To Boldly Go…

This lesson guides student investigations into reasons for ocean exploration. Other lessons in *Volume I, Why Do We Explore* guide additional investigations into key topics of Ocean Exploration, Energy, Climate Change, Human Health, and Ocean Health.

Focus
Ocean Exploration

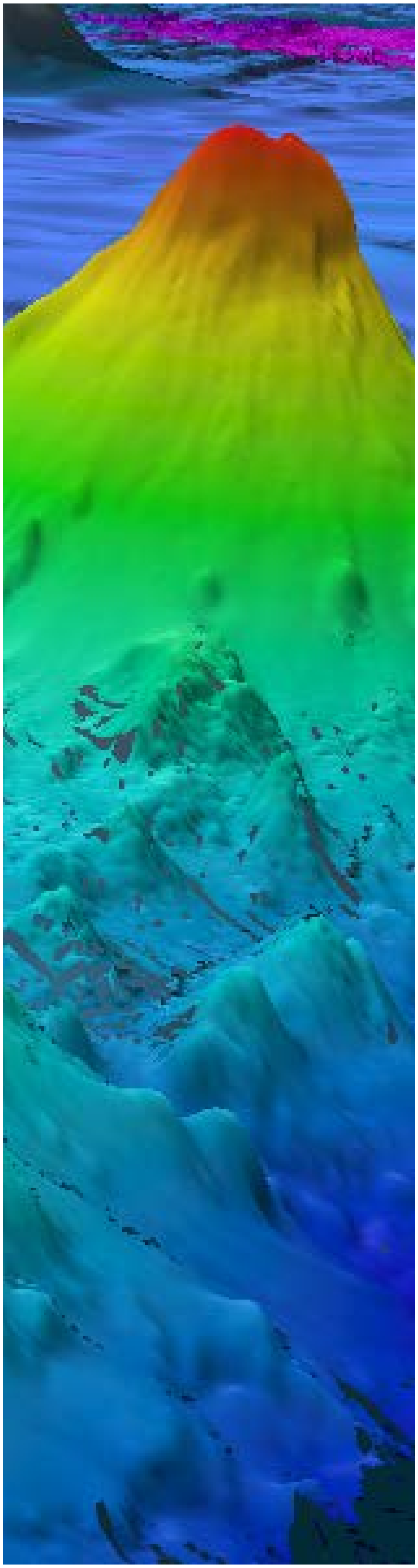
Grade Level
Target Grade Level: 6-8; suggested adaptations for grades 5 and 9-12 are provided on page 17.

Focus Question
Why do we explore the ocean?

Learning Objectives
- Students discuss why scientists believe there are important undiscovered features and processes in Earth's ocean.
- Students discuss at least three motives that historically have driven exploration.
- Students explain how ocean exploration helps understand feedback processes that cause changes to Earth systems, including patterns of atmospheric and oceanic circulation and energy flow that affect climate.
- Students discuss how ocean exploration helps develop technological solutions that reduce impacts of human activities on ocean systems.

Materials
- Internet and/or library access for student research
- Stiff paper such as card or cover stock
- Learning Shape patterns (photocopied from page 18, or downloaded from the Internet)
- Scissors
- Markers and/or photo images
- Glue or glue stick

Giant clams (*Tridacna maxima*) symbiotically photosynthesize in the shallow, sun-drenched lagoon of Orona Island, an uninhabited atoll in the Phoenix Islands Protected Area. Image courtesy of Dr. Randi Rotjan/PIPA. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/background/biogeography/media/clams.html*



- Two stopwatches or other time interval measuring devices (*e.g.,* stopwatch apps)
- Seaweed crackers, fish crackers or other ocean-themed prizes

Audiovisual Materials

- Multimedia board, marker board, or overhead projector

Key Words and Concepts

Ocean exploration
NOAA Ship *Okeanos Explorer*
Climate change
Deep-sea medicines
pH
Ocean acidification
Telepresence
Methanogenic
Archaea

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.

"We know more about the dead seas of Mars than our own ocean."
~ Jean-Michel Cousteau

Most of Earth's ocean floor has never been seen by human eyes. While recent satellite maps of Earth's ocean floor seem to show seafloor features in considerable detail, satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. Moreover, at the scale of a typical wall map (about 1 cm = 300 km) a dot made by a 0.5 mm pencil represents an area of over 60 square miles! Modern ocean exploration begins with high resolution mapping that allows explorers to focus on areas of particular interest and importance. Multibeam sonar mapping systems can produce images that are thousands of times more detailed than satellite imagery. Under ideal conditions, multibeam systems can map features as small as 40 meters wide at 4000 meters depth. However, only about 15% of Earth's deep ocean has been mapped at a resolution that is adequate for modern exploration.

NOAA Ship *Okeanos Explorer*

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only federal U.S. ship whose sole assignment is to systematically explore our

Multibeam bathymetry of Pao Pao Seamount. Image courtesy of the NOAA Discovering the Deep: Exploring Remote Pacific MPAs 2017.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/dailyupdates/media/mar9.html

The NOAA Ship *Okeanos Explorer*, America's ship for ocean exploration. Image courtesy NOAA. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/mar1/media/okeanos.html*

largely unknown ocean for the purposes of discovery and the advancement of knowledge. Similar ships are operated by the Schmidt Ocean Institute (R/V *Falkor*) and the Ocean Exploration Trust (E/V *Nautilus*). Please see the *Introduction to Ships and Their Strategy for Exploration http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf* for details.

To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6,000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate the water column and seafloor through high definition video and still imaging as well as collect biological and geological samples; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and participate in activities at remote locations. This allows live video to be transmitted from the seafloor to scientists ashore, classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shorebased members of the science community to share their expertise with shipboard scientists and ROV pilots in real time. This allows more scientists to participate in expeditions at a fraction of the cost of traditional oceanographic expeditions.

Okeanos Explorer Vital Statistics:

Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 49, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit http://oceanexplorer.noaa.gov/okeanos/welcome.html.
Follow voyages of America's ship for ocean exploration and all other NOAA OER expeditions via the Digital Atlas at *https://www.ncddc.noaa.gov/website/google_maps/OE/mapsOE.htm*

Modern Reasons for Ocean Exploration

Ocean exploration supports and enhances the work of many individuals and organizations working on America's key science issues, including:

- **Climate Change –** The ocean has a major influence on weather and climate, but we know very little about deep-ocean processes that affect climate.
- **Energy –** Ocean exploration contributes to the discovery of new energy sources, as well as protecting unique and sensitive environments where these resources are found.
- **Human Health –** Expeditions to the unexplored ocean almost always discover species that are new to science, and many animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs.
- **Ocean Health –** Many ocean ecosystems are threatened by pollution, overexploitation, acidification and rising temperatures. Ocean exploration can improve understanding of these threats and ways to improve ocean health.
- **Research –** Expeditions to the unexplored ocean can help focus research into critical areas that are likely to produce tangible benefits.
- **Innovation –** Exploring Earth's ocean requires new technologies, sensors and tools and the need to work in extremely hostile environments is an ongoing stimulus for innovation.
- **Ocean Literacy –** Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering and mathematics and offers vivid examples of how concepts of biology, physical science, and earth science are useful in the real world.

The science and ship crew of the HMS *Challenger* in 1874. The original crew of 216 had dwindled to 144 by the end of the long expedition. Image courtesy NOAA.

Many Reasons to Explore

Historically, explorers have been driven by a variety of motives. For some, the primary reason to explore was to expand their knowledge of the world. For others, economic interests provided powerful incentives, and many expeditions have launched on such missions as finding a sea route to access the spices of Asia, or quests for gold, silver, and precious stones. Political power and the desire to control large empires motivated other explorations, as did the desire to spread religious doctrines. In the case of space exploration, additional reasons have been offered, including understanding our place in the cosmos, gaining knowledge about the origins of our solar system and about human origins, providing advancements in science and technology, providing opportunities for international collaboration, and keeping pace with other nations involved in developing space technology. The first ocean exploration for the specific purpose of scientific research is often considered to be the voyage of the HMS *Challenger*, conducted between 1872-1876 (visit *http://oceanexplorer.noaa.gov/explorations/03mountains/background/challenger/challenger.html* and *http://www.coexploration.org/hmschallenger/html/AbouttheProject.htm* for more information about the HMS *Challenger* expedition and comparisons with modern oceanographic exploration).

Curiosity, desire for knowledge, and quest for adventure continue to motivate modern explorers. But today, there are additional reasons to explore Earth's ocean, including climate change, energy, human health, ocean health, innovation, research and ocean literacy.

Oblique view of Grinnell Glacier taken from the summit of Mount Gould, Glacier National Park. The relative sensitivity of glaciers to climate change is illustrated by the dramatic recession of Grinnell Glacier while surrounding vegetation patterns remain stable.

The retreat of Grinnell Glacier from 1938 to 2013. Image from the Repeat Photography Project of the Northern Rocky Mountain Science Center (NOROCK). *https://www.usgs.gov/centers/norock/*

Climate Change

Earth's average temperature is warmer than it has been at any time since at least 1400 AD. While there is ongoing political debate about the causes of climate change, there is a growing body of scientific evidence that shows:

- Mountain glaciers are melting;
- Polar ice is decreasing;
- Springtime snow cover has been reduced;
- Ground temperature has been increasing in many areas; and
- Sea level has risen by several inches in the last 100 years.

Potential impacts of global climate include weakening the deep-ocean thermohaline circulation (THC), which plays an important role in transporting heat, dissolved oxygen and nutrients, accelerating the widespread decline of coral reefs, extinction of species such as the polar bear, and year-round access to sea routes through the Arctic. Ocean exploration can provide some of the essential knowledge about ocean-atmosphere interactions that is needed to understand, predict, and respond to these impacts. For additional discussion about climate change and the THC, please see the Diving Deeper section starting on page 20.

Energy

"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."

from *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 hydrates are ice-like substances formed when molecules of water form an open lattice that surrounds molecules of methane without forming chemical bonds between the two materials. In deep-ocean sediments, conditions of low temperature and high pressure allow methane hydrate deposits to form. There is growing interest in these deposits as an alternative energy source, because 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. In addition, methane hydrates are associated with unusual and possibly unique biological communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials. These communities include microorganisms that eat methane (methanotrophs), as well as animals that are able

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 Miriam Jones, U.S. Geological Survey.
https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/PA240043.JPG

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*

to feed directly on methanotrophs, and others (such as highly specialized mussels and tubeworms) that keep a population of methanotrophs in their bodies. The latter is a symbiotic relationship in which the mussel or worm gets some carbon from the methanotroph and the methanotroph gets a protected habitat inside the animal. For more information, please see "Methane in the Ocean" by Monica Heintz *http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/methane.html*.

While there have been concerns that the sudden release of methane from methane hydrates might trigger catastrophic climate change or tsunamis caused by underwater landslides, recent research does not suggest that these are likely events (Talling et al., 2014; Ruppel and Kessler, 2017). Released methane, however, may resuilt in increased acidity of ocean waters and reduced levels of dissolved oxygen (Ruppel and Hamilton, 2014).

Besides methane hydrates, regions such as the Gulf of Mexico produce significant quantities of petroleum. Often, the presence of hydrocarbons at the surface of the seafloor is accompanied by cold-seep communities which are biological communities that derive their energy from gases (such as methane and hydrogen sulfide) and oil seeping out of sediments. In addition to locating new sources of hydrocarbon fuels, exploration of these communities frequently reveals species that are new to science and provides information on ecology and biodiversity that is needed to protect these unique and sensitive environments. For additional discussion about energy, methane hydrates and cold-seep communities, please see Diving Deeper page 36.

Human Health

Improving human health is another motive for ocean exploration. Almost all drugs derived from natural sources come from terrestrial plants. But recent explorations have found that some marine invertebrates such as sponges, tunicates, ascidians, bryozoans, and octocorals can also produce powerful drug-like substances. Many of these are sessile (non-moving), bottom-

Tectitethya crypta is a large, shallow-water sponge found in the Caribbean. First studied for medical purposes in the 1950s, scientists isolated two chemicals which were used as models for the development of a number of anti-viral and anti-cancer drugs. These include the HIV drug AZT, a breakthrough in AIDS treatment in the late 1980s, anti-viral drugs to treat herpes, and an anti-leukemia drug. Image Credit: Sven Zea (*http://www.spongeguide.org/*) Info credit: *http://ocean.si.edu/ocean-photos/sea-sponge-hiv-medicine* dwelling animals that do not appear particularly impressive; yet, they produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. The potential for discovering important new drugs from deep-ocean organisms is even greater when one considers that most of Earth's seafloor is still unexplored, and deep-sea explorations routinely find species that have never been seen before. For additional discussion about drugs from the sea, please see the Diving Deeper section on page 38.

Ocean Health

"The First Global Integrated Marine Assessment" under the United Nations' Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects (Inniss et al., 2016) documents multiple stresses that currently affect Earth's ocean, including acidification; changes in sea temperature and salinity; competing demands for marine space; increased mortality of animal populations due to excessive fishing; physical alteration of sea-bed habitats; and inputs of explosives, hazardous gases, hydrocarbons, nutrients, plastics, pathogens, and other hazardous substances.
"Life will find a way," according to chaos theorist Ian Malcolm in Jurassic Park (Crichton, 1990). But the question is, "Which life?" Deep-sea explorers often find biological organisms thriving in conditions that would be extremely hostile to humans. But his does not mean that species can simply adapt to stresses from falling pH, rising sea levels and temperatures, pollution and overfishing. We urgently need to learn more about ocean ecosystems and how they affect the rest of our planet. This is one of the most important modern reasons for ocean exploration. Without a doubt, human curiosity, the desire to understand our world, and the excitement of discovery are still among the reasons we explore Earth's ocean; but we also explore to survive. For more information about ocean health issues, please see Diving Deeper page 39.

Research

It is important to note that expeditions to the unexplored ocean can help focus research into critical geographic and subject areas that are likely to produce tangible benefits. Telepresence technology aboard the *Okeanos Explorer* allows many explorers to participate at a fraction of the cost of traditional expeditions, as well as opportunities for students and the general public to have a first-hand look at the processes of scientific exploration.

Technological Innovation

The challenges of working in the extremely hostile environments of the deep ocean are an ongoing stimulus for technology innovation and development. For example, the hazards and expense of putting humans into deep ocean environments has stimulated the development of robot systems that can allow humans to see these environments with video technology, and

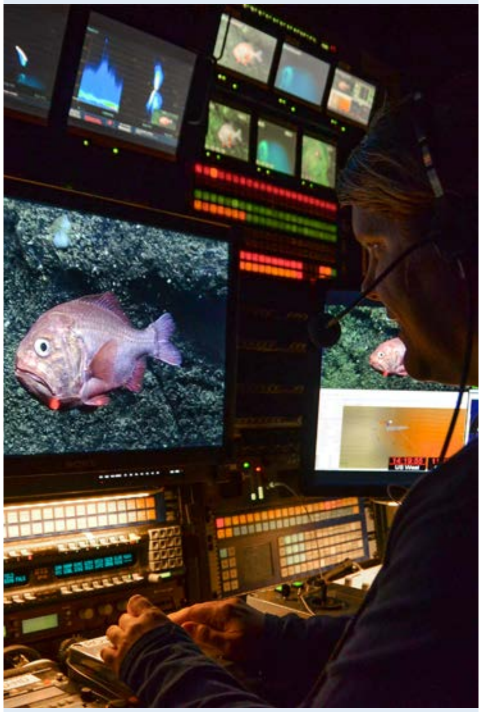
Coral bleaching in the Maldives captured by The Ocean Agency / XL Catlin Seaview Survey / Richard Vevers in May 2016.
http://www.globalcoralbleaching.org/#latest-imagery-released-23-sept-2016

Expedition Science Leads Daniel Wagner (foreground) and Jonathan Tree (background) use transit days to take a look at samples collected. Image courtesy of the NOAA Office of Ocean Exploration and Research, 2016 Hohonu Moana. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1603/dailyupdates/media/mar12.html*

obtain information about physical and chemical conditions (such as temperature an pH) with electronic sensors.

Science Education and Ocean Literacy

Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering and mathematics, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world. Similarly, the challenges of exploring the deep ocean can provide the basis for problem-solving instruction in technology and engineering. Ocean exploration also provides an engaging context for improving ocean literacy, understanding how the ocean influences our lives, and how we influence the ocean. An ocean literate citizenry is increasingly vital as we confront issues such as ocean health and climate change.



A technician in the control room of the *Okeanos Explorer* controls the remotely operated vehicle cameras. Image courtesy of the NOAA Office of Ocean Exploration and Research, Discovering the Deep: Exploring Remote Pacific MPAs. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/logs/mar27/welcome.html#caitlin*

Note that many of the topics discussed above apply to more than one reason to explore. Methane hydrates, for example, are relevant to climate change as a potential source of a greenhouse gas that could accelerate trends toward warmer temperatures. Similarly, pH changes discussed under ocean health are also linked to climate change since increased dissolved carbon dioxide in the ocean is the result of increased carbon dioxide in the atmosphere that may be partially responsible for observed changes in Earth's climate. The same issues are also relevant to drugs from the sea, since warmer temperatures and changes in ocean circulation patterns are among the stressors that threaten some of the marine organisms that produce pharmacologically-active substances.

The key point is that ocean processes do not operate in isolation; they interact and affect each other in ways that we are just beginning to understand. We separate these topics as individual examples of reasons to explore, and for improved clarity in an introductory discussion; but it is important to realize that the ocean is an integrated system—individual organisms and processes always interact with many others, and the whole is much more complex than the sum of the parts.

Learning Procedure

This lesson is designed as a student investigation into the question: Why do we explore the ocean? It is possible to make this lesson an individual student assignment, but a group of students will probably produce a more dynamic exchange of ideas. The basic lesson design is as follows: Assign the guidance questions below to groups of three or four students. Then have each group construct ocean exploration learning shapes as part of its investigation, and use these shapes to reinforce concepts resulting from student research. Finally, use oral reports from these groups as the basis for a full class discussion. The primary curriculum topics of the lesson are interactions between Earth systems, and how ocean exploration can help us understand and mitigate human impacts on natural systems. It is targeted to grade levels 6–8, but suggested adaptations for grades 5 and 9–12 are provided following the Learning Procedure section.

1. To prepare for this lesson:
   - Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html* and *http://oceanexplorer.noaa.gov/okeanos/about.html* and the *Introduction to Ships and Their Strategy for Exploration* *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/hdwe-StrategyBkgnd.pdf*.
   - Review video presentations "Hotspots of Biodiversity" by Kasey Cantwell *oceanexplorer.noaa.gov/okeanos/explorations/ex1605/dailyupdates/media/video/hotspots/hotspots.html*; "Introduction to NOAA Ship *Okeanos Explorer*" by John McDonough *http://ps.connect230.com/coexploration/mcdonoughjune09/f.htm* and "Deep Ocean Exploration: New Discoveries and Implications for Our Warming Planet by Steve R. Hammond *http://ps.connect230.com/coexploration/StephenHammond/index.htm*
   - (Optional) Download some images from sources provided in the sidebar on the right for use during discussions.
   - (Optional) Additional information about the history of ocean exploration is available at *http://oceanexplorer.noaa.gov/history/history.html*.

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*.

Image and Video Resources

Below are links to a selection of images and videos from recent expeditions that can be used to ignite interest in and spark curiosity about deep-sea exploration.

Pharmacology :
Submarine Ring of Fire 2012: NE Lau Basin
http://oceanexplorer.noaa.gov/explorations/12fire/background/pharmacology/pharmacology.html

Cold seeps, deep corals, seamounts
Northeast U.S. Canyons Expedition 2013
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/logs/photolog/welcome.html

Canyons, seamounts, deep-sea communities:
Our Deepwater Backyard: Exploring Atlantic Canyons and Seamounts 2014
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1404/logs/photolog/welcome.html

Deepwater communities in the Gulf of Mexico:
Exploration of the Gulf of Mexico 2014
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/logs/photolog/welcome.html

Mapping, deepwater corals off Hawai'i:
2015 Hohonu Moana: Exploring Deep Waters off Hawai'i
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1504/logs/photolog/welcome.html

Bioluminescence:
Bioluminescence and Vision 2015
http://oceanexplorer.noaa.gov/explorations/15biolum/logs/photolog/photolog.html

Hydrothermal vents, deep-sea corals:
2016 Deepwater Exploration of the Marianas
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/photolog/welcome.html

Deep-sea biodiversity, mapping, telepresence:
2017 American Samoa Expedition:
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/logs/photolog/welcome.html

Color correcting in the dark abyss:
Discovering the Deep: Exploring Remote Pacific MPAs 2017
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1703/logs/mar14/welcome.html

Color in Deep-sea Octocorals:
Exploring the Central Pacific Basin 2017
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1705/logs/may16/welcome.html

A "black smoker". Where the super-hot vent fluid meets very cold ambient sea water (2°C) of the deep sea, minerals that are carried in the fluid precipitate out of solution, forming spectacular vent chimneys. Here, the temperature of the vent fluid measured 339°C. Image courtesy of NOAA 2016 Deepwater Exploration of the Marianas. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/logs/may11/media/1605vent.html*

Close-up view of one of the undescribed species of Lamellibrachia (tube worm) that scientists discovered during a 2007 Gulf of Mexico cruise. Image courtesy of Expedition to the Deep Slope 2007 and Aquapix.*http://oceanexplorer.noaa.gov/explorations/07mexico/logs/june14/media/lam_600.html*

Briefly discuss why this kind of exploration is important (see background information starting on page 3). Highlight the overall exploration 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;
  - 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 sidebar on page 9 to accompany this review.

3. Tell students that their assignment is to answer the question, "Why do we explore the ocean?" Each student or student group should prepare an oral report that addresses the following guidance questions:
   1) "We know more about the dead seas of Mars than our own ocean." (Jean-Michel Cousteau). How can this be true? And even if it is, so what? Isn't the deep ocean more or less the same, wherever you go?
   2) Historically, what are some reasons for human exploration?
   3) Today, are there any other reasons to explore Earth's ocean?
   4) If time permits, you may also want to have students address the question, "Who are today's ocean explorers?" and refer them to the Ocean Explorer OceanAGE Careers Web page (*http://oceanexplorer.noaa.gov/edu/oceanage/welcome.html*).

- The following links to Ocean Exploration Web pages provide examples of some benefits that can result from ocean exploration:

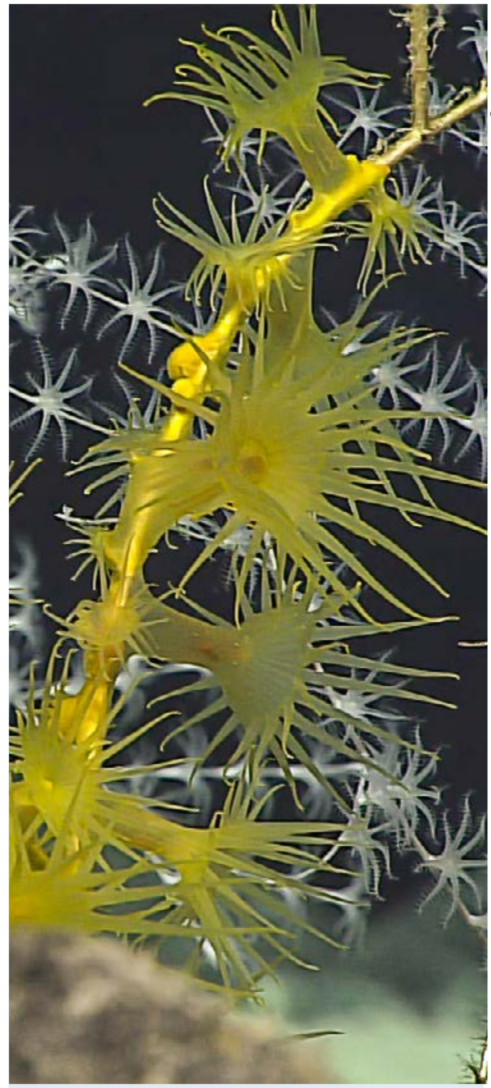
Energy:
http://oceanexplorer.noaa.gov/explorations/17atlantic-margin/welcome.html
http://oceanexplorer.noaa.gov/explorations/07mexico/welcome.html

Human Health:
http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html

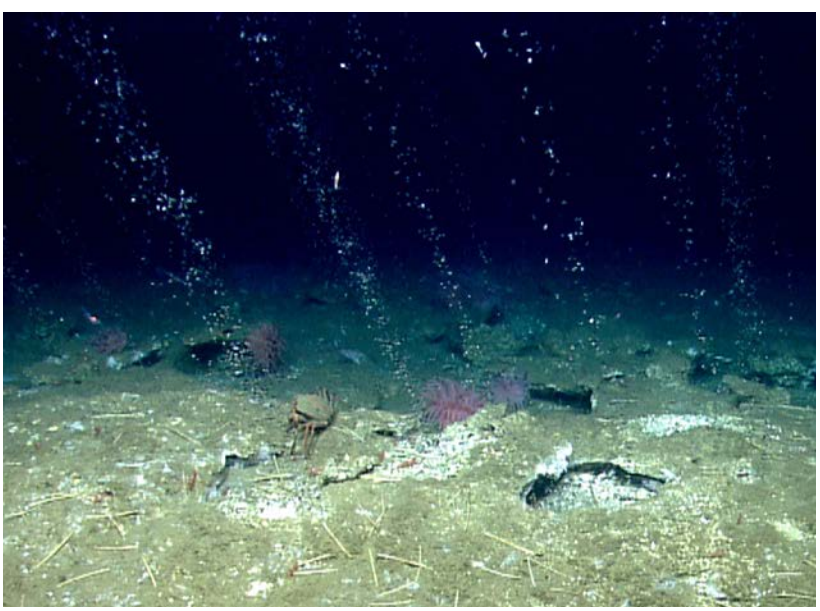
Ocean Health:
http://oceanexplorer.noaa.gov/facts/acidification.html

Climate Change:
http://oceanexplorer.noaa.gov/explorations/16glacierbay/welcome.html
http://oceanexplorer.noaa.gov/explorations/16arctic/welcome.html

4. Have each group make an oral presentation of their findings. When all groups have reported, facilitate a class discussion of these results. Key points for guidance questions should include:
   1) "We know more about the dead seas of Mars than our own ocean." (Jean-Michel Cousteau). How can this be true? And even if it is, so what? Isn't the deep ocean more or less the same, wherever you go?
   Key Points: Considering the difficulty of photographing large areas of the ocean floor, as well as the three-dimensional nature of ocean habitats, it is easy to see how we might know more about the surface of Mars. While many people think that the deep ocean is more or less homogenous overlarge areas, recent discoveries of hydrothermal vents, deep-sea cold seeps, underwater volcanoes, seamounts, and other features



Yellow zoanthids colonize the base of a dead golden octocoral skeleton. Image courtesy of the NOAA Office of Ocean Exploration and Research, 2017 American Samoa.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/dailyupdates/media/feb22.html



A ~425 meter-deep seep site on the Virginia margin. Authigenic carbonates pave the seafloor in the foreground and at least nine methane bubble streams can be seen in the background. Image courtesy NOAA 2013 Northeast U.S. Canyons Expedition.
http://oceanexplorer.noaa.gov/explorations/17atlantic-margin/welcome.html

Operation IceBridge, NASA'a aerial survey of polar ice, flies over a lead, or opening in the sea ice cover, near the Alaskan coast on March 11, 2017.
Image courtesy NASA/Jeremy Harbeck
https://www.nasa.gov/feature/goddard/2017/sea-ice-extent-sinks-to-record-lows-at-both-poles

The pteropod, a sea snail as small as the head of a pin, is found in the Pacific Ocean and provides food for salmon, sablefish and rock sole. Because it's shell dissolves in waters rich in carbon dioxide, it's been considered an indicator of ocean acidification. Image credit: NOAA
http://research.noaa.gov/News/NewsArchive/LatestNews/TabId/684/ArtMID/1768/ArticleID/12006/NOAA-research-links-human-caused-CO2-emissions-to-dissolving-sea-snail-shells-off-US-West-Coast.aspx

suggest that there is much more variety than was once supposed. Images from "Key Image and Video Resources" (see sidebar on page 9) may enhance discussions.

2) Historically, what are some reasons for human exploration?
Key Points: Students may suggest a considerable variety of motives, including to gain knowledge about the world, obtain economic benefits, increase political power, spread religious doctrines, advance science and technology, and keeping pace with other nations. Simple curiosity and/or the challenge of the unknown are also valid suggestions, though often these are accompanied by more pragmatic considerations as well.

3) Today, are there any other reasons to explore Earth's ocean?
Key Points: Ocean exploration contributes directly to priority issues and needs, including:

- ***Climate Change*** – The ocean has a major influence on Earth's climate; but we don't even know, let alone understand, all of the processes involved in the interactions between the ocean and climate, because most of the ocean is unknown. You may want to show images that document the decline in polar sea ice and/or glaciers (*https://www.nasa.gov/feature/goddard/2017/sea-ice-extent-sinks-to-record-lows-at-both-poles*; and *http://nsidc.org/data/glacier_photo/repeat_photography.html*).

- ***Energy*** – Methane hydrates are an example of potential alternative sources of energy. The U.S. Geological Survey estimates that methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. Students should also realize that in addition to discovering new energy sources, information from ocean exploration can be used to protect unique and sensitive environments where these resources are found.

- ***Human Health*** – Animals in deep-sea habitats have been found to be promising sources for powerful new antibiotic, anti-cancer and anti-inflammatory drugs. Expeditions to the unexplored ocean almost always discover species that are new to science, creating a high probability of finding important new natural products.

- ***Ocean Health*** – Rapid changes in Earth's climate, pollution, and overfishing have serious negative impacts on some ocean ecosystems. Mention the potential impact of rising temperatures on tropical species that are already near their upper thermal tolerance limit, such as corals. Be sure students understand that corals are also subject to a variety of other stresses, and the combined stress from multiple sources amplifies the impacts of climate change.

If it is not mentioned by students, introduce the effect of increased atmospheric carbon dioxide on ocean pH. A simple demonstration of the impact of dissolved carbon dioxide on pH can be found in the Diving Deeper section. Be sure students understand that while there are different opinions about whether increased atmospheric carbon dioxide from human activity is the cause of climatic temperature increase, ocean acidification is not a matter of opinion: the increase in atmospheric CO_2 and decline in ocean pH have been confirmed by actual measurements and are in no way theoretical.

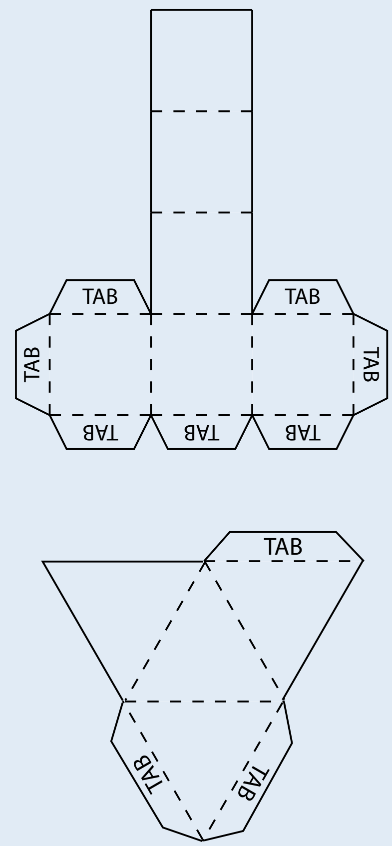
- ***Research*** – Expeditions to the unexplored ocean can help focus research into critical geographic and subject areas that are likely to produce tangible benefits. Telepresence technology aboard the *Okeanos Explorer* allows many scientists to participate at a fraction of the cost of traditional expeditions, as well as opportunities for students and the general public to have a first-hand look at the processes of scientific exploration.

- ***Technological Innovation*** – The challenges of working in the extremely hostile environments of the deep ocean are an ongoing stimulus for technology innovation and development.

- ***Science Education and Ocean Literacy*** – Ocean exploration can help inspire new generations of youth to seek careers in science, technology, engineering, and mathematics, and offers vivid examples of how concepts of biology, physical science, and Earth science are useful in the real world. Similarly, the challenges of exploring the deep ocean can provide the basis for problem-solving instruction in technology and engineering. Ocean exploration also provides an engaging context for improving ocean literacy, understanding how the ocean influences our lives, and how we influence the ocean. An ocean literate citizenry is increasingly vital as we confront issues such as ocean health and climate change.

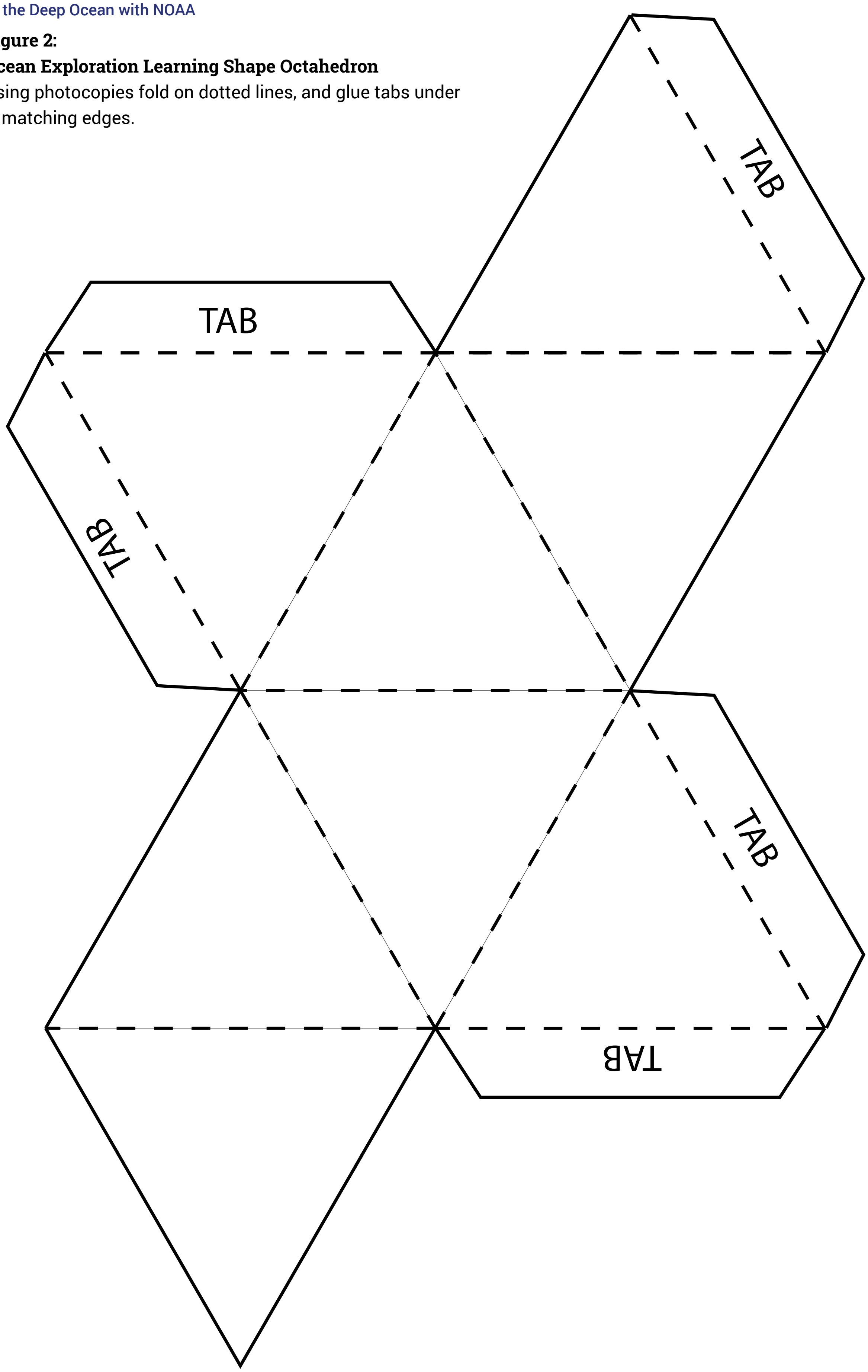
5. **Ocean Exploration Learning Shapes and the Ocean Exploration Bowl Game** – Learning Shapes are geometric solids constructed by students to provide three-dimensional surfaces for displaying concepts, images, and other information. Many curricula require students to communicate ideas to other groups, and Learning Shapes provide a novel tool that can enhance communication activities. Learning Shapes can be constructed in many sizes, shapes, and colors using a variety of materials (stiff paper such as card stock is inexpensive, versatile, and widely available). In addition to their use as a learning and communication tool, constructing Learning Shapes also provides a basis for potential cross-curricular

Figure 1: Simple Learning Shapes



Learning Shapes are fun to make! Image courtesy Mel Goodwin.

Figure 2:
Ocean Exploration Learning Shape Octahedron
Using photocopies fold on dotted lines, and glue tabs under matching edges.



activities with Language Arts and Mathematics, and helps develop engineering skills including layout and design, material selection, modeling, and prototyping. The simplest Learning Shapes are tetrahedrons and cubes, which provide four and six surfaces, respectively, and can be constructed as illustrated in Figure 1. There are numerous books and Web sites that describe how to construct various polygons.

To reinforce concepts resulting from student investigations, students construct Learning Shapes to summarize modern reasons for ocean exploration (*i.e.*, climate change, energy, human health, ocean health, research, technological innovation and ocean literacy), and will use their creations to play a competitive "Ocean Exploration Bowl" game.

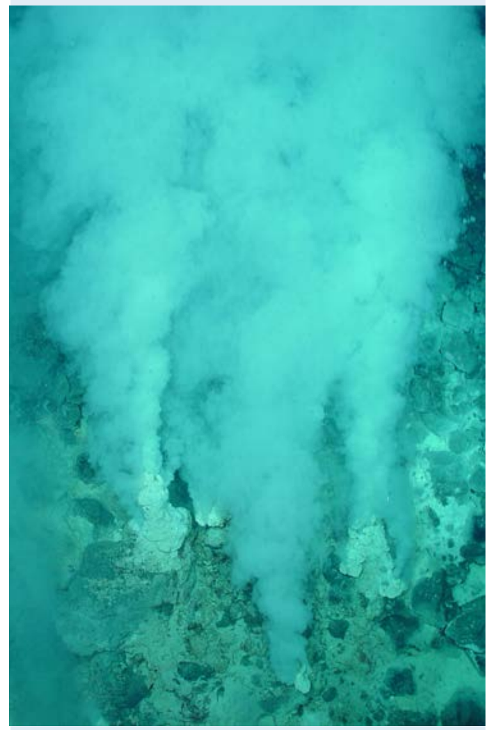
a. Each student group should construct five octahedrons using the pattern illustrated in Figure 2 (page 14). If larger Learning Shapes are desired, the pattern can be copied onto tabloid-size paper or cover stock with an enlarging photocopier.

b. Students should attach images or text to the eight faces of the Learning Shapes as follows:

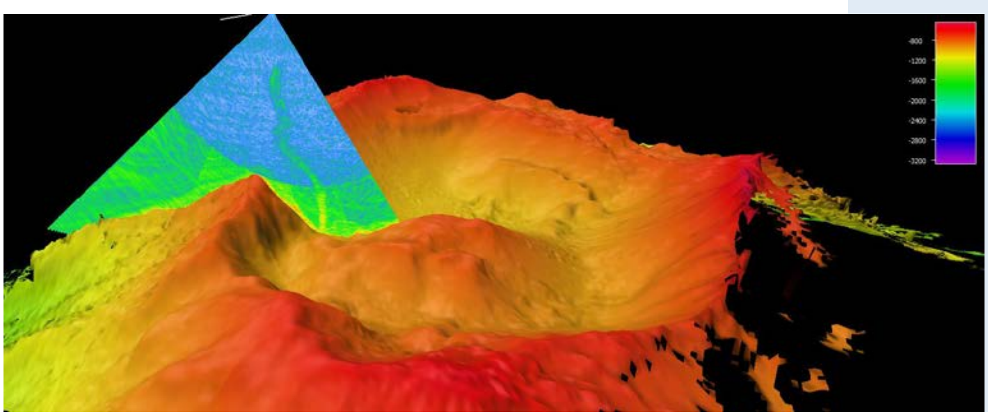
- One Learning Shape should have images attached to seven faces that illustrate the seven modern reasons for ocean exploration discussed above. So one face will have an image representing climate change, another face will have an image that represents energy, and so on. The remaining face should have an image of the NOAA Ship *Okeanos Explorer*. Since this eighth face is used as a neutral image, it could be completely blank, but using an image of America's Ship for Ocean Exploration makes the Learning Shape much more interesting!

- One of the Learning Shapes should have text on seven faces that provide a descriptive title for one of the modern reasons for ocean exploration. So there should be one face that says "Energy," another that says "Ocean Health," and so on. The eighth face should have an image of the *Okeanos Explorer*, or other neutral image.

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



Champagne vent, NW Eifuku seamount in the Marianas region. Image courtesy of Submarine Ring of Fire 2006 Expedition, NOAA/PMEL. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/history/media/vent.html*



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*

•The three remaining Learning Shapes should also have one neutral face containing an image of the *Okeanos Explorer*. The other seven faces should contain brief text describing a single fact about one of the seven modern reasons for ocean exploration, with a different reason each of the seven faces. So one of the shapes might have a face that says "Methane hydrates are a potential energy source found in the deep ocean" (representing energy as a reason for exploration), another face that says "Deep-sea animals can be promising sources of new drugs" (representing human health as a reason for exploration), and so on.

Note: It is easier to attach images and text before Learning Shapes are fully assembled. Cut out and pre-fold the Shapes, but attach images and/or text before gluing the tabs into place. For sample Learning Shapes, see To Boldly Go Addendum *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/toboldlygo_addendum.pdf*

When all five Learning Shapes are completed, it should be possible to orient the shapes so that the upper face of one shape shows a picture representing one of the modern reasons for ocean exploration, the upper face of another shape shows a descriptive title stating the reason in words, and the upper faces of the remaining two shapes show facts relevant to that reason. It should also be possible to orient the four shapes so that the upper face shows a "neutral" image that is not specifically related to a specific reason to explore the ocean.

c. Now it's time to play "Ocean Exploration Bowl!" The object of this game is for student groups to correctly associate, in the shortest possible time, descriptive titles and relevant facts with an image representing a reason for exploration. Groups compete one at a time, and when all groups have competed, one round has been completed. When a group has finished, ask members of other groups to verify that the selected title and facts correctly match the image. Students have to pay attention to make this verification, and because play proceeds rapidly from group to group, there is minimal down time during which students may become distracted.

Assign two students to act as timekeepers. Since groups compete one at a time, timekeepers can be members of other competing groups. Provide each timekeeper with a stopwatch (or stopwatch app). Have one group arrange their five Learning Shapes on a desk or table so that the image of *Okeanos Explorer* (or other neutral image) shows on the upper face of each Learning Shape.

You (the educator) should pick up the Learning Shape that has images attached, hold it out of students' sight, and orient the Learning Shape so that one of the images representing a reason for ocean exploration is facing the palm of your hand. Put the Learning Shape back onto the table, and say "Boldly Go!" as you remove your hand. The timekeepers should start their stopwatches as soon as you say "Boldly Go!", and students in the group should orient the remaining four shapes as quickly as possible so that the appropriate descriptive title and two relevant facts are facing upward. As soon as they have done this, the group should say "Discovery!" which is the signal for the timekeepers to stop their stopwatches. Have group members state their reason for ocean exploration, and the relevant facts. Record the average time from the two rounds on a score sheet for the competing group. If the educator considers the group's response inadequate, no score is recorded.

Repeat this process for the remaining groups. At least three rounds should be completed to cover all seven reasons and a good selection of relevant facts. When the winning group has been determined (by the shortest average time over all rounds), award prizes such as small bags of seaweed crackers, goldfish crackers, or other ocean-related items. Be sure every group receives something, but it's fine if the winner's share is larger!

If time is short, you may want to have groups construct only the first Learning Shape with images, then have group members state as many relevant facts as possible when a particular image is turned face up. This eliminates the need for timekeepers, but you should probably have several rounds since student research is likely to yield more facts for some reasons than others.

Adaptations for Other Grade Levels

Considerations for Grade 5 – Some students may not be familiar with hydrothermal vents, deep-sea cold seeps, underwater volcanoes, and seamounts that have been relatively recently discovered, so be sure to have images of these habitats available to show after receiving students' comments on the Cousteau quotation. Similarly, students may not be aware of the potential for new medicines or alternative energy sources from deep-sea ecosystems. Depending upon their existing knowledge, you may want to focus primarily upon these potentials as contemporary reasons for ocean exploration, since the relationship between deep-ocean processes and climate change may be difficult to understand at this grade level. In addition, students may be intrigued by how little is known about the deep ocean, and may feel that this is sufficient justification for exploration. Be sure students understand that the *Okeanos Explorer* is the first federal U.S.

ship to be dedicated specifically to exploring the largely unknown ocean.

Considerations for Grades 9-12 – Ocean acidification, pH, buffers, carbon dioxide sources and sinks, methane hydrates, deep-sea medicines, and deep-ocean habitats (hydrothermal vents, deep-sea cold seeps, underwater volcanoes, and seamounts) can all be explored in greater detail. Consider assigning these topics to individual student groups prior to beginning a discussion focused on ocean exploration. When groups have completed their reports, lead a discussion to address the Guidance Questions and invite groups to present relevant information from their reports in the context of "why explore."

The BRIDGE Connection

www.vims.edu/bridge/ – In the navigation menu on the left side of the Web page, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to information and activities involved with ocean exploration, including satellites, underwater robots, and deep-sea medicines.

The "Me" Connection

Have students write a brief essay about what ocean life might be like in the second half of the 21st century, and how ocean exploration might affect that future.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Written reports may be required as part of Learning Procedure Step 3. These reports, discussions and/or the Ocean Exploration Bowl game provide a basis for assessment.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 3, 5, 11, and 14 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Energy from the Oceans, and Seamounts.

Lessons from the NOAA Ship Okeanos Explorer Education Materials Collection, Volume 1: Why Do We Explore?

These lessons are accessible online at *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe.html*.

Other Resources

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Holmes, R., S. Natali, S. Goetz, and P. Duffy. 2015. Permafrost and global climate change. Woods Hole Research Center Policy Brief. June 2015. *http://whrc.org/wp-content/uploads/2015/06/PB_Permafrost.pdf*

Inniss, L. A. Simcock, A. Ajawin, A.. Alcala, P. Bernal, H. Calumpong, P. Araghi, S. Green, P. Harris, O. Kamara, K. Kohata, E. Marschoff, G. Martin, B. Ferreira, C. Park, R. Payer, J. Rice, A. Rosenberg, R. Ruwa, JT. Tuhumwire, S. Van Gaever, J. Wang, J. Weslawski "The First Global Integrated Marine Assessment" under the United Nations' Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects *http://www.un.org/depts/los/global_reporting/WOA_RegProcess.htm*

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

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Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. *http://nca2014.globalchange.gov*

National Energy Technology Laboratory. 2011. Energy Resource Potential of Methane Hydrate. *https://www.netl.doe.gov/File%20Library/Research/Oil-Gas/methane%20hydrates/MH-Primer2011.pdf*

NOAA, National Centers for Environmental Information. 2017. Global Climate Report -Annual 2016. available online: *https://www.ncdc.noaa.gov/sotc/global/201613*

Parada, J., X. Feng. E. Hauerhof, R. Suzuki, U. Abubakar. 2012. The deep sea energy park: harvesting hydrothermal energy for seabed exploration. *https://eprints.soton.ac.uk/349890/*

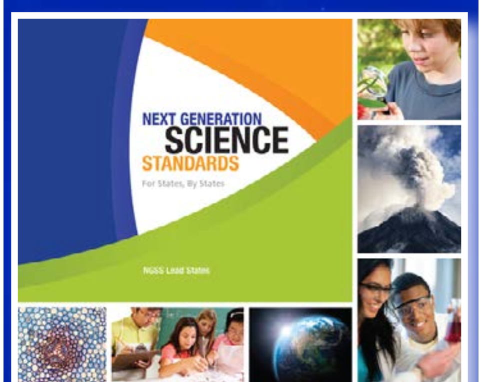
Ruppel, C., and H. Hamilton. 2014. Natural Methane Seepage Is Widespread on the U.S. Atlantic Ocean Margin. USGS Sound Waves. *https://soundwaves.usgs.gov/2014/10/*

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 questions and 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*



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.

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

Santer, B., C. Mears, F. Wentz, K. Taylor, P. Gleckler, T. Wigley, T. Barnett, J. Boyle, W. Brüggemann, N. Gillett, S. Klein, G. Meehl, T. Nozawa, D. Pierce, P. Stott, W. Washington, and M. Wehner. 2007. Identification of human-induced changes in atmospheric moisture content. PNAS _ 104 (39):15248-15243.

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USGS Volcano Hazards Program, *https://volcanoes.usgs.gov/vhp/gas.html*

Van Dover, C. 2014. Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: A review. Marine Environmental Research 102:59-72.

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 this lesson not intended to target specific Next Generation Science Standards (NGSS), activities in the lesson may be used to address specific elements of the NGSS as described below.

Some Suggestions for Using Lesson Content to Address Specific NGSS Performance Expectations:

5-ESS2-1. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact. [Clarification Statement: Examples could include the influence of the ocean on ecosystems, landform shape, and climate; the influence of the atmosphere on landforms and ecosystems through weather and climate; and the influence of mountain ranges on winds and clouds in the atmosphere. The geosphere, hydrosphere, atmosphere, and biosphere are each a system.]

Discuss the interactions of atmospheric warming with sea temperature, salinity, and oceanic circulation; and/or interactions between atmospheric chemistry and ocean acidification; and/or effects of these interactions on the biosphere.

5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Discuss ways that ocean exploration ("science ideas") can be used to address ocean health issues.

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. [Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.]

Discuss how unequal heating and Earth's rotation are involved with the THC, and how the THC affects regional climates.

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.]

Discuss feedbacks that are relevant to rising atmospheric temperatures, melting snow and sea ice, changes to the THC, and biological responses to increased atmospheric carbon dioxide concentrations.

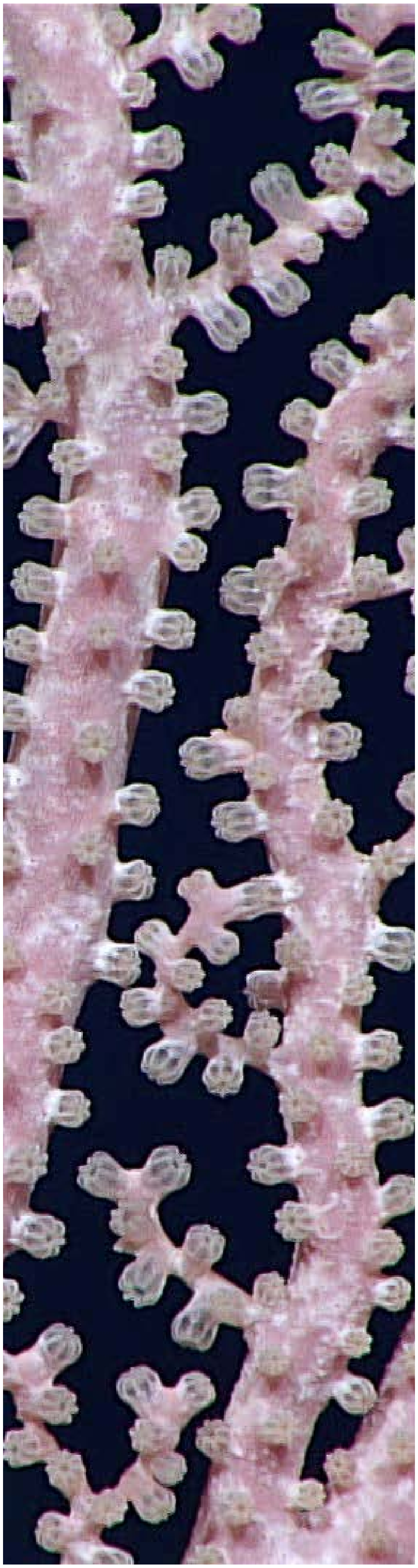
HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.]

Use a model to explain how greenhouse gases modify the flow of energy into and out of Earth's systems.

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.* [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

** Performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.*

Consider technological solutions to one or more ocean health issues; or how energy from ocean systems might reduce human impacts on natural systems.



Diving Deeper:
Additional Information about Key Topics

This section provides additional details and discussion of selected topics mentioned in "Background Information."

Overview of Some Key Data Concerning Global Climate Change
Since the middle of the 1800's, Earth's average temperature has warmed by about 1°F. This doesn't sound like much of a change, but it is important to realize that Earth's average temperature is now warmer than it has been at any time since at least 1400 AD. We say "at least" because 1400 AD is as far back as scientists have good estimates of temperatures. Other evidence suggests that Earth's temperature is warmer now than it has been in many thousands of years, maybe nearly 100,000 years. It is also important to remember that most averages include numbers that are higher and lower than the "average" value. So the warming in some areas can be much higher than 1°F, while other areas may actually be cooler.

According to the Annual 2016 Global Climate Report *https://www.ncdc.noaa.gov/sotc/global/201613* (NOAA, 2017), 2016 was:

- The warmest year in NOAA's 137-year series;
- The third consecutive year in which a new global annual temperature record was set;
- The fifth time in the 21st century a new record high annual temperature was set (along with 2005, 2010, 2014, and 2015); and
- The 40th consecutive year (since 1977) that the annual temperature has been above the 20th century average.

The Report also notes that all 16 years of the 21st century rank among the seventeen warmest on record, and the five warmest years have all occurred since 2010.

The Third National Climate Assessment (Melillo, Richmond, and Yohe, 2014 *http://nca2014.globalchange.gov*) includes findings that:

- Global climate is changing and this is apparent across the United States in a wide range of observations.
- The global warming of the past 50 years is primarily due to human activities.
- Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.
- Human-induced climate change is projected to continue, and it will accelerate significantly if global emissions of heat-trapping gases continue to increase.
- Climate change threatens human health and well-being in many ways.

This pink precious Hemicorallium in the family Coralliidae, found at ~2,400 meters (~7,875 feet), had most of its tentacles drawn in. Image courtesy of the NOAA OER, 2017 Laulima O Ka Moana. *http://oceanexplorer.noaa.gov/okeanos/explorations/ex1706/dailyupdates/media/july25-2.html*

- Infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat.
- Water quality and water supply reliability are jeopardiized by climate change in a variety of ways that affect ecosystems and livelihoods.
- Climate disruptions to agriculture have been increasing and are projected to become more severe over this century.
- Climate change poses particular threats to Indigenous Peoples' health, well-being, and ways of life.
- Ecosystems and the benefits they provide to society are being affected by climate change. The capacity of ecosystems to buffer the impacts of extreme events like fires, floods, and severe storms is being overwhelmed.
- Ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life.
- Planning for adaptation (to address and prepare for impacts) and mitigation (to reduce future climate change, for example by cutting emissions) is becoming more widespread, but current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.

