



Section 4: Water Column Investigations

Lesson 8: A Quest for Anomalies

Focus

CTD (conductivity, temperature, depth profiler)

Grade Level

9-12 (Earth Science/Physical Science/Technology)

Focus Question

How is a CTD used aboard the *Okeanos Explorer* to help explore Earth's deep ocean?

Learning Objectives

- Students will explain how properties of redox potential and optical backscatter are related to deep-sea ecosystems and geologic features.
- Students will analyze and interpret data from the *Okeanos Explorer* to detect potential anomalies.

Materials

- Copies of *Introduction to CTD Data Worksheet*; one copy for each student or student group

Audio Visual Materials

- Video projector or large screen monitor for showing downloaded images (see Learning Procedure, Step 2)

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

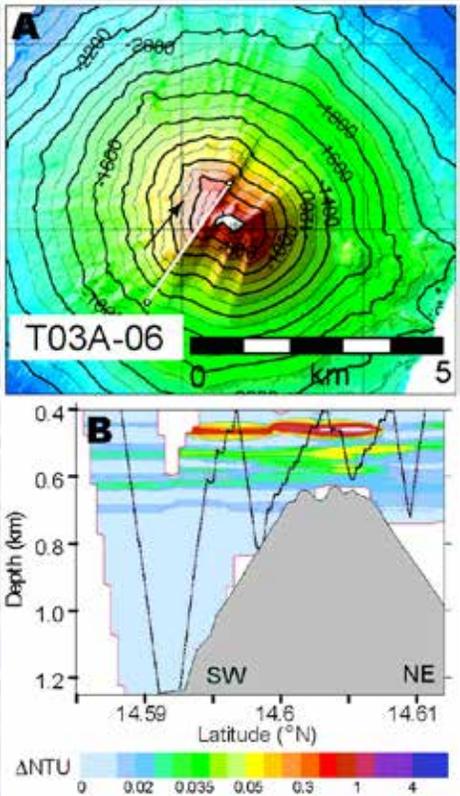
Groups of two to four students

Maximum Number of Students

30

Key Words and Concepts

Ocean Exploration
Okeanos Explorer
 CTD
 Oxidation-reduction potential (ORP)
 Optical backscatter (OBS)
 Plume



These images represent aspects of a towed hydrocast (tow-yo) at NW Rota-1 submarine volcano, located at 14° 36' N. The tow-yo was performed February 12, 2003. A) The bathymetric map shows (in white) the tow line of the hydrocast. B) The hydrothermal plume above the volcano shown as delineated by optical backscatter. The black saw-tooth pattern is the track of the CTD-rosette package as it passed over the volcano. The stair-step features in the track are the locations where samples were taken. ΔNTU= nepelometric turbidity units above ambient seawater.
http://oceanexplorer.noaa.gov/explorations/06fire/background/hirez/nwrota1_tow_hires.jpg



Background

For discussion about the exploration strategy used aboard the *Okeanos Explorer*, please see the *Introduction to Volume 2: How Do We Explore?* beginning on page 9. For background about CTD instruments, please see the *Introduction to Water Column Investigations* on page 87.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977 at a divergent plate boundary near the Galapagos Islands. Here, researchers found large numbers of animals that had never been seen before clustered around underwater hot springs flowing from cracks in the lava seafloor. The presence of thriving biological communities in the deep ocean was a complete surprise, because it had been assumed that food energy resources would be scarce in an environment without sunlight to support photosynthesis. Researchers soon discovered that the organisms responsible for this biological abundance do not need photosynthesis, but instead are able to obtain energy from chemical reactions through processes known as chemosynthesis. Photosynthesis and chemosynthesis both require a source of energy that is transferred through a series of chemical reactions into organic molecules that living organisms may use as food. In photosynthesis, light provides this energy. In chemosynthesis, the energy comes from other chemical reactions. Energy for chemosynthesis in the vicinity of hydrothermal vents often comes from hydrogen sulfide.



