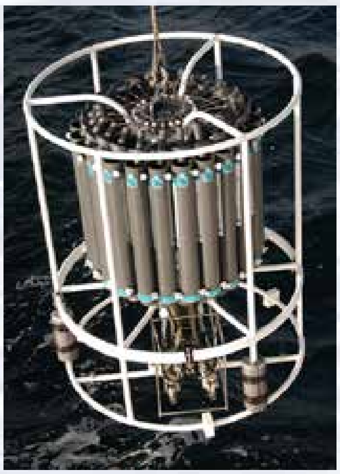
Lesson 6: What's a CTD?



A CTD rosette with water sampling bottles attached is lowered to measure the salinity, temperature, depth and concentration of particles in the water column. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/june27/media/ex_ctd.html

Focus
Measuring physical properties of seawater for ocean exploration

Grade Level
5-6 (Physical Science)

Focus Question
What is the relationship between temperature, salinity, pressure, and density of seawater, and why is this important to ocean exploration aboard the *Okeanos Explorer*?

Learning Objectives
- Students will explain how a CTD is used aboard the *Okeanos Explorer* to reveal patterns that help ocean explorers answer questions about the natural world.
- Students will analyze and intepret data from the *Okeanos Explorer* to make inferences about relationships between density, salinity, temperature, and pressure of seawater.

Materials
- Copies of *CTD Data Collected on* Okeanos Explorer *Cruise EX1004, Leg 3 Worksheet*; one copy for each student or student group
- Graph paper

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

Seating Arrangement
Groups of three to four students

Maximum Number of Students
30

Key Words and Concepts
Ocean Exploration
Okeanos Explorer
CTD
Salinity
Density

Background

For discussion about the exploration strategy used aboard the *Okeanos Explorer,* please see the introductory section beginning on page 9. For background information about CTD instruments, please see the *Introduction to Water Column Investigations* on page 87.

This lesson introduces students to simple analysis of CTD data, how these data are related to seawater density, and how they may be used to search for hydrothermal vents.

Learning Procedure

1. To prepare for this lesson:
   a) Review:
   - Introductory essays for the INDEX-SATAL 2010 Expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html*);
   - Background information on CTD technology at *http://www.pmel.noaa.gov/vents/PlumeStudies/WhatIsACTD/CTDMethods.html*

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

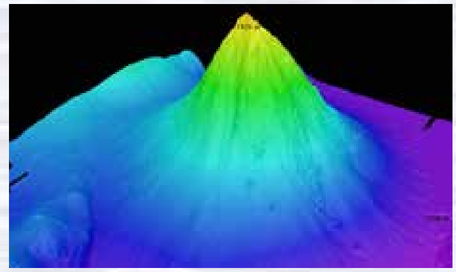
   (c) If students are not familiar with deep-sea chemosynthetic communities, you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (*http://oceanexplorer.noaa.gov/edu/learning/welcome.html*), and/or information from *http://www.pmel.noaa.gov/vents/nemo/explorer.html*.

   (d) Review procedures on the *CTD Data Collected on* Okeanos Explorer *Cruise EX1004, Leg 3 Worksheet*.

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

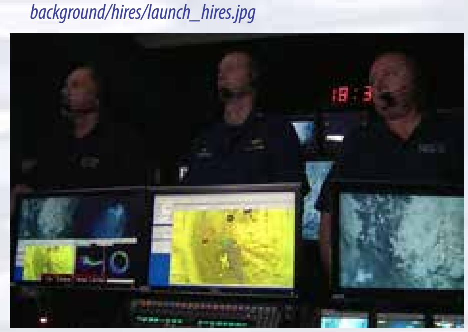
   You may want to show some or all of the images in the adjacent sidebar to accompany this review.



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

A closeup of a 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

3. If students are familiar with the concepts of seawater density, briefly review:
   - The definition of density;
   - The relationships between temperature, salinity, pressure, and density in seawater; and
   - The meaning of conductivity and its relationship to salinity.

   When this review is complete, proceed to Step 4.

