OCEAN EXPLORATION & RESEARCH

Bermuda Deepwater Caves:
Dive of Discovery

Living in a Cave

Image captions/credits on Page 2.

lesson plan

Focus

Life in anchialine and marine caves

Grade Level

7-8 (Biology,English/Language Arts [Technical Reading])

Focus Question

What kinds of habitats are found in anchialine caves, and what adaptations are seen in organisms that live in these habitats?

Learning Objectives

- Students will compare and contrast anchialine and marine caves.
- Students will describe the biological significance of animals that live in anchialine and marine caves.
- Students will explain why it is important to protect individual caves from destruction or pollution.
- Students will describe some of the precautions that scientists must take when studying these caves.

Materials

- ❑ Copies of *Save the Cave! Student Guide,* one copy for each student group

Audio-Visual Materials

- ❑ (Optional) Interactive white board, computer projector or other equipment for showing images of underwater caves

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of two to four students

Maximum Number of Students

32

Key Words

Anchialine
Cave
Stygobite
Conservation
Multibeam sonar

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.

Anchialine caves are partially or totally submerged caves that are located within a few kilometers inland from coastal areas. Anchialine (pronounced "AN-key-ah-lin") is a Greek term meaning "near the sea," and anchialine caves often contain freshwater and/or brackish water in addition to seawater. These caves may be formed in karst landscapes as well as in rock tubes produced by volcanic activity. Karst landscapes are areas where limestone is the major rock underlying the land surface, and often contain caves and sinkholes formed when acidic rainwater dissolves portions of the limestone rock. Water in anchialine caves tends to stratify according to salinity, with the heavier seawater below the level of fresh and brackish water. This stratification produces distinctive habitats occupied by a variety of species that are endemic to these environments (endemic means that these species are not found anywhere else). Some of these species are "living fossils" known as relict species, which means that they have survived while other related species have become extinct.

Animals that live only in anchialine habitats are called stygofauna or stygobites. Investigations of these species have revealed some puzzling relationships, including:

- Some stygobite species appear to have been in existence longer than the caves they inhabit, which implies that these species must have arrived in the caves from somewhere else; but how could this happen if these species are only found in caves?
- Some stygobite species are found in caves that are widely separated, such as certain crustacean species found in caves on opposite sides of the Atlantic Ocean and certain species in Australian anchialine caves that are also found in Atlantic and Caribbean caves.
- Geographic distribution of some species suggests a possible connection with mid-ocean ridges, such as shrimps belonging to the genus *Procaris* that are only known from anchialine habitats in the Hawaiian Islands, Ascension Island in the South Atlantic, and Bermuda in the North Atlantic.
- Some anchialine species are most closely related to organisms that live in the very deep ocean.

Images from Page 1 top to bottom:
The peracarid crustacean order Mictacea is represented by only a single species, *Mictocaris halope*, from inland marine caves in Bermuda. Image courtesy Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/media/caves.html

Overhead view of Bermuda showing the island and the reef platform. Photo courtesy of Bermuda Zoological Society.
http://oceanexplorer.noaa.gov/explorations/09bermuda/media/bda.html

Divers swim between massive submerged stalagmites in Crystal Cave, Bermuda. Such stalactites and stalagmites were formed during glacial periods of lowered sea level when the caves were dry and air-filled. Image courtesy of Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/bermudaorigin/media/bermudaorigin_3.html

Ostracods are small, bivalve crustaceans that can inhabit underwater caves. The ostracod genus *Spelaeoecia* is know only from marine caves and occurs in Bermuda, the Bahamas, Cuba, Jamaica and Yucatan (Mexico). Image courtesy of Bermuda: Search for Deepwater Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/spelaeoecia.html

- Some anchialine species are most closely related to organisms that live in deep-sea hydrothermal vent habitats.
- An unusually large proportion of anchialine cave species in Bermuda are endemic to these caves, suggesting that these habitats have been stable for a long period of time.

Most investigations of anchialine caves have been confined to relatively shallow depths; yet, the observations described above suggest that connections with deeper habitats may also be important to understanding the distribution of stygobite species. Bermuda is a group of mid-ocean islands composed of limestone lying on top of a volcanic seamount. Because these islands are karst landscapes, Bermuda has one of the highest concentrations of cave systems in the world. Typical Bermuda caves have inland entrances, interior cave pools, underwater passages, and tidal spring outlets to the ocean. Bermuda's underwater caves contain an exceptional variety of endemic species, most of which are crustaceans. Most of these organisms are relict species with distinctive morphological, physiological, and behavioral adaptations to the cave environment that suggest these species have been living in caves for many millions of years. Yet, all known anchialine caves in Bermuda were completely dry only 18,000 years ago when sea levels were at least 100 m lower than present because of water contained in glaciers. Such observations suggest the possibility of additional caves in deeper water that would have provided habitat for anchialine species when presently-known caves were dry.

The primary goal of the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition is to explore the uppermost 200 meters of the Bermuda seamount and adjacent seamounts to confirm the existence of underwater caves at depths between 60 and 200 meters. A related goal is to document underwater features that indicate sea level during the last Ice Age, which was much lower than at present.

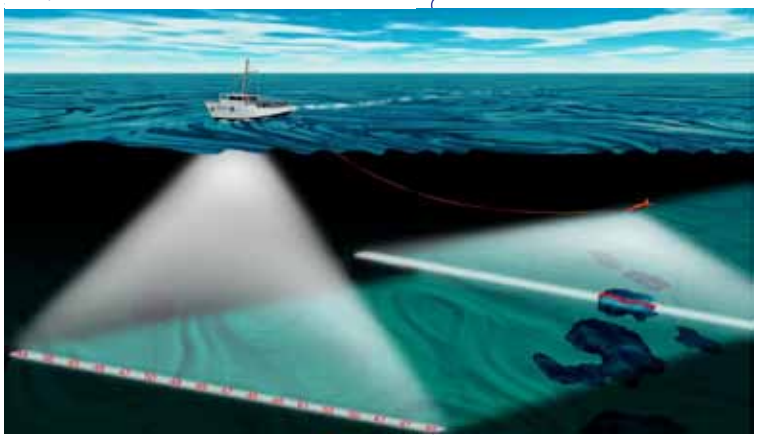
During the Bermuda: Search for Deepwater Caves 2009 Expedition, high-resolution multibeam sonar was used to produce detailed maps that assisted with locating deep-water caves and sea level benchmarks. Sites of interest identified by the multibeam survey were examined and photographed using a remotely operated vehicle (ROV), an underwater robot. In particular, Expedition scientists were looking for signs of water movements around possible cave entrances, such as congregations of schooling fish, plumes of brackish water, sand ripples, or an unusual abundance of filter-feeding organisms such as sponges. During the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition, technical divers will explore selected caves to collect biological specimens and place or recover instrument packages. For more information about results from the 2009 Expedition, see http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/summary/summary.html.

In this activity, students will use information from a technical paper authored by the principal investigator for the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition to prepare a public education presentation about the importance of conserving anchialine and marine caves.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition at http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html.
   (b) Download a few images of anchialine caves from http://www.tamug.edu/cavebiology/index2.html
   (c) Review the *Save the Cave! Student Guide*
   (d) Decide which types of presentation(s) you want students to create. These may include scientific posters, written essays, PowerPoint® presentations, original drama, or other formats depending upon the availability of time and technical resources. For more information about scientific posters, see page 11 of the *Living Light* lesson (http://oceanexplorer.noaa.gov/explorations/09bioluminescence/background/edu/media/ds_09_livinglight.pdf).
   (e) Download the technical paper by Iliffe and Kornicker, 2009 (http://www.tamug.edu/cavebiology/reprints/Reprint-195.pdf). Make a copy for each student group.

2. Briefly introduce the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition, and show some images of marine caves. Tell students that Bermuda has an unusually large number of species living in marine caves that are not found anywhere else, and that some are called "living fossils" because they have survived while other related species have become extinct. Say that very little is known about deep water marine caves, and discuss why scientists might want to find and explore these caves. Briefly describe how anchialine caves may be formed.



Use of multibeam sonar to map the seafloor. Image courtesy of Jill Heinerth, Bermuda: Search for Deep Water Caves 2009. http://oceanexplorer.noaa.gov/explorations/09bermuda/background/multibeam/media/multibeam_fig3.html

Tell students that high-resolution multibeam sonar was used in 2009 to produce detailed maps of the entire shelf edge around the Bermuda Platform in water depths greater than 150 m, and that sites selected from these maps were explored and photographed using an underwater robot called a remotely operated vehicle (ROV). Say that a major activity during the 2011 Expedition is further exploration of some caves by human divers who will collect biological specimens and install instruments to measure currents,

Dr. Rikk Kvitek and graduate student Krystle Gomez prepare the ROV for deployment in the waters off the Bermuda Platform. Image Courtesy of Bermuda: Search for Deepwater Caves 2009 Exploration.
http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/summary/media/bc_msp1_01.html

Entrance to one of Bermuda's caves. Image Courtesy of Bermuda: Search for Deepwater Caves 2009 Exploration.

temperature, and chemical conditions (salinity, pH, dissolved oxygen and chlorophyll concentration) inside the caves.

