The Oceanographic Yo-yo

Focus
CTD (Conductivity, Temperature, Depth profiler), ocean chemistry and hydrothermal vents

Grade Level
6-8 (Physical Science)

Focus Question
How do ocean explorers aboard NOAA Ship *Okeanos Explorer* and other vessels of exploration use chemical clues to locate hydrothermal vents in the deep ocean?

Learning Objectives
- Students will analyze and interpret data from the *Okeanos Explorer* to make inferences about the possible presence of hydrothermal vents.
- Students will explain how interaction with hydrothermal vents affects chemical and physical properties of seawater.

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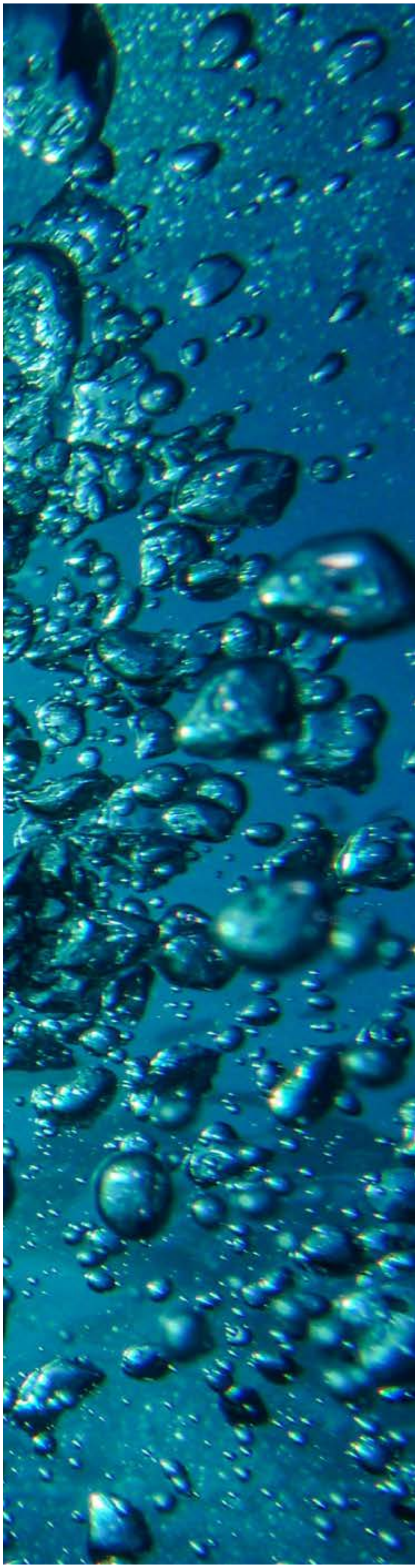
Materials
- One gallon of water, chilled in a refrigerator
- Vinegar; 1 tablespoon for each student group
- A heat source (microwave oven or hot plate)
- One eyedropper
- One tablespoon
- For each student group:
  - Copy of *CTD Sample Analysis Worksheet*
  - Two thermometers
  - 5 strips wide range (approximate pH 2-9) pH paper with color chart
  - Five 100ml beakers or plastic cups labeled A, B, C, D, and E

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

A closeup of a Conductivity, Tmeperature, Depth profiler (CTD), the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD, which is housed in the steel container in the center of the rosette. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/ctd_closeup_hires.jpg



Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of three to four students

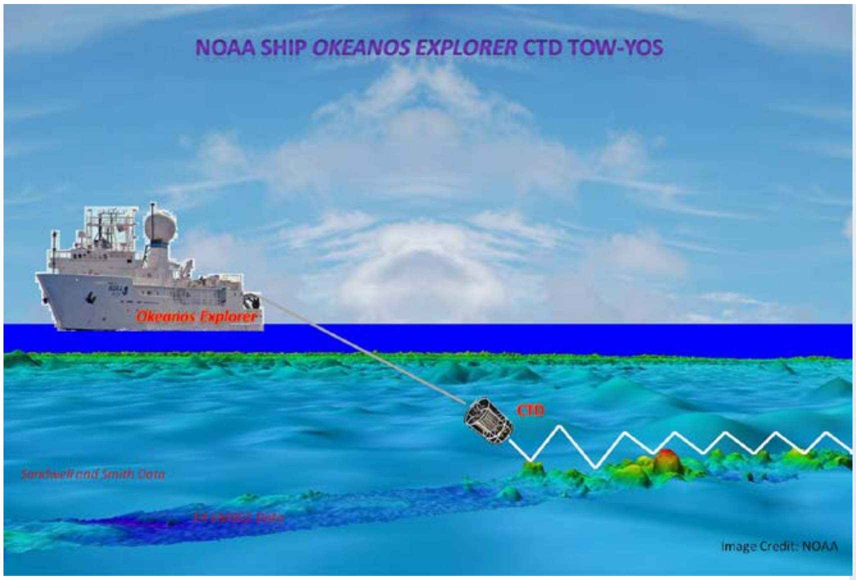
Maximum Number of Students
30

Key Words and Concepts
Ocean Exploration
Okeanos Explorer
CTD
Conductivity
pH
Hydrothermal vent
Plume

Background Information
The “water column” extends from the ocean surface to the seafloor. The water column usually refers to the volume of water underlying a specific area of Earth’s ocean. In the broadest sense, the water column may mean the entire volume of water in the ocean, from coast to coast. Because the ocean covers 71% of Earth’s surface with an average depth of nearly 4 km, the water column is the largest habitat for life on this planet. A variety of technologies are used to explore the water column, including nets and other devices to capture living organisms, sonar, and underwater vehicles (please see the *Introduction to Water Column Investigations* http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-WCIntro.pdf for additional details).

A CTD is water column exploration technology that includes a package of electronic devices that measure conductivity, temperature, and depth. Devices to measure other parameters also may be included, but the package is still called a CTD. 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. CTDs are often 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. For additional details about CTDs, please see the *Introduction to Water Column Investigations* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-WCIntro.pdf*.

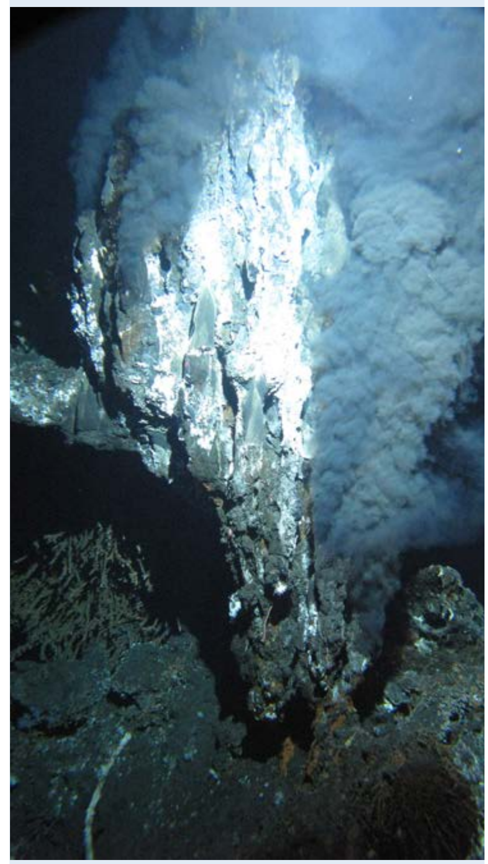
Temperature measurements from CTD sensors can be used to detect changes in water temperature that may indicate the



This image demonstrates the concept of a CTD Tow-Yo. The CTD is lowered to within 20 meters of the seafloor, and then is cycled between near-bottom and 300 meters above the seafloor (like a yo-yo) as it is towed behind the ship. Sensor data is recorded and monitored continuously to look for signs that plumes from hydrothermal vents are present. Image courtesy of NOAA *Okeanos Explorer* Program. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow_yo_diagram_hires.jpg*

presence of underwater volcanoes or hydrothermal vents. 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 from just above the seafloor to 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.

This lesson introduces students to simple analysis of CTD data as a method for finding underwater volcanoes and hydrothermal vents.



