What's the Big Deal?

Focus

Significance of methane hydrates

Grade Level

Target Grade Level: 9-12 (Earth Science)

Focus Question

Why should a NOAA Ocean Exploration and Research expedition focus investigations on methane hydrates?

Learning Objectives

- Students will define methane hydrates, describe where these substances are typically found, and explain how they are believed to be formed.
- Students will ask questions to clarify evidence that methane hydrates could be involved with changes to Earth systems.
- Students will describe how additional knowledge of methane hydrates during Ocean Exploration and Research expeditions could provide human benefits.

Materials

- Copies of *Methane Hydrate Investigation Guide*, one for each student group
- Copies of the *Methane Hydrate Model Construction Guide*, one for each student group
- Materials for constructing a methane hydrate model:

For constructing a pentagon:

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

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

- Scissors
- Cardboard or card stock (enough to make 7 pentagons)
- Pentagon template
- Ruler, 12-inch
- Fishing line, or light colored thread

Fire ice. Methane hydrates burn and drip water. Image courtesy J. Pinkston and L. Stern USGS.

- Toothpicks (34 per table - 30 blue, 4 red)
- Gumdrop candy (such as "Tootsie Dots") (20 of one color, 4 of another color, and 1 of a third color, per table)

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods plus time for student research

Seating Arrangement

Five groups of 3-6 students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Methanogenic Archaea
Clathrate
Greenhouse gas
Greenhouse effect
Paleocene extinction
Cambrian explosion
Alternative energy
Natural hazards

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

"Methane trapped in marine sediments as a hydrate represents such an immense carbon reservoir that it must be considered a dominant factor in estimating unconventional energy resources; the role of methane as a 'greenhouse' gas also must be carefully assessed."

Gas (Methane) Hydrates -- A New Frontier; Dr. William Dillon, U.S. Geological Survey; *http://physics.oregonstate.edu/~hetheriw/projects/energy/topics/doc/fuels/fossil/methane_hydrate/methane_hydrate_japan_geo_survey/usgs_hydrate.html*

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form

When ice-rich permafrost thaws, former tundra and forest turns into a thermokarst lake as the ground subsides. The carbon stored in the formerly frozen ground is consumed by the microbial community, who release methane gas. When lake ice forms in the winter, methane gas bubbles are trapped in the ice. Image courtesy of Miriam Jones, U.S. Geological Survey.
https://www.usgs.gov/media/images/methane-bubbles-trapped-thermokarst-lake-ice

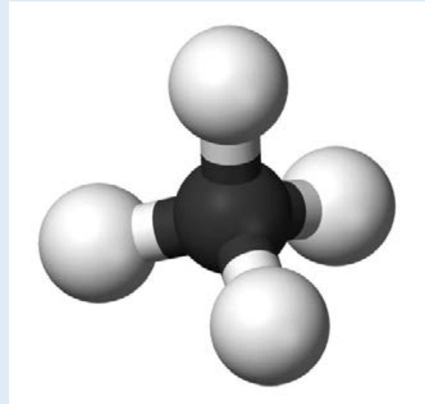
an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as methanogenic Archaea. These Archaea obtain energy by anaerobic metabolism through which they 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.

Methane hydrate deposits are significant for several reasons. A major interest is the possibility of methane hydrates as an energy source. 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. At present, however, no technology exists to exploit methane hydrates for energy.

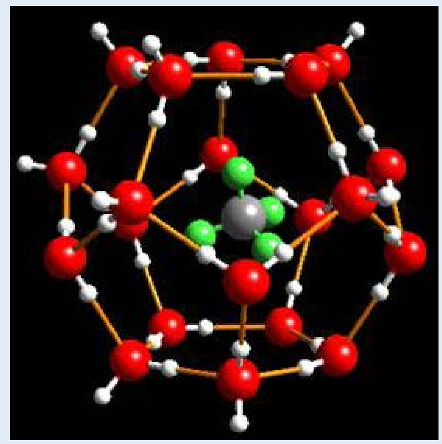
In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September 2001, the NOAA Ocean Exploration Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously unknown species that may be sources of beneficial pharmaceutical materials.

Methane hydrates remain stable in deep-sea sediments for long periods of time; but if the surrounding temperature rises the clathrates may become unstable and release free methane gas. This is probably happening now in at least two settings. In the deep ocean, as sediments become deeper and deeper they are heated by the Earth's core; eventually to a point at which free methane gas is released. (At a water depth of 2 km, this point is reached at a sediment depth of about 500 m. *See Phase Diagram on page 7.*) Methane hydrates are also widespread on continental margins and permafrost areas. Here, oceanic and atmospheric warming may also make hydrates unstable and lead to methane release into overlying sediments and soils (Ruppel and Kessler, 2016). In deepwater sediments, pressurized methane remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. On continental shelves, methane may be released as bubbles at the seafloor. Areas where this is happening are called methane seeps. Not all methane seeps are caused by decomposing methane hydrates; many are probably the result of microbial activity in shallow sediments (Ruppel and Hamilton, 2014).

