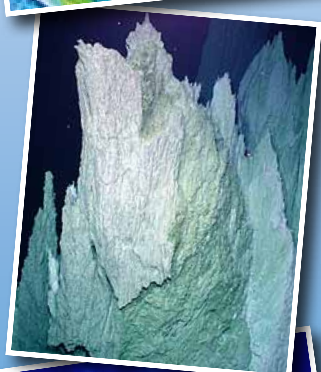


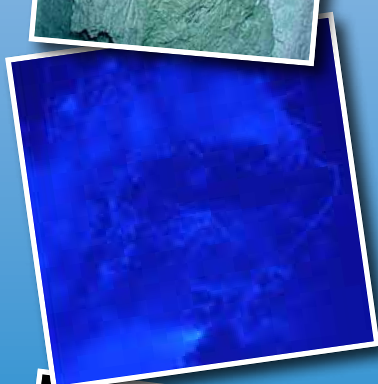


Image captions/credits on Page 2.

lesson plan

The Mid-Cayman Rise Expedition 2011

To Sink, To Rise, or To Float

Focus

Buoyancy applied to exploration for hydrothermal vents

Grade Level

5-6 (Physical Science)

Focus Question

How does the principle of buoyancy help ocean explorers find hydrothermal vents?

Learning Objectives

- Students will be able to define buoyancy and density.
- Students will be able to compare and contrast positive buoyancy, negative buoyancy and neutral buoyancy.
- Students will be able to explain how the concepts of buoyancy and density are relevant to exploration for hydrothermal vent systems.

Materials

For one student group:

- ❑ Piece of Styrofoam, about 2 cm x 2 cm x 4 cm, cut as a right rectangular prism
- ❑ Plastic tape (*e.g.*, duct tape, electrical tape, package tape)
- ❑ Fishing weights or washers, at least 10 pieces with a total mass of about 60 g
- ❑ 100 ml graduated cylinder (be sure the Styrofoam pieces will fit inside the cylinder)
- ❑ Scissors
- ❑ Copies of *Buoyancy and Vents Guided Design Portfolio Sheet*

May be shared by several student groups:

- ❑ Triple-beam balance
- ❑ An aquarium filled with water

For demonstration:

- ❑ Clear cylindrical container, about 250 ml capacity (*e.g.*, graduated cylinder, tall flower vase, tall glass)
- ❑ Hot (about 50°C) and cold (about 4°C) water, 500 ml or more each; if not available at school, may be brought from home in vacuum beverage bottles

Images from Page 1 top to bottom:
The Mid Cayman Rise (MCR) is an undersea ridge deep in the Caribbean Sea at the tectonic boundary where the North American Plate and the Caribbean Plate are spreading apart. (Map courtesy of NOAA)
http://www.whoi.edu/oceanus/viewImage.do?id=125232&aid=86988

Typical morphology of active chimney at Lost City on the Mid Cayman Rise showing multiple, delicate pinnacles of young carbonate material. The tall, white, carbonate structures emit clear, warm fluids that form no particles in the water. The fluids coming out of these chimneys have very high pH (10-11) and maximum temperatures of less than 100°C. Image courtesy of Lost City 2003, University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/chem/media/active.html

Colonies of microbes are attached to carbonate material from within the chimney walls. There are microbes that eat methane and help to counter-balance the methane production of the methanogens (organisms that generate methane). Some colonies form filamentous strands, such as the one shown in the far right of this microphotograph. Each small dot (microbe) that makes up the strand is about 1 micron in size. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/overview/media/fig8microbe.jpg

Black smokers are formed when volcanic action emits metal sulfides. The calcium carbonate white chimneys at Lost City were formed when fluids with a very high pH and calcium content mixed with seawater. This vigorously venting black smoker, called Sully, emits jets of particle-laden fluids that create the "black smoke". The particles are predominantly very fine-grained sulfide minerals formed when the hot hydrothermal fluids mix with near freezing seawater. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/chem/media/sully2.html

- ❑ Oral medication syringe, 10 ml capacity
- ❑ Plastic tubing, inside diameter to fit syringe tip; about 75 cm or long enough to reach to the bottom of the clear cylinder
- ❑ Food coloring
- ❑ Small clear container, about 100 ml capacity (*e.g.*, beaker, plastic cup, storage dish)
- ❑ (Optional) Thermometer, 0 – 100° C

Audio-Visual Materials
- ❑ Interactive white board or computer projection equipment; see Learning Procedure Step 1.

