



Geomorphology

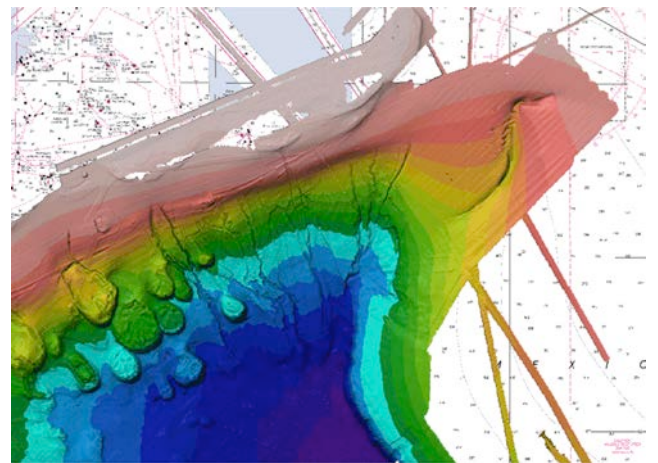
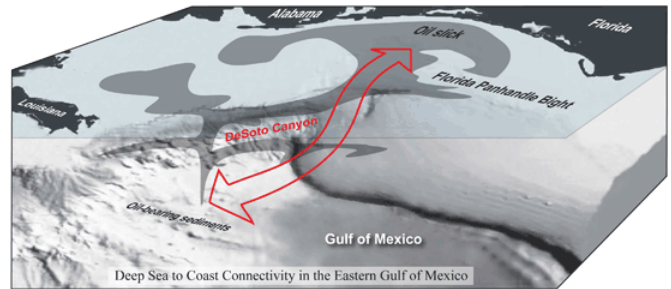
In the Gulf of Mexico

What is Geomorphology?

The scientific study of the origin and evolution of topographic and bathymetric features created by physical or chemical processes operating at or near Earth's surface.

A Quest to Map the Gulf's Seafloor

Mapping the seafloor and the use of digital imaging are two important methods for understanding how geological formations influence habitat and ecosystem development. After the 2010 Deepwater Horizon (DWH) oil spill occurred, two main questions emerged: *how were organisms and ecosystems impacted* and *what measures could be taken to protect them in the future?* The eastern Gulf of Mexico was largely unmapped at the time and many of its topographic features were unknown. So Deep-C researchers undertook basic mapping and descriptive studies of the seafloor in this region because: (1) oil from the DWH oil spill moved toward the Alabama and Florida coasts through a specific feature of the area, the De Soto Canyon, and there was a need to understand the mechanism by which this occurred; and (2) the region is considered a hotspot of biological diversity and has the highest biological productivity in the Gulf of Mexico thus it has tremendous economic value.



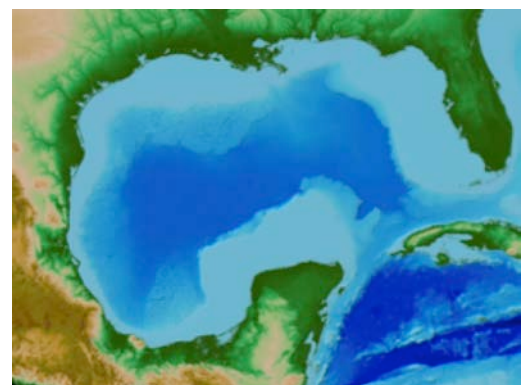
Multibeam image of numerous small downslope channels distributed within the broader De Soto Canyon indentation.

How Were Benthic Habitats Impacted by the Oil Spill?

Deep-C's geomorphology team was tasked with characterizing the seafloor geomorphology, bathymetry, sediment, and primary benthic habitats specific to the De Soto Canyon, with an emphasis on topographical features that influence deep sea-to-shelf connectivity. These results are being used to hindcast estimates of damage resulting from past oil spills and forecast vulnerabilities of key communities to future spills.

The De Soto Canyon

The De Soto Canyon is a broad southwest to northeast feature formed at the intersection between the Florida Peninsula and the southeastern portion of the continental U.S. The two components contain distinct features, which often support different ecosystems. The west/north side is the North American margin where river flows have deposited sediment layers that are literally miles thick. In many places, these layers are characterized by salt domes, economic hydrocarbon reserves and natural seeps. The east/south side is the Florida Platform – a huge structure comprised of carbonate rock with much less sediment accumulation.

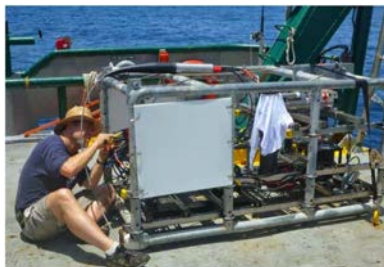


Source: www.ngdc.noaa.gov (public domain)

Deep-C Geomorphology and Habitat Classification Research

Innovative MILET system aids environmental monitoring in the Gulf

A team led by FSU's Dr. Ian MacDonald developed the Modular Instrument Lander and Equipment Toolshed (MILET) that allows scientists to map the seafloor and water column. This benthic imaging platform is a cost-effective alternative for deep-ocean surveys that can be deployed from the type of coastal ships most readily available for academic users. The MILET has been used by Deep-C scientists to investigate the downslope channel of the De Soto Canyon. Using this tool, continuous video and high-resolution digital images can be taken at altitudes of 2-5 m above bottom.



Ian MacDonald (FSU) working on the MILET benthic imaging platform during a summer 2013 research cruise.



FSU PhD student Chris Malinowski flies the MILET 2-3 m above bottom by reeling cable in or out from the winch.

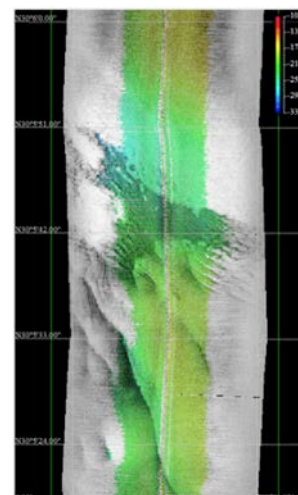
Mapping the seafloor with a C3D side scan sonar

A C3D side scan sonar maps the seafloor using sound to create maps of bottom type and bathymetry (elevation). These maps help us to understand how contaminants might move around in the marine environment and where monitoring for impacts



Chief scientist Stan Locker (USF) preparing his sonar system for deployment on a 2013 geomorphology research cruise.

might be warranted. The sonar is deployed on a cable in deeper water or mounted to the side of the research vessel. C3D side scan sonar is used to understand sediment transport patterns and to locate sensitive habitat hosting important benthic communities (i.e. coral) and essential fish habitat. High-resolution topographic imaging of the seafloor reveals new details about both high-relief and low-relief benthic habitats. Processed and interpreted geophysical data from side scan images collected on Deep-C research cruises has facilitated map development that includes new hard-bottom habitat and improved data on sedimentary transport and resuspension processes.

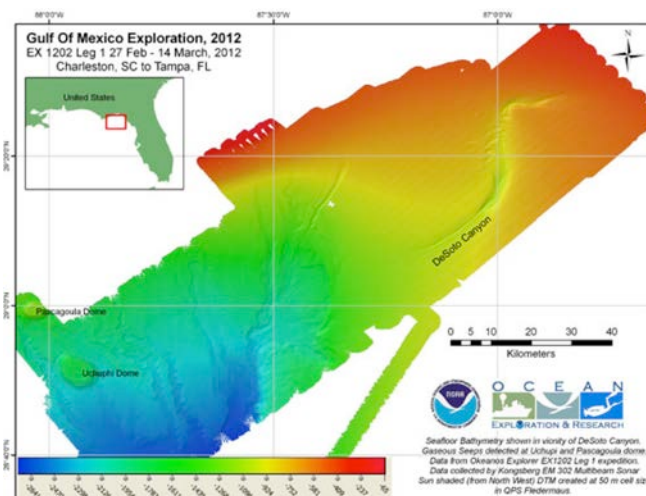


Side-scan imaging from the De Soto Canyon.

Bathymetry data from a 2012 NOAA expedition led to discovery of asphalt and oil seeps

The Deep-C geomorphology research team used bathymetry data collected during the 2012 NOAA R/V *Okeanos Explorer* cruise in the northern Gulf of Mexico to target a search for natural oil seeps in the De Soto Canyon region. Data indicated that natural hydrocarbon seeps could be found at salt domes on the western extent of De Soto Canyon. The use of bathymetry data from the 2012 NOAA expedition was vital to refining the Deep-C team's search strategy.

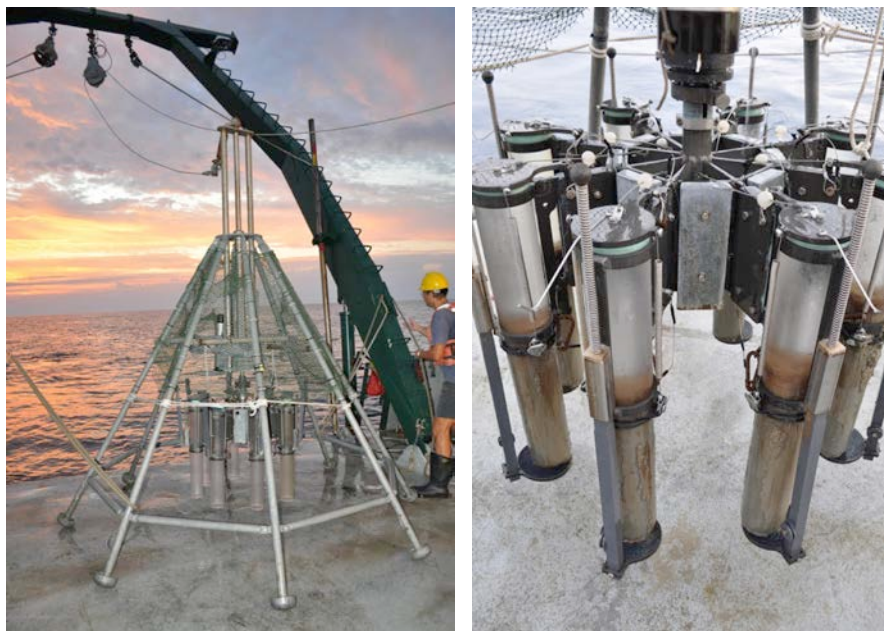
According to Dr. Ian MacDonald (FSU), "having the high-resolution bathymetry data that R/V *Okeanos Explorer* collected during its Gulf of Mexico surveys has lifted our ability to work smart in the De Soto Canyon by an order of magnitude or more. Because we had the bathymetric data set, we felt confident flying the MILET toolshed into the side of a seep mound which rose steeply about 400 meters above the surroundings. This effort resulted in remarkable imagery and the first-ever observation of asphalt volcanism in the eastern Gulf of Mexico." During a 2013 research cruise, MILET images confirmed benthic indicators of seeps at two potential sites.



Bathymetric data from NOAA R/V Okeanos Explorer, 2012 Northeastern Gulf of Mexico Expedition.

Multicore sampling of sediments helps with identification of benthic habitats

In addition to mapping the seafloor and utilizing digital imaging, geomorphologists are also incorporating sediment and water column data into their work on habitat classification in the De Soto Canyon region using tools such as a multi-corer, which is a simple, yet highly effective tool for collecting sediment cores that can be used to study benthic environments. This “spyder” device takes eight sediment cores from the ocean floor each time it is deployed.



Multi-corer on deck and an up close view of full cores. (Photo credit: Amy Baco-Taylor, FSU)

The instrument's pins and springs release through the motion of gravity and close as the tubes are lifted up. Each core tube is held in a separate detachable holder, enabling the sealed samples to be removed for analysis. It has no electronic connections or computer configuration, working off of gravity and precision-made moving parts. Deep-C scientists from multiple disciplines (i.e. biologists, chemists, and geologists) examine the sediments collected for the presence of oil, oxygen levels, benthic microorganisms, microbial communities, and degradation rate (rate at which materials breakdown).

Deep-C's Geomorphology Team



Dr. Ian MacDonald
Florida State
University



Dr. Albert Hine
University of
South Florida



Dr. Stan Locker
University of
South Florida

What Did We Learn?

- New innovations in instrumentation, such as the MILET system, can aid researchers in mapping the seafloor and the water column.
- Maps have helped us understand how contaminants might move around in the marine environment and where monitoring for impacts might be warranted.
- Collaboration with NOAA resulted in the discovery of asphalt seeps in the northeastern Gulf of Mexico.
- Using a multi-corer, scientists learned more about the benthic habitats on the two sides of the De Soto Canyon.

LESSON PLAN: Geologic Beginnings of the Gulf



Exploring the geologic history of the Gulf of Mexico

Objective: To describe the geologic development of the Gulf of Mexico’s oceanic features, with emphasis on the De Soto Canyon. Students should know about plate tectonics prior to this lesson.

Standards: OLP 1-2; SC.912.E.6.3, SC.912.E.6.5

Time Required: One 50-minute class period

Keywords: plate tectonics, seafloor spreading, topography, geologic processes, De Soto Canyon

Materials:

- Whiteboard
- Projector
- Images of oceanic features
- Copies of the “Geologic Beginnings in the Gulf” article (see page 10)

Background

The ocean floor is dynamic and has changed over the years due to tectonic activity. **Plate tectonics** is the theory in which the Earth's **lithosphere** (crust and upper mantle layer) is fragmented into pieces that are constantly moving and changing the geological features of the planet. There are **convergent boundaries** in which two plates come together (in the ocean, typically a trench is formed), and **divergent boundaries** where two plates move away from one another (in the ocean, typically a mid-ocean ridge is formed).

Seafloor spreading is a process of plate tectonics in which new oceanic crust is created and spreads outward. This process is how the Gulf of Mexico was formed. The seafloor spreading motion moving continental blocks occurred from about 160 to 140 Ma (million years ago). This process moved the Yutacan Block to the south and the Florida Straits Block to the southeast, thus creating the ocean basin of the Gulf. The original basin was much larger than the basin today, extending north nearly to Oklahoma and west to West Texas. The margins filled in with sediment to form land. Multiple flooding events evaporated to form halite (salt) deposits and sediment eventually covered them. Today, the Gulf of Mexico is an ~3,400 m deep, semi-enclosed ocean basin whose entrance is dominated by two huge carbonate platforms—Yucatan Peninsula/Campeche Bank on the west and the Florida Platform on the east. Both support very wide shallow, submerged shelves. The northern Gulf of Mexico basin is also dominated by one of the largest river deltas in the world — the Mississippi Delta. It also has many salt-movement related structures forming the “dimple-like” bathymetric appearance in the deeper water areas. In the northeast section, the De Soto Canyon can be seen as an indentation.

Procedure

1. **Completing a lesson on formation of oceanic features prior is strongly encouraged, to give students a background in plate tectonics and oceanic features.**

Possible Primer Lessons (see page 8 for links): “Formation of Oceanic Features” and “What’s Really Under the Ocean?” contains Ocean Floor Feature Cards (shown at right) – sonar images, classification, vocabulary, and an assessment.

Ocean Floor Features				
1. Rift Low land between hills or mountains	2. Trench Deep valley with high steep sides	3. Seamount An underwater peak formed by volcanic activity	4. Ridge A narrow, continuous range of mountains created by the rise of magma	5. Abyssal Plain Wide, flat areas of land far below the ocean surface

2. **Once the primer lesson is completed, review oceanic features by having small groups of students observe and explain features found in the images and then share ideas with the class.**

Ask the following questions:

- What geological features might one find on the ocean floor? (i.e. *seamounts, ridges, atolls, hills, continental shelf, continental slope, abyssal plain, abyssal hill, trench, and rifts*)
- How could you tell one feature from the other? (i.e. *differences in color, shades, shape, or other markings*)
- How do you think the feature formed? (i.e. *plate tectonic activities such as subduction, divergent boundaries, weathering erosion, current movement, or deposition of sediments*)

3. **Ask students how they think the Gulf of Mexico was formed?**
4. **Have students read the article, “*Geologic Beginnings of the Gulf of Mexico with Emphasis on the Formation of the De Soto Canyon*” (see page 10).**
5. **Conduct an article discussion, make a list of key points on the whiteboard, and explain the seafloor spreading process.**

Article Assessment Questions

1. The Gulf of Mexico was formed by the process of _____? *Seafloor spreading.*
2. Is it considered a true ocean basin? *Yes.*
3. What is the De Soto Canyon? *Not a true submarine canyon; it is an expansive, gently-sloped, geomorphic indentation in the modern shelf and shelf-slope system; contains a network of smaller canyons.*
4. What does the De Soto Canyon’s geologic future hold? *Sediment infill.*
5. Was the original Gulf of Mexico basin larger or smaller than the basin today? *Larger, extending north nearly to Oklahoma and west to west Texas.*

Extension

Create a three-dimensional model of the Gulf of Mexico basin or specific features using modeling clay.

Resources & References

“Formation of Oceanic Features” Lesson Plan

<http://www.cpalms.org/Public/PreviewResourceLesson/Preview/29756>

“Geologic Beginnings of the Gulf of Mexico” Article

<http://deep-c.org/news-and-multimedia/in-the-news/geologic-beginnings-of-the-gulf-of-mexico-with-emphasis-on-the-formation-of-the-de-soto-canyon>

Ocean Features Handout

<http://seagrant.uaf.edu/marine-ed/curriculum/images/stories/grade6/oceanfeatures.pdf>

Seafloor Spreading Defined

<http://education.nationalgeographic.com/education/encyclopedia/seafloor-spreading/>

“What’s Really Under the Ocean?” Lesson Plan

http://www.mbari.org/earth/mar_geo/bathy/under/under_ocean.html

Geologic Beginnings of the Gulf of Mexico with Emphasis on the Formation of the De Soto Canyon

By Albert C. Hine, Shane C. Dunn, and Stanley D. Locker, College of Marine Science, University of South Florida (Posted online August 14, 2013). Source: <http://deep-c.org/news-and-multimedia/in-the-news/geologic-beginnings-of-the-gulf-of-mexico-with-emphasis-on-the-formation-of-the-de-soto-canyon>

With the research now hitting full stride investigating the effects of the 86-day long BP oil spill triggered by the explosion and sinking of the Deepwater Horizon drilling platform (Macondo Site 252), it seems appropriate to review the geologic history of the Gulf of Mexico (Fig. 1). Here, we do that with a special emphasis on the De Soto Canyon, a feature in the northeastern Gulf of Mexico of particular interest to scientists.

One of the overlooked narratives of the disaster is why there is so much oil and gas in the Gulf of Mexico in the first place, since it is the center of huge investments in exploration and production. Indeed, today, the Gulf of Mexico provides 23% of the total US production of crude oil (according to US Energy Information Agency), 9% of the world's oil reserves, and 11% of the world's reserves (Nehring et al., 1991). Only the Arabian-Iranian Province supplies more. But, offshore drilling is a very fast-moving target worldwide, with reserve and production numbers changing monthly.

Contrary to political statements such as “drill baby drill”, or “drill here, drill there, drill everywhere,” which imply that drilling might occur *anywhere*, drilling can only be successful where oil and gas are found, and they are found in great abundance only where key geologic factors have allowed their development over geologic time. The key factors are:

- abundant and rich, organic source rocks,
- ideal pressure-temperature-time environments to convert organic matter in the source rock to kerogens and natural gas,
- abundant, highly porous and permeable reservoir rocks for hydrocarbon migration, and
- numerous suitable traps with seals to allow the upward migrating hydrocarbons to accumulate.

Oil and gas can form in trace amounts in many places, but economically-viable accumulations are realized only where these factors combine to form an ideal environment.

The Early Days— 200 to 160 million years ago (Ma)

The Gulf of Mexico, formed by the process of sea-floor spreading, and is considered a true ocean basin¹. It formed as part of the complex breakup of the mega-continent Pangea starting about 180 million years ago (Ma), when a 6,000-km long ragged crack split Pangea into two supercontinents, Laurentia (consisting mostly of what is now North America) and Gondwana (consisting of what is now South America and Africa) (Fig. 2).



Figure 1. The Gulf of Mexico is a ~3,400 m deep, semi-enclosed ocean basin whose entrance is dominated by two huge carbonate platforms—Yucatan Peninsula/Campeche Bank on the west and the Florida Platform on the east both supporting very wide shallow, submerged shelves. The northern Gulf of Mexico basin is also dominated by one of the largest river deltas in the world — the Mississippi. This small ocean basin also has many salt-movement related structures forming the “dimple-like” bathymetric appearance in the deeper water areas. Note the indentation in the northeast section, which is commonly named the De Soto Canyon on most maps and charts. (Illustration credit: Gulfbase.org)

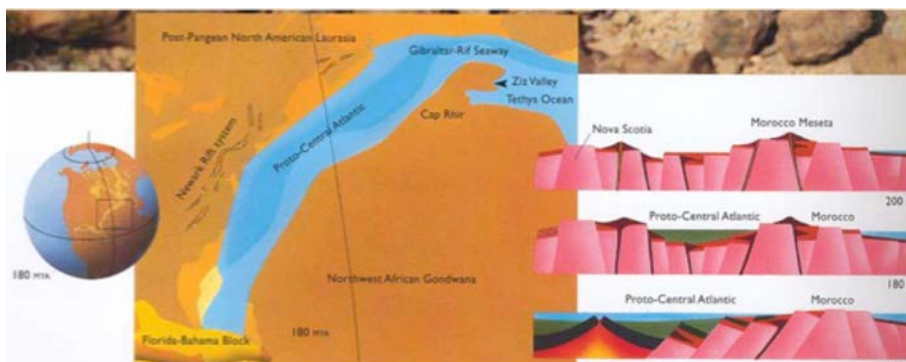


Figure 2. Simplified cartoon illustrating early ocean basin separating North America (Laurentia) from Africa (Gondwana). This water body was initially called the Tethys Sea and with further widening became the North Atlantic Ocean (modified from Redfern, 2001; Hine, 2013).

Prior to actual breakup, numerous long, narrow-rift basins formed due to extension and stretching of continental crust creating topographically low valleys surrounded by uplands, sometimes mountains, and bounded by large normal faults that were active during the Triassic and Early Jurassic periods, but are no longer active today (Fig. 3). Along the eastern continental margin of North America, they became filled with alluvial fans, deltas, rivers, and lakes, and shallow mud flats famous for their three-toed dinosaur footprints, but not filled with seawater. Some of these basins today control modern topography and drainage such as those in the lower Connecticut and Hudson River valleys. Other basins have been completely filled with non-marine sediments or buried and have little to no modern topographic expression.



Figure 3. Distribution of early rift basins along the eastern margin of North America formed when Pangea began to split apart. Note the position of the South Georgia Rift Basin (modified from

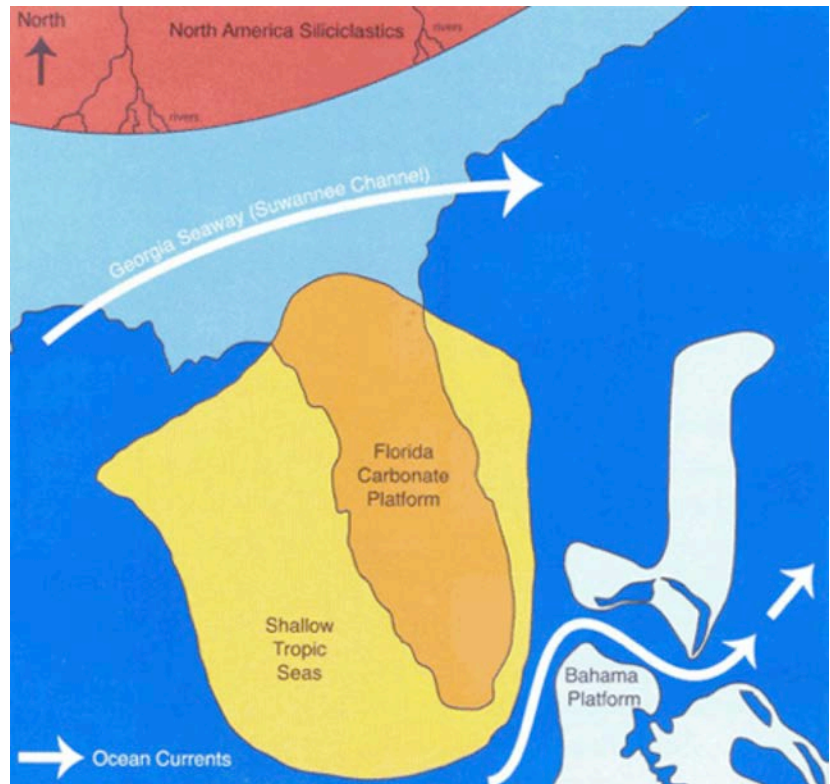


Figure 4. Illustration of seawater filling in the South Georgia Rift Basin forming the Georgia Seaway (modified from Redfern, 2001; Hine, 2013).

During this early extension and before the Tethys Sea (the proto-Atlantic Ocean) formed between Laurentia and Gondwana, a significant rift basin formed across South Georgia. This NE-SW trending structure, commonly called the South Georgia Rift Basin², was probably >500-km long, >100-km wide, and had about 1-km relief. Rifting ceased in this area but seafloor spreading continued to propagate around the peninsula Florida, splitting Laurentia from Gondwana and forming the Tethys Sea, where the southern and western parts became the Caribbean Sea and North Atlantic Ocean. Eventually, the South Georgia Rift Basin flooded with seawater, thus forming a seaway that has been referred to by a number of names—the Georgia Channel System, the Georgia Seaway the Suwannee Channel, and the Gulf Trough (Fig. 4). This seaway separated the Florida Platform from southeast North America, allowing carbonate sediments to accumulate in great abundance in Florida without being negatively influenced or even buried by continental sediments being shed off the rapidly eroding southern Appalachian Mountains.



Figure 5. Map illustrating opening on the Gulf of Mexico by movement of the Yucatan Block and Florida-Bahama blocks of continental/transitional crust (modified from Redfern, 2001; Hine, 2013).

The Early Gulf of Mexico—The Emplacement of Salt—160-140 Ma

The seafloor spreading motion moving continental blocks occurred from about 160 to 140 Ma. This process moved the Yucatan Block to the south and the Florida Straits Block (also known as the Florida Bahamas Block) to the southeast, thus creating the Gulf of Mexico basin (Fig. 5). The movement of these blocks of highly-stretched and extended transitional crust (continental crust intruded by oceanic crust-like rocks) eventually created a broad, deep basin still not yet permanently connected to the open ocean or filled with seawater. The primary early connections were to the Pacific Ocean to the west and the proto-Caribbean and Atlantic Ocean to the south and east respectively. Outline of original Gulf of Mexico basin (Fig. 6) extending beneath modern land areas. Salt beneath land areas in Texas, Louisiana, Alabama, and Florida were deposited in the earlier, much larger Gulf of Mexico Basin (Salvador, 1991).

The original Gulf of Mexico basin was much larger than the basin of today, extending north nearly to Oklahoma and west to West Texas (Fig. 6). Most of the original geologic basin filled along the margins with sediments to form land, leaving only a smaller portion of the original basin. As mentioned, the Gulf of Mexico basin also includes the Florida and Yucatan Platforms and their huge, now submerged, shelves.



Figure 6. Outline of original Gulf of Mexico basin extending beneath modern land areas. Salt beneath land areas in Texas, Louisiana, Alabama, and Florida were deposited in the earlier, much larger Gulf of Mexico Basin (Salvador, 1991).

Seawater poured into the developing Gulf of Mexico basin from the Pacific Ocean through small gaps in the Mexican terrain that would open and close with changes in local tectonics and global sea level. Due to the arid environment of this region, the seawater introduced during these multiple flooding events evaporated to form halite (NaCl) deposits up to 4-km thick. Eventually, the ocean crust formed by continued seafloor spreading, split the salt deposits into two provinces and the entire basin became permanently filled with open-marine, normal salinity seawater (Fig. 7). Sediments from the surrounding land mass began to accumulate on top of the salt (called the Louann Formation) and a huge physically-connected carbonate complex continued to grow (Yucatan-Florida-Bahama Platform). Continued infilling of the Gulf of Mexico basin from the North American continent explains why oil traps associated with salt structures are found well inland today—these traps originally evolved underwater within the earlier Gulf of Mexico basin (Figs. 6 & 7) but now lie beneath dry land.

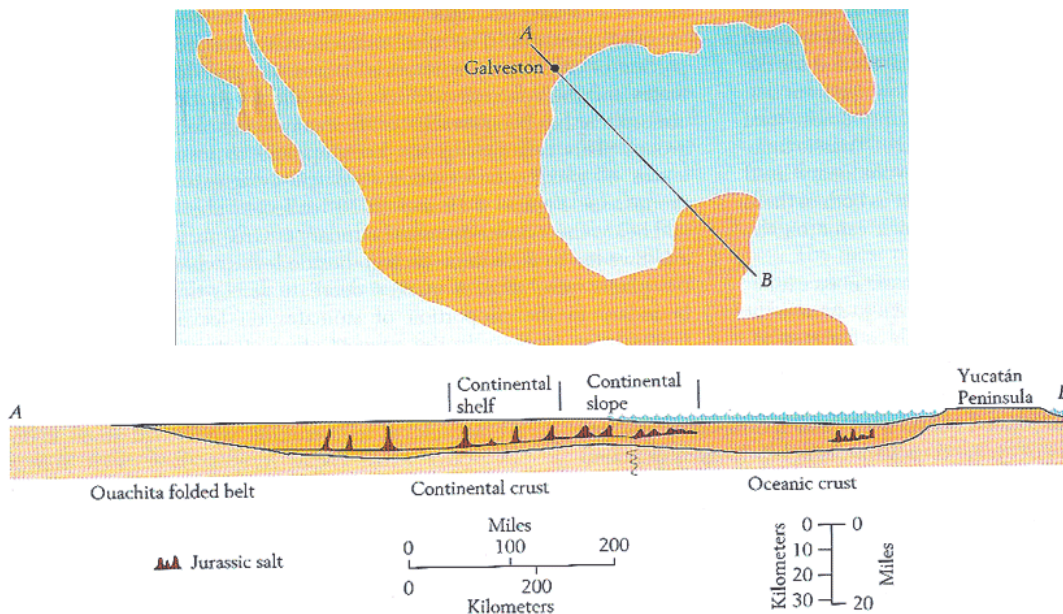


Figure 7. Cross section of the Louann Formation showing Jurassic salt deposits, which rose into domes in some places because of their low density. (Wilhelm and Dwing 1972).

The South Georgia Rift Basin also was partially filled with salt—particularly the western end that was connected to the larger Gulf of Mexico developing basin. It was this salt deposit that formed the highly visible diapirs that form topographic highs in the deeper portion of the modern De Soto Canyon.

What is the De Soto Canyon?

Based upon the presence of salt structures in the Apalachicola Embayment, most geoscientists think that the De Soto Canyon is fundamentally an indentation in the trend of the West Florida and North Florida shelf. As a result, the De Soto Canyon represents a modern, but incompletely filled in western portion of the Jurassic South Georgia Rift Basin (Fig. 8). Most of the South Georgia Rift Basin and the flooded Georgia Seaway were completely filled by continental sediment eroding from the Appalachian Mountains by the Oligocene (~28 Ma). The Appalachian Mountains are thought to have been as high as the Himalayas when they were first formed. Given that the Himalayas are over 8,000-m high and the present day Appalachians are barely 2,000-m high, this suggests that approximately 6,000-m of rock were eroded, transported, and re-deposited over the past 300 Ma. These sediments formed the Mesozoic-Cenozoic continental margins of the southern United States, including much of peninsular Florida. This filling during sea-level lows allowed existing river deltas to migrate from South Georgia to North Florida. Today, one can drive from Florida up through Georgia on roads built on a flat coastal plain that covers the once 100-km wide x 500-km long x 1-km deep basin.

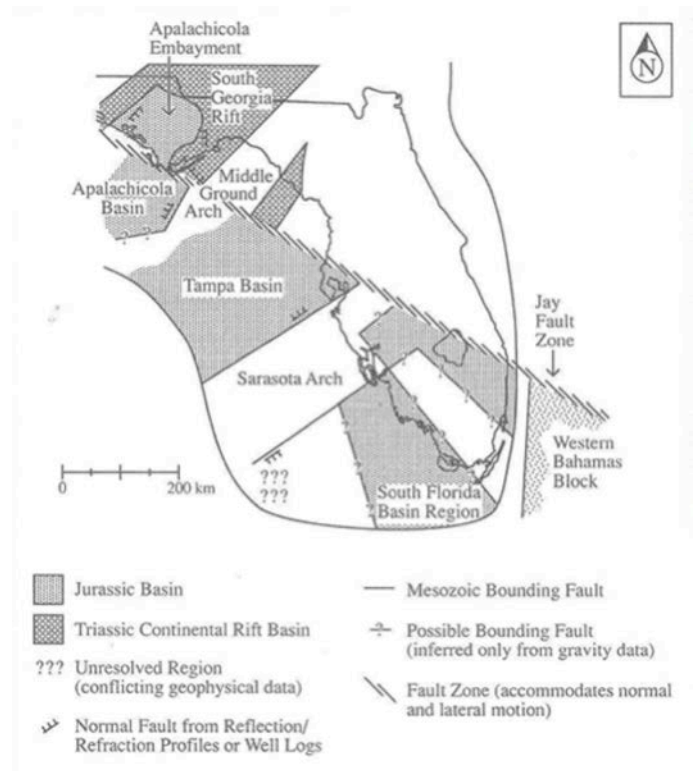


Figure 8. Illustration showing that the Apalachicola Embayment is actually part of the western end of the South Georgia Rift Basin. The De Soto Canyon occupies the western portion of the Apalachicola Embayment. (Smith and Lord, 1997).

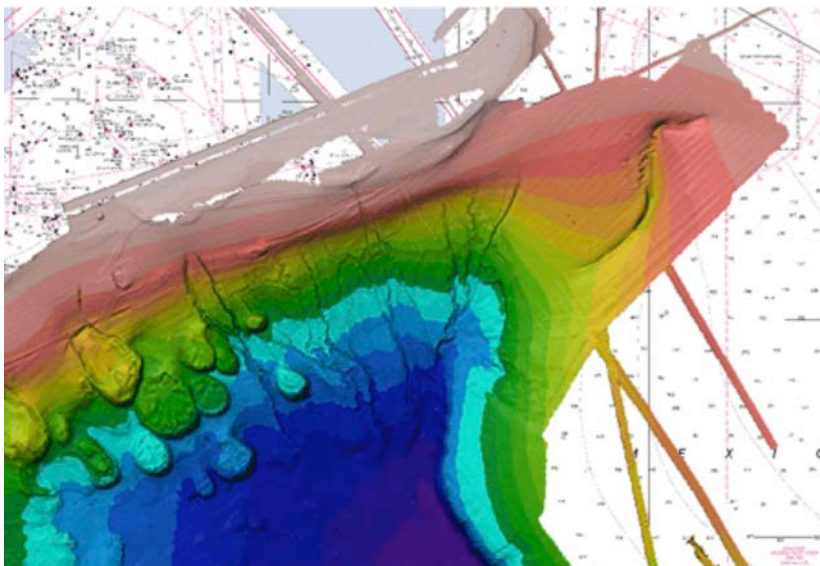


Figure 9. Multibeam image of numerous small downslope channels distributed within the broader De Soto Canyon indentation (Source: Source map data from NGDC - National Geophysical Data Center, includes RV Okeanos Explorer and other multibeam data - Dr. Stanley D. Locker).

The De Soto Canyon area clearly is part of the Gulf of Mexico megaprovince (Fig. 9). But is it really a canyon? A submarine canyon, traditionally defined in geological oceanography, is a steep-sided (sometimes near vertical walled), narrow feature incised into a submarine slope. It can extend landward onto the continental shelf and seaward to depths of several (2-3) kilometers.

By this definition, the De Soto Canyon, in its broadest sense, is not a submarine canyon similar to the narrow, highly-incised, precipitous, steep-walled features such as the Hudson or Monterey Canyons or the hundreds of other well-known features around the world's continental slopes considered to be true submarine canyons (Fig. 10). It is, rather, an expansive, gently-

sloped, geomorphic indentation in the modern shelf and shelf-slope system that is structurally controlled from below and represents the last unfilled segment of a huge Jurassic rift.

The details of this interpretation are the subject of the Ph. D. dissertation research of graduate student Shane Dunn at the University of South Florida, College of Marine Science.

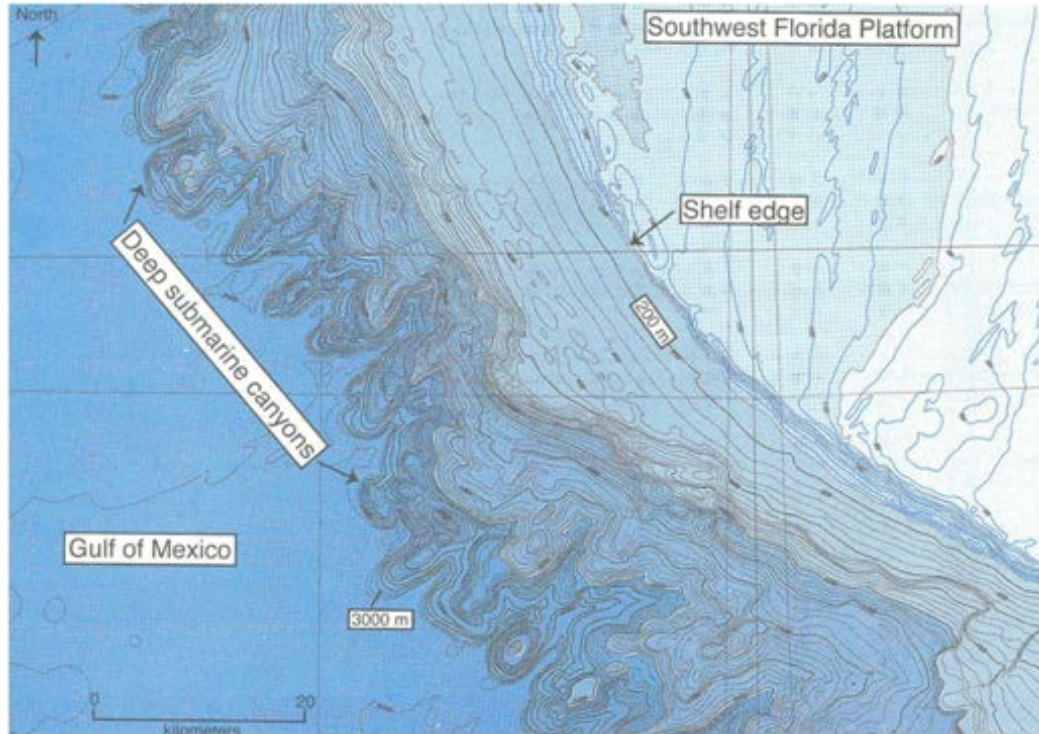


Figure 10. Submarine canyon complex along the base of the southwest Florida Platform. Some canyons have ~2 km of relief. These are headward-eroding, high-relief, steep-sided features that fit the classic definition of submarine canyon (NOAA National Ocean Survey map; Hine, 2013).

The modern De Soto Canyon contains a network of smaller canyons (many are more channel-like than canyon-like, given that the maximum relief of its canyons is ~100 m and most are much smaller) that will contribute sediment to its ultimate infill sometime in the geologic future. The De Soto Canyon also marks the long-term physical transition from the continental, siliciclastic sedimentary regime dominated by rivers along the north to the carbonate sedimentary regime dominated by shallow (pre mid-Cretaceous) and deeper water benthic and planktonic input (post mid-Cretaceous) to the south. Perhaps a more accurate term for this geologic feature is the De Soto embayment.

The De Soto Canyon in the Icehouse World—2.5 Ma to present

From the mid-Late Cretaceous (70 Ma) to the late Pliocene-early Pleistocene (~2.5 Ma), the Earth transitioned from a Greenhouse Earth—driven by very high CO₂ concentrations in the atmosphere that resulted in a very warm Earth with persistently high sea level—to an Earth that first accumulated a permanent ice sheet on Antarctica (beginning ~45 Ma). By ~2.5 to present, the Earth experienced high-frequency (23, 41, and 100 kya cycles; the well-known Milankovitch Cycles) glacial/interglacial events marked by the waxing and waning of the great northern hemisphere Laurentide and Fenno-Scandinavian ice sheets. Global sea levels fluctuated many dozens of times from ~50 to ~150 m amplitude during this latter period. We are still experiencing an Icehouse Earth, although at an interglacial stage having just come out of a the Last Glacial Maximum ending about 18 ka (18 thousand years ago) when sea level was about 120-125 m lower than present-day sea level.

The long-term transition from Greenhouse to Icehouse Earth, particularly in the past ~2.5 Ma, must have fundamentally changed the style of sedimentary infilling in the De Soto Canyon embayment. This transition and the nature of infilling resulting from many high frequency, high amplitude sea-level fluctuations that rarely occurred on the Greenhouse Earth is largely unknown. However, the imagery shown in Figure 9 clearly reveals erosive events creating a complex series of channels (small canyons) that accommodated transfer of sedimentary material from the upper slope or even the outer shelf to the base of the De Soto Canyon embayment. When and under what conditions this sedimentary transfer occurred creating this incised channel network is not known. Possibly, during sea-level highstands, infilling was not channelized and finer-grained

sediments accumulated whereas during sea-level lowstands and stillstands, infill was coarser-grained and more channelized. But, existing published deeper penetrating seismic data and unpublished industry-based data do not indicate that the De Soto Canyon is a long-term erosional feature that is incising landward. Rather, it is a broad sedimentary basin that has undergone long-term infilling prograding seaward only interrupted by short-term, relatively small-scale erosional events.

Endnotes

¹Other large bodies of water such as Hudson Bay, while geographically large, are not considered ocean basins because they did not form by seafloor-spreading tectonics. These are considered shallow, epicontinental (defined as “up on the continent”) seas that filled with seawater flooding large areas on top of continental rocks generally sea-level highstands.

²We maintain that the western end of this structural feature underlies and controls the location of the modern De Soto Canyon.

Acknowledgments

We thank Dr. Felicia Coleman for the wonderful review, which greatly helped to change the geologic prose to one more understandable for the general reading public. We thank Tracy Ippolito for additional editing, her patience, and her help while we generated this document.

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LESSON PLAN: Mapping the De Soto Canyon



Underwater exploration using marine technology

Objective: To become aware and understand bathymetry and ways in which scientists can explore and map the seafloor using marine technology.

Standards: OLP 1, 2, 5, 7; SC.912.E.6.4, SC.912.E.6.5, SC.912.E.6.6

Time Required: One 50-minute class period

Keywords: bathymetry, side-scan sonar, ROV, AUV, MILET

Materials: Computer, projector, copies of the student worksheet (see page 16)

Background

The characteristics of the ocean floor in the Gulf of Mexico change greatly with depth and distance from shore. In many areas there are geological features such as rocky areas, canyons, steep slopes, and even natural oil and gas seeps. Together, these features influence the development of the many different and unique ecosystems. Mapping the floor of the Gulf is an important first step as scientists try to understand the diversity and abundance of marine life. On land, elevation is referred to as topography. In the ocean, the seafloor elevation is referred to as **bathymetry**. Bathymetry is the measurement of the depth of water bodies, including the ocean, rivers, streams, and lakes. Using sonar, scientists are able to map ocean trenches, ridges, plains, and submerged islands, creating maps that help them predict where different marine ecosystems—such as coral reefs and fishing grounds—may be found. Today, scientists make use of many different types of sonar systems for bathymetric mapping that range from single-beam depth measurements directly below a boat, to multi-beam and interferometric sidescan systems that record a broad swath of depth measurements extending to both sides of the boat. The swath mapping sonars can be attached to the boat or towed closer to the seafloor behind the boat in a towfish. The mapping sonars are also routinely operated on **Remotely Operated Vehicles** (ROVs – tethered to the boat) and **Autonomously Operated Vehicles** (AUVs – unattached and freely maneuvering small vehicles).



An area of particular interest to researchers is the De Soto Canyon. It is a broad southwest to northeast feature formed at the intersection between the Florida Peninsula and the southeastern portion of the continental U.S. The two components contain distinct features, which often support different ecosystems. The west/north side is the North American margin, where river flows have deposited sediment layers that are literally miles thick. In many places, these sediment layers are characterized by salt domes, economic hydrocarbon reserves and natural seeps. The east/south side is the Florida Platform – a huge structure comprised of carbonate rock with much less sediment accumulation.

Deep-C scientists Drs. Ian MacDonald (FSU) and Stan Locker (USF) are investigating the role that the De Soto Canyon plays in the transport of material and energy between the coast and the deep sea. Detailed bathymetric data collected by the NOAA *R/V Okeanus Explorer* on its 2011 expedition to the Gulf of Mexico was used to establish ten sampling sites for repeated measurement for sediment geochemistry, microbiology, macrofauna, and geomorphology of the benthic habitat. The sites are distributed at depths from 500 to 2500 m in two transects, one along the main axis of De Soto Canyon, southwest to northeast (along-canyon) and one northward across the steepest slope of the canyon (cross-canyon).

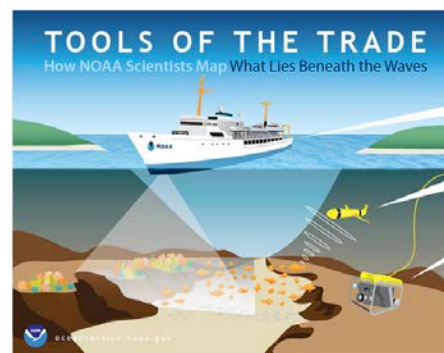
Using equipment such as **side-scan sonar** and the Modular Instrument Lander and Equipment Toolsled (**MILET**) system, quantitative imaging has been conducted to investigate the fine-scale geomorphology of the benthic transect. The Okeanos Explorer surveys and existing data had indicated that natural hydrocarbon seeps could be found at salt domes on the western extent of De Soto Canyon. MILET images confirmed benthic indicators of seeps at two potential sites. A brief survey of a location known as Peanut Hill revealed bacterial mats and asphalt extrusions. This is the first report of surface asphalts from the eastern Gulf of Mexico.



An unexpected patch of asphalt on Peanut Hill indicates natural hydrocarbon seepages.

Procedure

1. Ask students how scientists map the seafloor. How do they explore underwater topography, what tools do they use, why would we want to know what lies beneath the water?
2. Watch *Mapping the Seafloor* by NOAA at <http://oceanservice.noaa.gov/caribbean-mapping/mapping-video.html> (2:01min)
3. Visit the *Gallery: Sonar Operations* at <http://oceanservice.noaa.gov/caribbean-mapping/gallery-sonar.html> to learn about how sonar is used to map the seafloor and how scientists can determine whether the ocean bottom is smooth (mud or sand) or rough (coral or rocks).
4. Look at NOAA's infographic: *Tools of the Trade* <http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html>
5. Ask students if they have heard of the De Soto Canyon and if so what do they know about it?
6. Pass out student worksheets. Discuss the background information and describe how and why Deep-C scientists wanted to map the De Soto Canyon region.
7. Have students ID features on the map.
8. Collect student worksheets.



Source: <http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html>

Extensions

Have students read *Working Smart: Deep-C and NOAA Collaboration Improves Gulf Oil Research* <http://gulfresearchinitiative.org/working-smart-deep-c-and-noaa-collaboration-improves-gulf-oil-research/>

Read and Watch the ROV *Deep Discover*. *Okeanos Explorer* EX1402L3: Gulf of Mexico 2014 Expedition Dive 12: April 24, 2014: Tar Lilies <http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/apr24/apr24.html>

Resources & References

Learning Ocean Science through Ocean Exploration, Section 2: Mapping the Ocean Floor: Bathymetry <http://oceanexplorer.noaa.gov/edu/curriculum/section2.pdf>

Leg 1 Mission Summary: DeSoto Canyon Mapping Mission

<http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/leg1-summary/welcome.html>

Gallery: Sonar Operations <http://oceanservice.noaa.gov/caribbean-mapping/gallery-sonar.html>

Mapping the Seafloor by NOAA <http://oceanservice.noaa.gov/caribbean-mapping/mapping-video.html>

Tools of the Trade Infographic <http://oceanservice.noaa.gov/caribbean-mapping/seafloor-map.html>

USGS - National Seafloor Mapping and Benthic Habitat Studies: Head of De Soto Canyon, Northeastern Gulf of Mexico <https://walrus.wr.usgs.gov/pacmaps/ds-index.html>

Contributing Experts

Dr. Stan Locker at the University of South Florida, College of Marine Science

Dr. Al Hine at the University of South Florida, College of Marine Science

Dr. Ian MacDonald at the Florida State University, Department of Earth, Ocean, and Atmospheric Science

STUDENT WORKSHEET – Mapping the Seafloor in the Gulf of Mexico

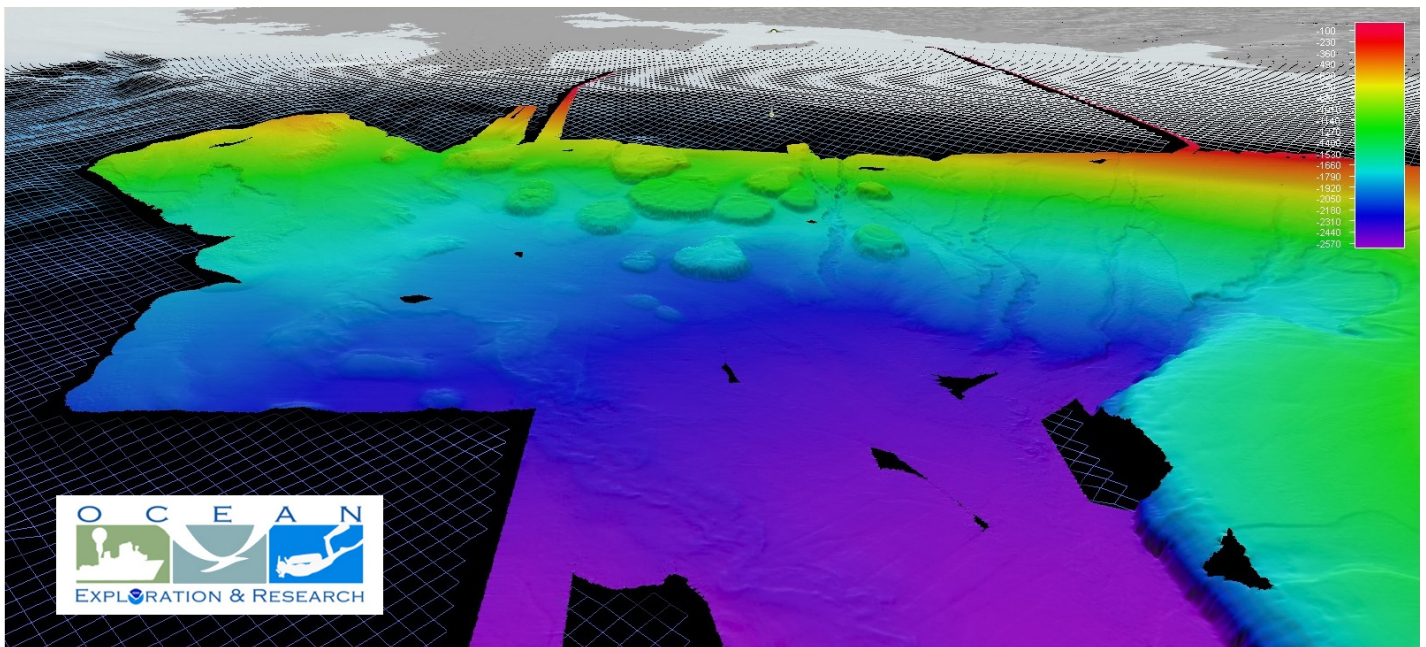
Bathymetric maps show the depth to, or elevation of, water bodies—including the ocean, rivers, streams, and lakes. These maps allow new information to be discovered and revealed about ocean geology and benthic habitats.

About the De Soto Canyon

- The De Soto Canyon lies approximately 100 kilometers south-southwest of Pensacola, Florida.
- The canyon's gradual gradients and unusual S-shape makes it distinct.
- It cuts through the continental shelf in the northern part of the Gulf, hosting an upwelling of deep nutrient-rich water and resulting in relatively high primary productivity in this area.
- The origin and distinct shape of the canyon has been debated to be a result of the presence of salt domes, erosion, and deposition due to bottom currents, and subsurface structure of possibly a salt ridge (Harbison, 1968).
- The canyon's bottom depths range from ~ 400-1,000 meters.

Source: <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1202/logs/leg1-summary/welcome.html>

The De Soto Canyon is a key geologic boundary between two different sedimentary depositional regimes. The canyon is a geologic enigma in that the north side is dominated by complex topography associated with downslope movement, whereas the south side looks much more “pelagic” in nature—soft sediment cover, morphologically featureless. ~ Al Hine, USF Professor



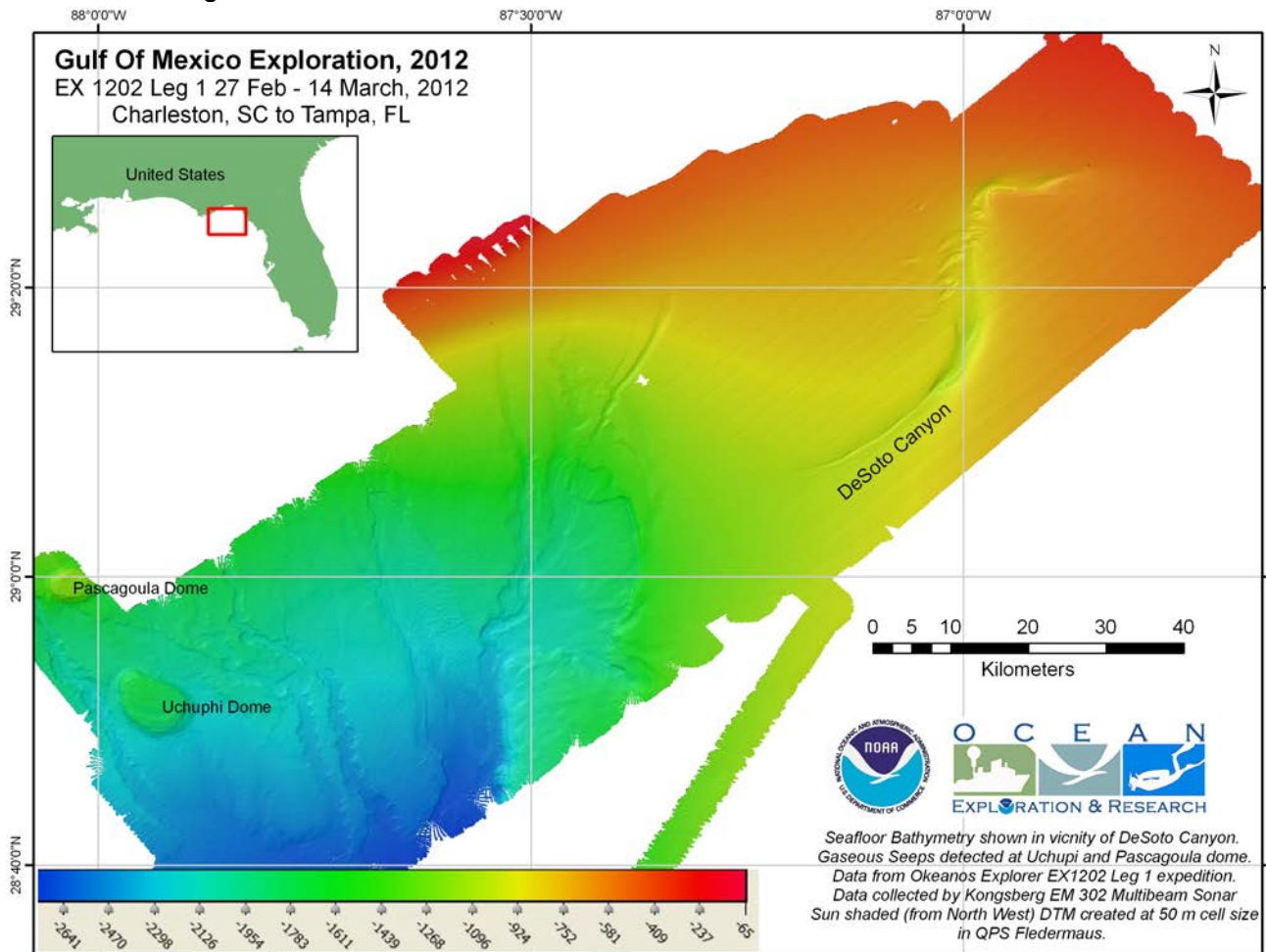
Multibeam bathymetry data showing the DeSoto Canyon (right) and Salt Domes (middle) in the northern Gulf of Mexico. EM302 bathymetry data acquired by NOAA vessel *Okeanos Explorer* during five cruises in 2011 and 2012. Image courtesy of NOAA *Okeanos Explorer* Program. Source: http://oceanexplorer.noaa.gov/oceanos/explorations/ex1202/logs/dailyupdates/media/apr15_update.html

About the Channel Systems

The channel systems seen in the R/V *Okeanos Explorer* map formed off the front of these deltas. One phase was 20,000 years ago during the last sea level lowstand. The shallow shelf was exposed, rivers deposited deltas at what is now the outer shelf break. Sediment from the deltas was channeled downslope (turbidities and debris flows) through the De Soto Canyon area into the deep Gulf of Mexico. Those channels may be mostly inactive now—but we do not know how much present-day ocean currents may cause sediment to move in the channels. This would be important for understanding if the 2010 Deepwater Horizon oil spill contaminants are being reworked and redistributed, further impacting bottom communities. Further research is needed—a project waiting for future students-turned-scientists to tackle.

Mapping Activity

On this map, identify the following features: salt domes, slope channel systems, the De Soto Canyon, and the continental shelf margin.

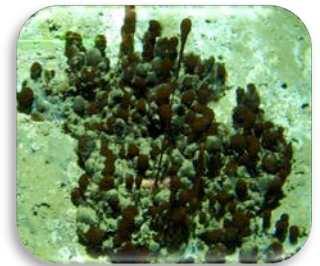


Bathymetric map of the De Soto Canyon generated at 50 meter grid cell size resolution based on preliminary data processing onboard during the expedition. Source: <http://oceanexplorer.noaa.gov/oceanos/explorations/ex1202/logs/leg1-summary/media/desoto.html>

Questions

1. What is the general shape of the De Soto Canyon?
2. Are there other canyons or features? Are these features easy to distinguish?
3. Are there any abrupt transitions?
4. What do the colors represent?
5. What is the depth on the deepest part shown on the map?
6. Why is it important to know the bathymetry of the De Soto Canyon?
7. How might the physical features of this region affect ocean currents and circulation in the area?

LESSON PLAN: Seeping through the Seafloor



Natural Oil Seeps - Part 1

Objectives: To learn about natural hydrocarbon (oil) seeps in the Gulf of Mexico and their associated animal communities. To understand the presence and movement of oil and gas are essential for specific deep-sea organisms to flourish.

Standards: OLP 1, 5; SC.912.E.6.5, SC.912.E.6.6

Time Required: One 50-minute class period

Keywords: natural seep, reservoir, gas hydrate, oil slick, deep-sea communities

Materials: Computer, projector, photos

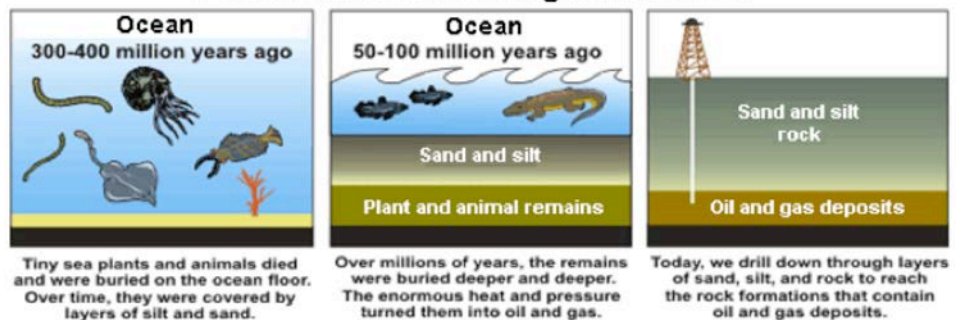
Background

According to Woods Hole Oceanographic Institution, as much as one half of the oil that enters the coastal environment comes from **natural seeps** of oil and natural gas. The oil was formed from plants and animals (organic matter) that died and were buried over millions of years on the seafloor. With time, heat, and pressure, oil and natural gas were created.

Geologic exploration is continually under way in search of new oil and gas deposits, which are often found together. These mixtures are less dense than rock and migrate upward through porous rock layers accumulating in pools beneath nonporous or impermeable rock layers. This process created expansive **reservoirs** that lie deep beneath the seafloor. Petroleum companies tap into these reservoirs to pull oil to the surface, to be refined and sold. But at natural seeps, oil leaks out of these reservoirs little by little, slowly making its way through sediments to the seafloor.

Natural seeps are geologic features known to occur in clusters around the world, such as off the southern coast of California and in the Gulf of Mexico. They are still relatively unstudied. In the Gulf, they can be found from depths of about 300ft to 12,000ft and concentrated in the central and western Gulf, from the U.S. south to Mexico. In locations where seeps are found, oil flows slowly up through networks of cracks forming springs of hydrocarbons. Lighter compounds rise buoyantly to the surface and evaporate or become entrained in the ocean currents; others fall to the seafloor and collect over hundreds or thousands of years. Seeps are often found in places where oil and gas extraction activities are also located.

Petroleum and natural gas formation



Source: U.S. Energy Information Administration (public domain)

Natural Seep Formations in the Gulf of Mexico

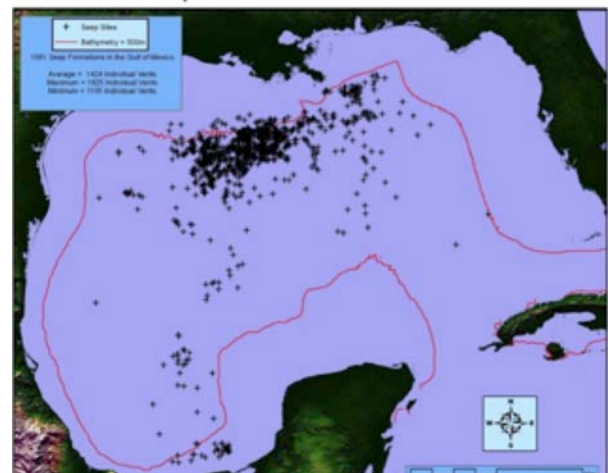
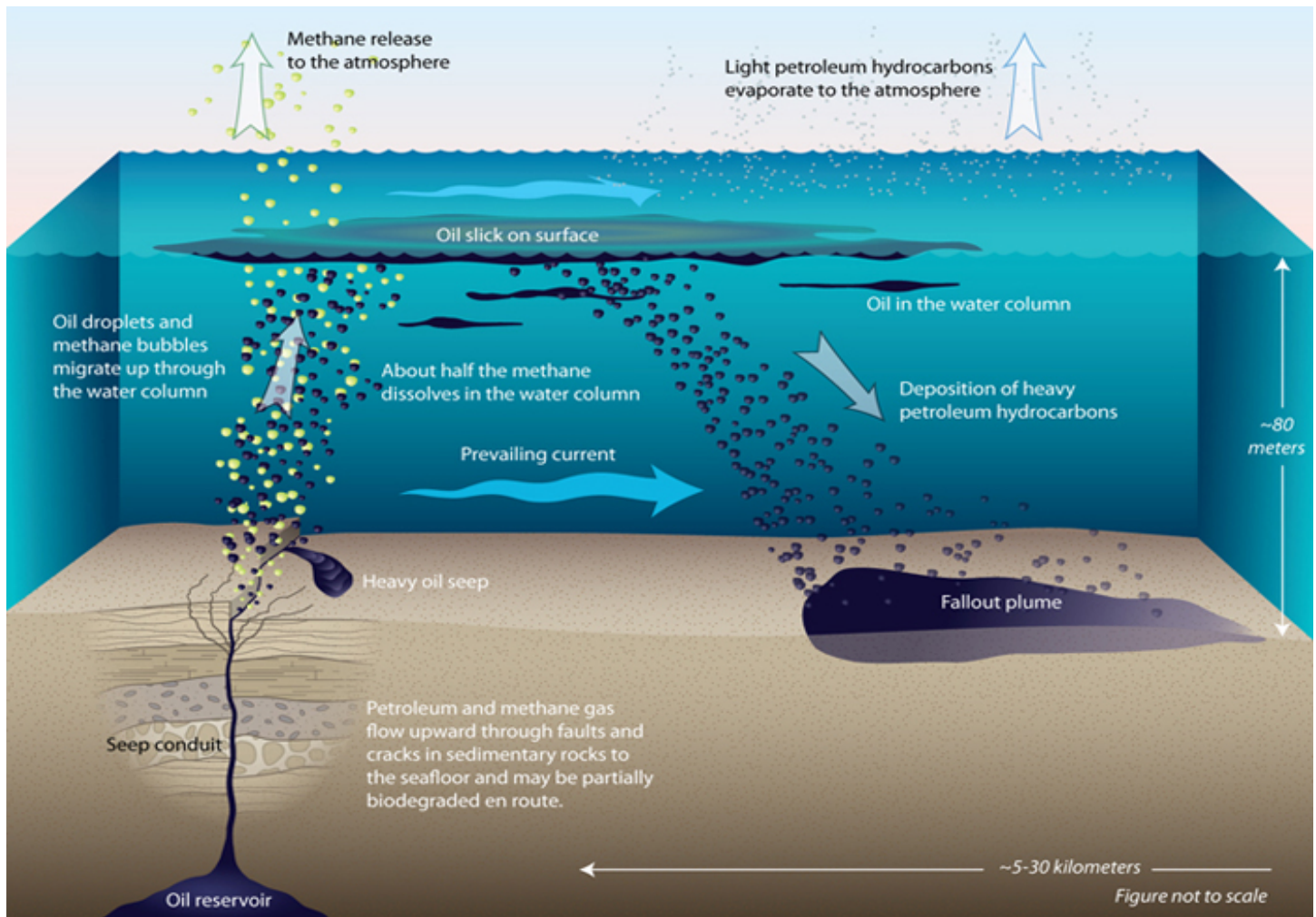


Image Credit: Dr. Ian MacDonald, FSU (2012)

As a result, many **surface oil slicks** and **tar balls** caused by seeps are often attributed to releases from oil and gas platforms. NASA uses satellite images of the sea surface to locate and track the oil slicks (see image to the right), which then can be used to locate the oil seeps at the seafloor. The question arises, then: If oil occurs naturally in the ocean and if seeps are the biggest single source, why is there concern about the occasional accidental spill? The answer lies in the nature and rates of oil inputs by these different sources. Seeps are generally very old and flow at a very slow rate. Flow rates will be discussed in Part 2 of this lesson.



Satellite imagery of oil slicks in the Gulf of Mexico. Source: NASA Earth Observatory



This illustration shows the route traveled by oil leaving the subseafloor reservoir as it travels through the water column to the surface and ultimately sinks and falls out in a plume shape onto the seafloor where it remains in the sediment. (Illustration by Jack Cook, Woods Hole Oceanographic Institution)

Surviving Near the Seeps: How Oil Feeds the Deep Sea

Excerpts from Caroline Johansen's Smithsonian Blog

Posted online November 18, 2014

Source: <http://ocean.si.edu/blog/how-oil-feeds-deep-sea>

When a large amount of oil is spilled into the ocean, there can be catastrophic results. But did you know that a little bit of oil in the ocean is actually necessary for many organisms to survive?

In the Gulf of Mexico, oil seeps are often associated with solid ice-like structures called gas hydrates (also called methane hydrates), which accumulate on the bottom around the seep. Gas hydrate is made up of a gas molecule (often methane, CH₄) trapped in a cage of water molecules. These gas-trapping cages are rigid in structure but very sensitive to temperature and pressure and will break apart if there is a drastic change. When they do break apart, the gas is released into the water. We see an abundance of wildlife including bacterial mats, ice worms (which burrow through the gas hydrates and graze on the bacteria), mussels, clams, crabs, eels, and fish living around these seep sites. These organisms are adapted to these toxic conditions. A few unique species of animals are actually able to use the hydrocarbons and other chemicals as a source of metabolic energy. Microbial (bacteria) degradation is active in these locations. The migration of natural oil and gas is extremely important for deep-sea communities.

The deep sea is often thought to be a barren, unfavorable place for life; however, we see a diverse congregation of organisms flourish around these natural seeps.

Communities Near Natural Oil Seeps



Unique deep sea communities near natural oil seeps in the Gulf of Mexico. These ecosystems are an oasis of life where deepwater corals, crabs, mussels, tubeworms, and bacteria thrive.



Ice worms on a methane hydrate. Methane is the simplest hydrocarbon, and is the primary component of the natural gas that we burn for energy. Image courtesy of NOAA Okeanos Explorer Program.

Fun Fact from Ocean Explorer: If you hold a hydrate nodule in your hand and light it with a match, it will burn like a lantern wick. There is fire in this ice!

Procedure

1. Begin a class discussion on natural oil seeps by asking the students where they think oil in the Gulf of Mexico comes from. Brief students on how oil is formed.
2. Guess how many known natural oil seeps are in the Gulf? (*Approximately 900-1,000*)
3. Project map images of the natural seeps in the Gulf of Mexico http://sarsea.org/natural_seepage.html
4. Watch “Geology in the Gulf” video https://www.youtube.com/watch?v=bcv8yUK_iWU and discuss the key points:
 - In the northern Gulf of Mexico, there is oil and gas-bearing shale with a salt sheet underneath and a layer of sediment on top.
 - As these different geological forces interact, cracks in the oil bearing shale form and natural seepage comes out of the seafloor.
 - Thousands of places on the Gulf’s seafloor, oil is naturally seeping.
 - Special communities of animals such as mussels, tubeworms, and bacteria thrive in those environments.
 - Bacteria eat oil and as a byproduct they create a chemical environment, which rocks form. In places where oil seeps are located, carbonates form and where there is rock, deep-water corals grow.
 - The type of species that are seen near these natural seeps change with depth.
5. Discuss communities that thrive in these environments.

Questions

1. What is a natural seep and where are they located? *A place where oil naturally seeps from the seafloor; they are located in clusters off the southern coast of California and in the Gulf of Mexico*
2. Where does the oil go that is leaked out of the seep? *Travels through the water column to the surface*
3. How does NASA track the oil slicks? *Using satellite imagery*
4. Is oil always bad for the environment? *No, some communities thrive on these natural seeps*
5. What animals thrive in natural seep environments? *Bacteria, ice worms, mussels, clams, crabs, eels, and fish*

Resources & References

Gas Hydrates <http://oceanexplorer.noaa.gov/facts/hydrates.html>

“Geology in the Gulf” Video by coexploration https://www.youtube.com/watch?v=bcv8yUK_iWU

Natural Gas http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_home

Natural Seepage of Hydrocarbons in the Gulf of Mexico http://sarsea.org/natural_seepage.html

NOAA Ocean Explorer: The Ecology of Gulf of Mexico Deep-sea Hardground Communities
<http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html>

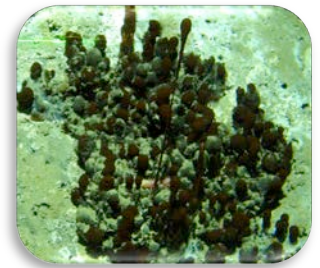
Oil in the Ocean: Natural Oil Seeps <http://www.whoi.edu/oil/natural-oil-seeps>

Ocean Portal Blog “How Oil Feeds the Deep Sea” <http://ocean.si.edu/blog/how-oil-feeds-deep-sea>

Perspectives Video – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1
http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GGMD13_CJ_1.aspx

LESSON PLAN:

Calculating Flow Rate



Natural Oil Seeps - Part 2

Objectives: To define flow rate, conduct experiment, calculate flow rate, and convert units. To understand how rates are calculated from natural oil seeps.

Standards: OLP 1, 5, 6; SC.912.E.6.5, SC.912.E.6.6, SC.912.N.1.7

Time Required: One or two 50-minute class period(s)

Keywords: flow rate, natural seep, experiment

Materials:

- Calculator

For Faucet Flow Rate Lab each group needs:

- Faucet Flow Rate Worksheet
- Water faucet
- Gallon jug (i.e. empty milk jug)
- Stopwatch

For Demonstrations:

- Water Bottles or Small Aquariums (2)
- Straws or Air Stone/Bubblers (2)
- Water
- Vegetable Oil

Background

Seeps release toxic chemicals, but they generally flow at a very low rate. The organisms that live near the seeps are adapted to these conditions. Some unique species of animals are able to use the hydrocarbons and other chemicals as a source of metabolic energy. The material flowing from seeps is often heavily biodegraded by microbial action deep below the ocean floor.

“Seeps are often looked upon as a living laboratory for scientists to study how natural processes affect the fate of released oil or how individual species or communities of plants and animals are capable of dealing with the burden of otherwise toxic chemicals. From this may one day come a better understanding of how to help places affected by oil spills recover and regain much of their pre-spill health and function” (WHOI-Oil in the Ocean: Natural Oil Seeps, 2014).

Calculating the Number and Size of Bubbles

Excerpts from *“How Oil Feeds the Deep Sea”* by Caroline Johansen, FSU PhD student

“One of my research goals is to determine how much oil and gas is released by these natural seeps. We use video cameras to film the exit points of oil bubbles at the sea floor. A video time-lapse camera is placed close to the seep site and is left to take video footage for extended periods of time. We deploy the cameras at depths of around 4,000 feet (1,200 meters), which is deeper than any diver can go. Instead, we use remotely operated vehicles (ROVs) controlled by pilots on a research vessel to place the camera in the right spot at the bottom of the ocean...When we bring the camera back up, I use automated image processing techniques that I developed to count the bubbles filmed. Calculating the number and size of bubbles can give us an idea of how much oil and gas is released from natural seeps.



Some areas have rapid bubble release, and some areas extremely slow. The amount of oil and gas in the bubbles also differs. Some natural seep areas release very oily bubbles, which we can identify by their dark

brown color. Others have much higher gas content, where you see shiny clear spheres bubbling out of the gas hydrate. We are still in the process of investigating exactly why we see such differences between the bubble releases at separate natural seep areas, but this bubble counting technique I have developed allows us to get a range of bubble release rates. By knowing where this oil and gas comes from, how it travels through the sediments to the sea floor, and how much oil and gas is being released, we can begin to understand the complex dynamics of these deep-sea seep systems.

We know that the migration of this oil and gas is extremely important for deep-sea communities. The deep sea is often thought to be a barren, unfavorable place for life; however, we see a diverse congregation of organisms around these natural seeps. The presence and movement of oil and gas is essential for these organisms to flourish and could possibly give us insight to how the first life forms evolved on Earth.”

Comparing Natural Oil Seeps with the BP Discharge

Source: Testimony of Ian R. MacDonald, Professor of Oceanography, FSU. (2010). *Determining the Rate of the BP Oil Discharge and Comparison with Natural Oil Seeps*. National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

“An active natural seep discharges about 10 barrels of oil per day (BOPD) with variable magnitudes of gas. The BP discharge was as much as 62,000 barrels of oil and over 31,000 barrels of oil equivalent gas during the initial phases of the emergency, decreasing to an estimated 53,000 BOPD at the end.”

“Oil from natural seeps, like the oil that rose to the surface from the BP well, leaves traces that can be detected by satellite remote sensing. Natural seeps create floating layers (slicks) that are <1% of the thickness of human hair (<1 μ m) and cover surface areas of 0.5 to 1 km². The oil from BP's discharge created large slicks with similar thicknesses and included substantial areas around the well where the oil was at least 100 fold thicker. In all, the surface oil from the discharge covered an area over 20,000 km² during much of the discharge episode.”

“The BP oil discharge was at least 10,000 times more concentrated in space and time and about 12 times greater in magnitude than the total annual release from natural seeps of the Gulf of Mexico.”

Procedure

1. **Review Background Information and Read aloud** “Calculating the Number and Size of Bubbles (Excerpts from *How Oil Feeds the Deep Sea* by Caroline Johansen)” to the class.
2. **Watch the CPALMS Perspectives Video** – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1
http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GG_MD13_CJ_1.aspx (5:42min)
3. **Faucet Flow Rate Activity** *Adapted from Teaching Engineering*
Summary: Students conduct experiments to determine the flow rate of faucets by timing how long it takes to fill gallon jugs. They do this for three different faucet flow levels (quarter blast, half blast, full blast), averaging three trials for each level. They convert their results from gallons per second (gps) to cubic feet per second (cfs).

One important aspect of good experiments is repeating the experiment and averaging the data from numerous trials. Averaging the data from repeated trials reduces data error.

1. Divide the class into three groups and hand out the Flow Rate Experiment worksheet.
2. Explain the experiment and read the procedure.
3. Instruct Group 1 to complete Table 1 gathering the Full-Blast Data; Group 2 to complete Table 2 and gather the Half-Blast Data; and Group 3 to complete Table 3 and gather the Quarter-Blast Data.

Flow rate is the volume of water passing a point in a fixed period of time. Flow rate is usually measured in cubic feet per second (cfs or ft³/sec) but it can also be measured in gallons or liters per minute or second.

For example, if a running faucet took one minute to fill a gallon container, its flow rate would be one gallon per minute.

Water flow in a stream, river or pipe also has a flow rate. The flow rate in a river, stream or pipe can be determined by multiplying water velocity by the cross-sectional area. For example, if water was flowing through a 1 foot diameter pipe (area = 0.8 ft²) at 5 feet per second, the flow rate would be 0.8 ft² x 5 ft/sec = 4 ft³/sec.

4. Have groups begin the experiment and make sure that they record the data in the correct locations (tables) on the worksheet.
 5. When students are finished with the faucet, timing and jug filling, instruct them to dry their lab area and share data across the different groups.
 6. Then groups can begin graphing and calculating. The calculation of flow rates in gallons per second takes place in Tables 1, 2 and 3. The calculation of flow rates in cubic feet per second takes place in Table 4. (If necessary, assign calculations as homework.)
4. **Discuss and Demonstrate.** How it would be different with oil. (Density difference between water and oil and how this affects fluid flow)...Stokes Law of Fluid Flow
 Demonstration that represents two different substances that flow in the ocean with differing densities: Place a straw to the bottom of a water-filled ($\frac{3}{4}$ full) bottle, blow air through the straw, and watch the flow rate of “gas” rise up. Repeat using a bottle $\frac{3}{4}$ filled with vegetable oil and compare. Discuss what factors would change the rate.
- *This could also be demonstrated using small aquariums and bubblers (air stones). Fill one aquarium with water and the other with oil. Place a bubbler or air stone in the bottom on the tank. Compare and contrast the flow rate in the different substances.
- Food for Thought:** Introduce the three-dimensional aspects of the ocean...meaning the flow rate of less dense substances will want to flow upwards (vertically), but there are also horizontal factors in the ocean such as currents which would deflect the path of the flow.
5. **Discuss “Comparing Natural Oil Seeps with the BP Discharge”** Talk with the students about how they think the amount of 2010 BP oil spilled compared to the natural oil seeps.

Questions

1. What is flow rate? Why is it important? *The volume of water passing a point in a fixed period of time; gives us an idea of how much oil and gas is released from natural seeps*
2. How is flow rate calculated? *Cubic feet per second (cfs or ft³/sec)*
3. What is the difference between the flow rate of oil and water? *Oil should have a slower flow rate*
4. How is flow rate calculated for natural oil seeps? *Using automated image processing techniques to count the bubbles filmed by the ROV; then calculating the number and size of bubbles*
5. How do you think the amount of oil that flows out of natural oil seeps compares to the amount of oil discharged by the 2010 Deepwater Horizon Spill? *Answers will vary*

Resources & References

Ocean Portal Blog “How Oil Feeds the Deep Sea” <http://ocean.si.edu/blog/how-oil-feeds-deep-sea>

Oil in the Ocean: Natural Oil Seeps <http://www.whoi.edu/oil/natural-oil-seeps>

Perspectives Video – Standard: MAFS.912.G-GMD.1.3 - Caroline Johansen - Video 1
http://www.cpalms.org/CPALMS/perspectives_professional_MACC912GGMD13_CJ_1.aspx

Teaching Engineering Lesson: Flow Rates of Faucets and Rivers

Contributed by: Civil and Environmental Engineering Department, Colorado School of Mines

https://www.teachengineering.org/view_lesson.php?url=collection/csm_/lessons/csm_engineering_our_water/csm_lesson1_flow_rate_experiment.xml

Testimony of Ian R. MacDonald, Professor of Oceanography, Florida State University. (2010). *Determining the Rate of the BP Oil Discharge and Comparison with Natural Oil Seeps*. National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling

<http://www.motherjones.com/files/092710macdonaldtestimonyrevised.pdf>

Contributing Expert: Caroline Johansen, PhD student at Florida State University

Group Members: _____

Flow Rate Experiment Worksheet

Adapted from Teaching Engineering



Brainstorm with your group and then summarize your answers in the spaces provided.

What is flow rate? How does it relate to your life?

You will conduct experiments to determine the flow rate of faucets by timing how long it takes to fill gallon jugs. The class will do this for three different faucet flow levels (quarter blast, half blast, full blast), averaging three trials for each level. Your group will convert the results from gallons per second (gps) to cubic feet per second (cfs).

Materials

- A water faucet
- An empty gallon jug
- A stopwatch

Procedure

1. Select one person to be the timer and one to hold the gallon jug.
2. Turn the faucet on full blast. Estimate the time you think it will take to fill up the gallon jug. Record your answer in Table 1.
3. Start the timer at the same time as the jug is placed under the faucet.
4. Determine how much time (in seconds) it takes to fill the jug all the way to the top. Record the time in Table 1 on Data Sheet 1 in the line called Full-Blast Trial #1.
5. Empty out the jug.
6. Repeat steps 3-6 two more times, and fill in the lines called Full-Blast Trial #2 and Full-Blast Trial #3 in Table 1.
7. Now turn the faucet on half-blast. Repeat steps 2-6 and record your data in Table 2. **Make sure to open the faucet to the same place for each trial!**
8. After you have done three tests at half-blast, turn the faucet to quarter- blast, and repeat steps 2-6. **Make sure to open the faucet to the same place for each trial!** Record your data in Table 3.
9. Use your data to determine the flow rate for each of your trials; record the answers in each table.

HINT: You know how many seconds it took to fill up one gallon, so IF it took 17 seconds to fill up the gallon jug your calculation might look like this:

$$\frac{1 \text{ gal}}{17 \text{ sec}} = 0.059 \text{ gallons / second}$$

Table 1 – FULL-BLAST DATA

Faucet Level: Full Blast	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

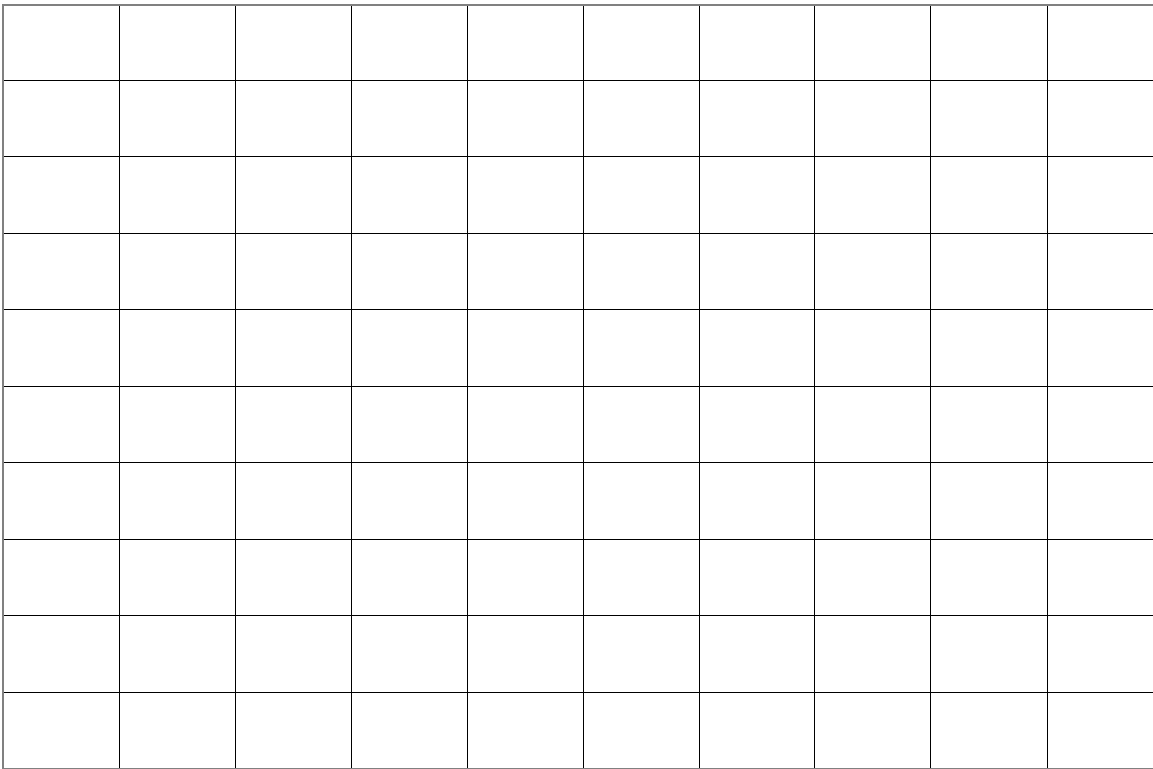
Table 2 – HALF-BLAST DATA

Faucet Level: Half-Blast	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

Table 3 – QUARTER-BLAST DATA

Faucet Level: Quarter-Blast	Prediction time needed to fill the jug (seconds)	Actual time to fill the jug (seconds)	Flow Rate (gallons per second)
Trial #1			
Trial #2			
Trial #3			
Average of Trials			

10. Create a graph of your average flow rate (on y-axis) versus average time to fill the jug (on x-axis). Your graph should have three data points. Include a title and labels on each axis.



11. Draw a “best fit” straight line through the data points.
12. What percent does the flow rate increase as you go from half blast to full blast?

13. Using the graph, what would the flow rate be at $\frac{3}{4}$ blast?

14. Now that you have your flow rates in gallons per second, you need to convert them to cubic feet per second. Cubic feet per second are very common units for flow rate. Fill in Table 4 using the following conversion:

$$1 \text{ gallon} = 0.134 \text{ ft}^3 \text{ or } 0.134 \text{ cubic feet}$$

HINT: IF your flow rate was 0.059 gal/sec you would divide by 0.134 ft^3/gal (given above), and your calculation would look like this:

$$\frac{0.059}{0.134} = 0.44 \text{ ft}^3 / \text{sec}, \text{ or } 0.44 \text{ cfs}$$

Table 4: Converting Gallons/Second to Cubic Feet/Second

Faucet Level	Flow rate (gal/sec) <i>FROM DATA SHEET 1</i>	Flow rate (cubic feet per second)
Quarter-blast		
Half-blast		
Full-blast		

Flow rate is the volume of water passing a point in a fixed period of time. Flow rate is usually measured in cubic feet per second (cfs or ft³/sec) but could also be measured in gallons or liters per minute or second. For example, if a running faucet took one minute to fill a gallon container, its flow rate would be one gallon per minute. Water flow in a stream, river or pipe also has a flow rate. The flow rate in a river, stream or pipe can be determined by multiplying water velocity by the cross-sectional area. For example, if water was flowing through a 1 foot diameter pipe (area = 0.8 ft²) at 5 feet per second, the flow rate would be 0.8 ft² x 5 ft/sec = 4 ft³/sec.

LESSON PLAN:

Sifting through Sediments

Investigating sediment cores from the NE Gulf of Mexico

Objectives: To understand the role that sediment investigations play in understanding ecosystem development. To investigate seafloor composition, discuss the potential effects of Deepwater Horizon oil settling on the seafloor, and analyze a sediment core. Students should know about geology of the Gulf of Mexico.

Standards: OLP 1, 6; SC.912.E.6.4

Time Required: One 50-minute class period

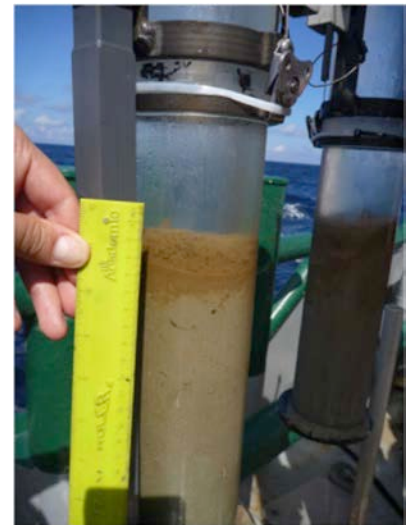
Keywords: sediment, multi-corer, benthic, smear slide analysis

Materials:

- Whiteboard
- Modeling clay
- An 8-inch cylindrical vessel filled $\frac{3}{4}$ full with corn syrup; mark off the top of the liquid with tape/marker and then mark off a line 20cm below that
- Stopwatch
- Rocks in various sizes
- Copies of the article “*Scientists Find Thick Layer Of Oil On Seafloor*” (on page 33)
- Sediment cores (see lesson for more information)
- Microscope
- Slides
- Toothpicks

Background

The ocean floor is made almost entirely of different types of **sediment** such as mud, sand, and gravel. This sediment comes from a variety of places including materials washed into the ocean from rivers, the decomposition of plankton and sea animals, chemical reactions (i.e. volcanoes and vents), and dust carried by the wind that settles in the ocean. Surprisingly, material from land makes up 75% of seafloor sediment. The Mississippi River deposits 145 million metric tons of sediment per year into the Gulf of Mexico and much of this settles on the continental shelf. In the deep ocean however, most of the seafloor is composed of organic matter that has fallen to the seafloor from the surface. This happens continuously. Finally, sediment can form around deep sea volcanoes and vents and from other chemical process in the ocean. These sediments are rare comparatively, but they often serve as a home for unique habitats and niche ecosystems. An example of this in the Gulf of Mexico is the asphalt seeps discovered near the De Soto Canyon. Ocean currents and tides also play a part in distributing and filtering sediments. A strong storm can change the composition of the seafloor overnight. Protected areas, such as harbors, estuaries and fiords encourage silt and clay to settle. Deep-C scientists went on several research cruises in the northeastern Gulf of Mexico to collect data on seafloor sediments, particularly in the De Soto Canyon region. Using a tool called a **multi-corer**, they are able to extract sediment cores from the seafloor. These cores are analyzed to determine their composition as well as to make predictions regarding the amount of Deepwater Horizon oil that settled to the seafloor. Soft sediments characterize the De Soto Canyon, and the two sides of the canyon have different sediment compositions because of the influence of the Mississippi River on the western edge. An easy methodology for determining sediment

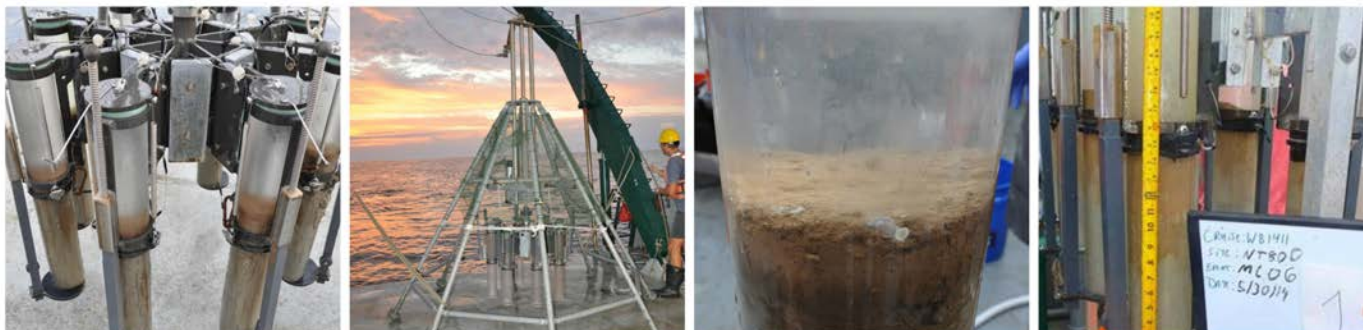


Sediment core with a layer of oil on top.



Asphalt extrusion with coral attached. Image courtesy of NOAA Okeanos Explorer Program, Gulf of Mexico 2014 Expedition.

composition is to perform a **smear slide analysis**. A small amount of sediment is observed under a microscope and grain types are put into three different categories: minerals, microfossils, and volcanic glass. In this lesson, students will investigate seafloor composition, discuss the potential effects of Deepwater Horizon oil settling on the seafloor, and analyze a sediment core.



A device called a multi-corer is used to take sediment core samples from the seafloor.

Procedure

1. Sediment Particle Speed Demonstration: Use modeling clay to create sediments of various sizes (at least six). Measure the diameter of each sediment sample and write it on the whiteboard (see table below for an example). Ask students to hypothesize which sediment will settle the fastest when dropped into the cylinder of corn syrup. Drop the clay pieces into the tube one at a time, recording the time it takes to reach the bottom and writing it in the table on the board. Have students calculate the average settling rate by dividing the diameter of the clay pieces by the time it took them to settle on the bottom (cm/sec) and discuss. Repeat the experiment using the rocks.

Particle Size	Trial	Time (seconds)	Settling Rate (cm/sec)
.5 cm			
1 cm			
3 cm			

2. Sediment Settling: Have students read the article, “*Scientists Find Thick Layer Of Oil On Seafloor*” and answer the following questions.

- If oil is less dense than water, how could it settle on the seafloor? Describe the process that makes this happen.
- What are the potential impacts of a layer of oil covering the seafloor?
- How might this influx of oil change the composition of seafloor sediment?

3. Sediment Core Analysis: For this portion of the lesson you can choose from a variety of options:

- Make a core for students to analyze out of various sediments of different sizes, such as gravel, sand, clay, etc. Use one-liter soda bottles with the ends cut off for an inexpensive tube.
- Buy pre-made cores from ENSCO (<https://www.ensco.com/product/SB27465M>)
- Have students take sample cores from an area water source such as a lake, river, pond, or the ocean using a soil sampler. You can purchase soil samplers from Carolina Biological Supply, among other places.

Using their sediment cores, have students conduct a smear slide analysis by swiping a toothpick across the cross section of the core and examine it under a microscope. They should record their observations and make note of grain size, color, texture, and composition.

Have students research sediment composition and create a dichotomous key using their notes from the smear slide analysis.



Nick Myers (FSU) and Kala Marks (Georgia Tech) sectioning a sediment core from a sampling site near the De Soto Canyon.

Questions

1. What kinds of materials do you expect to find on the seafloor? *Mud, sand, gravel, microfossils, volcanic glass, etc.*
2. Where does the majority of sediment on the seafloor come from? *Land.*
3. What factors can affect sediment settling rates? *Currents, wind, waves, topographic features.*
4. How could this influence how oil from the Deepwater Horizon oil spill reached the seafloor? *Open-ended.*
5. Think of a water source near where you live. What might the sediment in that place be composed of? *Open-ended.*

Extension

Combine this lesson with the “*What can we learn from Sediment Profiling?*” in the Geochemistry module (see page 52) to investigate other information that scientists can glean from sediment cores.

Resources & References

John, Kristen. *Reconstructing Earth's Climate History: Inquiry-based Exercises for Lab and Class.* Hoboken, N.J.: Wiley, 2012. Print.

Lewis, Keith. *Sea Floor Geology – How sediment forms.* Te Ara – The Encyclopedia of New Zealand, updated 13-Jul-12. <http://www.TeAra.govt.nz/en/sea-floor-geology/page-6>

Scientists Find Thick Layer Of Oil On Seafloor

By Richard Harris (Posted online September 10, 2010)

Source: NPR <http://www.npr.org/templates/story/story.php?storyId=129782098>

© 2010 National Public Radio, Inc. NPR news report titled “Scientists Find Thick Layer Of Oil On Seafloor” was originally published on All Things Considered on September 10, 2010. The article was included in a limited print version of the Deep-C Gulf of Mexico Multi-disciplinary Curriculum for High School Science with the permission of NPR. However online duplication was prohibited.

To obtain a copy of the article, go to: <http://www.npr.org/templates/story/story.php?storyId=129782098>

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LESSON PLAN: Remotely Operated Vehicles (ROVs)



An Essential Tool for Underwater Exploration

Objective: To provide students with an opportunity to build and test a working ROV and to gain knowledge related to the way in which ROVs are used in scientific research.

Standards: OLP 6-7; SC.912.N.1, SC.912.P.12.3

Time Required: Several class periods or afterschool sessions

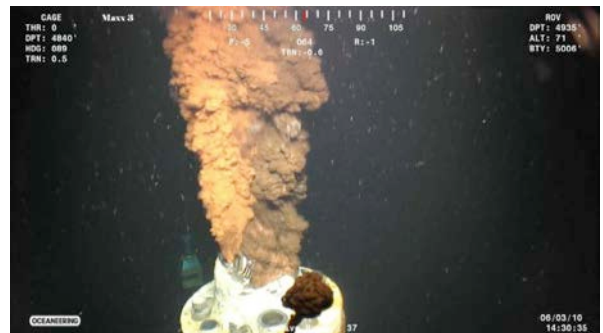
Keywords: marine technology, ROVs, tether, propulsion, buoyancy, pressure

Materials:

- 16 oz. plastic soda bottle
- Marshmallows
- Vacuum pump (needs to fit bottle)
- Index card
- Eye-droppers
- Pre-made ROV kits or Parts to construct ROVs (see lesson for more information)
- Pool

Background

Underwater **Remotely Operated Vehicles (ROVs)** are exploration robots that are operated by a person on a boat. They are safer than manned submarines and relatively easy to maneuver. ROVs are linked at all times to the boat by a **tether**, which consists of cables that carry electrical signals back and forth between the operator and the vehicle. ROVs come in many shapes and sizes, ranging from the size of a small computer to a small truck. The larger ones are very heavy and require additional equipment just to put them over the side of a ship. Most ROVs include a camera and lights, but other gear, such as sonar, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature can be installed and enhance their capabilities.



ROVs were used to monitor and attempt to cap the well during the Deepwater Horizon oil spill.



The ROV operator (or pilot) controls the device from the ship, similar to how you would play a videogame. Using a joystick, camera control, and video monitor, the pilot flies the ROV to desired locations. The pilot can see what the ROV is seeing, steer the ROV, take photos and video, and capture samples using robotic arms. ROVs, and other innovations in **marine technology**, are enabling scientists to more fully explore underneath the surface of the ocean. In the Gulf of Mexico, researchers are investigating deep sea corals, natural oil seeps, and much more with the help of ROVs. In this lesson, students will discover the science behind ROVs, practical applications, and build their own ROV.

Procedure

- 1. How ROVs work:** Understanding how pressure and buoyancy work in the ocean is essential to building an ROV. Review with the students by conducting the following demonstrations.
Pressure: Fill the plastic bottle halfway with marshmallows. Use the vacuum pump to create a vacuum in the bottle that will cause the marshmallows to expand in order to fill the bottle. As you release the vacuum the marshmallows will decrease in size!
Pushy Air: Place water in a clear plastic cup. Place a piece of cardstock (index card) over the cup and make sure that it has a good seal. Turn the cup upside down and remove your hand from the cardstock. The cardstock continues to stay in place because air is exerting pressure upward on the cardstock.

Buoyancy: Fill a plastic bottle with water and fill an eyedropper two-thirds full of water. Place dropper in the bottle. The eyedropper should float about 1-2 inches from the top of the bottle. If not, repeat changing the amount of water in the dropper until you obtain neutral buoyancy. Place the cap on the bottle and tighten. Try to make the dropper become negatively buoyant so that it sinks to the bottom of the bottle without turning the bottle upside down. Once the dropper sinks, then make the dropper become positively buoyant and return to its neutral buoyant position.

2. Have students explore the NOAA Ocean Explorer 2014 Pulley Ridge

Mission site, <http://oceanexplorer.noaa.gov/explorations/14pulleyridge/welcome.html> and answer the following questions:

- What are the main research goals of this mission?
- How are ROVs being used to collect data?
- Who are ROV pilots and what are their main duties?
- What are some other examples of marine technology that are being used to complete this mission?
- Where is Pulley Ridge and why is it important to study?



ROV with a plankton tow made by Deep-C intern Rachel Holliday.

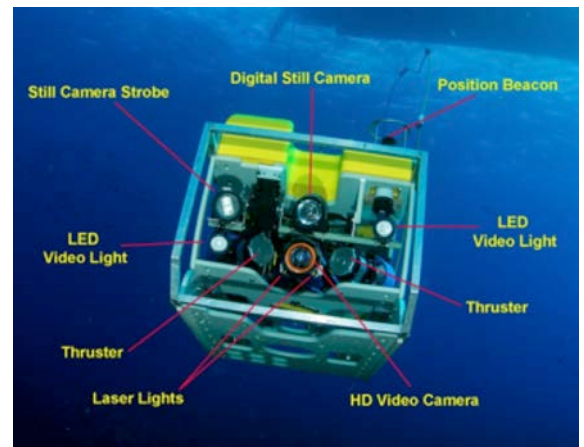
3. Ask students to find a video of ROVs being used for scientific research and write a review.

Review must include source of the video as well as information about the types of observations being made and the scientists involved. Here is an example of a seafloor mapping expedition aided by the use of ROVs:

<http://oceanservice.noaa.gov/caribbean-mapping/>

4. Have students build their own ROVs and stage a class competition in a pool or off of a dock.

MATE (Marine Advanced Technology Education) will lend ROV kits to teachers for a fee. See <http://www.marinetech.org/mate-loaner-rov-kit-request-form-/> for more information and watch the video tutorial. Alternately, you can buy ROV kits from MATE or SeaPerch (http://www.seaperch.org/order_kit), or you can purchase parts individually to permit students the maximum flexibility in ROV design. See the NOAA resource “ROV in a Bucket” for a detailed list of items needed to construct an ROV.



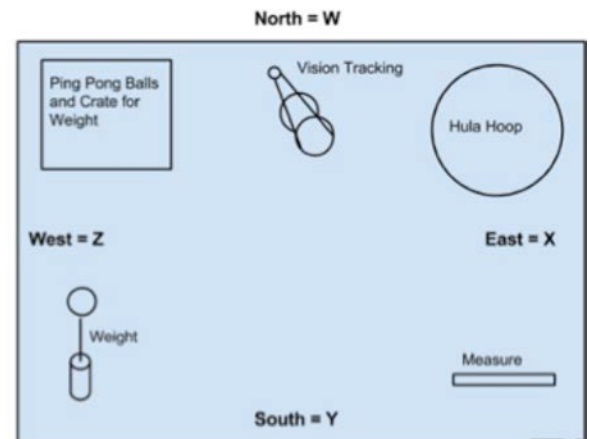
Source: <http://flowergarden.noaa.gov/science/mohawkrov.html>

Assign students into teams of at least 2-3 to build an ROV for a class competition. Building can take place during class or as part of an after-school program. Give the teams the following mission:

“Your team has been sent to the northeastern Gulf of Mexico to help Deep-C scientists assess the impact of the Deepwater Horizon oil spill on Gulf ecosystems. You must design an ROV that can take measurements, maintain neutral buoyancy, and be able to manipulate objects underwater.”

Arrange for the use of the pool and set up a course that the students have to complete (see diagram). Ask parents, other teachers, or professionals in the field to come to judge the teams (see sample score sheet) on their ability to complete the challenges, as well as on the design of their ROV and a short presentation on their building process (using the judging rubric on the following page). Have each team run through the course twice, tally up the scores, and declare a winner.

Pool Layout: All distances within 30 feet.



Pool diagram developed by JaSun Burdick of SAIL High School in Tallahassee, FL

Specification	Tasks	Scoring (Max 25pts/Task)	Round 1	Round 2
1 Neutral Buoyancy	# of consecutive seconds able to keep a visual target aligned on the side of the pool, lined up between two 4" rings 1 meter apart	2 pt / sec		
2 Navigate	Retrieve to tether person as many 4" rings as possible. 2 hanging from the surface 2 suspended, and 1 on the bottom.	5pt each		
3 Navigate	Flip a milk crate to release 5 ping pong balls at the bottom of the pool. Collect and deliver to tether person.	5pt each		
4 Navigate small spaces	Pass in and out of a 38" Hulla hoop	25 pts		
5 Motor Power	Lift a 1lb weight into a milk crate. Weight will be tied to a floating 4" ring to help lifting.	25 pts		
6 Vision, Data Collection	Measure the size of a unknown object (Possible range 5-30cm)	25pt right (-1pt for every cm off)		
7 Vision, Data Collection	Read 4 signs on each side of pool (N,S,E,W). Solve simple order of operations math problem	5pts / sign (math +5)		
	Deductions			
	Pulling on tether to assist robot motion	5pts / infraction		
	Communicating with the driver	5pts / infraction		
	Driving ROV before round start	5pts		
		Best Round used for Final Scoring		
Design Presentation	Sections	Scoring		
	Presentation illustrating the strategy, difficulty, design iterations	10		
	Creativity, inventiveness, originality	10		
	Engineering Design concepts (thrust, buoyancy,...)	10		
	Open Questions by the judges	10		
		Presentation Score		

Score sheet and Pool Diagram developed by JaSun Burdick of SAIL High School in Tallahassee, FL

Resources & References

Marine Advanced Technology Education (MATE) - MATE is a national partnership of educational institutions and organizations working to improve marine technical education in the U.S. The MATE Center and its partners have developed several curriculum modules and programs including: an introduction to Aquaculture, career scenarios (problems) for the classroom, technology rich lab exercises, a new A.S. degree program, high school pathways, and a careers course. Some of these materials are available online. <http://www.marinetech.org/home.php>

NOAA Ocean Explorer - Discover how NOAA uses ROVs and learn more about the various NOAA ROVs currently in use. Read how ROV Hercules was built just for scientific research and can travel to depths of 4,000 meters. <http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html>

Office of National Marine Sanctuaries – National Oceanic and Atmospheric Administration - http://monitor.noaa.gov/education/pdfs/rov_lesson.pdf

Remotely Operated Vehicles Curriculum Guide - This curriculum introduces middle and high school students to ROVs and careers in marine science and underwater archaeology. Students use problem based learning and hands-on STEM activities to solve real world problems, while learning about the engineering design process. Curriculum can be used in its entirety or activities can be used independently.

Teacher One-Pager (http://monitor.noaa.gov/education/pdfs/rov_teacher.pdf)

Student One-Pager (http://monitor.noaa.gov/education/pdfs/rov_student.pdf)

ROV Curriculum Guide (http://monitor.noaa.gov/education/pdfs/rov_lesson.pdf)

Remotely Operated Vehicle (ROV) In a Bucket - This is an excellent manual to get you started building your own underwater robot. The manual includes a detailed list of ROV parts and pieces and where to find them. (Doug Levin, NOAA Chesapeake Bay Office). http://monitor.noaa.gov/publications/education/rov_manual.pdf

Woods Hole Oceanographic Institution - Though ROVs have been used extensively by the oil and gas industry for several decades, *Jason/Medea* was the first ROV system to be adopted and extensively used by ocean researchers. Visit this site to learn how scientists and researchers use *Jason/Medea* to conduct underwater expeditions. <http://www.whoi.edu/page.do?pid=8423>

Geomorphology Quiz

1. How was the Gulf of Mexico formed?
2. What is the De Soto Canyon?
3. How is bathymetric data of the seafloor collected?
4. Why is it important to know the bathymetry of the De Soto Canyon?
5. How is a natural oil seep formed?
6. What are some factors that could influence the flow rate of an oil seep?
7. What kind of information can scientists gather from taking sediment core samples?
8. Where does the sediment on the Gulf of Mexico seafloor come from?
9. What do ROVs do?
10. Provide three specific examples of ways in which ROVs can be used in research.

Geomorphology Glossary

AUV: Autonomously Operated Vehicle, unattached and freely maneuvering small underwater vehicles

Bathymetry: the measurement of the depth of water bodies, including the ocean, rivers, streams, and lakes

Benthic: refers to the ecological region at the lowest level of a body of water

Buoyancy: the upward force, caused by fluid pressure, that keeps things afloat

Continental Shelf: an extension of the continent that is under shallow water; varies from place to place, potentially not existing in some places; sediment from the continents can accumulate on the shelf

Convergent boundaries: two plates coming together (in the ocean, typically a trench is formed)

Divergent boundaries: two plates moving away from one another (in the ocean, typically a mid-ocean ridge is formed)

Flow Rate: the volume of water passing a point in a fixed period of time

Hydrocarbon: organic compounds that contain hydrogen and carbon

Lithosphere: crust and upper mantle layer for which the tectonic plates are made of

Mantle: liquid layer containing magma. Layer between the crust and outer core

Marine technology: tools that are developed to aid in ocean exploration

Methane hydrates: aka gas hydrates are reserves of natural gas located in porous rock in the deep ocean sediments

Mid-Ocean Ridge: similar to a mountain chain underwater; two oceanic plates are diverging and magma rises from the mantle to add new crust to the ridge

MILET: Modular Instrument Lander and Equipment Toolsled, marine technology that maps the seafloor

Multi-Corer: a device used to take core samples from the seafloor

Natural gas: a mixture of gaseous hydrocarbons (primarily methane) that occurs, often with oil deposits, in the Earth's crust

Oil: a thick, yellow to black, flammable liquid hydrocarbon mixture found in the Earth's crust

Oil Seep: oil that escapes from its reservoir through a naturally occurring crack in the bedrock

Oil Slick: oil at the surface of the water

Plate Tectonics: theory in which the Earth's lithosphere is fragmented into pieces that are constantly moving and changing the geological features of the planet

Propulsion: a means of creating force that leads to movement

ROV: Remotely Operated Vehicle, which is a tethered robot that operates underwater and is controlled from a boat or ship by an operator

Sediment: solid material that is moved and deposited in a new location and can consist of rocks and minerals, as well as the remains of plants and animals

Side-scan sonar: a tool used to detect objects and geological features on the seafloor

Smear slide analysis: a laboratory technique used to analyze sediment core samples

Tar Balls: oil that has been weathered after floating in the ocean and washed ashore

Tether: a cord or flexible attachment that anchors something movable to a reference point, which may be fixed or moving