

Bermuda Deepwater Caves:
Dive of Discovery

Stygabites to Shakespeare



Image captions/credits on Page 2.

lesson plan

Focus

Anchialine caves of Bermuda

Grade Level

9-12 (Earth Science, English/Language Arts [Literature])

Focus Question

What are anchialine caves, why are they important, and what is their connection to Shakespeare's *The Tempest*?

Learning Objectives

- Students will describe anchialine caves.
- Students will explain the relationship between anchialine caves of Bermuda, the wrecking of the merchant ship *Sea Venture*, and Shakespeare's *The Tempest*.
- Students will use the historic relationship defined above in a presentation to promote conservation of Bermuda's anchialine caves.

Materials

- Copies of *Stygobites to Shakespeare Worksheet*, 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
The Tempest
Conservation



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

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.
- 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

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 known 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>

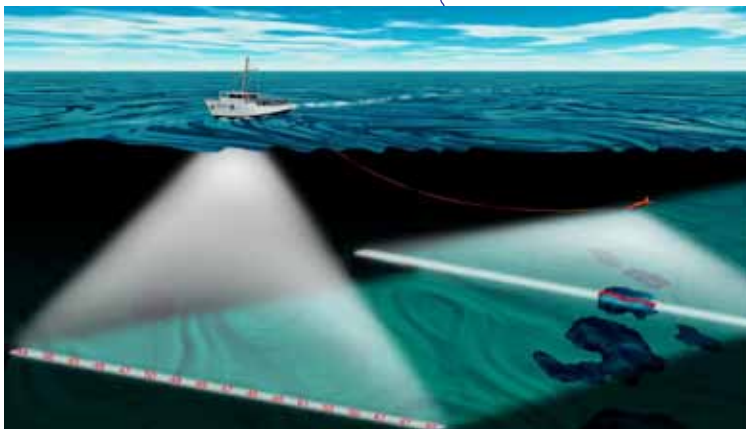


Dr. Rikk Kvitek and graduate student Krystle Gomez prepare the ROV for deployment in the waters off the Bermuda Platform. Image Courtesy of Bermuda: Search for Deepwater Caves 2009 Expedition.

http://oceanexplorer.noaa.gov/explorations/09bermuda/logs/summary/media/bc_msp1_01.html

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.



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

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. 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>.

The existence of extensive caves on Bermuda has been known for hundreds of years. In fact, these caves may have inspired the setting for Shakespeare's *The Tempest*, following the wrecking of the English sailing ship *Sea Venture* on Bermuda in 1609. Anchialine caves contain abundant and diverse endemic fauna (endemic means that these organisms are not found anywhere else), and more than 400 new species have been found in anchialine caves. Unfortunately,

Iliffe and Kornicker (2009) report that human activities are having serious impacts on many anchialine and marine cave 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.

Communication is an essential component of scientific practice; a scientist’s results, analyses, and insights are meaningless unless they are effectively communicated to others. Today, it is increasingly important for this communication to include a larger audience than scientists alone, and new forms of communication are needed.

In this activity, students explore the relationship between anchialine caves of Bermuda, the merchant ship *Sea Venture*, and Shakespeare’s *The Tempest*; and use this relationship to communicate the need for conservation of anchialine 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) Review the *Stygobites to Shakespeare Worksheet*, and decide whether students’ assignment for Part II will include actually producing their planned presentation. Student interest and learning are likely to be enhanced if their planned presentation becomes reality, but this decision depends upon available time and instructional objectives.
- (c) Decide how students will become acquainted with content of *The Tempest*. If possible, this may be coordinated as a cross-curricular activity with English/Language Arts instruction. Alternatively, the play may be assigned as homework reading.

2. Briefly introduce the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition. 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. Tell them that very little is known about deepwater marine caves, and discuss why scientists might want to find and explore these caves. Emphasize that more than 400 new species have been found in anchialine caves, and that human activities are “either destroying or grossly polluting numerous caves, resulting in extinction of untold numbers of species.”

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

3. Informally review the characters, setting, and story for *The Tempest*.
4. Briefly discuss the importance of communication in science, and why it is important for this communication to include other audiences in addition to scientists. Tell students that their assignment is to:
 - Learn more about anchialine caves;
 - Discover how Bermuda's anchialine caves are related to Shakespeare's *The Tempest*; and
 - Use this knowledge to design a creative way to communicate the need for conservation of Bermuda's anchialine caves.

You may want to point out that the central character in *The Tempest* (Prospero) is a magician who produces illusions and conspires with spirits to accomplish his purposes; so there is a lot of room for creativity!

5. Provide each student group with a copy of the *Stygobites to Shakespeare Worksheet*. Review the following terms (or have students find definitions):
 - 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
6. Lead a discussion of students' answers to questions on the *Worksheet*. The following points should be included:
 - Caves may be formed by:
 - Flowing lava (volcanic tube caves);
 - Acidic water flowing over limestone (solutional caves);
 - Wave erosion of coastal cliffs (sea caves); and
 - Erosion of rocks and ice by water- and wind-borne particles (erosional and glacier caves)
 - Bermuda has an unusually large number of caves because the island is composed of limestone lying on top of a volcanic

seamount, and limestone is easily dissolved by acidic rainwater to form caves.

- A speleothem is a mineral deposit formed in a cave.
- A stalactite is an icicle-shaped formation that hangs from the ceiling of a cave and is produced by precipitation of minerals from water dripping through the cave ceiling. Most stalactites have pointed tips.
- A stalagmite is an upward-growing mound of mineral deposits that have precipitated from water dripping onto the floor of a cave. Most stalagmites have rounded or flattened tips.
- Splattermite is an informal name for a type of stalagmite that has plate-shaped upright protrusions that arc around a central axis. The formation is the result of drops that splash off of a stalagmite’s growing tip. Splattermites only form where conditions are favorable for rapid deposition of calcite.
- A coralloid is a mineral formation shaped like knobs, globs, buttons, corals, or bunches of grapes.
- A conulite is a “splash cup” that forms when water dripping rapidly through the cave ceiling flings aside loose particles on the cave floor.
- Boxwork is a network of thin blade-shaped mineral deposits protruding from the walls, ceiling, or floor of a cave.
- A helictite is a twisted filament-shaped mineral deposit formed when water seeps through tiny pores in the rock ceiling, walls, or floor of a cave. Helictites may resemble tiny threads or may be as large as deer antlers.
- Anchialine and marine caves are important because they contain large numbers of new species and species that are not found anywhere else. The role of these species in other ecosystems and their potential importance to humans are not presently known.
- Anchialine and marine caves are threatened by human activities that include water pollution, waste disposal, limestone quarrying, and tourism development. The literary connection to *The Tempest* has been used to advertise some caves in Bermuda for tourist activities.
- The English sailing vessel *Sea Venture* was wrecked during a hurricane on Bermuda on July 24, 1609, during a voyage

that was intended to provide supplies to the settlement at Jamestown, Virginia. All of the people aboard *Sea Venture* survived the wreck, and were stranded on Bermuda for about nine months while new ships were constructed. Most of them eventually arrived in Jamestown on May 23, 6010. The story of the wreck and the events that followed were told two months later in a letter by William Strachey. Strachey was critical of management of the Jamestown colony, so his letter was suppressed by the Virginia Company in England and was not published until 1625. Even so, news of the wreck and experiences while on Bermuda almost certainly reached the public, and possibly William Shakespeare. Strachey’s description of the hurricane is similar in many ways to Shakespeare’s description of the tempest at the beginning of the play.

- Prospero’s “cell” (generally understood to mean “cave”) is the setting for Act 1, Scene II; Act 3, Scene I; Act 4, Scene I; and Act 5, Scene I.

7. Have each student group explain their planned presentation, or if circumstances permit, present their creation to the rest of the class and/or to a larger audience. Dramatic devices used in *The Tempest* such as magic, odd characters (Caliban), and storms may provide inspiration for innovative approaches to presenting information. If presentations are made to audiences other than the students’ class, evaluations may include assessments of what audiences learned as a result of the presentations.

The BRIDGE Connection

www.vims.edu/bridge/ - In the “Site Navigation” menu on the left, scroll over “Ocean Science Topics,” then click “Atmosphere” for links to resources about storms.

The “Me” Connection

Have students write a brief essay discussing how science and literature are (or could be) connected.

