OCEAN EXPLORATION & RESEARCH

Lessons from the Deep:

Exploring the Gulf of Mexico's Deep-Sea Ecosystems

Education Materials Collection

Image captions/credits on Page 2.

lesson plan

What's the Big Deal?

(adapted from the Expedition to the Deep Slope 2007)

Focus

Significance of methane hydrates

Grade Level

9-12 (Life Science)

Focus Question

Why are deep ocean explorers interested in methane hydrates?

Learning Objectives

- Students will be able to define methane hydrates, and describe where these substances are typically found and how they are believed to be formed.

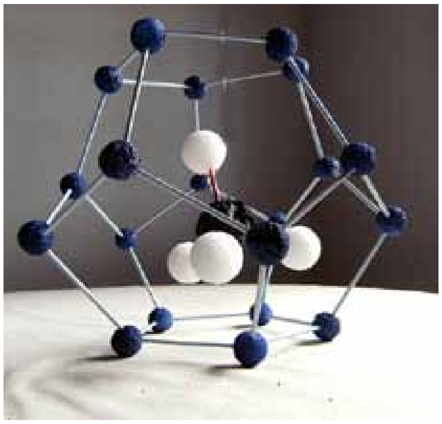
- Students will be able to describe at least three ways in which methane hydrates could have a direct impact on their own lives.

- Students will be able to describe how additional knowledge of methane hydrates could provide human benefits.

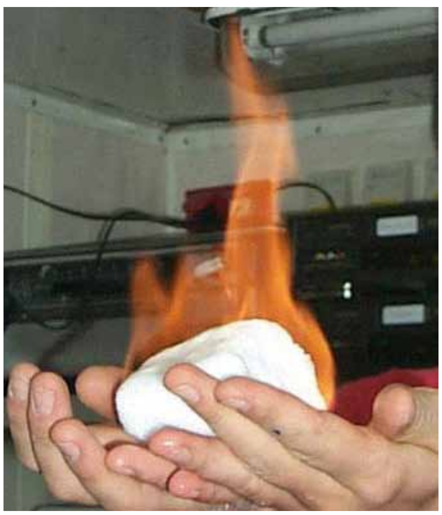
Materials

- Copies of *Methane Hydrates Inquiry Guide* and *Methane Hydrate Molecule Construction Guide Student Handout*, one for each student group
- Materials for constructing a methane hydrate molecule model:
  For constructing a pentagon:
  - Paper, unlined 8-1/2" X 11"
  - Pencil
  - Protractor or compass

  For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 13 pentagons)



Methane hydrate model. Image courtesy Mellie Lewis.



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

Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

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

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

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

- Ruler, 12-inch
- 11 Bamboo skewers, 12" long
- 20 Styrofoam balls, 1/2" diameter
- 4 Styrofoam balls, 1-1/2" diameter
- 1 Styrofoam ball, 1" diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored

Audio/Visual Materials

- None

Teaching Time

One to one-and-a-half 45-minute class periods, plus time for research

Seating Arrangement

Five groups of 3-6 students

Maximum Number of Students

30

Key Words

Cold seeps
Methane hydrate ice
Clathrate
Gulf of Mexico

Background Information

For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire.

"They're easy to light. You just put a match to them and they will go," says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass.

If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate.

– from "The Mother Lode of Natural Gas" by Rich Monastersky
www.sciencenews.org/pages/pdfs/data/1996/150-19/15019-12.pdf

Methane hydrates received unprecedented attention in May of 2010, when methane hydrate crystals formed a slush inside the huge cofferdam that was one of the first strategies to control oil escaping from the Deepwater Horizon blowout. The methane hydrate buildup made the cofferdam too buoyant and clogged it up, forcing responders to seek other ways to deal with the oil.

Methane Hydrate Clathrate

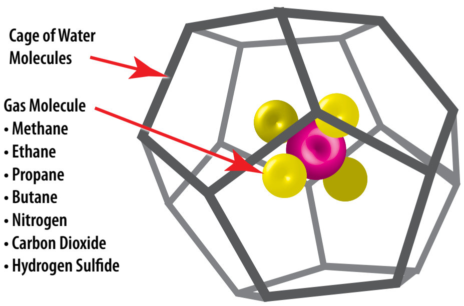


Illustration courtesy Mel Goodwin

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. Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other 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 chemosynthetic community of tube worms and mussels adjacent to exposures of outcropping gas hydrate. The image was taken in the Mississippi Canyon Lease Area, Block 118, at 888 m depth.Photograph courtesy of Harry H. Roberts. http://oceanexplorer.noaa.gov/explorations/06mexico/background/geology/media/tubeworms_600.html

Lophelia pertusa coral, with opened polyps, attached to an authigenic carbonate rock. Seep-dependent tubeworms are visible behind the coral. Image courtesy of, *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks. http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/lophelia_insitu_.html

Methane hydrates are one of the chemicals that are often found in areas where gases (such as methane and hydrogen sulfide) and oil seep out of sediments. In the Gulf of Mexico, these cold seeps are often associated with rocky substrates or "hardgrounds." 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 that may be important in other ways as well.

While the potential benefits from methane hydrates are exciting, they may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

The release of large quantities of methane gas can have other consequences as well. Methane is one of a group of the so-called "greenhouse gases." In the atmosphere, these gases allow solar radiation to pass through but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. Many scientists have suggested that increased carbon dioxide in the atmosphere produced by burning fossil fuels is causing a "greenhouse effect" that is gradually warming the atmosphere and the Earth's surface. A sudden release of methane from deep-sea sediments could have a similar effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene Epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about six degrees Celsius. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists have suggested that similar events could have contributed to mass extinctions during the Jurassic Period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian Period (the "Cambrian explosion, about 520 million years ago).

This activity focuses on the significance of methane hydrates.

Learning Procedure

1.To prepare for this lesson:
   (a) Review the following essays:
      Chemosynthetic Communities in the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html); and

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html).

(b) You may also want to review the following visual resources and consider presenting some of these to your students:

- Image collections from Sulak, *et al.* (2008). Master Appendix D of this large report contains many images of deep-water coral communities. Download the pdf files "Master Appendix D - Megafaunal Invertebrates of Viosca Knoll, *Lophelia* Community Investigation," and "Key to Plates in Master Appendix D" from http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

- 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)

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

- Virtual tour of a cold-seep community (http://www.bio.psu.edu/cold_seeps)

- 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)

(c) Review procedures on the *Methane Hydrate Molecule Construction Guide*, and gather necessary materials. This activity may be done as a cross-curricular mathematics lesson using student-constructed pentagons and dodecahedrons. Correlations with Principles and Standards for School Mathematics are provided in Appendix A on page 23.

2. Ask students if they have ever heard of methane hydrates, and if so, what these substances are. Some students may have heard about methane hydrates in connection with the Deepwater Horizon blowout, and may have an impression that these are "ices" or "frozen methane" since these were common (and inaccurate) descriptions provided in news reports. Tell students that they are

going to investigate methane hydrates, and that they may be surprised to find out how important these substances could be to their own lives.

3. Provide each student group with a *Methane Hydrate Research Questions and Tips* sheet. Tell students that they will be expected to present a written group report that addresses these questions, and participate in a class discussion of their results. Suggest that they divide the questions among the group members to simplify the research process.

4. Have each group submit their written report and model for evaluation.

5. Lead a discussion of students' research results. Begin by asking for one group to explain what methane hydrates are, where they are found, and how they are formed. Next, ask for another group to explain one way in which methane hydrates are significant to humans. Continue this process until all five groups have had a chance to present one piece of the whole story. Now, ask students what scientific research priorities and public policies should be established concerning methane hydrates. Encourage students to comment on the potential significance of global warming, alternative energy sources, useful biological products, and natural hazards.

   The discussion should include the following points:

   - A clathrate is a chemical substance in which molecules of one material (e.g., water) form an open solid lattice that encloses, without chemical bonding, molecules of another material (e.g., methane).

   - Methane hydrate is a clathrate in which a lattice of water molecules encloses a molecule of methane.

   - In general, methane hydrates are formed under conditions of low temperature and high pressure, such as are found in deep ocean environments. See http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html for a phase diagram illustrating combinations of pressure and temperature that are suitable for methane hydrate formation.

   - Clathrates have been known as a type of chemical substance since the 1800's, but methane hydrates first received serious attention when they were found to be plugging natural gas pipelines, particularly pipelines located in cold environments.

In the late 1960s, naturally-occurring methane hydrate was observed in subsurface sediments in Western Siberia and Alaska. Marine methane hydrate deposits were first found in the Black Sea and subsequently in cores of ocean bottom sediments collected by the R/V *Glomar Challenger* from many areas of Earth's ocean.

- Methane is a greenhouse gas that is ten times more effective than carbon dioxide in causing climate warming. Carbon isotope variations in carbonate rocks and sediments indicate that large-scale releases of methane from ocean hydrates could have occurred at various times in Earth's history, including the Pre-cambrian and Cretaceous Periods. Such releases could have caused significant climate change that may be related to extinction events, as well as to the rapid evolution of new species during the Cambrian Period.

- Methane can be released from methane hydrates when deposits are disrupted by earthquakes or landslides; or when pressure on hydrates is reduced due to a sea-level drop, such as occurred during glacial periods; or when clathrates become unstable due to warming.

- Methane is a fossil fuel that could be used in many of the same ways that other fossil fuels (e.g., coal and petroleum) are used. According to the U.S. Department of Energy, the quantity of methane potentially available is enormous. For example, the U.S. domestic natural gas recoverable resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

- Oil and gas drilling and production activities may disturb methane hydrate deposits that are near the seafloor surface, and such disruption poses hazards to personnel and equipment. Ongoing natural phenomena (e.g., subsidence and uplift of the seafloor, global climatic cycles, changes in ocean circulation patterns, changes in global sea level) continually alter the temperature and pressure conditions in sea-bottom sediments. These processes affect the stability of natural methane hydrates, and can result in potentially massive destabilization of these hydrates. If a large quantity of methane enters the atmosphere, it will reside there for roughly 10-20 years, during which it will act as a very efficient greenhouse gas. Over the longer term, the atmospheric impact of methane will continue at lesser levels as the methane slowly dissipates through oxidation into water and carbon dioxide.

- In September, 2001, the Ocean Exploration Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science" in the navigation menu to the left, then "Habitats," then "Deep Sea" for resources on deep-sea communities.

The "Me" Connection

Have students write a short essay describing why ocean exploration expeditions such as the Deep East Expedition are, or are not, relevant and important to them personally.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry, Mathematics

Assessment

Students' responses to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

See the "Resources" section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-sea Ecosystem Education Materials Collection Educators Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

Multimedia Discovery Missions

http://www.learningdemo.com/noaa/ Click on the links to Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

This Life Stinks (9 pages, 276 Kb)

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_stinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

Students define the process of chemosynthesis, and contrast this process with photosynthesis. Students also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

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

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

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

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

Biochemistry Detectives (8 pages, 480 K)

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

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

In this activity, students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three energy-obtaining strategies used by organisms in cold-seep communities. Students will also be able to interpret analyses of enzyme activity and ^{13}C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

This Old Tubeworm (10 pages, 484 KB)

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

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

In this activity, students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals of the same species. Students will also be able to estimate the age of an individual of a specific size, given information on age specific growth in individuals of the same species.

C.S.I. on the Deep Reef (Chemotrophic Species Investigations, That Is) (6 pages, 444 KB)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_csi.pdf
Focus: Chemotrophic organisms (Life Science/Chemistry)
In this activity, students will describe at least three chemotrophic symbioses known from deep-sea habitats and will identify and explain at least three indicators of chemotrophic nutrition.

Gellin (4 pages, 372 KB)
http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf
Focus - DNA analysis (Life Science)
In this activity, students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Hot Food (4 pages, 372 KB)
http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_hotfood.pdf
Focus - Energy content of hydrocarbon substrates in chemosynthesis (Chemistry)
In this activity, students will compare and contrast photosynthesis and chemosynthesis as processes that provide energy to biological communities, and given information on the molecular structure of two or more substances, will make inferences about the relative amount of energy that could be provided by the substances. Students will also be able to make inferences about the potential of light hydrocarbons as an energy source for deep-water coral reef communities.

How Does Your (Coral) Garden Grow? (6 pages, 456 KB)
http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf
Focus - Growth rate estimates based on isotope ratios (Life Science/Chemistry)
In this activity, students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

What's the Difference? (20 pages, 300 kb)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/difference.pdf
Focus - Identification of biological communities from survey data (Life *Science)*
In this activity, students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

Monsters of the Deep (6 pages, 464 KB)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf
Focus - Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)
Students describe major features of cold seep communities, list at least five organisms typical of these communities, and infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm (8 pages, 476 KB)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf
Focus - Physiological adaptations to toxic and hypoxic environments (Life Science)
Students explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment. Students also describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

The Big Burp: Where's the Proof? (5 pages, 364 KB)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf
Focus - Potential role of methane hydrates in global warming (Earth Science)
In this activity, students will be able to describe the overall events that occurred during the Cambrian explosion and Paleocene

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

Other Links and Resources

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

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

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm – Web site for the National Methane Hydrate Research and Development Program

http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html – Gas (Methane) Hydrates—A New Frontier; Web page from the U.S. Geological Survey's Marine and Coastal Geology Program

Van Dover, C.L., P. Aharon, J.M. Bernhard, E. Caylord, M. Doerriesa, W. Flickinger, W. Gilhooly, S.K. Goffredi, K.E. Knick, S.A. Macko, S. Rapoport, E.C. Raulfs, C. Ruppel, J.L. Salerno, R.D. Seitz, B.K. Sen Gupta, T. Shank, M. Turnipseed, R. Vrijenhoek. 2003. Blake Ridge methane seeps: characterization of a soft-sediment, chemosynthetically-based ecosystem. Deep-Sea Research Part I 50:281–300. (Available as a PDF file at http://www.mbari.org/staff/vrijen/PDFS/VanDover_2003DSR.pdf)

MacDonald, I. and S. Joye. 1997. Lair of the "Ice Worm." Quarterdeck 5(3); http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html; article on cold-seep communities and ice worms

Siegel, L. J. 2001. Café Methane. http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86; article on cold-seep communities and ice worms from NASA's Astrobiology Institute

Kirschvink, J. L. and T. D. Raub. 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. Comptes Rendus Geoscience 335:65-78. Journal article on the possible role of methane release in rapid diversification of animal groups. Also available on-line at http://www.gps.caltech.edu/users/jkirschvink/pdfs/KirschvinkRaubComptesRendus.pdf

Simpson, S. 2000. Methane fever. *Scientific American* (Feb. 2000) pp 24-27. Article about role of methane release in the Paleocene extinction event

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

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

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill 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://response.restoration.noaa.gov/ – Click "Students and Teachers" in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

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

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

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

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

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

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Transfer of energy

Content Standard C: Life Science

- Structure and function in living systems
- Populations and ecosystems

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 3.
The ocean is a major influence on weather and climate.
Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustainthe ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
Fundamental Concept f. Ocean exploration is truly interdisciplinary.

It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson.
Please e-mail your comments to: oceanexeducation@noaa.gov

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Methane Hydrates Inquiry Guide

Research Questions

1. What is a clathrate?

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

2. What is methane hydrate? Include a model of a methane hydrate with your written report (refer to the *Methane Hydrate Molecule Construction Guide*).

3. How are methane hydrates formed?

4. Where are methane hydrates found?

5. What is the effect of methane in the atmosphere? Is there any evidence of a direct effect on life on Earth in geological time?

Methane Hydrates Inquiry Guide - page 2

6. In what ways can methane be released from methane hydrates?

7. Is there any practical use for methane hydrates?

8. Do methane hydrates pose any immediate danger to coastal areas?

9. Are any unusual biological organisms or communities associated with methane hydrates? If so, do these communities have any known or potential significance to humans?

Research Tips

1. Try a keyword search using the following terms, alone or in combination:
   Cold seeps, Methane hydrate, Clathrate, Methanogenic Archaeobacteria
   Paleocene extinction, Energy hazard
   Note: Use quotation marks or underlined spaces to tell your search engine to look for two-word phrases as a single term

2. Explore the following Web sites:
   http://oceanexplorer.noaa.gov
   http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm
   http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html

Methane Hydrate Molecule Construction Guide

Materials

Materials for constructing a methane hydrate molecule model:

For constructing a pentagon:

- Paper, unlined 8-1/2" X 11"
- Pencil
- Protractor or compass

For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:

- Scissors
- Cardboard or card stock (enough to make 13 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12" long
- 20 - Styrofoam balls, 1/2" diameter
- 4 - Styrofoam balls, 1-1/2" diameter
- 1 - Styrofoam ball, 1" diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

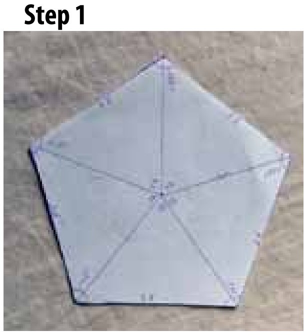
Procedure

General Notes:

- Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
- Be sure the skewers are inserted into the middle of the Styrofoam balls.

Part 1 – Build a pentagonal dodecahedron

Step 1



1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long.

Step 2

2. Trace the paper pentagon onto cardboard or card stock and cut in out. Each group will cut out 13 pentagons.

Step 3

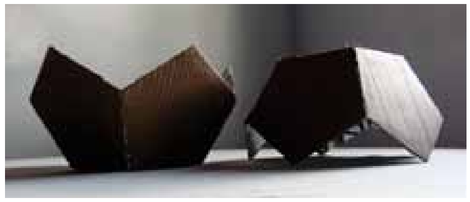
3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.

4. Carefully pull up one pair of pentagons and tape their common sides together. Repeat until the five pentagons have been taped together, forming a five-sided bowl. This is the bottom half of the pentagonal dodecahedron.

Methane Hydrate Molecule Construction Guide - Page 2

5. Repeat Steps 3 and 4 to make the top half of the pentagonal dodecahedron. The two halves are identical. Place the top half over the bottom half to form the pentagonal dodecahedron. Do not tape the bottom to the top.

Step 5



Part 2 – Build the Model Molecules

1. Spray paint skewers and Styrofoam balls:
   a. Paint ten skewers light blue to represent hydrogen bonds between water molecules
   b. Paint one skewer red to represent the electrostatic bonds in the methane molecule
   c. Paint twenty 1/2" Styrofoam balls dark blue to represent water molecules
   d. Paint one 1" Styrofoam ball black to represent the carbon atom
   e. Note: the 4 1-1/2" Styrofoam balls remain white to represent hydrogen atoms

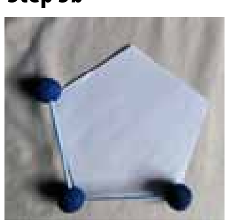
2. Cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths.

Build the clathrate cage:

3. Place the 13th pentagon on a flat surface. Place a blue stick on one side and two blue balls at each end. Carefully insert the end of the blue stick into the middle of each ball. Repeat with three more balls and four more sticks to form a ball-and-stick pentagon.

Step 3a

Step 3b



Step 3c

Step 3d

Step 3e

Step 4

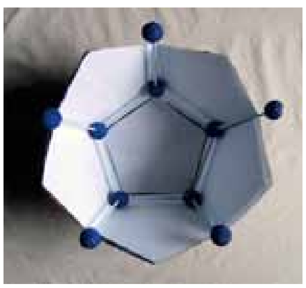
4. Place the ball-and-stick pentagon in one of the dodecahedron halves—be careful, it will lay approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the ball and stick dodecahedron with the correct stick angle.

Methane Hydrate Molecule Construction Guide - Page 3

Step 5

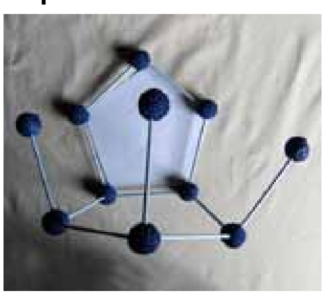
5. Place five light blue sticks inside the center of each of the dark blue balls using the dodecahedron half as a guide for the correct stick angle. It's very important to insert the sticks into the center of the ball at the same angle as the side of the dodecahedron half.

Step 6



6. Insert a dark blue ball on top of each light blue stick. Carefully remove the incomplete cage from the dodecahedron and place it on a flat surface.

Step 7



7. Use the 13th pentagon to complete the bottom half of the cage. Turn the ball-and-stick model onto one side and, using the pentagon to determine the correct angle, insert a light blue stick into the center of the two dark blue balls. Then, attach another dark blue ball to connect the two light blue sticks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

Step 8

8. Repeat Step 7 four more times to form the remaining faces for the bottom half of the cage.

9. Repeat Steps 3, 4, and 5 to construct the top half of the cage.

10. Carefully place the bottom half of the cage into the bottom of the cardboard dodecahedron. Attach the two halves of the cage together: Working together with your partners, hold the top half of the cage over the bottom half. The two halves will only fit together one way. Rotate the top half until all of the unattached sticks line-up with a ball. Insert each light blue stick into the center of the corresponding dark blue ball.

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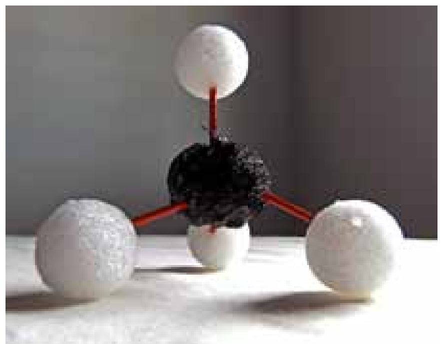
Build the Methane Molecule:

11. Insert four red sticks into the black Styrofoam ball so that they are evenly spaced (when the model is placed on a flat surface, three of the sticks and the black ball should look like a tripod with the fourth stick pointing straight up. Attach a white Styrofoam ball to the other end of each of the red sticks.

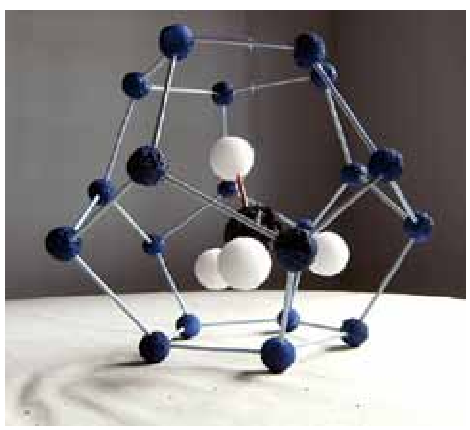
Step 11



Assemble the Methane Hydrate Molecule Model:

12. Suspend the methane molecule model in the middle of the clathrate cage by attaching fishing line from one of its electrostatic bonds (red sticks) to two opposing hydrostatic bonds (light blue sticks) at the top of the cage. Your Methane Hydrate Molecule Model is finished!

Step 12



Note: Each of the dark blue Styrofoam balls represents a water molecule consisting of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

All photographs by Mellie Lewis, Teacher Facilitator, The College of Exploration.

Appendix A
Adapting the Methane Hydrate Molecule Construction Activity as a Cross-curricular Mathematics Lesson

Learning Objectives

- Students will demonstrate geometric properties through hands on manipulation of geometric shapes.
- Students will be able to construct a pentagonal dodecahedron.
- Students will be able to construct a model of a methane hydrate molecule.

Teaching Time

Three or four 50-minute class periods or may be sent home as an enrichment activity

Definitions

- **Polygon** – a geometric shape made up of vertices that are connected with line segments
- **Vertex** – a point where the sides of an angle meet
- **Pentagon** – a geometric shape with five equal sides and five 108° angles
- **Dodecahedron** – a three-dimensional geometric shape that has 12 faces (regular pentagons), 20 vertices, and 30 edges

Prerequisite Skills

Students should have basic knowledge of geometric shapes and know how to draw a pentagon. If not, directions for drawing a pentagon using a compass or protractor may be found in middle school mathematics textbooks or in the links below.

Procedure

1. Lead an introductory discussion of how mathematical models help us understand science concepts.
2. Tell students that they will be using concepts and skills they have learned in mathematics class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
3. Provide students with copies of the *Methane Hydrate Molecule Construction Guide* and required materials.

Resources

http://wiki.answers.com/Q/How_would_you_draw_a_regular_pentagon
http://www.barryscientific.com/lessons/polygon.html

Appendix A - Page 2

Correlations with Principles and Standards for School Mathematics

Analyze characteristics and properties of two-and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships.

In grades 9-12 all students should-

- Analyze properties and determine attributes of two- and three-dimensional objects;
- Explore relationships (including congruence and similarity) among classes of two- and three-dimensional geometric objects, make and test conjectures about them, and solve problems involving them.

Use visualization, spatial reason, and geometric modeling to solve problems.

In grades 9-12 all students should-

- Draw and construct representations of two- and three-dimensional geometric objects using a variety of tools;
- Use geometric models to gain insights into, and answer questions in, other areas of mathematics;
- Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture.