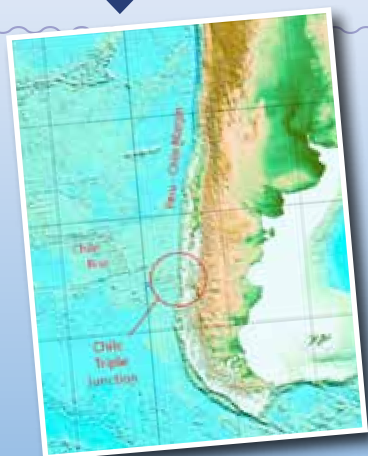
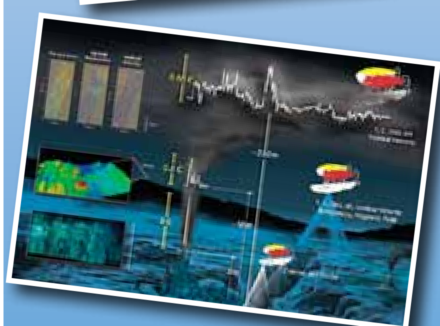
INSPIRE: Chile Margin 2010

The Oceanographic Yo-Yo





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lesson plan

Focus

Ocean chemistry and hydrothermal vents

Grade Level

7-8 (Physical Science)

Focus Question

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

Learning Objectives

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

Materials

- ❑ One gallon of water, chilled in a refrigerator
- ❑ Vinegar: one cup
- ❑ 5 100ml glass beakers for each student group
- ❑ A heat source (microwave oven)
- ❑ One eyedropper
- ❑ One tablespoon

For each student group:

- ❑ Copy of *CTD Sample Analysis Worksheet*
- ❑ Two thermometers
- ❑ 20 strips pH paper
- ❑ pH color indicator chart
- ❑ Samples labeled A,B,C,D,E

Audio-Visual Materials

- ❑ (Optional) video or computer projection equipment to show images from the INSPIRE: Chile Margin 2010 Web page (http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html)

Teaching Time

Two 45-minute class periods

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

CTD (Conductivity, Temperature, Depth)
MAPR (Miniature Autonomous Plume Recorder)
TOBI (Towed Ocean Bottom Instrument)
Tow-yo
Conductivity
Redox potential
pH
Hydrothermal vent
Plume

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.

Earthquakes and volcanoes are among Earth's most spectacular and terrifying geological events. The Mount St. Helens eruption of 1980 and the Haiti (7.0 magnitude) and Chile (8.8 magnitude) earthquakes of 2010 are recent and memorable examples of the extreme power that often accompanies these events. The Indian Ocean tsunami of 2004 was caused by an underwater earthquake that is estimated to have released the energy of 23,000 Hiroshima-type atomic bombs, and caused the deaths of more than 150,000 people.

Volcanoes and earthquakes are both linked to movements of 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

Images from Page 1 top to bottom:
Map of the Southeast Pacific Ocean and South American continent showing the Chile Rise spreading center, the Peru-Chile Margin, and the location of the Chile Triple Junction. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/geology/media/geology1.html