   If students are not familiar with these concepts, perform the following demonstrations:

   (a) While students watch, dissolve 2 tablespoons of table salt in approximately 250 ml of hot tap water. Add three drops of liquid food coloring, and stir to mix. Wait at least three minutes. Pour approximately 400 ml of hot tap water into a clear 500 ml beaker. Hold the beaker so that the water is visible to students, and slowly pour the colored salt water down along the inside wall of the beaker. A shimmering pool of colored water should form on the bottom of the beaker, below the uncolored tap water. Have students record their observations in writing.

   (b) While students watch, place approximately 100 ml of ice into a container with approximately 150 ml cool tap water. Add three drops of liquid food coloring. Pour approximately 400 ml of hot tap water into a clear 500 ml beaker. Tell students to watch closely as you hold the beaker so that the water is visible to students, and slowly pour the colored ice water down along the inside wall of the beaker. The colored water will flow to the bottom of the beaker and form a layer beneath the warmer water, but will soon disperse into the larger volume of water. Have students record their observations in writing, being sure to include what happened when the colored ice water first flowed into the warmer water.

   Remind students that the density of a substance is related to an object's mass (how much material it contains) and volume (the object's physical size). A handful of styrofoam, for example, weighs much less than a handful of rocks because the density of the styrofoam is less than the density of the rocks. Density is usually defined as "mass per unit volume," and the density of an object or substance is stated in "grams per cubic centimeter."

   Have students record their inferences about the effect of dissolved salt on the density of water, and the effect of temperature on the density of water. When students have finished writing, lead a discussion of their inferences. Students should understand that dissolved salt increases the density of water, and that the density of water also increases as temperature decreases. Tell students that in the ocean, density is also affected by water pressure. Since water pressure increases with increasing depth, the density of seawater also increases as depth increases.

4. Show an image of a CTD, and explain that this is actually a collection of several electronic instruments that measure properties of seawater. The basic instruments measure temperature, depth, and conductivity. Tell students that conductivity measures how easily electric currents pass through a liquid, and that electric current passes much more easily through water containing salt than through fresh water. Also say that CTDs actually measure water pressure as a way to measure depth.

CTD monitoring crew. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/hires/ctd_cast_hires.jpg

Most of the device seen in the image in the sidebar 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.

5. Give each student or student group a copy of the *CTD Data Collected on* Okeanos Explorer *Cruise EX1004, Leg 3 Worksheet*. Be sure students understand that CTD graphs are constructed with depth on the y-axis with zero at the top of the axis because this is the way we imagine depth when we think of a cross-section of the ocean. You may also need to point out that the vertical and horizontal scales of graphs do not have to begin at zero, and explain that adjusting these scales to the minimum and maximum values of the data has the advantage of making the relationships between the variables much more clear.

When students have completed the worksheet assignment, lead a discussion of their results. Students' graphs should resemble Figures 1, 2, and 3.
The discussion should include the following points:
- Density changed most rapidly near the surface.
- In general, density increases as depth increases.
- As depth increases, temperature and salinity tend to level out, while density continues to increase because pressure continues to increase with increasing depth.
- If an underwater robot is neutrally buoyant, the robot will sink if it enters a water mass that has a lower density.
- If the water mass has a greater density, the robot will rise until it encounters a water mass with density equaling that of the robot.

Figure 1.

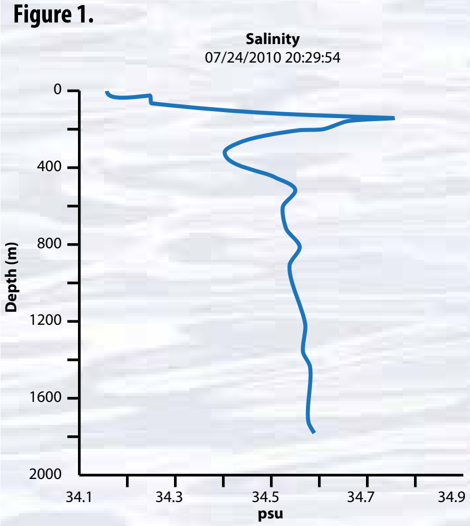


Figure 2.

