LESSON 4

OF CORAL REEFS AND ATOLLS

Stone Gardens of Tropical Seas

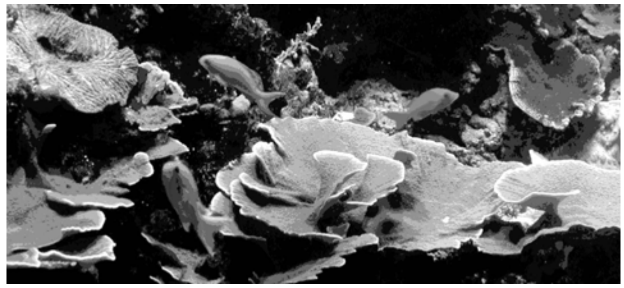


Fig. 4.01. Many types of corals (here, whorled palmate forms that look like large rhubarb leaves) are shaped much like plants on land.

Reef-forming stony corals potentially can grow everywhere in the tropical and subtropical realm of the planet – about one third of its surface – where the water is warm throughout the year (> 20ºC).

For stony corals to grow, the sea floor has to be shallow and the ground firm. Also, the water has to be clear, so that plenty of sunlight reaches the sea floor. The reason is that the coral animals bear inside their bodies, within the outermost cells, photosynthesizing microscopic algae (symbiotic dinoflagellates called "*zooxanthellae*"), which need light. This association between animals and green microbes (which gives most corals olive-green and -brown colors) is one of the most impressive symbiotic arrangements on the planet (1). It is one reason why many corals tend to look like plants (Fig. 4.01). The symbiosis allows corals to flourish in the nutrient-starved warm-water deserts of the sea, by setting up ecosystems where animals (corals) capture nutrients through predation and recycle them with minimum loss to captive photosynthesizing organisms (dinoflagellates). The coral-dinoflagellate symbiosis makes the reefs, and thus provides the basis for a proliferation of animals and plants that live within these stony gardens (2). Reefs are living oases in a vast desert.

Tropical reefs are striking centers of marine diversity, across all types of reef organisms, led off by a great diversity in "coral" itself (Fig. 4.02), and extending to fishes, snails and other mollusks, crustaceans, echinoderms, bryozoans, foraminiferans, and many types of coralline algae (3).

Reefs, as ecosystems, are in serious trouble in many parts of the world, wherever there is strong impact from human activities. Because of the requirement for shallow water, most reefs are next to land, and are readily accessible to commercial exploitation, mainly fishing, but also collecting of corals and mollusks for the shell market. The removal of large fishes benefits the stony coral's competitors for space: algae, sponges, and soft coral. With fewer predators checking their expansion, they tend to take over. Runoff from agriculture, soil erosion and sewage bring nutrients into the system, and this removes the competitive advantage of corals in a nutrient-starved environment. Algae, sponges and tunicates take advantage. With a dwindling cover of coral, a reef system becomes degraded and finally "collapses," that is, it changes irrevocably into a new and much less diverse system (4).