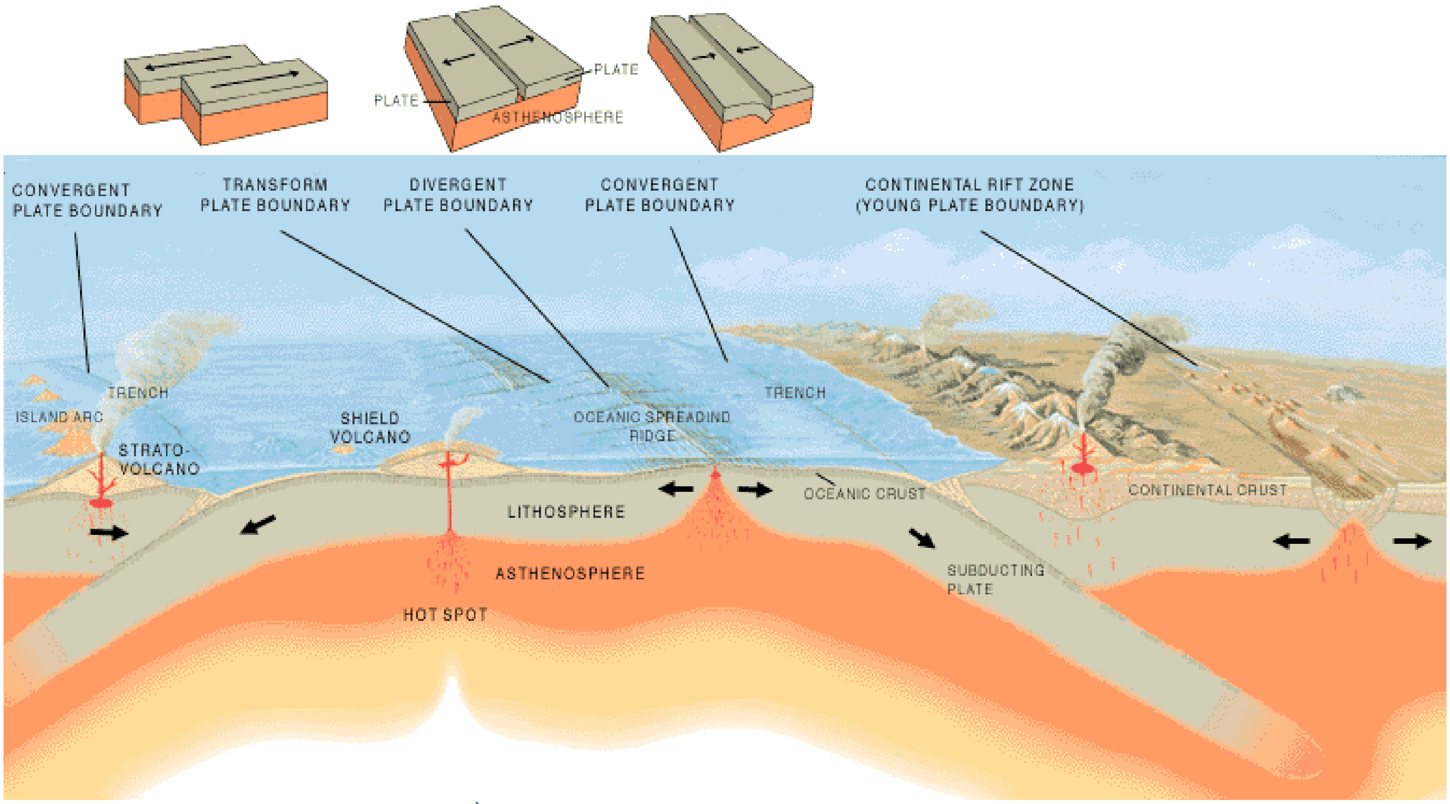
Our 3-phased approach to ocean exploration with ABE. First, guided by chemical measurements made aboard ship, we program ABE to fly around within the water column "sniffing" for where the chemical signals are strongest using specialized in situ sensors. Second, once we know where the strongest chemical signals from a hydrothermal vent are, we program ABE to fly closer to the seafloor, making detailed maps of the seabed and, ideally, also intercepting the stems of hot buoyant hydrothermal plumes of water rising up above the seafloor. Third, and finally, we program ABE up once more to descend to right above the seabed and drive to and fro, very carefully – using obstacle avoidance techniques to stop it from crashing into the rough rocky terrain it finds – while taking photographs of whatever it is we have found: hydrothermal vents, cold seeps, and whatever new and unique animals they might host. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html

The ABE (Autonomous Benthic Explorer) autonomous underwater vehicle (free-swimming robot) about to be set loose to explore the bottom of the SW Indian Ocean from aboard the Chinese research ship RV Da Yang Yi Hao in Spring 2007. Over the past 5 years, ABE has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. *Photo credit: Christopher German.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/plan/media/missionplan3.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate. *Photo credit: INSPIRE: Chile Margin 2010.*
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

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.

Figure 1: Types of Plate Boundaries

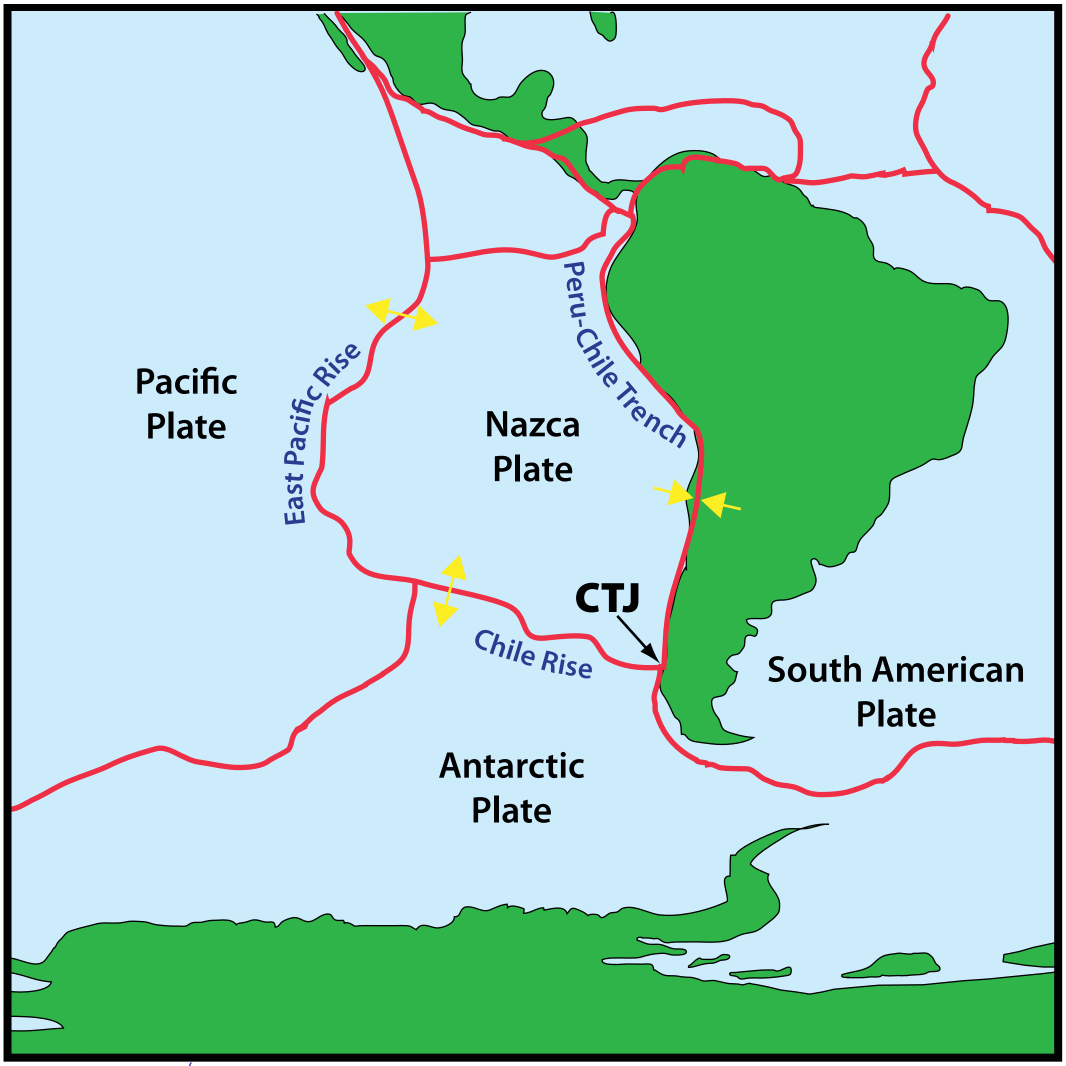


Artist's cross section illustrating the main types of plate boundaries. (*Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.*) http://pubs.usgs.gov/gip/dynamic/Vigil.html