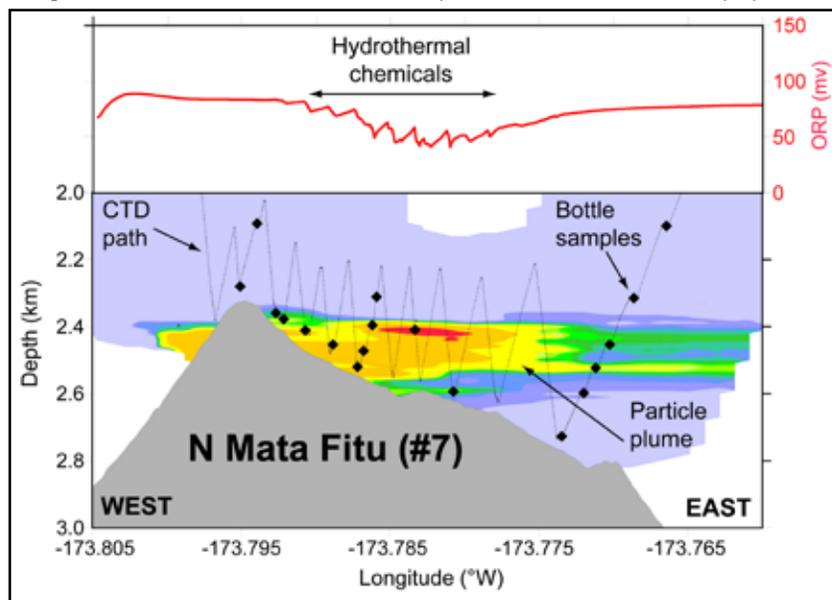
Image of hydrothermal vents found during the second ROV dive on the Kawio Barat volcano. The yellow deposits are molten sulfur. Multiple species of hot-vent shrimp are also visible. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june30_update_hires.jpg

In chemosynthesis, energy from chemical reactions is captured and stored in other molecules. This energy moves from one molecule to another when electrons are transferred between the molecules. These transfers take place in a series of reactions called an electron transport chain. The electron transport chain begins with the loss of an electron from a substance such as hydrogen sulfide or methane. This electron is captured by an organic molecule, which releases an electron to a second organic molecule, and the process continues through several other molecules. Each time an electron is transferred, the molecule that gains the electron also gains energy; and the molecule that loses the electron loses energy. The last molecule in the chain keeps the electron, and has a higher energy content than before it received the electron. Some energy is lost each time an electron moves from one molecule to another. The energy captured by the electron transport chain is used by chemosynthetic organisms to convert carbon dioxide into molecules that can serve as energy sources (food) for living organisms.

When an atom or molecule loses an electron it is said to be oxidized, and when an atom or molecule gains an electron it is said to be reduced. A reducing substance is a substance that causes another substance to be reduced; in other words, a reducing substance donates electrons. Similarly, an oxidizing substance is a substance that causes another substance to be oxidized; that is, an oxidizing substance receives electrons. A reaction in which one or more electrons are transferred between two molecules is called a redox reaction. Note that the terms oxidation, reduction, and redox may also be used in slightly different ways for some types of chemistry, but these distinctions are not important for this discussion. Chemosynthesis depends upon the availability of reducing substances such as hydrogen sulfide or methane that can donate electrons. Habitats in which these substances occur are called reducing habitats.

Hydrothermal vents and chemosynthetic communities are often associated with changes in the chemical properties of seawater. To look for these changes, ocean explorers use an instrument known as a CTD, which stands for conductivity, temperature, and depth. A CTD is a package of electronic instruments that measure these properties. Conductivity is a measure of how well a solution conducts electricity and is directly related to salinity, which is the concentration of salt and other inorganic compounds in seawater. Salinity is one of the most basic measurements used by ocean scientists. When combined with temperature data, salinity measurements can be used to determine seawater density, which is a primary driving force for major ocean currents. Often, CTDs are attached to a much larger metal frame called a rosette, which may hold water sampling bottles that are used to collect water at different depths, as well as other sensors that can measure additional physical or chemical properties.