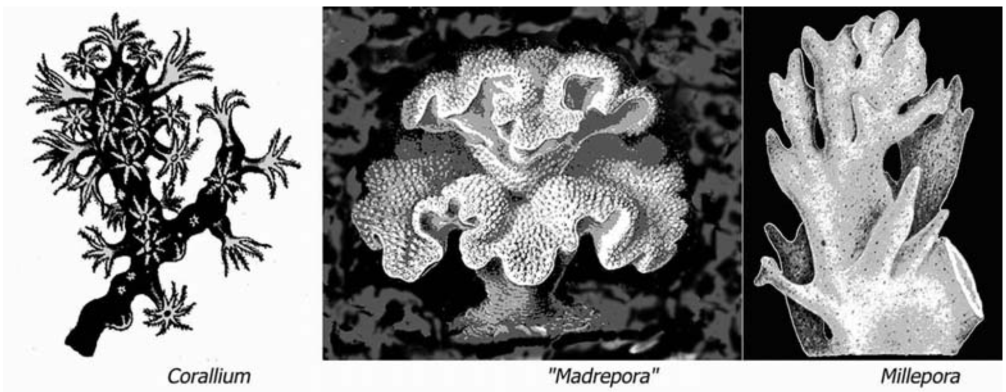
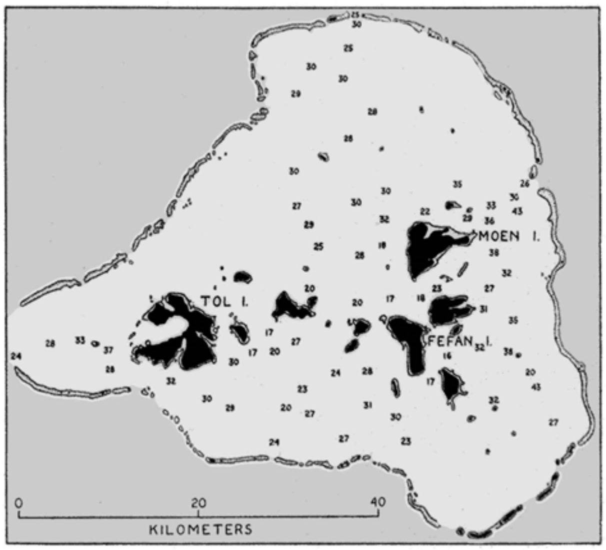


Fig. 4.02. Different types of organisms called "coral." The gem-quality red coral named *Corallium rubrum* (by Linné), a reef-building stone coral (drawn by Haeckel), a stony hydrozoan known as "fire coral" because of its painful sting upon touching it.

Another, more general, threat to the health of coral reefs is *coral bleaching*, that is, the loss of photosynthesizing symbionts, which accompanies unusually high water temperatures. Bleaching events apparently have become more abundant, and more widespread, with the progressive global warming that characterizes climate change for the last quarter century. The process is not well understood. Invasive species, brought from far away in bilge waters, are a problem in some regions.

Stony corals are the masons of the sea; they build enormous cities that offer food, shelter, substrate and diversity of habitat. They have done so for many millions of years, and the remains of ancient coral cities are now found in mountain belts wherever the shallow deposits of warm seas partook in the collision of great plates on the surface of Earth, to make new land. Thus, a hike in the Alps may well include a picnic on a reef structure made in the Mesozoic!

Some continents have large accumulations of reef rubble off their tropical shores. The biggest of these accumulations is off northeastern Australia and forms the foundations for the Great Barrier Reef. Tropical islands extend their girth by acquiring a thick mantle of coral rock, bearing active fringing reefs and barrier reefs in the sunlit zone at the top of the volcanic structure (Fig. 4.03). Some of them have turned into atolls, quasi-circular barrier reefs rimming lagoons in the middle of the sea, edifices built on sunken volcanoes.



Barrier reef, Truk group, Carolines. Depths in fathoms.

Fig. 4.03. Extension of girth of the remains of a sinking island by reef growth, as drawn by R. A. Daly (1936). Numbers (maximum, 43) are depths in fathoms.

Notes and references

1. *Anthozoans*, the animal class of corals, means "flower animals." Originally coined because the tentacles of polyps look somewhat like flower petals, the designation turns out to be a good one: flower animals participate in photosynthesis thanks to their algal symbionts.
2. Technically, *symbiosis* means “living together” which can be of advantage to both, or detrimental to one of the organisms involved. The word is used here in the older common usage of a “mutually beneficial” arrangement.
3. Naturalists of the 19th century distinguished “Madrepora,” stony structures with regularly spaced identical polyps anchored within their cups, from “Millepora,” stony structures with abundant pinholes bearing very small polyps of different size and function. The “Madrepora” are “stony corals” in the modern sense, while the “Millepora” belong to the “fire corals,” so called because their sting penetrates the skin on touch. Fire corals are more closely related to jellyfishes than to stony corals. Many forms closely related to the stony corals do not make a solid carbonate skeleton. They are referred to as “soft corals.” Best known among these are the sea anemones, the sea pens, the sea fans and the horny branching corals such as the precious “black coral.”
4. J.B.C. Jackson, M.X. Kirby, W.H. Berger, K.A. Bjorndal, L.W. Botsford, B.J. Bourque, R. Bradbury, R. Cooke, J. Erlandson, J.A. Estes, T.P. Hughes, S. Kidwell, C. B. Lange, H.S. Lenihan, J.M. Pandolfi, C.H. Peterson, R.S. Steneck, M.J. Tegner, and R.R. Warner, 2001. *Historical overfishing and the recent collapse of coastal ecosystems.* Science, 293, 629-638.