A convergent plate boundary is formed when tectonic plates collide more or less head-on. When two continental plates collide, they may cause rock to be thrust upward at the point of collision, resulting in mountain-building. (The Himalayas were formed by the collision of the Indo-Australian Plate with the Eurasian Plate). When an oceanic plate and a continental plate collide, the oceanic plate moves beneath the continental plate in a process known as subduction. Deep trenches are often formed where tectonic plates are being subducted, and earthquakes are common. As the sinking plate moves deeper into the mantle, fluids are released from the rock causing the overlying mantle to partially melt. The new magma (molten rock) rises and may erupt violently to form volcanoes, often forming arcs of islands along the convergent boundary. These island arcs are always landward of the neighboring trenches. View the 3-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

Figure 2: Chile Triple Junction



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 3-dimensional structure of a mid-ocean ridge at: http://oceanexplorer.noaa.gov/explorations/03fire/logs/ridge.html.

Along the western coast of Chile, three of Earth's tectonic plates intersect in a way that does not occur anywhere else on the planet (see Figure 2). Chile, and the other countries of South America, lie on top of the South American tectonic plate. To the west of Chile, the Nazca Plate extends beneath the Pacific Ocean and meets the Pacific Plate along a divergent plate boundary called the East Pacific Rise. The southern edge of the Nazca Plate adjoins the Antarctic Plate along another divergent plate boundary called the Chile Rise. The eastern edge of the Chile Rise is being subducted beneath the South American plate at the Chile Triple Junction (CTJ), which is unique because it consists of a mid-oceanic ridge being subducted under a continental tectonic plate. The eastern portion of the Nazca Plate is also being subducted along the Peru-Chile Trench, and the Andes mountains are one consequence of this process. Not surprisingly, complex movements of three tectonic plates at the CTJ result in numerous earthquakes. In fact, the largest earthquake ever recorded (magnitude 9.5) occurred along the Peru-Chile Trench in 1960. While earthquakes and volcanoes are often associated with massive destruction and loss of human life, the same processes that cause these events are also responsible for producing unique habitats for very different life forms.

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. Similar hot springs, known as hydrothermal vents, have since been found in many other locations where underwater volcanic processes are active. Hydrothermal vents are formed when the movement of tectonic plates causes deep cracks to form in the ocean floor. Seawater flows into these cracks, is heated by magma, and then rises back to the surface of the seafloor. The water does not boil because of the high pressure in the deep ocean, but may reach temperatures higher than 350° C. This superheated water dissolves minerals in Earth's crust. Hydrothermal vents are locations where the superheated water erupts through the seafloor. The temperature of the surrounding water is near-freezing, which causes some of the dissolved minerals to precipitate from the solution. This makes the hot water plume look like black smoke, and in some cases the precipitated minerals form chimneys or towers.

The presence of thriving biological communities in the deep ocean was a complete surprise, because it was 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 a process 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. Cold seeps are another type of chemosynthetic deep-sea community in which hydrocarbons (such as methane or oil) seeping out of sediments provide an energy source for living organisms. Cold seeps are commonly found along continental margins, and are home to many species that have not been found anywhere else on Earth.

A primary purpose of the INSPIRE: Chile Margin 2010 Expedition is to locate new chemosynthetic ecosystems near the CTJ. Because hydrothermal vents and cold-seeps cause changes to the chemistry and physical characteristics of surrounding seawater, these geologic features 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 and cold-seeps.

To search for these clues, expedition scientists will use deep-tow sidescan sonar and data recorders that can detect chemical and physical water characteristics that signal the presence of hydrothermal vents and cold-seeps. Once plumes have been located, the depth and size of selected plumes will be investigated in more detail using instruments that measure conductivity, temperature, depth, optical backscatter, and redox potential so that the source of the plume can be located within an area of about 1 km. High resolution maps of this area will be prepared using an autonomous underwater vehicle (AUV). Finally, the AUV will collect overlapping photographs of the vent or cold-seep site. This lesson focuses on physical and chemical measurements and some of the technologies used to make these measurements. For more information and activities about ocean floor mapping, please see the "Mapping the Deep Ocean Floor" lesson. For more about AUVs, please see "The Ridge Exploring Robot" lesson. Both of these lessons can be found in the lesson plan collection for INSPIRE: Chile Margin 2010 Expedition.

