Bermuda

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BERMUDA is a group of more than 100 islands clustered along the southern margin of a volcanic seamount located east of Cape Hatteras, North Carolina in that part of the western Atlantic known as the Sargasso Sea (see Chapter 1, Figure 1.1). The islands, interconnected by bridges and causeways, are less than a mile (1.6 km) wide and extend about 40 km in length. The land is hilly, with no freshwater streams, but with a number of freshwater ponds and marshes. The highest elevation is 76 m at Town Hill. Several large bodies of saltwater including Great Sound, Harrington Sound, and Castle Harbour are almost completely surrounded by land.

Bermuda, at 32°20’N, 64°45’W, is sometimes referred to as the World’s northernmost atoll. Although its fringing coral reef, central lagoon, and volcanic basement are consistent with the classic description of an atoll, the seamount is not subsiding; as in a true atoll. The top of the Bermuda seamount occupies an area of 665 km², of which 55 km² is land, while the remaining area consists of an inner lagoon composed of patch reefs, sea-grass beds, and sand, surrounded by fringing coral reefs (composed of hard corals and calcareous algae) on the outer edge (Fig. 14.68). Bermuda’s reefs are the northernmost in the Atlantic Ocean and owe their existence to warm water brought by the Gulf Stream.

![Figure 14.68: Cross section of the Bermuda seamount.](image)

**Origin and Geology of Bermuda and its Caves**

The Bermuda Pedestal is the eroded stump of a mid-to-late Eocene shield volcano. Bermuda and three other adjacent submerged seamounts form a NE-trending, 100-km-long line located near the summit of the Bermuda Rise, a NE-trending oval swell, 1500 km long and 500–1000 km wide, on the floor of the Atlantic Ocean.

Over the past million years, up to 115 m of limestone has been deposited by calcareous algae and other marine organisms, completely covering the island’s underlying volcanic basalt. During interglacial periods of high sea level in the Pleistocene, windblown carbonate sand accumulated as coastal dunes. During glacial episodes, sea levels were lower and carbonate production and dune formation stopped due to the absence of shallow water habitats around the island. At that time, a red soil or terra rossa paleosol accumulated, which consisted of windblown dust coming from the Sahara Desert. Acidic freshwater from rain percolated through the soil into the dunes, cemented sand grains together, and created the eolianite limestone so common in Bermuda today. Rising sea level during later interglacial periods restarted shallow-water carbonate production and created new dunes, thus burying older limestone and soils. The oldest (and basal) limestone unit in Bermuda is the Walsingham Formation of early Pleistocene age (Fig. 14.69). This is overlain by the middle Pleistocene

![Figure 14.69: Stratigraphic column for Bermuda. Orange formations are paleosols separating the eolianite formations. All are of Pleistocene age; Walsingham is early Pleistocene. See text for details.](image)
Lower and Upper Town Hill Formations, and finally by the Belmont, Rocky Bay and Southampton Formations, all associated with the last interglaciation. In general, the older geologic formations are located in the interiors of the islands, whereas younger rocks are located closer to the coasts (Fig. 14.70). Six to nine glacial-interglacial cycles over the last million years are currently recognized in Bermuda. For more on the geology and hydrology of Bermuda see Vacher and Rowe (1997).

Bermuda contains well-developed karst topography (Fig. 14.71), including numerous caves and sinkholes, especially in Bermuda’s oldest and most compact limestone, the Walsingham Formation. More than 160 caves are known from Bermuda with the majority being located between Harrington Sound and either Castle Harbour or the North Lagoon (Fig. 14.72). Bermuda’s caves were initially formed as large solutional voids and passageways during glacial periods when sea level was 100 m lower. Later, as post-glacial sea flooded large portions of the caves. Continuing collapse of overlying rock created the irregular breakdown chambers (Fig. 14.73) and fissure entrances that are commonly seen in Bermuda’s caves. Extensive networks of submerged passageways, developed mainly at depths of 17–20 m below present sea level, interconnect otherwise isolated cave pools (Fig. 14.74). These passages, accessible only to divers, are well decorated at all depths with impressive stalactites and stalagmites, confirming that the caves were dry and air-filled for much of their existence.

The sea-level brackish pools in the interior and/or entrances of many Bermuda caves are classified as anchialine habitats. The term “anchialine” was coined to describe pools with no surface connection to the sea, containing salt or brackish water, which fluctuates with the tides. Bermuda’s cave pools have a thin brackish layer at the surface, overlying fully marine waters at depth. Differences in phase and amplitude between tides in the nearly enclosed Harrington Sound and those in the open sea generate reversing tidal currents through coastal karstic springs via submerged cave passages. Caves farther inland typically contain slowly moving or nearly stagnant waters.

Although many Bermuda caves at first glance appear to be rather small and end in tidal saltwater pools, diving explorations have resulted in the discovery of extensive networks of highly integrated passages. For example, the Walsingham Caves consist of two larger and mostly underwater cave systems. Walsingham (1300 m long with 7 known entrances) and Palm (500 m long with 5 entrances), in addition to numerous smaller caves.
Speleological History of Bermuda

The caves of Bermuda have been a source of mystery and fascination since the earliest colonists landed on the island. Shakespeare's play "The Tempest," inspired by the Bermuda shipwreck of Sir George Somers in 1609, takes place in and around a cave. The first published reference to Bermuda's caves was by Captain John Smith in 1623, who reported, "in some places vraye strange, darke, and cumbersome Caves."

Bermuda's caves have been variously used or abused for many hundreds of years. At least nine caves in Bermuda have been shown commercially to tourists at one time or another. These include Island, Cathedral, Admiral's, Castle Grotto, Wonderland (now Fantasy), Crystal, Walsingham, Leamington, and Tucker's Island Caves. Today only Fantasy and Crystal remain as tourist attractions. Speleothems have been occasionally mined from the caves. The Catalogue of the 1872 Bermuda Industrial and Loan Exhibition lists stalactites as an "article of industry" for which prizes were awarded to the best collections. Prisoners on convict hulks moored at Bermuda's Naval Dockyard in the early 1800s sculpted stalactite carvings in the form of chess pieces, rosary beads, jewelry and other items.

The presence of submerged stalagmites in Bermuda caves (Fig. 14.75) led to a debate among geologists as to the tectonic stability of the island and to possible changes in sea level over geologic time. Lieut. R.J. Nelson (1837) mistakenly suggested that these speleothems were formed underwater. Many researchers, especially stratigraphers, have worked in Bermuda because it is a beautiful island with a relatively cool "tropical" climate because of its northern location. Because Bermuda was considered very stable tectonically, it has been used as a tidal gauge for Pleistocene and recent sea-level changes. Using fossils, stratigraphic evidence, speleothem dates, and radiocarbon dates from peat, there have been attempts to construct a history of sea-level fluctuation from the Bermuda data; however, some of the crucial evidence is based on interpretation and is still debatable (Vacher and Rowe, 1997).

Several hypotheses have been proposed for the origin of the caves. J.H. 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 groundwater body necessary for cave formation could only have occurred in Bermuda during low stands of glacial sea level when the island's total landmass would have been about 13 times as large as it is today.

Of recent ideas, it appears that mixing between saltwater and freshwater is the most likely origin. Most of the caves on the island have formed in the Walsingham Formation (oldest limestone), leading to salt water as the cavernous porosity links them with the sea, whereas the freshwater lens in Bermuda is located mainly in the primary pores of the younger formations (Plummer et al., 1976). This implies that caves do not form by freshwater alone.

Simple chemical measurements have shown that groundwater in shallow Bermuda wells is saturated with respect to calcite most of the time but aggressive at least part of the time (Plummer et al., 1976). Vadose water in the young carbonate rock is so diffuse that it generally becomes saturated within a meter of the surface. Below that it tends to fill the porosity with calcite. There are no shafts, and dripwater in the caves is not aggressive. In fact, the caves contain a great many speleothems. However, sea-level pools, usually supersaturated with calcite, are solutionally aggressive during periods of high infiltration, particularly at and just below the water surface. Salinity measurements in the pools increases downward from at least 35% to 90%. This implies that cave enlargement occurs at the freshwater/seawater interface mainly after rainfall events (Palmer et al., 1977).

Examples of Bermuda's Principal Caves

Admiral's Cave (Hamilton Parish) is named for Admiral Sir David Milne and is one of the more historically significant caves in Bermuda. It is located at Walsingham on the side of a hill. The cave (Fig. 14.76) is highly irregular in plan and contains many stalactites and stalagmites of various sizes. The bottom of the cave reaches salt water, which rises and falls with the tides, although it is almost half a kilometer from the ocean.

In 1819, Admiral Milne, then commander of the British North American and West Indian Station in Bermuda, collected a number of speleothems from Bermuda caves that he presented to the University of Edinburgh. The largest was a stalagmite removed from Admiral's Cave, 3.4 m high, 63 cm in average diameter, and weighing about 3000 kg (~3.5 tons). His son returned 45 years later and measured the amount of deposition that had taken place on the stump from a drip site on the ceiling. From this it was calculated that it would have taken "the astounding and incredible period of more than 600,000 years" to form the original stalagmite. Later a slice from the stump was taken to show the amount of precipitation that took place and was sent as an accessory to the Edinburgh specimen.

Crystal Cave (Hamilton Parish) is a show cave near Castle Harbour. The tour descends 27 m down a steep set of stairs to water level, where a pontoon walkway continues over the clear "crystal" water, which is >10 m deep in places. The lake is subject to tidal changes, indicating a
The terrestrial fauna of Bermuda's caves is very limited, with no cave-adapted species, and almost exclusively limited to the vicinity of entrances and pathways where there is some organic debris. In contrast, an incredibly rich and diverse marine biota inhabits the submarine passageways and anchialine pools of these caves (Iliffe, 2004). The connection with the ocean. Numerous stalagmites and stalactites cover the walls and continue below water level, indicating that at some time in the past the water level was lower.

**Green Bay Cave** (Hamilton Parish) is totally underwater. It is presently the longest known cave in Bermuda, with more than 2 km of surveyed passages (Fig. 14.77). The main entrance is a wide submerged passageway extending inland from the end of Green Bay on Harrington Sound. From shallow depths at the Green Bay entrance, the cave slopes progressively deeper to the Rat Trap at −17 m. The Rat Trap continues northeast to a spacious, deeper chamber with a massive boulder choke at one end and a room with distinctly lower visibility (Fog Room) at the other.

From the Rat Trap, the Connection Passage leads to the Trunk Passage. This is the largest passage in the cave, averaging 15 m wide and 9 m high. The far end of the Trunk Passage terminates in a breakdown slope to the surface and a murky inland sinkhole (Cliff Pool), the only other entrance to the Green Bay System. On the east side of the Trunk Passage, the Harrington Sound Passages consist of two interconnecting passageways with much clearer water than adjacent sections of the cave. The Bath Tub Ring Room, at −15 m depth near the end of the Harrington Sound Passage, contains a horizontal bleached band of bedrock about 50 cm thick cutting across the rock strata. In the same area are bones of a sea turtle that apparently became lost and died in the cave sometime in the distant past.

The North Shore Passage is the longest single passage in the cave. It begins on the west side of the Trunk Passage and extends for nearly 500 m to a point past (but below) the northern shoreline of the island, where the passage becomes too low for divers to follow. Several extended interconnected loops characterize this part of the cave. Undercut walls and the level nature of this part of the cave at about −18 m indicate that an underground stream must have flowed through these tunnels during glacial periods, when sea level was low. Massive stalactites and stalagmites are present in virtually all parts of the underwater cave, giving another indication of the cave's long history as a dry cave.

**Bermuda Cave Biology**

The terrestrial fauna of Bermuda's caves is very limited, with no cave-adapted species, and almost exclusively limited to the vicinity of entrances and pathways where there is some organic debris. In contrast, an incredibly rich and diverse marine biota inhabits the submarine passageways and anchialine pools of these caves (Iliffe, 2004). The stygobitic (aquatic cave-adapted) fauna of Bermuda's anchialine caves includes at least 83 species with 11 genera and one order (the peracarida crustacean Micraces) restricted to the island's caves (Fig. 14.78). The majority of Bermuda's stygobitic species are crustaceans, including 23 copepods, 18 ostracods, 8 amphipods, 6 shrimp, 6 cumaceans, and 5 isopods, in addition to 5 species of aquatic mites, 3 annelids, 2 ciliates and 2 molluscs. This is among the highest density of aquatic subterranean biodiversity known on Earth. In comparison, the entire Bahamas archipelago, which occupies an area hundreds of times larger than Bermuda, has 107 known anchialine stygobiotics.

Included among this fauna are extremely ancient relic organisms that can be legitimately classified as "living fossils." For example, the copepod *Erebonectes* is one of the most primitive of known calanoids, while *Antriscopia* agrees in many ways with the description of a theoretical ancestral copepod. Some of Bermuda's cave-dwelling species exhibit close affinities with European cave and groundwater fauna and probably colonized subterranean habitats on Bermuda early in the island's history when the Atlantic was much narrower. The amphipod *Pseudoniphargus*, which was originally known only from caves and groundwater around the Mediterranean, the Azores and Canary Islands, includes two species from Bermuda caves. Other animals inhabiting Bermuda caves have close relatives in caves on other isolated oceanic islands from the Atlantic and Pacific. The misophrioid copepod genus *Speleophipropis* also includes cave species from Palau in the South Pacific, the Canary Islands in the Eastern Atlantic, and the Balearic Islands in the Mediterranean. The isopod family *Atlantaspelaeidae* includes only two species, which inhabit caves in Bermuda and the Dominican Republic. Thus, Bermuda's cave species are providing important clues in establishing the evolution and dispersal of present oceanic species.

**Conservation**

Bermuda is one of the most densely populated countries in the world, and therefore land is at a premium (Fig. 14.79). Although most of Bermuda's caves are located on private property so that access is limited or prohibited, anthropogenic impacts on caves have been considerable. The IUCN Red List of Threatened Species currently recognizes 25 cave species from Bermuda as critically endangered. The four primary threats to Bermuda caves are (1) construction and quarrying activities, (2) water pollution, (3) dumping and littering, and (4) vandalism. Quarrying has destroyed many significant caves, particularly at Government Quarry and Wilkenson Quarry, both in the Walsingham district. Construction of luxury town homes directly on top of Church and Bitumen Caves may adversely impact their endangered anchialine fauna. The Karst Waters Institute twice named these two caves on their list of the Top Ten Most Endangered Karst Ecosystems on Earth. The anchialine pool of Basset's Cave, reported in 1840 to be the longest and geologically most instructive cave in Bermuda, was used by the U.S. Navy as a cesspit for disposal of raw sewage and waste fuel oil. Many Bermuda caves have been used as dumping sites. The bulldozing of large piles of partially burned rubbish into the anchialine pool of Government Quarry Cave resulted in depletion of dissolved oxygen and the anaerobic production of hydrogen sulfide. Groundwater...
circulation transmitted this pollution to at least five other caves half a kilometer or more away. In such polluted caves, all stygobitic species have disappeared. Since many of Bermuda's cave species are endemic and are often restricted to only one cave or cave system, pollution or destruction of these habitats can result in the extinction of entire species. Finally, few of Bermuda's larger caves have escaped the effects of vandals maliciously breaking and removing fragile stalactites and stalagnites or defacing cave walls with their names.

With the enactment of the Bermuda Protected Species Act of 2003, all threatened species must be assessed and appropriate recovery plans developed. Protection of cave-adapted species of course involves protection of caves and monitoring of their environmental quality. The delicate speleothems and endangered species present in many Bermuda caves have not been heavily impacted by cave diving exploration due to their limited access. To further protect these fragile areas, a permit requirement is under consideration. Planning legislation in Bermuda requires that "protection of caves shall take precedence over all other planning considerations." Although laws for protection of caves and cave species in Bermuda are very good, destruction and contamination of caves is still occurring at an alarming rate.

References

Figure 14.79: Surveying through the jungle to the entrance of Turtle Cave, Bermuda, only a few meters from a well-manicured golf course at Castle Harbour. Pressure from development is threatening the integrity of karst and caves on the islands. Photo by A.N. Palmer.