Lessons from the Deep:

Exploring the Gulf of Mexico's Deep-Sea Ecosystems

Education Materials Collection

Educators' Guide

What's Inside

Close-up view of one of the undescribed species of *Lamellibrachia* that scientists discovered during last year's cruise. Image courtesy of Expedition to the Deep Slope 2007 and Aquapix.

Introduction

Around 10:00 pm CDT on April 20, 2010, a gas explosion occurred on the mobile offshore drilling unit Deepwater Horizon about 40 miles southeast of the Louisiana coast. The explosion killed 11 workers, injured 17 others, ignited an intense fire that burned until the Deepwater Horizon sunk 36 hours later, and resulted in a massive release of crude oil that is now considered the greatest environmental disaster in U.S. history. The total volume of oil released into the Gulf of Mexico has not been determined, but exceeds 30 million gallons, dwarfing the 11-million gallon Exxon *Valdez* spill of 1989. Ecological impacts of the released oil have received extensive media attention, particularly those affecting beaches, marshes, birds, turtles, and marine mammals; but other, less visible, organisms may be affected as well. Many scientists are particularly concerned about the unusual and biologically-rich communities on the Gulf of Mexico seafloor.

Between 2001 and 2009, NOAA's Office of Exploration and Research (OER) sponsored eleven expeditions to study deep-sea organisms and ecosystems in the Gulf of Mexico (Table 1, Figure 1). Some of the sites studied are within a few miles of the Deepwater Horizon well. Each of these expeditions was documented with an extensive Web site that included lesson plans for educators at grade levels 5 through 12. OER's *Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection* includes a selection of these lesson plans together with new lessons and additional background information about the Deepwater Horizon blowout event. The purpose of this collection is to provide a foundation for student inquiries into deep-sea ecosystems, and to build capabilities for comparing data from OER expeditions with post-event information as the latter information becomes available. This *Educators' Guide* is accompanied by 16 lessons as described under "Initial Lessons in the Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection." Additional lessons and activity guides will be added to the *Collection* as more information is produced from ongoing research activities in the Gulf.

Table 1.
OER Expeditions to the Gulf of Mexico
(Colored dots next to Expedition titles correspond to colored dots on Figure 1.)

Islands in the Stream (May 11 - July 13, 2001) *
http://oceanexplorer.noaa.gov/explorations/islands01/islands01.html
(*No colored dot as sites visited by this Expedition are outside the area depicted in Figure 1.)

Chemosynthetic Life in the Gulf of Mexico (June 15–October 19, 2002)
http://oceanexplorer.noaa.gov/explorations/02mexico/welcome.html

Gulf of Mexico Deep-Sea Biology (February 9 - 16, 2003)
http://oceanexplorer.noaa.gov/explorations/03mexbio/welcome.html

Medicines from the Deep-Sea: Exploration of the Gulf of Mexico (September 8-19, 2003)
http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html

Gulf of Mexico Deep-Sea Habitats 2003 (September 21 - October 2, 2003)
http://oceanexplorer.noaa.gov/explorations/03mex/welcome.html

Operation Deep Scope: Seeing with "New Eyes" (August 7-17, 2004)
http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html

Operation Deep Scope 2005 (Aug 19 - Sept 4, 2005)
http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html

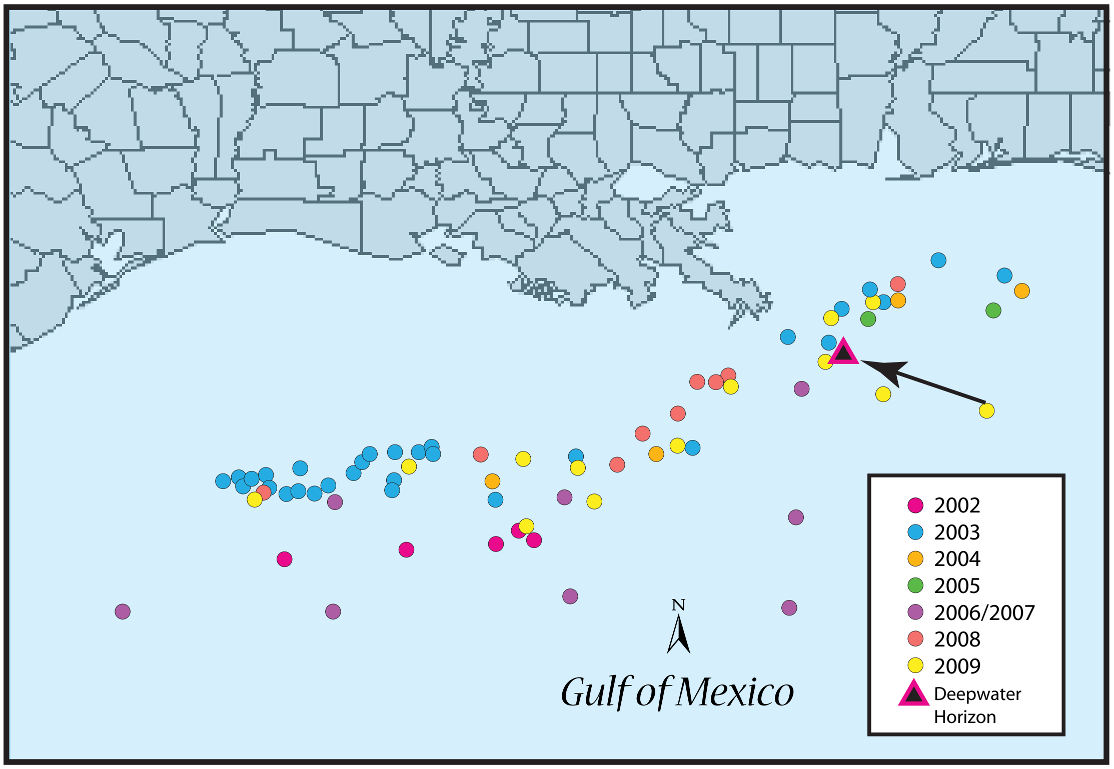
Expedition to the Deep Slope (May 7 - June 2, 2006)
http://oceanexplorer.noaa.gov/explorations/06mexico/welcome.html

Expedition to the Deep Slope 2007 (June 4 – July 6, 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html

***Lophelia* II 2008: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (September 20 - October 2, 2008)**
http://oceanexplorer.noaa.gov/explorations/explorations.html

***Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (August 19 - September 12, 2009)**
http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html

Figure 1.
Representative sites included in OER expeditions to the Gulf of Mexico (NOTE: The 2003 Medicines from the Deep-sea Expedition included additional sites in the eastern Gulf of Mexico not shown on this figure).



Background Information

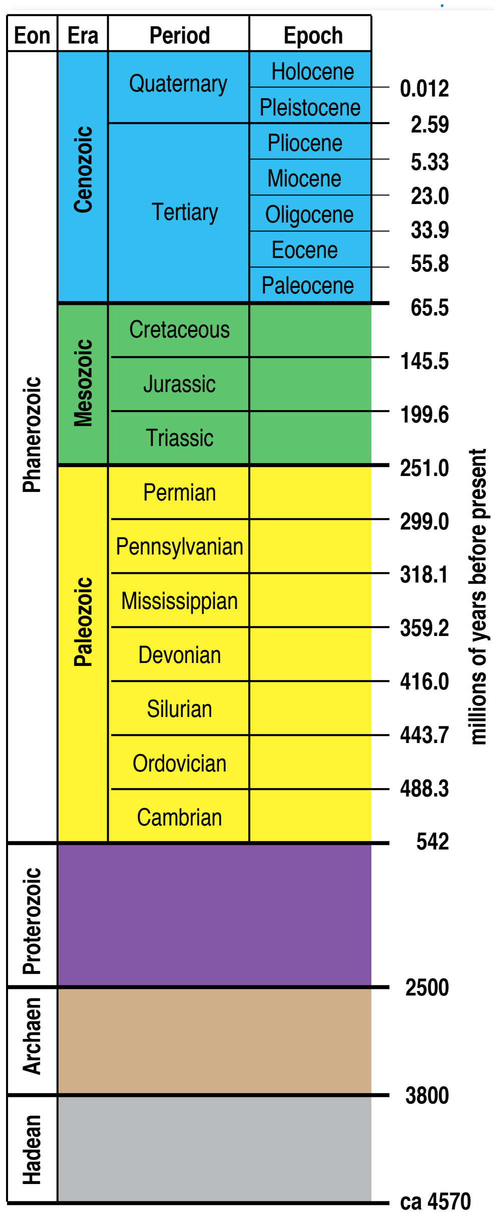
Geology

Petroleum (which literally means "rock oil") refers to many different substances including gases such as methane, propane, and butane; liquid oils; and semi-solid materials such as asphalt and tar. Hydrocarbons (compounds composed of hydrogen and carbon) usually are the major components of petroleum; but a variety of non-hydrocarbon compounds such as carbon dioxide, hydrogen sulfide, and helium may also be present.

In 2009, oil production from the Gulf of Mexico accounted for 30 percent of U.S. domestic production and 11 percent of natural gas production. Why are petroleum deposits so abundant in the Gulf of Mexico? A brief review of the geologic history of this region provides the answer.

During the early part of the Triassic Period (199 – 251 million years ago [MYA]), most of Earth's land mass was contained in the supercontinent Pangaea. During later Triassic time, Pangaea began to break up and the North American Plate began to drift away from the African and South American plates. Throughout the Jurassic Period (199 – 145 MYA) the space that we now know as the Gulf of Mexico continued to expand. At the same time, the space between the continents also expanded to become the basin of a new ocean–the Atlantic (for an animated illustration of the Pangaea breakup, see http://geomaps.wr.usgs.gov/parks/pltec/pangea.html). An alternative theory for the origin of the Gulf of Mexico was proposed in 2002 by geologist Michael Stanton, who suggested that a meteor struck this region at the end of the Permian Period (251 MYA), creating the Gulf of Mexico basin as well as causing the Permian–Triassic extinction event. (See Figure 2).

Figure 2: Geologic Time Scale



In middle Jurassic time, the Gulf of Mexico basin was only a rift between the North American and South American plates, and was not permanently connected to any ocean. Periodically, though, ocean water flowed into the rift and evaporated. This process resulted in the formation of extensive salt deposits in the basin (under Michael Stanton's hypothesis, the meteor crater was surrounded by a sill that isolated the impact basin from the open ocean and formed a large "evaporating pan" in which salt deposits formed). One of the largest salt deposits is the Louann Salt which extends along much of the northern Gulf coast, and also underlies large areas of the coastal plains of Mississippi, Louisiana and Texas. Other salt deposits include the Campeche Salt on the southern Gulf coast, and the Sigsbee Salt which underlies large areas of the Gulf basin. The evaporation processes that produced these salt deposits also created underwater lakes called brine pools (see http://oceanexplorer.noaa.gov/explorations/02mexico/background/brinepool/brinepool.html), as well as numerous salt domes which are important in the formation of petroleum deposits and are discussed below.

Although the Gulf of Mexico basin grew larger during the Jurassic Period, it was (and is) surrounded on roughly three-fourths of its perimeter by the land masses of North America, the Yucatan Peninsula, and Cuba. As a result, sediments flowing into the Gulf from these land masses tend to accumulate in the basin. As more sediment accumulates, increasing pressure is exerted on lower sediment layers. Over millions of years, this pressure converts sediments to rocks. Some familiar rocks formed by this process include sandstone (formed from small grains of quartz and feldspar; limestone (formed from calcite, coral skeletons, and shells of ocean animals); and shale (formed from clay).

This geographic and geologic history provides all of the key elements needed for petroleum deposits to form:

- organic material;
- "source rock" containing organic material;
- heat and pressure under which organic material is converted to petroleum;
- carrier beds through which petroleum can migrate;

• reservoir rock that contains petroleum; and
• a seal that traps the petroleum in reservoir rock.

Organic material from which petroleum is formed comes from the remains of once-living organisms. In the Gulf of Mexico, marine algal blooms provide a major source of organic material. When the algae die, they sink to the seafloor where they are buried beneath silt and clay sediments. Bacteria decompose the algal remains, releasing oxygen in the process. This concentrates the hydrogen and carbon molecules required to produce petroleum. At this stage, the solid organic material is called kerogen. As sediments accumulate, increasing heat and pressure cause the sediments to form rocks. Because these rocks contain kerogen, they are source rocks.

When the temperature of the source rocks increases to 100–150°C, kerogen is converted to oil. This usually occurs at depths of about 3 – 5 km. At greater depths and higher temperatures, gas is produced. The conversion of kerogen to petroleum is called maturation. Kerogen within source rocks is under pressure from overlying sediments. As kerogen is converted to petroleum, this pressure is transferred to the fluid petroleum and tends to drive petroleum out of the source rock. If source rocks are adjacent to other porous rocks, called carrier beds, petroleum fluids migrate into the carrier beds.

Carrier beds are porous and permeable rocks such as sandstone, limestone, or fractured rocks. Porous spaces in carrier beds contain water, which has a higher density than petroleum. In the Gulf of Mexico basin, petroleum migrates vertically over several kilometers through mudstones and faults. In some places, called oil and gas seeps, this migration brings petroleum to the seafloor where it enters waters of the Gulf. The National Research Council (2003) estimates that the amount of oil seeping into the entire Gulf of Mexico ranges from 80,000 to 200,000 tonnes per year (a tonne is equal to 1,000 kg or about 2,205 lb, and is approximately the mass of one cubic meter of water at 4°C). For comparison, the amount of oil released by the Deepwater Horizon blowout is estimated to have been about 4.9 million barrels or about 780,000 cubic meters of crude oil. Since the density of crude oil is about 80% to 90% the density of water, 780,000 cubic meters of crude oil is approximately 624,000 – 702,000 tonnes.

In other locations, carrier beds are overlain by other geologic structures that trap petroleum in the carrier rocks. When this happens, the carrier beds are called reservoir rocks. Note that carrier beds and reservoir rocks may be the same geologic rock type; the distinction is based upon whether petroleum can move through the rock or is trapped in place. Formation of a petroleum reservoir

Figure 3. An anticline trap.

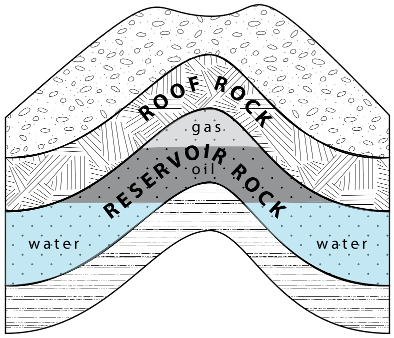


Figure 4. A fault trap.

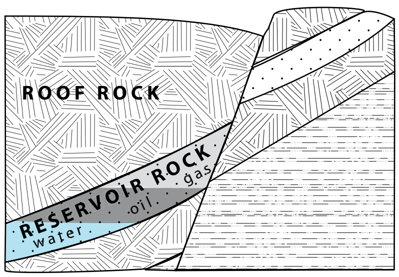
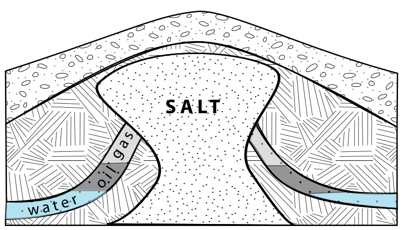


Figure 5. A salt dome.



requires that the rock containing petroleum is completely sealed. A variety of geologic formations may provide this seal. If a layer of fine-grained rocks that are not permeable to petroleum (such as shales) is bent into an arch and reservoir rocks are beneath this layer, oil in the reservoir rocks will be trapped in place. This is called an **anticline trap** (Figure 3). The impermeable rocks that create the seal are called roof rocks. Another type of trap, called a **fault trap** (Figure 4), is formed when rocks move along a fault line so that reservoir rocks are moved against a layer of impermeable rock. In some fault traps, the fault itself forms a barrier to oil flow.

Salt deposits can form a third type of trap. This may seem confusing, since the history of the Gulf of Mexico suggests that salt deposits were formed long before sediments accumulated. This might seem to suggest that salt deposits should be underneath reservoir rocks formed from sedimentary materials. High heat and pressure, however, can cause salt to behave strangely. Under these conditions, salt slowly flows upward, and can break through many layers of rock along the way. This upward flow produces structures called **salt domes** (Figure 5), and these structures are very effective petroleum traps. Many oil reservoirs in the Gulf of Mexico are associated with traps produced from salt deposits. **See Appendix 1 for some suggested activities about the basic geology of petroleum formation.**

Oil and the Deepwater Horizon Blowout

The Deepwater Horizon and its associated blowout site are located at 28°44.20' N latitude, 88°23.23' W longitude. This site is on a steep slope in an area known as Mississippi Canyon Block 252, where the continental shelf drops sharply to depths that exceed 2,000 m. The blowout site is about 1,500 m (5,000 ft) deep.

Oil spill responders classify oils based on properties of viscosity (how easily it flows), volatility (how quickly it evaporates), and toxicity (how poisonous it is to living organisms). Table 2 compares the four basic types of oil recognized by spill responders. In all of these categories, "oil" is a mixture of many different chemicals, and the exact composition can vary depending upon where the oil occurs. Oil released from the Deepwater Horizon blowout is classified as "light crude," but the released material is a mixture of pressurized oil and gas. As the more volatile components evaporate, oil becomes thicker and tar-like. As the oil moves through the water, turbulence breaks the oil mass into smaller particles that become tar balls. Oil and water may become mixed into thick emulsions called mousse. Small droplets of oil rise more slowly than larger oil masses, and very small droplets (less than about 100 μm in diameter), rise so slowly that they may remain in the water column for several months. **See Appendix 2 for simple demonstrations and activities about properties of oil in water.**

Table 2
Oil Type Categories and Properties

Oil Type	Viscosity	Volatility	Toxicity	Clean-up
Type 1 Very Light Oils (Jet Fuels, Gasoline)	low	high evaporates in 1-2 days	high concentrations of soluble toxics	not possible
Type 2 Light Oils (Diesel, Light Crudes)	low	moderate about one-third remains as residue	moderate concentrations of soluble toxics	can be very effective
Type 3 Medium Oils (Most Crude Oils)	moderate	moderate to low about two-thirds remains as residue habitat contamination	severe impacts to birds & mammals; severe, long-term	most effective if conducted quickly
Type 4 Heavy Oils (Heavy Crude Oils)	high	low; little or no evaporation long-term sediment contamination	severe impacts to birds & mammals;	difficult under all conditions

Source: NOAA Office of Response and Restoration

Oil masses may also be broken up by chemical dispersants. The idea is to disperse the oil into a much larger volume of water in hopes that dilution will reduce toxic effects, and to remove large masses of oil from the water surface where they are harmful to birds and other organisms. Preventing landfall of oil from the Deepwater Horizon blowout has been a major objective of response efforts. Initially, these efforts used mechanical recovery techniques (skimmer vessels and booms) and in situ burning. When poor weather conditions interfered with these techniques, dispersants (Corexit 9500A and Corexit 9527A) were applied to disperse surface oil. Beginning in early May, dispersants were also injected at the wellhead to reduce the amount of oil that reached the surface. As of June 14, more than 1,279,000 gallons of dispersant had been applied to oil from the blowout.

Natural and/or chemically-induced dispersal of oil into the water column poses potential risks to mid-water and bottom-dwelling animals. However, at the end of May a group of engineers, scientists, and spill responders concluded that "…up to this point, use of dispersants and the effects of dispersing oil into the water column has generally been less environmentally harmful than allowing the oil to migrate on the surface into the sensitive wetlands and near shore coastal habitats." (Coastal Response Research Center, 2010). This group also recommended that " …effects of using 2.5 MG [million gallons] of dispersants during the Ixtoc spill in 1979… should be considered as part of the evaluation of the DWH incident." The Ixtoc spill was the result of a blowout in Bahia de Campeche, 600 miles south of Texas, and released more than 130 million gallons of oil until it was finally capped after 290 days. Chemical dispersant were used to treat 1,100 square miles of sea surface, but were not used in U.S. waters because they would not have been very effective due to the viscosity of the oil. As a result of natural and chemical dispersal, over 3,200,000 gallons of oil sank to the bottom of the Gulf (Jernelov and Linden, 1981). Early investigations of the Deepwater Horizon blowout found indications of possible deepwater (700 – 1300 m) plumes, which have since been confirmed (see "Notes About Scientific Investigations," below).

