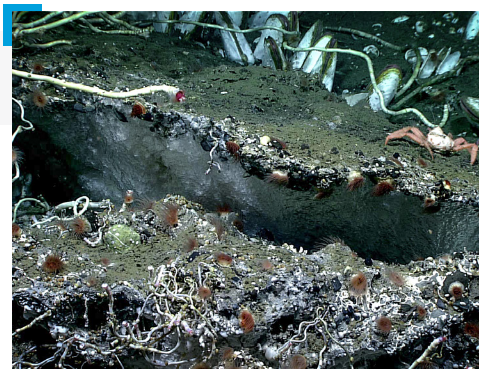
Methane Hydrates in the Deep Sea

Overview



Exposed methane hydrate, a translucent white, smooth ice-like substance, attached to a carbonate overhang seen at a depth of 2,018 meters (1.25 miles) off the Aleutian Islands in Alaska. This overhang is home to tubeworms, clams, anemones, and crabs. *Image courtesy of NOAA Ocean Exploration.*

TOPIC: Methane Hydrates in the Deep Sea

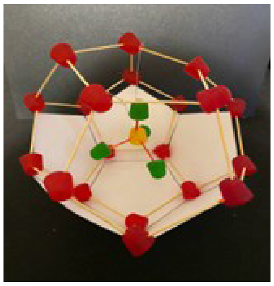
FOCUS: Students will learn the chemistry and importance of methane hydrates.

GRADE LEVEL: 6-8 Chemistry (adaptable to high school level)

TIME NEEDED: One 50-minute class period

PHENOMENON/ DRIVING QUESTION: What are methane hydrates made from and how do they form in the deep sea?

OBJECTIVES/ LEARNING OUTCOMES: Students will:
- Construct a methane gas hydrate model.
- Describe the molecules and bonds that form a methane hydrate.
- Explain how methane hydrate forms.



Model of a methane hydrate. *Image courtesy of NOAA Ocean Exploration.*

MATERIALS:

Student Handouts
- Student Worksheet: Methane Hydrate Model (1 per student)
- Methane Hydrate Model Instructions (1 per group)
- *Optional:* Gas Hydrate Schematic and Seeps Location Map

Methane Hydrate and Methane Molecule Models

Set-up for each group of 3-4 students
- Cardstock (to print pentagon templates)
- Pentagon templates - (each pentagon is 6 cm or 2 ⅜ in. per side)
- Tape
- Scissors
- Fishing line, or light colored thread
- Toothpicks [30 plain (blue if available) and 2 colored (red if available)]
- Gumdrop candy (such as "Tootsie Dots")
  (20 of one color, 4 of another color, and 1 of a third color)

Videos
- Methane Hydrate and Bubbles (1:08 min) *NOAA Ocean Exploration*
- Searching for Methane Hydrates of Cascadia Margin (4:23 min) *Ocean Exploration Trust*

NEXT GENERATION SCIENCE STANDARDS (NGSS)
MS-PS-1 Matter and Its Interactions

Performance Expectation (PEs)
MS-PS1-4

Disciplinary Core Ideas (DCIs)
MS-PS 1.A. Structure and Properties of Matter

Crosscutting Concepts (CCs)
Energy and Matter
Structure and Function

Science & Engineering Practices (SEPs)
Constructing Explanations and Designing Solutions

COMMON CORE CONNECTIONS
ELA/Literacy RST.6-8.7

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS
Principle 3: FC e
Principle 5: FC g

Overview cont.

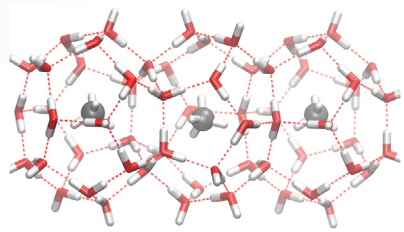
EQUIPMENT:
- Computer and projector for class viewing of videos
- *Optional: Student laptops or tablets for extensions and/or additional research*

SET-UP INSTRUCTIONS:
- Cue up any selected videos to show the class.
- Print copies of the instructions.
- Print the pentagon templates on cardstock. Students will cut these out.

Educator Guide

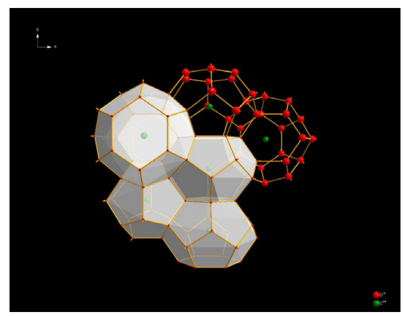
Background

A **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/cage that encloses molecules of another material (methane, in this case) without actually forming chemical bonds between the two materials. These methane hydrates have a dodecahedral shape formed by the shared water molecules and are only visible via SEM (Scanning Electron Microscope).



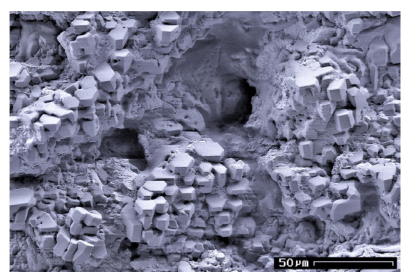
Molecular structure of a methane hydrate. *Image courtesy of NIST.*

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, where there is high pressure and relatively low temperatures, methane hydrate develops. These conditions are common at specific depths within the seafloor sediment along continental margins but methane hydrates also form in permafrost areas.

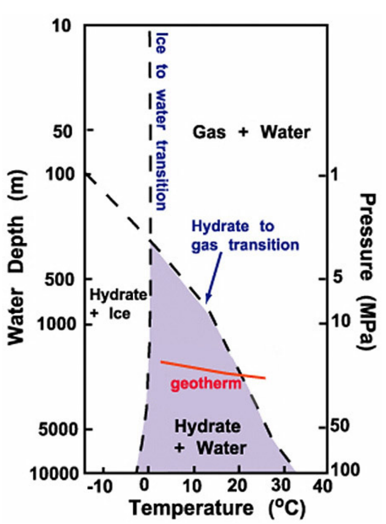


The dodecahedrons share water molecules, forming the honeycomb pattern seen in this image. *Image courtesy of Wikimedia.*

Methane hydrates remain stable in deep-sea sediments for long periods of time; but if the surrounding temperature rises, they may become unstable. This occurs due to geologic or oceanographic processes that raise the temperature of deep-sea sediments to a point at which the methane hydrate ice cage melts and the free methane gas is released. This gas then percolates through the seafloor. These areas are called **methane seeps**. In some cases, these bubbles may get trapped by a shelf on the seafloor and form into patches of methane hydrate.

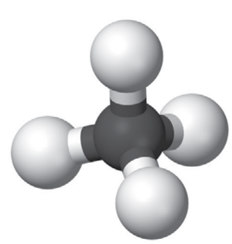


Scanning electron microscope image of gas hydrate crystals in a sediment sample. The scale is 50 micrometers (μm) or approximately 0.002 inches. *Image courtesy of USGS.*



Methane hydrate deposits are significant for several reasons. The possibility of being able to collect methane hydrates as an energy source is of substantial interest to society. 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. However, humans have not yet developed methods and technologies to efficiently and safely collect these gases for commercial use.

Phase diagram showing the water depths (and pressures) and temperatures for gas hydrate (purple area) stability. The red line shows a geotherm or temperature in the Earth as a function of depth. *Image courtesy of NOAA Ocean Exploration.*

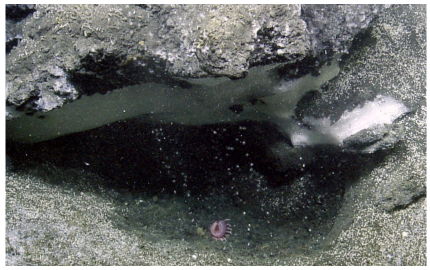


Methane Molecule. *Image courtesy of NOAA Ocean Exploration.*

Educator Guide cont.

Background cont.

Additionally, scientists have found that methane hydrates are associated with incredibly unusual and possibly unique biological communities, subsisting on this chemical-rich environment through chemosynthesis. These habitats can be found across the global ocean.



Exposed methane hydrate (frozen methane) and methane gas bubbles found on the seafloor near Astoria Canyon off the Pacific Northwest coast of the U.S. *Image courtesy of NOAA PMEL.*

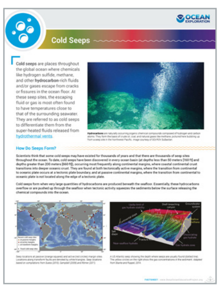
Chemosynthetic mussels found at a seep site found in U.S. waters off the coast of New England. *Image courtesy of NOAA Ocean Exploration.*

Educator Notes

- Students should have a basic understanding of water chemistry, molecules, bonds, and physical and chemical changes.
- This activity can be used to learn about the basic chemistry of methane hydrate components and formation or as a pre-lab to the NOAA Ocean Exploration Student Investigations Fire Ice in the Deep Sea (MS) and Methane Ice Worms (HS).

FOR MORE INFORMATION:

- *Cold Seeps* *Fact Sheet*



- *Cold Seeps of the U.S. Atlantic* *Exploration Note*

- *An Update on Cold Seeps in the Northwestern Atlantic Ocean* *Exploration Note*

Introduction

- **Play** the Methane Hydrate and Bubbles (1:08 min) and Searching for Methane Hydrates of Cascadia Margin (4:23 min) videos to introduce and discuss methane seeps.
- **Tell** students they will now construct their own methane hydrate model using the instructions provided.
- **Hand out** all instructions, student worksheet, and building materials, and have students construct their own model of a methane hydrate.

Video courtesy of NOAA Ocean Exploration.

Learning Procedure

Before constructing their model, **have** students answer questions 1-3 and study the components of the methane hydrate model.

Walk around the classroom and check student models for accurate completion.

Video courtesy of the Ocean Exploration Trust.

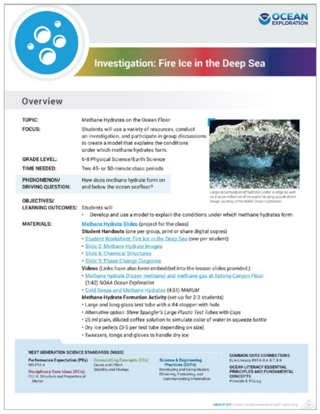
Put the Pieces Together

Have students complete their discussion questions.

