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Bermuda: Search for Deep Water Caves 2009

Living Fossils

Image captions/credits on Page 2.

lesson plan

Focus
Relict species

Grade Level
9-12 (Life Science)

Focus Question
Why are relict species associated with anchialine caves?

Learning Objectives
- Students will be able to define relict species.
- Students will be able to identify and describe at least three examples of relict species associated with anchialine caves.
- Students will be able to discuss why anchialine caves may have unusually high proportions of relict and endemic species.
- Students will be able to explain the importance of preserving anchialine caves and species, and discuss ways in which they are threatened by human activity.
- Students will be able to extract specific information from excerpts of technical journal articles.

Materials
- ❑ Copies of *Relict Species 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
Relict species
Conservation

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

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

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 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 the relationships between anchialine caves and relict species, as well as ways in which these resources are threatened by human activity.

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 *Relict Species Inquiry Guide*.

2. Briefly introduce the Bermuda: Search for Deep Water Caves 2009 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. Explain 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 *Relict Species Inquiry Guide* and explain that their assignment is to extract specific information from excerpts of technical journal articles. In addition to the questions included in the *Inquiry Guide*, you may also want to have students briefly describe the various taxa mentioned in the background readings.

4. Lead a discussion of students' results for Part I of the *Inquiry Guide*. The following points should be included:

- Anchialine refers to partially or totally submerged caves near the sea, and that often contain freshwater and/or brackish water in addition to seawater.

- A relict species is a species that has survived while other related species have become extinct.

- Stygobite refers to an organism that is adapted to living in caves and cannot survive outside of the cave environment.

- The distribution of anchialine fauna of Western Australia is considered "highly anomalous" because it appears to be closely related to organisms in caves thousands of miles away.

- By definition, stygobites cannot live outside of caves and would not be able to survive long distance migrations through the open ocean. For this reason they are considered to have "poor long distance dispersal."

- The widely separated caves referred to in Question 4 were much closer together when present-day continents were joined together in the supercontinent Pangaea. The continents separated and moved to their present positions as a result of plate tectonics, but caves that are now widely separated could have been colonized by the same organisms before this separation occurred.

- Troglobitic refers to organisms that are adapted to living in caves and cannot survive outside of the cave environment. Troglobitic

is sometimes used to refer only to terrestrial organisms, in which case stygobitic is used to refer to aquatic organisms.

- A species is said to be endemic to a particular location when that species is not found anywhere else.
- Crevicular refers to cracks in seafloor rock called crevicular habitats.
- Hypogean means located beneath Earth's surface.
- Species in anchialine habitats in the Canary Islands could have affinities with cave fauna on the other side of the Atlantic Ocean through the mechanism of plate tectonics described above.
- Species from the deep sea could have entered a marine lava tube near the surface of Lanzarote Island via cracks in seafloor rock connected to cracks in the volcanic rock underlying Lanzarote Island; in other words, via crevicular habitats.
- Anchialine caves act as preserving centers for relict species because they are highly stable over very long periods, and may connect with other habitats (e.g., in deep water below the influence of sea level changes) that are also very stable.

5. Discuss threats to anchialine habitats and species described in Part II of the *Inquiry Guide*. The situation of anchialine caves is similar to that of many ocean habitats: out of sight, out of mind, but severely threatened by human activity. Public understanding and support are essential to reducing or eliminating these threats, and this requires effective communication from scientists and others who understand the issue. Brainstorm approaches to communication that students think would be most effective. You may also want to explore ways in which students could have a direct impact on this problem, either as individuals or as a group.

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 why they should be personally concerned and involved with protecting anchialine species and habitats.

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.

2. Have students use scientific posters, multimedia software, or other communication devices to create persuasive presentations designed to convince key audiences about the importance of conserving anchialine habitats and species.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

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; describe some potential advantages and disadvantages to species whose larvae are retained in the vicinity of seamounts where the larvae are produced; and 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 – 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

Kornicker, L., T. M. Iliffe, and E. Harrison-Nelson. 2007. Ostracoda (Myodocopa) from Anchialine Caves and Ocean Blue Holes. Zootaxa 1565. Magnolia Press. Auckland, New Zealand; available online at http://www.mapress.com/zootaxa/2007f/zt01565p151.pdf

Wilkens, H., J. Parzefall, and T. M. Iliffe. 1986. Origin and Age of the Marine Stygofauna of Lanzarote, Canary Islands. Mitt. hamb. zool. Mus. Inst. 83: 223-230; available online at http://www.tamug.edu/cavebiology/reprints/Reprint-39.pdf

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

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

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

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

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

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 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

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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Living Fossils
Relict Species Inquiry Guide

Part I. Relict Species

Background Reading

A.

Many anchialine taxa are relict, long term survivors of ancient lineages, which have inhabited caves for hundreds of thousands, if not millions of years. For example, great age is implied by the biogeographic distribution of the anchialine fauna of Western Australia including the remipede *Lasionectes*, the thermosbaenacean *Halosbaena*, the ostracod *Danielopolina* and the misophrioid copepod *Speleophria* that are otherwise known primarily from caves on opposite sides of the Atlantic. This highly anomalous distribution, coupled with the poor long distance dispersal of stygobites and the tectonic history of Earth, suggests that these species may have initially colonized caves along the margins of the Tethys Sea prior to the breakup of Pangea some 180 million years B.P. and were subsequently dispersed by plate tectonics. Remipedes, with fossil relatives from the Carboniferous Period, are considered to be among the most primitive of living crustaceans; their highly segmented bodies resemble the polychaete worms from which crustaceans are thought to have evolved. The copepod *Antrisocopia prehensilis* from Bermuda caves resembles in many ways the theoretical ancestral copepod. *Erebonectes nesioticu*, also from Bermuda caves, is considered one of the most primitive copeods. The presence of numerous primitive and apparently ancient taxa in anchialine caves attests to the great age and long term stability of this habitat. Thus, anchialine caves act as preserving centers for relict taxa, known from nowhere else on Earth.

Paradoxically, many of the caves that are today inhabited by anchialine fauna are geologically quite young. The Monte Corona lava cave on Lanzarote in the Canary Islands is only 2,000 to 3,000 years old, yet is inhabited by a rich anchialine fauna including species that are among the most primitive organisms in their taxonomic groups. Likewise, the limestone caves in Bermuda are no more than one to two million years old, but its caves are inhabited by a diverse group of anchialine taxa that are much older.

~ adapted from Kornicker *et al.*, 2007

B.

Five species of troglobitic crustaceans, previously known only from the Jameos del Agua marine lava tube in Lanzarote, Canary Islands, have been collected from wells in other, geologically older areas of the island. Most, and possibly all, of the endemic species inhabiting the Jameos del Agua probably entered the cave from adjacent crevicular groundwater habitats. The endemic hypogean fauna of Lanzarote can be divided into 2 groups: (1) relict species with affinities to the cave fauna of other oceanic, primarily Western Atlantic, islands and (2) species with close relatives from the deep sea. The origin of the first group can be correlated to Mesozoic plate tectonics. The species of the second group are probably derived from widely spread deep sea ancestors and may have colonized the crevicular system of Lanzarote at different times.

Living Fossils
Relict Species Inquiry Guide – 2

~ adapted from Wilkens, *et al.*, 1986

Research, Analyze, and Infer

1. What does anchialine mean?

2. What is a relict species?

3. What is a stygobite?

4. Why do the authors of Article A say that the distribution of anchialine fauna of Western Australia is "highly anomalous?"

5. Why do stygobites have "poor long distance dispersal?"

6. How does plate tectonics explain the "highly anomalous distribution" mentioned in Question 4?

7. What does troglobitic mean?

8. What does endemic mean?

9. What does crevicular mean?

10. What does hypogean mean?

11. The authors of Article B refer to "relict species with affinities to the cave fauna of other oceanic, primarily Western Atlantic, islands." The Canary Islands are in the Eastern Atlantic, so how could species there have affinities with cave fauna on the other side of the Atlantic Ocean?

12. How could species from the deep sea have entered a marine lava tube near the surface of Lanzarote Island?

13. Why do anchialine caves act as preserving centers for relict species?

Part II. Endangered Species

Unfortunately, many of these unique and fascinating animals are threatened with extinction due to the actions of man. In Bermuda alone, 25 species of cave animals are internationally recognized as "critically endangered" (IUCN 2006). This is the highest level of threat and roughly equates to a 50% chance of the species going extinct within the next decade if nothing is done. All too frequently, anchialine cave animals can be considered endangered since 1) they have very limited distributions, commonly being known only from a single cave, and 2) environmental conditions in these caves are often deteriorating through the effects of water pollution or cave destruction.

Living Fossils
Relict Species Inquiry Guide – 3

Threats to caves include sewage and waste disposal, deep well injection, quarrying and construction activities, as well as diver and other human disturbances (Iliffe 1979). As an example, the small oceanic island of Bermuda is the third most densely populated country in the world and has the largest number of private cesspits per capita. Disposal of sewage and other waste water into cesspits or by pumping down boreholes is contaminating the ground and cave water with nitrates, detergents, toxic metals and pharmaceuticals; depleting the very limited amounts of dissolved oxygen in cave water; and generating toxic levels of hydrogen sulfide (Iliffe et al. 1984). Some ocean caves such as the Blue Holes of the Bahamas have strong tidal currents sweeping through them for very considerable distances. In one such cave, plastic bottles and other trash have been observed littering the floor of the cave nearly a mile back into virgin passage. Far too many caves and sinkholes are viewed as preferred locations for the dumping of garbage and other waste products.

Another serious environmental problem concerns the destruction of caves by limestone quarries or construction activities. At least half a dozen or more caves have been totally destroyed by Bermuda limestone quarries which produced crushed aggregate for construction purposes. Untold other caves have been lost to enormous limestone mines in the Yucatan Peninsula. Many caves have been filled and built over by golf courses, hotels and housing developments in Bermuda. Recently, a series of luxury town homes were built directly on top of the largest cave lake in Bermuda.

Sometimes seemingly innocent activities can threaten caves and cave animals. Along the Caribbean coast of the Yucatan Peninsula, many open water cenote pools are inhabited by several species of freshwater fishes. One of these fish, *Astyanax mexicanus* (De Filippi 1853), has learned to follow divers into caves, moving in front of the dive team and voraciously darting in to devour any crustaceans that chance to stray into the beam of a dive light. Considering the many hundreds to thousands of cave divers who use these systems each year, it is not surprising that the caves most heavily visited by tourist divers are now essentially devoid of life.

Even the gas exhaled by divers may have untold and unknown effects on cave animals. Since anchialine cave waters typically contain extremely low levels of dissolved oxygen in the micrograms per liter range, the oxygen in exhaust bubbles from open circuit scuba divers could have profound effects on the cave ecosystem (Humphreys *et al.* 1999). Several anchialine caves in Western Australia with unique fauna are currently off limits to open circuit divers and may only be visited by those using closed-circuit rebreathers.

Living Fossils

Relict Species Inquiry Guide - 4

Some anchialine caves in Bermuda, the Canary Islands and Mallorca have been developed into commercial tourist attractions. Unfortunately, many of the tourists visiting these sites have viewed the deep clear water cave pools as natural wishing wells in which to throw a coin or two. Copper coins tend to rapidly deteriorate and dissolve in salt water, producing high levels of toxic copper ions in the cave waters. In one such cave in Lanzarote, an endemic, cave-adapted galatheid crab, *Munidopsis polymorpha* Koelbel 1892, is showing a marked decline in abundance over the last ten years or more, possibly in response to high levels of copper in the cave water.

Our knowledge of the biology and ecology of anchialine caves is still in its infancy. Possibly hundreds to thousands of new anchialine taxa await discovery. In the Yucatan Peninsula, more than 5,000 caves have been catalogued, but only about 1–2% of these have been surveyed biologically. A similar situation exists in the Bahamas and in numerous other locations around the world where many hundreds of caves remain unexplored. Furthermore, almost nothing is known about the nutritional requirements, life history, reproduction, behavior, physiology, dispersal abilities, etc. of most anchialine species. Considering the unprecedented number of new higher taxa already discovered in anchialine caves, their highly anomalous distribution, and their affinities to deep sea fauna, new hypotheses on the evolution and dispersal of life in the ocean are likely to be forthcoming. However, if these potentially endangered habitats and the unique animals within them are to survive, it is critical that we all strive to promote an awareness and appreciation of their worth among the general public and especially government officials and resource managers. To this end, we have created a Web site on this subject at www.cavebiology.com.

~ adapted from Iliffe and Bishop 2007