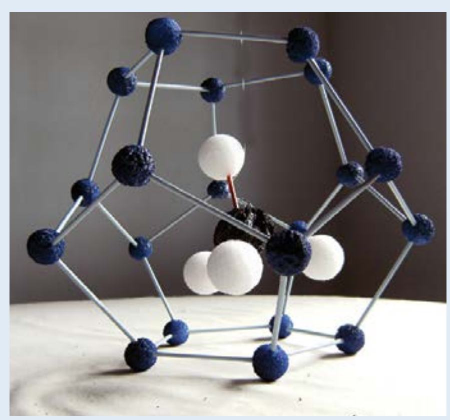
Recent ocean exploration expeditions have found that methane seeps may be much more abundant than previously realized. In 2012, a series of acoustic images from the NOAA Ship *Okeanos*



Methane is composed of one carbon atom surrounded by four hydrogen atoms. It is the simplest hydrocarbon. Image courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane1.html



Water molecules (1 red oxygen and 2 white hydrogens) form a pentagonal dodecahedron around a methane molecule (1 gray carbon and 4 green hydrogens). This represents 2 of the 8 parts of the typical Structure I gas hydrate molecule.
https://woodshole.er.usgs.gov/project-pages/hydrates/primer.html



Build your own model of a methane hydrate! See page 15. Image courtesy of Mellie Lewis.

Explorer suggested that there might be dozens of previously unknown seafloor methane seeps on the U.S. Atlantic margin from Cape Hatteras to Georges Bank. Continued exploration discovered many more seeps, and by 2014 more than 550 newly-discovered methane seeps had been identified on the northern U.S. Atlantic margin (Skarke et al., 2014). In 2017, NOAA's Office of Ocean Exploration and Research joined with the U.S. Geological Survey (USGS), and the U.S. Department of Energy to support the Interagency Mission for Methane Research at Seafloor Seeps expedition to focus on the geology, ecology, chemistry, and physics of methane seeps on the U.S. Mid-Atlantic margin between Baltimore Canyon and Hatteras Canyon at water depths of 400-1,600 meters (*https://woodshole.er.usgs.gov/project-pages/hydrates/mission-immerss.html*). On the Pacific coast, several methane hydrate ecosystems along the coast of Washington have been extensively studied, and oceanographic and geologic conditions suggest similar habitats should stretch all along the Cascadia Subduction Zone. In 2016, E/V *Nautilus* conducted the first comprehensive study of the region using advanced multibeam mapping technology, discovering 450 methane bubble streams and two new sites of methane hydrate exposure on the seafloor.

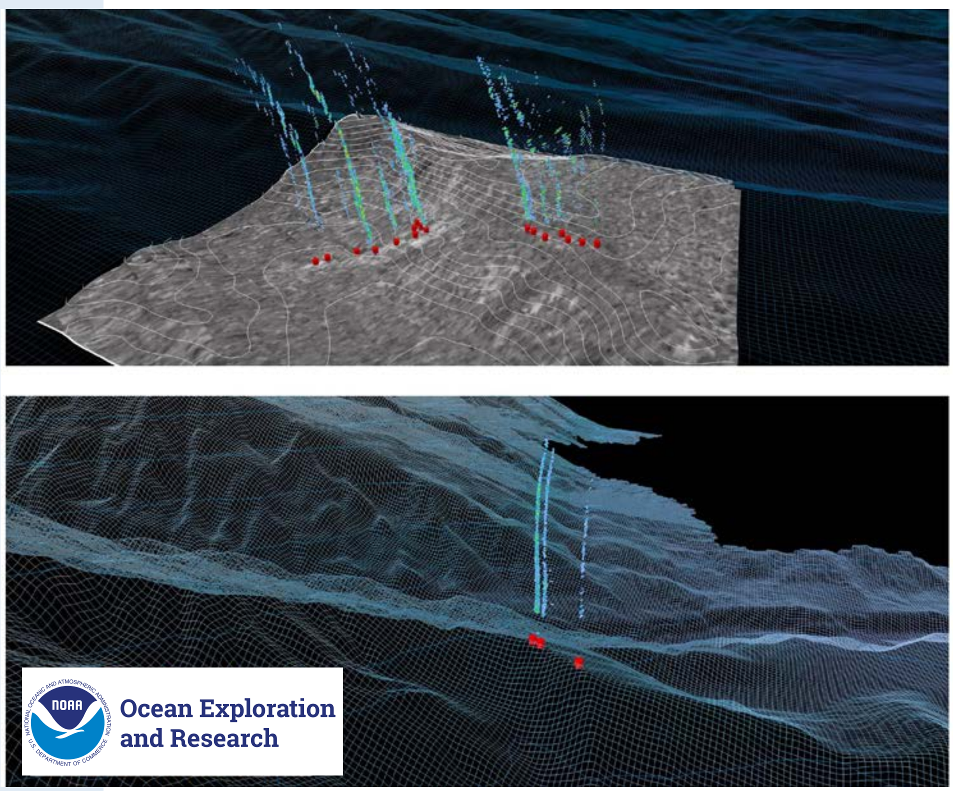
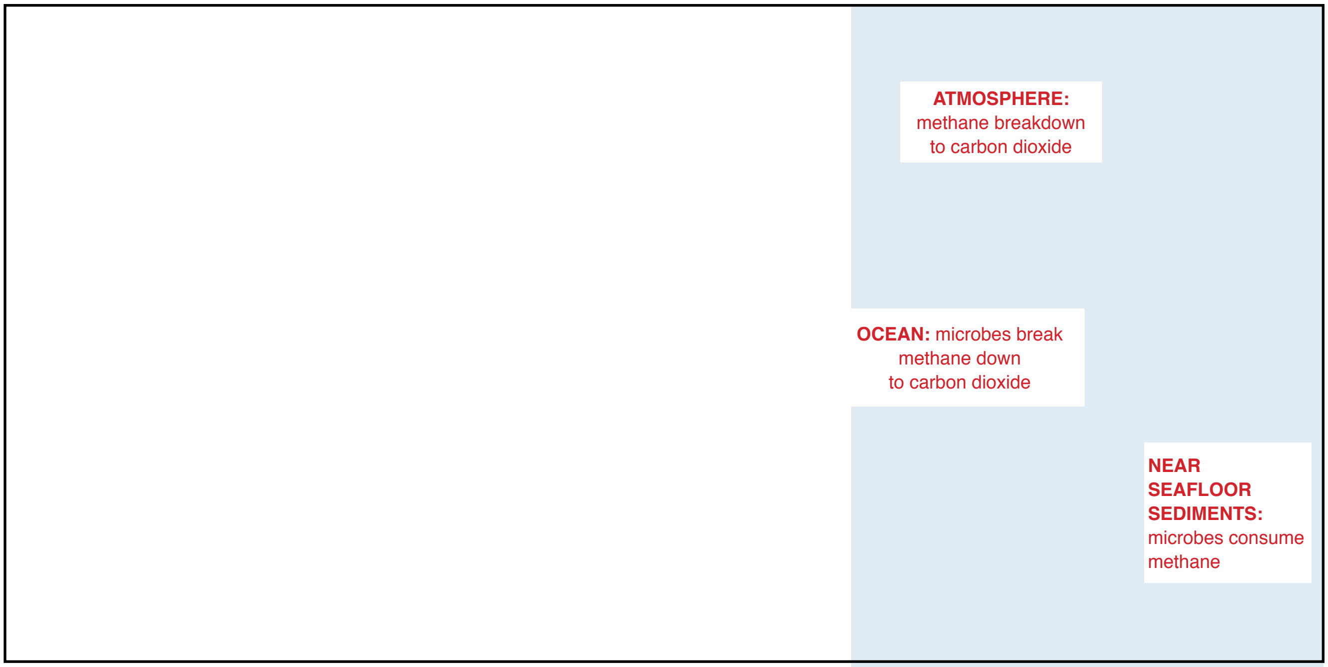


Image of gaseous seeps derived from water column acoustic reflectivity observations and associated bathymetry and seafloor backscatter. Image courtesy of NOAA OER, Northeast and Mid-Atlantic Canyons Expedition 2012. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1206/summary/seeps.html*

While these discoveries are exciting, there has also been concern about the possible effects of methane release. 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 6° C. The result was the



Summary of the locations where gas hydrate occurs beneath the seafloor, in permafrost areas, and beneath some ice sheets, along with the processes (shown in red) that destroy methane (sinks) in the sediments, ocean, and atmosphere. The differently colored circles denote different sources of methane. Gas hydrates are likely breaking down now on shallow continental shelves in the Arctic Ocean and at the feather edge of gas hydrate stability on continental margins (1000-1650 feet). Image courtesy Ruppel and Kessler (2017)
https://www.usgs.gov/media/images/gas-hydrate-schematic

extinction of many deep-sea organisms known as the Paleocene extinction event. Kirschvink and Raub, (2003), on the other hand, suggested that methane released from methane hydrates is a possible cause of the dramatic increase in biodiversity that took place during the Cambrian Period. Other concerns have focused on the possibility that sudden release of methane might trigger submarine landslides that could cause disastrous tsunamis.

Recent research, however, has found that while large quantities of methane may have been released at various points in Earth's history, the time scale of these releases is on the order of thousands of years, rather than sudden catastrophic releases (Archer, 2007). The available evidence also does not show a strong relationship between submarine landslides and methane emissions (Talling et al., 2014). While current warming of ocean waters is probably causing some gas hydrate deposits to break down, this is unlikely to lead to massive amounts of methane being released to the atmosphere because the annual emissions of methane to the ocean from these deposits is very small, and most of the methane released by gas hydrates never reaches the atmosphere (Ruppel and Kessler, 2017). Methane in the water column, though, can be oxidized to carbon dioxide, which increases the acidity of ocean waters and reduces oxygen levels.

At present, there is no known technology for tapping methane hydrates as a source of useful energy. Current research in the U.S. and other countries is focused on the feasibility of methane hydrates as an energy source, as well as interactions between climate change and gas hydrates (Ruppel and Hamilton, 2014).

This lesson guides a student investigation into the significance of methane hydrates.

Chemosynthetic mussels encrusting a carbonate mound at one of the so-called Norfolk Canyon seeps at ~1,400 meters water depth. Bubbles that make up one of the observed water column plumes are visible in the center. Image courtesy of NOAA 2013 Northeast U.S. Canyons Expedition.
http://oceanexplorer.noaa.gov/explorations/17atlantic-margin/media/norfolk.html

Participants at an *Exploring the Deep Ocean with NOAA* professional development workshop mastering the methane hydrate model. Image courtesy of NOAA.

NOAA Ship *Okeanos Explorer.* Image courtesy of NOAA. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/mar1/media/okeanos.html*

Scientist Scott France participates in the dives from his home office via telepresence. Image courtesy of NOAA OER, 2016 Deepwater Exploration of the Marianas. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/jun28/media/1605scott-france.html*

Learning Procedure

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/about.html* and *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go….* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_toboldlygo.pdf*
   - Visit:
     http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/oct1/oct1.html and *http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html* for background on the 2001 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition;
     "Exploration of Cold Seeps on the North Atlantic Continental Margin" by Taylor Heyl *oceanexplorer.noaa.gov/okeanos/explorations/ex1304/background/coldseeps/welcome.html*;
     "Methane in the Ocean" by Monica Heintz *http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/methane.html*;
     http://oceanexplorer.noaa.gov/explorations/17atlantic-margin/welcome.html for background on the 2017 Exploring Methane Seeps on the U.S. Mid-Atlantic Margin: IMMeRSS expedition.
     and
     http://www.nautiluslive.org/expedition/2016 for background on the 2016 E/V *Nautilus* Seeps and Ecosystems of the Cascadia Margin expedition.
   - Review questions on the *Methane Hydrates Investigation Guide*.
   - Review procedures on the *Methane Hydrate Model 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 Common Core State Standards for Mathematics are provided in Appendix A.

2. Briefly introduce the ships of exploration NOAA Ship *Okeanos Explorer*, E/V *Nautilus*, and R/V *Falkor*; (see *Introduction to the Ships and Their Exploration Strategy* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf*) and the 2017 Discovering the Deep: Exploring Remote Pacific MPAs Expedition *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/background/plan/welcome.html*.

   Briefly discuss why this kind of exploration is important (for background information, please see the lesson, *To Boldly Go* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_toboldlygo.pdf*). Highlight the overall strategy used by ships of exploration, including the following points:

- The overall strategy is to develop baseline information about the biological, geological, and water chemistry features of unexplored areas to provide a foundation for future exploration and research.

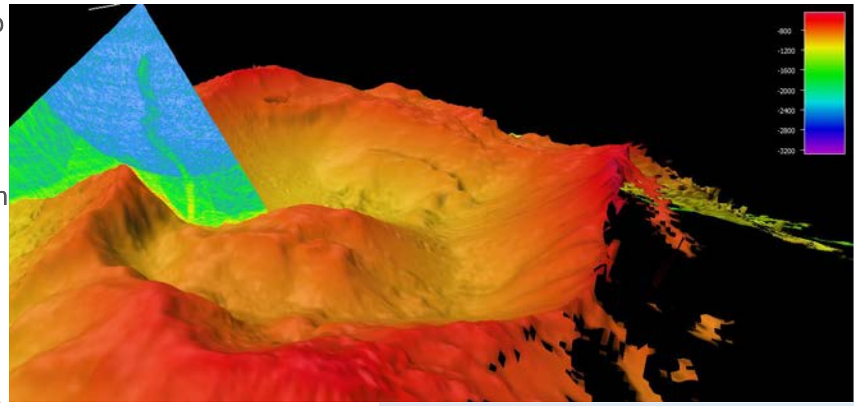
- This information includes:
  - High resolution maps of the area being explored, as well as areas that the ship crosses while underway from one location to the next (underway reconnaissance)
  - Exploration of water column chemistry and other features
  - High definition close-up video of biological and geological features in the exploration area (site characterization)

- This strategy relies on four key technologies:
  - Multibeam sonar mapping system and other types of sonar that can detect specific features in the water column and on the seafloor;
  - Conductivity, Temperature, and Depth profilers (CTD) and other electronic sensors to measure chemical and physical seawater properties;
  - A Remotely Operated Vehicle (ROV) capable of obtaining high-quality imagery and samples in depths as great as 6,000 meters; and
  - Telepresence technologies that allow scientists with many different areas of expertise to observe and interact with exploration activities, though they may be thousands of miles from the ship.

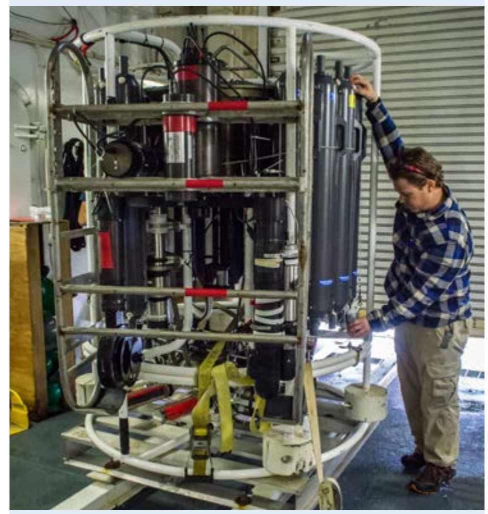
You may want to show some or all of the images in the adjacent sidebar to accompany this review.

Lead an introductory discussion about the 2017 Exploring Methane Seeps on the U.S. Mid-Atlantic Margin: IMMeRSS expedition. Depending upon available time, you may also want to include information from one or more of the other expeditions referenced above. Briefly describe methane hydrates and why these substances are potentially important to human populations. You may also want to visit *http://oceanexplorer.noaa.gov/edu/themes/cold_seeps/welcome.html* for more information and activities on cold seeps.

3. Provide each student group with a copy of the *Methane Hydrates Investigation Guide* and the *Methane Hydrate Model*

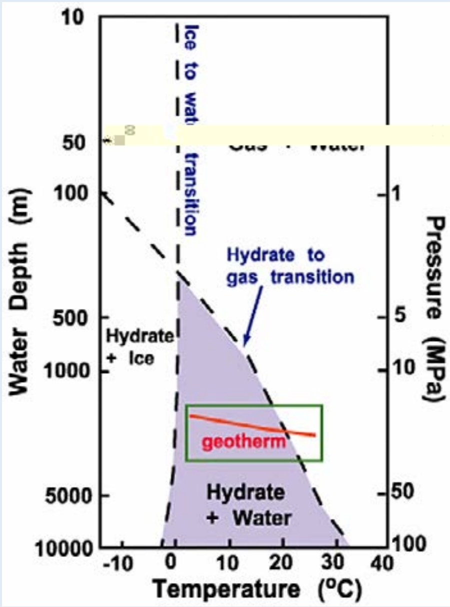


Multibeam sonar imagery shows a plume of bubbles rising from the seafloor at Vailulu'u Seamount near American Samoa. Image courtesy of the NOAA 2017 American Samoa Expedition.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/feb22/media/vailulu2.html



Water samples are collected from the niskin bottles on the CTD. All 20 niskin bottles take water samples from various depths, starting near the seafloor and ending close to the surface. Photo courtesy The Hidden Ocean 2016: Chukchi Borderlands.
http://oceanexplorer.noaa.gov/explorations/16arctic/logs/july24/media/shipton.html

Sometimes form wins—*Deep Discoverer* (D2) is an elegant and powerful 9,000 pounds, designed to bring optimal imagery topside, where it is then shipped to shore in real time. Image courtesy of NOAA *Okeanos Explorer* Program, Gulf of Mexico 2014 Expedition.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/apr15/media/drfront.html



Phase diagram showing the water depths (and pressures) and temperatures for gas hydrate (purple area) stability. The Windows to the Deep expedition explores areas of the Blake Ridge and Carolina Rise in which the uppermost sediments lie within the range denoted by the green box. The red line shows a geotherm or temperature in the Earth as a function of depth. Note that, at greater depths in the sediments, the geotherm crosses from the hydrate zone (purple region) to the gas zone. This means that gas hydrate in sediments usually overlies free gas.
http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html

An aggregation of methane ice worms inhabiting a white methane hydrate seen in the Gulf of Mexico, 2012. Studies suggest that these worms eat chemoautotrophic bacteria that are living off of chemicals in the hydrate. Image courtesy of NOAA *Okeanos Explorer* Program.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/logs/dailyupdates/media/apr12_update.html

Construction Guide. Tell students that they will be expected to present a group report, including a model of a methane hydrate, that addresses these questions, and participate in a class discussion of their results.

4. Lead a discussion of students' research results. Referring to students' models, begin with a discussion of what methane hydrates are, where they are found, and how they are formed. Next, ask for a group that can 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 climate change, alternative energy sources, useful biological products, and natural hazards.

   Be sure the following points are included in the discussion:

   • 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 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, 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 domestic resource base could be on the order of 5,000 Tcf (in 2016, the total U.S. consumption of natural gas was about 27 Tcf. 5,000 Tcf is more than ten times the volume of Lake Superior).

- 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

The first dive of the 2014 Gulf of Mexico Expedition had a fantastic "amphitheater of chemosynthetic life." Here we saw bathymodiolus mussels, methane hydrate or ice, and ice worms. There were also a number of sea urchins, sea stars, and fish in this area. Most impressive was the large accumulation of hydrate mussels on the underside of the ledge. Image courtesy of NOAA *Okeanos Explorer* Program, Gulf of Mexico 2014 Expedition.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/highlight_imgs/media/ampitheater.html

Methane hydrates are extremely difficult to study, and could either be an important energy source or a source of methane, a greenhouse gas that is 20 times more potent than CO_2. These reasons led a Norwegian, Dutch and Chinese research team to explore the mechanical properties of this poorly understood substance. Credit: Geir Mogen, NTNU Read more at: *https://phys.org/news/2015-11-key-properties-methane-hydrates-permafrost.html*

The Next Generation Science Standards
The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations and each combines Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

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 2001, the Deep East Expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing species that may be sources of beneficial pharmaceutical materials. Since then, expeditions supported by NOAA's Office of Ocean Exploration and Research have discovered more than 550 previously unknown methane seeps on the northern U.S. Atlantic margin, and more than 450 seeps on the northwestern U.S. Pacific coast.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Habitats," the "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write an essay describing why ocean exploration expeditions are, or are not, personally relevant and important.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry, Mathematics

Assessment

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

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have students investigate events in Earth's history that may have been influenced in some way by methane hydrates. The next-to-last paragraph in the Background section refers to some of these.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 5 and 11 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life, and Energy from the Oceans.

Other Relevant Lessons from NOAA OER

(All of the following Lessons are targeted toward grades 9-12)

This Life Stinks

http://oceanexplorer.noaa.gov/edu/lessonplans/03win_lifestinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

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

The Big Burp: Where's the Proof?

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

Focus: Potential role of methane hydrates in climate change (Earth Science)

Students will describe the overall events that occurred during the Cambrian Explosion and Paleocene Extinction events and will define methane hydrates and hypothesize how these substances could contribute to climate change. Students will also describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian Explosion and Paleocene Extinction events.

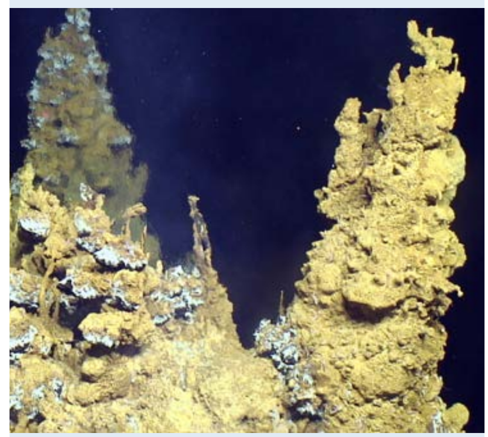
The Benthic Drugstore

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

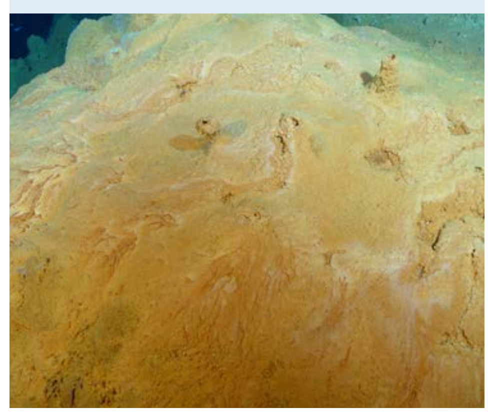
Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)

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

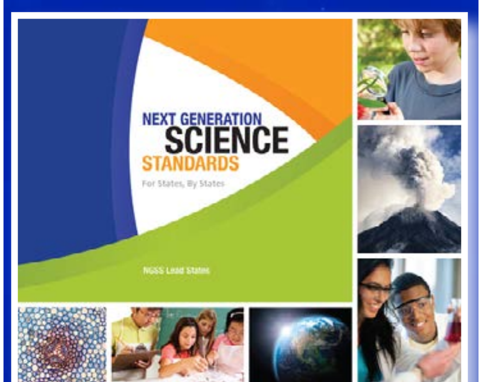
Squat lobsters, shrimp, and scaleworms crawl on mussels. The squat lobsters appear "hairy" because of bacteria growing on their shells. Image courtesy of NOAA Submarine Ring of Fire 2014.
http://oceanexplorer.noaa.gov/explorations/14fire/logs/december09/media/mussels-lobsters.html
The mussel, *Bathymodiolus brevior*, is one of those hosts with symbiotic bacteria embedded in the gill tissue. Thus, the mussel needs to grow near vent water to supply hydrogen sulphide, oxygen, and carbon dioxide to its symbionts. Similar mussels at vents around the world can dominate the biomass of the community. See the following daily log for more information on these communities:
http://oceanexplorer.noaa.gov/explorations/14fire/logs/december09/december09.html



Sulfide chimneys coated with iron-based microbial mat at the Urashima vent site. Image courtesy of NOAA Submarine Ring of Fire 2014 .
http://oceanexplorer.noaa.gov/explorations/14fire/logs/december02/media/urashima_chimneys.html



Right: Deep-sea hydrothermal vents are dynamic and extremely productive biological ecosystems supported by chemosynthetic microbial primary production. In the absence of photosynthesis, these microorganisms derive energy via the oxidation of reduced chemicals emitted in hydrothermal fluids. Photograph of iron-oxide-encrusted microbial mat. Image courtesy NOAA Submarine Ring of Fire 2014.
http://oceanexplorer.noaa.gov/explorations/14fire/background/microbio/microbio.html



The Next Generation Science Standards
The Next Generation Science Standards integrate three dimensions within each standard: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The standards are written as student performance expectations. While specific performance expectations may emphasize only a few of the practice categories, teachers are encouraged to utilize several practices in any instruction. Similarly, only a few crosscutting concepts may be emphasized, but this is not intended to limit instruction.

Chemosynthesis for the Classroom

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_chemo.pdf

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

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

Other Resources

Archer, D. 2007. Methane hydrate stability and anthropogenic climate change. Biogeosciences Discuss. 4:993–1057; *www.biogeosciences-discuss.net/4/993/2007/*

Dickens, G., J. O'Neil, D. Rea, and R. Owen. 1995. Dissociation of oceanic methane hydrate as a cause of the carbon isotope excursion at the end of the Paleocene. *Paleoceanography* 10(6):965–971.

Kirschvink, J., and T. Raub. 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. C. R. *Geoscience* 335:65–78.

Ruppel, C., and H. Hamilton. 2014. Natural Methane Seepage Is Widespread on the U.S. Atlantic Ocean Margin. USGS Sound Waves. *https://soundwaves.usgs.gov/2014/10/*

Ruppel, C., and J. Kessler. 2017. The interaction of climate change and methane hydrates. *Reviews of Geophysics*. 55(1): 126–168.

Skarke, A., C. Ruppel, M. Kodis, D. Brothers, and E. Lobecker. 2014. Widespread methane leakage from the sea floor on the northern US Atlantic margin. *Nature Geoscience* 7:657–661. *http://www.nature.com/ngeo/journal/v7/n9/abs/ngeo2232.html*

Talling, P., M. Clare, M. Urlaub, E. Pope, J. Hunt, and S. Watt. 2014. Large Submarine Landslideson Continental Slopes: Geohazards, Methane Release, and Climate Change. *Oceanography* 27(2):32-45

Next Generation Science Standards

This lesson supports the Ocean Literacy Essential Principles and Fundamental Concepts as indicated here *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_standards.pdf*. Additionally, while it is not intended to target specific Next Generation Science Standards, activities in this lesson may be used to address specific elements of the NGSS as described below.

Specific NGSS Performance Expectations relevant to this lesson:

MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century. [Clarification Statement: Examples of factors include human activities (such as fossil fuel combustion, cement production, and agricultural activity) and natural processes (such as changes in incoming solar radiation or volcanic activity). Examples of evidence can include tables, graphs, and maps of global and regional temperatures, atmospheric levels of gases such as carbon dioxide and methane, and the rates of human activities. Emphasis is on the major role that human activities play in causing the rise in global temperatures.]

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

Discussion of students' responses to questions of the *Methane Hydrate Investigation Guide* can be guided to address both of these Performance Expectations by focusing on the role of methane as a greenhouse gas, and on processes that may result in methane being released to the atmosphere from methane hydrates. For example, how warmer temperatures in the arctic may reduce snow cover, resulting in a darker terrestrial surface that absorbs more heat.

