On the Formation of Atolls – Proposed Modification of Darwin's Theory

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7 May 2019

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Aug. 4, 2012, last revised May 1, 2019
Submitted to *Principia Scientific Intl.* as a PROM paper for open public review.

Introduction

Atolls are annular (meaning circular or ring-shaped) low level islands, occurring in tropical waters of the world's oceans, primarily in the western Pacific.

Dictionary.com [1] defines "atoll" as "a ring-shaped coral reef or a string of closely spaced small coral islands, enclosing or nearly enclosing a shallow lagoon." The number of atolls in the world is approximately 500; there does not appear to be a definite count.

Origin of Atolls

The great explorer Charles Darwin (1809-1882) described the principles of atoll formation nearly 150 years ago [2]. According to Wikipedia, Darwin defined atolls as "...circular groups of coral islets [...] and [the word] is synonymous with 'lagoon-island'."

Darwin's observations and interpretations continue to be recognized as the leading theory on atoll formation. He concluded that atolls are originating from extinct underwater volcanic events, where magma was pushed up to the oceans' surface and, after being settled by corals and subsequent sinking of the earlier volcanic domes, resulted in annular atolls.

Corals

Corals are organisms of the animal kingdom which take up calcium (Ca^{++}) and carbonate (CO_3^{--}) and bicarbonate (HCO_3^-) ions from the surrounding water and deposit them as hard calcium carbonate ($CaCO_3$), in a crystal lattice of either the minerals calcite or aragonite. As the corals live close to the surface, but not out of the water, and grow more or less constantly, they have to expand their colonies outward. Over time, in the order of millions of years, that process leads to annular islands enclosing shallow lagoons.

DARWIN'S THEORY

Darwin concluded that atolls were the result of **two simultaneously occurring events**, namely that of coral reef growth and the gradual sinking of the (original) volcanic islands.

There is (an implied) corollary to Darwin's theory, namely that the original volcanic domes never extended much beyond the sea surface. Despite rising from ocean depths of several thousand meters, the atolls are barely out of the water. (Alternatively, they were all eroded to the same level, irrespective of their original height above the sea).

My point here is this: Darwin may well be right in terms of the basic process but something else is needed to explain the similarities between so many atolls found far from each other, even in different oceans. This commonality in their small elevation above the ocean surface can hardly be explained by identical rates of growing and sinking. The occurrence of hundreds of atolls on all tropical oceans, with all being barely elevated above the sea, must have a more causative

explanation than the "**simultaneous sinking**" of the volcanic domes at a rate equal to that of coral growth.

Underwater Volcanoes

One question which has vexed me for some time is "How did the underwater volcanoes know when to stop growing when their domes were hitting the water surface?" Of course, there is no such knowledge by the volcano at the bottom of the sea.

Even if the coral (upward) growth was simply a factor of the rate of sinking of the former volcano, it still leaves the question as to why the volcano stopped growing once its dome was near or barely above the water surface. Many of the atolls' volcanic domes rise thousands of meters above the sea floor, to just below the ocean's surface.

Even if Darwin's theory about their "sinking" were correct, it still leaves open the question as to how the volcanoes "knew" when they reached the ocean's surface, either stopped growing near there and/or started sinking?

I think I have found the answer and it entails a small modification of Darwin's theory.

MY THEORY

My theory is a modification of Darwin's theory, specifically in regard to his postulate of the "sinking" of the original volcanic islands. My theory also explains why there are so many atolls that barely rise above the sea level.

Point-1

The first point is that not all volcanoes are alike. There is certainly nothing new here. However, it begs the question as to their similarities as well as their differences – both are critical to the understanding of atoll formation.

Point-2

The second point is many "atolls" are indeed rising far above the sea level, though it depends somewhat on the definition of atoll. If that definition entails the two **concurrent** requirements of both "a ring-shaped coral reef" and "enclosing or nearly enclosing a shallow lagoon" then islands with a surrounding coral reef but without a lagoon would not be atolls. For example, some tropical ocean islands certainly have large "ring shaped coral reefs" while not enclosing a central lagoon. Can they be considered "atolls" as well? I would like to think so.

The most important point of my theory is that the differentiation as to whether a volcanic dome rising from the sea floor will end up to become an island or an atoll is based on the type of volcanic material emitted. It is the actual composition of the volcanic emission which determines whether a subsea volcano has or will become an "island" or an "atoll" over time.

As is well known, volcanoes emit magma and gases. The ratio of magma to gases (mostly carbon dioxide, CO_2) varies from near nil to near infinite. Most volcanoes though emit both at comparable rates. Of course, if rising from the deep ocean, the magma and gas mixture will quickly be cooled and solidified by the surrounding water.

For underwater volcanoes, the mixture of liquid magma with a high content of gas will produce a type of frothy rock material that has a very low density, close to the density of water, or even less than water. In fact, some volcanic pumice has an initial **density** as low as 0.25 g/cm^3 [3] and actually floats on water until its minute glassy spheres become waterlogged. Indeed, floating masses of pumice, a loose assemblage of gas-filled hardened magmatic emissions from underwater volcanoes have repeatedly been observed, some as large as several hundred square kilometers [4].

Point-3

Because of that low density (of the magma and gas combined), such volcanic emissions from subsea volcanoes deep in the ocean will quickly expand until the dome reaches the ocean's surface. This is also evident from the near vertical slopes of the volcanic dome of many atolls. Essentially, they will rapidly grow towards the surface because of the positive buoyancy. One could say: the domes grow by themselves caused by a density less than the water and – if not fully rigid yet – by the expanding gas volume in water closer to the surface, hence less compression by the surrounding water pressure. Any SCUBA diver can observe that effect of expelled air bubbles increasing in size and speed as they rise to the surface. This likely also explains the near vertical slopes of the volcanic domes of many atolls.

Point-4

Once the gas-rich and solidified magma reaches the ocean's surface, the situation changes abruptly. The effective density of the solid magma changes from substantially less than 1 (in the water column) to 2-3 for the part extending beyond the ocean surface in the air. Just like a human body has near neutral buoyancy in water, standing or walking on land requires not only strength but also a solid surface that can take a foot's pressure.

Prior to reaching the ocean surface, the magma plume essentially was lifted towards the surface by its positive buoyancy (**negative weight**, relative to water). Once the dome extends above the ocean surface that part's suddenly appearing **positive weight** will tend to do two things.

One effect is that the sudden appearance of a considerable weight of the mass above the water will tend to slow down the further expansion of the dome into the air. Very simply, the volcano has now to push really hard to elevate that mound further up into the sky. The second effect is that this weight will tend to **compact** the material below in the water column, which would be a very porous structure with both gas and water filled cavities. In combination, both effects will rapidly reduce or entirely eliminate the volcanic domes' growth beyond the surface.

Point-5

Not only will the rock/gas type mixture which has pushed up above the ocean surface be more difficult to elevate further, because of its porous structure, it will also be much more prone to **EROSION** by water and wind than its underwater part. It is already a sponge cake to begin with. Therefore, the erosion forces will take it down – back to the water level, or a little lower – in a hurry. That **combined process of COMPACTION (the more important force) and EROSION will be forming atolls.** Examples of that are the many atolls in the Pacific, the Maldives, and the Cocos Islands.

Point-6

In contrast to the high gas-content magma leading to the formation of atolls, sub-sea volcanoes that emit magma of little gas content cannot compact, and can keep pushing their domes well above the ocean surface. Their material is also much harder and much more resistant to

erosion and, therefore, remains there for a long time. Consequently, those volcanoes **will be forming islands.** Examples of that process are the Hawaiian Islands, and the Azores.

SUMMARY

I propose a modification of Darwin's theory on the formation of atolls as from requiring the assumption of the concurrent and equal rates of the volcanic domes "**sinking**" and "**coral growth**" (his theory) to the concurrent and equal rates of the volcanic domes "**compacting as they rise above sea level**" and "**coral growth**" (my theory). The ability to compact (or not) is a function of the volcanic material emitted, in particular the rock/gas ratio of the emission and its resulting apparent density in the water column.

This proposed revision of Darwin's theory readily explains both the formation of atolls, such as found in Melanesia or Micronesia, and the existence of mountainous islands with hard basalt type rocks, such as in Hawaii.

References and Definitions

[1] http://dictionary.reference.com/browse/atoll
[2] C. Darwin, 1842. *The structure and distribution of coral reefs*.
[3] pumice density: wiki
[4] https://nerc.ukri.org/planetearth/stories/1686/

Compaction

http://dictionary.reference.com/science/compaction defines compaction as the process by which the porosity of a given form of sediment is decreased as a result of its mineral grains being squeezed together by the weight of overlying sediment or by mechanical means.

Sinking

The term has many different meanings, according to all dictionaries. The one most relevant to this subject would be "to cause to submerge or go beneath the surface."