g9 Slope of oceanic rises, atolls and guyots < plate thickening >

> "I wish," Darwin had written, in the year preceding his death, to the American oceanographer Alexander Agassiz, "that some doubly rich millionaire would take it into his head to have borings made in some of the Pacific and Indian atolls, and bring back cores for slicing from a depth of 500 or 600 feet."
> —Norman D. Newell *Questions of the Coral Reefs,*1962.[1]

> The scientific expedition that was dispatched to the Ellice Islands by the Sydney Geographical Society has ... confirmed Darwin's theory of the formation of coral islands. Reports from Samoa are that the diamond drill went down 557 feet in the coral without reaching the bottom. Beyond 487 feet, the results strongly favor Darwin's theory, though a final judgment depends upon microscopic examination of the drill cores [for shallow-water coral species and algal reef rock, as the finding of only *deepwater* coral species at depth would negate Darwin's theory]. —*Scientific American,* December, 1897.[2]

> The main purpose of the voyage [HMS Beagle, 1831-1836] was to survey the coastlines of southern South America. In addition, the Admiralty had requested that Captain FitzRoy should make geological maps of coral islands and record their shape and slope in order to provide information that might test the recently proposed theory that they were underlain by volcanoes. —Sally Gibson.[3]

In the plate tectonic model of seafloor spreading, the lithosphere thickens as it cools (isotherms in it become lower) away from the ridge and, in obedience to isostasy, the seafloor deepens. There should also exist a correlation between the rate of seafloor spreading and the slope of the oceanic rise: the faster the rate of seafloor spreading, the gentler should be the slope of the oceanic rise. This is so: Accurate world topographic-data are available from the National Oceanographic and Atmospheric Administration in Boulder, Colorado. Their ETOP05 digital database gives land and seafloor elevations on a 5' x 5' grid. Simple thermal models of conductive cooling of oceanic plates, seafloor subsidence B and mean depth A of mid-ocean ridges are described by a function of the type: A+B x $(age)^{½}$. A 1989 model by J. C. Marty[4] is: 2,400+315 x $(age\ in\ My)^{½}$ meters.

DARWIN'S THEORY OF ATOLLS

Darwin's "theory of atolls," first read to the Geological Society of London, May 1837, is given in outline in his *Journal of Researches,* 1846, Vol. II, pages 261-281.[5] His theory does not so much address the origin of atolls as it does marshal evidence for his proposed (but false, we now know) see-saw model of: Andes-mountains-up where volcanism is active and Indo-Pacific-basin-down where volcanoes have gone extinct.[6] The motions, in accordance with Lyell's *Principles,* will have been gradual (i.e. multiple Maria Graham events—she had recorded that after the 1822 earthquake in Chile "shells adhering to [coastal] rocks ... being all dead and exhaling most offensive effluvia" evidenced that the land had risen).[7] Marine fossils of familiar species at high altitudes show them to have been raised geologically recently from below sealevel. At Valparaiso "Beds of shells were traced by [Darwin] at various heights above the sea, some a few yards, others 500 or even 1300 feet elevations, the shells being in a more advanced state of decomposition in proportion to their elevation."[8] While a measure of the actual rate of Andean uplift eluded Darwin, the gradual subsidence of the Indo-Pacific seafloor, he would argue, can be inferred from atolls, which idea occurred to him at Tahiti, November 1835.

Observations To corroborate his already-in-place "theory," Darwin noted:

1) Although living corals look flowerlike, the brightly colored polyp that secretes the cup-shaped shell in which it sits, is an animal. This knowledge dates back to the findings of the French naturalist René de Réaumur (1683-1757). Unlike a plant that needs sunlight to live, an animal can live in the dark. So Darwin sought to satisfy himself of Jean R. C. Quoy and Joseph P. Gaimard's finding in 1825 that reef-building corals are not found alive in water deeper than sunlight reaches.[9]

2) On the steep outside of Keeling atoll (where the *Beagle* tarried April 1-12, 1836, in the Indian ocean mid-way between Australia and Sri Lanka and about 600 miles south of volcanic Sumatra), living reef-corals cannot be found at depths greater than 35 to 55 meters. Captain Fitz Roy determined this by the sounding practice of putting tallow on the weight at the end of a lead line to obtain impressions of the seafloor (***Footnote g9.1***). Living coral does not tolerate sand that may