Studies of the impacts of the Ixtoc spill are limited. One of these reports that the most persistent issues are pollution of estuaries and coastal lagoons, as well as effects on breeding and growth of several food fish species. John Tunnell has studied environmental impacts of the Ixtoc spill for many years (see http://www.harteresearchinstitute.org/ixtoc-i-references/142-ixtoc-i-references for references and links to pdfs). His investigations included portions of the south Texas coast, which was coated by a 20- to 30-foot wide band of oil and tar that extended about 30 miles. Severe impacts were found among populations of marine worms and amphipods, which were reduced on average by 80 percent in the inter-tidal zone and 50 percent in the sub-tidal zone. Follow-up studies two and half years later indicated that worm and amphipod numbers had rebounded (reported by Berger and Godoy, 2010).

Jackson, *et al.* (1989) reported on a 2,100,000 gallon spill of light crude oil that impacted mangrove, coral, and seagrass ecosystems on the coast of Panama. Extensive mortality was observed among intertidal mangroves, seagrasses, algae, and associated invertebrates. In addition, subtidal coral reefs and seagrass ecosystems were severely impacted.

Scientists who have studied deep-sea ecosystems in the Gulf of Mexico are concerned about the potential impacts of dispersed oil on these ecosystems. In a series of fact sheets titled "Dispersants: A Guided Tour," NOAA's Office of Response and Restoration states that "Because coral reefs can be harmed by dispersed oil, dispersant use in the vicinity of coral reefs is usually restricted to areas where dispersed oil is unlikely to contact coral. These are areas far from the reefs, or located where currents would carry the dispersed oil away from the coral."

As discussed below, deepwater corals are a conspicuous feature of deep-sea ecosystems in the Gulf of Mexico. These ecosystems are often found in close proximity to hydrocarbon seeps, so it might be supposed that deepwater corals might have some tolerance for small droplets of oil from the Deepwater Horizon blowout. When these droplets are mixed with chemical dispersants, however, the situation may be different. Shafir, Van Rijn, and Rinkevich (2007) exposed several species of corals to various combinations of chemical dispersants and crude oil. At concentrations recommended by the manufacturer, dispersants were highly toxic and resulted in mortality among all corals tested. In addition, the combination of dispersed oil and dispersants was significantly more toxic than water soluble fractions of crude oil alone. The authors conclude that, "As corals are particularly susceptible to oil detergents and dispersed oil, the results of these assays rule out the use of any oil dispersant in coral reefs and in their vicinity."


These small oil droplets have seeped through the sediment and adhered to the top of methane hydrate. Image courtesy of Ian MacDonald, Texas A&M-Corpus Christi.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may08/media/oil_on_methane_600.html

Deepwater Ecosystems in the Gulf of Mexico

Deepwater ecosystems in the Gulf of Mexico are often associated with rocky substrates or "hardgrounds." Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems may indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose importance is presently unknown.


This group of very old tubeworms (*Lamellibrachia luymesi* and *Seepiophila jonesi*) live on the same piece of carbonate rock as large colonies of the gorgonian *Callogorgia Americana*. Note the brittle stars and a galatheid crab crawling on the gorgonians. Image courtesy Derk Bergquist.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/signature_600.html

Chemosynthetic Communities – The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the Earth's tectonic plates. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food web. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:

$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$
(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water).

A close-up of the mussel *Bathymodiolus brooksi*, with one of the common species found in tubeworm and mussel habitats — the shrimp *Alvinocaris muricola*. Image courtesy of AquaPix, Chuck Fisher, Expedition to the Deep Slope 2006.
http://oceanexplorer.noaa.gov/explorations/07mexico/background/conservation/media/mussels_600.html

These methane mussels (*Bathymodiolus childressi*) live at the edge of Brine Pool NR1 at 650 m depth in the Gulf of Mexico. The pool of brine in the foreground is nearly four times as salty as seawater and is so dense that the submarine can float on the pool to take pictures such as this. Image courtesy Stephane Hourdez.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/mussels_600.html

Iceworms (*Hesiocaeca methanicola*) infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene Epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image courtesy Ian MacDonald.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg

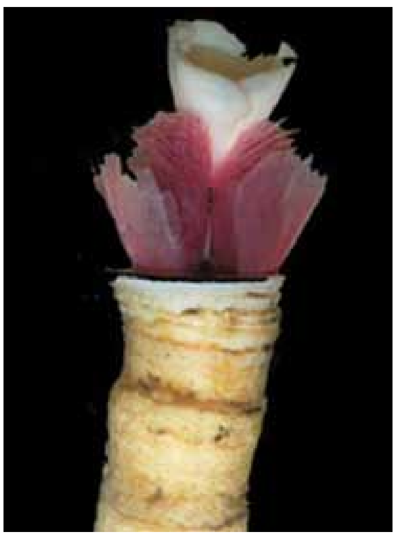
Visit http://www.pmel.noaa.gov/vents/ for more information and activities on hydrothermal vent communities.

Chemosynthetic communities in the Gulf of Mexico were found by accident in 1984. These communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for the Galapagos communities is derived from underwater hot springs, deep-sea chemosynthetic communities in the Gulf of Mexico are found in areas where gases (such as methane and hydrogen sulfide) and oil seep out of sediments. These areas, known as cold seeps, are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as the methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. These deposits are significant for several reasons:

- The U. S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined.
- Methane hydrates can decompose to release large amounts of methane which is a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate.
- Sudden release of pressurized methane gas may cause submarine landslides which in turn can trigger catastrophic tsunamis.
- Methane hydrates are associated with unusual and possibly unique biological communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

A close-up of the undescribed *Lamellibrachia* sp. Several *Alvinocaris muricola* shrimp are also in view. Image by Ian MacDonald, Texas A&M-Corpus Christi.



A close-up of the plume of the undescribed *Lamellibrachia* sp., collected during the cruise. The plume consists of the gills and the obturaculum. This specimen will be used to write the formal species description. Image courtesy of Expedition to the Deep Slope.
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may13/media/plume_486.html

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html

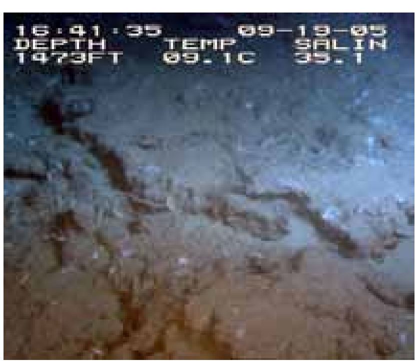
Where hydrogen sulfide is present, large tubeworms known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. At present, vestimentiferans are generally considered to be part of the phylum Annelida, but they are sometimes grouped as a separate phylum (Pogonophora). These unusual animals do not have a mouth, 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 which are transported to the 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, starfish, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

Deepwater chemosynthetic communities 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. Organisms from hydrothermal vent communities have proven to be useful in a variety of ways, including treatment of bone injuries and cardiovascular disease, copying DNA for scientific studies and crime scene investigations, and making sweeteners for food additives. Because their potential importance is not yet known, it is critical to protect deepwater chemosynthetic ecosystems from adverse impacts caused by human activities.

Deepwater Coral Reefs — Deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, but very little is known about the ecology of these communities or the basic biology of the corals that produce them. These corals are usually found on hard-bottom areas where there are strong currents and little suspended sediment (but extremely strong currents may interfere with feeding and cause breakage). *Lophelia pertusa*, the best-known deepwater coral species, prefers water temperatures between 4-12 °C, dissolved oxygen concentrations above 3 ml/l, and salinity between 35 and 37

An unidentified large white anemone densely populates thinly-sedimented goethite (iron oxide) slab rock, the fundamental Viosca Knoll substrate for attachment of sessile particulate-feeding invertebrates. Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/ANEMONES.jpg

Viosca Knoll is an elevated salt dome with dormant and active chemo-seeps. Where hydrocarbons are actively escaping from the substrate, dense clusters of tightly entwined vestimentiferan tubeworms grow. As the submersible approaches, it disturbs a blackbelly rosefish (*Helicolenus dactylopterus*), and a conger eel (*Conger oceanicus*). Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_TUBEWORM_BUSH.jpg



Areas of active, if subdued, hydrocarbon seeps are notably devoid of large sessile invertebrates. A fluffy gray biofilm coats the underlying rock, dotted with small white patches of the chemo-seep-associated bacteria *Beggatoia*. Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_SEEP_BIOTOPE.jpg

ppt. The influence of other factors, including pH, is not known. Recent studies suggest that deepwater reef ecosystems may have a diversity of species comparable to that of coral reefs in shallow waters, and have found deepwater coral species on continental margins worldwide. One of the most conspicuous differences between shallow- and deepwater corals is that most shallow-water species have symbiotic algae (zooxanthellae) living inside the coral tissue, and these algae play an important part in reef-building and biological productivity. Deepwater corals do not contain symbiotic algae (so these corals are termed "azooxanthellate"). Yet, there are just as many species of deepwater corals (slightly more, in fact) as there are species of shallow-water corals. Sulak (2008) provides extensive information on deepwater hard-bottom coral communities at Viosca Knoll in the Northern Gulf of Mexico, including illustrations of fishes, benthic invertebrates, and typical biotopes associated with these communities.

The major deepwater structure-building corals belong to the genus *Lophelia*, but other organisms contribute to the framework as well, including antipatharians (black corals), gorgonians (sea fans and sea whips), alcyonaceans (soft corals), anemones, and sponges. While these organisms are capable of building substantial reefs, they are also quite fragile, and there is increasing concern that deepwater reefs and their associated resources may be in serious danger. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels. These impacts are especially likely in the Gulf of Mexico, since the carbonate foundation for many deepwater reefs is strongly associated with the presence of hydrocarbons. Potential impacts include directly toxic effects of hydrocarbons on reef organisms, as well as effects from particulate materials produced by drilling operations. Since many deepwater reef organisms are filter feeders, increased particulates could clog their filter apparatus and possibly smother bottom-dwelling organisms.

Why are deepwater coral reefs in the Gulf of Mexico so often associated with hydrocarbon seeps? One reason is that the carbonate rock resulting from microbes feeding on hydrocarbons provides a substrate where larvae of many other bottom-dwelling organisms may attach, particularly larvae of corals. It has also been suggested that microorganisms that feed on hydrocarbons could also provide a food source for corals, many of which obtain their nutrition through filter-feeding. Recent research, however, has shown that the skeletons of corals from seep communities do not have a chemical composition that supports this hypothesis (Becker, *et al.*, 2009).