Learning Procedure

[NOTE: The water sample analysis activity described in Step 4 is adapted from the 2002 Galapagos Rift Expedition lesson, "Yo-Yos, Tow-Yos and pH, Oh My!" by Stacia Fletcher, Monterey Bay Aquarium, Monterey, CA.]

1. To prepare for this lesson:
   (a) Review introductory essays for the INSPIRE: Chile Margin 2010 Expedition at http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html
   (b) If students are not familiar with deep-sea chemosynthetic communities you may want to use Multimedia Discovery Mission Lesson 5, Chemosynthesis and Hydrothermal Vent Life (http://oceanexplorer.noaa.gov/edu/learning/welcome.html), and/or information from http://www.pmel.noaa.gov/vents/nemo/explorer.html.
   (c) Review procedures for the simulated analysis of CTD samples (Step 4). 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 with chilled water and label each with an A, B, C, D or E.
   3. Heat the water in all beakers labeled D for 60 seconds in the

microwave oven shortly before the start of class.

4. Add 3 drops of vinegar to all beakers labeled C and E and stir.
5. Add one tablespoon of vinegar to all beakers labeled D and stir.

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

   Introduce the INSPIRE: Chile Margin 2010 Expedition, and say that a primary purpose of the expedition is to locate new chemosynthetic ecosystems near the Chile Triple Junction. Tell students that ocean explorers searching for chemosynthetic ecosystems make use of the fact that hydrothermal vents and cold seeps cause changes in the chemical and physical properties of seawater. These changes can be measured and used as clues to find the location of previously undiscovered vents and seeps.

   Discuss some of the clues that might result from changes that hydrothermal vents might cause in seawater. Increased temperature is fairly obvious, since heat from Earth's core is the energy source that causes vents to form. Temperatures of hydrothermal fluids may be more than 300°C, since the high pressure of deep-sea environments prevents water from boiling. Fluids from hydrothermal vents are often highly acidic, in contrast to normal seawater which is slightly basic; so pH is another potential clue. You may need to explain that pH is a measure of the concentration of hydrogen ions (which actually exist as hydronium ions, H_3O^+). For a more detailed discussion about pH, please see page 20 of the lesson, "Why Do We Explore?" (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09whydoweexplore.pdf).

   Hydrogen sulfide is often found in hydrothermal vent fluids, while methane is a common component of cold seeps. Seawater does not normally contain either of these fluids, so a chemical analysis that indicates their presence in a seawater sample would be another clue that signals vents or cold seeps may be nearby. When methane in cold seep fluids is oxidized, the chemical reaction leads to the precipitation of carbonate minerals from seawater. These precipitates appear as bright areas in sidescan sonar images, and are reliable indicators of the presence of cold seeps. Iron dissolved in hydrothermal vent fluids also forms precipitates when the fluids combine with seawater. Fine particles of iron oxyhydroxide have been found in plumes that were tens of kilometers away from the source vents, and cause the plume to appear cloudy. This cloudiness is called optical backscatter. Since deep ocean water normally has very little suspended material, optical backscatter is another clue to the presence of hydrothermal vents.

Another clue is provided by chemicals that provide energy for chemosynthetic communities. This energy comes from a series of reactions called an electron transport chain, and is based on chemicals that can provide electrons to start these reactions. These chemicals are called reducing substances, because they cause other substances to become reduced, which means that the latter substances gain electrons. Common reducing substances in chemosynthetic environments are methane and hydrogen sulfide. The tendency of a substance to gain or lose electrons can be measured as redox potential. Redox potential increases directly with the tendency of a substance to gain electrons and become reduced. So the presence of chemicals that tend to lose electrons (such as methane and hydrogen sulfide) causes the redox potential of the surrounding water to be lower than the redox potential of normal seawater. See the INSPIRE: Chile Margin 2010 Expedition Education Module for more discussion about chemosynthesis and reducing habitats.

3. Explain the three-phase strategy that the INSPIRE: Chile Margin 2010 Expedition uses to search for chemosynthetic ecosystems:

Figure 3: CTJ's 3-phased approach to ocean exploration with ABE.

