

...what is an atoll?

by Jan Newhouse

It is characteristic of humans that we attempt to define precisely and/or categorise all that surrounds us. It is also characteristic that such attempts often lead to difficulty and disagreement (e.g., at what height does a hill become a mountain?). So it is with the application of terms to reef types. Definitions and classifications have often resulted from limited personal experience or bias, rather than from a consideration of the broad range which exists. Thus it seems wise to seek an operational definition for "atoll".

The word atoll is taken from the Malayalam *atolu*, "reef", which is the native name for the Maldive Islands. However, many of us do not consider all atolls to be exactly like those of the Maldives. Neither would we wish to be as restrictive as required by the dictionary definition: "A ringlike coral island and reef that nearly or entirely encloses a lagoon". (By such a definition, one would have to exclude from consideration places such as Makatea, Helen Reef and Johnston Island. Besides, what is meant by "nearly"?).

Given the full range of atoll topography, features such as islets and lagoons should not be considered in the definition. It also follows that we wish to exclude islands with lithic features which are volcanic in origin, and other reef types such as fringing, barrier and patch. Such a definition is as follows:

"An atoll is a living reef which is separated from the nearest land of volcanic origin by water having a depth greater than that at which hermatypic corals can grow".

Hermatypic — that is, reef-building — corals are symbiotic organisms. They are

invested by photosynthetic algae (zooxanthellae) which can only survive, grow and complete their role(s) within the euphotic zone — the water layer which is penetrated by sufficient radiant energy to permit these activities. Though the thickness of this water layer varies from place to place depending on turbidity, a generally accepted figure is 80 metres. Hence, relatively shallow reefs (fringing and barrier) bordering volcanic islands are automatically excluded, as are patch reefs found in atoll lagoons.

In any case, since the interest here is mainly focused on the primarily calcareous materials found above the high tide levels (*motu* or islet), whether they be on an atoll or barrier reef, it is this focus which should dominate.

The following discussion of the origin of both barrier and atoll reefs is theoretical but well supported by knowledge pieced together from the clues we have at the present time.

Geological origin

The numerous theories which have been proposed to account for atolls are about as profuse as the definitions. All of them presuppose one or both of two possible conditions: either the submarine basement on which the atoll reef stands and the water level of the ocean have been static during atoll formation, or they have undergone relative shifts up or down.

Since some of these theories stretch the bounds of credibility (e.g., floating coral platforms, coral pounded by waves into volcanic fissures to depths greater than 1300 metres), only the major theories will be taken up here:

(a) **Truncation.** This theory is based on the supposition that a high, volcanic island has slowly eroded away because of atmospheric and ocean-generated forces. After complete erosion had taken place, the resulting surface was covered by reef-building corals. Sufficient evidence exists to discount this theory.

(b) **Antecedent platform.** This theory supposes that, at some time in the past, the floor of the ocean was, or came, within the euphotic zone. Corals began to grow on the bottom and, eventually, broke (or came close to) the ocean's surface to become an atoll. It is possible that several of the Caribbean atolls arose in this manner.

(c) **Subsidence.** A rift, a crack or a "hot spot" opens on the ocean floor and, through this, lava is extruded. If this process should continue for a very long geological period, two phenomena result. For one thing, the floor will slowly sink because of the weight of the new volcanic mass and, secondly, the mass may eventually reach or rise above the surface.

If the new island is in an oceanic area where reef growth can take place, four activities follow: there may be continued island growth (as on the island of Hawaii), subsidence is an ongoing process, fringing reefs will develop, and atmospheric erosion will inhibit reef growth where there is freshwater run-off.

Should the island continue to sink more rapidly than it is being built up by



View to the lagoon, Huahine, French Polynesia.

continued lava flow, the ultimate result would be a broad "table reef" with no material of volcanic origin above the ocean surface.

We suppose that such processes started millions of years ago, and are still continuing today. The resulting oceanic features we see today are of four kinds but, before taking these up, it would be well to discuss eustatic shifts in the level of the ocean.

Carbon dioxide (CO_2) acts as a blanket, holding in the heat from the radiant energy reaching earth's surface. It is found in both the atmosphere and as a solute in the ocean. Let us suppose that we are in a period when the ocean level is low — that is, a cold period when much of the water is held in solid form at the poles. This means that there is less water in the oceans, and a relatively large quantity of CO_2 is in the atmosphere. With such a condition, the temperature of earth will begin to increase, glaciers and polar regions will melt, and the level of the oceans will rise. As this occurs, more liquid water will be available for the solution of CO_2 , the quantity of CO_2 in the atmosphere will become less, and the earth cools.

