A JOURNEY TO A COLD SEEP

How scientists study methane in the arctic ocean:
A paired teaching lesson plan

VIDEO accompanying this lesson plan:
https://youtu.be/k0awmdQQITA

Focus: Where are and what happens at cold seeps and how scientists study them.

Learning objectives: After this lesson, students should be able to:

1. Relate different datasets by observing and describing scientific maps
2. Differentiate between carbon dioxide and methane gases
3. Clarify misconceptions about greenhouse gases
4. Explain what cold seeps are and why most gas/methane hydrates occur at continental margins
5. Describe some of the methods scientists use to locate and study methane/gas hydrates

Prerequisties: Prior to this lesson, students should be familiar with understanding maps, molecular structure and bonding, and the greenhouse effect and gases.

Key words: *Arctic Ocean, Methane, Carbon Dioxide, Gas Hydrate, Cold Seep, Greenhouse Gases.*

In short (for the teacher): This video lesson contains 4 video segments and 3 classroom activities in between the segments. During the classroom activities, students will

1. Discuss the differences and similarities between two greenhouse gases (methane and carbon dioxide).
2. Use scientific maps to observe and describe what they see.
3. Explain their scientific map to others and relate different maps to answer questions about where most gas hydrates locate and why.

The teacher can play the video segments and extra footage and photographs provided in the supplemental material to engage and prepare the students for the classroom activities, and to introduce them to some of the tools scientists use to study cold seeps in the ocean.

Materials: 3 Maps for Activity #2 and #3. Print maps in color, preferably of the size 60x90 cm. The maps should be printed at the same scale with legends clearly shown. Uniformity of the map scale makes it easy for students to compare data from map to map. The PDFs of these maps are included at the end of the lesson package (pages 15-17). You can also find them here:
Map 1: https://plateboundary.rice.edu/DPB_map_gifs/topo.grad.50percent.gif
Map 2: https://doi.org/10.1016/j.dsr.2004.06.014
Map 3: https://www.usgs.gov/media/images/map-gas-hydrates

Optional:
Molecular modeling kit for Activity 1 (alternatively use modeling clay and straws to construct the methane and carbon dioxide models).
Extra imagery and video footage of the seafloor and the Remotely Operated Vehicle (ROV) sampling – These files are included in the lesson package, and available at: https://akma-project.com/

Visual/audio materials: This is a video lesson. You will need audio-visual equipment (and internet connection if you plan to stream the video). About 20 minutes of the class time is covered by the video-scientist and teacher. At the end of the last segment, we have included a teacher's guide to the classroom activities. We encourage teachers watching this segment prior to using this video lesson. The teacher's guide is about 7 minutes. In addition, there are extra video footage including videos of the seafloor and an ROV (a remotely operated underwater vehicle) sampling available at: https://akma-project.com/

Teaching time: The video lesson takes about 60 minutes. This includes 20 minutes of video segments taught by the video-scientist and teacher plus 40 minutes of classroom activities facilitated by the in-class teacher.

Background Story:

This section is intended to be read by those interested in using this video lesson in their classrooms.

1. What are cold seeps and why do they matter?

Cold seeps or cold vents are areas of the ocean floor where methane (CH_4) and other gases escape and are released into water. You might have heard of hydrothermal vents (or hot springs) where seawater circulates through hot volcanic rocks. Cold seeps are different from hydrothermal vents because they occur under cold temperatures. Where we have cold seeps, we have carbonate rocks. These form because of reactions between methane and seawater. There are also lots of microbial activity at cold seeps. These microbes oxidize (or eat) methane anaerobically (in the absence of oxygen). Cold seeps are easily recognizable because of the white bacterial mats that mark their locations on the seabed.

Cold seeps are an important part of deep-sea ecosystems. As mentioned above, they feed communities that rely on bacteria that convert chemicals (e.g., methane) to food. Some of these bacteria form white mats that can be detected on the seafloor (see below image), and some live in symbiosis within animals such as tube worms or mussels. The animals provide a safe home to the bacteria, and in return, the bacteria make food for the animal. This makes cold seeps oases in the deep sea! Cold seeps could also be important contributors to climate change because they are emitting methane into the ocean. In addition, since cold seeps generally indicate large amounts of hydrocarbons below the seabed, they can be considered as new sources of hydrocarbons for addressing our increasingly energy demands.

Example of bacterial mats found at the sea floor in the Arctic Ocean. (Image: AKMA)

2. How do scientists study cold seeps?

Scientists use underwater technology such as remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) to study cold seeps. These machineries have several cameras and powerful lights to take photos of cold seep sites deep in the ocean. They are also equipped with devices that can sample sediments, rocks, biologic communities, gas and water, and help with bathymetric mapping of the ocean floor.

Other tools used to study the seafloor include multi-corer, gravity corer, heat flow probe, and seismic datasets which are used for imaging the subsurface fluid and gas flows. To learn more about some of these techniques, we suggest watching the scientific videos on the website of the AKMA project: https://akma-project.com/video

ÆGIR 6000 is a remotely operated vehicle (ROV) designed to be used by scientists to access and study the sea floor. It is suitable for depths of up to 6000 meters. ÆGIR is operated by the Norwegian Marine Robotics Laboratory at the University of Bergen (UiB). Image credit: Solmaz Mohadjer.

3. What is methane and how is it produced?

As mentioned above, methane and other gases are released into water at cold seeps. But what is methane and how is it produced? Methane (CH_4) is a hydrocarbon (made of a single carbon atom with four arms of hydrogen atoms) and the main component of natural gas.

Methane occurs in nature both below the ground and under the seafloor due to biological and geological processes. Under the seafloor, methane is produced by microorganisms that live in the sediment layers. These organisms slowly convert organic materials into methane. The organic materials are the remains of other organisms that once lived in the ocean, sank to the ocean floor when they died, and finally became a part of the sea sediments.

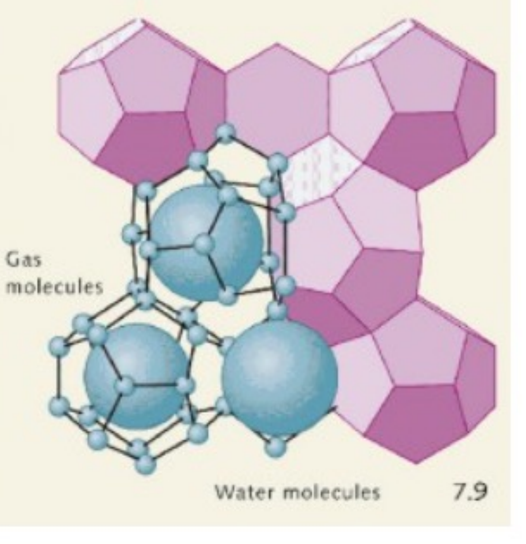
The methane released from natural sources only makes up a small percent of the total methane emissions in the atmosphere. More than half of the methane in the atmosphere, in fact, comes from certain human activities such as oil and gas production, agricultural activities and waste management. In fact, methane levels in the atmosphere are mainly driven by emissions from the fossil fuel and agriculture/livestock sectors.

You might have heard of cows and other grazing animals, for example, as methane producers. They have microbes in their stomachs to help with digestion. These microbes produce methane as they break down the food. The methane can then be released into the atmosphere when animals burp or pass air. Even their manure is a place for microbes to hang out and produce more methane. Similarly, rice paddies when flooded, create a perfect home (calm water and low oxygen) for methane-producing bacteria. Microbes also hang out and produce methane at landfills and sewage treatment facilities.

Methane can also be intentionally or unintentionally released from oil and gas wells during drilling and production, and even after a well has ceased production. This can happen when wells are not plugged properly, emitting large volumes of methane into the atmosphere.

4. What are natural methane gas hydrates (burning ice)?

Natural methane gas hydrates (also known as burning ice) are an ice-like **solid** (not gas) composed of water and methane gas. The gas is locked up in water molecules, and if you dig out a chunk of this if you put a match to it, you'll notice that it won't melt. Instead, it will make a fizzing sensation, and if you put a match to it, it catches on fire. Natural gas hydrates are made from living organisms and carbon in decayed and partially decayed plant and animal tissues and natural organic matter like those that form in soil when plant and animal matter decays. Gas hydrates are found where we have deposits of organic matter consumed by microbes, typically along margins of continent where temperature is low, and pressure is high. In the ocean, we find them in cold seeps.



(Image left) methane hydrates with its honeycomb structure, (right) structure of gas hydrates: methane gas molecules (large spheres) trapped in cages made of water molecules (smaller spheres), if the cages break (due to increasing temperature, for instance), the methane gas escapes and can enter the water column/atmosphere. Image source: https://worldoceanreview.com/en/wor-1/energy/methane-hydrates/

A vast amount of methane gas hydrates exists at the deep sea though the exact amounts and locations are not entirely known. These hydrates are generally stable unless something like warm water disturbs them. When destabilized, these hydrates can release methane from the seafloor into the atmosphere and warming it up by trapping heat in the atmosphere.

5. Why do methane emissions matter? How can they be reduced?

Methane emissions matter because methane is a powerful greenhouse gas, with a warming effect 40 times that of carbon dioxide. This means that methane is more potent than carbon dioxide at trapping heat in the atmosphere, so its presence in the atmosphere affects the Earth's temperature and climate system. Most of the methane in the atmosphere are from man-made (anthropogenic) sources, not the cold seeps where methane gas enters the water column.

Carbon dioxide gets a lot of attention in climate change discussions. This is because there is a lot of it in the atmosphere and its concentration is increasing. Carbon dioxide can also last for centuries in the atmosphere. Methane, however, is much less abundant in the atmosphere and lasts there for only about a decade on average. This means that methane has a large effect over a relatively short period. Therefore, reducing methane emission can have a rapid and significant effect on atmospheric warming potential.

Learning procedure:

Follow the process in the accompanying paired teaching video:
https://youtu.be/k0awmdQQITA

Group work:

Activity 1 (mystery bottle) is discussion-based and can be done either in small groups or as a whole group.

For Activity 2, students form three groups with each group standing near where their assigned map is displayed. Group 1 is assigned Map 1 (Bathymetry), Group 2 is assigned Map 2 (Organic carbon content in marine sediments), and Group 3 is assigned Map 3 (methane/gas hydrates locations). To divide students into groups, have them count off by 3 to determine their group number. This ensures random selection of students per group. One of the benefits of this random selection is to have students work with others outside their usual social groupings.

For Activity 3, students form three new groups (Group A, B, and C). This will be a different group of students than they worked with during Activity 2. Each new group should have at least one person from previously formed groups in Activity 2. For example, Group A should have at least one person from Group 1, 2 and 3. Each group needs to sequentially visit each of the maps to become familiar with all the maps.

Practical:
In addition to the instruction provided below, please check out the 'Teacher Segment' of this video lesson for more detailed instructions.

Activity 1 (Mystery Bottle, 5 minutes):

This is a discussion-based activity where students are asked to discuss how to identify a bottle with methane gas from a bottle containing carbon dioxide.

1. Start the video lesson by playing the first video segment. The video-scientist and teacher will provide some background information and introduce Activity 1. Pause the video at the end of the segment.

2. Divide your students into small groups or have a whole class discussion.

3. Ask students how they'd identify which bottle contains methane and which one contains carbon dioxide. Allow students to freely explore ideas and explain their reasoning to support each idea. Consider writing down their ideas on the board.

4. After they are done with the discussion (5 minutes), return to the video lesson to play the next segment during which the video-scientist and teacher explain the similarities and differences between the two gases, and introduce Activity 2.

Activity 2 (observing maps, 5 minutes):

[Video segment 5:40 - 8:30]

This is an exercise based on observing and describing maps. You will use 3 maps: Map 1 (Bathymetry), Map 2 (Organic carbon content in sea sediments) and Map 3 (Location of methane/gas hydrates). Each map is described below:

a. Map 1 shows the topography and bathymetry of the Earth. This is the elevation of the land surface and the depth of the oceans. The map uses color to indicate varying elevations and depth and simulates sun shading to add a sense of 3D to the map. The scale bar on the right shows colors on the map correspond to elevation in meters.
b. Map 2 shows the global distribution pattern of the total organic carbon content (in wt%) in the ocean sediments found at <5 cm sediment depth.
c. Map 3 shows the location of gas hydrates (recovered, inferred and drilling sites).

1. Before students arrive in the class, print the 3 maps and attach them to the walls of your classroom, far enough apart that groups of 8-10 students can stand around a map and not interfere with a group standing around and discussion another map. You may choose to print the maps large and laminate them. Students may discuss the maps more readily if they are standing rather than sitting, but if you are limited by space, feel free to tape the maps on a table (e.g., lab table) and have students sit around the table. Keep in mind that these maps are reusable, especially if you laminate them.

2. After students are in the class, divide them into three groups. Each group stands around their assigned map (e.g., Group 1 stands around Map 1).

3. Ask students to become familiar with their maps. They should read the side label to see what is being displayed and how it is displayed. They should work as a group to find out what they are looking at. Once they have studied their maps, they can start to describe what they see. Their description should include words like *deep* or *shallow*, *high organic carbon* or *low organic carbon*, etc. While students are doing this, circulate among the groups listening and clarifying misconceptions.

4. Once students are done with studying their maps (10 minutes), return to the video lesson and play the next segment. The video-scientist and teacher will discuss the maps and introduce Activity 3.

Activity 3 (relating maps, 15 minutes):

[Video segment 8:45 – 9:50]

1. Divide students into new groups (Group A, B and C). This will be a different group of students than they worked with during Activity 2. Each new group should have at least one person from previously formed groups in Activity 2. For example, Group A should have at least one person from Group 1, 2 and 3. This ensures that each group has members familiar with each of the three maps.

2. Remind students of the three questions they are asked to discuss:
   a. At what depth do most gas hydrates locate?
   b. Where do you see high amounts of organic carbon in sea sediments?
   c. Where do you expect to find gas hydrates and why?

   To answer these questions, students need to relate the three maps to one another. Consider writing these questions on the board.

3. Ask each group to visit each of the maps to become familiar with all the maps. During each visit, the expert(s) of that map from Activity 2 will brief the group. For example, when Group A visits Map 1, those already familiar with Map 1 brief the rest of the group, and together they try to answer the questions. Students can choose to write down their answers in a notebook or on the board. As students do this, feel free to circulate among the groups listening and clarifying misconceptions.

4. Once students are done (15 minutes), return to the video lesson and play the last segment. The video-scientist and teacher will discuss the three questions and show some of the tools scientists use to study cold seeps. This is the last video segment and the end of the lesson.