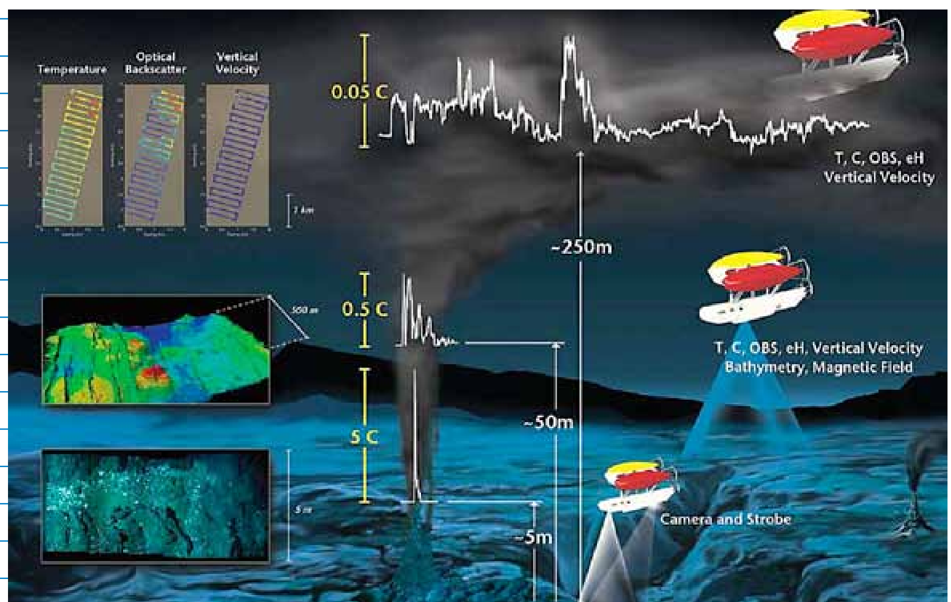


Illustration courtesy of Christopher German, INSPIRE: Chile Margin 2010 Expedtion.
http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html

First, expedition scientists will tow sidescan sonar and data recorders that can detect chemical and physical water characteristics that signal the presence of hydrothermal vents and cold-seeps. Sidescan sonar systems are mounted on a Towed Ocean Bottom Instrument (TOBI), which is a platform that can be towed at depths ranging from

200 m to 6000 m. TOBI systems provide a scale of seafloor mapping that is intermediate between surface sidescan systems and seafloor photography. To detect the chemical and physical clues that signal the presence of plumes, six Miniature Autonomous Plume Recorders (MAPRs) will also be attached along the tow wire that connects the TOBI with the ship at the surface. The MAPRs used to explore the CTJ will include sensors to measure temperature, pressure, optical backscatter, and redox potential. Optical backscatter is important because the oxidation of methane from cold-seeps causes precipitates of carbonate material to form. These precipitates cause the normally clear deep-ocean water to become cloudy so that light shining through the water is scattered and reflected back toward the light source.

Ben Grupe begins to prepare the CTD bottles for deployment, an instance when being tall comes in handy. Normally, scientists have to climb onto the white frame to cock the bottle caps. As the CTD is lowered into the ocean, a computer is used to watch the data and order bottles to snap shut, collecting water samples from different depths. Photo courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar2/media/1mar2.html

Once plumes have been located, the depth and size of selected plumes will be investigated in more detail using instruments that measure conductivity (used to estimate salinity), temperature, and depth (CTD). The purpose of this step is to narrow the location of the plumes' source to within about 1 km. The CTD used by the INSPIRE: Chile Margin 2010 Expedition is mounted on a metal frame called a rosette, which holds bottles that can collect water samples from different depths for chemical analysis. Before lowering the CTD into the water, the caps of each sampling bottle are cocked open. When scientists want to obtain a sample they send an electronic signal down the cable connecting the CTD with the ship, and this signal causes the cap on one of the bottles to snap shut.

Next, scientists program the Autonomous Benthic Explorer (ABE) underwater robot to fly around within the water column "sniffing" for where the chemical signals are strongest. Once the strongest chemical signals have been located, ABE is programmed to fly closer to the seafloor, making detailed maps of the seabed and, possibly intercept streams of hot buoyant hydrothermal plumes rising up from the seafloor.

Finally, ABE is programmed to descend to just above the seabed and collect overlapping photographs of the vent or cold-seep site. You may want to show students Figure 3 which summarizes this strategy, and can be downloaded from http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration2.html.

Before MAPRs became available, ocean explorers would repeatedly raise and lower CTDs as they were towed behind a research vessel to obtain information about ocean chemistry. Because the up-and-down movement reminded some observers of the motion of a yo-yo, this kind of sampling was nicknamed "tow-yo." See http://oceanexplorer.

noaa.gov/explorations/10chile/logs/mar2/media/1mar2.html for an image of a CTD being prepared for sampling.

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

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

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. Suggested measurements might include redox potential, and chemical analysis to detect the presence of reducing substances.

The BRIDGE Connection

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

The "Me" Connection

Have students review information about the explorers participating in the INSPIRE: Chile Margin 2010 Expedition (http://oceanexplorer.noaa.gov/explorations/10chile/background/explorers/explorers.html), and write a brief essay discussing whose job they would like to have if they were personally taking part in the expedition.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/10chile/welcome.html for the latest activities and discoveries by the INSPIRE: Chile Margin 2010 Expedition.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

I, Robot, Can Do That!
(PDF, 315 kb) (from the Lost City 2005 expedition)
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater robotic vehicles for scientific exploration (Physical Science/Life Science)

In this activity, students will be able to describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

Life is Weird
(PDF, 315 kb) (from the 2003 Windows to the Deep expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_lifeisweird.pdf

Focus: Biological organisms in cold seep communities (Life Science)

Students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities. Students will also be able to infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment, and describe the process of chemosynthesis in general terms, and will be able to contrast chemosynthesis and photosynthesis.

How Does Your Magma Grow?
(PDF, 224 kb) (from the 2005 GalAPAGos: Where Ridge Meets Hotspot expedition)
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_magma.pdf

Focus: Hot spots and midocean ridges (Physical Science)

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

One Tough Worm
(PDF, 476 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_toughworm.pdf

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

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

Sonar Simulation
(PDF, 308 kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/sonarsim.pdf

Focus: Side scan sonar (Earth Science/Physical Science)

Students will describe side-scan sonar, compare and contrast side-scan sonar with other methods used to search for underwater objects, and make inferences about the topography of an unknown and invisible landscape based on systematic discontinuous measurements of surface relief.

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/explorations/10chile/welcome.html – Web site for the INSPIRE: Chile Margin 2010 Expedition

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

Yoerger, D., A. Bradley, M. Jakuba, M. Tivey, C. German, T. Shank, R. Embley. 2007. Mid-ocean ridge exploration with an autonomous underwater vehicle. Oceanography 20(4):52-61(available online at http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/20_4/20.4_yoerger_et_al.pdf)

German, C., D. Yoerger, M. Jakuba, T. Shank, C. Langmuir, K. Nakamura. 2008. Hydrothermal exploration with the Autonomous Benthic Explorer. Deep-Sea Research I 55:203-219

Tunnicliffe, V., S. Juniper, M. Sibuet. 1999. Reducing Environments of the Deep-Sea Floor. In: P. Warneck (ed) Chemistry of the natural atmosphere. Academic Press. San Diego. 927 pp (available online at http://cmbc.ucsd.edu/Students/Current_Students/SIO277/ch4%20reducing%20env.pdf)

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard B: Physical Science

- Transfer of energy

Content Standard C: Life Science

- Populations and ecosystems
- Diversity and adaptations of organisms

Content Standard D: Earth and Space Science

- Structure of the Earth system

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal health
- Populations, resources, and environments

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.

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

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

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

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

Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy".

Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

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

Essential Principle 7.
The ocean is largely unexplored.

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

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

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

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

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
oceanexeducation@noaa.gov

For More Information

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

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The Oceanographic Yo-Yo

CTD Sample Analysis Worksheet

Group Name: ______________________

Sample	Temperature	pH
A		
B		
C		
D		
E		

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

____

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How do your data support this inference?

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