Teaching Time
One or two 45-minute class periods

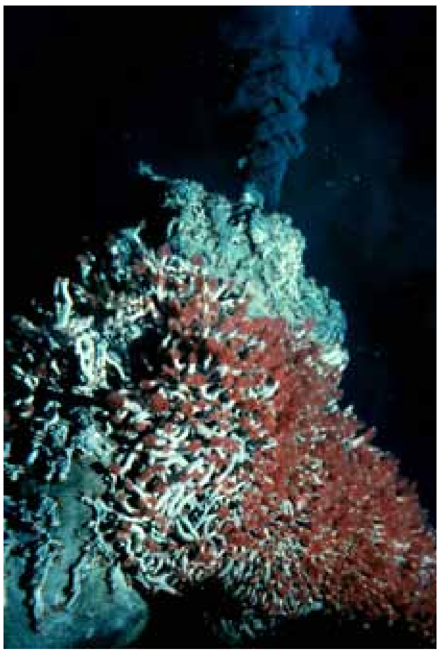
Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Buoyancy
Density
Volume
Mass
Hydrothermal vent
Plume

Background Information
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.

One of the most exciting and significant scientific discoveries in the history of ocean science was made in 1977, deep on the ocean floor near the Galápagos 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 seawater flows into deep cracks in the ocean floor, is heated by molten rock to temperatures that may be higher than 350° C, and then rises back to the surface to form hydrothermal vents where the superheated water erupts through the seafloor. 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 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.



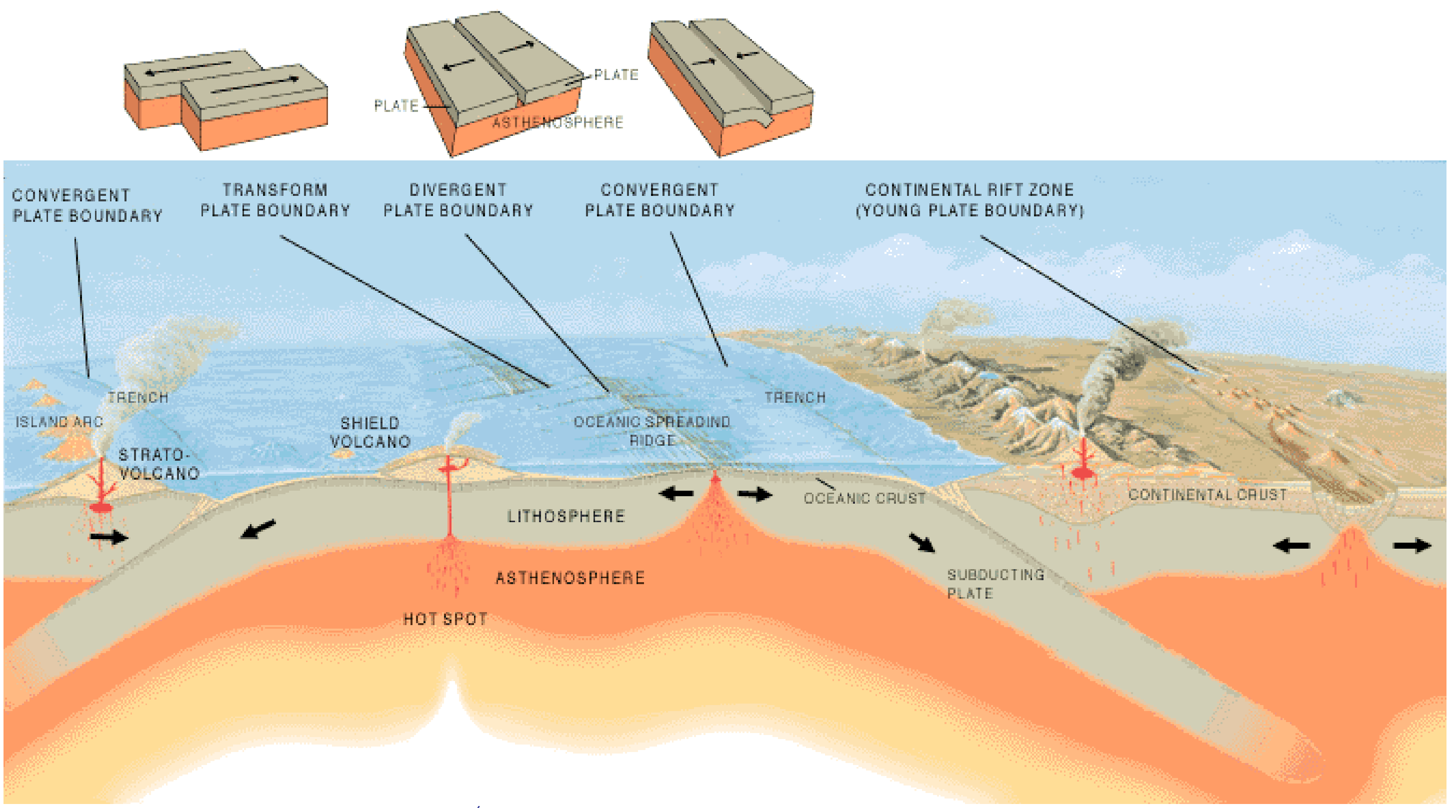
Part of a 360°C black smoker chimney with the Main Endeavour hydrothermal field on the Juan de Fuca Ridge in the N.E. Pacific ocean. Black smokers have now been found throughout the mid-ocean ridge spreading system. Since their discovery, the billowing 360°C jets of metal sulfide- and gas-laden fluids were believed to typify submarine hot spring systems. They are oases for vibrant colonies of animals such as tubeworms, giant clams, and spider crabs whose symbionts depend on volcanic gases such as carbon dioxide (CO_2) for survival. Vibrant colonies of tube worms with red gills thrive on this large edifice, which is predominantly composed of iron- and sulfur-bearing minerals. Image courtesy of University of Washington.
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/overview/media/fig2strawberry.jpg

