Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 3

The Darwin Point: a conceptual and historical review

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Abstract. The term "Darwin Point" is defined as the geographic or depth limit (threshold) beyond or below which coral reefs drown. Reef drowning occurs when net production of $CaCO_3$ or vertical accretion of the reef no longer keeps up with relative sea level. If sea level is rising very fast, then reef drowning can occur even if there is very low vertical accretion. If present ecological conditions were to change, due to a rise or fall in sea-level, geophysical uplift or subsidence, or Global Climate Change, the geographic location or depth limit of a Darwin Point would also change. In this paper, the history of the Darwin Point concept is reviewed and several examples are given of reefs and atolls that have drowned having exceeded a Darwin Point threshold. Such appears to be the case for: 1) guyots beyond the northwestern end of the Hawaiian Archipelago, 2) atolls that crossed equatorial latitudes due to plate movement in the Pacific during Cretaceous Time, and 3) many drowned reefs extant at the present time; a result of sea-level rise since the last Glacial Maximum 21,000 years ago.

Key words: Darwin Point, coral reef drowning, coral growth, bio-erosion

Introduction

Darwin Points define thresholds of reef drowning. A Darwin Point is reached when the net production or the accretion rate of $CaCO_3$ by reef building corals no longer keeps pace with relative sea level. In 1972, K. Chave (Chave et al. 1972) described net production of $CaCO_3$ as the $CaCO_3$ permanently retained by the reef. Reef drowning occurs when production rates due to coral growth are exceeded by rates of bio-erosion and physical induced loss, and/or rates of subsidence or sea level rise.

Application to the Hawaiian Archipelago

The Hawaiian Islands consist of a long and linear chain of volcanic islands, coral islands and atolls, which are slowly subsiding and gradually drifting (by tectonic displacement) to the northwest from tropical into subtropical latitudes and cooler water. The growth rate of reef building corals surrounding the islands should therefore decrease with increasing latitude within the island chain. At one point the growth of corals should no longer support and sustain atolls at sea-level. This point defines a threshold for atoll development. The research needed to test this hypothesis was conducted between 1978-1981 (Grigg 1982). Rates of gross production of $CaCO_3$ per unit area were measured from the first island of Hawaii to the last island in the Hawaiian Archipelago, Kure Atoll, a range of latitude of about 10 degrees (~19.5–29.5 N. Latitude). The data were collected at comparable stations and depths. All stations were located off southwest exposures off the islands or banks at depths of 10 m in areas of maximum reef development.

At each station, coral growth was measured by averaging the width of at least ten annual growth bands (Knutson et al. 1972) in skeletal cross sections of ten colonies of the most abundant species, *Porites lobata*. Colony mass accretion in kg $CaCO_3$ was calculated as the product of mean linear growth rate and mean colony density. Mean values of mass accretion for colonies of *P. lobata* were then computed for each island and multiplied by measures of mean coral cover for all species of coral, producing mean rates of accretion due to all corals in Kg $CaCO_3/m^2$/year (Fig. 1). *P. lobata* is considered representative of other Hawaiian coral because of its massive growth form, and because it is intermediate in growth rate (Buddemeier et al. 1974). It is also the dominant framework builder in the Hawaiian Archipelago (Grigg 1983).

All measures of growth were taken along axes of maximum growth in each colony. Estimates of coral bottom cover were taken from optimal areas, where rates of accretion were considered estimates of maximum gross production for corals. In optimal environments in Hawaii, rates of erosion and dissolution are small and gross production is a reasonable approximation of net production. In fact, estimates of calcification based on the method used here agree well with measures of net calcification based on alkalinity depression for comparable areas in Hawaii (Kinsey 1979).

The results of the study showed that islands drown at a point very close to 29 degrees north latitude, although consideration of historical patterns of sea-level change or climatic change may have periodically shifted this threshold, dubbed the Darwin Point, northwest or southeast in response to changing sea level or thermal structure (Grigg 1997).

The data illustrates that coral reef accretion declines linearly as a function of latitude from Hawaii in the southeast to Kure Atoll in the northwest (Fig. 1). Mean accretion rates of the reefs due to coral growth alone at the southeast and northwest extremes of the Archipelago were 11 mm/yr (15 kg $CaCO_3/m^2/yr$) and 0.2 mm (0.3 kg $CaCO_3/m^2/yr$), respectively. The accretion rate at Kure Atoll of 0.2 mm/yr is very close to zero and taking into account biological and physical erosion, it is reasonable to conclude that it is virtually zero. On a longer time scale, Kure Atoll will likely undergo drowning and join 12 other drowned atolls (guyots) that exist in a linear sequence to the northwest. These drowned features are known as the Emperor Seamounts and all were once thriving atolls southeast of a Darwin Point latitude. They range in age between 30 and70 Ma. Their geomorphology and fossil summits strongly suggest they were all thriving atolls before drifting northwestward past a paleo-Darwin Point. The Darwin Point thus separates the Hawaiian Archipelago into two approximately equal halves; islands that are presently at or above sea-level and those that have drowned. All sub-aerial islands are southeast of the Darwin Point; all drowned guyots are northwest of the Darwin Point.

Application to atoll drowning near the equator during Cretaceous Time

In 1993, the Ocean Drilling Program (ODP), legs 143 and 144, recovered cores from seven guyots in the northwest Pacific Ocean. Analysis of the cores showed that these volcanic edifices underwent prolonged volcanism (128-84 Ma), followed by subsidence, accumulation of shallow-water coral reef carbonates, emersion due to a sea-level fall, and then continued subsidence, submergence and eventual drowning. According to Peter Flood (1999), five of the seven guyots drowned at latitudes within 8 degrees of the equator having been transported there by plate movement during the Mid-Cretaceous. Flood ascribed the drowning events to be the result of the atolls entering a crisis zone (Darwin Point) near the equator where upwelling produced nutrient rich waters that inhibited carbonate production (Figs. 2 and 3). Flood also suggested that sea-level rise could have been an additional factor causing the drowning of these atolls. In support of this hypothesis, Schlanger et al. (1981) concluded that wide-spread mid-plate volcanism between 100-70Ma caused thermally induced uplift of the Pacific and Farallon plates leading to global Cretaceous transgressions (Fig. 4). Thus a shifting Darwin Point near the equator in the Western Pacific Ocean could be the explanation for the drowning of these and other atolls that were transported through equatorial waters by plate motion during Mid-Cretaceous time.

Application to a depth limit for the accretion of coral reefs

It is well known that the critical depth for the formation and accretion of coral reefs in optimal environments is generally found at depths between 30-50 m (Grigg 2006, Grigg and Epp 1989, Hopley 1982, Darwin 1962 Reprinted). In environments less than optimal, critical depth would be expected to be shallower. Critical depth as described herein may conceptually be viewed synonymously with a Darwin Point in the third dimension, e.g., a vertical Darwin Point. While this synonymy is somewhat semantic, the factor or factors producing a Darwin Point are not.

Because calcification rates in hermatypic corals are significantly greater than species lacking zooxanthellae, light has long been considered the primary factor setting the lower depth limit for the reef building process (Barnes and Chalker 1990, Wells 1957). This is particularly true for gross production of $CaCO_3$ by reef building corals (Chave et al. 1972). However, if depth limitation depends on the net carbonate production retained by the reef, then many other intervening factors such as temperature, turbidity, bio-erosion and mechanical losses due to waves must be considered. In whatever case, when net production is zero (assuming constant sea-level change) the over-all reef is at a drowning threshold or vertical Darwin Point.

Recent measures of a vertical Darwin Point have been made off Lahaina, Maui in the Au'au Channel in the Southeast Hawaiian Islands (Grigg 2006). The threshold depth of reef drowning there was found to exist at 50 m (Fig. 5). Below 50 m, the rate of bio-erosion of the holdfasts of the major reef building species, *P. lobata*, exceeded the growth of basal attachments causing colonies to detach from the bottom. Continued bio-erosion further eroded colonies until they were dislodged by bottom currents leading to their breakdown and ultimate formation of carbonate rubble and sand. Coral colonies of species that grow deeper than 50 m in the Au'au Channel, (some down to 120 m [Kahng and Maragos 2007]), do not permanently attach and accrete. A Darwin Point is reached at 50 m in the Au'au Channel, off Maui, because gross carbonate production minus bio-erosion is zero (Fig. 5). In an analogous manner, biological and mechanical erosion at Kure Atoll in the NWHI reduces a positive net rate of $CaCO_3$ production there to zero, giving way to a zoogeographic Darwin Point near 29° North latitude. Similarly, Darwin Point thresholds were surpassed many times along the outer edge of the Great Barrier Reef during the last transgression (Hopley 2006).

In summary, Darwin Points are found at both latitudinal and depth limits where the net production of $CaCO_3$ retained by the reef is zero relative to sea level. The critical depth for the entire reef is a Darwin Point, but it may be deeper for individual corals. Historically, Darwin Points have existed since the evolution of reef building corals at the beginning of the Mesozoic Era. They have set both the zoogeographic and depth boundaries for coral reefs for 240 Ma and continue to do so. Interestingly, in 1837, while viewing the island of Moorea from an elevation of about 300 m above Point Venus on the island of Tahiti, both limits were conceived conceptually by Charles Darwin himself (Darwin 1851).

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