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, UMass Amherst. *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/microbes/media/boardwalk_black_smoker.html*

Learning Procedure

1. To prepare for this lesson:
   a) Review background information on CTD technology at
      - *http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html*;
      - *http://oceanexplorer.noaa.gov/explorations/14fire/logs/december04/december04.html#dec4-video9*; and
      - *http://oceanexplorer.noaa.gov/explorations/16arctic/logs/video/ctd/ctd_video.html*

      Decide whether you want to use one or both of these videos during introductory instruction in Step 2.

   b) Review the *Introduction to Ships of Exploration and Their Strategy for Ocean Exploration* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf*.

   c) If students are not familiar with deep-sea chemosynthetic communities, you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent

Water samples are collected from the Niskin bottles on the CTD. All 20 Niskin bottles take water samples from various depths, starting near the seafloor and ending close to the surface. Photo courtesy of Caitlin Bailey, GFOE, The Hidden Ocean 2016: Chukchi Borderlands. *http://oceanexplorer.noaa.gov/explorations/16arctic/logs/july24/media/shipton.html*

Remotely operated vehicle *Deep Discoverer* being recovered after a dive. Image courtesy of NOAA Office of Ocean Exploration and Research, 2016 Deepwater Exploration of the Marianas. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/may1/media/1605rovrecovery.html*

Scientist Scott France participates in the dives from his home office via telepresence. Image courtesy of NOAA OER, 2016 Deepwater Exploration of the Marianas. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/jun28/media/1605scott-france.html*

Life (*http://oceanexplorer.noaa.gov/edu/learning/welcome.html*), and/or information from *http://www.pmel.noaa.gov/vents/nemo/explorer.html*.

d) Review procedures for the simulated analysis of CTD samples (Step 4). Prepare materials for this activity:
1) Chill one gallon of water overnight in a refrigerator.
2) For each group of four students, fill five 100ml beakers or plastic cups with chilled water and label each with an A, B, C, D and E.
3) Heat the water in all beakers or plastic cups labeled D for 60 seconds in the microwave oven about 15 minutes before the start of class. The water should be above 50°C, but not boiling.
4) Add 3 drops of vinegar to all beakers or plastic cups labeled C and E and stir.
5) Add one tablespoon of vinegar to all beakers or plastic cups labeled D and stir.

e) If desired, download images referenced in Step 2.

2. Briefly introduce the ships of exploration NOAA Ship *Okeanos Explorer*, E/V *Nautilus*, and R/V *Falkor*; the *Introduction to Ships of Exploration and Their Strategy for Ocean Exploration* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf;* and the 2017 Discovering the Deep: Exploring Remote Pacific MPAs Expedition *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/background/plan/welcome.html*.

Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *To Boldly Go* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_toboldlygo.pdf*. Highlight the overall exploration strategy used by ships of exploration, including the following points:

The NOAA Ship *Okeanos Explorer*, America's ship for ocean exploration. Image courtesy NOAA. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/mar1/media/okeanos.html*

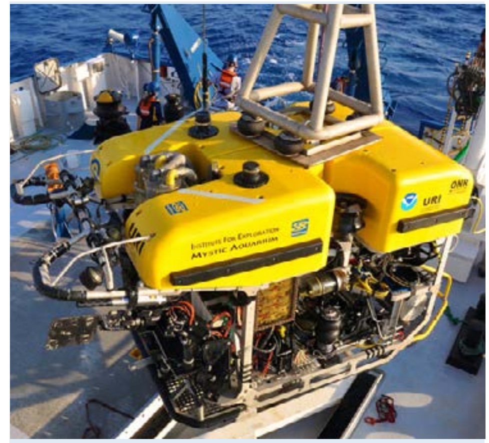
- The overall strategy is to develop baseline information about the biological, geological, and water chemistry features of unexplored areas to provide a foundation for future exploration and research.

- This information includes
  - High resolution maps of the area being explored, as well as areas that the ship crosses while underway from one location to the next (underway reconnaissance);
  - Exploration of water column chemistry and other features; and
  - High definition close-up video of biological and geological features in the exploration area (site characterization).