Connections to Other Subjects

Life Science, Fine Arts

Assessment

Presentation plans and class discussions provide opportunities for assessment.

Extensions

1. Visit <http://oceanexplorer.noaa.gov/explorations/11bermuda/welcome.html> for more about the Bermuda Deepwater Caves 2011: Dive of Discovery Expedition.
2. See <http://www.astrocappella.com/doppler.shtml> for a musical explanation of the Doppler effect in astronomy, and a great example of using fine arts to explain science!

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

Now Take a Deep Breath

(14 pages, 548 Kb) (from the Submerged New World 2009 Expedition)

<http://oceanexplorer.noaa.gov/explorations/09newworld/background/edu/media/breath.pdf>

Focus: Physics and physiology of SCUBA diving (Physical Science/Life Science)

Students define Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures, and explain their relevance to SCUBA diving; discuss the causes of air embolism, decompression sickness, nitrogen narcosis, and oxygen toxicity in SCUBA divers; and explain the advantages of gas mixtures such as Nitrox and Trimix and closed-circuit rebreather systems.

My Wet Robot (300kb)

(9 pages, 300 Kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

<http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf>

Focus: Underwater robotic vehicles (Earth Science)

Students discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

No Escape

(12 pages, 1Mb) (from the 2006 Exploring Ancient Coral Gardens Expedition)

<http://oceanexplorer.noaa.gov/explorations/06davidson/background/edu/escape.pdf>

Focus: Fate of benthic invertebrate larvae in the vicinity of seamounts (Earth Science)

Students use field data to evaluate an hypothesis about the influence of a water circulation cell on the retention of benthic invertebrate larvae in the vicinity of a seamount, and describe some potential advantages and disadvantages to species whose larvae are retained in the vicinity of seamounts where the larvae are produced. Students will also describe the consequences of partial or total larval retention on the biological evolution of species producing these larvae.

Round and Round

(11 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf

Focus: Circulation cells in the vicinity of seamounts (Earth Science)

Students interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation, hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae, and describe the importance of measurements to verify theoretical predictions.

Living in Extreme Environments

(12 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_extremeenv.pdf

Focus: Biological Sampling Methods (Biological Science)

Students understand the use of four methods commonly used by scientists to sample populations; understand how to gather, record, and analyze data from a scientific investigation; begin to think about what organisms need in order to survive; and understand the concept of interdependence of organisms.

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

<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 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>

Strachey, W. 1610. A true reportory of the wracke, and redemption of Sir Thomas Gates Knight; vpon, and from the Islands of the Bermudas: his comming to Virginia, and the estate of that Colonie then, and after, vnder the gouernment of the Lord La Warre, Iuly 15. 1610; letter to an unnamed English lady about the wreck of the *Sea Venture* and subsequent events on Bermuda and in Jamestown; available online at Virtual Jamestown (http://www.virtualjamestown.org/fhaccounts_date.html) in original- and modern-spelling versions

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard D: Earth and Space Science

- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality

Content Standard G: History and Nature of Science

- Historical perspectives

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.

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 b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

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

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to:

oceaneducation@noaa.gov.

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Stygobites to Shakespeare Worksheet

Part I – Research

1. What are four ways that caves can be formed?
2. Why does Bermuda have an unusually large number of caves?
3. Describe the following features found in solutional caves:
 - Speleothem
 - Stalactite
 - Stalagmite
 - Splattermite
 - Coralloid
 - Conulite
 - Boxwork
 - Helictite
4. Why are anchialine and marine caves important?
5. How are anchialine and marine caves threatened by human activities?
6. The Literary Connection—Some scholars think that Bermuda’s caves inspired the setting for Shakespeare’s *The Tempest*.

What historic evidence supports this idea? (Hint: What is the *Sea Venture*?)

How many scenes in *The Tempest* are set in or near a cave? (Hint: The word “cell” is generally believed to mean a cave)

Part II – Communication

Design a presentation for an audience of non-scientists that communicates the need for conservation of Bermuda’s anchialine and marine caves using characters, settings, and/or dramatic events from *The Tempest*. This presentation should include important technical facts about caves from your research, but can also include fictional characters and events to create an entertaining story. Your teacher will tell you if you are expected to actually produce the presentation, or whether your assignment is only to provide a plan for the presentation.