Bermuda: Search for Deep Water Caves 2009

Out of Darkness

Image captions/credits on Page 2.

lesson plan

Focus
Evolution of anchialine cave fauna

Grade Level
9-12 (Life Science)

Focus Question
What evolutionary processes may explain the occurrence of animals in marine caves?

Learning Objectives
- Students will be able to describe anchialine cave habitats.
- Students will be able to discuss ways in which anchialine caves fauna are unusual.
- Students will be able to compare and contrast four biogeographical models to explain observed distribution patterns of anchialine cave fauna.

Materials
- Copies of *Evolution in Anchialine Caves Inquiry Guide,* one for each student

Audio-Visual Materials
- (Optional) Computer projector or other equipment for showing images of underwater caves

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of 3-4 students

Maximum Number of Students
32

Key Words
Anchialine cave
Evolution
Biogeography

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 in 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. Volcanic caves are formed when the surface of flowing volcanic lava cools and hardens, while molten lava continue to flow underneath. If the molten lava continues to flow away from the hardened surface, a hollow tube will be formed that becomes a lava tube cave.

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 locations. (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 crustacean species found in caves on opposite sides of the Atlantic Ocean and species in Australian anchialine caves that are also found Atlantic and Caribbean caves.
- Geographic distribution of some species suggests a possible connection with mid-ocean ridges. For example, shrimps belonging to the genus *Procaris* 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.

Images from Page 1 top to bottom:
Water in inland tidal cave pools in Bermuda is brackish at the surface, but reaches fully marine salinity by a depth of several meters. Image credit: NOAA, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/bermudaorigin/media/bermudaorigin_5.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 credit: NOAA, Bermuda: Search for Deep Water 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 credit: Tom Iliffe, NOAA, Bermuda: Search for Deep Water Caves 2009.
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/plan/media/spelaeoecia.html

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

- 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 they are karst landscapes, the islands of Bermuda have 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.

In this activity, students will investigate evolutionary processes that may explain the occurrence of animals in marine caves.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the Bermuda: Search for Deep Water Caves 2009 expedition at http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html. You may also want to visit http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html for images and discussions of various types of ROVs used in ocean exploration. If you want to explain multibeam sonar, you may also want to review information and images at http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html.
   (b) Download a few images of anchialine caves from http://www.tamug.edu/cavebiology/index2.html.
   (c) Review the *Evolution in Anchialine Caves Inquiry Guide*.
   (d) Decide whether you want to have students work individually or in groups. Groups are preferred, since students may divide the task of explaining technical terms and help each other with analyzing and making inferences from the technical reading.

2. Briefly introduce the Bermuda: Search for Deep Water Caves 2009 expedition, and show some images of anchialine caves. Emphasize 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 (do not use the term "relict" at this point). Point out that very little is known about deep water marine caves, and discuss why scientists might want to find and explore these caves.

3. Provide each student with a copy of the *Evolution in Anchialine Caves Inquiry Guide*. You may need to review the concept of species diversity mentioned in Part E.

   The simplest measure of species diversity is the number of species present in an environment. This is called species richness. But there is more to diversity than just the number of species in an environment. A community that has more or less equal numbers of individuals within the species present is usually thought of as more diverse than a community that is dominated by one species. For example, samples from two separate communities might each contain the same seven species, with distribution of individuals as follows:

Species	**Number of Individuals**	
	Community 1	Community 2
Species a	43	7
Species b	1	7
Species c	1	7
Species d	1	7
Species e	1	7
Species f	1	7
Species g	1	7
Total	**49**	**49**

   Our notion of what diversity means leads us to consider Community 2 as more diverse than Community 1, even though they both have the same number of species and total individuals.

4. Have students answer questions on the Inquiry Guide. In addition to these questions, you may also want to have them find illustrations of organisms listed in Part B. Lead a discussion of students' results. The following points should be included:

   - A species is said to be endemic to a particular location when that species is not found anywhere else.

   - Remipedia is a class of blind crustaceans found in solutional caves that contain brackish water, and have been found in Central America, the Caribbean, the Canary Islands, and western Australia.

- Cavernicolous organisms are those that inhabit caves.
- Troglobitic organisms are adapted to living in caves and cannot survive outside of the cave environment.
- A cavernicole is a organism that inhabits caves.
- A nematode is a roundworm belonging to the phylum Nematoda.
- A polychaete is a worm belonging to the phylum Annelida and the class Polychaeta, and has a pair of fleshy, bristle-covered protrusions called parapodia on each segment.
- A copepod is a small crustacean that includes planktonic as well as benthic species.
- A mysid is a small shrimp-like crustacean.
- A thermosbaenacean is a crustacean belonging to the family Thermosbaenacea, which are found in caves, aquifers, and hot springs.
- An isopod is a crustacean belonging to the order Isopoda, which includes marine and fresh water species as well as terrestrial species known as woodlice.
- An amphipod is a crustacean belonging to the order Amphipoda, which are mostly marine species though there are a few fresh water and terrestrial species as well.
- A relict species is a species that has survived while other related species have become extinct.
- An anchialine cave is a partially or totally submerged caves near the sea, and often contains freshwater and/or brackish water in addition to seawater.
- Salinity stratification occurs when water masses containing different concentrations of dissolved salts form distinct layers in a water column, with the higher salinity masses (which have the highest density) beneath those having lower salinity.
- Solutional caves are formed when a solution dissolves part of the materials that make up a landscape. Typical solutional caves are formed in landscapes that are formed primarily by limestone when acidic rainwater dissolves portions of limestone rock.
- Volcanic caves are formed when the surface of flowing volcanic lava cools and hardens, while molten lava continue to flow

underneath. If the molten lava continues to flow away from the hardened surface, a hollow tube will be formed that becomes a lava tube cave.

- The Dispersal Model cannot fully explain the origins of troglobitic fauna because troglobitic organims by definition cannot survive outside of the cave environment, and therefore could not be dispersed over or through the open sea.

- The Vicariance Model cannot fully explain the origins of troglobitic fauna because Bermuda, with a large number of endemic anchialine cave species, was never part of a continental land mass.

- The Regression Model cannot fully explain the origins of troglobitic fauna because sea levels around Bermuda have never been more than a few meters above present levels, so it is unlikely that the ancestors of cave species there were stranded.

- The open sea entrance zone would be expected to have a variety of organisms similar to those found outside the cave entrance. Encrusting organisms such as sponges, bryozoans, and hydroids are usually abundant.

- The middle zone would be expected to have some species found in the entrance zone that are able to survive in cave conditions (such as low light and less available food), as well as some species that are adapted in various ways to the cave habitat.

- Species in the far interior zone must be highly adapted to cave conditions, and many would not be able to live anywhere else (so they are troglobites). Less food is available in this zone and it is usually completely dark, so animals must be highly specialized for finding and capturing food without eyesight.

- The greatest diversity of species would be expected in the entrance zone, because conditions there are most similar to the open sea which has a wide variety of species. Diversity would be expected to be lowest in the far interior zone, because survival in this zone depends upon specialized adaptations that are not found in most species.

- The greatest abundance of food would be expected in the open sea entrance zone, since conditions in this zone are favorable to more organisms than conditions in the other two zones.

- Food availability in the far interior zone of solutional caves would increase dramatically if sunlight were able to penetrate into the cave environment, allowing algae and other plant material to grow. This might happen if the roof of a cave collapsed, as often occurs in solutional caves, forming a sinkhole.

- The first step in the evolution of a cave dwelling organism adapted to freshwater would be the arrival of a species in the entrance zone that had characteristics compatible with conditions in this zone (such as the ability to live under conditions of low light). Next, the species might extend its range farther into the cave, taking advantage of stable conditions and less competition from organisms that cannot tolerate the cave habitat. Members of the species living deepest within the cave would interbreed less and less with members of the species living closer to the entrance, eventually becoming genetically isolated. At the same time, conditions inside the cave would favor individuals who, through chance mutation, developed various adaptations to these conditions, such as the ability to acquire food with little or no light, tolerance to low oxygen conditions (which occur because of reduced water circulation), or tolerance to brackish water which would allow these individuals to expand their range into the interior of the cave. Individuals that acquired the ability to tolerate fresh water conditions would be able to take advantage of increased food resources in anchialine pools exposed to sunlight.

- The species in Question E.e could return to the open sea in the early stages of the adaptive process, when they had acquired some adaptations for cave habitats, but still retained characteristics needed for survival in the open sea. But eventually a point of no return would be reached after which the species could only exist as a true troglobite.

The BRIDGE Connection

www.vims.edu/bridge/ – Type “evolution” in the Search box for links to resources and activities involving evolution in marine organisms.

The “Me” Connection

Have students write a brief essay describing ways in which they are adapted to their own environment, and what other adaptations might give them a survival advantage over other humans.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/09bermuda/welcome.html for more about the Bermuda: Search for Deep Water Caves 2009 expedition.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(The following Lesson Plans are targeted toward grades 9-12 unless otherwise noted)

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)

In this activity, students will be able to 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 be able to describe the consequences of partial or total larval retention on the biological evolution of species producing these larvae.

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/09bermuda/welcome.html – Web site for the for the Bermuda: Search for Deep Water 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. 1986. The zonation model for the evolution of aquatic faunas in anchialine caves. Stygologia 2:2-9.

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

- Biological evolution

Content Standard D: Earth and Space Science

- Geochemical cycles

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.

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Please send your comments to:
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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Layout and design by 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/

Out of Darkness
Evolution in Anchialine Caves Inquiry Guide

A. Technical Reading

Recent biological investigations of marine caves have revealed the presence of an unexpected variety of endemic species including relict organisms such as the Remipedia, a new class of Crustacea. Several puzzling inconsistencies have turned up as a result of these discoveries:

- Cavernicolous species from some caves appear to be much older than the caves they inhabit.
- Some troglobitic species inhabit isolated but widely separated caves. Remipedia., for example, has species on both sides of the Atlantic, as well as on oceanic islands such as Bermuda which has never been part of continental land masses.
- Fresh water cavernicoles including many nematodes, polychaetes, copepods, mysids, thermosbaenaceans, isopods, and amphipods are marine relicts.

Anchialine caves have several characteristics in common. First, they occur primarily on islands. Second, waters of marine caves are tidal, with salinities of deeper waters nearly the same as those of the open sea. Third, inland cave waters are more or less isolated from the sea, have little tidal exchange, and show salinity stratification in the water column. Fourth, organisms living in these caves are distributed in distinct zones: the open sea entrance zone, a middle zone, and a far interior zone.

Three biogeographical models have been proposed to explain the observed distribution pattern of flora and fauna of islands in the Caribbean region. The Dispersal Model states that change dispersal over or through the sea produced present-day flora and fauna. The Vicariance Model states that the distribution of flora and fauna is the result of plate tectonics. The Regression Model states that species that inhabit fresh water and brackish water habitats are descended from marine species that were stranded by falling sea level and subsequently adapted to fresh water and brackish water conditions.

Each of these models has certain drawbacks in explaining the origins of troglobitic fauna.

~ Adapted from Iliffe, 1986

B. Understand

Explain the following words:

Endemic	**Nematode**	**Isopod**
Remipedia	**Polychaete**	**Amphipod**
Cavernicolous	**Copepod**	**Relict**
Troglobitic	**Mysid**	**Anchialine cave**
Cavernicole	**Thermosbaenacean**	**Salinity Stratification**

Out of Darkness

Evolution in Anchialine Caves Inquiry Guide – 2

C. Research

1. How are solutional caves formed?

2. How are volcanic caves formed?

D. Analyze

In the last sentence, the author implies that each of the three models doesn't fully explain the origins of troglobitic fauna. Based on the information in the reading, what drawbacks do you see for these models? [Hint: Sea level around Bermuda has never been more than a few meters above present levels.]

Dispersal Model
Vicariance Model
Regression Model

E. Infer

Since the Dispersal, Vicariance, and Regression Models are all inadequate for explaining the origins of troglobitic fauna, the author proposes a fourth model which he calls the Zonation Model. This model is based on the distinct zonation patterns seen in marine caves.

a. What kinds of animals would you expect to find in each of the three zones described in the second paragraph?

b. In which zone would you expect the greatest diversity of species? Which zone would you expect to have the lowest diversity of species? Why?

c. Which zone would have the greatest abundance of food?

d. What might happen to alter the availability of food in the far interior zone of solutional caves?

e. Considering three zones, describe the steps that might take place when a marine species settles in a deepwater cave and gradually becomes adapted to live in freshwater.

f. At what point might the species in Question e. return to the open sea and migrate to another cave?