DEEP SEA EXPLORATION
INDEX2010
Sangihe Talaud
Indonesia-USA

INDEX/SATAL 2010

# Let's Make a Tubeworm!

(adapted from the 2002 Gulf of Mexico Expedition)

## Focus

Hydrothermal vent ecosystems

## Grade Level

5-6 (Earth Science/Life Science)

## Focus Question

Why is it important to explore the deep ocean in places such as Indonesia?

## Learning Objectives

- Students will be able to explain the overall structure of hydrothermal vents and how they are related to the motion of tectonic plates.
- Students will be able to describe the process of chemosynthesis in general terms, and contrast chemosynthesis and photosynthesis.
- Students will be able to describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

## Materials

- ❑ Copies of *Hydrothermal Vent Tubeworm Inquiry Guide*, one copy for each student group
- ❑ (If posters are to be made; see *Inquiry Guide* Step 12) Poster materials (bristol board, markers)
- ❑ (If models are to be made; see *Inquiry Guide* Step 12) Cardboard tubes (mailing tube or paper towel roll), colored markers, pipe cleaners (to simulate tentacles), modeling clay, paper and glue (to make a model trophosome)

## Audio-Visual Materials

- ❑ (Optional) Video or computer projection equipment; see Learning Procedure Step 1.

## Teaching Time

Two 45-minute class periods, plus time for student research and creation of vestimentiferan models

## Seating Arrangement

Groups of 3-4 students

## Maximum Number of Students

30

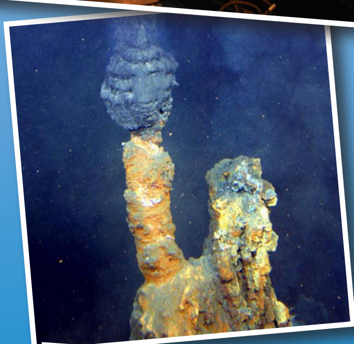


Image captions/credits on Page 2.

lesson plan

**The NOAA Ship *Okeanos Explorer***
Formerly: USNS *Capable*
Launched: October 28, 1988
Transferred to NOAA: September 10, 2004
Commissioned: August 13, 2008
Class: T-AGOS
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46 (19 Mission/science)
Speed: 10 knots
Range: 9600 nm
Endurance: 40 days

**Systems and Instumentation:**
Kongsberg EM302 Multibeam rated to 7,000 m
SBE 911 Plus CTD
ROVs -
Little Hercules - 4,000 m depth rating; USBL tracking; depth, altitude, attitude/heading sensors; Seabird SBE 49 FastCat CTD; HD camera and HMI lights
Camera platform with depth/altitude/heading sensors, HD cameraand HMI lights.
Telepresence

**Operations:**
Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation; Mission equipment operated by NOAA's Office of Ocean Exploration and Research

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

**Images from Page 1 top to bottom:**
The ROV Hercules being lowered into the water from the NOAA Ship *Okeanos Explorer*. Image credit: NOAA OER.

NOAA scientists examining live video feed from the ROV Hercules. Image credit: NOAA OER.

Mussels, shrimp, limpets, and crabs cover the slope of an underwater volcano near a hydrothermal vent. Image credit NOAA
http://www.photolib.noaa.gov/bigs/expl0071.jpg

Black smokers on the Kermadec Arc. Image courtesy of New Zealand American Submarine Ring of Fire 2007 Exploration, NOAA Vents Program, the Institute of Geological & Nuclear Sciences and NOAA-OE.
http://oceanexplorer.noaa.gov/explorations/07fire/logs/july31/media/brothers_blacksmoker_600.jpg

## Key Words

Hydrothermal vent
Magma
Mantle
Tectonic plate
Vestimentifera
Trophosome
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.*

During the summer of 2010, scientists from Indonesia and the United States will work together on an expedition to explore the deep ocean surrounding Indonesia. This mission is called INDEX/SATAL 2010, since the expedition is focussed on INDonesia, EXploration, and the Sangihe Talaud (SATAL) region. Working from the Indonesian Research Vessel *Baruna Jaya IV* and the NOAA Ship *Okeanos Explorer*, these ocean explorers expect to find new deep-sea ecosystems, undiscovered geological features, and living organisms that have never been seen before. New discoveries are always exciting to scientists; but information from ocean exploration is important to everyone, because:

