo operation aboard the *Okeanos Explorer* on June 24 and 25, 2011. The first row shows the contents of each column: Elapsed Time; Greenwich Mean Time (UTC); Latitude in decimal degrees; Longitude in decimal degrees; Depth of the CTD in meters; Altitude (distance above the seafloor) in meters; Temperature in °C; Conductivity in Siemens per meter; Salinity in Practical Salinity Units; Light Scattering Sensors (LSS-1 and LSS-2); and Oxidation-Reduction Potential (Upoly). The units of LSS aren't really important, because we are only concerned with finding readings that are distinctly different from other readings (anomalies). The numbers in the two LSS columns are the voltages recorded from the two LSS sensors.

2. How much time elapsed between each set of readings recorded in the data file? What is the total time covered by the data in this file?

3. Plot Depth as a function of Elapsed Time to produce a graph that resembles Figure 1. Be sure to:
    - Label the x- and y-axes;
    - Make the color of the plotted line orange;
    - Make the vertical axis orange;
    - Make the vertical axis gridlines orange; and
    - Drag the legend to the upper right corner.

4. Your graph shows the path of the CTD as it was raised and lowered while the ship slowly towed it through the water. During the two raising-lowering cycles shown on the graph, what was the maximum depth reached by the CTD? What was the minimum depth during these two cycles? How close to the bottom was the CTD at its maximum depth? About how much time was required to complete one cycle?

Figure 1

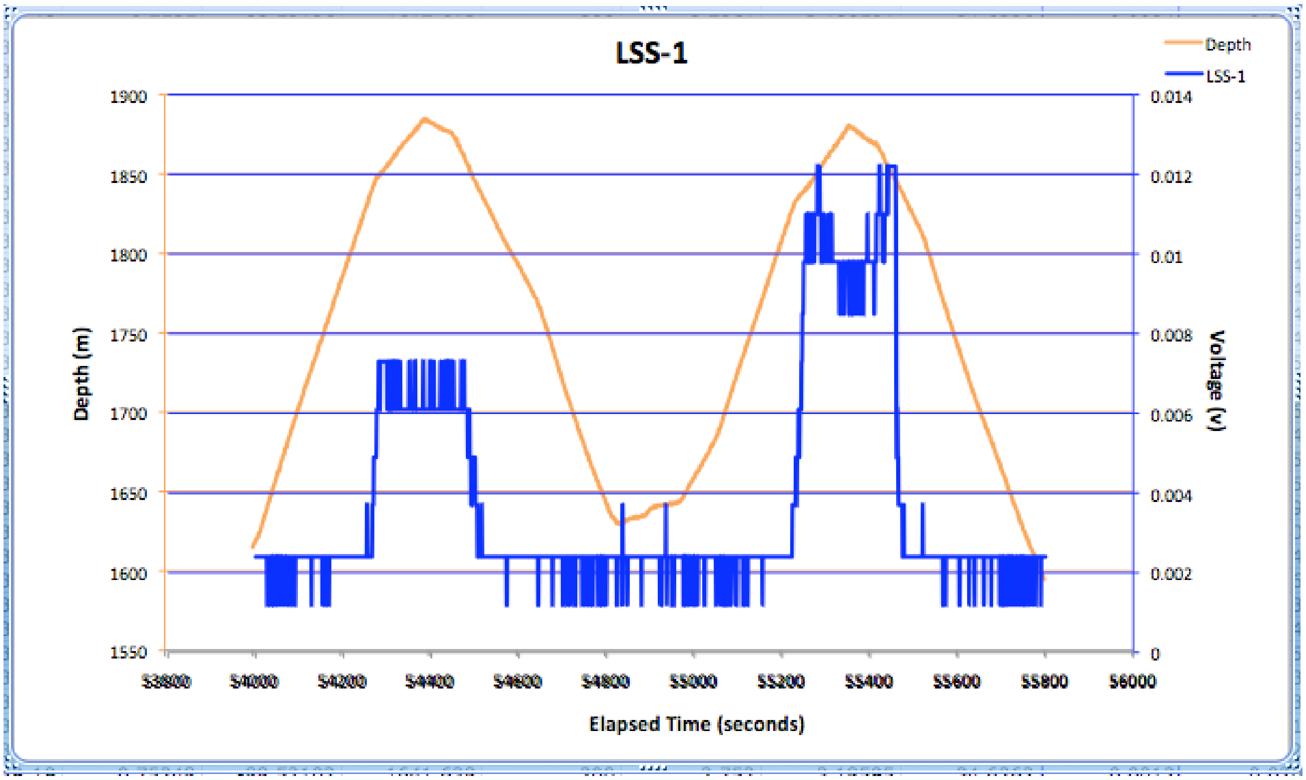


5. Now let's look for anomalies!

Make a plot of readings from the light scattering sensor LSS-1 as a function of elapsed time. Format your graph as follows:

- Move the vertical axis to the right side of the plot;
- Make the color of the plotted line blue;
- Make the vertical axis blue;
- Make the vertical axis gridlines blue;
- Move the Legend to the upper right of the chart area, but not quite as far as you moved the Legend for Depth;
- Make the chart background and plot area background transparent (set the background fill to "No Fill"); and
- Move your graph for LSS-1 to the same sheet with the graph for Depth, and drag your plot for LSS-1 over the plot for Depth. Adjust the position of the plot so that the numbers on the x-axis line up on both plots. Your combined plots should resemble Figure 2.

Figure 2



6. Do the data from LSS-1 show any anomalies? If so, do they correspond to any particular depth?

7. Let's dig into the data a little more. Make plots of salinity, temperature, LSS-2 and ORP as functions of elapsed time. If you want to overlay these onto your depth plot, follow Step 5, and give each plotted line a different color. Do any of these plots show anomalies? If so, do the anomalies correspond to any particular depth?

8. Read *Reality Check: When the CTD Stops Working*, by Senior Survey Technician Colleen Peters. The events Colleen describes occurred earlier in the day of June 24, 2011. Note that she says one of the LSS sensors is more sensitive than the other. From your data plots, do you think LSS-1 or LSS-2 is more sensitive? Why?

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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.