Deepwater biological communities associated with hydrothermal vents are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. These species include some of the most primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Many species are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Although much remains to be learned, new drugs and other useful products have already been discovered in hydrothermal vent organisms. At present, almost all drugs produced from natural sources come from terrestrial plants, but marine animals 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.

The geologic processes that produce hydrothermal vents are 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; when tectonic plates collide more or less head-on, convergent plate boundary is formed; where tectonic plates are moving apart, they form a divergent plate boundary. At divergent plate boundaries, magma (molten rock) rises from deep 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. A rift valley is typically present along the top of the ridge. While the process is volcanic, volcanoes and earthquakes along oceanic spreading ridges are not as violent as they are at convergent plate boundaries. For additional discussion about convergent and transform plate boundaries, see the Galapagos Rift 2011 Expedition Purpose: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/purpose.html.

Types of Plate Boundaries



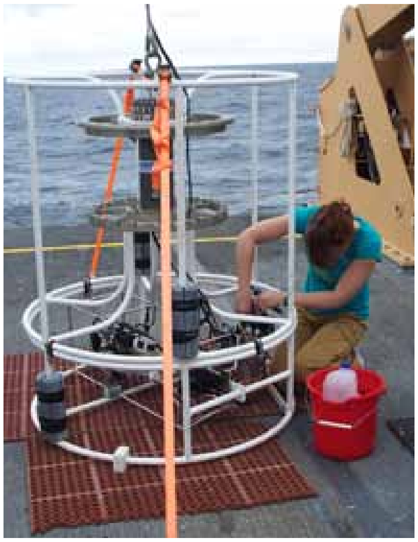
Artist's cross section illustrating the main types of plate boundaries. (Cross section by José F. Vigil from This Dynamic Planet -- a wall map produced jointly by the U.S. Geological Survey, the Smithsonian Institution, and the U.S. Naval Research Laboratory.)
http://pubs.usgs.gov/gip/dynamic/Vigil.html

On a global scale Earth's oceanic spreading ridges are connected and form a single mid-ocean ridge system that is part of every ocean. This mid-ocean ridge system is about 50,000 km long, and is the longest mountain range in the world. Although they are connected, the ridges that make up the global mid-ocean ridge system are not all the same. This is because tectonic plates adjacent to different ridges may move apart at different rates. Plates that are part of fast-spreading ridge systems may move apart at rates of 20 cm/yr or more, while plates that are part of ultraslow-spreading ridge systems may move at rates of 2 cm/yr or less. In general, hydrothermal vents are most common along fast-spreading ridge systems; but about 50% of the global mid-ocean ridge system consists of slow- or ultraslow spreading ridges, and there is greater variety in the types of hydrothermal vents founds along these ridges.