- Biodiversity in deep-sea ecosystems includes new species that can provide important drugs and other useful products;
- Some deep-sea ecosystems include organisms that can be used for human food;
- Information from deep ocean exploration can help predict earthquakes and tsunamis; and
- Human benefits from deep ocean systems are being affected by changes in Earth's climate and atmosphere.

Indonesia is well-known as one of Earth's major centers of biodiversity (which means the variety of all forms of life). Although Indonesia covers only 1.3 percent of Earth's land surface, it includes:

- 10 percent of the world's flowering plant species;
- 12 percent of the world's mammal species;
- 16 percent of all reptile and amphibian species;
- 17 percent of the world's bird species;
- 15 percent of the world's coral reefs;
- the highest number of coral species in the world (more than 600 identified species); and
- more than 2000 species of near shore fishes.

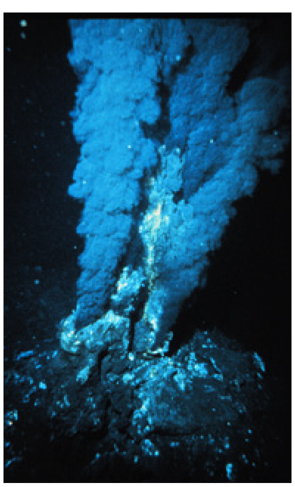
**Indonesia's Research Vessel**
***Baruna Jaya IV***

Port of Registry - Jakarta, Indonesia
Purpose - Oceanography, Fishery
Launched - 1995
Length - 60.4 m
Width - 12.10 m
Draft - 4.15 m
Draft mean - 4.15m
Cruising speed - 10 kts
BPPT Indonesia - owner
17 crew, 33 scientists, and engineers

**Deck Gear:**
6 ton A-Frame
3 ton Crane
2 - Gilson Winches
2 - Otter Trawl Winches
Hydrographic Winch

**Oceanographic Equipment:**
Seabeam ELAXC1050D Multibeam
Seabeam ELAC 1190 Multibeam
ELAC 4700
Acoustic Doppler Current Profiler RDI Broadband
Sea Bird SBE-911 CTD
Rosette
Aanderaa, MORS, RDI current meters
Gravity Core Sediment Sampler
Oretech 3000 Subbottom Profiler
Edge Tech 4200-MP Sidescan Sonar

**Fishery Equipment:**
Mid- and Deep-water Fisheries Trawl
Koden Fish Finder
Simrad EK 500
Plankton Net



Hydrothermal vent; Image credit: NOAA
http://www.nmfs.noaa.gov/rss/podcasts/weirdfins/images/Hydrothermal_vent.jpg

Very little is known about Indonesia's deep ocean, but scientists expect to find high biodiversity there as well, along with new ecosystems and many species that have never been seen before.

Conditions in the deep-sea environment include very high pressures, total darkness, extreme temperatures, and toxic chemicals. Hydrothermal vents, for example, are deep ocean habitats where hot fluids erupt from the seafloor. These habitats are found near mid-ocean ridges where Earth's tectonic plates are spreading apart. The ridges are formed by hot lava that erupts between spreading tectonic plates. Hydrothermal vents are produced when cold seawater seeps down into Earth's crust through cracks in the ocean floor near mid-ocean ridges. As the seawater moves deeper into the crust, it is heated by molten rock. As the temperature increases, sulfur and metals such as copper, zinc, and iron dissolve from the surrounding rock into the hot fluid. Eventually, the mineral-rich fluid rises again and erupts from openings in the seafloor. The temperature of the erupting fluid may be as high as 400°C, and contains hydrogen sulfide. When the hot hydrothermal fluid meets cold (nearly freezing) seawater, minerals in the fluid precipitate. The precipitated mineral particles give the fluid a smoke-like appearance, so these vents are often called black smokers or white smokers, depending upon the types of minerals in the fluid. Precipitated minerals may also form chimneys that can be several meters high.

One of the most exciting and significant scientific discoveries in the history of ocean science is that many hydrothermal vents are surrounded by large numbers of animals. 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 to rely on 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.
Where hydrogen sulfide is present, large tubeworms known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. Vestimentifera have been regarded previously as a distinct phylum or a group within the phylum Pogonophora. Recent molecular evidence suggests that Vestimentifera and Pogonophora should be considered part of the polychaete family Siboglinidae within the phylum Annelida. These unusual animals do not have a mouth,

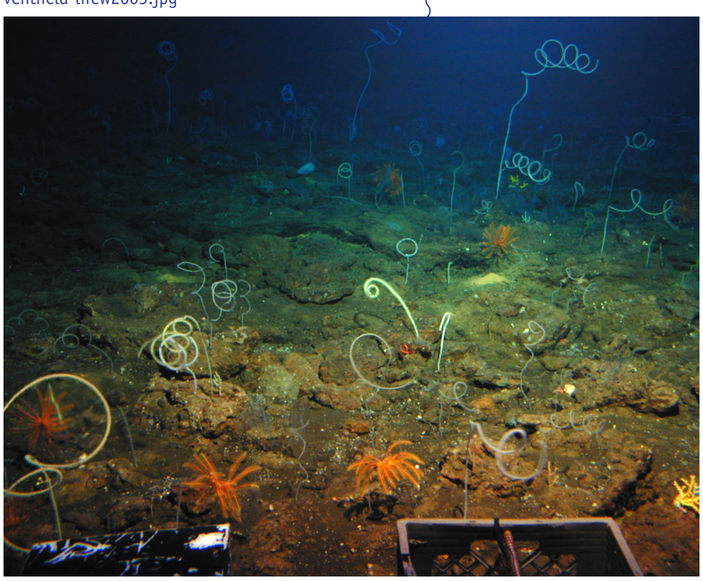
The giant tubeworm, *Riftia pachyptila*, from the hydrothermal vents at the East Pacific Rise at 2,500 m depth. Each individual in the photo exceeds one meter in length. Image courtesy of Monika Bright, University of Vienna, Austria.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/hires/riftia_hires.jpg

stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Vestimentiferans have tentacles that extend into the water. The tentacles are bright red due to the presence of hemoglobin which can absorb hydrogen sulfide and oxygen and transport these chemicals to bacteria in the trophosome. The bacteria produce organic molecules that provide nutrition to the tubeworm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills. Bacteria are also found living independently from other organisms in large bacterial mats. A variety of other organisms are also found in cold seep communities, and probably use tubeworms, mussels, and bacterial mats as sources of food. These include snails, eels, sea stars, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships among these organisms have not been well-studied. Visit http://www.pmel.noaa.gov/vents/home.html for more information and activities on hydrothermal vent communities.

Some of the adaptations that allow hydrothermal vent organisms to live also produce substances that may be useful to humans. At present, almost all drugs produced from natural sources come from terrestrial plants, but marine organisms produce more drug-like substances than any group of organisms that live on land. Some chemicals from microorganisms found around hydrothermal vents (the exopolysaccharide HE 800 from *Vibrio diabolicus*) are promising for the treatment of bone injuries and diseases, while similar chemicals may be useful for treating cardiovascular disease. Other examples of useful products include *Thermus thermophylus*, a microorganism that is adapted to live under extremely high temperature conditions near hydrothermal vents. One of these adaptations is a protein (Tth DNA polymerase) that can be used to make billions of copies of DNA for scientific studies and crime scene investigations. Another microorganism (genus Thermococcus) produces a type of protein (an enzyme called pullulanase) that can be used to make sweeteners for food additives.

This lesson guides student inquiries about a typical hydrothermal vent organism.