Notes About Scientific Investigations

In the weeks following the explosion, scientific investigations concerned with the Deepwater Horizon focused primarily on documenting the location, extent, and movement of released oil. Using specialized computer models that integrate information on currents and winds, NOAA oceanographers produced daily Oil Trajectory Maps that showed the predicted movement of spilled oil on the water surface. These predictions also incorporated satellite imagery analysis and observations from trained observers who made helicopter overflights across potentially affected areas (for more information, see http://response.restoration.noaa.gov/book_shelf/1926_TrajectoryFieldGuide.pdf).

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010. http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html

Investigations below the surface rely heavily on a standard instrument for oceanographic studies known as a CTD. CTD stands for conductivity, temperature, and depth, and refers to a package of electronic instruments that measure these properties. 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 sensors that can measure additional physical or chemical properties.

One such property that is particularly important to Deepwater Horizon investigations is colored dissolved organic matter (CDOM), typically measured with a sensor called a CDOM fluorometer. CDOM absorbs light, typically in the blue to ultraviolet range, which makes water appear greenish to yellow-green to brown (the color changes with increasing CDOM concentration). Oil is a type of CDOM. In addition to the CDOM fluorometer, CTD packages used for studying the Deepwater Horizon blowout often include sensors for measuring suspended particles and dissolved oxygen.

In early May, scientists working about 5 nautical miles from the blowout site discovered several layers in the water column which showed strong fluorescence (an indication of oil or another substance with similar fluorescent properties), depleted dissolved oxygen, and reduced water clarity (an indication of increased concentration of suspended particles). These layers ranged from depths of 700 m to over 1300 m. Additional CTD casts at sites 2.5 nm and 1.25 nm from the well showed that all three signals (fluorescence, oxygen depletion, and decreased water clarity) increased as the sample sites approached the well. The strongest signals appeared to be southwest of the wellhead.

Similar results were subsequently obtained by other investigations (e.g., www.epa.gov/bpspill/dispersants/bp-may23-lisst.pdf; http://www.noaanews.noaa.gov/stories2010/20100620_jefferson.html). A working hypothesis to explain these observations is that bacteria were degrading deepwater oil suspensions, and consumed enough oxygen in the process to cause measurable depletions in the surrounding water. Note that the amount of oxygen depletion was not large enough to pose a serious threat to living organisms. Decreased water clarity may be due to concentrations of bacteria or some particulate matter suspended with or by the oil. Additional information to support or refute this hypothesis may come from analysis of water samples collected at the same sites with CTD rosettes.

Survey Technician Frankie Daniel retrieves the Moving Vessel Profiler. Image courtesy NOAA.
http://www.noaa.gov/features/04_resources/images/tj6.jpg

In early June, the NOAA Ship *Thomas Jefferson* completed an eight-day research mission to investigate the presence and distribution of subsurface oil and to test the feasibility of using acoustic and flourometric scanning to help find potential pockets of subsurface oil clouds. This mission included the use of a Moving Vessel Profiler (MVP), which allows data to be collected throughout the water column while the vessel is underway. The MVP system includes a computer-controlled smart winch and an instrument package called a free fall fish. Sensors that have been used in the free fall fish include sound velocity, CTD, laser optical plankton counter, and fluorometer. The largest MVP is capable of deploying a free fall fish to a depth of 800 meters at a ship speed of 12 knots (for more information see http://www.brooke-ocean.com/mvp_main.html; mention of proprietary names does not imply endorsement by NOAA). The MVP used aboard the *Thomas Jefferson* was used to collect flourometric data from the surface down to about 100 meters deep with the free fall fish moving from the surface to the bottom and back to the surface approximately every 1.5 miles. This method proved to be an effective way to detect water masses with high fluorometry in the coastal zone.

Another innovative technology providing important information about impacts from the Deepwater Horizon blowout is a group of underwater robots called gliders. These are autonomous underwater vehicles (AUVs), which means that they operate independently without any physical connection to their operators. Gliders are capable of operating on their own for long periods of time (over five months in some cases), and carry sensors that record depth, conductivity, temperature, dissolved oxygen, and fluorescence. For more information about gliders and how they are being used in the Gulf of Mexico, see http://rucool.marine.rutgers.edu/deepwater and http://iop.apl.washington.edu/seaglider/about.html.

As oceanographic investigations continue, biologists who have studied the Gulf of Mexico's deep-sea ecosystems are concerned about how these systems will be affected by the Deepwater Horizon blowout [see, for example (Broad, 2010) and Musgrove and Koenig (2010)]. Potential impacts range from oil-clogged respiratory structures to depleted oxygen levels caused by bacteria metabolizing dispersed oil. As noted above, potential impacts from combinations of crude oil and dispersant chemicals are a particular concern for deepwater corals. Data collected during Ocean Explorer expeditions to the Gulf of Mexico between 2002 and 2009 will provide an important baseline when scientists return to these sites.

Overview of OE Expeditions to the Gulf of Mexico

From 2001 to 2009, NOAA's OER sponsored 11 expeditions to study deep-sea organisms and ecosystems in the Gulf of Mexico (Table 1 and Figure 1). This section provides a link to each of these expeditions on the Ocean Explorer Web site and a brief overview of each expedition.

Islands in the Stream (May 11 - July 13, 2001)

http://oceanexplorer.noaa.gov/explorations/islands01/islands01.html

Scientists explored coral reef and hard-bottom communities throughout the Gulf of Mexico. Following the Yucatan current from Belize to Mexico to the northern Gulf of Mexico and then south to the Dry Tortugas, scientists discovered and documented links between the physical and biological components of these deepwater reef systems.

Gulf of Mexico Deep-Sea Biology (February 9 - 16, 2003)

http://oceanexplorer.noaa.gov/explorations/03mexbio/welcome.html

A student team studied the reproductive biology and biochemistry of cold-seep mussels and various other seasonally reproducing deep-sea animals.

Chemosynthetic Life in the Gulf of Mexico (June 15–October 19, 2002)

http://oceanexplorer.noaa.gov/explorations/02mexico/welcome.html

Explorers used Harbor Branch Oceanographic Institution's Johnson Sea-Link submersible to explore and study communities around deep-sea oil seeps in the Gulf of Mexico; collected animals, sediments, microbial mats, samples from brine pools, and methane hydrates; and studied reproduction and embryology of seep animals.

Medicines from the Deep-Sea: Exploration of the Gulf of Mexico (September 8-19, 2003)

http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html

Using an industrial ROV aboard the NOAA Ship *Ronald H. Brown*, the expedition explored Gulf of Mexico deepwater habitats in search of organisms with potential as sources of pharmaceutical products or biomedical research tools.

Gulf of Mexico Deep-sea Habitats 2003 (September 21 - October 2, 2003)

http://oceanexplorer.noaa.gov/explorations/03mex/welcome.html

Explorers used an industrial ROV aboard the NOAA Ship *Ronald H. Brown* to explore deep-sea coral habitats in the Northern Gulf of Mexico.

Operation Deep Scope: Seeing with "New Eyes" (August 7-17, 2004)

http://oceanexplorer.noaa.gov/explorations/04deepscope/welcome.html

Innovative, one-of-a-kind equipment was used to see deep-sea animals under extremely dim light, without disturbing them; discoveries include giant predators such as six-gill sharks, a deep-sea squid, fluorescent animals, and flashing corals.

Operation Deep Scope 2005 (August 19 - September 4, 2005)

http://oceanexplorer.noaa.gov/explorations/05deepscope/welcome.html

With new instruments, explorers used color, fluorescence, polarization, and bioluminescence to explore the nature of light and life in the ocean.

Expedition to the Deep Slope (May 7 - June 2, 2006)

http://oceanexplorer.noaa.gov/explorations/06mexico/welcome.html

This was the first systematic exploration of hydrocarbon-seep communities deeper than 1,000 m in the Gulf of Mexico.

Expedition to the Deep Slope 2007 (June 4 – July 6, 2007)

http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html

This expedition continued the exploration and study of deep hydrocarbon seep communities in the Gulf of Mexico.

***Lophelia* II 2008: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (September 20 - October 2, 2008)**

http://oceanexplorer.noaa.gov/explorations/explorations.html

Explorers used a combination of remote sensing, quantitative community collections, and genetic analyses to investigate cold water corals and the communities associated with them.

Lophelia II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks (August 19 - September 12, 2009)

http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html

This expedition continued the search for new deep coral communities in the Gulf of Mexico, and examined coral communities associated with shipwrecks.

Suggested Learning Procedures For Lessons

Lessons included in this collection touch on a wide variety of topics related to physical science, life science, and Earth science, and offer many opportunities for cross-curricular activities involving social studies, language arts, mathematics, and fine arts. In addition to formal lesson plans, Web pages for most OER expeditions include a variety of background essays as well as photo and video collections. These materials may be used in a variety of ways to enhance class discussions and student research. Initial lessons included in this collection are described beginning on Page 19, followed by lists of "Key Background Essays" and "Video and Photo Resources." Optional additions to lesson plan activities are listed as "Extensions" on Page 27, followed by a listing of "Other Relevant Lessons" lessons that connect to additional topics found in many curricula.

The following suggestions represent one approach that uses these materials to guide students' inquiries into deep-sea ecosystems in the Gulf of Mexico, and how these systems may be affected by the Deepwater Horizon blowout. Educators are encouraged to adapt these materials as needed to suit specific student needs and curriculum requirements.

1. Review focus topics for lessons (described below) to select those that are appropriate to desired class content or curriculum objectives. Note that grade levels are provided as a general guide to the level of difficulty, but many lessons can be adapted to grades higher or lower than those indicated. Also note that these lessons are "stand alone," and do not have to be presented in any specific combination or sequence.

2. Review selected lessons, as well as Key Background Essays appropriate to these lessons. This is a good time to select video and photographic resources if you want to use these during class discussions. Decide on the overall structure of students' inquiries: whether they will be done entirely during class time, whether they will involve independent research outside of class, whether there will be optional or required longer-term projects or by some other means.

3. During the first class session devoted to these inquiries, lead a discussion that includes the following aspects of the Deepwater Horizon blowout:
   - Recent estimates of the total volume of oil released, how much oil has been recovered, how much has contaminated coastal areas;
   - What strategies and techniques have been used to capture released oil or clean-up contaminated areas;
   - Pros and cons of using dispersants;
   - Impacts of spilled oil (this list will probably be long, and should include economic impacts, health impacts, and impacts on natural ecosystems); and
   - Ecosystems that have been affected by spilled oil.

   If the latter list does not include deep-sea coral reefs and chemosynthetic communities, briefly introduce these and ask whether students think they might have been affected by spilled oil. The key point here is that although oil rises in water, natural and chemically-induced dispersion can slow the rate of ascent and may form mixtures with other substances that keep the oil near or on the bottom.

4. Present the lessons selected in Step 1. Table 2 illustrates one way that materials in this collection could be used in grades 5–6 to include lessons on the biology of Gulf of Mexico deep-sea ecosystems, the importance of these ecosystems to humans, and some of the technology being used to investigate impacts of the Deepwater Horizon blowout on these systems.

Table 2. Sample Unit Using Materials from the Lessons from the Deep Collection

Lesson 1: Entering the Twilight Zone (Deep-sea habitats; Life Science)

Key Background Essays: Geological Setting; Chemosynthetic Communities in the Gulf of Mexico

Video Resources: Videos showing some of the extraordinary biological diversity of the Gulf of Mexico and of deepwater corals and coral communities; slideshow of highlights from Expedition to the Deep Slope 2006

Lesson 2: Keep Away (Effects of pollution on diversity in benthic communities; Life Science)

Key Background Essays: Currents in a Cul-de-Sac; Conservation in the Deep-Sea

Video Resources: Videos of oozing tar and natural asphalt

Lesson 3: What's In That Cake? (Exploration of deep-sea habitats; Earth Science/Physical Science)

Key Background Essay: The Ecology of Gulf of Mexico Deep-Sea Hardground Communities

Video Resources: Videos of ROVs used to sample deepwater habitats in the Northern Gulf of Mexico, and devices used to sample organisms from seafloor communities

Lesson 4: Chemists with No Backbones (Importance of deep-sea ecosystems; Life Science)

Key Background Essays: Medicines from the Deep-Sea: Discoveries to Date; What is a Natural Product?

Video Resources: Slideshow of sponges and octocorals collected during the Deep-sea Medicines 2003 Expedition

Initial Lessons in the Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection

Methane Hydrates

What's the Big Deal? (Grades 9-12)

Focus - Significance of methane hydrates (Life Science)

Students define methane hydrates, describe where these substances are typically found, and describe how they are believed to be formed. Students also describe at least three ways in which methane hydrates could have a direct impact on their own lives, and describe how additional knowledge of methane hydrates expected from the Blake Ridge Expedition could provide human benefits.

Deep-Sea Ecosystems

Entering the Twilight Zone (Grades 5-6)

Focus - Deep-sea habitats (Life Science)

Students describe major features of cold seep communities, and list at least five organisms typical of these communities and will infer probable trophic relationships within and between major deep-sea habitats. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major deep-sea habitats, and list at least three organisms typical of each habitat.

Life is Weird (Grades 7-8)

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

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

Cool Corals (Grades 7-8)

Focus - Biology and ecology of *Lophelia* corals (Life Science)

Students describe the basic morphology of Lophelia *corals and explain the significance of these organisms, interpret preliminary observations on the behavior of* Lophelia *polyps, and infer possible explanations for these observations. Students also discuss why biological communities associated with* Lophelia *corals are the focus of major worldwide conservation efforts.*

Chemosynthesis for the Classroom (Grades 9-12)

Focus - Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

Students observe the development of chemosynthetic bacterial communities, and recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students also explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

A Tale of Deep Corals (Grades 9-12)

Focus - Deep-sea corals and hydrocarbon seeps (Life Science/ Earth Science)

Students analyze data on deep-sea corals and evaluate hypotheses to explain why these corals are often found in the vicinity of hydrocarbon seeps.

Importance of Deep-Sea Ecosystems

Chemists with No Backbones (Grades 5-6)

Focus - Benthic invertebrates that produce pharmacologically-active substances (Life Science)

Students identify at least three groups of benthic invertebrates that are known to produce pharmacologically-active compounds and describe why pharmacologically-active compounds derived from benthic invertebrates may be important in treating human diseases. Students also infer why sessile marine invertebrates appear to be promising sources of new drugs.

What Killed the Seeds? (Grades 7-8)

Focus - Bioassays (Life Science)

Students explain and carry out a simple process for studying the biological effects of chemicals, and infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

How Diverse is That? (Grades 9-12)

Focus - Quantifying biological diversity (Life Science)

Students discuss the meaning of biological diversity, and compare and contrast the concepts of variety and relative abundance as they relate to biological diversity. Given abundance and distribution data of species in two communities, students calculate an appropriate numeric indicator that describes the biological diversity of these communities.

The Benthic Drugstore (Grades 9-12)

Focus - Pharmacologically-active chemicals derived from marine invertebrates (Life Science)

Students identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Biological Oceanographic Investigations

Call to Arms (Grades 5-6)

Focus - Robotic analogues for human structures (Physical Science)

Students describe the types of motion found in the human arm, and describe four common robotic arm designs that mimic some or all of these functions.

Keep Away (Grades 5-6)

Focus - Effects of pollution on diversity in benthic communities (Life Science)

Students discuss the meaning of "biological diversity" and compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity. Given information on the number of individuals, number of species, and biological diversity at a series of sites, students make inferences about the possible effects of oil drilling operations on benthic communities.

What's In That Cake? (Grades 5-6)

Focus - Exploration of deep-sea habitats (Earth Science/ Physical Science)

Students explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of the Gulf of Mexico. Students also describe and discuss at least three difficulties involved in studying deep-sea habitats, and describe and explain at least three techniques scientists use to sample habitats such as those found in the Gulf of Mexico.

I, Robot, Can Do That! (Grades 7-8)

Focus - Underwater robotic vehicles for scientific exploration (Physical Science)

Students 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.

Through Robot Eyes (Grades 9-12)

Focus - Imagery of deep-sea organisms and habitats (Physical Science)

Students describe typical applications and limitations of imagery obtained with remotely operated vehicles (ROVs), and use ROV imagery to make inferences about deep ocean habitats in the Gulf of Mexico.

Signals from the Deep (Grades 9-12)

Focus - Technology for detecting oil in the deep-sea: CTD (Physical Science)

Students describe oceanographic parameters that can be used to detect submerged oil; explain how oceanographers can use CTD data to measure these parameters; and analyze data from CTD casts in the Gulf of Mexico for signals that may indicate the presence of submerged oil.

Key Background Essays

Geological Setting

http://oceanexplorer.noaa.gov/explorations/02mexico/background/geology/geology.html

Bob Carney (Louisiana State University)

Chemosynthetic communities in the Gulf of Mexico are found where sulfide and/or methane are seeping from the deep-sea floor. Neither of these energy-rich compounds normally is abundant in the deep ocean, so their presence requires special geological processes.

Currents in a Cul-de-Sac

http://oceanexplorer.noaa.gov/explorations/02mexico/background/currents/currents.html

Bob Carney (Louisiana State University)

Ocean life in the Gulf of Mexico may be controlled to some extent by unusual current patterns that resemble a cul-de-sac.

Lakes Within Oceans

http://oceanexplorer.noaa.gov/explorations/02mexico/background/brinepool/brinepool.html

Bob Carney (Louisiana State University)

Brine pools are small lakes on the seafloor that exist inside of the ocean because their very salty water is denser than the surrounding water. They have a distinct surface and shoreline and may be as small as 1m across and up to 20km long. These lakes are created by a process called salt tectonics, which refers to the movement of large salt deposits.

Chemosynthetic Communities in the Gulf of Mexico

http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html

Erik Cordes (Penn State University)

Scientists once thought the sea bed in the Gulf of Mexico was nothing but mud. Suddenly, they found dense groups of organisms living on the bottom of the Gulf.

Cold-seep Tubeworms

http://oceanexplorer.noaa.gov/explorations/02mexico/background/tubeworms/tubeworms.html

Stephane Hourdez and Chuck Fisher (Penn State University)

Cold-seep tubeworms are big worms (sometimes as big as 10 feet long) that are found only in places called cold seeps. They have no digestive system at all; so how do they obtain food and oxygen?

Medicines from the Deep-Sea: Discoveries to Date

http://oceanexplorer.noaa.gov/explorations/03bio/background/medicines/medicines.html

Amy E. Wright (Harbor Branch Oceanographic Institution)

The discovery of novel chemical compounds from deep-sea marine organisms often takes explorers to new and exciting locations that include the Caribbean Azores, Canary Islands, Cape Verde, Galapagos Islands, Samoa, Papua New Guinea, Australia, the Seychelles and Thailand. Target organisms are often associated with hard-bottom habitats and include sponges, octocorals, bryozoans, tunicates, and algae.

What is a Natural Product?

http://oceanexplorer.noaa.gov/explorations/03bio/background/products/products.html

Amy E. Wright (Harbor Branch Oceanographic Institution)

Compounds synthesized by a plant, microorganism or animal that are known as "natural products," are of great interest to chemists. It takes a lot of energy to produce a natural product, so, why do the organisms bother?

The Wonderful World of Seaweeds

http://oceanexplorer.noaa.gov/explorations/03mex/background/seaweeds/seaweeds.html

Suzanne Fredericq (University of Louisiana at Lafayette)

Did you know that more than 70 percent of all foodstuffs you buy in the supermarket contains algal products (including ice cream, canned foods, toothpaste, cookies and beer)?

Connecting the Dots

http://oceanexplorer.noaa.gov/explorations/03mex/background/connectivity/connectivity.html

Emma Hickerson and Shelley DuPuy (Flower Garden Banks National Marine Sanctuary)

The northwestern Gulf of Mexico is scattered with underwater hills or mountains that form a system of islands that support higher biological productivity than the surrounding ocean floor, and are connected to each other by the currents flowing through the Gulf of Mexico.

Diversity of Deep-Sea Corals

http://oceanexplorer.noaa.gov/explorations/03mex/background/coral_diversity/coral_diversity.html

Peter Etnoyer (Marine Conservation Biology Institute)

Biodiversity recognizes and appreciates all the species in a healthy ecosystem, the niches they fill, and the habitat functions they perform. Deep-sea corals are an important part of deep-sea ecosystems because their branches provide refuge to associated species, including fish, crabs, shrimp, and basket stars.

Educated Guesses

http://oceanexplorer.noaa.gov/explorations/03mex/background/coral_distribution_abundance/distribution_abundance.html

Julie Olson (University of Alabama)

Educated guesses are often the foundation of many preliminary studies, and many of the major achievements of science have resulted from a "hunch" or educated guess by a scientist.

Geology: Deep Scope Sites in the Gulf of Mexico

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/geology/geology.html

Tammy Frank (Harbor Branch Oceanographic Institution)

Generally, the deep-sea floor contains many different species, but low numbers of each individual species. There are regions, however, that are highly productive; and in these regions, species abundances are quite high.

Underwater Imaging

http://oceanexplorer.noaa.gov/explorations/05deepscope/background/underwater/underwater_imaging.html

Sönke Johnsen (Duke University)

The world does not look the same to everyone. If we do not take this into account, we cannot really understand the lives of other animals. One of our goals is to see the ocean world as its inhabitants do, concentrating on two situations far from our own experience: 1) vision in the deep-sea and 2) ultraviolet vision.

A Complex Geologic Framework Prone to Fluid and Gas Leakage: Northern Gulf of Mexico Continental Slope

http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/geology.html

Harry H. Roberts (Louisiana State University)

The continental slope of the northern Gulf of Mexico is arguably the most geologically complex shelf-to-deep-basin transition in today's oceans because of the dynamic interplay between vast quantities of river-transported sediment deposited over thick layers of salt formed during the early stages of the Gulf's evolution.

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities

http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html

Erik E. Cordes (Harvard University)

Rocky substrates, or hardgrounds, in the Gulf of Mexico are usually found in association with cold seeps because most of the hardgrounds are a by-product of the breakdown of oil and gas by microbes.

Microbiology

http://oceanexplorer.noaa.gov/explorations/06mexico/background/microbiology/microbiology.html

Mandy Joye (University of Georgia)

Microorganisms account for about half of the carbon in organic biomass on the Earth, yet, their diversity and functional role in many habitats are still poorly understood; particularly in deep-ocean cold seeps.

Conservation in the Deep-Sea

http://oceanexplorer.noaa.gov/explorations/07mexico/background/conservation/conservation.html

Erik E. Cordes (Harvard University)

Deepwater communities in the northern Gulf of Mexico are associated with seepage of oil or gas at the seafloor, which is one indication of subsurface oil reserves. As exploration for new energy sources continues into deeper water, it is important to locate and set aside these sensitive areas so they are not disturbed.

Video and Photo Resources

Video showing some of the extraordinary biological diversity of the Gulf of Mexico
http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_biodiversity_cm3.html

Video of ROV used to sample deepwater habitats in the Northern Gulf of Mexico
http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_rov_cm2.html

Video and still images from Operation Deep Scope showing bioluminescence, fluorescence, and images of unusual animals captured by the Eye-In-The-Sea camera
http://oceanexplorer.noaa.gov/explorations/04deepscope/logs/photolog/photolog.html

Video of a very extensive mussel bed on the perimeter of a large mud flow and brine seep feature
http://oceanexplorer.noaa.gov/explorations/06mexico/logs/may17/media/movies/atwater_brine_video.html

Videos of oozing tar, natural asphalt, and devices used to sample organisms from sea-floor communities
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/photolog/photolog.html

Videos of a chain catshark, snowy grouper, redeye gaper, and a high-diversity hard-bottom habitat at 300 meters depth in the Gulf of Mexico
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/photolog/photolog.html

Videos of deepwater corals and coral communities
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html

U.S. Geological Survey scientist, Dr. Ken Sulak introduces some prominent fish and invertebrate inhabitants of deep-sea communities in the Gulf of Mexico, describes typical Viosca Knoll continental slope biotopes, and highlights submersible operations used to investigate deep-reef fauna
http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/wmv.html

NOAA video related to the Deepwater Horizon blowout
http://oceanservice.noaa.gov/deepwaterhorizon/video.html

Slideshow of highlights from Expedition to the Deep Slope 2006
http://oceanexplorer.noaa.gov/explorations/06mexico/background/media/slideshow/slideshow.html

Slideshow of images from the Expedition to the Deep Slope 2007
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/summary/media/slideshow/html_slideshow.html

Slideshow of sponges and octocorals collected during the Deep-Sea Medicines 2003 Expedition
http://oceanexplorer.noaa.gov/explorations/03bio/logs/summary/media/deep_sea_med_slideshow/slideshow.html

NOAA images related to the Deepwater Horizon blowout
http://oceanservice.noaa.gov/deepwaterhorizon/images.html
http://oceanservice.noaa.gov/deepwaterhorizon/video.html

Extensions

1. Coastal oil spill response: NOAA's National Ocean Service Office of Response and Restoration provides instructions and materials for an exercise in which students plan a protection strategy for a coastline threatened by an oil spill: http://response.restoration.noaa.gov/type_subtopic_entry.php?RECORD_KEY%28entry_subtopic_type%29=entry_id,subtopic_id,type_id&entry_id(entry_subtopic_type)=315&subtopic_id(entry_subtopic_type)=27&type_id(entry_subtopic_type)=3

2. "Oil Floats and Spreads" demonstration from NOAA's National Ocean Service Office of Response and Restoration: http://response.restoration.noaa.gov/topic_subtopic_entry.php?RECORD_KEY%28entry_subtopic_topic%29=entry_id,subtopic_id,topic_id&entry_id(entry_subtopic_topic)=13&subtopic_id(entry_subtopic_topic)=27&topic_id(entry_subtopic_topic)=3

3. Find animations of Loop Current predictions from NOAA's National Weather Service here: http://polar.ncep.noaa.gov/ofs/viewer.shtml?-gulfmex-cur-0-large-rundate=latest.

4. NOAA's GeoPlatform Web site allows the public to track Deepwater Horizon-BP oil spill recovery data online via a near-real-time interactive map at http://www.geoplatform.gov/gulfresponse/. The Web site includes a video tutorial.

5. NOAA's National Environmental Satellite Data Information Service provides links to products and operations involved in response to

the Deepwater Horizon blowout here: http://www.nesdis.noaa.gov/news_archives/gulf_spill.html

6. For information about fisheries closure areas, see NOAA's National Marine Fisheries Service (NOAA Fisheries Service) Web site: http://sero.nmfs.noaa.gov/deepwater_horizon_oil_spill.htm. NOAA FIsheries Office of Protected Resources also provides a Kids' Page about sea turtles: http://www.nmfs.noaa.gov/pr/education/turtles.htm

Other Relevant Lessons from NOAA's Ocean Explorer Program

Grades 5-6

Let's Make a Tubeworm! (6 pages, 464 KB)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

Focus - Symbiotic relationships in cold-seep communities (Life Science)

Students will be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. They will be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Animals of the Fire Ice (5 pages, 364 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/animals.pdf

Focus - Methane hydrate ice worms and hydrate shrimp (Life Science)

In this activity, students will be able to define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

The Robot Ranger (14 pages, 1.1 MB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09ranger.pdf

Focus - Robotic Analogues for Human Structures (Distance Estimation) (Life Science/Physical Science)

In this activity, students will describe how humans are able to estimate the distance to visible objects, and describe a robotic system with a similar capability.

Big Enough? (15 pages, 964 KB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09bigenough.pdf

Focus - Buoyancy (Physical Science)

In this activity, students will be able to define buoyancy, mass, volume, and density, and explain the relationships between these properties. Given the mass and volume of an object, students will be able to calculate the minimum buoyancy required to keep the object afloat in seawater. Students will also be able to explain why objects in seawater are more buoyant than the same objects in fresh water.

Cool Lights (7 pages, 220 KB)

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/coollights.pdf

Focus - Light-producing processes and organisms in deep-sea environments (Life Science/Physical Science)

Students compare and contrast chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Given observations on materials that emit light under certain conditions, students infer whether the light-producing process is chemiluminescence, fluorescence, or phosphorescence. Students explain three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

Now You See Me, Now You Don't (5 pages, 281 KB)

http://oceanexplorer.noaa.gov/explorations/05deepscope/background/edu/media/now_u_see_me.pdf

Focus - Light, color, and camouflage in the deep ocean (Life Science)

In this activity, students will be able to explain light in terms of electromagnetic waves, and explain the relationship between color and wavelength; compare and contrast color related to wavelength with color perceived by biological vision systems; and explain how color and light may be important to deep-sea organisms, even under conditions of near-total darkness. Students will also be able to predict the perceived color of objects when illuminated by light of certain wavelengths.

Microfriends (6 pages, 420 KB)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_microfriends.pdf

Focus - Beneficial microorganisms (Life Science)

In this activity, students will be able to describe at least three ways in which microorganisms benefit people, describe aseptic *procedures, and obtain and culture a bacterial sample on a nutrient medium.*

Grades 7-8

Monsters of the Deep (6 pages, 464 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf

Focus - Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)

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

One Tough Worm (8 pages, 476 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf

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

In this activity, 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.

Design a Reef! (5 pages, 408 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf

Focus - Niches in coral reef ecosystems (Life Science)

Students will compare and contrast coral reefs in shallow water and deep water, describe the major functions that organisms must perform in a coral reef ecosystem, and explain how these functions might be provided in a miniature coral reef ecosystem. Students will also be able to explain the importance of three physical factors in coral reef ecosystems and infer the fundamental source of energy in a deepwater coral reef.

Let's Go to the Video Tape! (7 pages, 552 KB)

http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/videotape.pdf

Focus - Characteristics of biological communities on deepwater reef habitats (Life Science)

Students will recognize and identify some of the fauna groups found in deep-sea coral reef communities, infer possible reasons for observed distribution of groups of animals in deep-sea coral reef communities, and discuss the meaning of biological diversity. Students will compare and contrast the concepts of variety and relative abundance as they relate to biological diversity, and given abundance and distribution data of species, will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

Forests of the Deep Ocean (12 pages, 300 KB)

http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/forests.pdf

Focus - Morphology and ecological function in habitat-forming deep-sea corals (Life Science)

In this activity, students will be able to describe at least three ways in which habitat-forming deep-sea corals benefit other species in deep-sea ecosystems, explain at least three ways in which the physical form of habitat-forming deep-sea corals contributes to their ecological function, and explain how habitat-forming deep-sea corals and their associated ecosystems may be important to humans. Students will also be able to describe and discuss conservation issues related to habitat-forming deep-sea corals.

Your Expedition of Discovery (17 pages, 764 KB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09yourexped.pdf

Focus - Global Positioning Systems (Physical Science/Earth Science)

Students will explain how global positioning satellites are used to determine the location of points on Earth's surface, and will identify at least three practical uses for the Global Positioning System (GPS). Students will also explain how the geographic position of objects may be described by latitude and longitude, and given latitude and longitude coordinates will use GPS technology to find the corresponding location.

