Deepwater Exploration Workshop:

Overview of NOAA's Gulf of Mexico Explorations 2001-2009

Office of Ocean Exploration and Research

July 23, 2010 | Silver Spring, MD

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 2002 and 2009, National Oceanic and Atmospheric Administration's Office of Exploration and Research (OER) sponsored 14 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 Ecosystem Education Materials Collection, from which these materials are taken, includes a selection of lesson plans together with new lessons and additional background information about the Deepwater Horizon blowout event. The purpose of the Education Collection is to provide a foundation for student inquiries into the environmental consequences of this event in deep-sea ecosystems, and to build capabilities for comparing data from OER expeditions with post-event information as the latter information becomes available. We are including a portion of these materials here to provide you with background information that you might find useful during this workshop.

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) (sites not shown in Figure 1.)
http://oceanexplorer.noaa.gov/explorations/islands01/islands01.html

Gulf of Mexico Deep-sea Biology (February 9 - 16, 2003) (sites not shown in Figure 1.)
http://oceanexplorer.noaa.gov/explorations/03mexbio/welcome.html

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

Medicines from the Deep-sea: Exploration of the Gulf of Mexico (September 8-19, 2003) (some sites not shown in Figure 1.)
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

World War 2 Shipwreck Survey (July 29 - August 15, 2004) (sites not shown in Figure 1.)
http://oceanexplorer.noaa.gov/explorations/04gmss/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

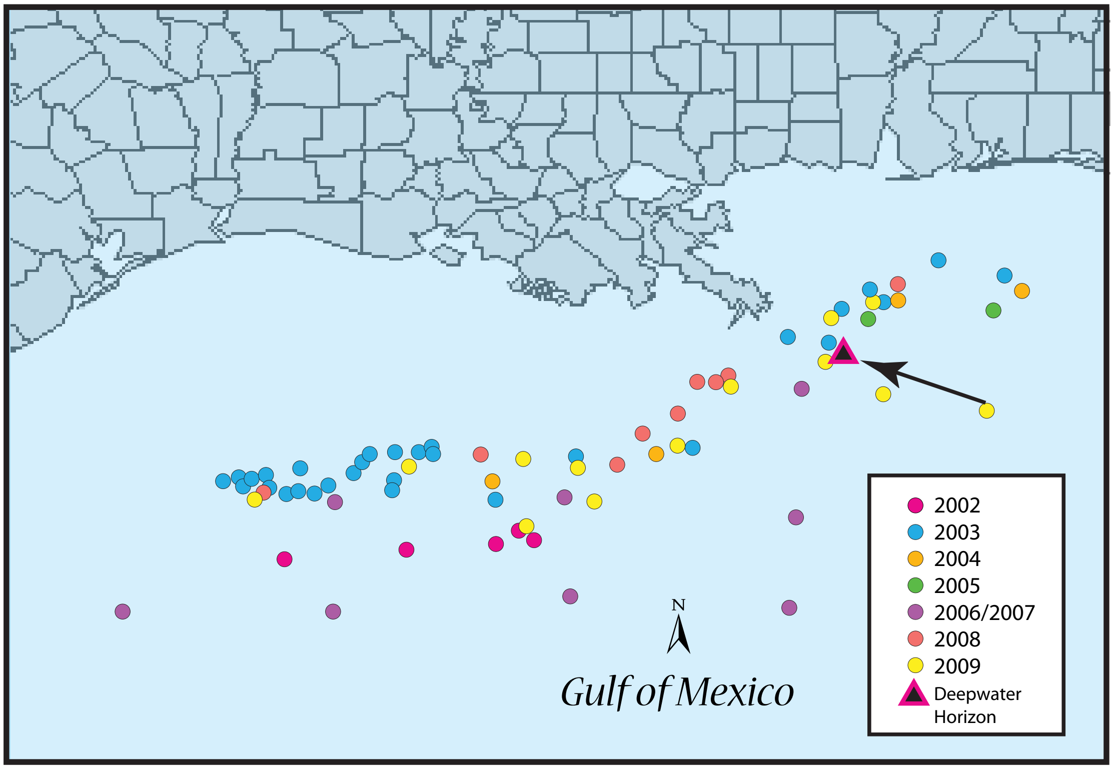
The Northeastern Gulf of Mexico (July 2008) (sites not shown in Figure 1.)
http://oceanexplorer.noaa.gov/explorations/08negmexico/welcome.html

***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

Exploring the Submerged New World (October 2-26, 2009) (sites not shown in Figure 1.)
http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html

Figure 1.
Representative sites included in OER expeditions to the Gulf of Mexico; locations are approximate based upon mission summaries provided on the Ocean Explorer Web site; a geo-referenced compilation of all OER sites in the Gulf of Mexico is in preparation.



Background Information

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.

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. Tunnell *et al.* (1981) investigated impacts on 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) report 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 *et al.* (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 + 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 rules out the use of any oil dispersant in coral reefs and in their vicinity."

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.

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 chain. 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).

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

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 credit: Ian MacDonald.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

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.

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, seastars, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

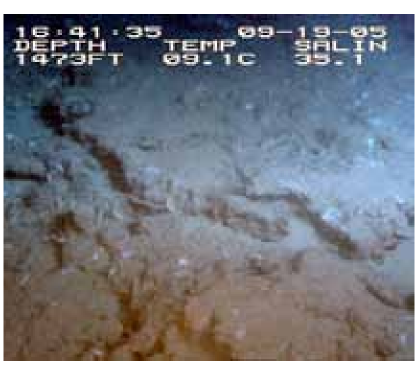
Deepwater chemosynthetic communities are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. These species include some of the most primitive living organisms (Archaea) 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.

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.

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 ppt. The influence of other factors, including pH, is not known.

ANEMONES: 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. Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.

CHEMO TUBEWORMS: 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*).



CHEMO SEEP BIOTOPE: 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*.

Recent studies suggest that deepwater reef ecosystems may have a diversity of species comparable to that of corals 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 focussed 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 show the predicted movement of spilled oil on the water surface. These predictions also incorporate satellite imagery analysis and observations from trained observers who make helicopter overflights across potentially affected areas (for more information, see http://response.restoration.noaa.gov/book_shelf/1926_TrajectoryFieldGuide.pdf).


Ben Grupe begins to prepare the CTD bottles for deployment, an instance when being tall comes in handy. Normally, scientists have to climb onto the white frame to cock the bottle caps. As the CTD is lowered into the ocean, a computer is used to watch the data and order bottles to snap shut, collecting water samples from different depths. Image courtesy of NOAA's INSPIRE: Chile Margin 2010.

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 from the University of Southern Mississippi aboard the Research Vessel *Pelican* 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. Asper (2010)

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 are degrading deepwater oil suspensions, and are consuming enough oxygen in the process to cause measurable depletions in the surrounding water. 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 will come from analysis of water samples collected at the same sites with CTD rosettes.

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 a depth of about 100 meters 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 include 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; 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 for assessing blowout impacts when scientists are able to return to sites near the blowout that were visited during these expeditions.

Overview of OE Expeditions to the Gulf of Mexico

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.

World War 2 Shipwreck Survey (July 29 - August 15, 2004)

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

Scientists explored deep waters of the Gulf of Mexico to document wreck sites with significance to American history, and to investigate whether man-made structures, such as shipwrecks, function as artificial reefs in deep water.

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.

The Northeastern Gulf of Mexico (July 2008)

http://oceanexplorer.noaa.gov/explorations/08negmexico/welcome.html

A team of maritime archaeologists returned to the Northeastern Gulf of Mexico to study inundated pleistocene landscapes for evidence of late ice-age human settlements.

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

Exploring the Submerged New World (October 2-26, 2009)
http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html
Scientists explored the Florida Middle Grounds in the eastern Gulf of Mexico for traces of early human occupation on a submerged late Pleistocene landscape.

Resources

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 habitat 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 (NOAA)
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)
Deep-water communities in the northern Gulf of Mexico are associated with seepage of oil or gas at the sea floor, 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

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

docs.lib.noaa.gov/noaa_documents/.../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 disaster 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://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html – "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 (2004-2006)"; Open-File Report 2008-1148 & OCS Study MMS 2008-015, April 15, 2008; Kenneth J. Sulak, Lead PI & Lead Editor, Co-editors: Michael Randall, Kirsten E. Luke, April D. Norem, and Jana M. Miller

www.noaa.gov/.../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://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://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.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

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

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