Abundant growth on vent field at Volcano 19. Image credit NOAA / NURP.
http://www.noaanews.noaa.gov/stories2005/images/ventfield-lifew2005.jpg



## Learning Procedure

[NOTE: There is a wealth of information available on the geology and ecology of hydrothermal vent ecosystems. Several sources and potential activities are highlighted below, and educators are encouraged to investigate these, and select combinations that are most appropriate to their own students and specific curriculum needs.]

1. To prepare for this lesson:
   (a) Review introductory essays for the INDEX/SATAL 2010 Expedition at http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html
   (b) Review background information on hydrothermal vents from one or more of these Web sites:
   - http://oceanexplorer.noaa.gov/explorations/02fire/logs/magicmountain/welcome.html – This site links to virtual fly-throughs and panoramas of the Magic Mountain hydrothermal vent site on Explorer Ridge in the NE Pacific Ocean, about 150 miles west of Vancouver Island, British Columbia, Canada. Explorer Ridge is a spreading center where two tectonic plates are spreading apart and there is active eruption of submarine volcanoes.
   - http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates. The "Explore" section of the site offers images and essays that include mid-ocean ridges, hydrothermal vents, and seafloor animals. The "Education" section of the site provides Powerpoint® presentations and curriculum materials.
   - http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, "We're in Hot Water Now: Hydrothermal Vents," includes links to National Geographic magazine articles and video with an emphasis on geography and geographic skills.
   - http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents includes details about vent formation, education resources, and the story of the discovery of the first hydrothermal vent in 1977.

   If video or computer projection facilities are available, you may also want to bookmark selected Web pages or download some images from these sites to show your students.

   (c) Review Multimedia Discovery Missions [http://oceanexplorer.noaa.gov/edu/learning/welcome.html] Lessons 1, 2, 4, and 5 on Plate Tectonics, Mid-Ocean Ridges, Subduction Zones, and Chemosynthesis and Hydrothermal Vent Life. Decide how much of this material to use with your students.

(d) Review the *Hydrothermal Vent Inquiry Guide*, and note any vocabulary in the background reading that may require additional explanation.

(e) Review optional hydrothermal modeling activities in Step 4, and decide whether you will use these, either as demonstrations or student activities.

2. Briefly introduce the INDEX/SATAL 2010 Expedition, and (if necessary) the concept of plate tectonics (see http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/whenplates.pdf for a lesson about plate tectonics). Review the basic concepts of photosynthesis, chemosynthesis, autotroph and heterotroph. Display definitions of photosynthesis and chemosynthesis so they are visible to all students. If your curriculum does not prescribe specific definitions for these processes, the following may be used:
   - "Photosynthesis is the process by which plants convert carbon dioxide into organic compounds, using energy from sunlight."
   - "Chemosynthesis is the process by which organisms convert carbon molecules (usually carbon dioxide or methane) into organic compounds using energy from other molecules."

   Ask students how photosynthesis and chemosynthesis are similar, and how they are different. Students should realize that both processes involve the conversion of carbon compounds into organic molecules (especially carbohydrates), and both require a source of energy. Differences include the fact that photosynthesis is carried out only by plants, while a variety of organisms are capable of chemosynthesis; and the source of energy for photosynthesis is light, while the energy for chemosynthesis comes from other chemical reactions.

   Ask students why photosynthesis and chemosynthesis are important in ecosystems? Students should identify the primary importance of both as providing a source of energy for life processes among organisms that make up ecosystems.

3. Tell students that their assignment is to investigate one of these hydrothermal vent organisms. Provide each student with a copy of the *Hydrothermal Vent Tubeworm Inquiry Guide*, and selected Web addresses or downloaded reference materials.

4. When students have answered questions on the *Inquiry Guide* and completed their posters or models, lead a discussion of their results. The following points should be included:

- Hydrothermal vents are underwater hot springs that form when seawater flows into cracks in the ocean floor and is heated by hot magma beneath Earth's crust.

- The temperature of hydrothermal vent fluid is often between 300°C and 400°C.

- Hot hydrothermal vent fluid is capable of dissolving elements and minerals from rock beneath the ocean floor, so this fluid often contains large amounts of substances such as sulfur, copper, zinc, gold, and iron, and is very acidic.