The Mid-Cayman Rise (MCR) is the world's deepest and slowest-spreading mid-ocean ridge. Exploration of the MCR was underway in the 1970's, but the discovery of the first hydrothermal vents on the Galápagos Spreading Center caused deep-sea researchers to change the focus of their investigations...until recently. In 2009, a systematic exploration along the MCR found evidence of three different types of hydrothermal vents within 100 km of each other. For more discussion about different vent types, see the Mid-Cayman Rise Expedition 2011 Exploration Purpose: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/background/edu/purpose.html.

Hydrothermal vent communities on the MCR are interesting to biologists because they probably contain species that are new to science, some of which may provide useful bioproducts. In addition, the MCR is isolated from the rest of the global mid-ocean ridge system, though it was connected to the Galápagos Spreading Center until about 5 million years ago when the Isthmus of Panama closed the seaway connecting the Caribbean Sea and Pacific Ocean. This raises intriguing questions about MCR vent organisms: Do they resemble vent biota on other ocean ridges such as the Galápagos Spreading Center or the Mid-Atlantic Ridge? How similar are they to organisms in chemosynthetic communities of the Gulf of Mexico? Answers to these questions can provide new insights about how new hydrothermal vent systems are colonized, and whether vent organisms move between widely separated vent systems. It is also possible that some MCR hydrothermal vent systems produce organic molecules by processes that do not involve living organisms. These processes are potentially relevant to the origins of life on Earth, as well as exploration for similar systems that support living organisms in other parts of our solar system.

The Mid-Cayman Rise Expedition 2011 is focused on locating new hydrothermal vent sites on the Mid-Cayman Rise, and exploring these sites with the *Little Hercules* remotely operated vehicle which will capture video images of biological and geological features of these sites. To find new vent sites, ocean explorers will take advantage of the fact that hydrothermal vents cause changes to the physical and chemical properties of seawater. These changes can be detected with a CTD, which stands for conductivity, temperature, and depth, and refers to a package of electronic instruments that measure these properties.



Senior Survey Technician Elaine Stuart works on the CTD while the altimeter battery recharges. Water sampling bottles, which are often attached to the rosette frame, have been removed for tow-yo operations. Sensors are mounted in the lower part of the frame where SST Stuart is working. Image courtesy of NOAA *Okeanos Explorer* Program.
http://tethys.gso.uri.edu/OkeanosExplorerPortal/ex1103l1/news-articles/update-for-june-25-2011/image/image_view_fullscreen

A CTD with water sampling bottles attached to the rosette frame. Image courtesy of NOAA *Okeanos Explorer* Program.

Conductivity is a measure of how well a solution conducts electricity and is directly related to salinity, which is the concentration of salt and other inorganic compounds in seawater. Salinity is one of the most basic measurements used by ocean scientists. When combined with temperature data, salinity measurements can be used to determine seawater density which is a primary driving force for major ocean currents. Often, CTDs are attached to a much larger metal frame called a rosette, which may hold water sampling bottles that are used to collect water at different depths, as well as other instruments that can measure additional physical or chemical properties.

Masses of changed seawater 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 usually raise and lower a CTD rosette through several hundred meters near the bottom as the ship slowly cruises over the area being surveyed. This repeated up-and-down motion of the towed CTD may resemble the movement of a yo-yo; a resemblance that has led to the nickname "tow-yo" for this type of CTD sampling.

In this activity, students will investigate properties of density and buoyancy, and will make inferences about how these properties are used to detect plumes from hydrothermal vents.

Learning Procedure

NOTES:

(a) Because the discovery of hydrothermal vents was so significant and exciting, there is a wealth of information available on the geology and ecology of 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.