CTD measurements provide evidence of volcanoes, hydrothermal vents, and other deep-sea features that cause changes to the physical and chemical properties of seawater. Masses of seawater with unusual characteristics are called plumes, and are usually found within a few hundred meters of the ocean floor. Since underwater volcanoes and hydrothermal vents may be several thousand meters deep, ocean explorers often 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



Results from a CTD tow-yo over Mata Fitu in 2010. The bottom panel shows the CTD path over the volcano profile. Light-scattering values define the plume; red colors are the highest particle concentrations, blue colors are the lowest concentrations. The top panel shows the change in oxidation-reduction potential (ORP) values during the tow. Higher chemical concentrations are denoted by negative deflections in the ORP value. Image courtesy of NOAA Vents Program.

http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_results_hires.jpg

resemblance that has led to the nickname “tow-yo” for this type of CTD sampling.

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

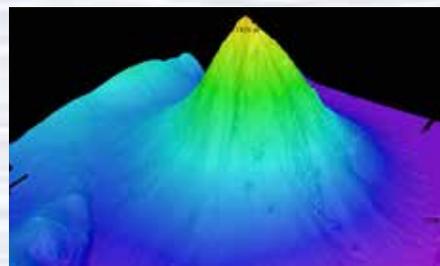
Temperature measurements from CTD sensors can be used to detect water temperature anomalies that may indicate the presence of volcanoes or hydrothermal vents. Two other sensors are also important to the search for these deep-ocean features. Optical backscatter (OBS) sensors detect the presence of suspended particles that may come from hydrothermal vents or from the oxidation of methane, which causes precipitates of carbonate material to form. Oxidation-reduction potential (ORP) sensors measure the tendency of a substance to gain or lose electrons. ORP 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.

This lesson introduces students to simple analysis of CTD data. In the future, students will have the opportunity to apply their analytic skills to investigate additional information from CTDs as the *Okeanos Explorer* continues its voyages of discovery in Earth’s deep ocean.

Learning Procedure

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions on the student worksheet.

1. To prepare for this lesson:
 - a) Review:
 - Introductory essays for the INDEX-SATAL 2010 Expedition (<http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html>);
 - Background information on CTD technology at <http://www.pmel.noaa.gov/vents/PlumeStudies/WhatsACTD/CTDMethods.html>
 - (b) Review background information about the *Okeanos Explorer* exploration strategy and technologies.
 - (c) Review questions on the *Introduction to CTD Data Worksheet*.
 - (d) Download the data file **EX0904_ctd_1.xls** from http://oceanexplorer.noaa.gov/okeanos/edu/resources/media/ex0904_ctd_1.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. Students will also need access to Microsoft Excel™ to complete this activity.
 - (e) If desired, download images referenced in Step 2.
2. Briefly introduce the NOAA Ship *Okeanos Explorer* and the INDEX-SATAL 2010 Expedition. Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *Earth’s Ocean is 95% Unexplored: So What?*; http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf). Highlight the overall exploration strategy used by *Okeanos Explorer*, including the following points:
 - The overall strategy is based on finding anomalies;



Okeanos Explorer’s EM302 multibeam sonar mapping system produced this detailed image of the Kawio Barat seamount, which rises around 3800 meters from the seafloor. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/june26fig1_hires.jpg



A CTD is attached to a metal frame called a rosette, or carousel, along with numerous water sampling bottles and when deployed, provides information about the composition of the water column. Image courtesy of NOAA.
<http://oceanexplorer.noaa.gov/technology/tools/sondectd/sondectd.html>



Okeanos Explorer crew launch the vehicle during test dives off Hawaii. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg



ROV Team Lead, Commanding Officer, and Science Team Lead discuss operations at the Mid-Cayman Rise with participants located at both the Silver Spring ECC, and URI’s Inner Space Center. Image courtesy of NOAA *Okeanos Explorer* Program, MCR Expedition 2011.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/logs/hires/daily_updates_aug9_1_hires.jpg



- This strategy involves
 - Underway reconnaissance;
 - Water column exploration; and
 - Site characterization;
- This strategy relies on four key technologies:
 - Multibeam sonar mapping system;
 - CTD and other electronic sensors to measure chemical and physical seawater properties;
 - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 4,000 meters; and
 - Telepresence technologies that allow people to observe and interact with events at a remote location.