- Seawater in hydrothermal vents does not boil because of the high pressure in the deep ocean.

- Vent chimneys are chimney-like structures formed by minerals that precipitate when hydrothermal vent fluids are cooled by surrounding seawater, because the solubility of many dissolved materials is reduced when temperature decreases.

- "Black smokers" are vent chimneys formed from deposits of iron sulfide, which is black.

- "White smokers" are vent chimneys formed from deposits of barium, calcium, and silicon, which are white.

- Hydrothermal vents, volcanoes, and earthquakes often happen at the junction of two of Earth's tectonic plates because movement of the plates causes cracks that allow molten rock to rise through Earth's crust, and allow seawater to flow through heated rock beneath the ocean floor.

- Hydrothermal vent tubeworms obtain their food from symbiotic chemosynthetic bacteria that live in a tubeworm organ called the trophosome.

- Major tubeworm organs include:
  - **Plume** – consists of numerous tentacles with blood vessels containing hemoglobin
  - **Vestimentum** – a muscular structure whose functions include holding the worm in its tube, generating new tube material, releasing sperm or eggs during spawning, and containing the tubeworm's version of a heart and a brain
  - **Trophosome** – a spongy, dark green-brown organ that contains billions of bacteria which use oxygen, carbon dioxide, and hydrogen sulfide to make food for themselves as well as the worm

- **Trunk** – A hollow structure that surrounds the worm's internal organs with a cavity where waste is stored (tubeworms do not have a mouth, stomach, intestines, or anus)
- **Tube** – a hard hollow cylinder that provides protection for the worm (like the shells of other animals); the tentacles can be pulled completely inside the worm to avoid predators.
- **Opisthosome** – like the vestimentum, this organ produces new tube material and helps anchor the worm in its tube

## The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" in the menu on the left side of the page, then select "Geology" or "Habitats" for activities and links about hydrothermal vent formation and ecology.

## The "Me" Connection

Have students write a brief essay discussing how hydrothermal vents might be useful to humans.

## Connections to Other Subjects

English/Language Arts, Fine Arts

## Assessment

Answers to *Inquiry Guide* questions, posters or models, and class discussions provide opportunities for assessment.

## Extensions

1. Visit http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html for the latest activities and discoveries by the INDEX/SATAL 2010 Expedition.

2. Create models of hydrothermal vent habitats (see http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/aydrothermal.pdf).

3. Have students research other hydrothermal vent organisms, and draw a food web that includes at least six organisms representing primary producers and consumers.

## Multimedia Discovery Missions

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

## Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

**And Now for Something Completely Different...**
(PDF, 172 kb) (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 (Life Science)

In this activity, students will 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.

**When Plates Collide**
(PDF, 1.1 Mb) (from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/whenplates.pdf

Focus:Plate Tectonics – Movement of plates, results of plate movement, and the Chile Triple Junction

Students will describe the motion of tectonic plates, compare and contrast three typical boundary types that occur between tectonic plates, describe the plate boundaries that occur and the Chile Triple Junction, and explain why a variety of chemosynthetic communities are expected to occur in this area.

**A Hydrothermal AdVENTure**
(PDF, 948 Kb) (from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/aydrothermal.pdf

Focus:Hydrothermal Vents

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

**The Volcano Factory**
(5 pages, 384k) (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 (Earth Science)

Students will be able to explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench, and will be able to explain why the Mariana Arc is one of the most volcanically-active regions on Earth.

**What's for Dinner?**

(6 pages, 285Kb) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_dinner.pdf

Focus: Sources of nutrition for biological communities associated with volcanoes of the Mariana Arc (Life Science)

Students will be able to compare and contrast photosynthesis and chemosynthesis as sources of primary production for biological communities, give at least three examples of organisms that live near hydrothermal vent systems, and describe two sources of primary production observed in biological communities associated with volcanoes of the Mariana Arc.

**Unexplored**

(7 pages, 264Kb) (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 (Life Science/Physical Science/Earth Science)

Students will be able to 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**

(PDF, 88 kb) (from the Submarine Ring of Fire 2002 Expedition)
http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_living_heat_5_6.pdf

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents. (Life Science/Physical Science)

Students will be able to 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 between organisms typically found in hydrothermal vent communities.

**InVENT a Deep-Sea Invertebrate**
(PDF, 460 kb) (from the 2002 Galapagos Rift Expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l3.pdf

Focus - Galapagos Rift Ecosystem: Structure and Function in Living Systems (Life Science)

Students will design an invertebrate capable of living near deep-sea hydrothermal vents, and in doing so, will learn about the unique adaptations that organisms must have in order to survive in the extreme environments of the deep sea.

## Other Resources

*The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.*

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/welcome.html – Web site for the INDEX SATAL 2010 Expedition, with links to lesson plans, career connections, and other resources

http://oceanexplorer.noaa.gov/okeanos/edu/welcome.html – Web page for the NOAA Ship *Okeanos Explorer* Education Materials Collection

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://www.pmel.noaa.gov/vents/nemo/index.html – Web site for NOAA's New Millennium Observatory (NeMO), a seafloor observatory at an active underwater volcano near the spreading center between the Juan de Fuca and Pacific tectonic plates

http://www.nationalgeographic.com/xpeditions/lessons/07/g35/seasvents.html – National Geographic Xpeditions lesson plan, "We're in Hot Water Now: Hydrothermal Vents," includes links to *National Geographic* magazine articles and video with an emphasis on geography and geographic skills.

http://www.divediscover.whoi.edu/vents/index.html – Woods Hole Oceanographic Institution's Dive and Discover Web site about hydrothermal vents includes details about vent formation, education resources, and the discovery of the first hydrothermal vent in 1977.

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)

http://explore.noaa.gov/special-projects/indonesia-u-s-scientific-and-technical-cooperation-in-ocean-exploration/files/Corals_for_WOC_-_FINAL.pdf – NOAA Fact Sheet about coral reefs

http://explore.noaa.gov/special-projects/indonesia-u-s-scientific-and-technical-cooperation-in-ocean-exploration/files/Okeanos_Explorer_for_WOC_-_FINAL.pdf – NOAA Fact Sheet about the NOAA Ship *Okeanos Explorer*

## National Science Education Standards

**Content Standard A: Science As Inquiry**
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

**Content Standard C: Life Science**
- Structure and function in living systems
- 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
- Science and technology in society

## 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.* Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

**Essential Principle 4.**
**The ocean makes Earth habitable.**
*Fundamental Concept b.* The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

**Essential Principle 5.**
**The ocean supports a great diversity of life and ecosystems.**
*Fundamental Concept b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.

**Essential Principle 6.**
**The ocean and humans are inextricably interconnected.**
*Fundamental Concept b.* From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

**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 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 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-chavis@noaa.gov

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## Let's Make a Tubeworm!

# Hydrothermal Vent Tubeworm Inquiry Guide

Visit the Web sites or use other materials provided by your teacher, and answer the following questions:

1. What are hydrothermal vents and how are they formed?

2. How hot is hydrothermal vent fluid?

3. How does the temperature affect the chemical composition of hydrothermal vent fluid?

4. Does seawater boil in hydrothermal vents? Why?

5. What are vent chimneys, and how are they formed?

6. What are "black smokers," and why are they black?

7. What are "white smokers," and why are they white?

8. Hydrothermal vents, volcanoes, and earthquakes often happen at the junction of two of Earth's tectonic plates. Why?

9. How do hydrothermal vent tubeworms obtain their food?

10. What is the symbiotic relationship between a hydrothermal vent tubeworm and chemosynthetic bacteria?

11. What is the function of these tubeworm organs:
    - Plume
    - Vestimentum
    - Trophosome
    - Trunk
    - Tube
    - Opisthosome

12. Make a poster or three-dimensional model of a tubeworm. A portion of your poster or model should be in cut-away form so that internal structures can be seen. Include all of the structures listed in Question #11.