(b) This lesson is divided into two parts. Part A is a review of density and buoyancy concepts, and a Neutral Buoyancy Design Challenge. In Part B, students observe the behavior of fluid from a simulated hydrothermal vent, and make inferences about the buoyancy of plumes that might be detected by ocean explorers.

1. To prepare for this lesson:
   (a) Review introductory essays for the Mid-Cayman Rise Expedition 2011 at http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/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

Port view of the *Okeanos Explorer*.
http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex2010/hires/port_view_hires.jpg

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 Instrumentation:
Kongsberg EM302 Multibeam rated to 7,000 m
SBE 911plus 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 camera and HMI lights.
Telepresence

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

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

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 an interactive white board 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 the *Buoyancy and Vents Guided Design Portfolio Sheet*.

2. Briefly introduce the Mid-Cayman Rise Expedition 2011, and NOAA Ship *Okeanos Explorer*, which is the only U.S. ship whose sole assignment is to systematically explore Earth's largely unknown ocean for the purposes of discovery and the advancement of knowledge. Be sure students understand that discoveries of deep sea chemosynthetic communities during the last 30 years are major scientific events that have changed many assumptions about life in the ocean and have opened up many new fields of scientific investigation. Highlight the fact that hydrothermal vents cause changes in the surrounding seawater, and that these changes can be used to locate undiscovered vents.


Portrait of Archimedes, by Domenico Fetti, about 1620

Archimedes' Principle

The idea of buoyancy was summed up by a Greek mathematician named Archimedes: any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. Today, this definition is called the Archimedes Principle.

Archimedes is considered one of the three greatest mathematicians of all time (the other two are Newton and Gauss). Archimedes was born in 287 B.C., in Syracuse, Greece. He was a master at mathematics and spent most of his time thinking about new problems to solve.

Many of these problems came from Hiero, the king of Syracuse. Archimedes came up with his famous principle while trying to solve this problem: The king ordered a gold crown and gave the goldsmith the exact amount of metal to make it. When Hiero received it, the crown had the correct weight but the king suspected that some silver had been substituted for the gold. He did not know how to prove it, so he asked Archimedes for help.

One day while thinking this over, Archimedes went for a bath and water overflowed the tub. He recognized that there was a relationship between the amount of water that overflowed the tub and the amount of his body that was submerged. This observation gave him the means to solve the problem. He was so excited that he ran naked through the streets of Syracuse shouting "I have found it!". The goldsmith was brought to justice and Archimedes never took another bath...(just kidding!).

(from "Discover Your World with NOAA: An Activity Book;" http://celebrating200years.noaa.gov/edufun/book/welcome.html)

Part A. Buoyancy, Density and the Neutral Buoyancy Design Challenge

A-1. If necessary, review Archimedes' Principle and the concepts of density and buoyancy. Be sure students understand the meaning of positive buoyancy, negative buoyancy and neutral buoyancy. If students are not already familiar with the Engineering Design Process, review information in the Engineering Design Process sidebar on Page 9.

A-2. Neutral Buoyancy Design Challenge – Provide each student group with:

- a piece Styrofoam
- plastic tape
- fishing weights or washers
- 100 ml graduated cylinder
- access to water and a balance.

Tell students that their assignment is to design a neutrally buoyant object using materials provided. This design should be based upon appropriate measurements and calculations, and they should prepare a written description of their design in Part A of the *Buoyancy and Vents Guided Design Portfolio Sheet* before actually constructing their object. If desired, you can have a competition between students groups based on which group's object is closest to neutral buoyancy.

A-3. When each group has completed their model, test the buoyancy of two or three objects at a time using an aquarium filled with water. Students should hold their objects about halfway to the bottom of the aquarium (you can use rulers to ensure that all objects are the

Engineering Design Process

The Engineering Design Process is a series of steps that engineers use to create solutions to problems. There are many versions of the Process, but the basic steps include:

- Define the problem.
- Gather relevant information.
- Brainstorm possible solutions.
- Analyze possible solutions and select the most promising.
- Test the solution by building a prototype.
- Revise and improve the solution.
- Repeat previous steps until results are acceptable.
- Report the design process and results.