All available evidence suggests that earth has gone through just such a series of pulsations, with the latest great drop

and rise being 100 and 80 metres respectively.

With this thought behind us, it is now possible to lay out the four oceanic features mentioned above:

- (1) Let us suppose that an island has sunk to the table reef stage *since* the latest great rise in ocean level. We would expect to find a flat-topped reef without a lagoon, e.g., Oeno.
- (2) If the island has been sinking during both the drop and rise, yet is still above the ocean level, one would expect a barrier reef to have developed at the margin of the old eroded fringing reef, e.g., Palau, Truk, Huahine.
- (3) If all volcanic portions had disappeared before the latest great drop and rise, one would expect a new reef margin to have grown up from the former table reef. In this case, there would be a classic lagoon in an atoll fitting the dictionary definition, e.g., Nukuoro, Puluwat, Manihi.
- (4) If, however, there have been tectonic forces as well as the eustatic rise and fall, we could expect a number of varied forms, e.g., Oroluk, Nauru, Swain's.

Since our interest here is with cultivation on islets, it is important to emphasize that there are six means by which materials can arrive on a reef in such a way as to be found above the high tide level:



Making a canoe in Majuro, Marshall Islands.

- (1) In rare instances, alluvium from the adjacent high island can flow out upon its fringing reef. Temae on Moorea is such an area, as was Fetuna on Raiatea following the hurricane of May 1978.
- (2) There can be erosional remnants from the latest drop in sea level of about two metres some 3000 years ago. These remnants are called beach rock or conglomerate, and are found on many atoll rims or even on patch reefs (e.g., Takapoto).
- (3) Due to shifting of the ocean's floor, reef materials can be raised considerably above the present water level (e.g., Makatea).
- (4) Incidental introduction from elsewhere – as, for example, pebbles or stones caught in the roots of a log, or pumice which has drifted in.
- (5) Through human introduction; e.g., soil to Eniwetok, Wake, Canton (often arriving as ballast) and basalt artifacts prized by aboriginal inhabitants.
- (6) Storm action. This is by far the prime origin of islet materials – the reef-derived magnesium and calcium carbonates which are deposited by strong wave action. It is ironic that the conditions feared most by atoll inhabitants are the same ones responsible for the land on which they live.

Climatic characteristics

Though, in theory, atolls should have some influence on their local weather and climate, studies have not been sufficiently definitive, long-term or accurate enough to document these effects statistically. Since, in any case, these effects could be only minor, it is sufficient to state that atolls are subject to the general conditions of the area in which they are located.

“The climate of the Pacific atoll realm is marine and tropical in character. The range in air temperature is about 2^oF annually, with a slightly greater range as one approaches 15 to 20^o N and S latitudes. Winds are mostly those of the trades and associated cyclonic depressions. In the western extremities of the realm, the Asiatic and Australian continental air masses are a factor also. Average relative humidity is high, but sensible tempera-

tures are moderated by the cooling breezes present on atolls. Atoll weather seldom seems oppressive where there is exposure to the prevailing winds”.

Surface winds in the Northern Hemisphere tend to be dominated by those which are easterly, and which rarely reach gale force. Though gales are somewhat more frequent in the Southern Hemis-

precipitation/year for the major island groups with atolls. All figures are rounded off:

The variability from season to season and year to year is extremely significant, almost as much so as the general average rainfall. Since drought occurs on even the wettest atolls and the range of variation can be great, it is mandatory that these extremes be taken into account when

TABLE 1: AVERAGE RAINFALL IN PACIFIC ISLAND ATOLL GROUPS

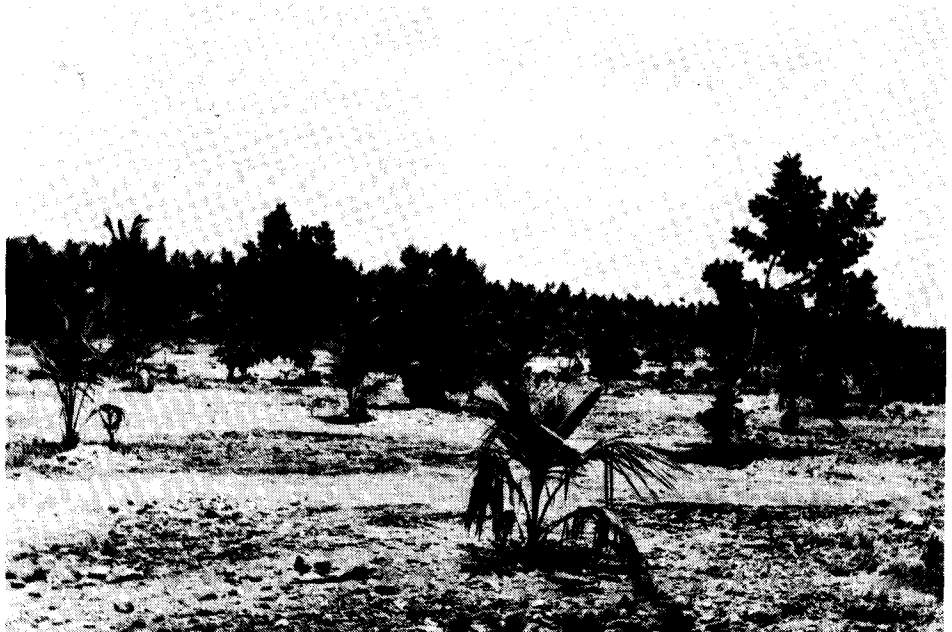
Group	Rainfall (cm)
Marshall Islands	140 (Eniwetok) to 400 (Jaluit): there is a decrease from south to north.
Caroline Islands	200–300
Line Islands	70–330, with the southern atolls drier than those to the north.
Cook Islands	200–280
Tokelau	300
Phoenix	40–130
Gilbert Islands	100–300
Tuvalu	230–360
Tuamotus	120–190

phere, and storms occur more often in the western Pacific, here, too, the winds are generally from an easterly direction.

Rainfall is considerably more variable: from one part of the Pacific to another, by season, and from year to year. Table 1 gives the relative magnitude (average) of

cultivation is considered. As examples of seasonality: dry months in Tokelau are from April to September, and in the Tuamotus from May through October.

Severe yearly droughts are most marked of all. On Onotoa the yearly rainfall has ranged from 17 cm to 220 cm.



Reclamation land with coconut and fruit trees in Tarawa, Kiribati.

Other examples are Fanning (70–530 cm), Penrhyn (90–380 cm) and Malden (10–240 cm). As we all realise, the extremes of weather on atolls have much more significance than they do on high islands. Atoll dwellers have long known that the two most feared natural phenomena are storms, usually accompanied by too much water, and droughts, with too little.

Although weather records have been much more complete these past few decades, I am not aware of any agency or institution which has compiled and coordinated these with atoll cultivation in mind. Since it is obvious that comparative crop studies made on several atolls should include weather records before and during the cultivation periods, it would be well to have a centralised clearing house for these data.

Humidity, temperature, incident sunlight, evaporation, rainfall and wind records should be taken daily, then analysed for both short-term correlations and cyclic phenomena (these latter may permit predictive ability).

Freshwater resources

For completeness, six sources will be considered, though, from the point of view of magnitude, several of these are quite insufficient for either *in situ* cultivation or irrigation:

- (a) The coconut. This certainly served as the prime source of drinking water for several thousand years. All things considered, including the future, it is the most dependable for this purpose.
- (b) Atoll peoples developed a technique for channelling the water running down the underside of coconut trees into containers. Generally speaking, a coconut leaflet was tied on the underside, close to the ground level. This was introduced into containers such as a coconut shell, a wooden bowl or the shell of *Tridacna*.
- (c) Water catchment above ground level is still practised today, but more often and with considerably more efficiency. Galvanised roofing and rain gutters catch and direct water into cisterns of various sizes and construction. In some cases, this water is passed through screens to remove foreign material (e.g., lizards and leaves),



Fresh water is often scarce on atolls.

and the cisterns are covered to discourage mosquitoes. For direct human purposes, this technique is more widely practised on atolls than any other.

- (d) On an atoll, the water may either be caught as above, evaporate from the land surface, be lost as evapotranspiration from plants, run off to the sea or lagoon (in small quantity), contribute to saturation of the matrix making up an islet, or percolate down to the water table.

Depending on three variables, islet size and shape (shape at least as important as size), rainfall (both frequency and quantity) and permeability, a freshwater lens of varying size and stability will form over the underlying salt water. This lens (often called Gyben-Herzberg) will tend to float because of the differences in density between fresh and salt water. It has one part above mean sea level for every forty below, is in dynamic equilibrium (a function of tidal change, rainfall, evaporation and withdrawal by plants and humans), and has a relatively short residence time compared with water tables on high islands.

“Further complications must be con-

sidered in dealing with . . . water inventories. In particular, because of tidal mixing, there may exist only a relatively thin layer of very fresh water, underlain by a deep transition zone of increasingly (with depth) brackish water”. (This mixing may be affected by the geological structure of an islet).

“There are some fundamental limitations to the exploitation of island ground water for a . . . water supply. Most obviously, average annual withdrawal must be less than average annual recharge, since some of the input is inevitably lost to natural mixing processes, etc. Perhaps less obvious is the problem created by withdrawing all or most of the potable water from the lens or some portion of it. This water is replaced in part by more saline water from the transition zone, and when the lens is recharged some of the salt remains behind in the sediments to mix with the incoming fresh water. If repeated, this will result in a gradual rise in surface salinity, even if the actual volume of fresh water is replaced each year.

“A related problem is that of upconing of saline water if withdrawal rates are too high; a wide, thin lens of potable water cannot be fully utilised by pumping hard

at a few isolated points, as this will pull up brackish water from below faster than the fresh water can recharge (the well laterally). Slow withdrawal from as wide an area as possible is the appropriate technique.

"Finally, it must be realised that if a lens system contains as its equilibrium inventory about 10 years' worth of recharge, it will be possible to withdraw water in excess of the recharge for several years before depletion becomes obvious . . . Without careful management, it will be possible to come to rely on a higher production rate than is actually sustainable on a long-term basis".

The management of the lens is vital, whether the concern be for use by plants which are growing on the surface (e.g., breadfruit) as in pits (e.g., taro), or for water to be used in irrigation. As a natural system, it needs to be understood in terms of present characteristics, seasonal variation and long-term averages. Parameters of particular interest are rainfall, evaporation, approximate "head", tidal responses and the chloride content.

Given these measurements, and accurate figures for drawdown by humans, a freshwater budget can be constructed.

The thickest part of a lens is generally nearer the lagoon shore than that of the ocean. This is because the smaller particles making up an islet are found nearer the lagoon: islets having their origin in storm-carried materials, and the smaller materials are carried further. As well, many lagoon shores are subject to local currents which bring and deposit finer particles.

- (e) There is a distinct possibility that distillation might be feasible to augment natural freshwater supplies. Highly technical means which rely on fuels are neither economic nor advisable, but simple yet possibly extensive systems, using black paint, cloth or plastic, could provide water for human consumption, thereby permitting the natural water to be used exclusively for crops.

Thus, in consideration of freshwater

stocks, there are three monitoring programmes and/or studies which are recommended here in connection with atoll cultivation:

- Records of precipitation, evaporation and incident sunlight.
 - Measures on the lens itself, as well as the factors which affect it.
 - The feasibility of distillation. This should include the reliability of sources of supply for all required materials.
- (f) Finally, there is the possibility of barging fresh water from outside the atoll in question. It should be mentioned that, for those who make a living by studying resources, water, though possibly the most important, is considered to be the least economic resource. The plan to tow an iceberg from the Antarctic to Saudi Arabia foundered on economic grounds even though the Saudis have plenty of money and icebergs are free! □

...an overview of agriculture on some Pacific atolls

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1. COOK ISLANDS

The Cook Islands lie roughly east of the Islands of Tonga, above the Tropic of Capricorn. They consist of seven coral atolls in the north (Pukapuka, Nassau, Palmerston, Suvarrow, Rakahanga, Manihiki and Penrhyn) and eight volcanic islands in the south (Rarotonga, Mangaia, Atiu, Mauke, Mitiaro, Aitutaki, Manuae and Takutea).

Cook Islanders have the right to stay or live in New Zealand. Cook Islands links with New Zealand go back to the early

days when ancestors travelled in their warlike canoes and happened to land on a strange island now called New Zealand. The population of the Cook Islands is approximately 25,000, not counting those who are now living in New Zealand.

The Cook Islands' main exports are fruit and vegetables, mostly grown in the southern group. The northern group's exports are mainly copra and pearl shells. Agricultural products are exported mainly to New Zealand. The northern group has very similar agricultural problems to those of other Pacific atolls.

2. FEDERATED STATES OF MICRONESIA

(i) Ponape

Ponape is one of the four States which make up the Federated States of Micronesia. It has eight atolls (Oroluk, Pakin, Ant, Mokil, Pingelap, Ngatik, Nukuoro and Kapingamarangi). Ponape itself is a high island. The total land area is about 162 sq. miles scattered over 170,000 sq. miles of ocean from the Equator to 12°N latitude and between 154° and 166°E longitude. The wet tropical maritime