- This strategy relies on four key technologies:
  - Multibeam sonar mapping system and other types of sonar that can detect specific features in the water column and on the seafloor;
  - Conductivity, Temperature, and Depth profilers (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 6,000 meters; and
  - Telepresence technologies that allow scientists with many different areas of expertise to observe and interact with exploration activities, though they may be thousands of miles from the ship.

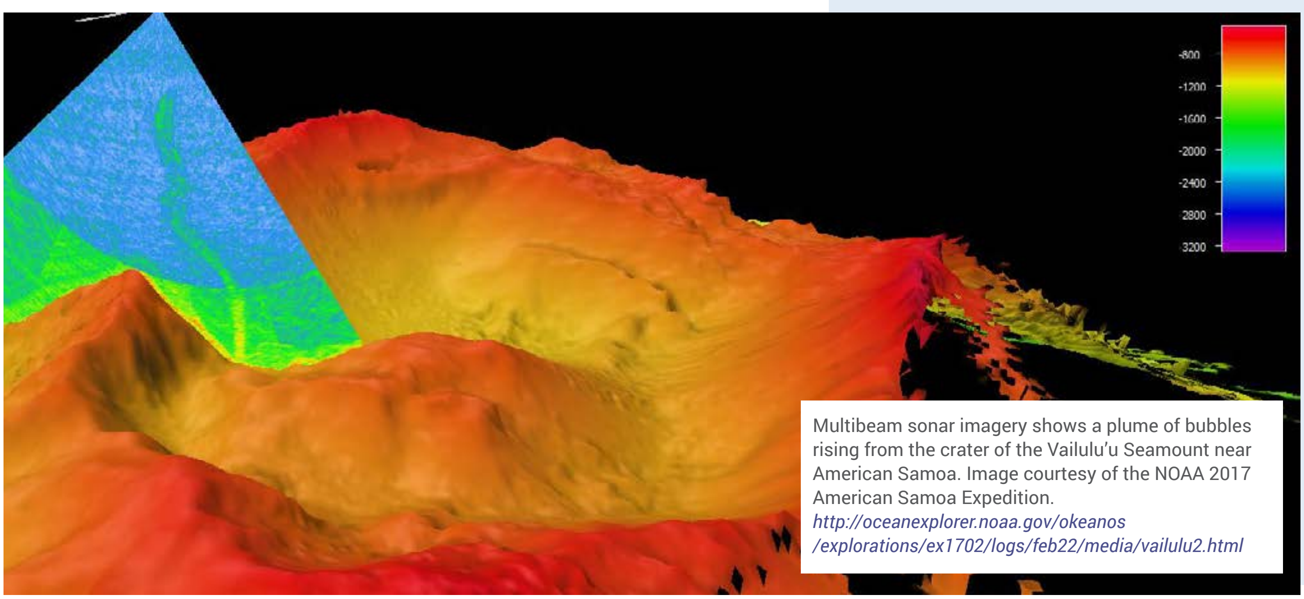
You may want to show some or all of the images in the sidebars to accompany this review.

Show an image of a CTD, and explain that this is actually a collection of several electronic instruments that measure various things about seawater. The basic instruments