These steps involve several key skills:

- Obtaining, evaluating, and communicating information;
- Analyzing and interpreting data;
- Using mathematics, information and computer technology, and computational thinking; and
- Using evidence to discuss the strengths and weaknesses of ideas and designs.

Most problems will include certain constraints that may relate to cost, size, environmental conditions, or other specific requirements. Some constraints may be identified in the statement of the problem, but most problems need additional analysis to be certain that all constraints are understood. Often, constraints will force designers to make trade-offs in their solutions. For example the strongest material may be too expensive, or too heavy to meet cost and size constraints. Identifying the solution that meets all of the constraints with the best combination of trade-offs is called optimization. Models are frequently used to help designers visualize possible solutions, and may be two-dimensional illustrations, three-dimensional physical shapes, or mathematical calculations that predict how well a potential solution will do what is necessary to solve the problem. Each step of the Engineering Design Process involves systematically examining information that is needed to move to the next step. This kind of examination is called analysis.

same distance from the bottom). When the "Go" signal is given, students release their objects and a timekeeper should begin timing with a stopwatch or watch with a sweep second hand. The time required for each model to sink to the bottom or rise to the surface should be recorded, and the competition repeated until the winner is determined. If desired, students may be given an opportunity to fine-tune their objects for a return engagement.

A-4. Lead a discussion of the design calculations that produced the most successful neutrally buoyant object. Students should realize that key parameters are :

- the total volume of the object, which will determine the volume of water displaced;
- the mass of the volume of water displaced, which will determine the buoyant force acting on the object (since this is fresh water, a volume of 1 cm3 can be assumed to have a mass of 1 gram); and
- the mass of the weights attached to the model.

The volume of the model can be determined by immersing the piece of Styrofoam in a partially-filled graduated cylinder (by placing the Styrofoam inside the cylinder, then pushing it down with the tip of a pencil or a straightened paper clip until all of the Styrofoam is **just** submerged) and noting the change in volume within the cylinder. Once the volume (and hence the buoyant force) is determined, an appropriate combination of weights can be selected. These calculations should be recorded before the object is constructed or tested. If necessary, could be broken into smaller pieces to bring the buoyant force closer to the mass of the weights. Once the appropriate combination of peanuts and weights has been determined, the components can be secured together with the plastic tape.

Ask students how they would modify their object for a competition in saltwater. Students should recognize that the density of saltwater is greater than the density of freshwater, so the volume of water displaced will have a greater mass, and hence the buoyant force on the model will be greater; so they would need to add additional weight to cause the model to sink.

Part B. Inferences About Buoyancy of Hydrothermal Vent Plumes

B-1. Arrange the following on a demonstration table so that they are within easy reach and visible to students:

- clear cylindrical container
- hot (about 50°C) and cold (about 4°C) water; about 500 ml each
- oral medication syringe with plastic tubing attached to tip
- food coloring
- small clear container
- (optional) thermometer, 0 – 100° C

B-2. Pour about 100 ml cold water into the small container, and add 10 drops of food coloring. Pour about 200 ml hot water into the cylindrical container. Optional: Have one or two students measure the temperature of the two fluids.

B-3. Draw the cold, dyed water through the plastic tubing by pulling out the syringe plunger until the syringe is full. Carefully position the open end of the plastic tubing at the bottom of the cylindrical container of hot water, then slowly expel the cold, dyed water by pushing in the syringe plunger.

B-4. Tell students to record their observations on the *Buoyancy and Vents Guided Design Portfolio Sheet*. Students should continue to observe the fluids in the cylindrical container for two minutes, and record any additional observations at the end of this time.

B-5. Empty both of the containers. Pour about 100 ml hot water into the small container, and add 10 drops of food coloring. Pour about 200 ml cold water into the cylindrical container. Optional: Have one or two students measure the temperature of the two fluids.

B-6. Draw the hot, dyed water through the plastic tubing by pulling out the syringe plunger until the syringe is full. Carefully position the open end of the plastic tubing at the bottom of the cylindrical container of cold water, then slowly expel the hot, dyed water by pushing in the syringe plunger. Tell students that this models some features of hydrothermal vent fluid when it enters the cold water of the deep ocean. Have students record their observations on the *Buoyancy and Vents Guided Design Portfolio Sheet*. Students should continue to observe the fluids in the cylindrical container for two minutes, and record any additional observations at the end of this time.