3. Provide each student with a copy of the *Save the Cave! Student Guide*. You may want to review Parts A through C with the entire class to ensure that students understand what they are expected to do, and how a technical review paper is organized. You may want to have students define the following potentially unfamiliar terms before creating their presentations:
   Stygofauna (animals that live in caves)
   Stygobite (organisms that can only live in cave environments)
   Stygophilic (organisms that live permanently in caves, but can also live in other habitats)
   Stygoxene (organisms that spend some of their time in caves but also leave periodically for some purpose, usually to find food; many fish and crayfish are stygoxenes)
   Endemic (organisms that are found only in a single habitat)
   Hypoxic (containing very little oxygen)
   Anoxic (containing no oxygen)
   Troglomorphy (biological process that produces adaptations for living in caves)
   Epigean (organisms that live near the surface of the ground)
   Hypogean (organisms that live beneath the surface of the ground)

4. Have each student group make their presentation to the entire class, then discuss key points that should include:
   - Anchialine caves are partially or totally submerged caves that are located within a few kilometers inland from coastal areas.
   - Marine caves are located either directly on the coastline, or are entirely submerged beneath the seafloor.
   - Anchialine caves contain abundant and diverse endemic fauna (endemic means that these organisms are not found anywhere else).
   - Crustaceans are the most abundant group of animals found in anchialine caves.
   - More than 400 new species have been found in anchialine caves.
   - Organisms that live only in anchialine or marine caves often have reduced pigment, and eyes are reduced or absent.
   - Cave organisms move with a glide-and-rest motion to conserve energy.
   - Some species are found only in a single cave system on one island, so pollution or destruction of the caves will result in their extinction.
   - The water column in most anchialine caves is highly stratified, and may include freshwater in upper layers, and seawater in lower layers.
   - There is no photosynthesis in anchialine and marine caves, and cave waters typically contain very little oxygen.

Prof. Tom Iliffe, diving with a Megalodon closed circuit rebreather, tows a plankton net through an underwater cave to collect small animals. Image courtesy of Jill Heinerth, Bermuda: Search for Deep Water Caves 2009. http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/plankton.html

- Exhaust bubbles from normal SCUBA equipment can disturb silt on cave ceilings and change the chemical composition of water in cave environments, so divers should use closed circuit rebreather equipment when entering anchialine or marine caves.
- Threats to anchialine and marine cave ecosystems include sewage pollution; wastewater containing nitrates, detergents, toxic metals, and pharmaceuticals; trash and litter; limestone quarries; and tourist development.

The BRIDGE Connection

www.vims.edu/bridge/ - Type "adaptation" in the Search box for links to resources and activities about other examples of adaptations in marine organisms.

The "Me" Connection

Have students write a brief essay describing why unique habitats such as anchialine caves and endemic organisms that live in these habitats should be protected.

Connections to Other Subjects

Earth Science

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

Visit http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html for more about the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the link to Lesson 15 for interactive multimedia presentations and Learning Activities on Seamounts.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

I, Robot, Can Do That!
(9 pages, 357k) (from the 2005 Lost City Expedition)
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater robotic vehicles for scientific exploration (Physical Science/Life Science)

Students describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and

disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

Sonar Simulation
(10 pages, 308kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/sonarsim.pdf

Focus: Side-scan sonar (Earth Science/Physical Science)

Students describe side-scan sonar, compare and contrast side-scan sonar with other methods used to search for underwater objects, and make inferences about the topography of an unknown and invisible landscape based on systematic discontinuous measurements of surface relief.

Biological Communities of Alaska Seamounts
(5 pages, 108k) (from the Exploring Alaska's Seamounts 2002 Expedition)
http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/biocomm7_8.pdf

Focus: Biological communities of Alaska seamounts (Life Science)

Students infer why biological communities on seamounts are likely to contain unique or endemic species, calculate an index of similarity between two biological communities given species occurrence data, make inferences about reproductive strategies in species that are endemic to seamounts, and explain the implications of endemic species on seamounts to conservation and extinction of these species.

Food Web Mystery
(4 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)
http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_foodweb.pdf

Focus: Food webs in the vicinity of seamounts (Life Science)

Students describe typical marine food webs, explain why food is generally scarce in the deep-ocean environment, and discuss reasons that seamounts may support a higher density of biological organisms than would appear to be possible considering food available from primary production at the ocean's surface.

Other Resources

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

http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html – Web site for the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition

http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html – Web site for the Bermuda: Search for Deepwater Caves 2009 Expedition

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book - A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

Koenemann, S. and T. M. Iliffe. 2009. The Atlántida 2008 Cave Diving Expedition. Mar Biodiv 39:153. http://www.tamug.edu/cavebiology/reprints/Reprint-189.pdf

Wilkens, H., T. M. Iliffe, P. Oromí, A. Martínez, T. N. Tysall, and S. Koenemann. 2009. The Corona lava tube, Lanzarote: geology, habitat diversity and biogeography. Mar Biodiv 39:155–167.

http://www.tamug.edu/cavebiology/index2.html – Web site, Anchialine Caves and Cave Fauna of the World

http://www.goodearthgraphics.com/virtcave/index.html – Virtual Cave Web site

Iliffe, T. M. and R. E. Bishop. 2007. Adaptations to Life in Marine Caves. In Fisheries and Aquaculture. Patrick Safran, ed., in Encyclopedia of Life Support Systems. UNESCO. EOLSS Publishers. Oxford, UK; available online at http://www.tamug.edu/cavebiology/reprints/reprint-176.pdf

Iliffe, T. M. and L. S. Kornicker. 2009. Worldwide diving discoveries of living fossil animals from the depths of anchialine and marine caves. Smithsonian Contributions to Marine Sciences 38:269-280; available online at http://www.tamug.edu/cavebiology/reprints/Reprint-195.pdf

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard C: Life Science

- Populations and ecosystems
- Diversity and adaptations of organisms

Content Standard D: Earth and Space Science

- Earth's history

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept c. Erosion—the wearing away of rock, soil and other biotic and abiotic earth materials—occurs in coastal areas as wind, waves, and currents in rivers and the ocean move sediments.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.
Fundamental Concept h. Tides, waves and predation cause vertical zonation patterns along the shore, influencing the distribution and diversity of organisms.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback. Please send any questions about these materials or other comments to: oceanexeducation@noaa.gov.

For More Information

Paula Keener, Director, Education Programs
NOAA Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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Credit

Save the Cave! Student Guide

A. The Problem

"Out of sight, out of mind" – Anchialine and marine cave ecosystems are completely unknown to most people. Yet, Iliffe and Kornicker (2009) report that human activities are having serious impacts on these ecosystems, "either destroying or grossly polluting numerous caves, resulting in extinction of untold numbers of species." Tourism development, limestone quarries, trash disposal, and water pollution are all part of the problem. Protecting these caves is difficult, though, because very few people are aware that they even exist.

B. The Plan

According to Senegalese environmentalist Baba Dioum, "In the end we will conserve only what we love. We will love only what we understand. We will understand only what we are taught."

Conservation of anchialine and marine caves depends upon public understanding, which can only be built through effective public education. Your assignment is to create a public education presentation that will explain:

- What anchialine and marine caves are;
- Why anchialine and marine caves are important, and what lives there;
- How anchialine and marine caves are threatened; and
- What precautions must be taken when entering anchialine and marine caves to protect their unique ecosystems.

Actions that should be taken to protect specific caves depend upon local circumstances, so the goal of your presentation is to convince your audience that anchialine and marine caves are important and should be protected, rather than asking them to take individual action. Your teacher will provide additional information about the type of presentation that your group should create.

C. Getting the Facts

You should have a copy of a technical review paper by Thomas Iliffe and Louis Kornicker titled, *Worldwide Diving Discoveries of Living Fossil Animals from the Depths of Anchialine and Marine Caves*. Technical review papers are a great way to learn a lot about a scientific subject. Often, there are some key ideas or words that are unfamiliar, but a little internet research will usually make their meanings clear. Technical review papers are different from research reports, because they do not have to include specific details about research methods or the results of experiments. Instead, technical review papers summarize what has been learned from many investigations. Usually, technical review papers include a long list of references that provide details about individual investigations that are summarized in the review.

The paper by Iliffe and Kornicker begins with an Introduction that defines anchialine and marine caves, explains why these caves are significant, discusses why cave-dwelling organisms need special adaptations, and describes how scientists study these caves. The rest of the paper is divided into sections that summarize what is known about

- Geology and geography of anchialine caves;
- Anchialine cave ecology;
- Biological organisms found in anchialine caves;
- Biogeography of these organisms;
- Where these organisms came from;
- Adaptations to cave life; and
- Conservation issues.

The last section is the long list of references that provided the information for the paper. This technical review paper contains most (maybe all) of the information your group will need to complete your assignment.