You may want to show some or all of the images in the sidebar on page 112 to accompany this review.

Plot showing light scattering (dNTU) sensor and oxygen reduction potential (ORP) data, versus time, acquired by the CTD/rosette as it passed through a plume over the top of Kawio Barat volcano. There was an intense particle anomaly and ORP decrease in the bottom 30 meters of the water column when the plume was encountered. A drop in the ORP, like you see here, means that there are more electron donor compounds in the water produced by enrichment of seawater in dissolved metals and chemicals billowing out of hydrothermal vents. The ORP values begin to increase again, recovering slowly, when the CTD leaves the plume. Image courtesy of Sharon Walker, PMEL.

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

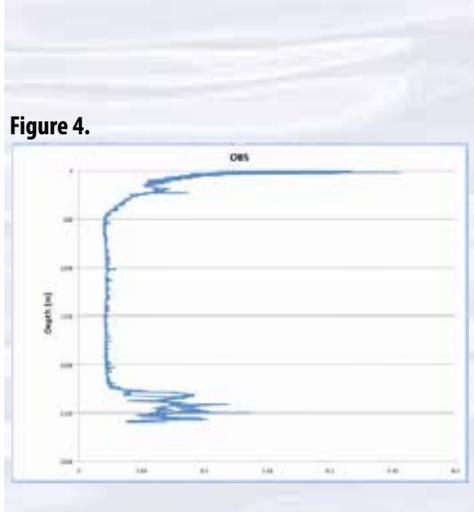
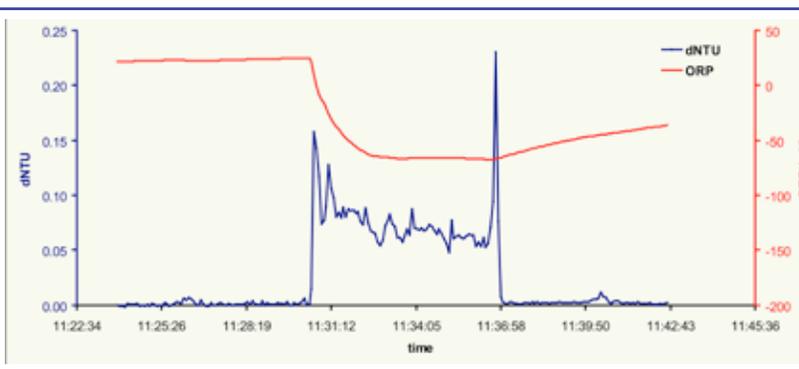


Figure 4.

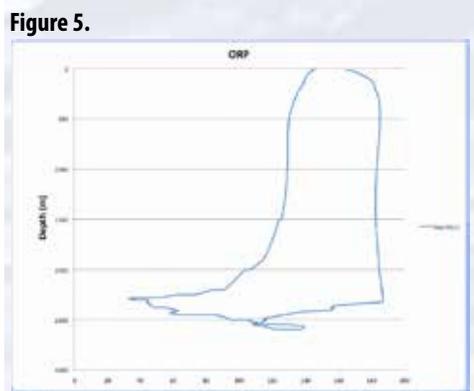


Figure 5.

3. Ask students why oceanographers would want to measure conductivity, temperature, and depth. Be sure students understand the relationship between conductivity and salinity. Briefly describe a CTD, emphasizing that these devices are often capable of measuring many other parameters in addition to conductivity, temperature, and depth. You may want to use information and/or images from the site referenced in Step 1a. Discuss how OBS and ORP may be affected by hydrothermal vent activity.
4. Tell students that their assignment is to look for anomalies in CTD data collected aboard the *Okeanos Explorer* in 2009. Provide each student group with a copy of the *Introduction to CTD Data Worksheet*, and ensure that students have access to the file referenced in Step 1d. Tell students 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 enable 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:
 - The time required to complete the entire CTD cast was 7,160 seconds; just under two hours.
 - The maximum depth recorded by the CTD was 2601.255 meters.
 - Students should notice that the maximum depth occurred about half-way through the cast; this is because data were recorded during the CTD's ascent (the "up cast"), as well as during its descent (the "down cast").
 - Students' plots of OBS and ORP should resemble Figures 4 and 5 respectively.

- Plots of OBS and ORP both show anomalies between depths of 2,000 and 2,500 meters; increased OBS due to precipitates or particulate material and a reduction in ORP are both indicative of plumes from hydrothermal vents.
- Two lines on the ORP plot represent data collected during the downcast and upcast; the numbers are different, in part, because the sensor that measures ORP continues to be affected by reducing substances for a period of time after it leaves the plume.
- OBS and ORP sensors are technologies produced by engineering that, in this case, made it possible to detect anomalies that led to the scientific discovery of a new hydrothermal vent site.

During the INDEX-SATAL 2010 Expedition, CTD data collected in late June showed anomalies that suggested the possible presence of hydrothermal vents nearby. On June 30, 2010, *Okeanos Explorer*'s ROV *Little Hercules* visited the site and found an active hydrothermal vent “surrounded by yellow and black molten sulfur, multiple species of hot-vent shrimp, a 10 cm scale worm, and a small patch of stalked barnacles. After departing from the vent, the ROV ascended the summit ridge and encountered fields of sulfide chimneys with vast aggregations of stalked barnacles at their base. The chimneys varied in terms of age and venting characteristics. Some chimneys were fairly oxidized and others covered in white sulfide. Some chimneys were venting clear fluid while others were venting black smoke.” You can read more about the site, and see images from *Little Hercules* here: <http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html>.

6. Discussion of CTD technology may also include the following components of technological literacy (ITEA, 2007):
- **Scope of technology** – Development of CTD technology is the result of specific, goal-directed research.
 - **Relationships between technologies and other fields of study**– Progress in the development of CTD technology is closely linked to advancements in science and mathematics.
 - **Effects of technology on the environment** – CTD sonar technology provides an effective way to monitor and explore the deep-ocean environment to provide information for decision-making.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics” in the menu on the left side of the page, then “Habitats” then select “Deep Sea” 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, Mathematics

Assessment

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





Extensions

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

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Chemosynthesis in the Classroom

(from the 2002 Gulf of Mexico Expedition)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_chemo_gr912.pdf

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Grades 9-12; Chemistry/Biology)

Students observe the development of chemosynthetic bacterial communities; recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive; and explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Hydrothermal Vent Challenge

(from the Submarine Ring of Fire 2004 Expedition)

http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF_ventball.pdf

Focus: Chemistry of hydrothermal vents (Grades 9-12; 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.

Thar She Blows!

(from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_13.pdf

Focus: Hydrothermal vents (Grades 9-12; Chemistry/Biology)

Students demonstrate an understanding of how the processes that result in the formation of hydrothermal vents create new ocean floor, and demonstrate an understanding of how the transfer of energy effects solids and liquids.

This Life Stinks

(from the 2003 Windows to the Deep Expedition)

http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_lifestinks.pdf

Focus: Methane-based chemosynthetic processes (Grades 9-12; Chemistry/Biology)

Students define the process of chemosynthesis; contrast this process with photosynthesis; explain the process of methane-based chemosynthesis; and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.



The Tell-Tale Plume

(from the INSPIRE: Chile Margin 2010 Expedition)

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

Focus: Hydrothermal Vent Chemistry (Grades 9-12; Chemistry/Biology)

Students describe hydrothermal vents; identify changes that they cause to the physical and chemical properties of seawater; and use oceanographic data to recognize a probable plume from hydrothermal activity.

Next Generation Science Standards

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



Send Us Your Feedback

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

Please send your comments to:

oceanexeducation@noaa.gov

For More Information

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

Acknowledgments

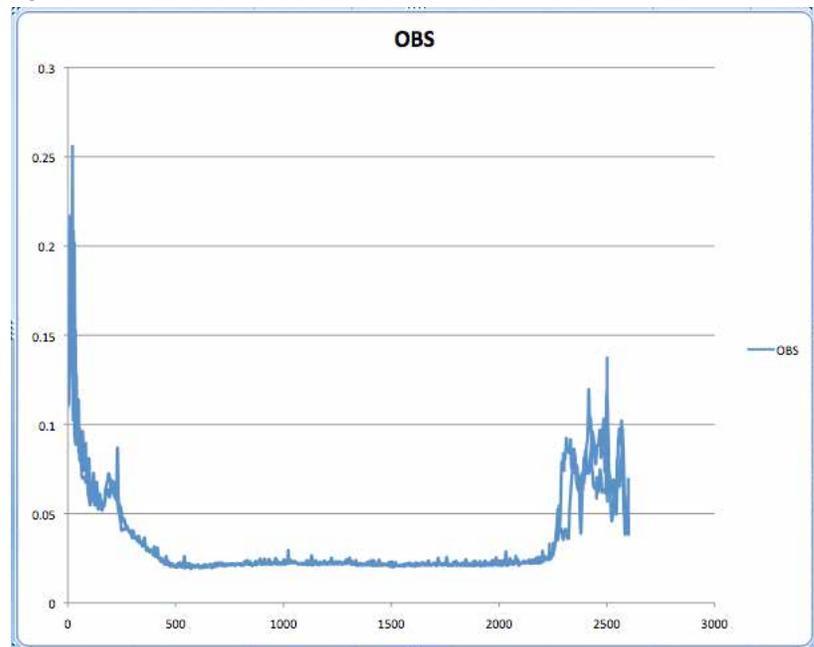
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Introduction to CTD Data Worksheet

NOTE: This lesson uses Microsoft Excel™ version 12.2.0. Other versions may require modifications to instructions on the student worksheet.

1. Open the **ex0904_ctd_1.xls** file in Microsoft Excel®. These data were collected during a CTD cast aboard the *Okeanos Explorer*. The first row shows the contents of each column: Date and time; Latitude in decimal degrees; Longitude in decimal degrees; Elapsed time since the start of the cast in seconds; Depth in meters; Temperature in °C; Conductivity in Siemens per meter; Salinity in Practical Salinity Units; Optical Backscatter (OBS); and Oxidation-Reduction Potential (ORP). The units of OBS and ORP aren't really important, because we are only concerned with finding readings that are distinctly different from other readings near the same depth (anomalies).
2. How much time was needed to complete the entire CTD cast?
3. What was the maximum depth recorded by the CTD?
4. Plot OBS as a function of Depth:
 - a. Select the Depth and OBS columns.
 - b. Under the "Insert" menu select "Chart..." A pop-up menu will appear.
 - c. In the popup menu, click on the "XY (Scatter)" tab.
 - d. Click on the "Smoothed Line Scatter" button. Now you should have a graph that resembles Figure 1.

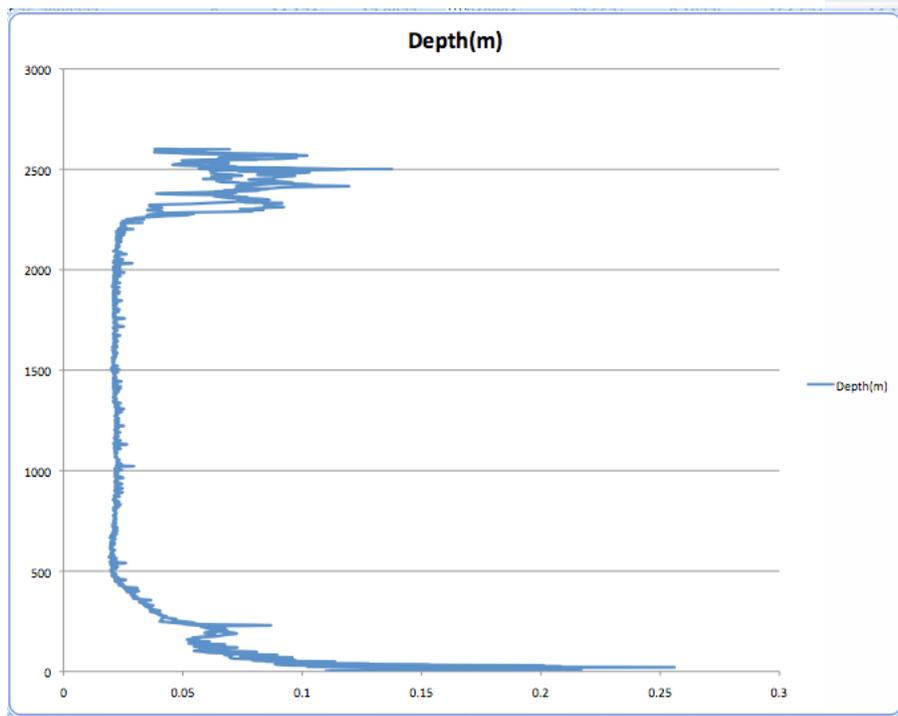
Figure 1.



5. Oceanographers 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. For an x-y plot, Excel plots the first column on the x-axis. So, to make an "oceanographer's plot" we need to re-arrange the data so that temperature values come before depth values.
 - a. Select the OBS column and the Depth column to the RIGHT of the Temperature column.

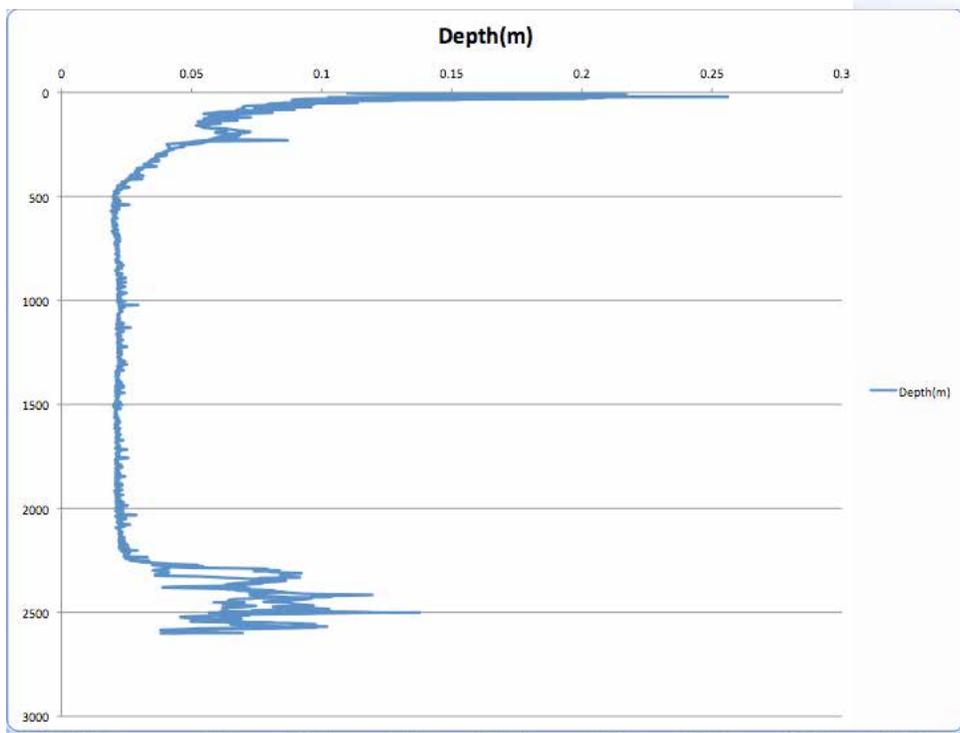
b. Click on the “Smoothed Line Scatter” button (the “XY (Scatter)” tab should still be selected). Now you should have a graph that resembles Figure 2.

Figure 2.



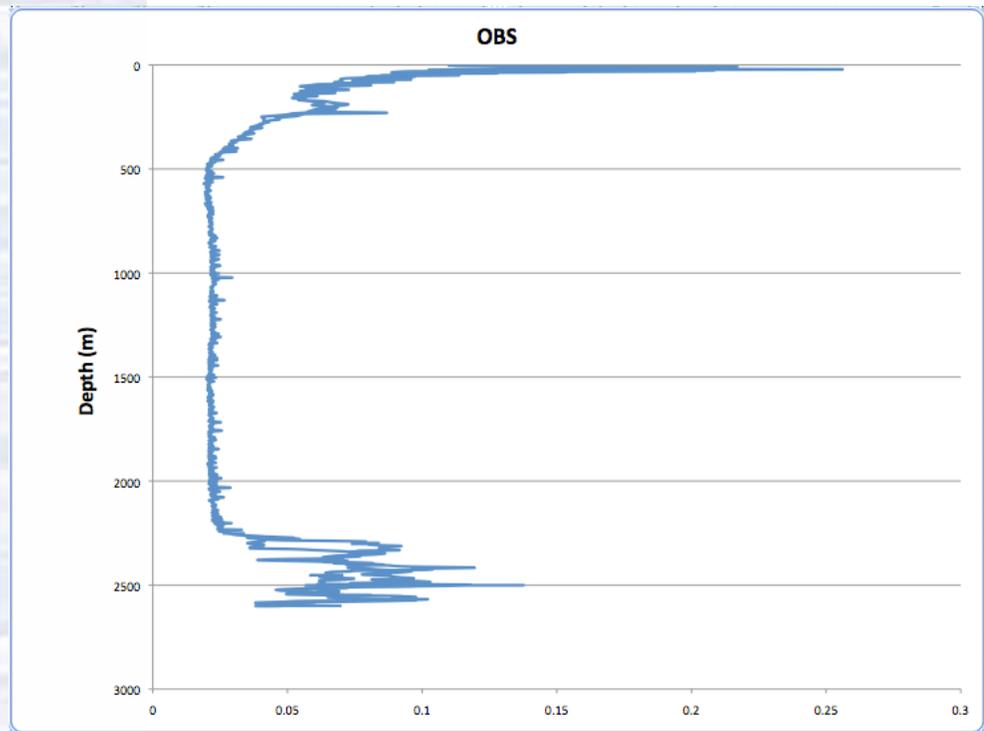
c. To make the greatest depths appear at the bottom of the plot, double click on the y-axis. The “Format Axis” window will appear. Click the “Scale” button on the left side of the window, then check the “Values in Reverse Order” box, then click “OK.” Now your graph should resemble Figure 3.

Figure 3.



- d. We need to make four more changes. First, the x-axis is now at the top of the plot. To fix that, double click the y-axis again and check the “Horizontal (category) axis crosses at maximum value” box. Then click “OK.” Next, the title of the graph needs changing: Click on the title, then highlight the text. Type in “OBS.” Now remove the legend on the right side of the graph by clicking on the legend and hitting the “Delete” key. Finally, let’s add a label to the y-axis: Click inside the plot area, then drag one of the handles on the left side of the plot toward the center to make space for a label. Make the “Drawing” toolbar visible (select from “Toolbars” in the “View” menu), and select the text tool. Click on the left side of the plot and type “Depth (m).” Format the text with tools in the Formatting toolbar (select from “Toolbars” in the “View” menu), then drag the green handle on the text box to rotate the text 90 degrees. Right-click (control click on a Macintosh platform) and drag the text box to the desired location. Now your graph should resemble Figure 4.

Figure 4.



6. Repeat the procedures in Steps 4 and 5 to make an “oceanographer’s plot” of ORP as a function of Depth.
7. Do either of your plots show any anomalies? Why does the ORP plot appear to have two lines?
8. What is the relationship between OBS, ORP, and hydrothermal vents?