B-7. Instruct students to answer questions in Part B of the *Buoyancy and Vents Guided Design Portfolio Sheet*. When all groups have completed their answers, lead a discussion of the results.

- Students should have observed that when dyed cold water enters hot water, it forms a more or less motionless mass at the bottom of the cylindrical container. The mass slowly mixes with the surrounding hot water. In this part of the demonstration, the cold water had the higher density, so the warm water remained above the cold water.

- When dyed hot water enters cold water, students should have observed that the hot water rises toward the top of the cylindrical container, and that swirls (eddies) form on the edges of the rising plume of hot water. The hot water mixes much more quickly with the cold water, and cannot be seen after a few minutes. In this part of the demonstration, the cold water had the higher density, so the warm water rose through the cold water toward the surface.

- When hydrothermal vent fluid rises through cold ocean water, it forms eddies similar to those observed in the second part of the demonstration. These eddies bring cold seawater into the plume, and this process gradually increases the density of the plume. At some point, usually within a few hundred meters of the bottom, the density of the plume becomes equal to the density of the surrounding seawater. At this point the plume is neutrally buoyant, and stops rising. This is why hydrothermal vent plumes are typically found within a few hundred meters of the bottom, instead of rising all the way to the ocean surface. Over time, the plume will gradually mix with the surrounding seawater. Students' inferences may vary from this description if they do not consider that the ocean is much deeper than the cylindrical container used in the demonstration, and that eddies will bring seawater into the plume and change its density.

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 the properties of density and buoyancy could be personally important.

Connections to Other Subjects

English/Language Arts; Life Science; Social Studies (Geography)

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/okeanos/explorations/ex1104/welcome.html for the latest activities and discoveries by the Mid-Cayman Rise Expedition 2011.
2. Visit the education sections of Web sites provided in Step 1 for additional activities about hydrothermal vents.
3. Visit the *Okeanos Explorer* Digital Atlas (http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm) and 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 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

The *Okeanos Explorer* Atlas
(from the Galapagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_exatlas.pdf

Focus: Time, speed, distance, and velocity (Physical Science)

Students define velocity, and explain why this is a vector quantity; use the *Okeanos Explorer* Atlas to obtain information about position and movement of the NOAA Ship *Okeanos Explorer*, and calculate velocity from information about geographic position at two different times.

A Hydrothermal AdVENTure
(from the Galápagos Rift 2011 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/background/edu/media/ex1103_htadvent.pdf

Focus: Hydrothermal vents (Earth Science)

Students 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.

Earth's Ocean is 95% Unexplored: So What?
(from the INDEX-SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/so_what.pdf

Focus: Importance of deep ocean exploration (Life Science/Earth Science)

Students describe at least three different deep ocean ecosystems; explain at least three reasons for exploring Earth's deep ocean; and explain at least three ways that deep ocean ecosystems may benefit humans.

Let's Make a Tubeworm!
(from the INDEX-SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/tubeworm.pdf

Focus: Hydrothermal vent ecosystems (Life Science)

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

A Day in the Life of an Ocean Explorer
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_dayinlife.pdf

Focus: Telepresence and communications for ocean exploration (Physical Science)

Students identify the basic requirements for human communication; describe at least three ways in which humans communicate; discuss the importance of scientific communication; and explain the concept of telepresence, how it is implemented aboard the NOAA Ship *Okeanos Explorer*, and how it is used to increase the pace, efficiency, and scope of ocean exploration.

Wet Maps
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_wetmaps.pdf

Focus: Bathymetric mapping (Physical Science/Earth Science)

Students describe three types of bathymetric map, and discuss how each type may be used by ocean explorers; compare and contrast bathymetric mapping technologies; explain why multibeam mapping is used aboard the *Okeanos Explorer*; and simulate a multibeam sonar system to create a three-dimensional map of a model seafloor.

What's a CTD?
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_ctd.pdf

Focus: Measuring physical properties of seawater for ocean exploration (Physical Science)

Students define "CTD" and explain how this instrument is used aboard the *Okeanos Explorer*; define salinity and density; explain how relationships between temperature, salinity, and density in seawater are useful to ocean explorers; and use data from the *Okeanos Explorer* to create and interpret graphs of temperature, salinity, and depth.