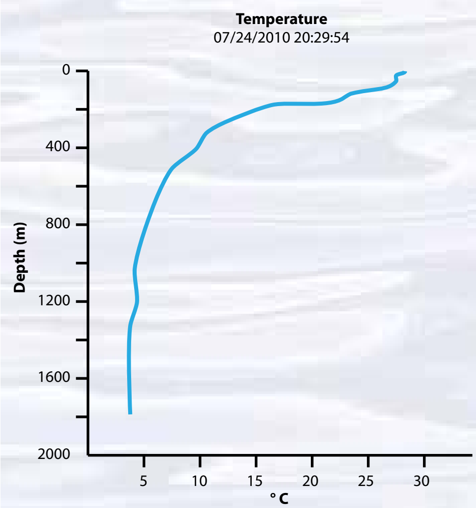
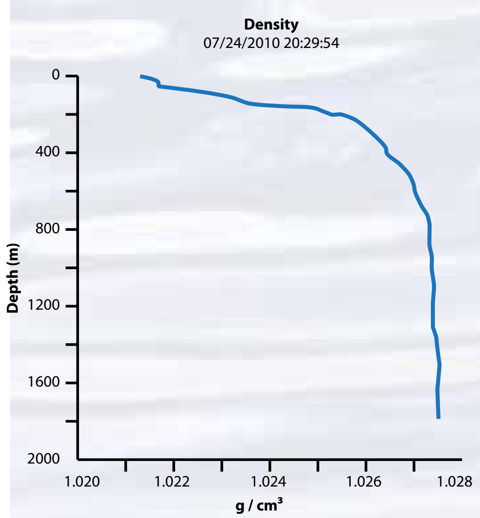


Figure 3.



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 the INDEX-SATAL 2010 Expedition was to locate submarine volcanoes, hydrothermal vents, chemosynthetic ecosystems, and seamounts associated with active geologic processes in Indonesia's deep sea.

Ask what kinds of clues might be found in CTD data that could reveal the presence of hydrothermal vents or volcanoes. 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. Other clues (not discussed in this lesson) may come from instruments that measure acidity (fluids from hydrothermal vents are often highly acidic), and from chemical analyses of seawater samples (hydrogen sulfide, for example, is often found in hydrothermal vent fluids, but is not normally found in seawater).

In late June, during the INDEX-SATAL 2010 Expedition, CTD data showed temperature 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 instrumentation allows many chemical and physical characteristics to be measured in the ocean, some of which could not be measured in deep water before this technology was created.
   - **Core concepts of technology –** A CTD is an example of several technological systems connected together; including different systems to measure various chemical and physical characteristics of seawater, and equipment for collecting water samples from very deep areas in Earth's ocean.
   - **Relationships between technologies and other fields of study –** Improvements to each of the technologies listed above improves the overall capability of water column investigations; and this information is useful to geologists, biologists, and many other branches of science.

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 brief essay describing how the density of fluids on Earth affects their own lives. Students may struggle with this initially, depending upon their understanding of what can be included in the term "fluids." You may need to suggest that this term includes gases as well as liquids, which may help students think in terms of atmospheric fluids (air) and issues concerning the density of these fluids (barometric pressure, which affects weather patterns, storms, etc.).

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

And Now for Something Completely Different…
(from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_dfferent.pdf
Focus: Biological communities at hydrothermal vents (Grades 5-6; Life Science)
Students identify and describe organisms typical of hydrothermal vent communities near the Galapagos Spreading Center, explain why hydrothermal vent communities tend to be short-lived, and identify and discuss lines of evidence which suggested the existence of hydrothermal vents before they were actually discovered.

A Hydrothermal AdVENTure
(from the INSPIRE: Chile Margin 2010 Expedition)
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 Volcano Factory
(from the 2004 Submarine Ring of Fire Expedition)
http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.volcanism.pdf
Focus: Volcanism on the Mariana Arc (Grades 5-6; Earth Science)
Students explain the tectonic processes that result in the formation of the

Notes About Density Calculations

The density of seawater depends on temperature, salinity, and pressure. The mathematical relationship between these factors is somewhat complicated, and is known as the "equation of state" of seawater. There are several online calculators, though, that compute density of seawater from input values of temperature, salinity, and pressure (e.g., *http://www.es.flinders.edu.au/~mattom/Utilities/density.html*). These calculators use several units that may be unfamiliar:

σ_T – The density of seawater is always greater than 1.000 g/cm^3 and less than 2.000 g/cm^3, so oceanographers often express density as sigma T (σ_T), which is [(Sea water density - 1) x 1000]. This way, oceanographers do not have to write 1 or the decimal places every time they want to record a density measurement.

units of density – Oceanographers often use density units of kg/m^3, instead of the more familiar g/cm^3. The relationship between these is 1 kg/m^3 = 1000 g/cm^3.

units of pressure – Oceanographers often use units of decibars (0.1 bar), which is approximately equal to the depth in meters. Pressure may also be stated in units of kilopascals (kPa). The relationship between these is

1 decibar = 10 kilopascals.

Mariana Arc and the Mariana Trench, and explain why the Mariana Arc is one of the most volcanically active regions on Earth.

Unexplored!

(from the New Zealand American Submarine Ring of Fire 2005 Expedition)

http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_unexplored.pdf

Focus: Scientific exploration of deep-sea volcanoes (Grades 5-6; Life Science/Physical Science/Earth Science)

Students compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Mariana Arc.

Living With the Heat

(from the Submarine Ring of Fire 2006 Expedition)

http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Grades 5-6; Life Science/Earth Science)

Students describe how hydrothermal vents are formed and characterize the physical conditions at these sites; explain what chemosynthesis is and contrast this process with photosynthesis; identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities; and describe common food pathways among organisms typically found in hydrothermal vent communities.

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/hdwe_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*

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Student Worksheet
CTD Data Collected on *Okeanos Explorer* Cruise EX1004, Leg 3

The data in the chart on page 98 are from a CTD cast made aboard the *Okeanos Explorer* on July 24, 2010, as part of the INDEX-SATAL 2010 Expedition.

1. Make a graph of salinity and depth. Put depth on the y-axis of each graph, and put zero at the TOP of the y-axis. 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.

2. Make a graph of temperature and depth, with depth on the y-axis as in Step 1.

3. Make a graph of density and depth, with depth on the y-axis as in Step 1.

4. Where did density change most rapidly?

5. In general, what happens to density as depth increases?

6. How do changes in density with increasing depth differ from changes in temperature and salinity with increasing depth?

7. If an underwater robot is neutrally buoyant (that is, it does not rise or sink in the water column) at a certain depth, what will happen if the robot enters a water mass that has a lower density?

8. What will happen if the water mass has a greater density?

A Senior Survey Technician holds onto the CTD rosette as it comes aboard the *Okeanos Explorer*. Image courtesy NOAA.
http://www.moc.noaa.gov/oe/visitor/photos/photospage-b/CAP%20015.jpg

CTD Data Collected on *Okeanos Explorer* Cruise EX1004, Leg 3

Depth (m)	Temperature (°C)	Salinity (psu)*	Density (g/cm3)
20	29.5	34.15	1.0213
40	28.5	34.24	1.0217
60	28.5	34.25	1.0217
80	27	34.35	1.0223
100	25.5	34.45	1.0228
125	24	34.6	1.0233
150	23.5	34.76	1.0236
175	18	34.65	1.025
200	16.5	34.6	1.0253
220	15	34.54	1.0256
320	11.5	34.4	1.0262
420	10	34.46	1.0265
520	8	34.55	1.0269
620	7	34.52	1.027
720	6	34.53	1.0272
820	5.5	34.56	1.0273
920	5	34.54	1.0273
1050	4.5	34.55	1.0274
1150	4.5	34.56	1.0274
1250	4.5	34.57	1.0274
1350	4	34.57	1.0274
1450	4	34.58	1.0275
1550	4	34.58	1.0275
1650	4	34.58	1.0275
1750	4	34.58	1.0275
1800	4	34.59	1.0275

* Salinity is measured by conductivity (how easily electricity flows through a seawater sample). The software used to process conductivity data from the *Okeanos Explorer*'s CTD converts the conductivity measurement to salinity values in practical salinity units (psu). Before psu was adopted as a standard unit, salinity was measured in parts-per-thousand (abbreviated ppt or o/oo), and you still may see references to these units, which are almost the same as psu.

Notes: