

# Bermuda's Caves: A Non-renewable Resource

by

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## INTRODUCTION

Caves, together with their often unique fauna and flora and delicate speleothems (defined as cave mineral deposits of a secondary nature, cf. Moore, 1952), constitute one of the rarest and most fragile environments on Earth. Even the largest caves known are small when compared with major scenic features on the surface of the land. The total volume of all the world's limestone caves is probably not much more than 10 cubic miles (42 cubic kilometres), which is less than one 10-millionth of the volume of the world ocean (Moore & Nicholas, 1964).

Considering the thousands of years required to form the delicate and beautiful speleothems, we all have an obligation to preserve them for future generations. The associated fauna and flora of caves have often evolved from species that colonized them tens or hundreds of thousands of years ago. These cave animals and plants are often severely restricted in their geographical distribution, sometimes being known only from a single location. Thus, destruction or significant alteration of the subterranean habitat can result in the extinction of entire species of cave inhabitants.

The caves of Bermuda provide a well-documented case-study of both the value of caves and the damage that can result from Man's abuse of this fragile environment. Bermuda is fortunate in having one of the highest concentrations of caves known in the world. Accounts of visits to these caves date back over 150 years and include descriptions by such eminent scientists as the Scottish naturalist Sir C. Wyville Thomson (1877), and the American naturalist and explorer A. Hyatt Verrill (1908). Bermuda's caves have been the site of many important geological and palaeontological investigations, while recently studies were begun on the biology and ecology of the island's caves. Unfortunately, a number of Bermuda caves have been damaged or destroyed through the action of Man. By examining in detail the history of Bermuda's caves and analyzing planned strategies of cave conservation, it is hoped that similar destruction of cave resources in other areas of the world can be prevented.

## GEOLOGICAL ORIGIN AND HISTORY

A discussion of Bermuda's caves must logically begin with a short introduction to the unique geology of this mid-ocean archipelago. The islands comprising Bermuda originated in a submarine volcanic eruption along the Mid-Atlantic Ridge about 110 million years ago (Reynolds & Aumento, 1974). As the volcano gradually cooled, the

sea began to erode the newly-formed land. A re-eruption of the volcano about 33 million years ago increased the size of the Bermuda 'seamount' by an estimated 35%, and probably caused its renewed emergence (*Ibid.*). The development of coral reefs around the margins of the volcanic platform led to the deposition of marine limestones and also provided a source of carbonate sand.

During the Pleistocene, changes in sea-level of up to 100 metres, associated with continental glaciation, alternately submerged and exposed much of Bermuda's land area (Sayles, 1931; Land *et al.*, 1967; Vacher, 1973). In periods of high sea-level, coastal sand-dunes formed along the shorelines. These dunes were 'solutionally' altered to form a soft eolianite limestone by the action of rain and circulating ground-water, which dissolved calcium carbonate and subsequently recrystallized it around sand-grains.

Just as these 'cemented' sand-dunes record interglacial high sea-levels, red-clay 'fossil' soils, formed principally from an accumulation of atmospheric dust (Bricker & Mackenzie, 1970) during low stands of sea-level, record periods of continental glaciation. Thus, the correlation of limestone stratigraphy with glacial-interglacial periods and changing sea-levels, makes Bermuda a scientifically invaluable 'tide gauge' of sea-level fluctuations during the Pleistocene (Land *et al.*, 1967). Since its formation, Bermuda's attachment to the North Atlantic Plate has resulted in a continued westward movement.

Several theories have been proposed concerning the origin of Bermuda's caves. In general, cave formation occurs when acidic ground-water, undersaturated with respect to calcium, dissolves surrounding limestone (calcium carbonate). Swinnerton (1929, 1932) believed that Bermuda's caves were formed above the water-table by downward-migrating rain-water along steeply dipping and intersecting joints. Davis (1930) classified Bermuda caves as 'one-cycle caverns in porous limestone', in contrast to most other caves which, he felt, were formed in two cycles: one cycle of solutional excavation occurred below the water-table, and another of depositional replenishment took place following lowering of the water-table when the cave above had become air-filled. Bretz (1960) interpreted the horizontal elongation of the caves as evidence for their formation beneath the water-table by horizontally circulating fresh ground-water, supplied and maintained by rain. According to Bretz, the large fresh ground-water body necessary for cave formation, could only have occurred in Bermuda during low stands of sea-level, when the islands' total land-mass was about 13 times as large as it is today.

Since limestone is not much dissolved by sea-water, as sea-water is normally saturated with calcium, the existence of cave extensions below current sea-level confirms that cave formation must have taken place when sea-levels were much lower and large bodies of fresh ground-water were present. As postglacial sea-levels rose, many of the caves were drowned in sea-water as it displaced the fresh water. Collapse of roof-rock and deposition of secondary 'dripstone' further contributed to the isolation of surviving chambers from what was once an extensive, integrated, cave system. Bretz (1960) believed that, as the fresh ground-water body has now virtually disappeared from the island, cave formation has ceased. Closely adjacent caves, with no traversable underground connections above sea-level, are thus probably remnants of one original cavern.

The currently most widely accepted theory of cave formation in Bermuda holds that the caves were formed, contemporaneously with the enclosing rock, by solution below the water-table during low stands of sea-level (Harmon, 1974; Palmer *et al.*, 1977; Mylroie, in press). Continued collapse of overlying rock into large solutional voids, created the irregular 'rooms' and fissure entrances that are commonly seen in Bermuda caves.

#### SPELEOTHEMS

Bermuda's caves are richly adorned with a variety of speleothems (see opening paragraph). Among the most notable of these are the stalactites and stalagmites. Stalactites are icicle-like deposits hanging from the cave's roof or walls, formed by the precipitation of calcium carbonate from supersaturated drip-waters. Water emerging from cracks in the cave ceiling hangs as drops before falling to the floor below. Deposition of calcite occurs where the surface of the drop intersects the ceiling and forms a ring with a diameter similar to that of the drop. This ring grows downwards, maintaining a constant diameter, as more material is deposited, thus creating the hollow tubular stalactites, locally called 'soda straws'. These soda straws may be up to 2 m or more in length, but their walls are less than half a millimeter thick. They are so fragile that they sometimes break from their own weight. Larger conical stalactites originated as soda straws in which the central canal has become plugged.

Stalagmites are the counterparts of stalactites in that they rise from the floors of caves. When a stalactite growing downwards meets a stalagmite growing upwards, a column is formed. One column in Admiral's Cave, Bermuda, is over 20 m in circumference.

There are many other types of speleothems formed in Bermuda's caves. Flowstone is deposited when films of water flow down the walls of a cave. Rimstone dams are wall-shaped deposits on the cave's floor that impound small pools of water. Cave pearls are formed when calcium carbonate deposition takes place around a nucleus while it is agitated by dripping water. Small, delicate, twisting, helectites, which seem to defy the laws of gravity, result from water seeping so slowly through minute central canals that calcite crystals are deposited

in irregular positions at the tips (Moore, 1954). A soft, white, putty-like substance known as "moonmilk" is, mineralogically, hydromagnesite—a hydrated carbonate-hydroxide of magnesium. Moonmilk is thought to be derived from flowstone by the action of Bacteria (Cau-martin, 1957).

Speleothems are known to form at extremely slow rates and may be many thousands of years old. Thorium-uranium dating has been used to obtain an age of 195,000 years for two submerged stalagmites from Crystal Cave, Bermuda (Harmon *et al.*, 1978). Home (1864) calculated the apparent age of a large stalagmite from Admiral's Cave as 600,000 years. This was done by measuring the volume of the newly deposited knobs on the stump, 44 years after the stalagmite had been removed from the cave by that author's father. Although this method of dating has several potential drawbacks, the calculated age for this Admiral's Cave stalagmite may not be too far off (Iliffe, in press).

Another distinctive feature of Bermuda's caves is the clear blue sea-water pools which rise and fall with the tides (Fig. 1). Some of the underwater portions of the caves are reported to extend as deep down as 24 m below sea-level (Bretz, 1960). Large stalagmites, stalactites, and other speleothems, which can only form in air, are found in them, little altered by their long submersion, as deep down as 23 m underwater. In Crystal Cave, divers have descended a steeply sloping fissure to 23 m (Latham, 1977). At this depth, another fissure passage began to climb just as steeply upwards, opening out into a large, previously unentered, chamber with no surface connections. Other underwater traverses may ultimately link many of these closely-spaced caves on the islands into large systems.

#### SPECIAL FLORA AND FAUNA

Many rare species of plants and animals are found exclusively in or close to the entrances of Bermuda's caves. The Bermuda Cave Fern (*Dryopteris speluncae*) and the Bermuda Shield-fern (*Dryopteris bermudiana*) are two endemic plants that are known primarily from caves, holes, and crevices, located between Harrington Sound and Castle Harbour (N. L. Britton, 1918). In addition, a variety of mosses are localized to cave entrances (E. G. Britton, 1915). Recently, an investigation of the caves by the present Author revealed a number of cave-adapted animals. These species, which lack eyes and pigments, include both terrestrial and marine representatives. The marine species may be descended from deep-sea animals, which could only compete with shallow-water forms in the specialized environment of the caves. For example, the only habitats, in the area around Bermuda, from which members of the amphipod suborder Ingolfiellidea have been identified, are caves (by the present Author) and deep sea (about 4,800 m, by Mills [1967]).

Cave-adapted animals may also have evolved from surface species that had, for example, been forced by the drastic climatic changes of the Ice Ages to seek shelter in the constant-temperature interior of the caves. The de-



Fig. 1. Tidal sea-water pool in Crystal Cave, Bermuda: Note rowboat in foreground on left and life-buoy in centre giving scale. The stalactites are electrically illuminated. Photo: Bermuda News Bureau.

velopment of troglobites (animals that live only in caves) requires genetic isolation; colonization of caves by troglaphiles (animals that complete their life-cycle in caves, but may also do so in suitable habitats outside caves) may have been accompanied by extinction of the surface form (Poulson & White, 1969). Significantly lowered temperatures in Bermuda during the Pleistocene probably caused the extinction of many tropical or subtropical species (Briggs, 1966, 1974). The only available refuge from these low temperatures will have been the climatically more stable cave environment.

Although several species of bats have been observed in Bermuda, the lack of any evidence of cave-inhabiting bats, of ancient bone deposits of them, or of their fossil remains, indicates that cave-inhabiting species of bats were never resident in Bermuda (Gelder & Wingate, 1961).

Large fossil deposits are found in many caves around the island. The most numerous of the cave fossils are those of the endemic land-snail, *Poecilozonites* (Gulick, 1904; Pilsbry, 1924; Gould, 1969). Fossils of birds are dominant among the vertebrate remains. Pleistocene fossil fauna is characterized by a wide variety of species, including a reptilian 'skink', and, representing birds, the Cahow (*Pterodroma cahow*), two extinct 'finches', and various endemic (and now extinct) marsh etc. birds—including a true crane, a mallard-like duck, and at least

four species of rails (Shufeldt, 1916, 1922; Wood, 1923; Wetmore, 1960, 1962).

The caves of Bermuda have been a source of mystery and fascination to Man since the earliest colonists landed on the islands. The first published reference to caves was by Captain John Smith, in 1623, who found 'in some places varye strange, darke, and combersome Caues' (Smith, 1623). The descriptions and history of Bermuda caves have been discussed by Thomson (1877), Verrill (1908), Rider (1922), and Forney (1973). A number of Bermuda caves, including Island, Cathedral, Admiral's, Castle Grotto, Wonderland, Crystal, Walsingham, Leamington, and Tucker's Island Caves, have been commercially shown at one time or other. New caves are continually being discovered, as evidenced by the numerous newspaper reports of such finds (Forney, 1973). However, caves still comprise the last relatively unexplored and undisturbed natural settings in Bermuda.

#### ECONOMIC, SOCIAL, AND SCIENTIFIC IMPORTANCE OF CAVES

Caves play an important role, as tourist attractions, in the economy of the islands. Bermuda's first commercial tourist attraction was probably the Devil's Hole, which was opened to the public in 1843, and is actually a col-

lapsed cave (Forney, 1973). Today, two caves, Crystal and Leamington, are commercially shown. The Devil's Hole is operated as a natural fish-pond. Blue Grotto, another collapsed cave, is the site of dolphin shows. Prospero's (or Island) Cave contains an underground bar and discotheque. The salt-water pool in Cathedral Cave is used as an 'indoor' swimming pool during inclement weather by guests at one of the islands' hotels. Each year, approximately 320,000 tourists visit these attractions, spending nearly one million dollars on such visits. Over 30 Bermudians are directly employed by these businesses. Thus, it is evident that cave-related tourist attractions make a significant contribution to the islands' economy.

Bermuda's caves have unquestioned scenic and recreational values. While recreational cave exploration has not yet become notable in Bermuda, many people visit cave-containing preserves, such as the Walsingham Trust. Organized 'cave crawls', held by the Grotto Bay Hotel at Cathedral Cave, introduce up to 100 persons per week to cave exploration. 'Caving', as a recreational activity, differs from other sports in that it is intentionally little publicized. The reason for this is that overuse or misuse of the caves by individuals who are not fully aware of the conservation and safety problems involved, may result in irreparable damage to the caves or in serious personal injuries. Publication of cave locations, which might lead to vandalism, is, therefore, to be discouraged.

As has been previously mentioned, important scientific studies, involving both geology and palaeontology, have been carried out in Bermuda's caves. However, there is still much important work left to be done in these fields. Only a few of the caves have been mapped, and this has been done in the last 10 years. Many of the caves are unnamed or, alternatively, are known by several different names. Studies were recently begun concerning the marine and terrestrial biology of the caves. Controversy still exists over the means of formation of the caves. It is to be hoped that studies of the caves will produce a better understanding of them and wider appreciation of their worth.

#### DESTRUCTION OF BERMUDA'S CAVES

A number of Bermuda's caves have been damaged or destroyed by the actions of Man. The four primary threats to the caves are: (1) filling and quarrying activities, (2) water pollution, (3) dumping and littering, and (4) vandalism. Among the caves that were destroyed by filling and quarrying activities are Wilson's Cave (a well-adorned cave located near the Government Quarry, which was bulldozed shut, and probably destroyed by quarrying, cf. Forney [1973]); Peniston's Cave (also destroyed by quarrying at Government Quarry—*Ibid.*); Wilkinson Quarry Cave (destroyed by quarrying—*Ibid.*), an unnamed cave (discovered by workers digging a cesspit for the Bermuda Telephone Company and incorporated as part of the sewage facility—*Ibid.*); Kindley Field Cave (discovered by engineers excavating for a playground and destroyed immediately after being explored—*Ibid.*);

Tucker's Island Caves (one of these two caves was termed 'the most exquisite bijou of Bermuda caverns' by Jones, [1859], destroyed during construction of the U.S. Naval Annex—*Ibid.*); North Bastion (Ireland Island) Cave (destroyed during construction of fortifications, cf. Nelson [1837]); and Cave Island (buried during construction of an airport, cf. Forney [1973]). Numerous other caves have been filled or destroyed during construction of hotels, golf courses, and private residences.

Bassett's Cave (Fig. 2), said to be Bermuda's largest (at more than 1 mile = 1.6 km in length), and geologically the most instructive (Nelson, 1837), has been used by the U.S. Navy for dumping waste fuel-oil and raw sewage (Forney, 1973). Although the Navy is considering building a sewage treatment plant for the site, the fate of this significant cave is still in doubt. Extensive dumping at Sears Cave may have destroyed a rare fern for which the cave was once noted (Forney, 1973). Beer cans, broken bottles and other litter, as well as bags of garbage, are common sights in many of the better-known, non-commercial, caves (Fig. 3). In these caves, vandals have broken and removed many irreplaceable speleothems and defaced cave walls with their names. Bermuda's caves have suffered much from Man's activities (cf. Rhodes, 1976; Ellis, 1978). Potential users of caves need to be made aware of the conservation problem. If this is not accomplished, the beauty and value of our caves will not long remain with us.



Fig. 2. Waste fuel-oil covers this tidal pool in Bassett's Cave, Bermuda, to a depth of at least half-a-metre. Photo: Dr T. Illiffe.



Fig. 3. Piles of garbage almost block the entrance of this small Bermuda cave. Photo: Dr T. Iliffe.

#### SOLUTIONS AND RECOMMENDATIONS

The following, taken largely from the conservation guidelines of the U.S. National Speleological Society (duly acknowledged below), are suggested as a means for protecting and preserving Bermuda's caves:

(1) *Establish Cave Preserves*:—Areas containing fragile or important caves should be set aside as parks or preserves. Acquisition of caves could be carried out either by governmental or private organizations. Care should be taken that such caves are not overly publicized until adequate protection can be established for them.

(2) *Place Entrance Gates Where Appropriate*:—A number of Bermuda caves, including several that were formerly operated commercially, are gated. Such gating permits regulation of visitors and protects the cave from vandalism.

(3) *Oppose the Sale of Speleothems*:—As speleothems are a non-renewable part of the cave unless it be over extremely long periods of time, and as their display and sale encourages cave vandalism, the sale of speleothems should be prohibited by law.

(4) *Support Effective Protective Measures*:—Laws are needed to protect caves from improper land-use (particularly from dumping, water pollution, quarrying, etc.) and vandalism. In the United States, vandals have been successfully prosecuted under cave protection laws (Ellis, 1978). Currently, Bermuda has no laws to protect its caves.

(5) *Clean and Restore Overused Caves*:—Cave clean-up projects, sponsored by conservation organizations, can restore caves to their original beauty (Rhodes, 1976).

(6) *Assist Cave-owners in Protecting their Caves*:—Education of cave-owners in the importance of cave conservation can be effective in protecting our caves.

(7) *Encourage Commercial Cave-owners to Aid the Public in Understanding Cave Conservation*:—A short discussion of cave conservation by guides in commercial caves can help to educate the public as to the fragility of the cave environment.

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#### SUMMARY

Bermuda's caves have proven to be extremely valuable from the scientific, economic, and recreational, viewpoints. Significant studies in geology, palaeontology, and biology, have been conducted in these caves, which are also an important asset as tourist attractions in a country whose economy is almost wholly dependent upon tourism. Caves and other karst landforms contribute much to the scenic beauty of Bermuda. However, a number of these caves have been destroyed or severely damaged by Man. The four primary threats to Bermuda's caves have been (1) filling and quarrying activities, (2) water pollution, (3) dumping and littering, and (4) vandalism.

Without a proper appreciation of the importance of cave conservation, much of our limited, non-renewable, cave resources may be lost for ever. The conservation policy of the U.S. National Speleological Society states in part that: 'All the contents of a cave—formations, life, and loose deposits—are significant for its enjoyment and interpretation. The collecting of mineral or biological materials for display purposes, including previously broken or dead specimens, is never justified, as it encourages others to collect and thus destroy the interest of the cave. Unique scientific, recreational, and scenic, values (of the caves) are endangered by both carelessness and intentional vandalism. These values, once gone, can never be replaced.'

In order to protect and preserve our caves, conservation guidelines need to be set up. These guidelines should encourage the establishment of cave preserves, the placing of entrance gates where appropriate, the enactment of laws to protect the caves and their contents, the clean-up and restoration of damaged caves, and the education of cave-owners and potential users of caves in the importance of cave conservation. Local conservation organizations can prove useful in assisting with the implementation of such projects. Positive actions are required, right now, to halt the irreversible damage that is being done to our exceptionally vulnerable cave resources.

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## Panama Declares National Park in Canal Zone

Panamanian President Aristides Royo recently declared the creation of the Parque Nacional de la Libertad, a 50,000-acres [20,000 ha] park which includes one of the world's most accessible and best-studied rain-forests. The Park, which contains the habitats of many rare and endangered species, is also important from an economic perspective, in that it will help to protect against siltation of the Canal.

Conservationists have applauded the President's action as a demonstration of Panama's commitment to come to grips with the problems of deforestation and soil erosion

which threaten the Canal Zone watershed. As a protected area, the Park will be a part of a project which will take into account the ecology of the total watershed and seek to institute suitable land-use practices.

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