Educator Guide cont.

Extensions

- Student Investigation: Fire Ice in the Deep Sea (HS)


OCEAN EXPLORATION

Investigation: Fire Ice in the Deep Sea

Overview

TOPIC: Methane Hydrates on the Ocean Floor

FOCUS: Students will use a variety of resources, conduct an investigation, and participate in group discussions to create a model that explains the conditions under which methane hydrates form.

GRADE LEVEL: 6-8 Physical Science/Earth Science

TIME NEEDED: Two 45- or 50-minute class periods

PHENOMENON/ DRIVING QUESTION: How does methane hydrate form on and below the ocean seafloor?

Large accumulation of hydrates under a ledge as well as a large collection of mussels hanging upside down. Image courtesy of the NOAA Ocean Exploration

OBJECTIVES/ LEARNING OUTCOMES: Students will:
- Develop and use a model to explain the conditions under which methane hydrates form.

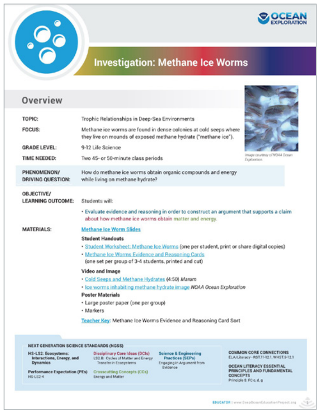
MATERIALS: Methane Hydrate Slides (project for the class)
Student Handouts (one per group, print or share digital copies)
- Student Worksheet: Fire Ice in the Deep Sea (one per student)
- Slide 2: Methane Hydrate Images
- Slide 8: Chemical Structures
- Slide 9: Phase Change Diagrams

Videos (Links have also been embedded into the lesson slides provided.)
- Methane hydrate (frozen methane) and methane gas at Astoria Canyon Floor (1:42) *NOAA Ocean Exploration*
- Cold Seeps and Methane Hydrates (4:51) *MARUM*

Methane Hydrate Formation Activity (set-up for 2-3 students)
- Large and long glass test tube with a #4 stopper with hole
- *Alternative option: Steve Spangler's Large Plastic Test Tubes with Caps*
- 25 ml plain, diluted coffee solution to simulate color of water in squeeze bottle
- Dry ice pellets (3-5 per test tube depending on size)
- Tweezers, tongs and gloves to handle dry ice

NEXT GENERATION SCIENCE STANDARDS (NGSS)
Performance Expectation (PEs) MS-PS1-4
Disciplinary Core Ideas (DCIs) PS1.A: Structure and Properties of Matter
Crosscutting Concepts (CCs) Cause and Effect; Stability and Change
Science & Engineering Practices (SEPs) Developing and Using Models; Obtaining, Evaluating, and Communicating Information
COMMON CORE CONNECTIONS ELA-Literacy RST.6-8.4; 8.7; 8.9
OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS Principle 5: FCs e,g

- Student Investigation: Methane Ice Worms (MS)


OCEAN EXPLORATION

Investigation: Methane Ice Worms

Overview

TOPIC: Trophic Relationships in Deep-Sea Environments

FOCUS: Methane ice worms are found in dense colonies at cold seeps where they live on mounds of exposed methane hydrate ("methane ice").

GRADE LEVEL: 9-12 Life Science

TIME NEEDED: Two 45- or 50-minute class periods

Image courtesy of NOAA Ocean Exploration

PHENOMENON/ DRIVING QUESTION: How do methane ice worms obtain organic compounds and energy while living on methane hydrate?

OBJECTIVE/ LEARNING OUTCOME: Students will:
- Evaluate evidence and reasoning in order to construct an argument that supports a claim about how methane ice worms obtain matter and energy.

MATERIALS: Methane Ice Worm Slides
Student Handouts
- Student Worksheet: Methane Ice Worms (one per student, print or share digital copies)
- Methane Ice Worms Evidence and Reasoning Cards (one set per group of 3-4 students, printed and cut)

Video and Image
- Cold Seeps and Methane Hydrates (4:50) *Marum*
- Ice worms inhabiting methane hydrate image *NOAA Ocean Exploration*

Poster Materials
- Large poster paper (one per group)
- Markers

Teacher Key: Methane Ice Worms Evidence and Reasoning Card Sort

NEXT GENERATION SCIENCE STANDARDS (NGSS)
HS-LS2: Ecosystems: Interactions, Energy, and Dynamics
Performance Expectation (PEs) HS-LS2-4
Disciplinary Core Ideas (DCIs) LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
Crosscutting Concepts (CCs) Energy and Matter
Science & Engineering Practices (SEPs) Engaging in Argument from Evidence
COMMON CORE CONNECTIONS ELA/Literacy - RST.11-12.1, WHST.9-12.1
OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS Principle 5: FC c, d, g

Assessment

Opportunities for formative assessment are embedded throughout the lesson through class discussions. The models constructed as well as the discussion questions can be used as an opportunity for summative assessment.

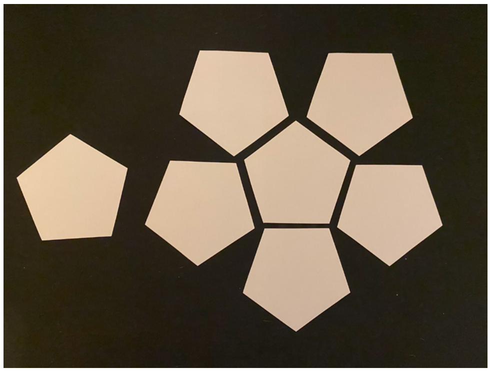
Scientific Terms

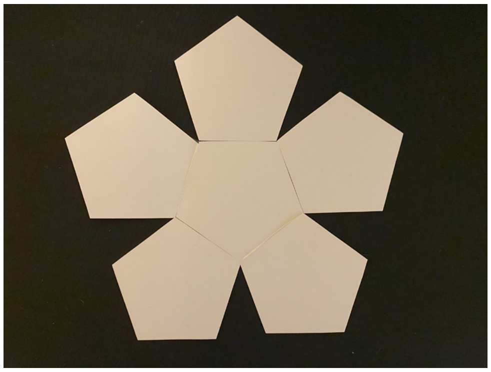
- **Cold seeps:** Places throughout the ocean where hydrogen sulfide, methane, and other hydrocarbon-rich fluids and/or gases escape from cracks in the ocean floor.
- **Methane:** CH_4, a hydrocarbon that is a primary component of natural gas.
- **Clathrate:** A compound in which molecules of one component are physically trapped within the crystal structure of another.
- **Hydrate:** A cage-like structure made specifically of water ice crystal structures.
- **Methane hydrate:** Water ice crystal structures that contain methane gas trapped (not chemically bonded) in a cage-like structure.

Methane Hydrate Model Instructions Guide

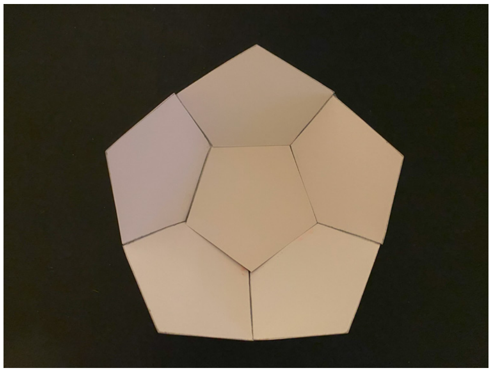
Part 1 - Build a Pentagonal Dodecahedron

1. 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.





2. 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.

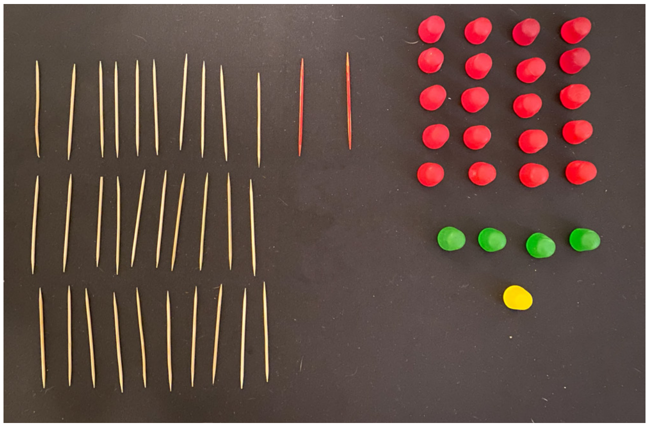


Part 2 - Build the Model Molecules

NOTE: Each of the red candy dots in the images represent ONE water molecule (two hydrogen atoms and one oxygen atom). To keep the model simple, these atoms are NOT shown separately.

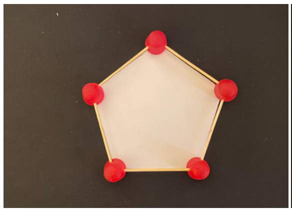
Methane Hydrate

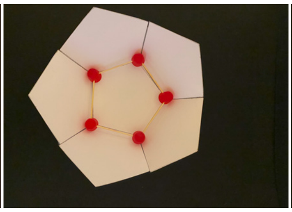
1. Separate candy dots and toothpicks:
   - 20 dots of the same color represent water molecules
   - 4 dots of a second color represent hydrogen atoms
   - 1 dot of a third color represents a carbon atom
   - 30 plain toothpicks (blue preferred if available) represent hydrogen bonds between water molecules.
   - 2 colored toothpicks (red preferred) represent covalent bonds in the methane molecule.

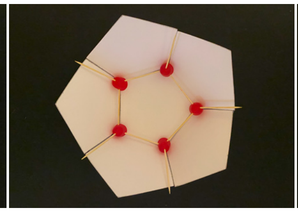


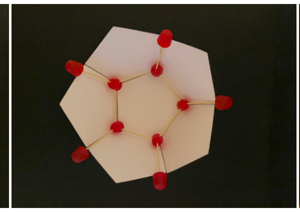
Methane Hydrate Model Instructions Guide cont.

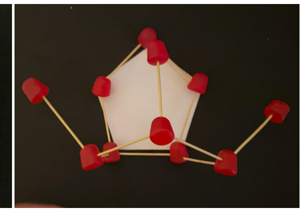
Part 2 - Build the Model Molecules cont.


Step 2


Step 3

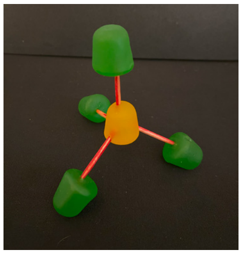

Step 4


Step 5

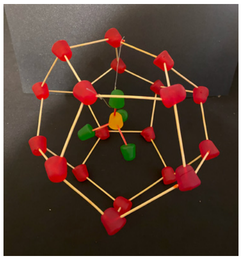

Step 6

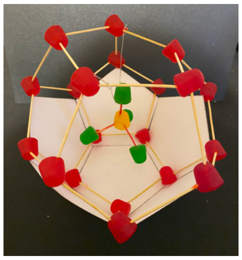
2. Place the 7th pentagon on a flat surface. Place a plain toothpick on one side and two dots representing water molecules at each end. Carefully insert the end of the plain toothpick into the middle of each candy dot. Repeat with three more dots of the same color and four more plain toothpicks to form a candy-and-toothpick pentagon.
3. Place the candy-and-toothpick pentagon in the dodecahedron half. The dodecahedron half (bowl) is used as a template to build the candy and toothpick dodecahedron with the correct toothpick angle.
4. Place five plain 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.
5. Insert a candy dot representing water molecules on top of each plain toothpick. Carefully remove the incomplete cage from the bowl and place it on a flat surface.
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 plain 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 plain 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.
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 plain toothpick into the center of the corresponding candy dot representing a water molecule.

Build the Methane Molecule

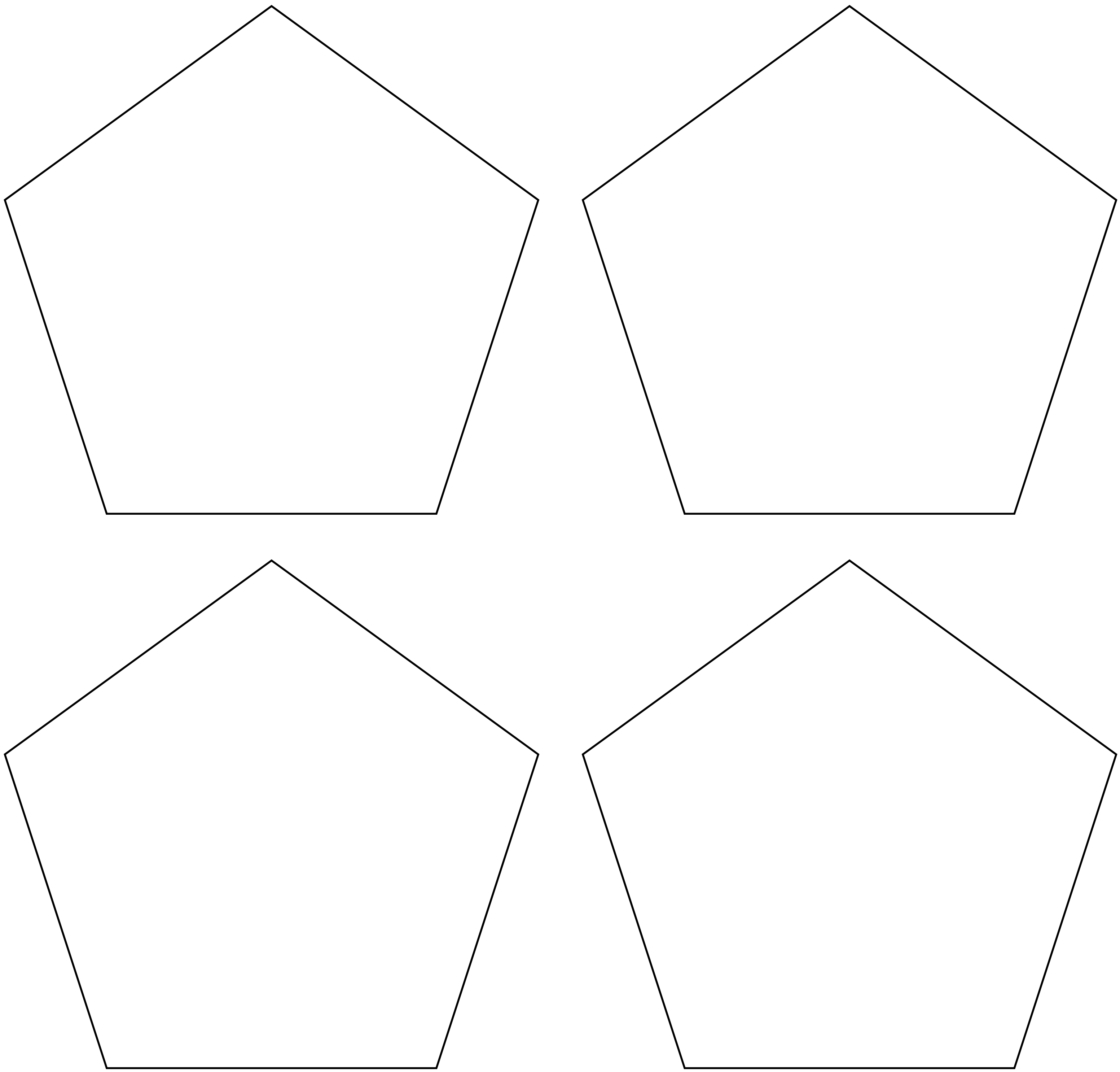


10. Break two red toothpicks in half, and insert the four half-toothpicks into the candy dot representing a carbon atom so that they are evenly spaced (when the model is placed on a flat surface, three of the toothpicks and the dot representing the carbon atom should look like a tripod with the fourth toothpick pointing straight up). Attach a candy dot representing a hydrogen atom to the other end of each of the red half-toothpicks.
11. Suspend the methane molecule in the middle of the clathrate cage by attaching fishing line or string from one of its covalent bonds (colored or red toothpicks) to two opposing hydrogen bonds (plain or blue toothpicks) at the top of the cage. Your Methane Hydrate Model is finished!

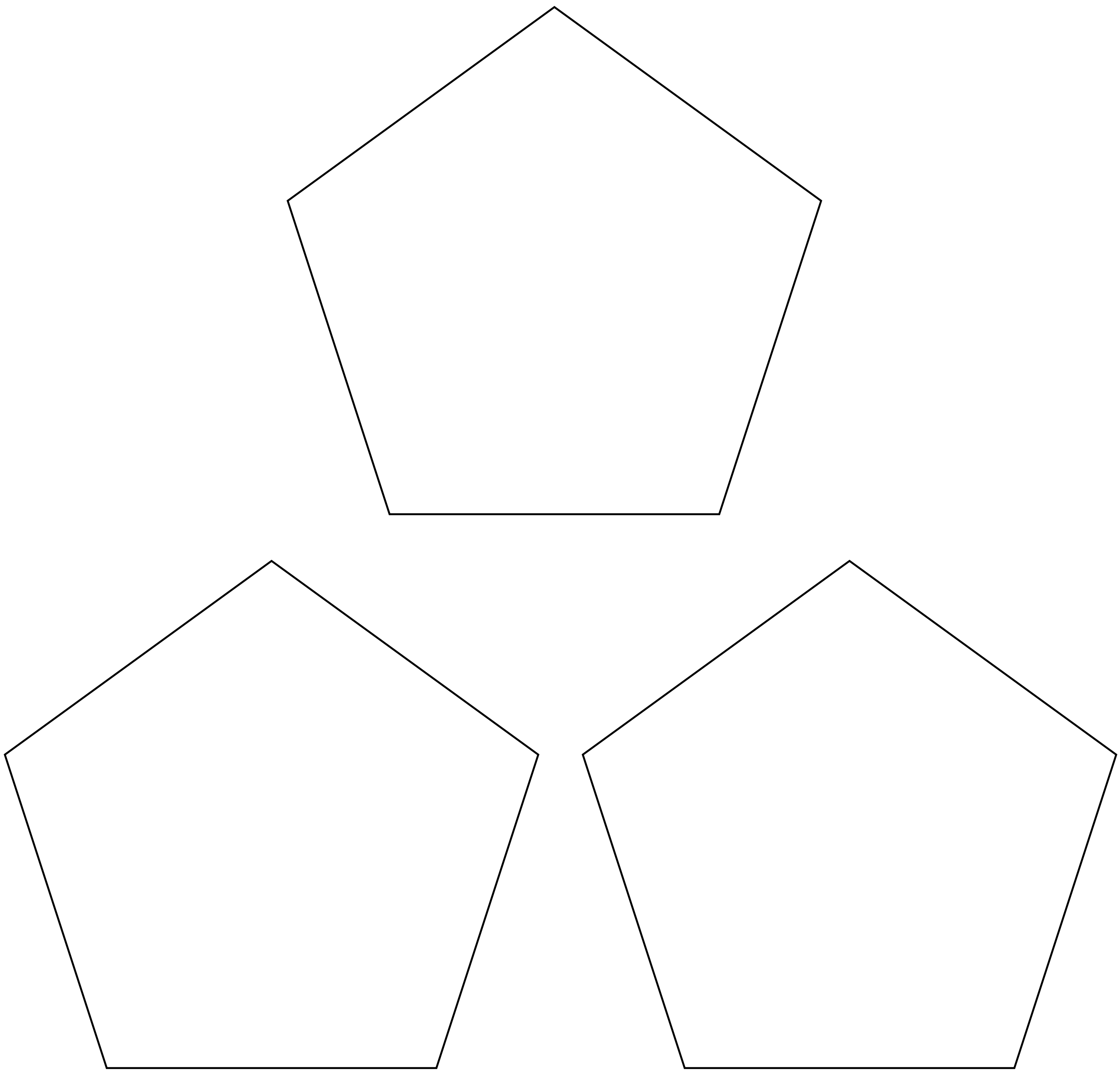




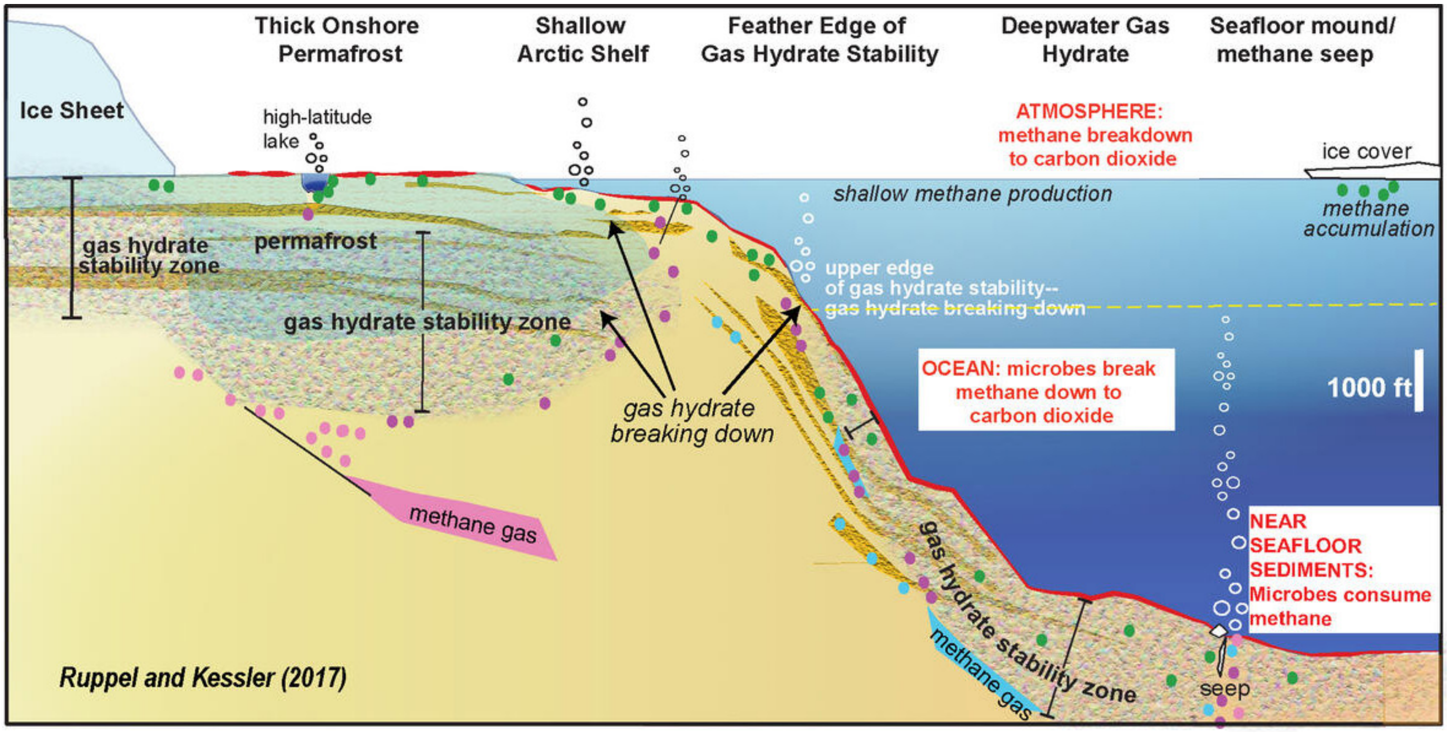
Methane Hydrate Model Template 1



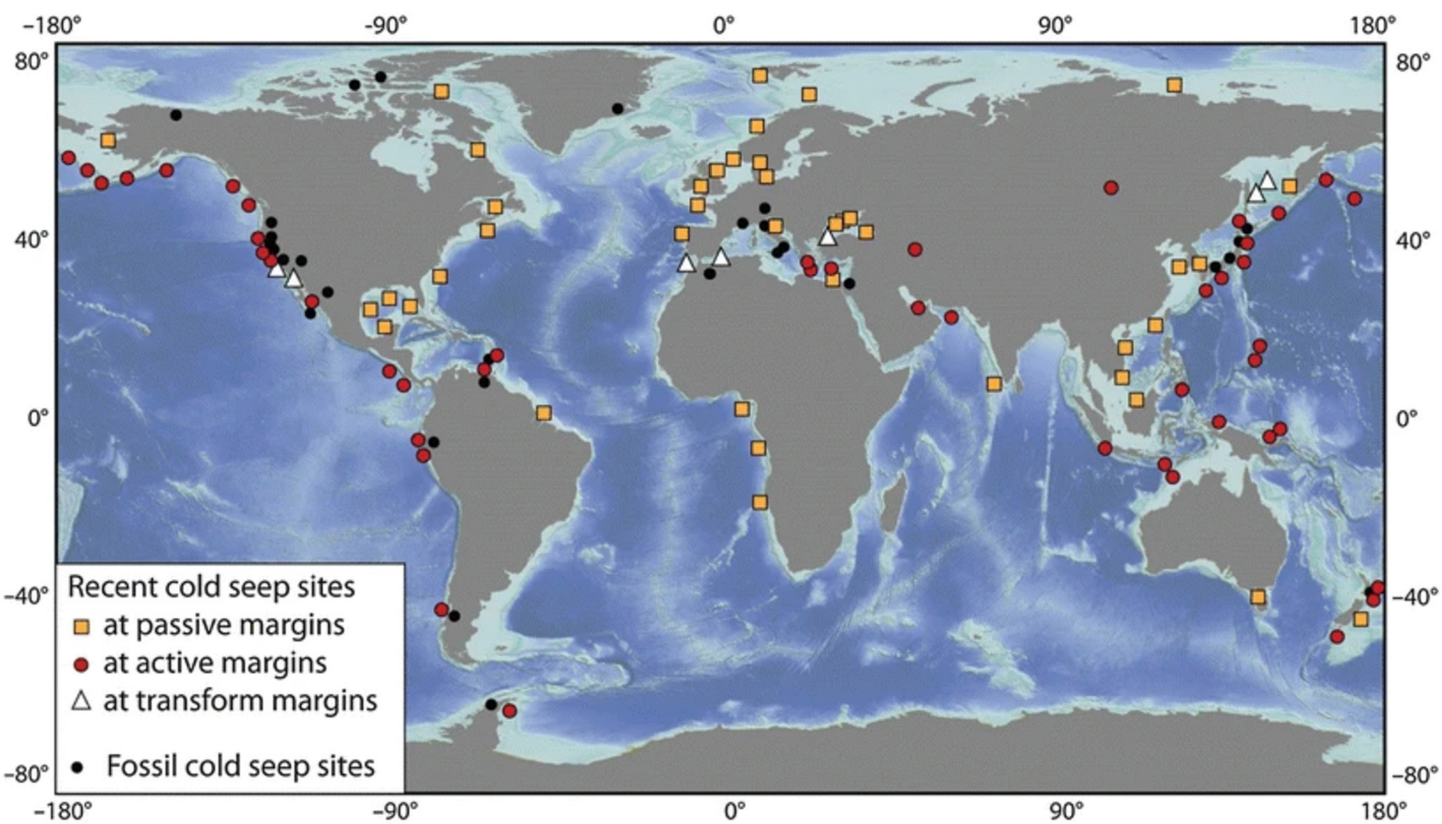
Methane Hydrate Model Template 2



Gas Hydrate Schematic and Seeps Location Map



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. *Image courtesy Ruppel and Kessler (2017).*



Seep locations at active (recent) locations, at passive (orange squares), and active (red circles) margin sites. Locations along transform faults are denoted by white triangles. Fossil sites are shown by black circles. *Seep locations based on compilations from Suess (2010), Campbell (2006) and Römer (2011).*

Methane Hydrates in the Deep Sea: Links and URLs

Page 1:
- Methane hydrate (image): https://oceanexplorer.noaa.gov/okeanos/explorations/seascape-alaska/ex2304/gallery/gallery.html#cbpi=/okeanos/explorations/seascape-alaska/ex2304/gallery/media/dive04-methane-hydrate.inc
- Student Worksheet: Methane Hydrate Model (pdf): https://oceanexplorer.noaa.gov/edu/materials/methane-hydrate-model_student_worksheet.pdf
- Methane Hydrate and Bubbles (video): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1711/dailyupdates/media/video/dive17-methane/methane-1280x720.mp4
- Searching for Methane Hydrates of Cascadia Margin (video): https://www.youtube.com/watch?v=MjqyGCZMBcQ

Page 2:
- Molecular structure (image): https://www.nist.gov/image/clathratepng-0
- Honeycomb pattern (image): https://upload.wikimedia.org/wikipedia/commons/b/b8/CH4_hydrate_sI.jpg
- Gas hydrate crystals (image): https://www.usgs.gov/index.php/media/images/gas-hydrate-crystals
- Methane molecule (image): https://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane1.html
- Phase diagram (image): https://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html

Page 3:
- Astoria Canyon methane hydrate (image): https://www.pmel.noaa.gov/eoi/Cascadia/images/astoriacanyon-850m-hydrate-bubbles-lg.jpg
- Chemosynthesis (fact sheet): https://oceanexplorer.noaa.gov/edu/materials/chemosynthesis-fact-sheet.pdf
- Chemosynthetic mussels (image): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/logs/aug2/media/mussels2-hires.jpg
- Fire and Ice in the Deep Sea (student investigation): https://oceanexplorer.noaa.gov/edu/themes/cold-seeps/lessons/fire-ice-in-deep-sea.html
- Methane Ice Worms (student investigation): https://oceanexplorer.noaa.gov/edu/themes/cold-seeps/lessons/methane-ice-worms.html
- Cold seeps (fact sheet): https://oceanexplorer.noaa.gov/edu/materials/what-are-cold-seeps-fact-sheet.pdf
- Cold Seeps of the U.S. Atlantic (web page): https://oceanexplorer.noaa.gov/explorations/18deepsearch/background/seeps/seeps.html
- An Update on Cold Seeps in the Northwestern Atlantic Ocean (web page): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1903/background/seeps/welcome.html
- Methane Hydrate and Bubbles (video): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1711/dailyupdates/media/video/dive17-methane/methane-1280x720.mp4
- Searching for Methane Hydrates of Cascadia Margin (video): https://www.youtube.com/watch?v=MjqyGCZMBcQ

Page 4:
- Fire and Ice in the Deep Sea (student investigation): https://oceanexplorer.noaa.gov/edu/themes/cold-seeps/lessons/fire-ice-in-deep-sea.html
- Methane Ice Worms (student investigation): https://oceanexplorer.noaa.gov/edu/themes/cold-seeps/lessons/methane-ice-worms.html

Information and Feedback

We value your feedback on this activity, including how you use it in your formal/informal education settings. Please send your comments to: **oceanexeducation@noaa.gov**. If reproducing this activity, please cite NOAA as the source, and provide the following URL: https://oceanexplorer.noaa.gov.