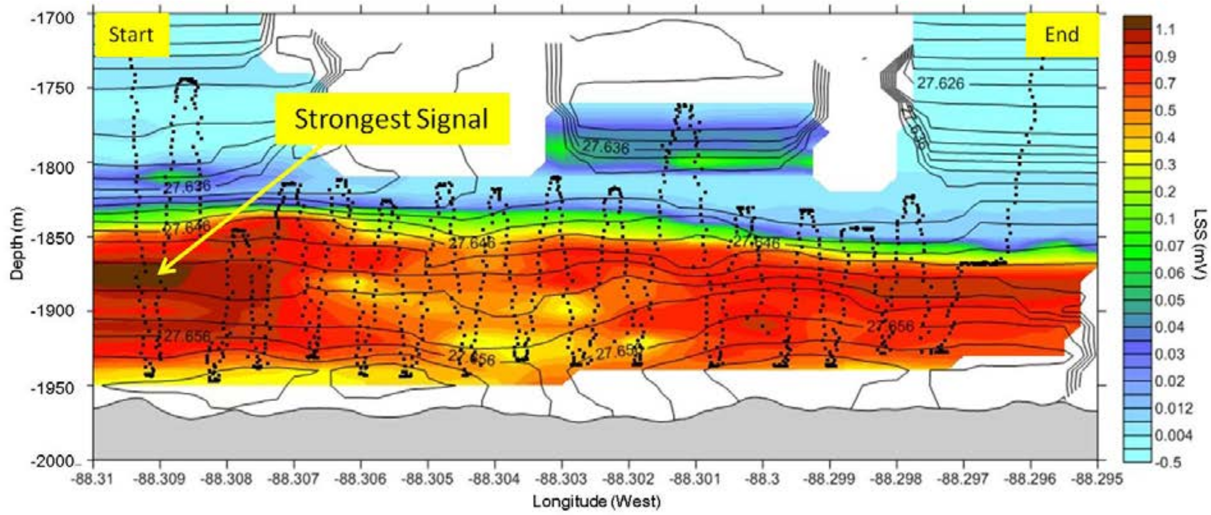


Hercules is one of the very few Remotely Operated Vehicles (ROV) specifically designed to be used as a scientific tool. Built for the Institute For Exploration (IFE), *Hercules* is equipped with special features that allow it to perform intricate tasks while descending to depths of 4,000 meters (2.5 miles). *http://oceanexplorer.noaa.gov/technology/subs/hercules/hercules.html*

Argus (right) acts as a stabilizing platform for *Hercules*, following the ROV into the water. Image courtesy of The Ocean Exploration Trust. *http://oceanexplorer.noaa.gov/technology/subs/hercules/argus.html*



Multibeam sonar imagery shows a plume of bubbles rising from the crater of the Vailulu'u Seamount near American Samoa. Image courtesy of the NOAA 2017 American Samoa Expedition. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/feb22/media/vailulu2.html*



Above is a plot of the data from a CTD tow. The x axis displays the longitude of the tow, the vertical axis is depth, and the shading along the tow is the Light Scattering Sensor data. The dark patch on the left (beginning of tow) is the strongest plume signal. Image courtesy of NOAA *Okeanos Explorer* Program. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/tow01_results_diagram_hires.jpg*

Image of hydrothermal vents found during an ROV dive on 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/dailyupdates/media/june30_update.html*

measure temperature, depth, and conductivity. Most of the device seen in the image is a water sampling device called a rosette or carousel, that contains water sampling bottles that are used to collect water at different depths. Before the rosette is lowered into the ocean, the bottles are opened so that water flows freely through them. As the rosette travels through the water column, scientists can monitor readings from the CTD sensors. If something unusual appears in the measurements, the scientists can send a signal through the CTD cable that closes one or more of the bottles to collect a water sample from the location where the unusual measurements appeared.

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 1c, present these now. Tell students that a major objective of ocean exploration is to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts as these are often associated with active geologic processes and highly productive biological communities in Earth's deep ocean.

3. Discuss some of the clues that might result from the interaction of hydrothermal vents with 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. For a more

detailed discussion about pH, please see "More About pH" in the lesson, *To Boldly Go*. 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.

4. The following activity simulates an analysis of water samples collected by a CTD. 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, 5 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 on page 10 and to plot the CTD data on the graphs provided on pages 11-12.

   Be sure students understand that the grids provided for their graphs have zero at the TOP of the y-axis. This is because 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.

5. 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. These might include chemical analysis to detect the presence of substances associated with hydrothermal vents, such as hydrogen sulfide.

   Students' graphs of CTD data should resemble Figures 1, 2, and 3. Students should recognize that Figure 1 is different from the others, in that water temperature increases near the bottom (even a small increase is significant). Since this is not what would ordinarily be expected, it may be a signal that something unusual is happening in this area! In fact, this CTD cast was made in the vicinity of an active hydrothermal vent. The next day, *Okeanos Explorer*'s ROV 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

Figure 1.