Images

Fig. 404. The astonishing diversity of coral gardens. Palmate, branching and massive corals in the tropical Pacific, close to the sea surface, and readily accessible for inspection (and use), therefore.

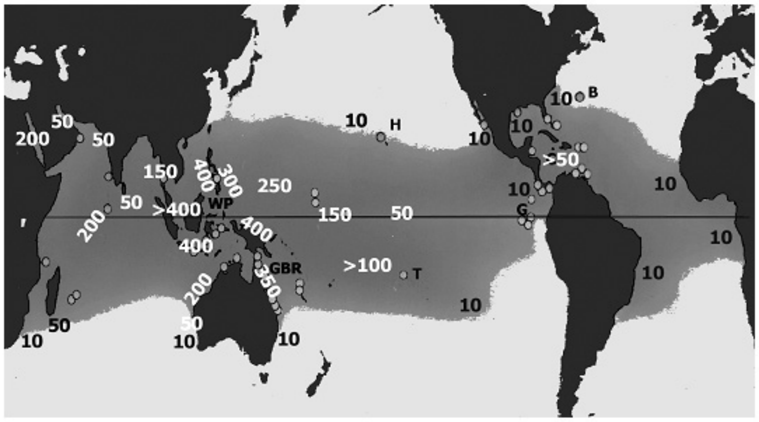


Fig. 4.05. Distribution limit (dark gray) and diversity of coral reefs (number of coral species). WP, warm pool of the western Pacific; GBR, Great Barrier Reef; H, Hawaii; T, Tahiti; G, Galapagos Islands; C, Caribbean (>50); B, Bermuda.

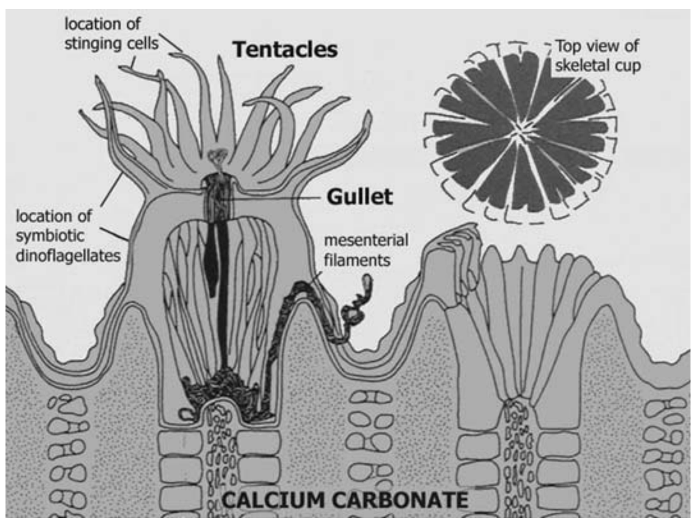


Fig. 4.06. Coral polyps sitting in their self-made stony cups. They host dinoflagellates (microscopic algae) for photosynthesis and use stinging cells (cells with *nematocysts*) on their tentacles for catching prey. The filaments are used in catching prey and digesting it outside of the stomach cavity.

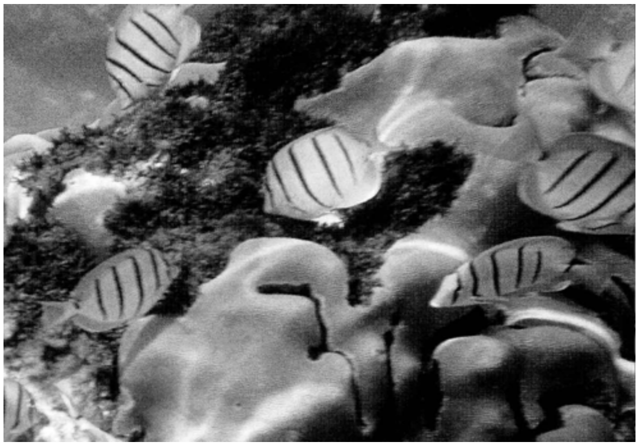


Fig. 4.07. The clean-up gang (convict tang, *Acanthurus triostegus*), coming through to remove algae growing between the coral. Hawaii.

Fig. 4.08. Competition for space in coral (branching *Pocillopora meandrina* vs. the knobby *Porites lobata*). Note the damage from coral-eating fish on the cauliflower coral (*P. meandrina*). Hawaii.

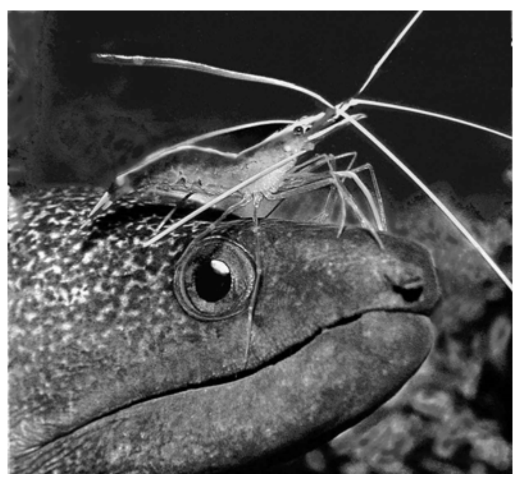


Fig. 4.09. Cleaning shrimp working on a customer (moray eel).

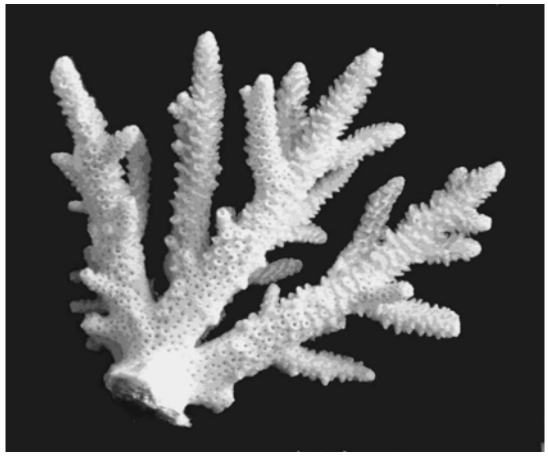


Fig. 4.10. Champion of fast growth: the
acroporid staghorn coral.

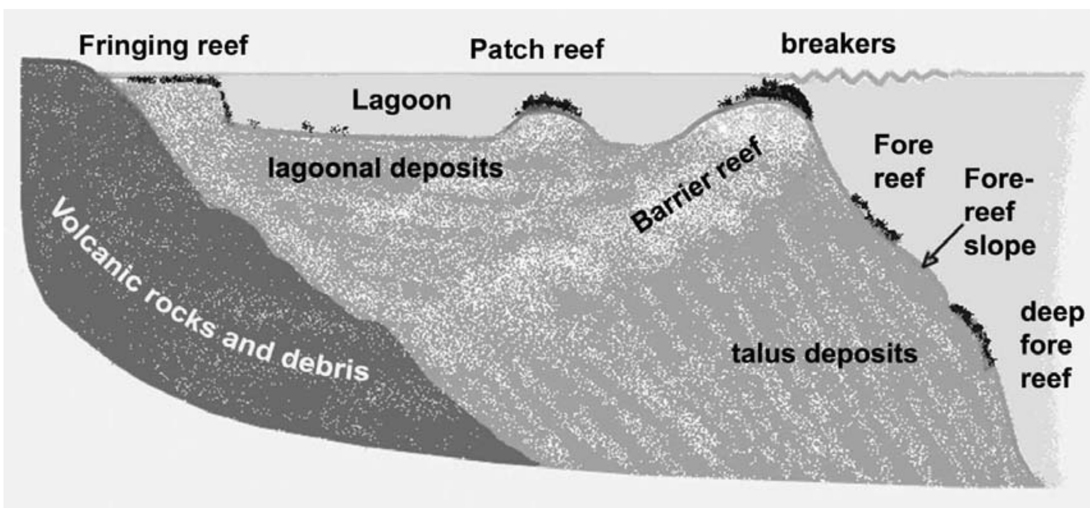


Fig. 4.11. Main environments of a typical reef structure. The width varies between hundreds of meters and several kilometers. Highest growth rates are in the barrier reef section, which delivers material both to the lagoon and to the fore-reef talus. At the edge of the reef the corals have access to plankton of the open sea. The lagoon is inherited from a time of lowered sea level, during the last ice age.

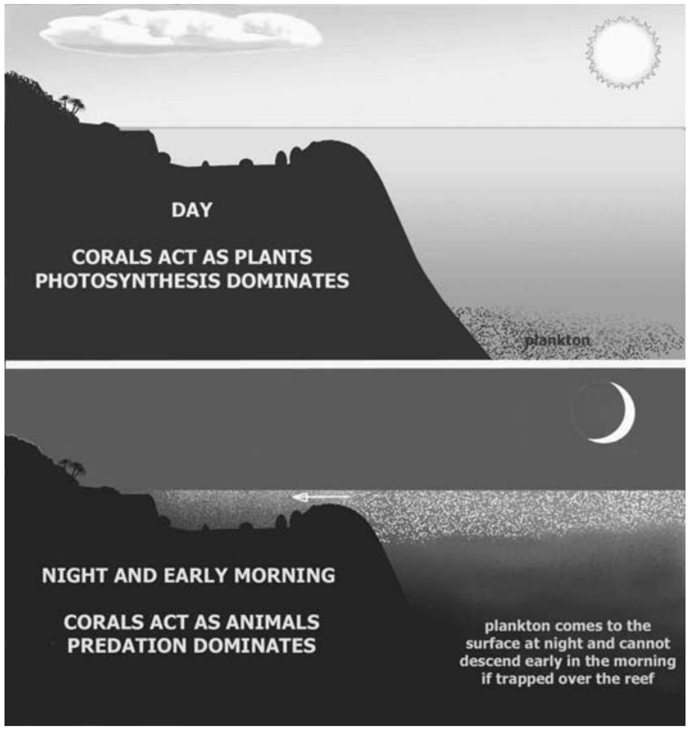


Fig. 4.12. Coral reefs are plankton traps that depend on vertical migration. At night, plankton animals are in surface waters and some drift into reefs. They will subsequently migrate downward into the open mouths of coral.

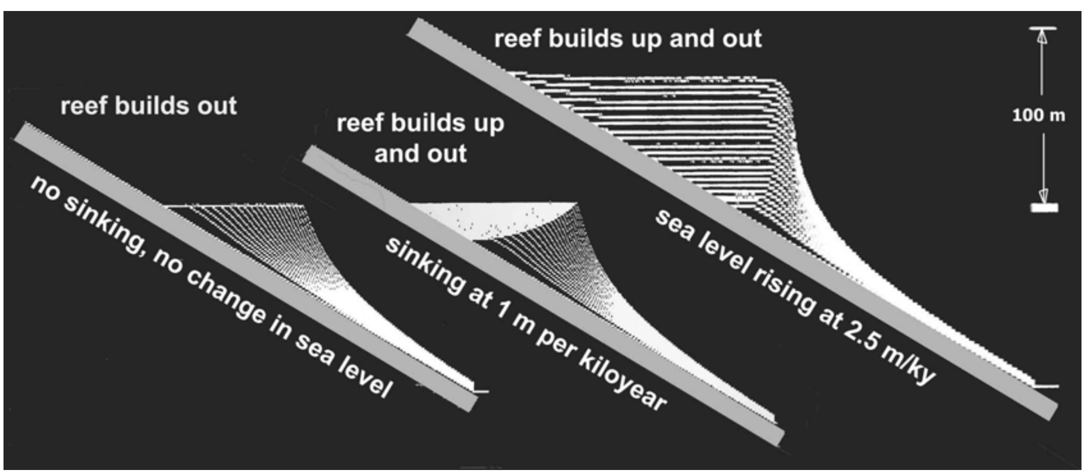


Fig. 4.13. Computer-aided thought experiments on growing a fringing reef, first with sea level constant, then with the base sinking slowly (1m in 1000 years), and finally with sea level rising (2.5 m in 1000 years). Time interval of calculation: 1000 y (= 1 kyr). Maximum rate of upward growth assumed: 4 m per thousand years. To make a lagoon, erosion has to be added to the list of processes (here missing).

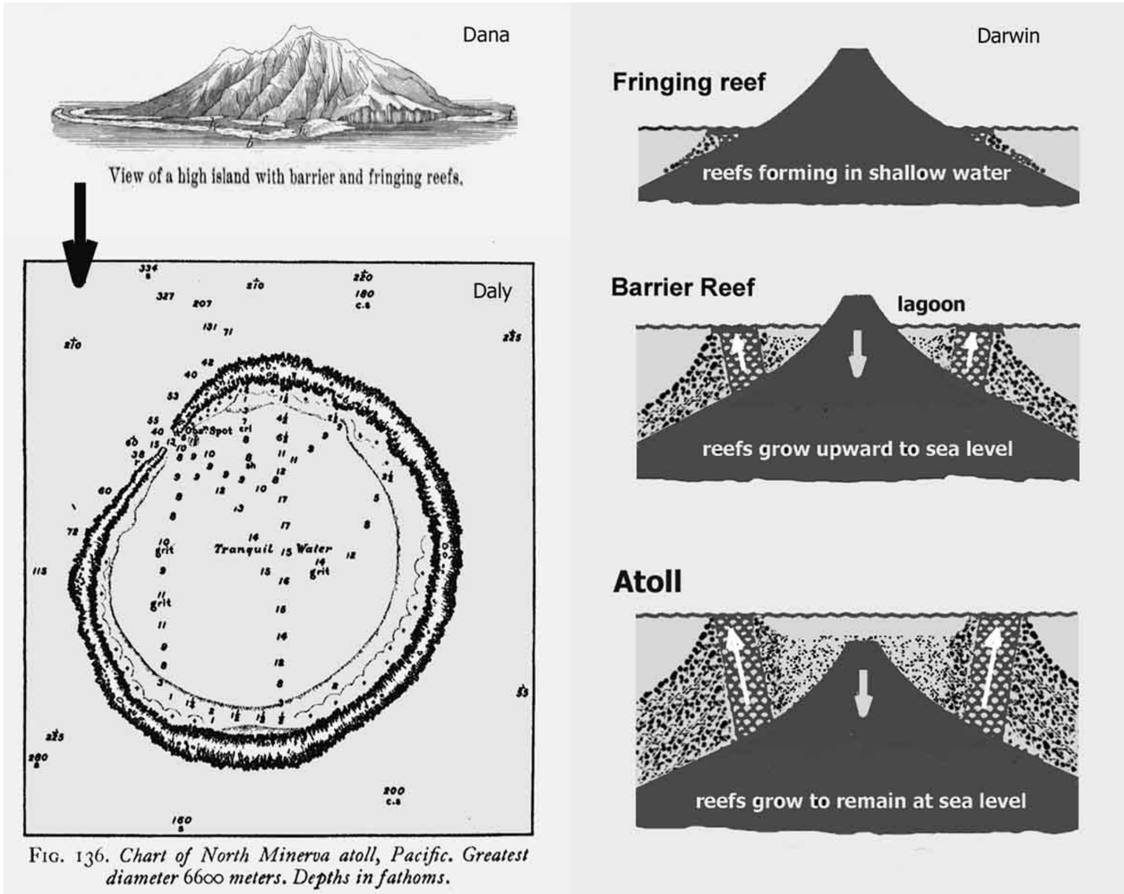


Fig. 4.14. Darwin put an arrow between fringing reef and atoll, postulating the sinking of islands (right). The drawings on the left are by Dana and Daly. Darwin's scenario, while correct in principle, does not address the origin of lagoons.