For Information and Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
oceanexeducation@noaa.gov

Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL:
http://oceanexplorer.noaa.gov

Methane hydrate models in progress during a professional dvelopment workshop. Image courtesy NOAA.

Methane Hydrate Investigation Guide

Research Questions

1. What is a clathrate?

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

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 Archaea, Paleocene extinction, Energy hazard

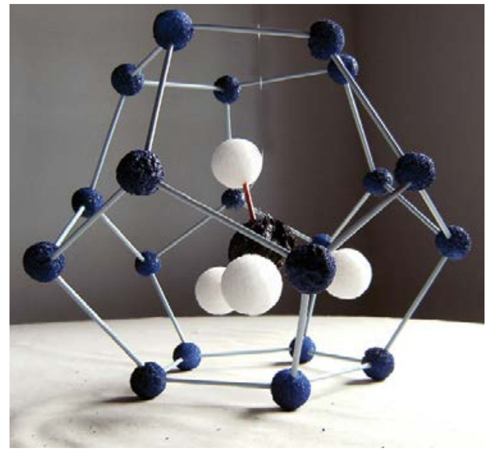
2. Explore the following Web sites:
   http://oceanexplorer.noaa.gov

   http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm

   https://pubs.usgs.gov/fs/fs021-01/fs021-01.pdf

Fire ice. Methane hydrates burn and drip water.Image courtesy USGS.

Methane Hydrate Model Construction Guide



A finished model of a methane hydrate.
Image courtesy Mellie Lewis

Materials

Materials for constructing a methane hydrate model:
For constructing a pentagon:
- Paper, unlined 8-1/2" X 11"
- Pencil
- Protractor or compass

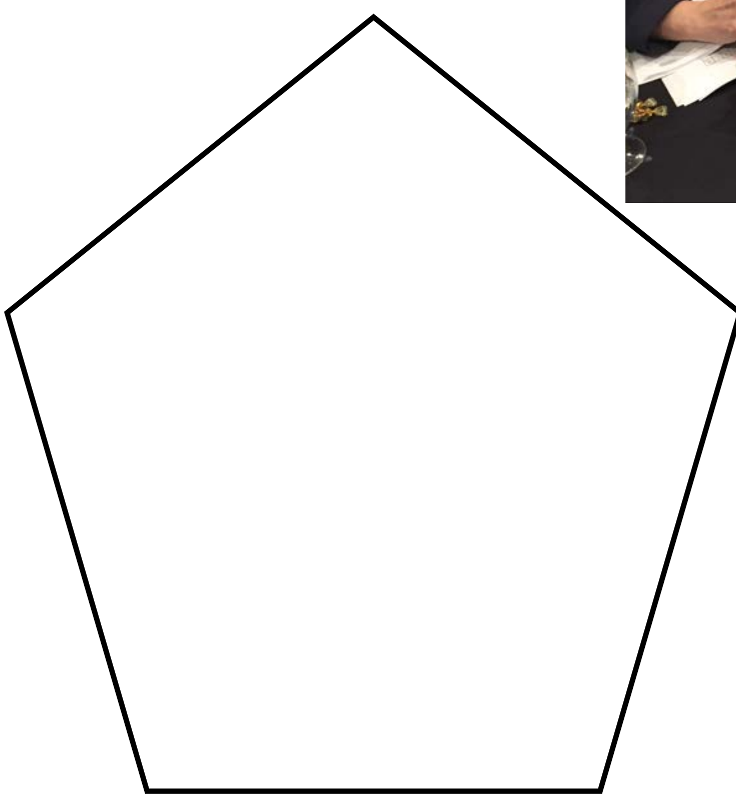
For constructing the dodecahedron half, clathrate cage, methane molecule and methane hydrate model:
- Scissors
- Cardboard or card stock (enough to make 7 pentagons)
- Ruler, 12-inch
- Tape
- Fishing line, or light colored thread
- Toothpicks; 34 per table - 30 blue, 4 red)
- Gumdrop candy (such as "Tootsie Dots"); 20 of one color, 4 of another color, and 1 of a third color, per table

Methane hydrate models in progress during a professional development workshop.Image courtesy NOAA.

Procedure

Part 1 – Build a pentagonal dodecahedron

1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be 6 cm (2-3/8 inches) long.



Step 2.

2. Trace the paper pentagon onto cardboard or card stock and cut it out. Each group will cut out 7 pentagons (6 for the top half and one for the pattern).

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 one half of a pentagonal dodecahedron.

Step 3.

Right: Participants at an *Exploring the Deep Ocean with NOAA* professional development workshop finishing half of a pentagonal dodecahedron.
Below: Sorting the candy dots (Colors may vary according to what kind of dots are available).
Images courtesy NOAA.

Part 2 – Build the Model Molecules

1. Separate candy dots and toothpicks:
   - 20 dots of the same color represent water molecules
   - 4 dots of a second color represent hydrogen atoms
   - 1 dot of a third color represents a carbon atom
   - Blue toothpicks represent hydrogen bonds between water molecules
   - Red toothpicks represent covalent bonds in the methane molecule

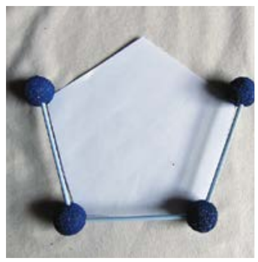
Build the clathrate cage:

2. Place the 7th pentagon on a flat surface. Place a blue toothpick on one side and two dots representing water molecules at each end. Carefully insert the end of the blue toothpick into the middle of each candy dot. Repeat with three more dots of the same color and four more blue toothpicks to form a candy-and-toothpick pentagon.

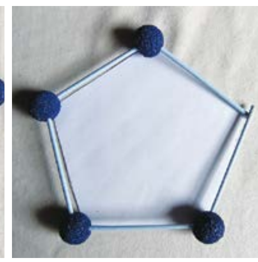
Step 2a.

Step 2b.

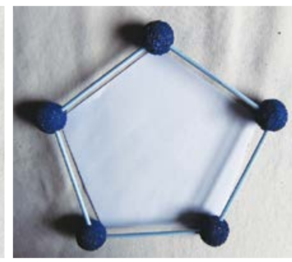
Step 2c.



Step 2d.

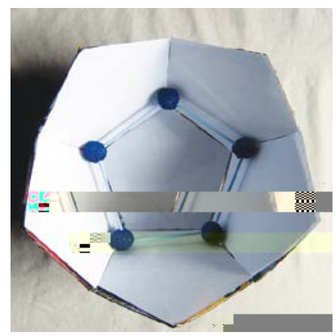


Step 2e.



3. Place the candy-and-toothkpick pentagon in the dodecahedron half—be careful, it will lay approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the candy and toothpick dodecahedron with the correct toothpick angle.

Step 3.

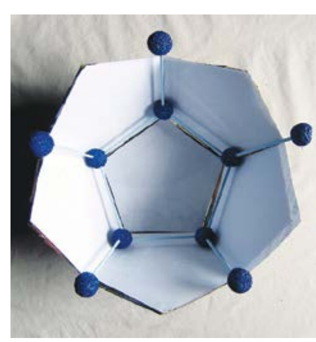


4. Place five blue toothpicks inside the center of each dot representing water molecules using the dodecahedron half as a guide for the correct toothpick angle. It's very important to insert the toothpicks into the center of the candy dot at the same angle as the side of the dodecahedron half.

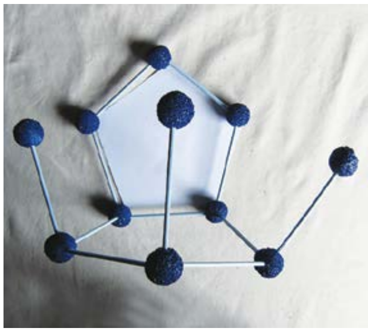
Step 4.

5. Insert a candy dot representing water molecules on top of each blue toothpick. Carefully remove the incomplete cage from the bowl and place it on a flat surface.

Step 5.



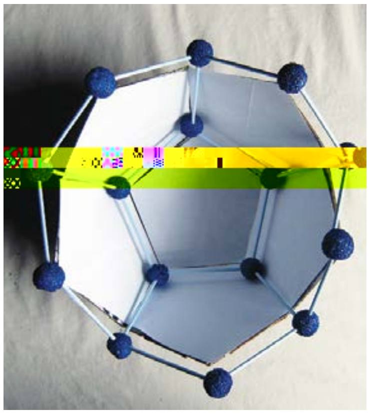
Step 6.



6. Use the 7th pentagon to complete the bottom half of the cage. Turn the candy-and-toothpick model onto one side and, using the pentagon to determine the correct angle, insert a blue toothpick into the center of the two candy dots representing water molecules. Then, attach another candy dot representing a water molecule to connect the two blue toothpicks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

7. Repeat Step 6 four more times to form the remaining faces for the bottom half of the cage.

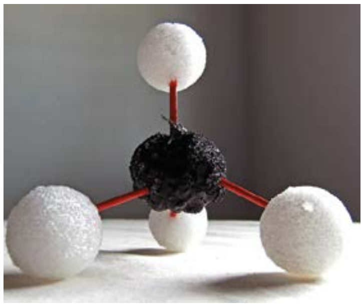
Step 8.



8. Repeat Steps 2, 3, and 4 to construct the top half of the cage.

9. Carefully place the bottom half of the cage into the bottom of the cardboard bowl. 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 toothpicks line-up with a candy dot. Insert each blue toothpick into the center of the corresponding candy dot representing a water molecule.

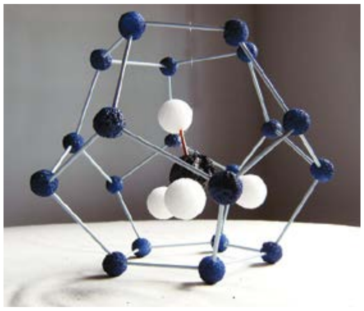
Step 11.



Build the Methane Molecule:

11. Break two red toothpicks in half, and insert the four half-toothpicks into the candy dot representing a carbon atom so that they are evenly spaced (when the model is placed on a flat surface, three of the toothpicks and the dot representing the carbon atom should look like a tripod with the fourth toothpick pointing straight up). Attach a candy dot representing a hydrogen atom to the other end of each of the red half-toothpicks.

Step 12.



All methane hydrate model images courtesy of Mellie Lewis.

Assemble the Methane Hydrate Model

12. Suspend the methane molecule in the middle of the clathrate cage by attaching fishing line from one of its covalent bonds (red toothpicks) to two opposing hydrogen bonds (blue toothpicks) at the top of the cage. Your Methane Hydrate Model is finished!

Note: Each of the candy dots representing a water molecule consists of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

Appendix A

Adapting the Methane Hydrate Model 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.

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 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

Common Core State Standards for Mathematics

High School:
HSG..MG.A.1. Use geometric shapes, their measures, and their properties to describe objects.

Notes