Invent a Robot!
(from the *Okeanos Explorer Education Materials Collection, Volume 2: How Do We Explore?*)
http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/hdwe_56_inventrobot.pdf

Focus: Engineering Design (Physical Science/Technology)

Students discuss advantages and disadvantages of using underwater robots in scientific explorations, and how underwater robots are used aboard the *Okeanos Explorer*; use the process of engineering design to develop potential solutions for an ocean exploration problem; and explain the principle of hydraulic power transfer systems, and construct a robotic arm that demonstrates this principle.

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/ex1104/welcome.html – Web site for the Mid-Cayman Rise Expedition 2011 Expedition

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

http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm – Web site for the *Okeanos Explorer* Atlas, which provides a map-based link to information about current and previous ocean exploration expeditions conducted aboard the NOAA Ship *Okeanos Explorer*

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.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.

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 *Okeanos Explorer*

Correlations

Framework for K-12 Science Education

A. Scientific and Engineering Practices

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

B. Crosscutting Concepts

2. Cause and effect: Mechanism and explanation
4. Systems and system models
7. Stability and change

C. Disciplinary Core Ideas

Physical Sciences
- Core Idea PS1: Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- Core Idea PS2: Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
  - PS2.C: Stability and Instability in Physical Systems

Earth and Space Sciences
- Core Idea ESS2: Earth's Systems
  - ESS2.B: Plate Tectonics and Large-Scale System Interactions

Engineering, Technology, and the Applications of Science
- Core Idea ETS1: Engineering Design
  - ETS1.A: Defining and Delimiting an Engineering Problem
  - ETS1.B: Developing Possible Solutions
  - ETS1.C: Optimizing the Design Solution

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 a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

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

Essential Principle 5.

The ocean supports a great diversity of life and ecosystems.

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.

Common Core State Standards for Mathematics

Grade 5

Geometric measurement: understand concepts of volume and relate volume to multiplication and to addition.

Grade 6

Solve real-world and mathematical problems involving area, surface area, and volume.

Send Us Your Feedback

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

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Credit

To Sink, To Rise, or To Float
Buoyancy and Vents Guided Design Portfolio Sheet

Part A. Neutral Buoyancy Design Challenge –

1. Define the problem.

State the problem in your own words:

2. Gather relevant information.

List information that you think is needed to find solutions for the problem:

3. Brainstorm possible solutions.

Use words or sketches to describe some possible solutions:

4. Analyze possible solutions and select the most promising.

State which of the possible solutions is most promising and why:

5. Test the solution by building a prototype.

The test will be a contest described by your teacher.

6. Revise and improve the solution.

Based on the results of the contest, describe improvements that you might make to the selected solution:

7. Report the design process and results.

Summarize your conclusions:

To Sink, To Rise, or To Float

Buoyancy and Vents Guided Design Portfolio Sheet

Part B. Buoyancy of Hydrothermal Vent Plumes

1. Your teacher will show you a demonstration that models some features of hydrothermal vent fluid when it enters the cold water of the deep ocean. Record your observations below.

   (a) Dyed, Cold Water Entering Hot Water:

   (b) Dyed, Hot Water Entering Cold Water:

2. In Part (a) of the demonstration (Dyed, Cold Water Entering Hot Water), which fluid had the higher density?

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How does this explain your observations during Part (a) of the demonstration?

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3. In Part (b) of the demonstration (Dyed, Hot Water Entering Cold Water), which fluid had the higher density?

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How does this explain your observations during Part (b) of the demonstration?

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4. Use your answers to Question 3 to predict what happens to hydrothermal vent fluid when it enters the cold water of the deep ocean:

5. Does the density of hydrothermal vent fluid change when it enters the cold water of the deep ocean? Why or why not?

6. When ocean explorers look for new hydrothermal vent sites, they look for masses of seawater that have been changed by hydrothermal vent fluids. Masses of changed seawater are called plumes, and are usually found within a few hundred meters of the ocean floor. How does your answer to Question 5 explain the presence of hydrothermal vent plumes a few hundred meters above the ocean floor?