Following is a brief review of a few key points.

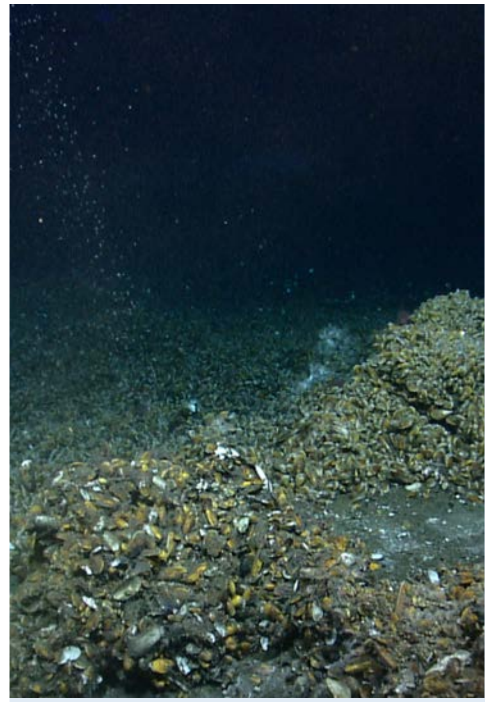
Cause of the Observed Warming

Earth's climate is affected by a number of factors, including changes in Earth's orbit, solar variability, volcanoes, and the greenhouse effect. But the only factor that coincides with the warming trend of the last century is the observed increase in greenhouse gases, particularly carbon dioxide. There is no credible scientific debate about this: Since the start of the Industrial Revolution, atmospheric carbon dioxide concentrations have increased from 280 parts per million (ppm) to 400 ppm. Today, the global concentration of carbon dioxide is significantly higher than the natural range over the last 800,000 years of 170 – 300 ppm.

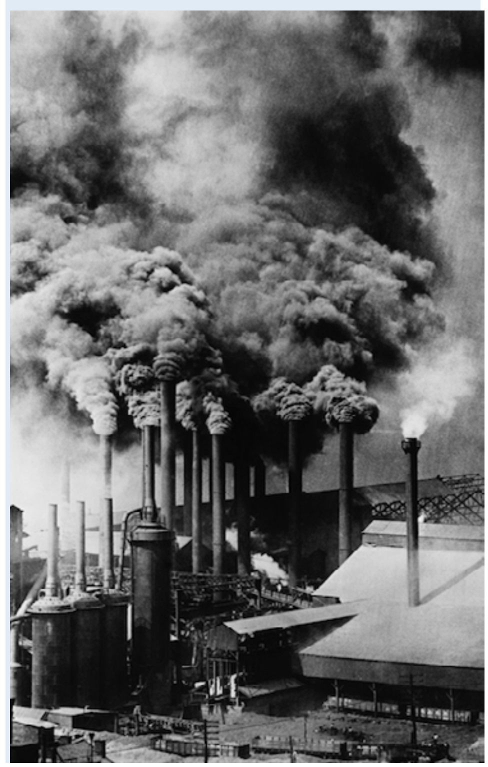
Cause of Increasing Atmospheric Carbon Dioxide

There is also no scientific debate about the source of increased atmospheric carbon dioxide. Humans burning fossil fuels release billions of tons of carbon into the atmosphere every year, and the quantity of fuels burned has been increasing for over 150 years (Access to data about fossil fuel and atmospheric carbon dioxide trends can be found through ESS-DIVE, the U.S. Department of Energy's new archive at Lawrence Berkeley National Laboratory; see *https://eesa.lbl.gov/tag/ess-dive/*).

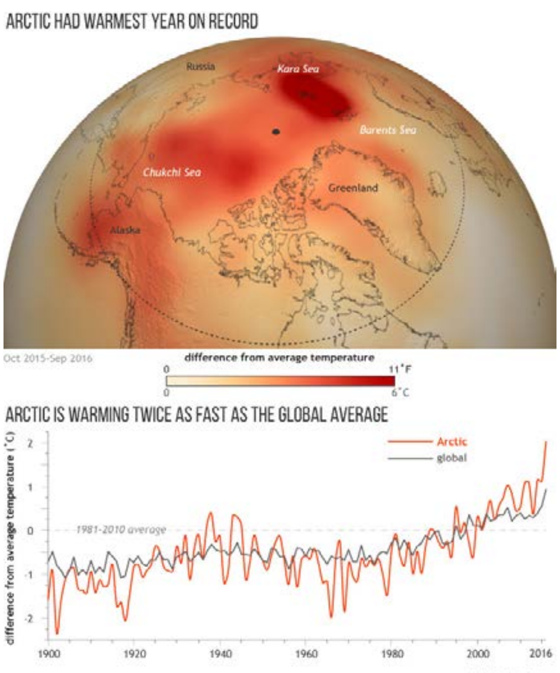
Volcanoes are sometimes suggested as an important source of atmospheric carbon dioxide. Scientists estimate that volcanoes (including underwater volcanoes) emit 200-485 million tons of carbon dioxide into the atmosphere each year (U.S. Geological



At 1400 meters deep, chemosynthetic mussels encrust a carbonate mount at a Norfolk Canyon seep. Bubbles that make up one of the observed water column plumes are visible on the left side. Image courtesy of NOAA 2013 Northeast U.S. Canyons Expedition.
http://oceanexplorer.noaa.gov/explorations/17atlantic-margin/media/norfolk.html



Top view of volcano erupting during daytime. Image courtesy Pexels.com. *https://www.pexels.com/photo/top-view-of-volcano-erupting-during-daytime-73828/*



(map) Temperatures across the Arctic from October 2015-September 2016 compared to the 1981-2010 average. (graph) Yearly temperatures since 1900 compared to the 1981-2010 average for the Arctic (orange line) and the globe (gray). NOAA Climate.gov map based on National Centers for Environmental Prediction (NCEP) reanalysis data from NOAA's Earth System Research Lab. Graph adapted from Figure 1.1 in the 2016 Arctic Report Card. *http://www.arctic.noaa.gov/Report-Card/Report-Card-2016*

Survey Volcano Hazards Program *https://volcanoes.usgs.gov/vhp/gas.html*. Emissions of carbon dioxide from human activities, however, are estimated at about 30 billion tons per year. So, the amount of carbon dioxide from human activities is more than 100 times greater than the amount of carbon dioxide emitted by volcanoes (*http://volcano.oregonstate.edu/man-versus-volcanos*). Further, if volcanoes had a significant impact on atmospheric carbon dioxide, data should show "spikes" on graphs of atmospheric carbon dioxide every time a volcano erupts; but such spikes are not present on these graphs.

It is also important to understand that concentrations of atmospheric carbon dioxide have fluctuated by over 100 ppm at various times in Earth's history, but these rises took place over 5,000 to 20,000 years. In contrast, the present increase of 120 ppm has happened in less than 220 years. Isotope analyses of carbon and oxygen atoms in atmospheric carbon dioxide molecules give additional clues to the cause of the present increase. These analyses show that the oxygen atoms in some of these molecules are much younger than the carbon atoms in the same molecule. Older carbon could only come from fossil fuel deposits, and the only way these deposits could become airborne is through combustion. Note that the amount of methane released by natural seepage as described below is much less than the amount of carbon released by combustion of fossil fuel, so natural seepage cannot account for the presence of older carbon.

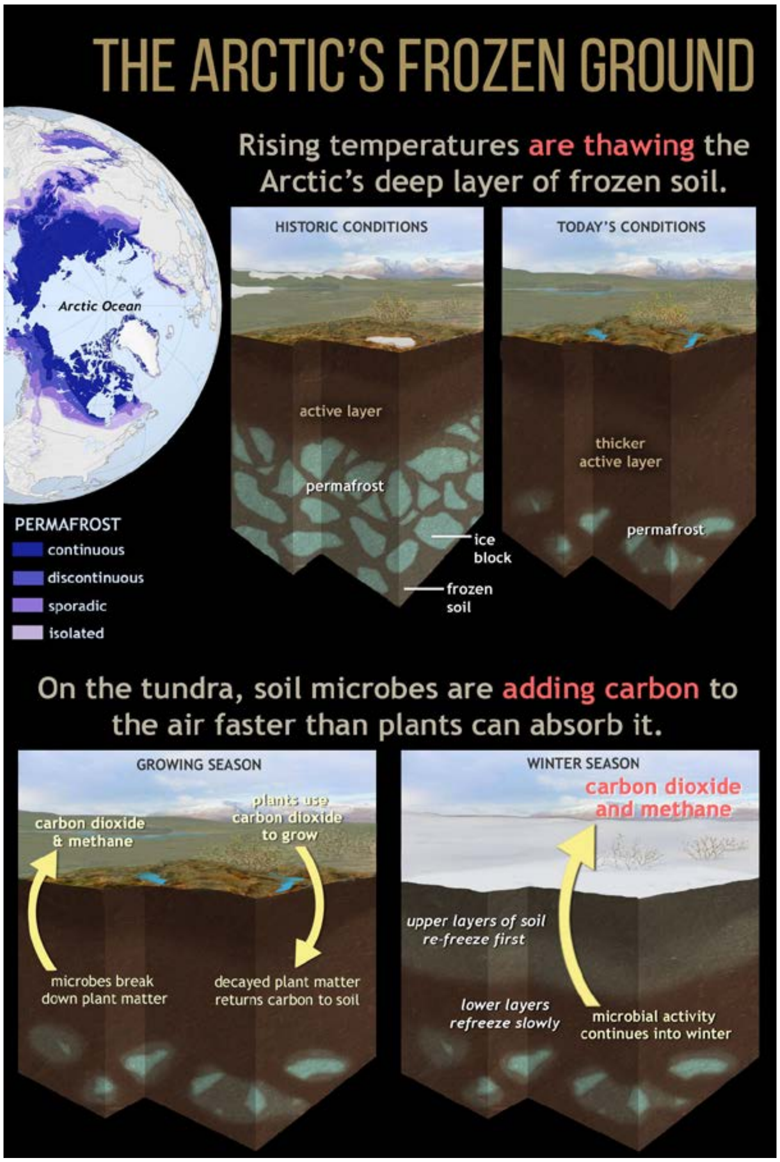
Effect of Continued Increase in Atmospheric Carbon Dioxide

Global Temperature Increase

If atmospheric carbon dioxide concentrations continue to increase and nothing is done to reduce carbon dioxide emissions, global temperatures are projected to increase by 2.8° to 5.5°C (5° to 10°F) by 2100 (Melillo, Richmond, and Yohe, 2014 *http://nca2014.globalchange.gov*). So, the minimum expected temperature increase under these conditions is nearly four times the increase that has already been observed. The actual increase could be much greater, depending upon the influence of feedbacks. For example, decreasing ice and snow in polar regions means that less solar radiation will be reflected away from Earth's surface. This would result in more radiation being absorbed at the surface, and increased warming.

Methane Hydrates

Warmer temperatures in the Arctic could also trigger another feedback process. Methane hydrates are a type of ice that contains methane molecules surrounded by a cage of frozen water molecules. Most methane hydrates are believed to exist in ocean sediments, but some are also found in high latitude soils called permafrost as well as in tropical wetlands. Increasing temperatures may cause methane hydrates to melt and release methane gas into the atmosphere. Since methane is a powerful greenhouse gas, and decomposes to form carbon dioxide, increased atmospheric methane could result in an increased greenhouse effect and additional warming of Earth's climate. In *Permafrost and Global Climate Change*, Holmes *et al*. (2015) *http://whrc.org/wp-content/uploads/2015/06/PB_Permafrost.pdf* conclude that "carbon emissions from thawing arctic permafrost will become substantial within decades, most likely exceeding current emissions from fossil fuel combustion," and the "emissions from permafrost could lead to out-of-control global warming."



(map) Stretching from Alaska to Scandinavia to Russia, and hundreds of feet deep in places, the Arctic's frozen soils--permafrost--contain twice as much carbon as what's already in the atmosphere. As the Arctic heats up, permafrost may become a major source of greenhouse gases, which would further accelerate global warming. (top middle) Permafrost is like a giant freezer for carbon: thousands of years worth of plant, animal, and microbe remains mixed with blocks of ice. Historically, only a shallow "active layer" thawed in the short summer. (top right) In today's warming Arctic, permafrost is thawing and the active layer is getting deeper. (bottom left) Warming in the growing season has increased plant growth and allowed plants to remove more carbon dioxide (CO_2) from the air during photosynthesis, but it is also thawing the frozen soils and stimulating decomposition of organic matter by soil microbes. Microbial activity releases the greenhouse gases CO_2 and methane (CH_4). (bottom right) When winter comes, the uppermost soil layer re-freezes quickly as air temperatures drop. But deeper layers, insulated from the frigid air, re-freeze more slowly. In the past decade, the parts of the Arctic tundra that are routinely observed have become a net source of carbon-containing greenhouse gases because microbial activity is continuing well into winter after plants go dormant. NOAA Climate.gov drawing. Permafrost map from National Snow and Ice Data Center (NSIDC). *https://www.climate.gov/news-features/understanding-climate/noaas-2016-arctic-report-card-visual-highlights*

Ocean Temperature

A warmer atmosphere also means warmer temperatures in Earth's ocean. Since the solubility of carbon dioxide decreases as temperature rises, warmer temperatures could decrease carbon dioxide absorption by the ocean creating yet another feedback mechanism. Temperature has an opposite effect on

the atmosphere's capacity for water vapor. Warmer air can hold more water vapor that evaporates from the ocean and land surface. Increased atmospheric water vapor has been observed from satellites, and is primarily due to human-caused changes in greenhouse gases (Santer, *et al.*, 2007). Water vapor is the most important and abundant greenhouse gas, and increased atmospheric water vapor can strengthen the greenhouse effect and result in additional warming. This effect may be counterbalanced to some extent if increased atmospheric water vapor causes increased cloud cover that reduces the amount of solar radiation reaching Earth's surface.

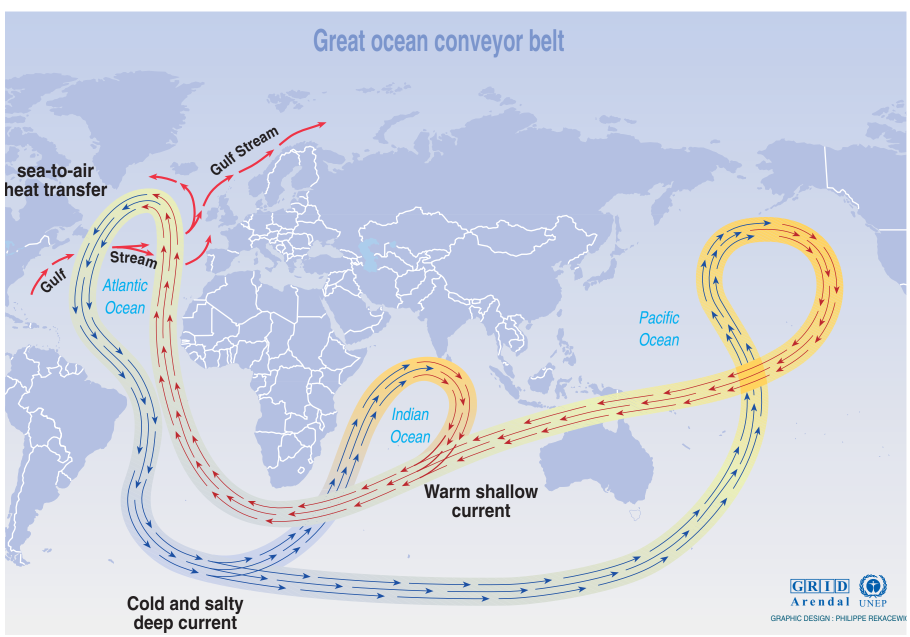
Ocean Circulation

Global climate is strongly influenced by interactions between Earth's atmosphere and ocean, but these interactions are complex and poorly understood. While the deep-ocean might seem far removed from the atmosphere, one of the most significant climatic influences results from the deep-ocean thermohaline circulation (THC).

The THC is driven by changes in seawater density. Two factors affect the density of seawater: temperature (the "thermo" part) and salinity (the "haline" part). Major features of the THC include:

- In the Northeastern Atlantic Ocean, atmospheric cooling increases the density of surface waters. Decreased salinity due to freshwater influx from melting ice partially offsets this increase (since reduced salinity lowers the density of seawater), but temperature has a greater effect, so there is a net increase in seawater density. The formation of sea ice may also play a role as freezing removes water but leaves salt behind causing the density of the unfrozen seawater to

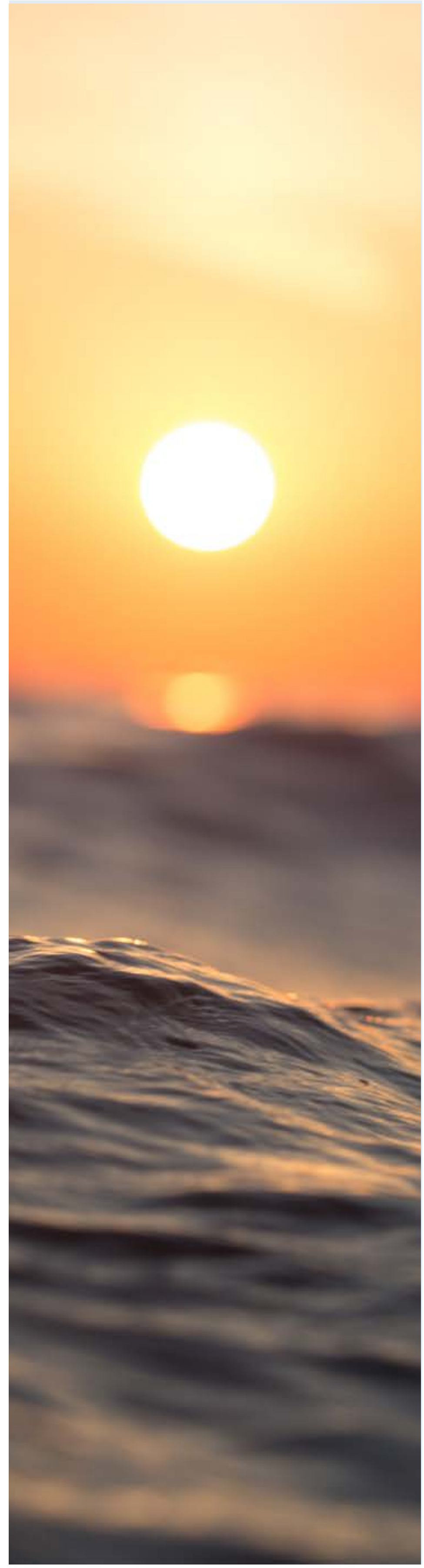
Deep-ocean Thermohaline Circulation (THC)



World ocean thermohaline circulation (THC) is driven primarily by the formation and sinking of deep water in the Norwegian Sea. When salinity decreases because of excess precipitation, runoff, or ice melt, the conveyor belt will weaken or even shut down. Variations in the THC may lead to climate change in Europe and also affect other areas of the global ocean.
Source: *http://www.grida.no/resources/5238*; data from Climate Change 1995 – Impacts, adaptations and mitigation of climate change: Scientific-Technical Analyses. Contribution of Working Group 2 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. United Nations Environment Programme and World Meteorological Organization. Cambridge University Press. 1996 Cartographer/Designer: Philippe Rekacewicz, UNEP/GRID-Arendal.

increase. The primary locations of dense water formation in the North Atlantic are the Greenland-Iceland-Nordic Seas and the Labrador Sea.
- The dense water sinks into the Atlantic to depths of 1,000 m and below, and flows south along the east coasts of North and South America.
- As the dense water sinks, it is replaced by warm water flowing north in the Gulf Stream and its extension, the North Atlantic Drift (note that the Gulf Stream is primarily a wind driven current, but portions of its circulation—the North Atlantic Drift—are also part of the THC).
- The deep south-flowing current combines with cold, dense waters formed near Antarctica, and flows from west to east in the Deep Circumpolar Current. Some of the mass deflects to the north to enter the Indian and Pacific Oceans.
- Some of the cold water mass is warmed as it approaches the equator, causing density to decrease. Upwelling of deep waters is difficult to observe, and is believed to occur in many places, particularly in the Southern Ocean in the region of the Antarctic Circumpolar Current.
- In the Indian Ocean, the water mass gradually warms and turns in a clockwise direction until it forms a west-moving surface current that moves around the southern tip of Africa into the South Atlantic Ocean.
- In the Pacific, the deepwater mass flows to the north on the western side of the Pacific basin. Some of the mass mixes with warmer water, warms, and dissipates in the North Pacific. The remainder of the mass continues a deep, clockwise circulation. A warm, shallow current also exists in the Pacific, which moves south and west, through the Indonesian archipelago, across the Indian Ocean, around the southern tip of Africa, and into the South Atlantic.
- Evaporation increases the salinity of the current, which flows toward the northwest, joins the Gulf Stream, and flows toward the Arctic regions where it replenishes dense sinking water to begin the cycle again.

The processes outlined above are greatly simplified. In reality, the deep-ocean THC is much more complex, and is not fully understood. Our understanding of the connections between the deep-ocean THC and Earth's ecosystems is similarly incomplete, but most scientists agree that:
- The THC affects almost all of the world's ocean (and for this reason, it is often called the "global conveyor belt");
- The THC plays an important role in transporting dissolved oxygen and nutrients from surface waters to biological communities in deep water; and
- The THC is at least partially responsible for the fact that countries in northwestern Europe (Britain and Scandinavia) are about 9°C warmer than other locations at similar latitudes.



A polar bear wanders the ice pack. Image courtesy of Katrin Iken, UAF.
http://oceanexplorer.noaa.gov/explorations/16arctic/background/marine_mammals/media/polarbear.html

In recent years, changes in the Arctic climate have led to growing concerns about the possible effects of these changes on the deep-ocean THC. Overall, the Arctic climate is warming more rapidly than elsewhere on Earth. Reasons for this include:

- When snow and ice are present, as much as 80% of solar energy that reaches Earth's surface is reflected back into space. As snow and ice melt, surface reflectivity (called "albedo") is reduced, so more solar energy is absorbed by Earth's surface;
- Less heat is required to warm the atmosphere over the Arctic because the Arctic atmosphere is thinner than elsewhere;
- With less sea ice, the heat absorbed by the ocean in summer is more easily transferred to the atmosphere in winter.

Dense water sinking in the North Atlantic Ocean is one of the principal forces that drives the circulation of the global conveyor belt. Since an increase in freshwater inflow (such as from melting ice) or warmer temperatures in these areas would weaken the processes that cause seawater density to increase, these changes could also weaken the global conveyor belt. Most climate models seem to show a general reduction in the Atlantic THC in response to global warming (e.g., Boulton et al., 2014).

Ocean pH

Increasing atmospheric carbon dioxide is also having a serious effect on ocean pH. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the

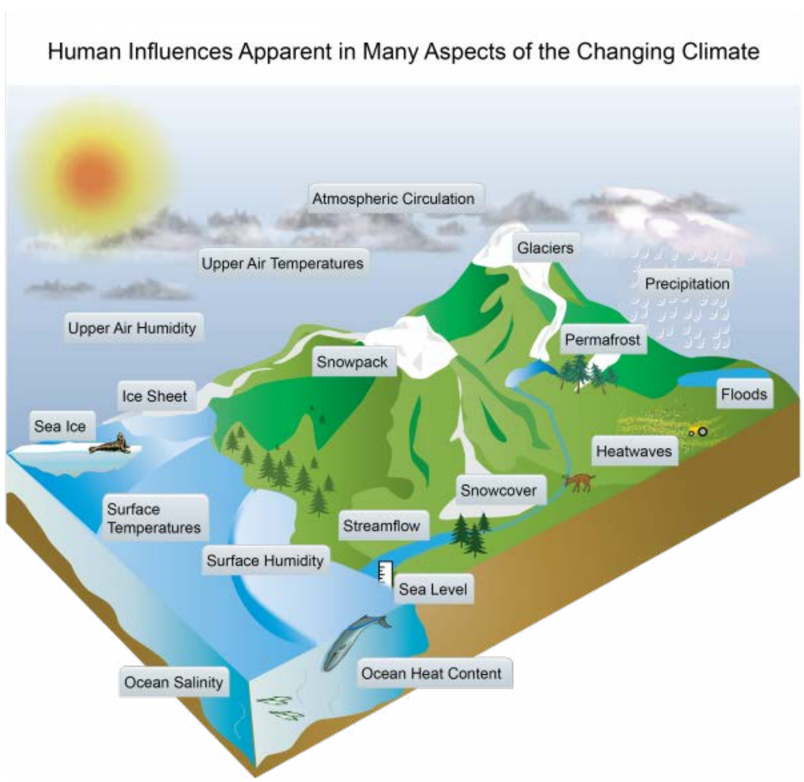
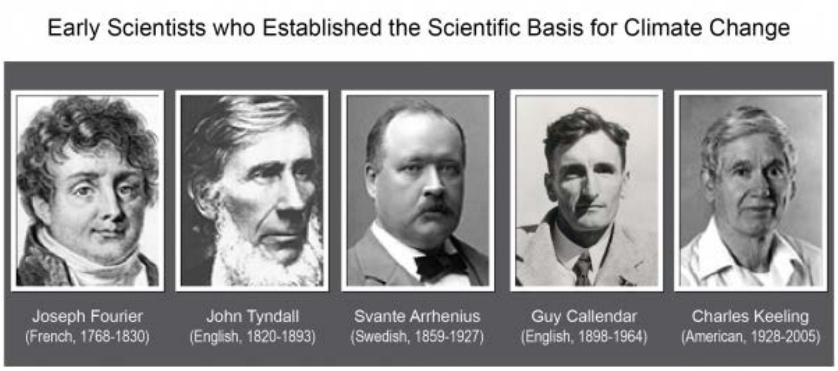


Figure shows examples of the many aspects of the climate system in which changes have been formally attributed to human emissions of heat-trapping gases and particles by studies published in peer-reviewed science literature. For example, observed changes in surface air temperature at both the global and continental levels, particularly over the past 50 years or so, cannot be explained without including the effects of human activities. While there are undoubtedly many natural factors that have affected climate in the past and continue to do so today, human activities are the dominant contributor to recently observed climate changes. (Figure source: NOAA NCDC).
http://nca2014.globalchange.gov/report/appendices/climate-science-supplement#intro-section-2



Scientists whose research was key to understanding the greenhouse effect and the impact of human activities on climate. *http://www.globalchange.gov/browse/multimedia/early-scientists-who-established-scientific-basis-climate-change*

beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others. See the lesson, Off Base, for additional discussion and references. *http://oceanexplorer.noaa.gov/okeanos/edu/collection/media/wdwe_offbase.pdf*

Impacts of Expected Climate Change if Trends Continue

The Intergovernmental Panel on Climate Change and U.S. Global Change Research Program (the leading providers of scientific advice to global and United States of America policy makers) have produced reports on some of the impacts that are occurring as a result of climate change as well as impacts that are anticipated if present trends continue. These impacts are summarized above. For additional information, please see Climate Change 2014: Synthesis Report (*http://www.globalchange.gov/browse/reports/ipcc-climate-change-2014-synthesis-report*), and Climate Change Impacts in the United States (*http://www.globalchange.gov/browse/reports/overview-climate-change-impacts-united-states-third-national-climate-assessment*)

Ocean Energy Overview

Earth's ocean contains enormous energy resources in its waters, in the adjacent atmosphere, and in the mantle and crust beneath the seafloor. Ocean energy resources include non-renewable sources such as oil and gas, as well as renewable sources, such as the energy of offshore winds, waves, and ocean currents. With the exception of oil and gas, ocean energy resources have not been extensively utilized in the United States, primarily because many of the technologies are not well-developed, nor have they been economically competitive with fossil fuels and nuclear power.

Underutilized ocean energy resources, though, are receiving increasing attention as technologies improve, prices of traditional energy sources continue to increase, and political considerations become more problematic. The following overview includes energy sources that are already being used in commercial-scale projects, as well as sources for which harvest technologies are still in the early stages of development.

A terminator device

A point absorber

An attenuator device

An overtopping device.
All images on this page from:
https://www.boem.gov/Ocean-Wave-Energy/

Note: "Ocean energy" is sometimes used as a term that includes only forms of renewable energy that may be derived from the sea. The following discussion also includes non-renewable methane hydrates, because of the significant quantity of energy that is potentially available from these substances, and the widespread occurrence of methane hydrates in deep-sea environments.

Waves

Significant amounts of kinetic energy exists in the moving waves of the ocean. In fact, waves have the highest energy density of any renewable resource. Wave-power is particularly rich in areas along the western coasts of Scotland, northern Canada, southern Africa, Australia, and the east, west, and Alaskan coasts of the United States. Devices to capture wave energy are designed to extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface caused by waves. Most of these devices being tested at commercial scales use one of the following technologies:

- Terminator devices are oriented perpendicular to the direction of wave travel and are analogous to a piston moving inside a cylinder. An Oscillating Water Column is a type of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. Wave action causes the column of water to move up and down in the chamber, forcing the air through an opening to rotate a turbine. Another type of terminator, called an Overtopping Device, consists of an enclosed reservoir that is filled by overtopping waves. Water collected in the reservoir is released back into the ocean through an outlet system that uses the energy of the falling water to rotate a turbine.
- Point absorbers are floating structures with components that move relative to each other due to wave action (for example, a floating piston inside a fixed cylinder). The motion of the components is used to drive electromechanical or hydraulic energy converters.
- Attenuators are segmented floating structures oriented parallel to the direction of the waves. As waves pass under the attenuator, the connections between segments flex and this flexing motion is transmitted to hydraulic pistons that drive electric generators inside the segments.
- Overtopping devices capture water from incoming waves in reservoirs to create a slight buildup of water pressure similar to a plastic wading pool. The captured water is released through a hydro turbine to generate electricity.

You can see illustrations and animations of these devices at *https://www.boem.gov/Ocean-Wave-Energy/*

Tidal Energy

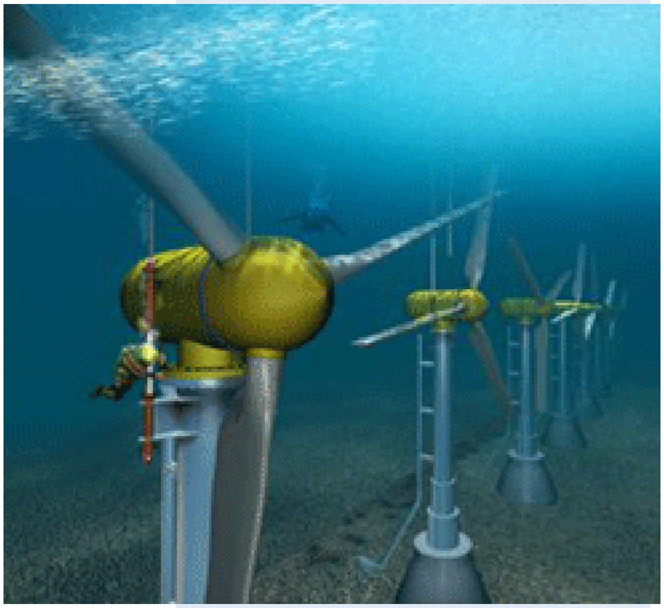
Humans have been using the energy of ocean tides since at least the eighth century AD. The basic principle is to build a dam (called a barrage) across an estuary or small tidal stream so that water is trapped behind the dam when the tide rises. Then when the tide falls, the trapped water can be released so that it turns a water wheel that can do work such as mill grains or turn a turbine to generate electricity. A tidal range of at least 10 feet is needed for economical electricity generation, which limits the number of locations where it is feasible to capture tidal energy in this way. One such location is the La Rance River estuary on the northern coast of France, where a tidal energy generating station has been in operation since 1966. Smaller stations have been established in Nova Scotia, Canada; China; South Korea; and Murmansk, Russia.

An alternative approach for capturing tidal energy is to place turbines in offshore tidal streams. The technology is similar to that used for capturing energy from ocean currents.

Current Energy

Ocean currents, such as the Gulf Stream, Florida Straits Current, and California Current, are driven by wind, solar heating, and density variations of large ocean water masses. These currents are relatively constant and flow in one direction only, while the velocity of tidal currents closer to shore varies constantly and their direction changes several times each day. Ocean currents contain an enormous amount of energy; for example, it has been estimated that all of Florida's electrical needs could be met by capturing less than 1% of the available energy in the Gulf Stream.

Technology to capture ocean current energy is presently in the early stages of development, and there are no commercial scale turbines producing electricity for regular distribution. Experimental projects include submerged water turbines similar to wind turbines, as well as doughnut-shaped turbines with blades resembling those seen in jet engines (see *https://www.boem.gov/Ocean-Current-Energy/* for illustrations).



Artist rendering of ocean current turbines.
https://www.boem.gov/Ocean-Current-Energy/

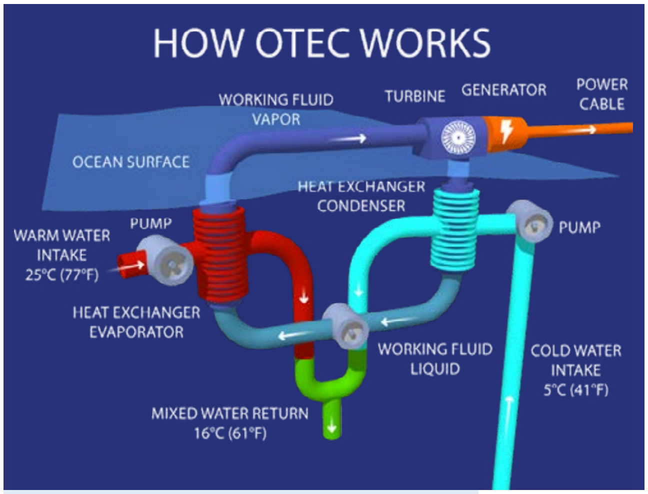
Thermal Energy

I owe all to the ocean; it produces electricity, and electricity gives heat, light, motion, and, in a word, life to the *Nautilus*.

— Jules Verne, 1870

Captain Nemo's explanation of engineering aboard the *Nautilus* in 20,000 Leagues Under the Sea provides the first documented reference to the use of ocean chemistry to produce electricity. A decade later, French Engineer Jacques D'Arsonval suggested the possibility of using ocean temperature differences to produce electricity.

This idea is based on the fact that Earth's ocean covers slightly more than 70 percent of the Earth's surface, making the ocean Earth's largest collector and storage system for solar energy.



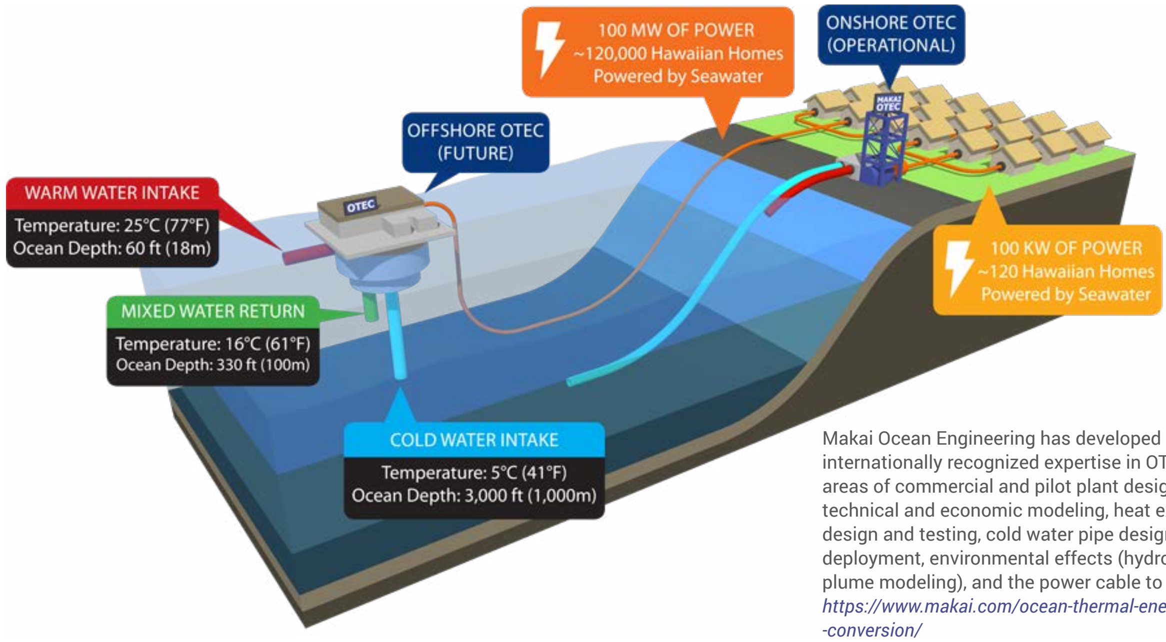
A basic closed-cycle Ocean Thermal Energy Conversion (OTEC) plant is shown in the figure at right. Warm seawater passes through an evaporator and vaporizes the working fluid, ammonia. The ammonia vapor passes through a turbine which turns a generator making electricity. The lower pressure vapor leaves the turbine and condenses in the condenser connected to a flow of deep cold seawater. The liquid ammonia leaves the condenser and is pumped to the evaporator to repeat the cycle. Image courtesy Makai Ocean Energy Research Center *https://www.makai.com/ocean-thermal-energy-conversion/*

On an average day, 60 million square kilometers (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil (in 2016, the world daily consumption of oil is estimated to have been 96 million barrels). So, harvesting even a very small fraction of the radiant energy absorbed by Earth's ocean could have a significant impact on human energy needs.

Ocean Thermal Energy Conversion (OTEC) is a technology to convert solar radiation absorbed by the ocean into electric power. The basis for this concept is that surface ocean waters receive most solar radiation and consequently are warmer than deeper waters. Where the temperature difference between surface water and deep water is about 20°C (36°F), an OTEC system can produce a significant amount of power.

D'Arsonval's original idea was to pump warm seawater through a heat exchanger to vaporize a fluid with a low boiling point (such as ammonia), and then use the expanding vapor to turn an electricity-generating turbine. Cold seawater would be pumped through a second heat exchanger to condense the vapor back into a liquid, which would be recycled through the system. This type of OTEC is called a closed-cycle system. Pilot-scale closed-cycle OTEC systems have been successful in producing electric power.

Open-cycle OTEC systems use warm seawater that boils when it is placed in a low-pressure container. The expanding steam drives an electricity-generating turbine. Cold seawater is used to condense the steam back to water. This water is almost pure fresh water, since the salt is left behind in the low-pressure



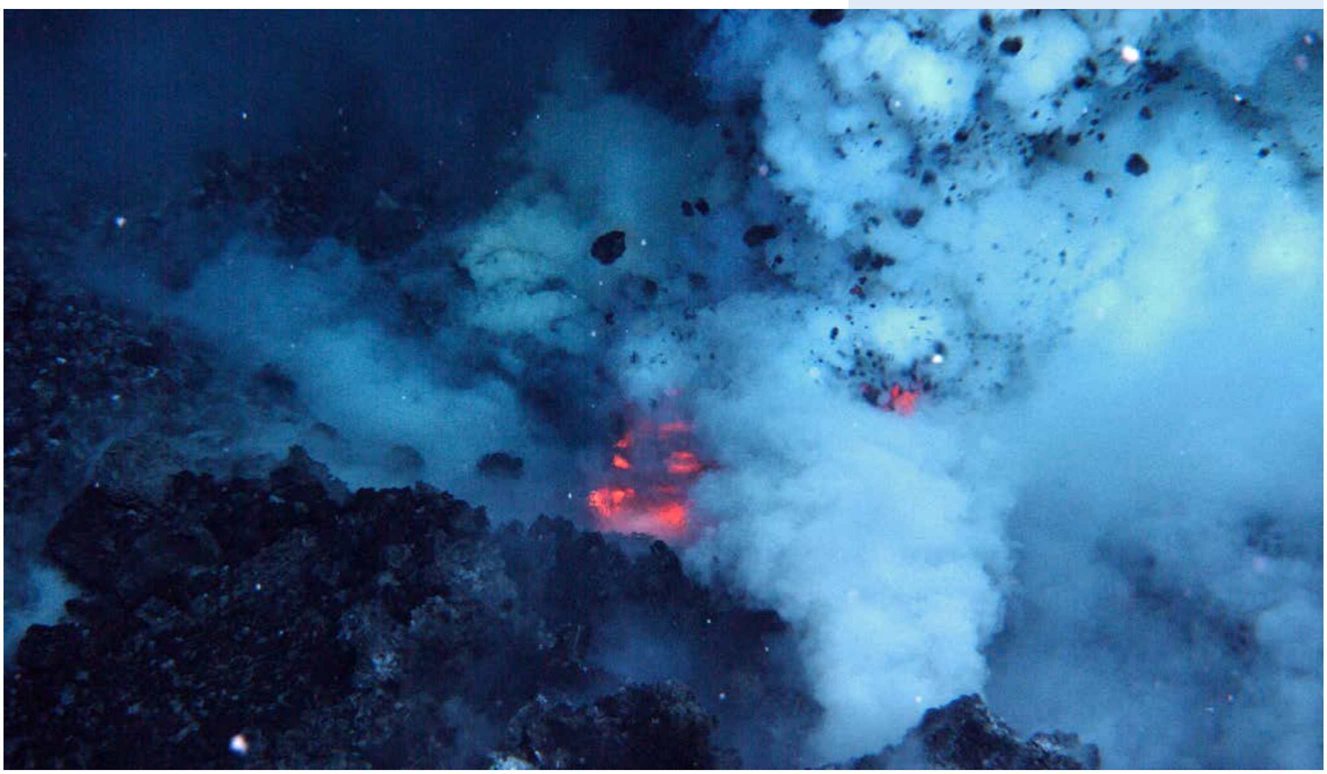
Makai Ocean Engineering has developed internationally recognized expertise in OTEC in the areas of commercial and pilot plant designs, overall technical and economic modeling, heat exchanger design and testing, cold water pipe design and deployment, environmental effects (hydro- and bio-plume modeling), and the power cable to shore. *https://www.makai.com/ocean-thermal-energy-conversion/*

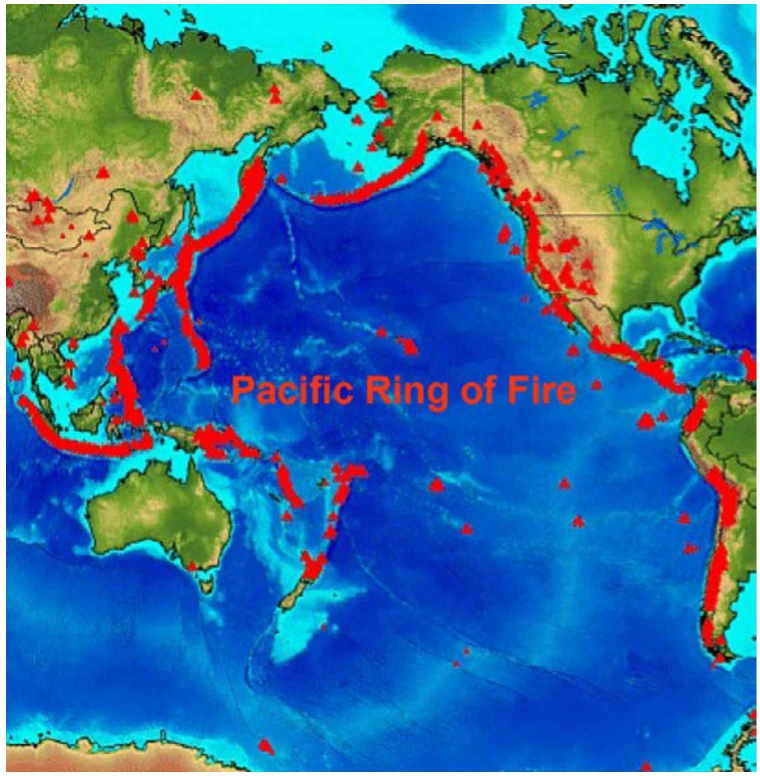
container when the seawater boils. Experimental open-cycle OTEC plants have also successfully produced electric power, in some cases with energy conversion efficiencies as high as 97%. Hybrid OTEC systems combine some features of both closed-cycle and open-cycle systems: Warm seawater enters a vacuum chamber where it is evaporated into steam (similar to the open-cycle evaporation process) that is used to vaporize a low-boiling-point fluid (as in closed-cycle system) that drives a turbine to produce electricity. For more information on OTEC, see *https://energy.gov/eere/energybasics/articles/ocean-thermal-energy-conversion-basics*.

Another type of thermal energy comes from the earth itself. This geothermal energy is produced in Earth's core by the decay of radioactive particles. Earth's core consists of an inner mass of solid iron and an outer core of melted rock called magma. The outer core is surrounded by Earth' s crust, which is 3 - 5 miles thick under the ocean and 15 - 35 miles thick under the continents. Volcanoes occur where magma comes close to the surface of the crust. In some areas, water enters cracks in the crust, comes close to hot magma, and turns into boiling hot water or steam. The heated water may emerge at the surface of Earth's crust as a hot spring, or may erupt into the air as a geyser. Geothermally heated water has been used for centuries to heat buildings, for bathing, and for cooking, and more recently to generate electricity.

Most geothermal activity in the world occurs along the boundaries of tectonic plates encircling the Pacific Ocean, in an

Geothermal energy has been used for centuries. Most of Earth's geothermal activity occurs along the Ring of Fire, which has been investigated by Ocean Explorer expeditions since 2002. This image shows an area on the summit of the West Mata Volcano erupting in 2009. Image courtesy of NOAA / NSF / WHOI. *http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/mata_2009_hires.jpg*





Map of the all the volcanoes around the Pacific (red triangles) making up the Ring of Fire. Image courtesy of Submarine Ring of Fire 2014 - Ironman, NOAA/PMEL, NSF.
http://oceanexplorer.noaa.gov/explorations/14fire/background/seamounts/media/volcano_map.html

NW Rota-1 seamount has been observed erupting explosively on previous visits. Image courtesy of Submarine Ring of Fire 2014 - Ironman, NOAA/PMEL, NSF.
http://oceanexplorer.noaa.gov/explorations/14fire/background/missionplan/media/nw_rota_lavabombs.html

area called the Ring of Fire. This area has been the subject of NOAA-funded research expeditions since 2002 documenting numerous underwater volcanoes, hydrothermal vent fields and other geothermal features, many of which were unexplored prior to these expeditions. Technology for capturing geothermal energy from these sources is in the early stages of development, but one system has been tested in the caldera of the Axial Volcano off the Oregon coast, at least one U.S. patent has been awarded for a 'hydrothermal energy and deep-sea resource recovery system', and a conceptual design for a 'deep-sea energy park' has been proposed. (See *Impacts of anthropogenic disturbances at deep-sea hydrothermal vent ecosystems: A review* by Cindy Van Dover, 2014 *http://www.sciencedirect.com/science/article/pii/S0141113614000506*)

Off Shore Solar

The sun is the primary energy source for all photosynthetic ecosystems, and also drives winds, waves, and deep-ocean currents. In fact, energy from wind, waves, currents, and OTEC could be considered as indirect forms of solar energy (similarly, tidal current energy could be considered as an indirect form of gravitational energy, since tidal currents are driven by gravitational forces between Earth, its moon, and the sun). Solar energy technologies that are presently used in land-based installations may also be developed for offshore use.

You can see illustrations of solar power devices at *https://www.boem.gov/Offshore-Solar-Energy/.*

Off Shore Wind

For many centuries, humans have harnessed wind power to do various types of work, from pushing ships through the ocean, to pumping water, to processing agricultural products. More recently, wind has been used to produce electricity. Most wind turbines have been located on land, but offshore wind turbines are being used in a number of countries, including Denmark and the United Kingdom where large offshore wind facilities have been installed to take advantage of consistent winds. Offshore winds tend to flow at higher speeds than onshore winds, which means that offshore wind turbines have the potential to produce more electricity than land-based installations. The first U.S. offshore wind farm became operational in December 2016 off the coast of Block Island, Rhode Island. Additional projects are being planned in the Northeast, Mid-Atlantic, Great Lakes, Gulf of Mexico, and Pacific Coast regions.

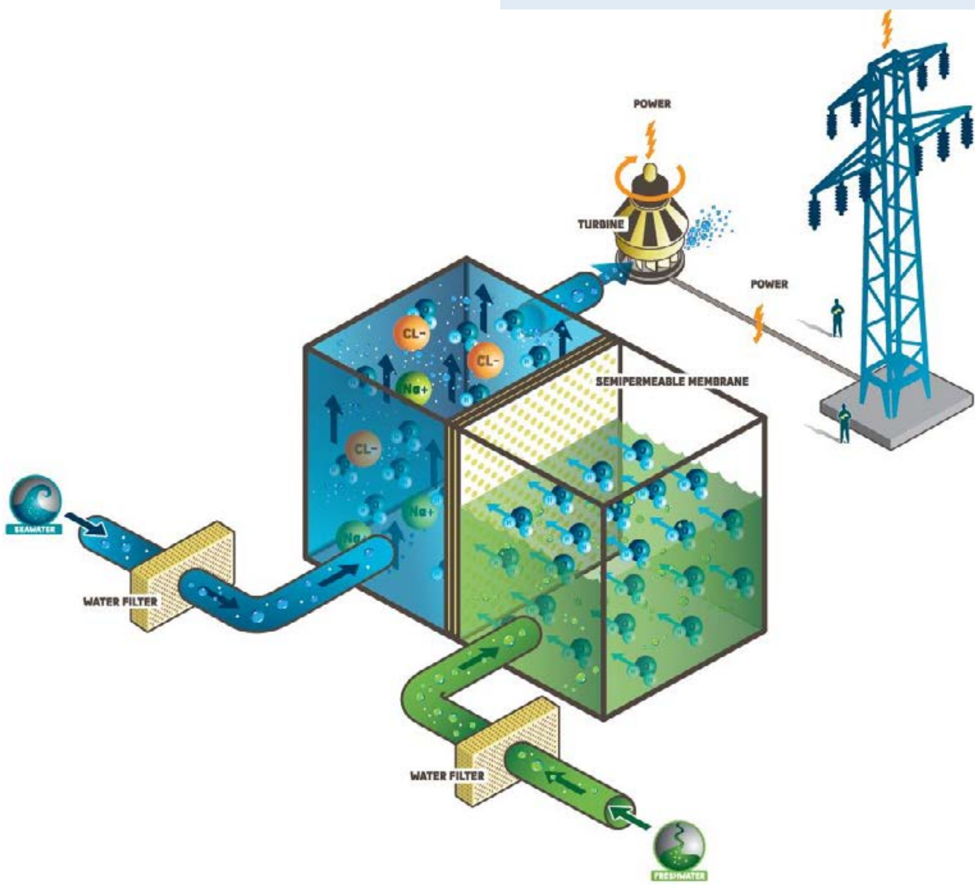
For more information, see *https://www.boem.gov/Offshore-Wind-Energy/*.

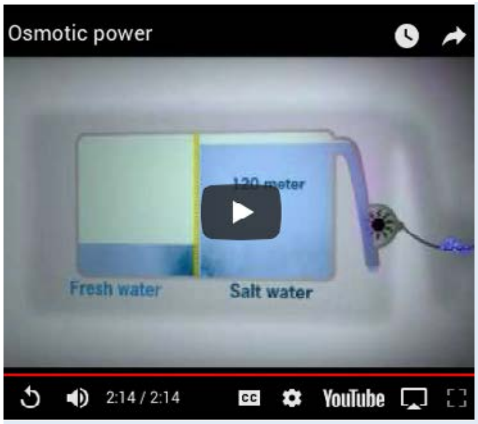
The first U.S. off shore wind farm, built off Block Island, R.I. in 2016.
http://dwwind.com/attachment/?projects=block-island-wind-farm#/1

Salinity Gradient (Osmotic) Energy

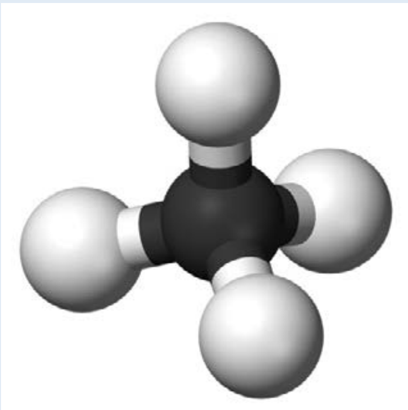
When fresh water and salt water are separated by a semipermeable membrane, water will move through the membrane into the salt solution (only water molecules can pass through a semipermeable membrane). This water movement is driven by a force called osmotic pressure, which is defined as the pressure that would have to be applied to the salt water solution to prevent the influx of water through the semipermeable membrane. Influx of fresh water will increase the volume of the salt water. If the salt water is in a closed container, the volume cannot increase because water is essentially incompressible, and the pressure in the container will rise until it equals the osmotic pressure. If the pressure in the container is released, it can be used to drive a turbine to generate electricity. This method for utilizing salinity gradient energy is called Pressure Retarded Osmosis.

Pressure Retarded Osmosis (PRO) uses the selective diffusion of water across a membrane in order to pressurize seawater. Freshwater and seawater are placed on either side of a membrane, and the seawater side is pressurized. As the seawater side increases in pressure and decreases in salinity, part of the water is discharged through a turbine while the rest is put in a pressure exchanger to pressurize the incoming seawater, as illustrated below.
http://www.climatetechwiki.org/technology/jiqweb-ro

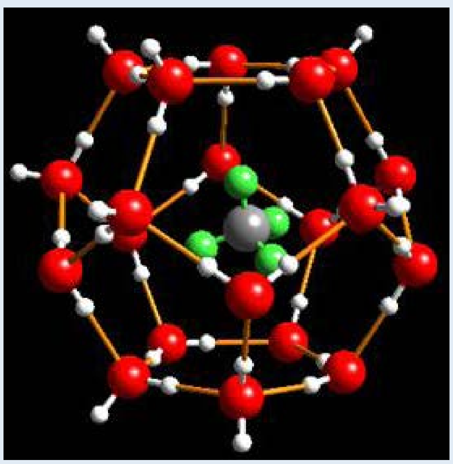




This video illustrates the Pressure Retarded Osmosis (PRO) concept.
https://www.youtube.com/watch?time_continue=134&v=T00KVPpLNGQ



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

Reverse Electrodialysis is another salinity gradient technique that uses a series of anion and cation exchange membranes (negatively charged ions can pass through anion exchange membranes; positively charged ions can pass through cation exchange membranes). When fresh water and salt water are separated by an anion exchange membrane, negatively charged ions will move from the salt water into the fresh water until the concentration on both sides of the membrane are equal. Similarly, when fresh water and salt water are separated by a cation exchange membrane, positively charged ions will move from the salt water into the fresh water until the concentration on both sides of the membrane are equal. A reverse electrodialysis cell is essentially a salt battery with alternating containers of fresh water and salt water separated by an alternating series of anion and cation exchange membranes. If electrodes are placed at opposite ends of the cell and connected to an electric circuit, a voltage will be produced in the circuit.

Development of salinity gradient energy technology is still in its infancy, though the potential energy is large in locations where rivers mix with salt water. For additional information, see Salinity Gradient Energy: Current State and New Trends, by O. Schaetzle and C. Buisman (2015) *http://engineering.org.cn/EN/10.15302/J-ENG-2015046*.

Methane Hydrates and Other Hydrocarbons

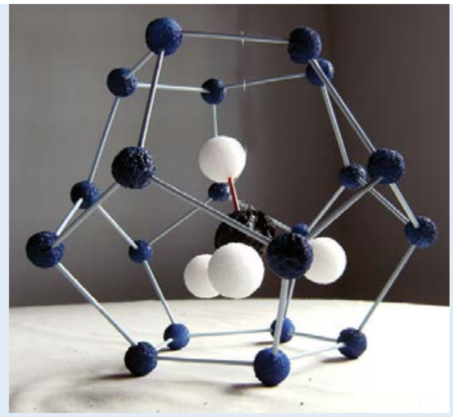
Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments as a by-product of the anaerobic metabolism of methanogenic Archaea through which the microorganisms break down 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. 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 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.

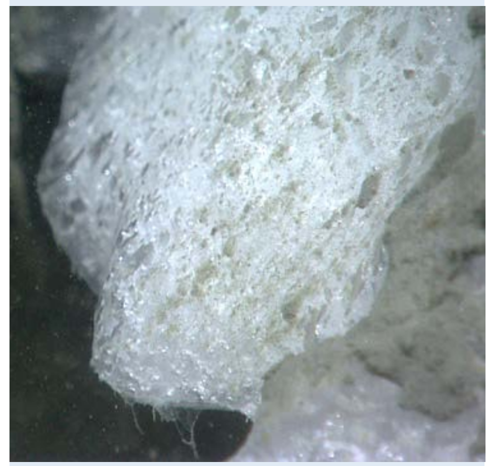
Methane hydrates remain stable in deep-sea sediments for long periods of time; but if the surrounding temperature rises the clathrates may become unstable and release free methane gas. This is probably happening now in at least two settings. In the deep ocean, as sediments become deeper and deeper they 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). 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, 2017). 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).

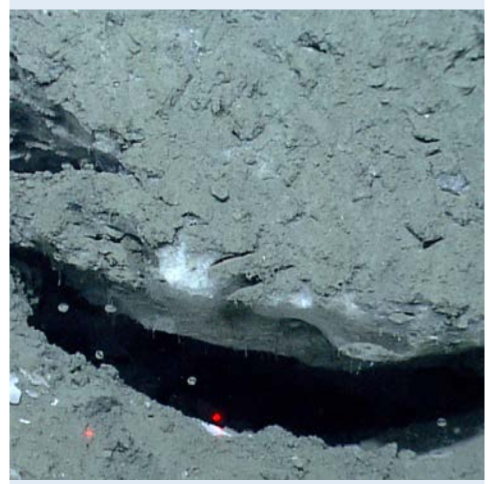
While these discoveries are exciting, there has also been concern about the possible effects of methane release. In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene Epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about 6° C. The result was the 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.



Build your own model of a methane hydrate! Find out how in the *What's The Big Deal?* lesson. Image courtesy Mellie Lewis.





Gas hydrates found at the seafloor on July 11 and July 12, 2013 had different forms. On the top image, a small piece of massive gas hydrate formed above leaking methane. In the bottom image, white gas hydrate formed under a rock overhang. Bubbles being emitted from the seafloor are visible in the shadow below the rock. Laser scale denotes 10 centimeters. Image courtesy of NOAA *Okeanos Explorer* Program, 2013 Northeast U.S. Canyons Expedition.
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/logs/july12/media/hydrate1.html
http://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/logs/july12/media/hydrate2.html

The first dive of the 2014 Gulf of Mexico Expedition had a fantastic "amphitheater of chemosynthetic life." There were 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

Laboratory cultures of deep-sea vent microbes: isolation and purification of organisms on solid agar media. Image courtesy of Oregon State University.
http://oceanexplorer.noaa.gov/explorations/12fire/background/hires/lab_cultures_hires.jpg

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). See *https://www.netl.doe.gov/File%20Library/Publications/factsheets/Program/Program-099.pdf* for information about methane hydrate R&D projects in 2017.

Besides methane hydrates, regions such as the Gulf of Mexico produce significant quantities of petroleum that are associated with unique deep-sea ecosystems. In the Gulf of Mexico, these ecosystems are typically found in areas with rocky substrates or "hardgrounds." Most of these hardbottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems can indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose importance is presently unknown. For more information about deep-sea ecosystems in the Gulf of Mexico, see Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems Education Materials Collection (*http://oceanexplorer.noaa.gov/edu/guide/welcome.html*) and the Exploration of the Gulf of Mexico 2014 expedition (*http://oceanexplorer.noaa.gov/okeanos/explorations/ex1402/welcome.html*).

Human Health Overview

Almost all drugs derived from natural sources come from terrestrial plants. But recent explorations have found that some marine invertebrates such as sponges, tunicates, ascidians, bryozoans, and octocorals can also produce powerful drug-like substances. In fact, these animals produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Chemicals produced by marine animals that may be useful in treating human diseases include:

Ecteinascidin – Extracted from tunicates; approved as Ylondelis for treatment of breast, prostate, and pediatric cancers; acts by blocking transcription of DNA

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; effective against viruses and certain tumors; inhibits DNA and RNA synthesis

Lasonolide – Extracted from the sponge *Forcepia* sp.; high and selective cytotoxicity against mesenchymal cancer cells, including leukemia, melanomas and glioblastomas; interferes with cell mitosis

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent; acts by interfering with microtubule networks

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia, non-Hodgkin's lymphoma, and Alzheimer's disease; acts as a differentiating agent, forcing cancer cells to mature and thus halting uncontrolled cell division

Pseudopterosins – Extracted from the octocoral *Pseudopterogorgia elisabethae* (sea whip); anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing; acts as an inhibitor of phospholipase A, which is a key enzyme in inflammatory reactions

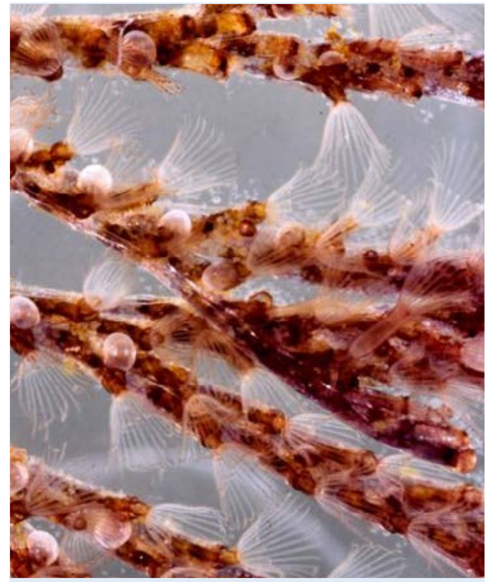
ω-conotoxin MVIIA – Extracted from the cone snail *Conus magnus*; potent pain-killer; acts by interfering with calcium ion flux, thereby reducing the release of neurotransmitters

A striking feature of this list is that all of the organisms (except the cone snail) are sessile (non-moving) invertebrates. To date, this has been true of most marine invertebrates that produce pharmacologically-active substances. Several reasons have been suggested to explain why sessile marine animals are particularly productive of potent chemicals. One possibility is that they use these chemicals to repel predators, because they are basically "sitting ducks." Another possibility is that since many of these species are filter feeders, and consequently are exposed to all sorts of parasites and pathogens in the water, they may use powerful chemicals to repel parasites or as antibiotics against disease-causing organisms. Competition for space may explain why some of these invertebrates produce anti-cancer agents. If two species are competing for the same piece of bottom space, it would be helpful to produce a substance that would attack rapidly dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

For more information about drugs from the sea, visit *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3783861/*

Ocean Health Overview

"The First Global Integrated Marine Assessment" under the United Nations' Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects (Inniss et al., 2016) documents multiple stresses that currently affect Earth's ocean. These are summarized below (unless otherwise cited, this information is from the Inniss et al. report).



The spiral-tufted bryozoan (*Bugula neritina*) is being studied for a potential Alzheimer's disease and cancer drug—but it's not the bryozoan that makes the chemical. The chemical, found in the bryozoan's tissues, is produced by its bacterial endosymbiont, *Candidatus Endobugula sertula*. In exchange for a protective home in the bryozoan's tissues, the bacteria produces a chemical called a bryostatin that makes the bryozoan larvae taste bad to predators. Image courtesy: Lovell and Libby Langstroth © California Academy of Sciences *http://ocean.si.edu/ocean-photos/bryozoans-medical-endosymbiont*

Ziconotide is a chemical derived from the *Conus magus* (cone shell) toxin that acts as a painkiller with a potency 1000 times that of morphine. Discovered by Dr. Baldomero Olivera at University of Utah, it was developed for treatment of chronic and intractable pain caused by AIDS, cancer, neurological disorders and other maladies, and was approved by the U.S. Food and Drug Administration in December 2004 under the name Prialt. Ziconotide works by blocking calcium channels in pain-transmitting nerve cells, rendering them unable to transmit pain signals to the brain. It is administered through injection into the spinal fluid. *https://en.wikipedia.org/wiki/Conus_magus*

Representative shells from pteropods incubated in seawater containing three different concentrations of dissolved carbon dioxide; lowest dissolved carbon dioxide concentration is on the left, largest dissolved carbon dioxide concentration is on the right. Note corrosion on the ribs of the shell in image (b) and the shell perforations in image (c). Tissue that was not dissolved during the sodium hypochlorite incubation is visible as yellow-white material inside of the shells. *https://doi.org/10.1371/journal.pone.0105884.g007*

During the Submarine Ring of Fire 2014 Expedition, two of the vent sites visited, NW Eifuku and NW Rota-1, were known to have extremely high concentrations of carbon dioxide (CO_2), with liquid CO_2 and CO_2 bubbles streaming from them. This high concentration of CO_2 leads to local acidification at much more extreme levels than expected as a result of global climate change. NW Eifuku hosts dense beds of mussels (*Bathymodiolus brevior*) whose shells are eroded and thin due to the acidity. Samples of these mussels were collected to determine whether the high-CO_2 habitats cause marked physiological stress or whether these mussels are thriving in spite of their thin shells. Image courtesy of Submarine Ring of Fire 2014 - Ironman, NOAA/PMEL, NSF. *http://oceanexplorer.noaa.gov/explorations/14fire/background/macrobio/media/mussels.html*

Acidification

Ocean acidification is "the other carbon dioxide problem," additional to the problem of carbon dioxide as a greenhouse gas. For many years, carbon dioxide in Earth's atmosphere has been increasing. Regardless of the reasons for this increase and the possible connection with climate change, about 26% of increasing carbon dioxide is absorbed by the ocean where it reacts with seawater to form carbonic acid resulting in a lower ocean pH. This, in turn, leads to a decrease in carbonate ions that are essential to the process of calcification through which many organisms produce shells and other skeletal structures. Corals, shellfish, echinoderms, and many marine plankton build body parts through calcification. Pteropods are planktonic snails that are an important component of food chains in high-latitude regions, and have been shown to have pitted or partially dissolved shells in waters where carbonate ions are depleted.

See Appendix I (pg 46) for more information about pH, the carbonate buffer system, and a demonstration of ocean acidification.

Changes in Sea Temperature and Salinity

Earth is absorbing more heat than it is emitting back into space, and nearly all that excess heat is being stored in the ocean. During the last thirty years, approximately 70 per cent of the world's coastline has experienced significant increases in sea-surface temperature. Global sea surface temperature is approximately one degree C higher now than 140 years ago. One degree may not sound like much, but the key point is the rate at which this increase has taken place. Over the past 25 years the rate of increase in sea surface temperature in all European seas has been about 10 times faster than the average rate of increase during the past century. Earth's ocean could warm by an additional one to two degrees C by the end of this century.

Many marine organisms live at temperatures close to their thermal tolerances, so even a slight warming could have serious effects on their physiological functioning and ability to survive. Coral reefs are a frequently-cited example. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30 degrees north or south of the equator) where water temperatures are close to the maximum temperature that corals can tolerate. Abnormally high temperatures result in thermal stress, and many corals respond by expelling symbiotic algae (zooxanthellae) that live within the coral's soft tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Zooxanthellae are important to corals' nutrition and growth, and expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to survive a bleaching event and eventually recover; but if other types of stress are present and the stress is sustained, the corals may die.

Even when individual species are able to tolerate increased temperatures, they may still be affected by changes within their food webs. For example, warmer waters in northwestern Europe have caused clams (*Macoma balthica*) to spawn earlier in the year, but blooms of phytoplankton on which the clams feed do not happen until later in the spring. Clam larvae also face increased predation from shrimp whose abundance has increased in early spring due to warmer temperatures.

Changes in rainfall along with melting glaciers and ice-caps have resulted in changes in patterns of ocean salinity. Observations suggest that surface salinity in subtropical ocean regions and the entire Atlantic basin has increased, while low-salinity regions, such as the western Pacific Warm Pool, and high-latitude regions have become even less saline. Salinity variations are one of the drivers of ocean currents, so salinity changes can affect seawater circulation, as well as directly changing the chemical environment of ocean plants and animals.

Differences in salinity and temperature among different bodies of seawater result in stratification, in which seawater forms layers, with limited exchange of oxygen and other dissolved chemicals between the layers. Increased stratification has been noted around the world, particularly in the North Pacific and,

The 3rd Global Coral Bleaching Event

In 1998, a huge underwater heatwave killed 16% of the corals on reefs around the world. Triggered by the El Niño of that year, it was declared the first major global coral bleaching event. The second global bleaching event that struck was triggered by the El Niño of 2010. NOAA announced the third global bleaching event in October 2015 and it has become the longest and most widespread event in recorded history.

The new phenomenon of global coral bleaching events is caused by ocean warming (93% of climate change heat is absorbed by the ocean). Corals are unable to cope with today's prolonged peaks in temperatures. Although reefs represent less than 0.1 percent of the world's ocean floor, they help support approximately 25 percent of all marine species. As a result, the livelihoods of 500 million people and income worth over $30 billion are at stake.

The two previous events caught society relatively unprepared. The world simply didn't have the technology, understanding or teams in place to reveal and record them properly. 2015 was different—sponsored by an insurance company interested in the risk resulting from ocean warming, the XL Catlin Seaview Survey, running off predictions issued by NOAA's Coral Reef Watch programme (which have proven to be accurate), was able to respond quickly. A major global bleaching event is considered one of the most visual indicators of climate change.

www.globalcoralbleaching.org/#overview

more generally, north of 40ºS. The resulting decreased mixing reduces oxygen content and the extent to which the ocean is able to absorb heat and carbon dioxide, because less water from the lower layers is brought up to the surface where absorption of heat and carbon dioxide takes place. Reduced vertical mixing also limits the amount of nutrients brought up from lower levels into the zone where photosynthesis takes place, and consequently reduces overall ecosystem productivity.

Melting polar sea ice associated with increased sea surface temperatures means that there are increasing opportunities for shipping between the Atlantic and Pacific Oceans via polar routes (which are shorter and therefore economically advantageous compared to more southerly routes). Increased shipping traffic in polar regions means increased risk of marine pollution, as well as increased risk of introducing non-native invasive species. Polar ecosystems generally have low rates of recovery, so pollution damage could be particularly serious.

Increased Mortality of Animal Populations

Global demand for seafood has grown steadily over the past century, resulting in increasingly sophisticated fishing industries that use powerful boats, freezer trawlers, acoustic fish finders, and other advanced technologies. The global harvest from capture fisheries is on the order 0f 80 million tons, which is near the upper limit of the ocean's productive capacity. Of the fish stocks that are scientifically monitored, about one-fourth are overfished, and more are still recovering from previous overfishing. The impacts of overfishing extend beyond the individual target species. Marine mammals, reptiles, sea birds, and other fish species are all vulnerable to increased mortality as "by-catch" to commercial fisheries. If all fisheries were effectively managed, the overall yield could increase by as much as 20 percent.

Reproductive success in many species is being reduced by multiple pressures from human activity, including invasive species (rats and other predators at sea bird breeding sites), coastal development at historical breeding and nursery sites, and impacts from hazardous substances.

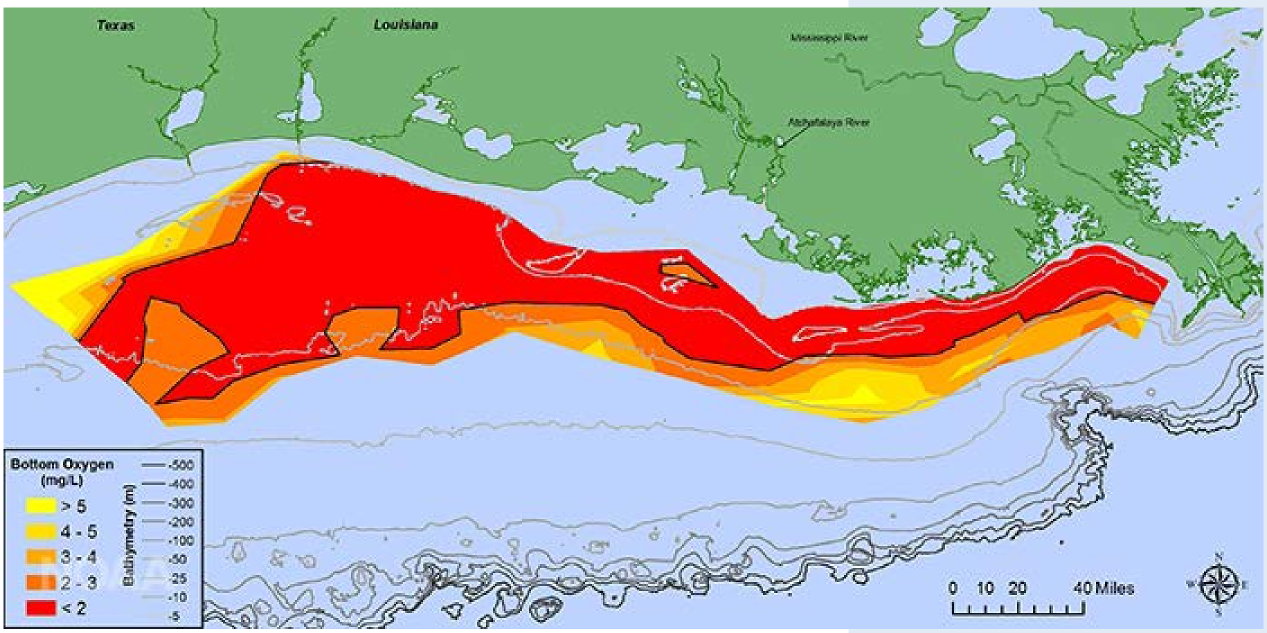
Physical Alteration of Sea-Bed Habitats

Benthic communities are particularly vulnerable to negative impacts from bottom-contacting fishing gear, and damage to coastal and shelf benthic habitats has been documented everywhere such gear is used. Deepwater coral and sponge communities that have been damaged by bottom trawling are expected to require at least a century to recover. Changes to physical and chemical habitat conditions including temperature, salinity, dissolved oxygen, nutrient levels, turbidity, pollutants, sedimentation, and sea floor disturbance have all been shown to influence fish-community composition and structure in every ocean basin.

Inputs of Harmful Materials

For thousands of years, Earth's ocean has provided a convenient means for disposing of unwanted products of human activity. The ocean's impressive size, coupled with the fact that it is largely out of sight, makes it easy to assume that this practice is of no particular consequence. But there is growing evidence that thousands of different inputs are having a significant impact. These inputs include:

- **Runoff from agriculture and from urban areas** — Water draining from agricultural areas often contains pesticides and fertilizers that eventually enter the marine environment. Nutrients from fertilizers cause algal blooms that lead to serious depletion of dissolved oxygen and large areas that do not have enough oxygen to support marine life (dead zones). The 2017 dead zone in the Gulf of Mexico, for example, covered 8,776 square miles—an area the size of New Jersey.



Gulf of Mexico dead zone in July 2017
At 8,776 square miles, the 2017 dead zone in the Gulf of Mexico is the largest ever measured. Image courtesy of N. Rabalais, LSU/LUMCON
http://www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

- **Littering and dumping of garbage and waste**—Marine debris is present is all ocean habitats, with an average density of 13,000 to 18,000 pieces per square kilometer. Plastics account for 60% to 80% of all marine debris. Nanoparticles (particles who dimensions are between 1 and 100 millionths of a millimeter) are a relatively new concern, arising from the breakdown of plastics and from the use of nanoparticles in cosmetics and other industries. Nanoparticles of titanium dioxide are a particular concern because when they are exposed to ultraviolet radiation from the sun they transform into a disinfectant that is known to kill phytoplankton, which are the basis of primary production in the ocean.

- **Sewage discharges** — Human wastes discharged into ocean waters cause human health problems through direct

Every year, the NOAA Marine Debris Program supports locally driven, community-based marine debris removal projects. These projects benefit coastal habitat, waterways, and wildlife including migratory fish. Image courtesy of NOAA. *https://marinedebris.noaa.gov/multimedia/photos*

contact with contaminated water, bacterial contamination of seafood, and by adding nutrients that produce algal blooms that can infect seafood with harmful toxins. These discharges often contain industrial wastes as well, including heavy metals, chlorinated compounds, and organic chemicals (including endocrine disruptors) that are harmful to many organisms including humans.

- **Lost, discarded, and abandoned fishing gear** — Derelict fishing gear (DFG) includes nets, lines, traps, and other recreational or commercial fishing equipment, much of which is made of synthetic materials and metals that last a very long time. DFG may continue to trap and kill fish, crustaceans, marine mammals, sea turtles, and seabirds for years after they are lost.

- **Garbage dumping and discharges from ships** — This was the first source of ocean pollution that was brought under global regulation (by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972), but there is some evidence that oil discharges, sewage pollution, and garbage dumping are still taking place, and some of the world's largest economies have not become party to ocean dumping agreements.

- **Spills from offshore hydrocarbon industries** — Although our economy depends on hydrocarbons, there is a risk of spills, and these industries can can also create harmful inputs from contaminated drilling muds, contaminated water, and chemicals used for exploration and production.

- Habitat destruction, increased turbidity, underwater noise, and other effects from deep sea and offshore mining.

Competing Demands for Marine Space

A large proportion of Earth's human population lives near the ocean; 38% lives within 100 km of the coast; 67% lives within 400 km. Humans want to use ocean resources in many different ways, including recreation, commercial fishing, subsistence fishing, aquaculture, marine ranching, shipping, ports, underwater cables and pipelines, hydrocarbon energy production, mineral mining, wind farms, ocean energy, marine parks and protected areas; and not all of these uses are compatible with each other. Developing effective ways to allocate marine space is a difficult challenge that requires fundamental knowledge about interactions between ocean systems. Providing that knowledge is a key reason for "why do we explore."

Invasive species are non-native species that have been introduced to a region, have established thriving reproductive populations, and are expanding their range. Invasive species often have no natural predators in their new environment, and can successfully compete with and possibly replace native species. Invasive species may compete with native species for habitat and food resources, and may also act as predators to which native species are not adapted. Invasive species are usually introduced accidentally or deliberately by humans.

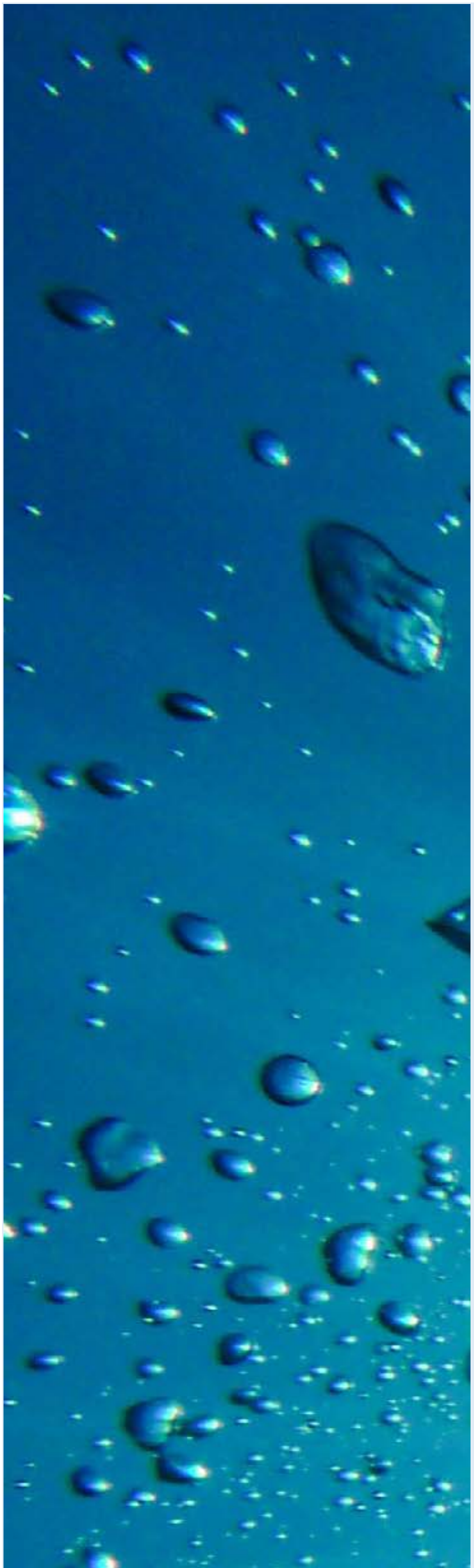
Reproductive success in many species is being reduced by multiple pressures from human activity, including invasive species (rats and other predators at seabird breeding sites), coastal development at historical breeding and nursery sites, and impacts from hazardous substances.

Where Do We Go From Here?

Ocean Health issues revolve around two points:

1) Earth's ocean is about systems; everything is connected.
2) Human activities have global impacts on Earth's ocean.

It's very easy to be overwhelmed by the magnitude of ocean health problems, and just assume we can do nothing. The reality is that these problems did not arise through a single, deliberate action. They are the result of numerous individual actions that took place without any consideration for their collective impacts on Earth's ecosystems. And another reality is that effective solutions to these problems will not occur in a single, global action, but rather will involve numerous individual actions that by themselves seem insignificant, but collectively can have global impacts. Individually, we are all insignificant on a global scale. Collectively, we have global impacts. The root cause of many ocean health problems is the cumulative impact of individual actions; and many solutions to these problems also depend upon the cumulative impact of individual actions.



Appendix I
More About pH

What Do pH Numbers Mean?

An "acid" is commonly defined as a chemical that releases hydrogen ions (abbreviated H^+). The pH (which stands for "power of hydrogen") of a solution is defined as the negative logarithm of the hydrogen ion concentration in moles per liter. So,

$$pH = -\log [H^+]$$

where brackets are understood to mean "concentration."

The logarithm of a number x is the power to which another number called the "base" must be raised to produce x. So, the logarithm of 1000 to the base 10 is 3 because 10 raised to the power of 3 is equal to 1000. Where pH is concerned, the base is always 10. If a solution has a hydrogen ion concentration of 1 x 10^{-7} moles/liter, the logarithm of this concentration is -7, and the pH is 7. The pH scale ranges from 0 to 14, which corresponds to a hydrogen ion concentration range of 1.0 mole/liter to 1 x 10^{-14} mole/liter. A pH of 7 is considered neutral. A pH below 7 (higher hydrogen ion concentration) is acidic; a pH above 7 (lower hydrogen ion concentration) is basic.

A decrease of 0.1 pH unit may not seem like much, until we remember that this is a logarithm. So a pH of 8.2 corresponds to a hydrogen ion concentration of:

$$1 \times 10^{-8.2} \text{ moles/liter} = 0.00000000631 \text{ moles/liter}$$

(10 raised to the -8.2 power)

and a pH of 8.1 corresponds to a hydrogen ion concentration of:

$$1 \times 10^{-8.1} \text{ moles/liter} = 0.00000000794 \text{ moles/liter}$$

so a drop of 0.1 pH unit represents a 25.8% increase in the concentration of hydrogen ions.

Note that while the term "ocean acidification" is commonly used, the ocean is not expected to actually become acidic (which would mean that the pH was below 7.0). "Acidification" in this case only means that the pH is declining.

The Carbonate Buffer System

pH is a measure of acidity, which is the concentration of hydrogen ions; increasing hydrogen ions causes increased acidity. A pH of 7 is considered neutral; a pH below 7 is acidic; a pH above 7 is basic. Dissolved chemicals cause seawater to act as a pH buffer; that is, seawater tends to resist changes in pH. This Carbonate Buffer System is described by the following equation:

The Carbonate Buffer System Equation

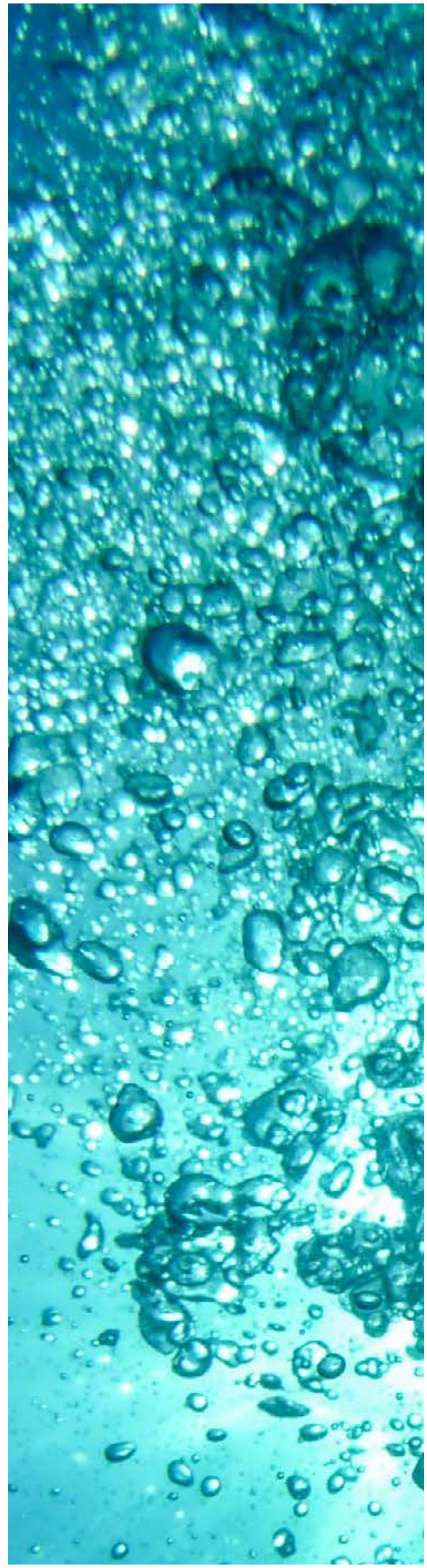
CO_2	+	H_2O	↔	H_2CO_3	↔	H^+	+	HCO_3^-	↔	$2H^+$	+	CO_3^{2-}
carbon dioxide		water		carbonic acid		hydrogen ion		bicarbonate ion		2 hydrogen ions		carbonate ion

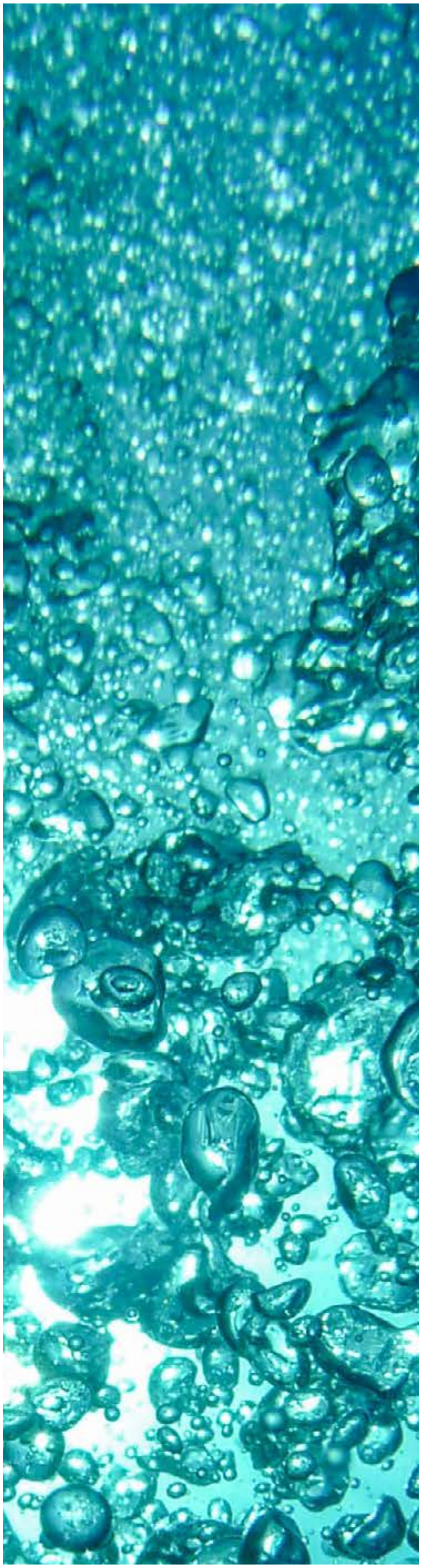
This equation shows that carbon dioxide dissolves in seawater to form carbonic acid, a weak acid. Most of the carbonic acid normally dissociates to form hydrogen ions, bicarbonate ions, and carbonate ions. Carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions are all present in normal seawater, although not in the same concentrations (about 87% of inorganic carbon is bicarbonate, about 12% is carbonate, and carbonic acid and carbon dioxide combined are about 1%). When these chemicals are in equilibrium, the pH of seawater is about 8.1 – 8.3 (slightly basic). More dissolved carbon dioxide causes an increase in hydrogen ions and a lower ocean pH. But the pH change in seawater is less than if the same amount of carbon dioxide were dissolved in fresh water because the carbonate buffer system in seawater removes some of the added hydrogen ions from solution.

In addition to the reactions described in the carbonate buffer system equation, other reactions also take place between carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions. One of these other reactions takes place between carbon dioxide, water, and carbonate ions:

CO_2	+	H_2O	+	CO_3^{2-}	$\leftrightarrow$	$2\ HCO_3^-$
carbon dioxide		water		carbonate ion		2 bicarbonate ions

So, adding carbon dioxide to the ocean system can also cause a decrease in carbonate ions; and carbonate ions are essential to the process of calcification through which many organisms produce shells and other skeletal structures.





Demonstrating the Effect of Dissolved Carbon Dioxide on pH

Increased atmospheric carbon dioxide has a demonstrable effect on ocean pH. A simple demonstration of the impact of dissolved carbon dioxide on pH can be found below. While there is some disagreement about the connection between climatic temperature increase and carbon dioxide from human activity, the increase in atmospheric CO_2 and decline in ocean pH are not theoretical; these changes have been confirmed by actual measurements. The following demonstration illustrates this concept.

Educators are urged to try the following procedures in advance of demonstrating before an audience. It is possible that enough atmospheric carbon dioxide may dissolve in distilled water to lower the pH so that the solution will turn yellow as soon as the indicator solution is introduced. If this happens, adjust the starting pH to slightly above neutral by adding a small pinch of baking soda to the distilled water before introducing the indicator solution.

Materials

- Drinking straw
- 100 ml of distilled water
- 100 ml of seawater (natural or artificial)
- Glass jar or beaker, about 200 ml capacity
- Bromothymol Blue Indicator Solution, 0.04% aqueous

Procedure

Step 1. Pour approximately 100 ml of distilled or tap water into a clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 2. Pour approximately 100 ml of seawater (artificial or natural) into a second clean, transparent container. Add 15 drops of bromothymol blue indicator solution.

Step 3. Blow steadily through a drinking straw into the water in the first container, and record the time required for the color to change from blue to yellow-green.

Step 4. Repeat Step 3 with the water in the second container. Note that it is possible to blow through two straws simultaneously, and if this is done there is no need to record elapsed time.

Step 5. Discuss the following:

- Blowing through the straw bubbles carbon dioxide through the liquid in the containers.
- Carbon dioxide dissolves in water to form a weak acid (carbonic acid).
- Bromothymol blue is blue in basic solutions, and yellow in acidic solutions. The color change happens in the approximate range of pH 6.0-7.6.
- A buffer is a solution that tends to resist changes in pH. Ask students to apply one or more of these facts to explain the results of the demonstration. Do these results suggest that seawater may act as a buffer?