Further discussion

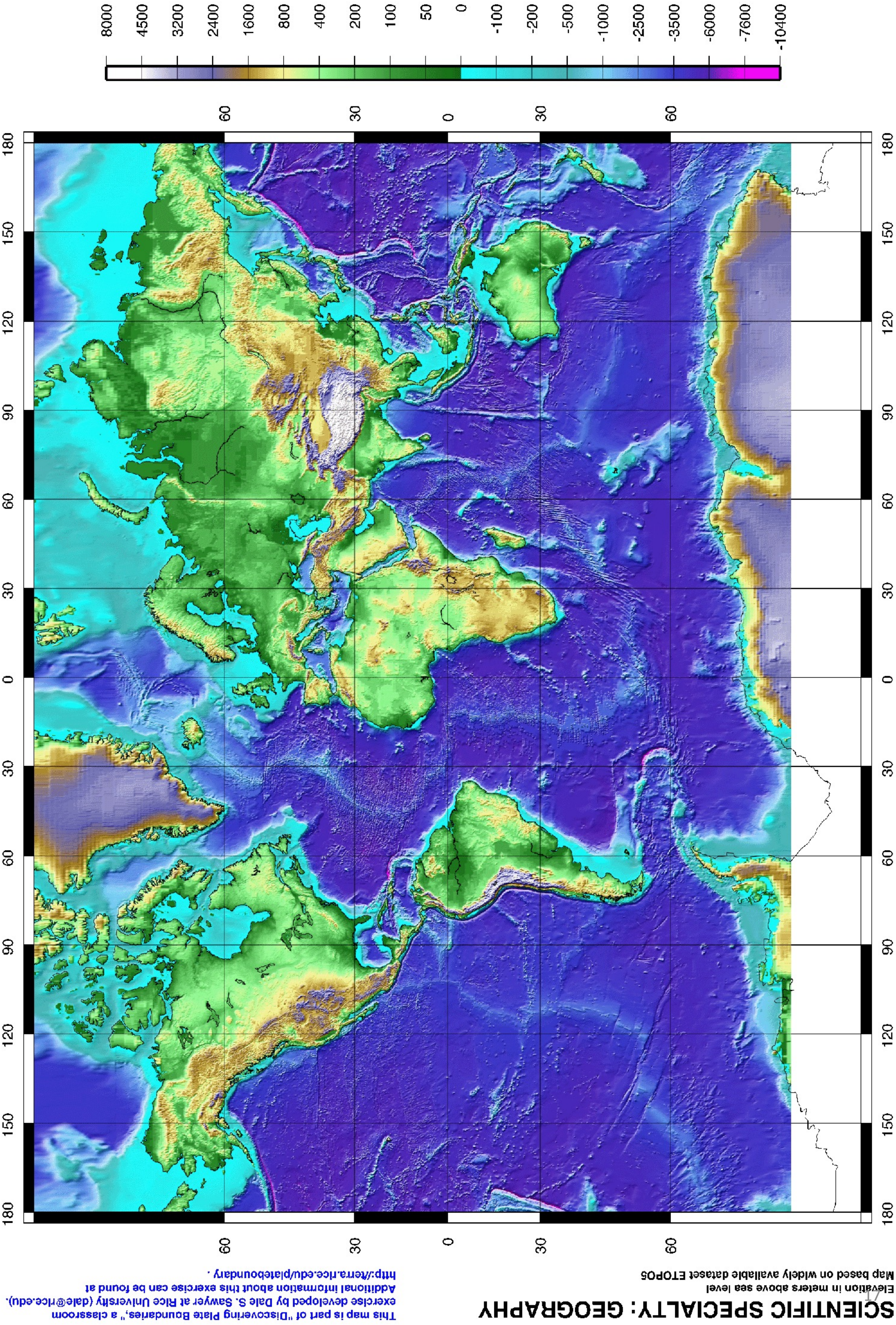
Now that you have learned about natural and man-made methane emissions, as well as cold seeps and how scientists find and study them, we encourage you to use the extra material (under resources) to discuss the following questions:

1. What kind of information can be obtained from using a gravity corer? How do cores obtained using this method differ from other coring methods (e.g., multi-corer, push cores using an ROV)?
2. What can you (as an individual) do to reduce methane emission? Give 2-3 examples.
3. How do scientists use seismic data to document methane emissions deep in the ocean?
4. Is there methane in the atmosphere of the Mars? How about its subsurface? What could the existence of methane on Mars potentially mean?

Resources

AKMA science videos:
https://akma-project.com/video
Cold seeps:
https://oceanexplorer.noaa.gov/edu/themes/cold-seeps/
Reducing methane emissions:
https://eos.org/editors-vox/methanes-rising-what-can-we-do-to-bring-it-down
Microbial consumption of methane on the seafloor:
https://eos.org/research-spotlights/investigating-rates-of-microbial-methane-munching-in-the-ocean
Martian methane:
https://eos.org/articles/how-scientists-search-for-martian-methane

MAP 1



Topography/Bathymetry map: https://plateboundary.rice.edu/downloads.html (last access: 24.11.2022)

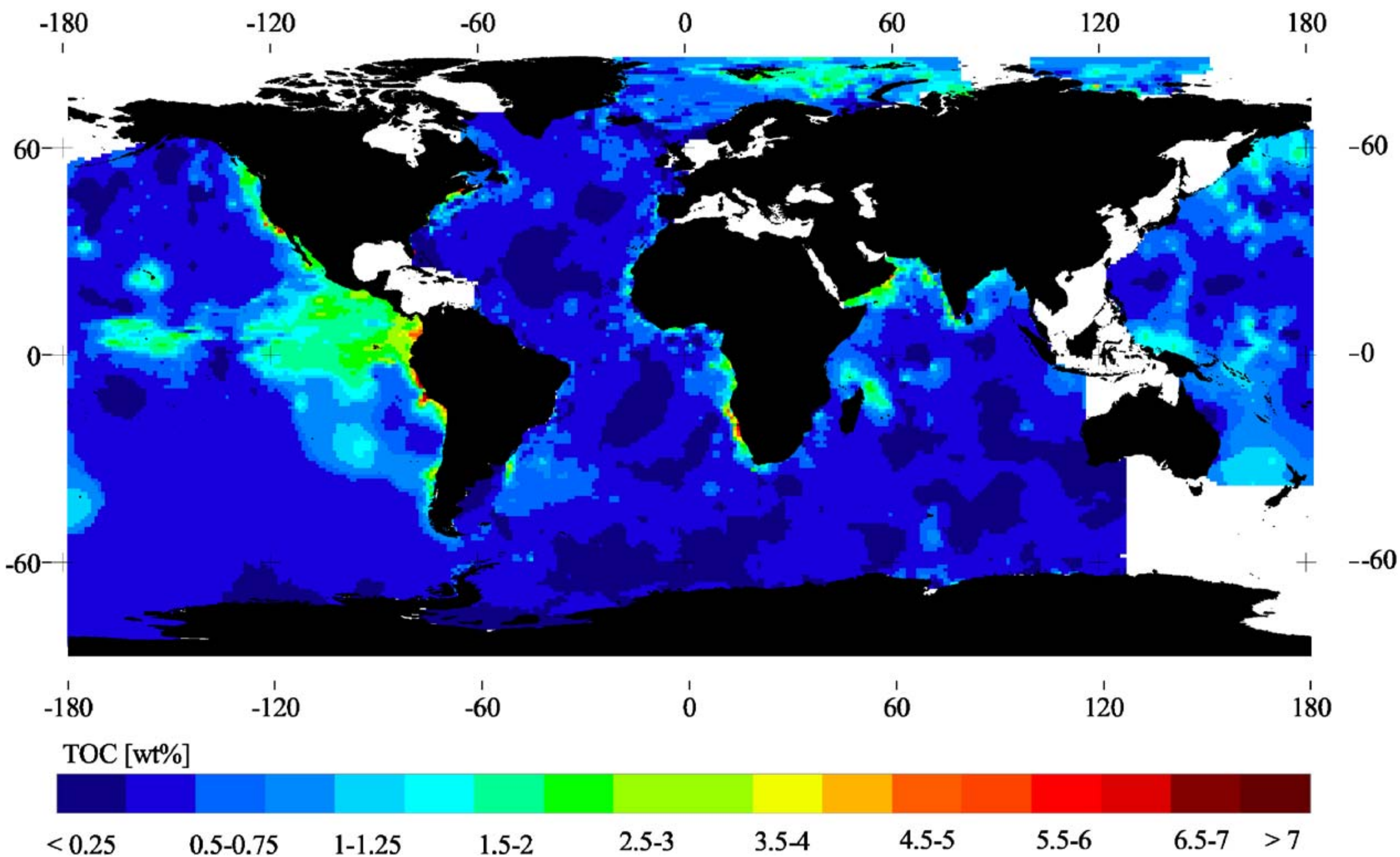
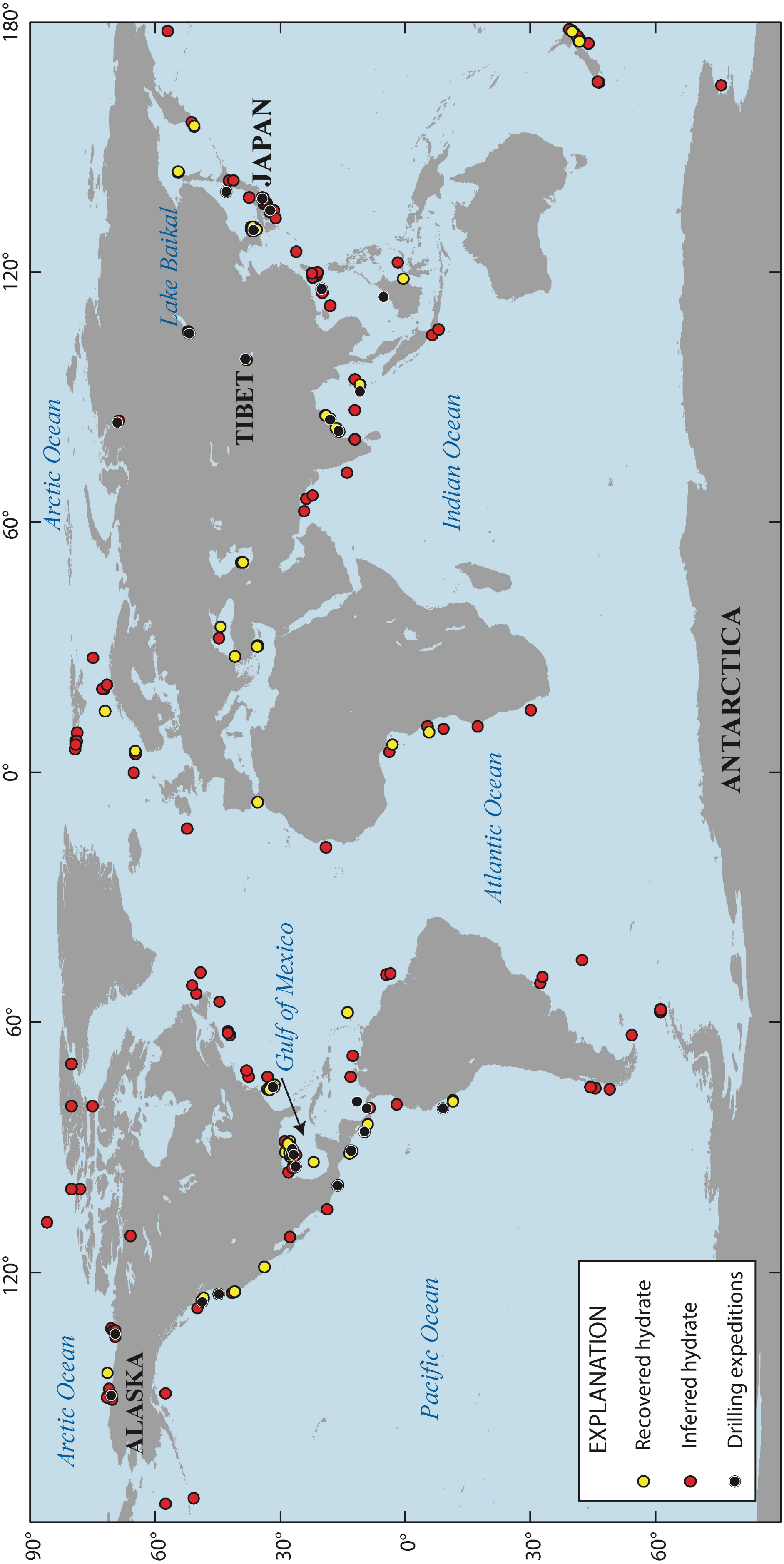


Fig. 11. Global distribution pattern of the TOC content in surface sediments (<5 cm sediment depth).

Seiter, Katherina, et al. "Organic carbon content in surface sediments—defining regional provinces." Deep Sea Research Part I: Oceanographic Research Papers 51.12 (2004): 2001-2026.

MAP 3



•Map of Gas Hydrates: US Geological Survey: https://www.usgs.gov/media/images/map-gas-hydrates (last access: 24.11.2022)

This lesson plan was developed as part of the project Advancing Knowledge of Methane in the Arctic (AKMA) based at UiT - The Arctic University of Norway in Tromsø with funding from INTPART - International Partnership for outstanding education, research and innovation - a Norwegian Research Council programme. The development work began during the AKMA Ocean Senses scientific expedition onboard RF Kronprins Håkon 11-22 May 2022. The expedition brought together scientists, social scientists, humanities scholars, teachers, and artists to collaborate and create lesson plans that would bring the ocean floor to life in the classroom

This specific lesson plan was developed in a close collaboration with:

Solmaz Mohadjer, Vibeke Aune, Giuliana Panieri, and Davide Oddone.

If you have further questions please get in touch with the leader of AKMA, Giuliana Panieri: giuliana.panieri@uit.no

Photo: Davide Oddone