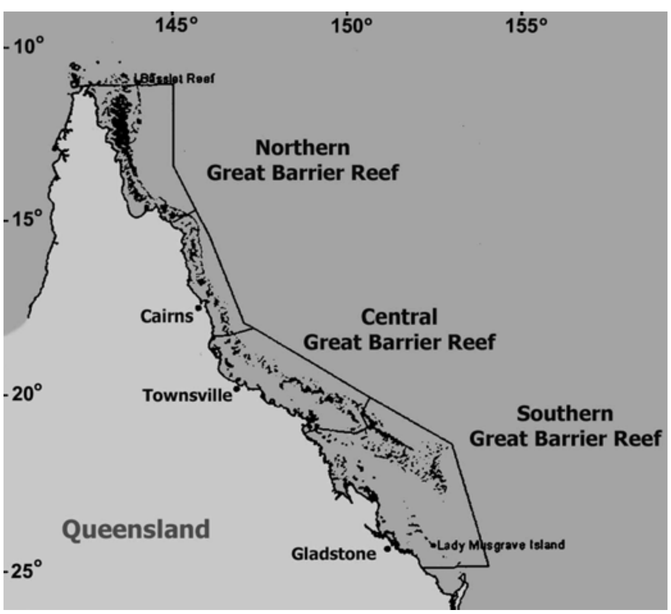
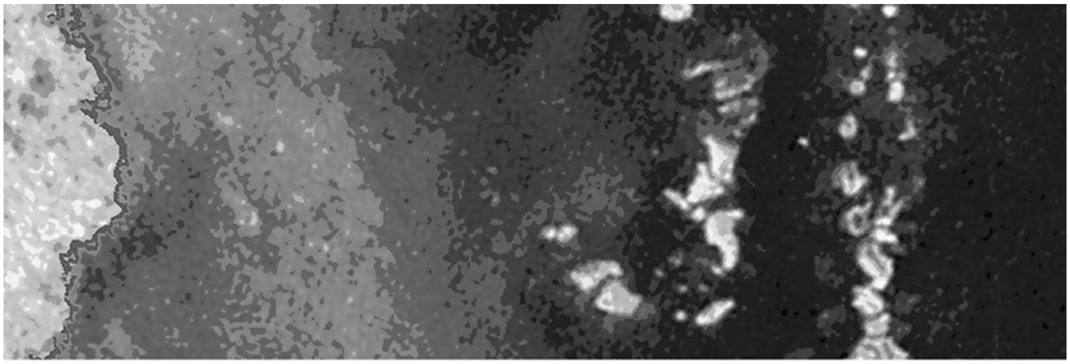


Fig. 4.15. Geographic position and extent of the Great Barrier Reef. The GBR is geologically very young (late Quaternary). Presumably its growth was stimulated by an expansion of the warm-water pool in the western tropical Pacific. Such expansion is expected from a clogging of the exit of the pool's water to the Indian Ocean, from increased production of coral rubble by fast-growing branched corals, whose dominance is newly favored by substantial fluctuations in sea level, in the last million years.



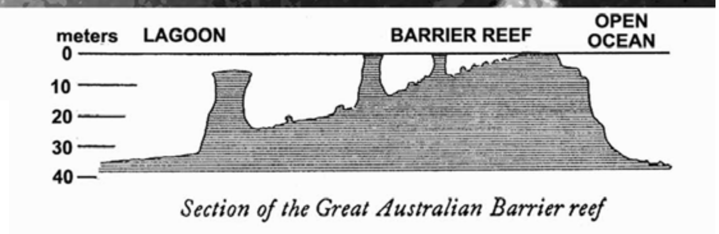


Fig. 4.16. Partial view of the Great Barrier Reef from space (top), showing patchy nature, and a cross section drawn by R.A. Daly, in 1936 (bottom).

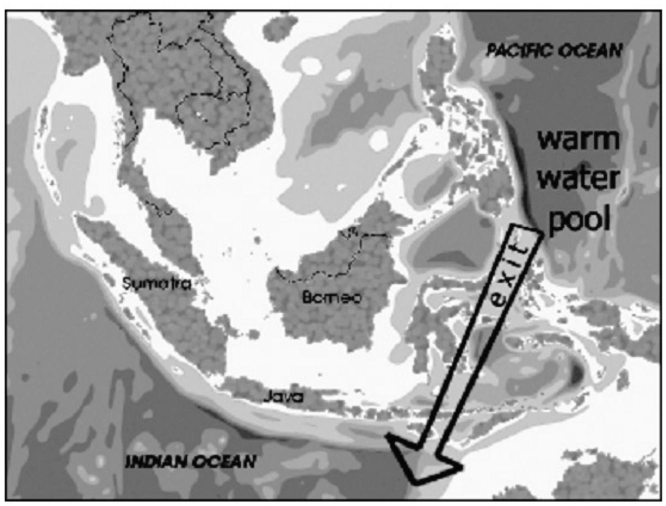


Fig. 4.17. Map of the Indonesian passage, where warm water moves from the western Pacific warm pool to the Indian Ocean. All land here is rimmed by coral reefs.

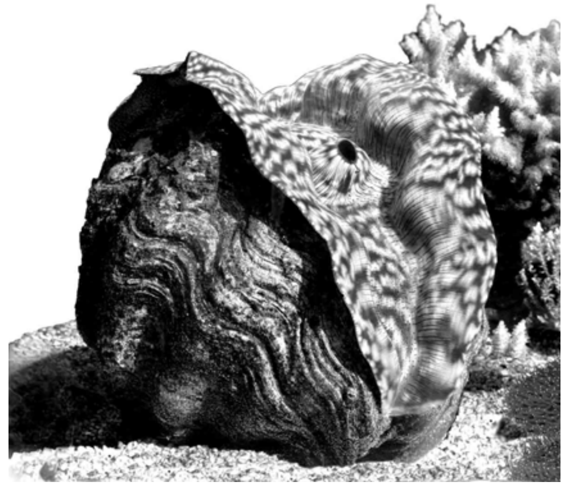


Fig. 4.18 *Tridacna*, largest bivalve on the planet. Like coral, it uses symbiotic algae to increase its food supply.

Figure sources (where based on sources in the literature, on the web or in museum exhibits: figures are considerably modified and adapted for present purposes, using Adobe Photoshop; drawings and photographs by the author are marked “orig.”): 1, Aquarium of the Pacific, Long Beach (orig.); 2, Parker and Haswell 1921, and E. Haeckel (center, see Ch. 1 for reference); 3, Daly 1936; 4, SIO Explorations; 5, Chadwick-Furman, 1996, and NOAA 1993; 6, Kinzie and Buddemeier 1996; 7, orig.; 8, orig.; 9, SIO Explorations; 10, L.A. Nat. Hist. Museum (orig.); 11, after R.A. Kinzie with orig. additions; 12, orig.; 13, orig.; 14, J. Dana, R. Daly, and C. Darwin; 15, Harriott and Banks 2002; 16, Landsat 7, NASA, and Daly; 17, orig.; 18, Aquarium Honolulu (orig.).

References: J.T. Parker and W.A. Haswell, 1921, *A Text-Book of Zoology*, v. 1, McMillan and Co., London, 816pp.; R.A. Daly, 1936, *The Changing World of the Ice Age.* Yale University Press, New Haven, 271pp; N. E. Chadwick-Furman, 1996. *Reef coral diversity and global change.* Global Change Biology, 2, 559-568, and National Oceanic and Atmospheric Administration, U.S. Department of Commerce (SST); R. A. Kinzie III and R. W. Buddemeier, 1996. *Reefs happen*. Global Change Biology, 2, 479-494; J. D. Dana, 1872. *Corals and Coral Islands.* Dodd and Mead, New York, 398pp., R. A. Daly, 1936 (*ibid.)*, and Charles Darwin, 1842. *The Structure and Distribution of Coral Reefs*. Smith Elder, London. (3rd ed. 1889: 344pp.) as interpreted in E. Seibold and W.H. Berger, 1993. *The Sea Floor, An Introduction to Marine Geology*, Second, Revised and Updated Edition. Springer Verlag, Heidelberg, 356pp.; V.J. Harriott and S.A. Banks, 2002, Coral Reefs 21, 85; U.S. National Aeronautics and Space Administration.