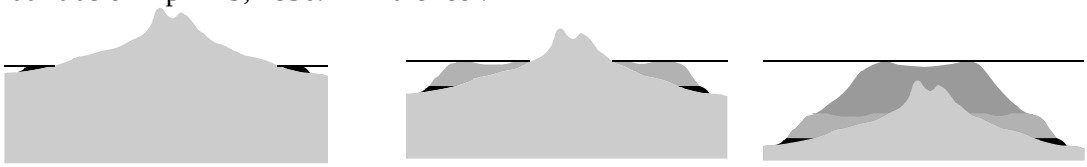
settle on it and will work to shift it away. To depths of 18 meters, living coral left impressions in the tallow but no sand clung to it. As depths increased outward from the reef, coral impressions became less numerous and sand came to cling, more and more, to the tallow. At depths greater than 55 meters on the steep-sided reef, there was only evidence of sand.

3) Three types of island organic reefs (*after* Darwin's illustrations in *J. of Researches*. 1846):

"*Fringing reef*" A coralline reef attached with no intervening deep water channel to the rocky shoreline of an active or dormant oceanic volcano. Term coined by Darwin for a shore reef of the type he first saw at Mauritius on April 29, 1836.

Barrier reef A coralline reef that stands seaward, well out from the shoreline of an extinct oceanic volcano (as at Tahiti). The lagoon between is shallow by comparison to the deep ocean on the far side of the reef.

Lagoon-island, or Atoll A coralline island (as is Keeling atoll) in the open, deep ocean, that consists of a shoaling coralline reef about a shallow, pellucid, lagoon.



Hypothesis Atolls originate as fringing reefs to land (as the shallow-water coral species that build them cannot have grown upwards from the deep seafloor). "... as Sumatra [600 miles distant] rises, ... the other end of the lever sinks down; Keeling Island thus acting as an index of the movement of the bottom of the Indian Ocean." The corals of its fringing reef die but upon this "drowned coral" living coral builds upward. The barrier reef is an intermediate stage of upward growth of the reef on a sinking fringing reef. The atoll is when, at a later stage, the land to which the fringing reef is attached has become entirely submerged. "Throughout the spaces interspersed with atolls, where not a single peak of high land has been left above the level of the sea, the sinking must have been immense in amount. The sinking, moreover, whether continuous, or recurrent with intervals sufficiently long for the corals again to bring up their living edifices to the surface, must necessarily have been extremely slow."[10]

Test of Darwin's hypothesis: Atolls evidence slow regional subsidence where volcanoes are extinct.

In 1904 the atoll of Funafuti was chosen by the Committee of the Royal Society as a site to drill.[11] All parts of the bore to its depth of 1114 feet yielded reef-building coral forms, most still living at Funafuti, and calcareous algae, such as *Halimeda* and coral encrusting *Lithothamnion*. Of the organisms examined in the cores, all, including foraminifera, mollusca, and echinoderms, are of forms characteristic of shallow water. No trace of deep-water forms was found.[12]

In 1952, two borings, on Eniwetok atoll (the Castle-Bravo test on March 1, 1954, yielded 15 megatons),[13] drilled through 4170 feet of shallow-water reef limestone and back in time (as dated by contained foraminifera) to the Eocene before reaching volcanic rock (olivine basalt) below.[14]

MODERN THEORY OF ATOLLS

Away from the volcanically active end of an aseismic ridge, extinct volcanoes are lowered progressively by isostatic adjustment to cooling that thickens the lithosphere and thins the asthenosphere). Erosion of an extinct volcanic mountain, in that part of it that stood above sealevelbefore it become submerged and where fringing-reef corals are not attached, results in a guyot.Where fringing reef corals attach and grow upward as the volcano submerges, a barrier reefresults and later, when the extinct-volcano's peak has disappeared below sealevel, an atoll. However, William R. Dickinson notes that the "annular Holocene reefs of modern intra-Pacific atolls grew during the past 8-9 ka after rising postglacial eustatic sea level overtopped the degraded [to -15 m] remnants of last-interglacial reefs exposed to subaerial weathering during the last glaciation. Raised atoll rims do not reflect the upward growth of ancient fringing reefs surrounding volcanic islands that have subsided beneath atoll lagoons, but were produced as solution ramparts rimming carbonate platforms exposed to the atmosphere during synglacial drawdowns [to -120 m] in sea level."[15] ❑