Who Has the Light? (7 pages, 200 KB)

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/whohaslight.pdf

Focus - Bioluminescence in deep-sea organisms (Life Science)

In this activity, students compare and contrast *chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Students also explain at least three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.*

Twisted Vision (7 pages, 303 KB)

http://oceanexplorer.noaa.gov/explorations/05deepscope/background/edu/media/now_u_see_me.pdf

Focus - Polarization vision (Life Science/Physical Science)

In this activity, students will be able to explain the meaning of polarized light, and will be able to identify three ways in which unpolarized light can become polarized; explain why some animals have polarization vision, and why humans do not have this ability; and discuss three ways in which polarization vision may be useful to marine organisms.

Grades 9-12

From the Gulf of Mexico to the Moons of Jupiter (6 pages, 207 KB)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_moons.pdf

Focus - Adaptations to unique or "extreme" environments (Earth Science)

In this activity, 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 will be able to compare physical conditions in deep-sea "extreme" environments to conditions thought to exist on selected moons of Jupiter. Students will also discuss the relevance of chemosynthetic processes in cold seep communities to the possibility of life on other planetary bodies.

Biochemistry Detectives (8 pages, 480 KB)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_biochem.pdf

Focus - Biochemical clues to energy-obtaining strategies (Chemistry)

In this activity, 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 energy-obtaining strategies used by organisms in cold-seep communities. Students will also be able to interpret analyses of enzyme activity and ^{13}C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

This Old Tubeworm (10 pages, 484 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/old_worm.pdf

Focus - Growth rate and age of species in cold-seep communities (Life Science)

In this activity, 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 construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals of the same species. Students will also be able to estimate the age of an individual of a specific size, given information on age-specific growth in individuals of the same species.

C.S.I. On the Deep Reef (Chemotrophic Species Investigations, That Is) (6 pages, 444 KB)

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_csi.pdf

Focus: Chemotrophic organisms (Life Science/Chemistry)

In this activity, students will describe at least three chemotrophic symbioses known from deep-sea habitats and will identify and explain at least three indicators of chemotrophic nutrition.

Gellin (4 pages, 372 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf

Focus - DNA analysis (Life Science)

In this activity, students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Hot Food (4 pages, 372 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_hotfood.pdf

Focus - Energy content of hydrocarbon substrates in chemosynthesis (Chemistry)

In this activity, students will compare and contrast photosynthesis and chemosynthesis as processes that provide energy to biological communities, and given information on the molecular structure of two or more substances, will make inferences about the relative amount of energy that could be provided by the substances. Students will also be able to make inferences about the potential of light hydrocarbons as an energy source for deepwater coral reef communities.

How Does Your (Coral) Garden Grow? (6 pages, 456 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf

Focus - Growth rate estimates based on isotope ratios (Life Science/Chemistry)

In this activity, students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

The Big Burp: Where's the Proof? (5 pages, 364 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf

Focus - Potential role of methane hydrates in global warming (Earth Science)

In this activity, students will be able to describe the overall events that occurred during the Cambrian explosion and Paleocene extinction events and will be able to define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also be able to describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian explosion and Paleocene extinction events.

What's the Difference? (20 pages, 300 kb)

http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/difference.pdf

Focus - Identification of biological communities from survey data (Life Science)

In this activity, students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

Sound Pictures (17 pages, 1 MB)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09sound.pdf

Focus - Sonar (Physical Science)

In this activity, students will explain the concept of sonar, describe the major components of a sonar system, explain how multibeam and sidescan sonar systems are useful to ocean explorers, and simulate sonar operation using a motion detector and a graphing calculator.

Where Is That Light Coming From? (PDF, 208 KB)

http://oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/whereislight.pdf

Focus - Bioluminescence (Chemistry/Life Science)

In this activity, students explain the role of luciferins, luciferases, and co-factors in bioluminescence and the general sequence of the light-emitting process. Additionally, students discuss the major types of luciferins found in marine organisms, define the "lux operon" and discuss at least three ways that bioluminescence may benefit deep-sea organisms. Students give an example of at least one organism that actually receives each of the benefits discussed.

Other Resources

http://oceanexplorer.noaa.gov/ – Ocean Explorer Web site

http://www.piersystem.com/go/site/2931/ – Main Unified Command Deepwater Horizon response site

http://response.restoration.noaa.gov/deepwaterhorizon – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

http://www.gulfallianceeducation.org/ – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click "Gulf States Information & Contacts for BP Oil Spill" to download the Word document

http://rucool.marine.rutgers.edu/deepwater/ – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program http://www.noaa.gov/sciencemissions/PDFs/tj_deepwaterhorizon_responsemissionreport_june3_11_2010final.pdf – NOAA Ship *Thomas Jefferson* Deepwater Horizon Response Mission Report Interim Project Report-Leg 2, June 3-11, 2010

http://response.restoration.noaa.gov/book_shelf/1889_Shorelines-fact-sheet.pdf – NOAA Fact Sheet: Shorelines and Coastal Habitats in the Gulf of Mexico

http://response.restoration.noaa.gov/book_shelf/1964_coral-reef-fact-sheet-v3.pdf – NOAA Fact Sheet: Oil Spills and Coral Reefs

http://response.restoration.noaa.gov/book_shelf/34_mangrove_complete.pdf – Oil Spills in Mangroves: Planning and Response Considerations

http://response.restoration.noaa.gov/book_shelf/70_coral_full_report.pdf – Oil Spills in Coral Reefs: Planning and Response Considerations

http://response.restoration.noaa.gov/book_shelf/35_turtle_complete.pdf – Oil and Sea Turtles: Biology, Planning, and Response

http://response.restoration.noaa.gov/book_shelf/1887_Marine-Mammals-Sea-Turtles-fact-sheet.pdf – NOAA Fact Sheet: Effects of Oil on Marine Mammals and Sea Turtles

http://response.restoration.noaa.gov/topic_subtopic_entry.php?RECORD_KEY%28entry_subtopic_topic%29=entry_id,subtopic_id,topic_id&entry_id%28entry_subtopic_topic%29=810&subtopic_id%28entry_subtopic_topic%29=8&topic_id%28entry_subtopic_topic%29=1#basics – Resources related to oil spills and the Deepwater Horizon blowout, from NOAA's Office of Response and Restoration

http://www.ccpo.odu.edu/~atkinson/VAMDSpill/UltraDeep%20Prosp%2010-22-02.pdf – Document about "Prospectivity of the Ultra-Deepwater Gulf of Mexico" by Roger N. Anderson and Albert Boulanger; from the Lean Energy Initiative of Columbia University's Lamont Doherty Earth Observatory

http://www.noaa.gov/sciencemissions/PDFs/JAG_Report_1_BrooksMcCall_Final_June20.pdf – Review of R/V *Brooks McCall* Data to Examine Subsurface Oil http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

http://ecowatch.ncddc.noaa.gov/jag/data.html – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://ecowatch.ncddc.noaa.gov/jag/reports.html – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.geoplatform.gov/gulfresponse/ – An online tool developed by NOAA, EPA, U.S. Coast Guard, and the Department of Interior that provides a "one-stop shop" for spill response information

http://www.harteresearchinstitute.org/ixtoc-i-references/142-ixtoc-i-references - A list of references about the Ixtoc oil spill prepared by Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi

http://www.icriforum.org/oil-spills – Oil and oil spills - Impacts on coral and coral reefs; annotated bibliography from the International Coral Reef Initiative

http://iop.apl.washington.edu/seaglider/about.html – Web page about sea gliders developed and used by the Integrated Observational Platforms group at the University of Washington's Applied Physics Laboratory

http://wetlabs.com/CrudeOilClientAdvisory2.pdf – Crude Oil Detection with WET Labs ECO CDOM Fluorometer [NOTE: Mention of proprietary names does not imply endorsement by NOAA]

Coastal Response Research Center. 2010. Deepwater Horizon Dispersant Use Meeting Report May 26-27, 2010. Coastal Response Research Center, University of New Hampshire. June 4, 2010; available online at www.crrc.unh.edu/dwg/dwh_dispersants_use_meeting_report.pdf

NOAA Office of Response and Restoration. Dispersants: A Guided Tour. http://response.restoration.noaa.gov/topic_subtopic_entry.php?RECORD_KEY%28entry_subtopic_topic%29=entry_id,subtopic_id,topic_id&entry_id(entry_subtopic_topic)=155&subtopic_id(entry_subtopic_topic)=8&topic_id(entry_subtopic_topic)=1

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Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. Oceanography 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

French, C. D. and C. J. Schenk. 2006. Map showing geology, oil and gas fields, and geologic provinces of the Gulf of Mexico region. USGS Open File Report 97-470-L.

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Jernelov, A. and O. Linden. 1981. Ixtoc I: A Case Study of the World's Largest Oil Spill" Ambio, 10(6):299-306.

Kellogg, C. A., 2009, Gulf of Mexico deep-sea coral ecosystem studies, 2008–2011: U.S. Geological Survey Fact Sheet 2009–3094, 4 p.

Musgrove, M. and J. Koenig. 2010. Marine Scientist Edie Widder: 'There's No Making This Right.' FloridaTHINKS.com, June 8, 2010; http://floridathinks.com/florida-issues/florida-issues/marine-scientist-edie-widder-there%E2%80%99s-no-making-this-right%E2%80%99/

Shafir, S., J. Van Rijn, and B. Rinkevich, 2007. Short and long term toxicity of crude oil and oil dispersants to two representative coral species. Environmental Science and Technology 41(15): 5571-5574.

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology.

USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

National Research Council. 2003. Oil in the Sea III: Inputs, Fates, and Effects. The National Academies Press. Washington, D.C.

http://coseenow.net/blog/oil-spill-resources – PowerPoint presentations and activities on topics related to oil in the Gulf of Mexico

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

http://www.geoplatform.gov/gulfresponse/ - Web page for GeoPlatform.gov/gulfresponse an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

Project "Deep Spill" reports – These reports document the results of an experimental release of oil and gas conducted in June 2000 off the coast of Norway. Project participants included 23 oil companies and the U.S. Minerals Management Service. The overall purpose of the project was to simulate a blowout or pipeline rupture in deep water and obtain information that could be used to predict the behavior of oil and gas under these conditions. Five reports document the project's results:

http://www.boemre.gov/tarprojects/377/DeepSpill%20Final%20Report.pdf – Johansen, O., *et al.* 2001. Deep Spill JIP – Experimental Discharges of Gas and Oil at Helland Hansen – June 2000. Final Technical Report

http://www.boemre.gov/tarprojects/377/DeepSpill%20Cruise%20Report.pdf – Johansen, O., *et al.* 2001. Deep Spill JIP – Experimental Discharges of Gas and Oil at Helland Hansen – June 2000. Final Cruise Report.

http://www.boemre.gov/tarprojects/377/DeepSpill%20ROV%20Report.pdf – Johansen, O., *et al.* 2001. ROV Sonar and Pictures from Project "Deep Spill" - June 2000. Final Data Report.

http://www.boemre.gov/tarprojects/377/Adams%20Review%204.pdf – Adams, E.E. and S. A. Socolofsky. 2005. Review of Deep

Oil Spill Modeling Activity Supported by the Deep Spill JIP and Offshore Operator's Committee. Final Report.

http://www.boemre.gov/tarprojects/377/UH_MIT_Final_2001.pdf – Masutani, S.M. and E. Adams. 2001. Study of Multi-Phase Plumes with Application to Deep Ocean Oil Spills. Hawaii Natural Energy Institute, University of Hawaii.

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Appendix 1: Some Activities and Resources About Basic Geology of Petroleum Formation

A. Activities

1. Have students create posters illustrating how petroleum is formed, and/or models of various types of petroleum traps.

2. Demonstrate the difference between reservoir rocks and trap rocks (adapted from The Paleontological Research Institution's Web site, http://www.priweb.org/ed/pgws/):

Materials

- 2 pieces of fine mesh window screen, approximately 25 cm square
- 2 wide mouth glass or clear plastic jars or beakers, approximately 15 cm diameter
- 2 large rubber bands or string
- 250 ml thick, clay mud
- 250 ml masonry or play sand, moistened with about 50 ml water
- 500 ml water

Procedure

a. Place a piece of window screen across the top of each jar, and hold in place with a large rubber band or string.
b. Smear mud evenly across one screen. Spread damp sand across the other screen.
c. Pour half of the water on the screen with sand, and have students observe the result.
d. Repeat Step c. with the muddy screen.
e. Tell students that shale is a type of rock formed from hardened clay, and that sandstone is a type of rock formed from hardened sand. Ask which rock would be most likely to contain oil, and which rock would block oil from moving through it?

3. Provide each student or student group with a copy of the *Basic Geology of Petroleum Formation Inquiry Guide*. You may provide students with links to resources listed below, or have them research answers to *Inquiry Guide* questions on their own. When students have answered questions on the *Inquiry Guide*, lead a discussion of their results. The following points should be included:
   • Six key elements required for petroleum formation are:
   - A source of organic material that has captured energy;
   - Rock or sediments containing organic material;
   - Heat and pressure under which organic material is converted to petroleum (sediment maturation);

- Carrier beds through which petroleum can migrate;
- Reservoir rock that contains petroleum; and
- Trap rocks that seal petroleum in reservoir rock.

• Most oil is not formed from dead dinosaurs, but comes from rocks that were formed underwater, and the carbon source for most oil is microscopic planktonic plants.

• Sediment maturation is conversion of organic material to petroleum.

• Sediment maturation is most likely to occur under conditions of high heat and pressure.

• Reservoir rock is a porous rock such as sandstone or limestone that can contain oil.

• A trap rock is a rock such as shale with very little space between the particles that make up the rock, which makes the rock impermeable to oil.

B. Additional Resources

http://www.geomore.com/ – Oil On My Shoes; information about petroleum geology

http://geology.com/teacher/ – A Collection of Classroom Activities and Lesson Plans for Teaching Earth Science

http://www.priweb.org/ed/pgws/ – "From the Ground Up - The World of Oil;" from The Paleontological Research Institution

http://education.usgs.gov/common/secondary.htm – USGS Educational Resources

http://www.glossary.oilfield.slb.com/Default.cfm – Schlumberger Oilfield Glossary; an illustrated, interactive guide that provides explanations and definitions for more than 4600 oil-related terms

http://www.earthscienceworld.org/games/index.html – "Virtual Oilwell," an interactive game about oil exploration from Earth Science World of the American Geological Institute

Appendix 1: Basic Geology of Petroleum Formation Inquiry Guide

1. What are six key elements required for petroleum formation?

2. Is most oil formed from dead dinosaurs? Why or why not?

3. What is sediment maturation?

4. Under what conditions of heat and pressure is sediment maturation likely to occur?

5. What is a reservoir rock?

6. What is a trap rock?

Appendix 2:
Demonstrating Some Properties of Oil in Water

Materials

For each group of 2-4 students:

- 50 ml **unused** motor oil (see Notes for Educators)
- 500 ml tap water
- 3 - 250 ml graduated cylinders; glass or clear plastic; tall glass jars, approximately 200 ml capacity (such as those containing olives, capers, or sauces) may also be used
- 1 - 50 ml graduated cylinder; glass or plastic (or other-size cylinder that can measure a 10 ml volume)
- 3 pieces of plastic wrap, approximately 20 cm square
- 3 rubber bands
- Paper towels
- Timer, stopwatch or clock
- 1 ml liquid dishwashing detergent
- Disposable gloves for each student
- Eye protection
- Copies of the *Student Handout* and the *Student Observation Worksheet*

Materials that may be shared among several student groups:

- Ultraviolet light source (http://www.24hours7days.com/Science/Blacklight_Items.html; or see http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/10journeyunknown.pdf to make your own; mention of proprietary names does not imply endorsement by NOAA)
- Cardboard box, approx. 50 cm x 50 cm x 50 cm (see #3 under Notes for Educators below)
- Black spray paint
- Newspapers for surface protection and easy cleanup

Notes for Educators

1. Do not use discarded motor oil for these demonstrations, since it is contaminated with heavy metals and polycyclic aromatic hydrocarbons, many of which are carcinogenic. Crude oil should also be avoided, since it contains a variety of volatile substances that are also harmful.

2. Be sure students wear gloves and eye protection while handling oil.

3. A darkened area in which to observe fluorescence may be created with a cardboard box, approximately 50 cm x 50 cm x 50 cm; cut holes for observing and handling objects inside the box; spray the inside with flat black paint to minimize reflections.

4. Caution students not to look directly at the ultraviolet light source.

5. Spread newspapers over work surfaces to simplify cleanup.

6. Students' observations should include:
   - Immediately after shaking, the contents of Cylinders A and B are cloudy and foamy, with a film of cloudy liquid adhering to the walls of the cylinder above the level of the liquid.

   - Immediately after shaking, the contents of Cylinder C appear cloudy, but clear rapidly and are clear (transparent) after five minutes.

   - After five minutes, the contents of Cylinders A and B appear to separate into three levels: a cloudy lower layer, a layer of colored liquid (oil) in the middle, and a cloudy foamy layer on top. The film of cloudy liquid still is present on the walls of the cylinder above the level of the liquid.

   - After resting for an hour:
     - The contents of Cylinder A have separated into two layers; a cloudy, whitish layer on the bottom, and a colored (oil) layer on top.
     - The contents of Cylinder B also have separated into layers that include a cloudy whitish layer beneath a colored (oil) layer. But there also appear to be additional thin layers above and below the oil layer. Also, the oil layer in Cylinder B is thinner than the oil layer in Cylinder A.
     - The film of cloudy liquid still is present above the level of the liquid on the walls of Cylinders A and B.
     - The contents of Cylinder C are transparent.

   - Oil fluoresces a blue-green color under ultraviolet light.

7. Discussion points:
   - The cloudy foam that appears on top of liquids in Cylinders A and B is called mousse. After an oil spill, mousse is formed when wind and waves mix oil, water, and air. Mousse can also be formed under water if other gases (besides air) are present and turbulence causes these gases to mix with oil and water.

   - The cloudy film that persists on the side of Cylinders A and B is an unstable emulsion of oil and water. An emulsion is mixture of liquids in which small droplets of one liquid (oil in this case) are suspended in another liquid. In an unstable emulsion, the liquids will eventually separate, but they may continue to move together for long periods of time.

   - Cylinder B illustrates how dispersants (in this case, a detergent) can affect the behavior of oil in water. Dispersants cause oil to form stable emulsions in oil. These emulsions are the "extra" layers in Cylinder B, and account for the smaller size of the oil layer in Cylinder B.

- Motor oil (like crude oil) is a mixture of many substances. The cloudiness that persists in the lower layers of Cylinders A and B demonstrates that some of these substances are still present in water even after much of the oil has apparently separated. Some substances may partially dissolve in water and form a solution that will not separate.

- The ecological significance of dissolved substances and stable emulsions depends upon length of exposure time and concentration. If currents and other mixing forces cause emulsions to be rapidly dispersed over a wide area, the length of exposure time and concentration will both be reduced. On the other hand, the adherence of an oil-water emulsion to the sides of the cylinders shows that even a brief exposure can have a coating effect that might affect functioning of gills, sight organs, and other physiological structures.

- The fact that oil fluoresces provides a way to detect oil, particularly oil suspended in deep water where direct observation is difficult or impossible. This is an important tool for oil spill investigations.

Appendix 2: Student Handout
Demonstrating Some Properties of Oil in Water

Procedure

1. Wear gloves and eye protection throughout this procedure.
2. Place 100 ml tap water in each of three 250 ml graduated cylinders. Label these cylinders A, B, and C.
3. Add 10 ml unused motor oil to Cylinders A and B.
4. Add ONE DROP of liquid dishwashing detergent to Cylinder B.
5. Place a square of plastic wrap on top of each cylinder, and secure it in place with a rubber band to make a tight seal.
6. Shake each cylinder vigorously for 30 seconds, then place the cylinders in a location where they can be observed without further disturbance. Record what you see in each cylinder every five minutes for one hour. Record your observations on the Observation Worksheet.
7. Does oil fluoresce? Fold a paper towel several times to make a thick pad. Place 1 or 2 ml of unused motor oil on the folded towel, then examine the towel under ultraviolet light. Record your observations on the Observation Worksheet.
8. It is common knowledge that oil and water don't mix. Is there anything you might add to this statement that would explain your observations?
9. What do you conclude about the effect of detergent on the behavior of oil in water?
10. Does oil fluoresce? How might this property be useful to scientists investigating oil spills?

Appendix 2: Student Observation Worksheet
Demonstrating Some Properties of Oil in Water

Resting Time	Cylinder A	Cylinder B	Cylinder C
5 min			
10 min			
15 min			
20 min			
25 min			
30 min			
35 min			
40 min			
45 min			
50 min			
55 min			
60 min			

Observations of oil under fluorescent light:

Draw a sketch of each cylinder after it has rested for one hour: