SAMPLE

Earth's Dynamic Systems: Coral Reefs

The Rainforests of the Sea

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Introduction

A coral reef is an underwater ecosystem characterized by reef-building corals. Reefs are formed of colonies of coral polyps held together by calcium carbonate. Most coral reefs are built from stony corals, whose polyps cluster in groups. Coral belongs to the class Anthozoa in the animal phylum Cnidaria, which includes sea anemones and jellyfish. Unlike sea anemones, corals secrete hard carbonate exoskeletons that support and protect the coral. Most reefs grow best in warm, shallow, clear, sunny, and agitated water.

Coral reefs first appeared 485 million years ago, at the dawn of the Early Ordovician, displacing the microbial and sponge reefs of the Cambrian.

Sometimes called rainforests of the sea, shallow coral reefs form some of Earth's most diverse ecosystems. They occupy less than 0.1% of the world's ocean area, about half the area of France. Yet, they provide a home for at least 25% of all marine species, including fish, mollusks, worms, crustaceans, echinoderms, sponges, tunicates and other cnidarians.

Coral reefs flourish in ocean waters that provide few nutrients. They are most commonly found at shallow depths in tropical waters, but deep water and cold water coral reefs exist on smaller scales in other areas. Shallow tropical coral reefs have declined by 50% since 1950, partly because they are sensitive to water conditions.

They are under threat from excess nutrients (nitrogen and phosphorus), rising ocean heat content and acidification, overfishing (e.g., from blast fishing, cyanide fishing, spearfishing on scuba), sunscreen use, and harmful land-use practices, including runoff and seeps (e.g., from injection wells and cesspools). Coral reefs deliver ecosystem services for tourism, fisheries, and shoreline protection. The annual global economic value of coral reefs has been estimated at anywhere from US$30-375 billion (1997 and 2003 estimates) to US$2.7 trillion (a 2020 estimate) to US$9.9 trillion (a 2014 estimate).

Chapter 1: The Discovery of Coral Reefs

Others have tectonic origins where plate movements lifted the deep ocean floor. In The Structure and Distribution of Coral Reefs, Charles Darwin set out his theory of the formation of atoll reefs, an idea he conceived during the voyage of the Beagle. He theorized that uplift and subsidence of Earth's oceanic crust beneath the oceans formed the atolls. Darwin set out a sequence of three stages in atoll formation. A fringing reef forms around an extinct volcanic island as the island and ocean floor subside.

As the subsidence continues, the fringing reef becomes a barrier reef and ultimately an atoll reef. Darwin predicted that underneath each lagoon would be a bedrock base, the remains of the original volcano. Subsequent research supported this hypothesis. Darwin's theory followed from his understanding that coral polyps thrive in the tropics where the water is agitated, but can only live within a limited depth range, starting just below low tide.

Where the underlying earth allows, corals grow along the coast to form fringing reefs, which can eventually become barrier reefs. Where the bottom is rising, fringing reefs can grow around the coast, but coral raised above sea level dies. If the land subsides slowly, the fringing reefs keep pace by growing upward on a base of older, dead coral, forming a barrier reef that encloses a lagoon between the reef and the land.

A barrier reef can encircle an island, and once the island sinks below sea level, a roughly circular atoll of growing coral continues to keep up with the sea level, forming a central lagoon. Barrier reefs and atolls do not usually form complete circles but are broken in places by storms. Like sea level rise, a rapidly subsiding bottom can overwhelm coral growth, killing the coral and the reef, due to what is called coral drowning.

Corals that rely on zooxanthellae can die when the water becomes too deep for their symbionts to adequately photosynthesize, due to decreased light exposure. The two main variables determining the geomorphology, or shape, of coral reefs are the nature of the substrate on which they rest, and the history of the change in sea level relative to that substrate. The approximately 20,000-year-old Great Barrier Reef offers an example of how coral reefs formed on continental shelves.

Sea level was then 120 m (390 ft) lower than in the 21st century. As sea level rose, the water and the corals encroached on what had been hills of the Australian coastal plain. By 13,000 years ago, sea level had risen to 60 m (200 ft) lower than at present, and many hills of the coastal plains had become continental islands. As sea level rise continued, water topped most of the

continental islands. The corals could then overgrow the hills, forming cays and reefs.

Sea level on the Great Barrier Reef has not changed significantly in the last 6,000 years. The age of living reef structure is estimated to be between 6,000 and 8,000 years. Although the Great Barrier Reef formed along a continental shelf, and not around a volcanic island, Darwin's principles apply. Development stopped at the barrier reef stage, since Australia is not about to submerge. It formed the world's largest barrier reef, 300-1,000 m (980-3,280 ft) from shore, stretching for 2,000 km (1,200 mi).

Healthy tropical coral reefs grow horizontally from 1 to 3 cm (0.39 to 1.18 in) per year, and grow vertically anywhere from 1 to 25 cm (0.39 to 9.84 in) per year; however, they grow only at depths shallower than 150 m (490 ft) because of their need for sunlight, and cannot grow above sea level. As the name implies, coral reefs are made up of coral skeletons from mostly intact coral colonies.

As other chemical elements present in corals become incorporated into the calcium carbonate deposits, aragonite is formed. However, shell fragments and the remains of coralline algae such as the green-segmented genus Halimeda can add to the reef's ability to withstand damage from storms and other threats. Such mixtures are visible in structures such as Eniwetok Atoll.

The times of maximum reef development were in the Middle Cambrian (513-501 Ma), Devonian (416-359 Ma) and Carboniferous (359-299 Ma), owing to extinct order Rugosa corals, and Late Cretaceous (100-66 Ma) and Neogene (23 Ma-present), owing to order Scleractinia corals.

Not all reefs in the past were formed by corals: those in the Early Cambrian (542-513 Ma) resulted from calcareous algae and archaeocyathids (small animals with conical shape, probably related to sponges) and in the Late Cretaceous (100-66 Ma), when reefs formed by a group of bivalves called rudists existed; one of the valves formed the main conical structure and the other, much smaller valve acted as a cap.

Measurements of the oxygen isotopic composition of the aragonitic skeleton of coral reefs, such as Porites, can indicate changes in sea surface temperature and sea surface salinity conditions during the growth of the coral. Climate scientists often use this technique to infer a region's paleoclimate. Since Darwin's identification of the three classical reef formations - the fringing reef around a volcanic island becoming a barrier reef and then an atoll - scientists have identified further reef types.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.