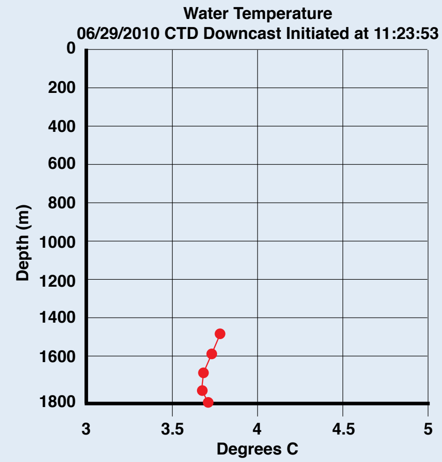


Figure 2.

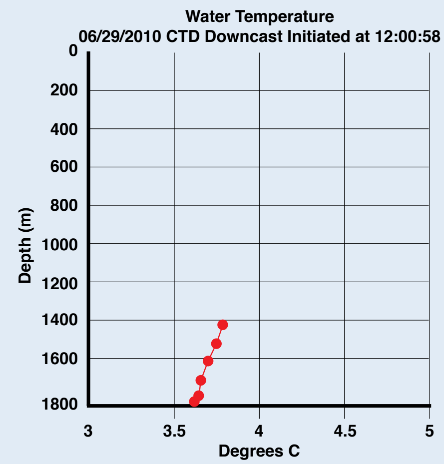
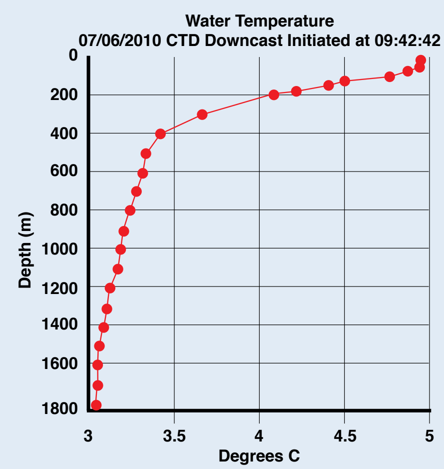


Figure 3.



Note: Graphs of temperature and other CTD data collected during *Okeanos Explorer* cruises in 2010.

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 the ROV dive here: *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june30/june30.html*.

Point out that this is an excellent example of the interdependence of science, engineering, and technology. The instrument technologies produced by engineering made it possible to make measurements that detected an anomaly. Other technologies made it possible to investigate the anomaly and provide scientific data from a new hydrothermal vent site.

The BRIDGE Connection

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

The "Me" Connection

Have students visit *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/welcome.html*, which is the Mission Logs page for the 2016 Deepwater Exploration of the Marianas expedition, select one entry that seems interesting, and write a brief essay about what job they would like to have if they were personally aboard the ship.

Connections to Other Subjects

English Language Arts, Social Studies, Mathematics

Assessment

Class discussions and students' work with the charting activity 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://www.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 Techtonics, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Hydrothermal-vent chimney. Look closely, and you will also see the chimney is crawling with *Chorocaris* shrimp and *Austinograea wiliamsi* crabs. Image courtesy of the NOAA OER, 2016 Deepwater Exploration of the Marianas.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/dailyupdates/media/may2.html

Other Relevant Lessons from NOAA OER

A Hydrothermal AdVENTure
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/aydrothermal.pdf

Focus: Hydrothermal vents (Grades 5-6; Earth Science)

Students explain the overall structure of hydrothermal vents and how they are related to the motion of tectonic plates, and create a model of a hydrothermal vent.

The Tell-Tale Plume
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf

Focus: Hydrothermal Vent Chemistry (Grades 9-12; Chemistry, Earth Science)

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 and Ocean Literacy Essential Principles and Fundamental Concepts

This lesson supports the Ocean Literacy Essential Principles and Fundamental Concepts as indicated here *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-Standards.pdf*. Additionally, while it is not intended to target specific Next Generation Science Standards, activities in this lesson may be used to address some Science and Engineering Practices and Crosscutting Concepts. These include:

Science and Engineering Practices
Defining problems (for engineering)
Developing and using models
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

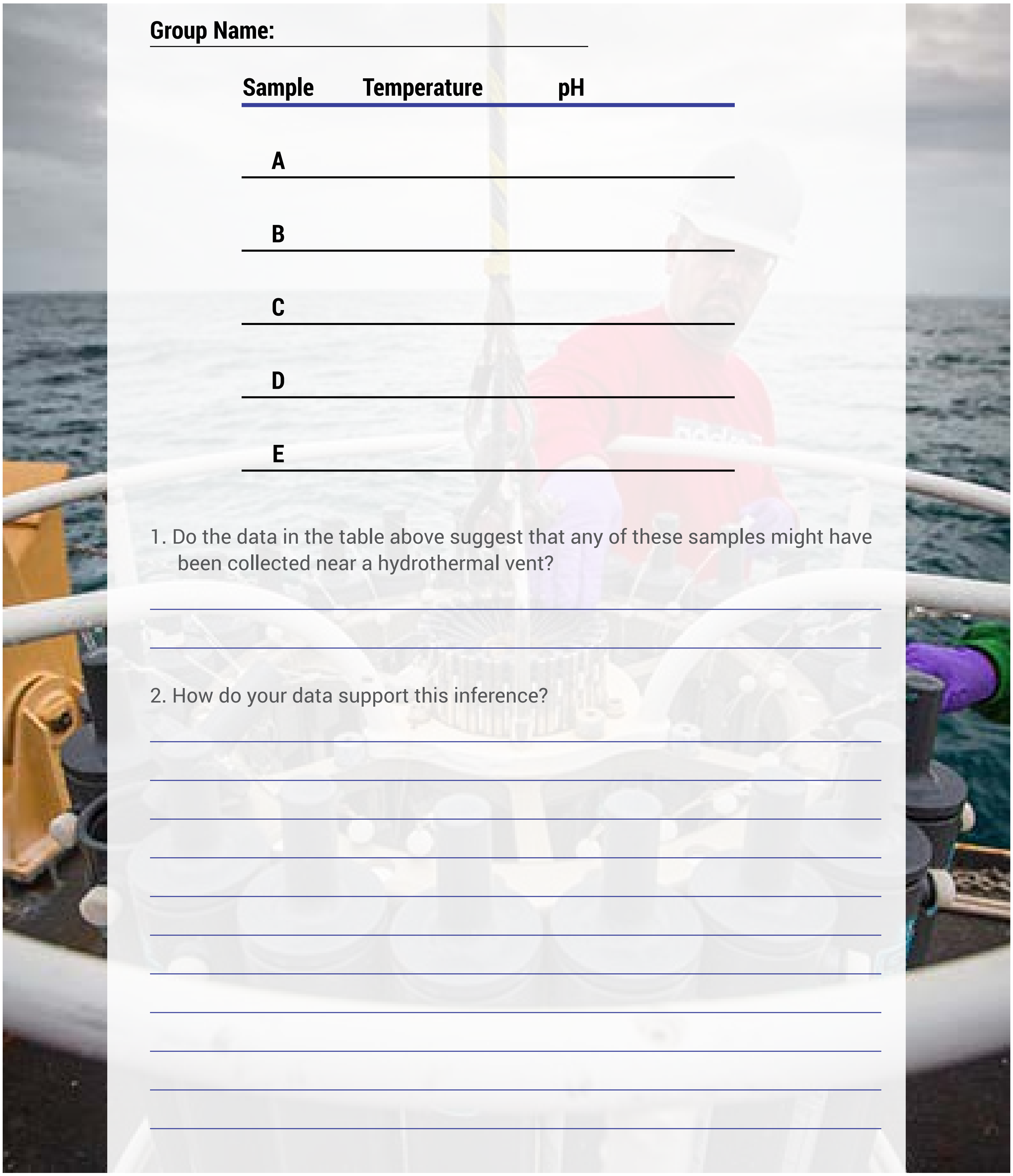
Crosscutting Concepts
Patterns
Cause and effect
Systems and system models
Stability and change

The Next Generation Science Standards
The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations. While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

For Information and 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

Acknowledgments
Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: *http://oceanexplorer.noaa.gov*

CTD Sample Analysis Worksheet



Group Name: ______________________________

Sample	Temperature	pH
A		
B		
C		
D		
E		

1. 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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2. How do your data support this inference?

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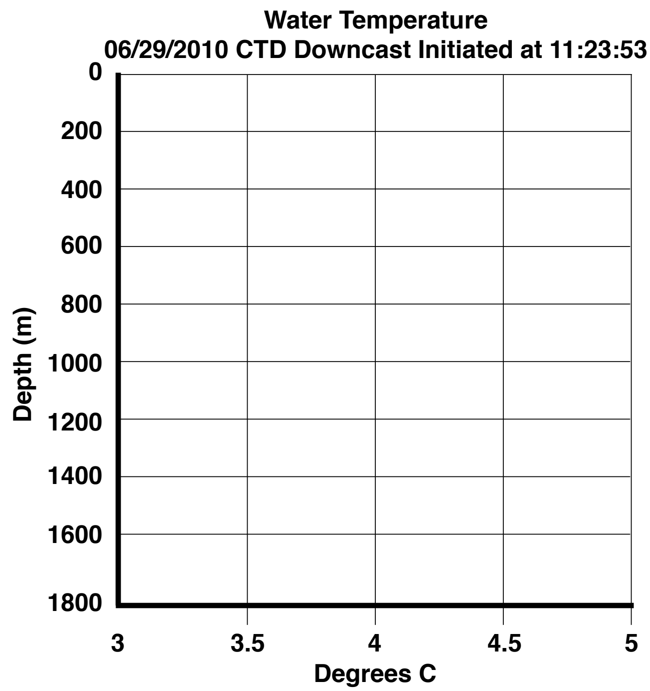
3. Here are some data from CTD casts made aboard the *Okeanos Explorer* during the INDEX-SATAL 2010 Expedition (these are just a few of the data points provided by the CTD instruments; the complete data sets contain thousands of points!). Plot these points on the grids. Do any of your graphs show any possible anomalies?

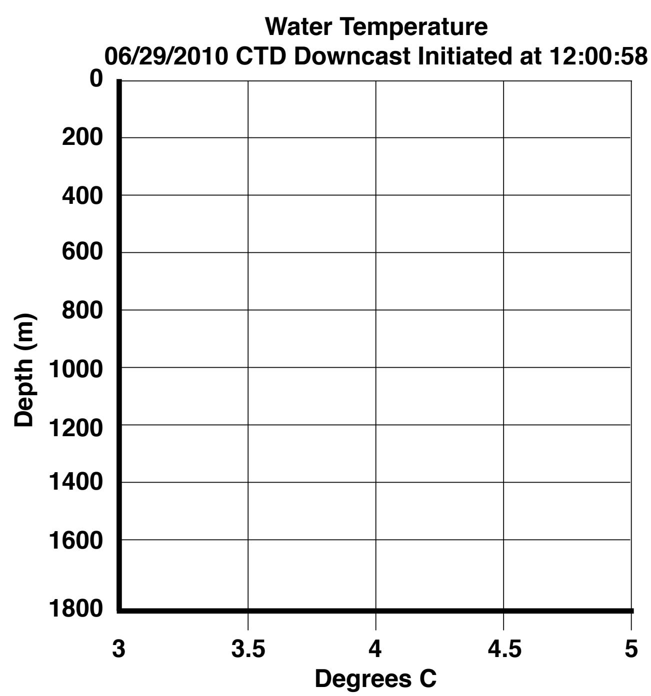
06/29/2010
CTD Downcast Initiated at 11:23:53

Depth (m)	Water Temperature (°C)
1450	3.8
1600	3.75
1680	3.6
1750	3.6
1800	3.7



06/29/2010
CTD Downcast Initiated at 12:00:58

Depth (m)	Water Temperature (°C)
1400	3.8
1500	3.75
1600	3.7
1700	3.67
1750	3.65
1800	3.6



07/06/2010
CTD Downcast Initiated at 09:42:42

Depth (m)	Water Temperature (°C)
10	4.95
50	4.9
80	4.85
100	4.8
150	4.5
175	4.4
190	4.2
200	4.1
300	3.7
400	3.4
500	3.35
600	3.32
700	3.30
800	3.25
900	3.20
1000	3.175
1100	3.16
1200	3.15
1300	3.12
1400	3.10
1500	3.08
1600	3.07
1700	3.06
1800	3.05