ATOLL RESEARCH BULLETIN

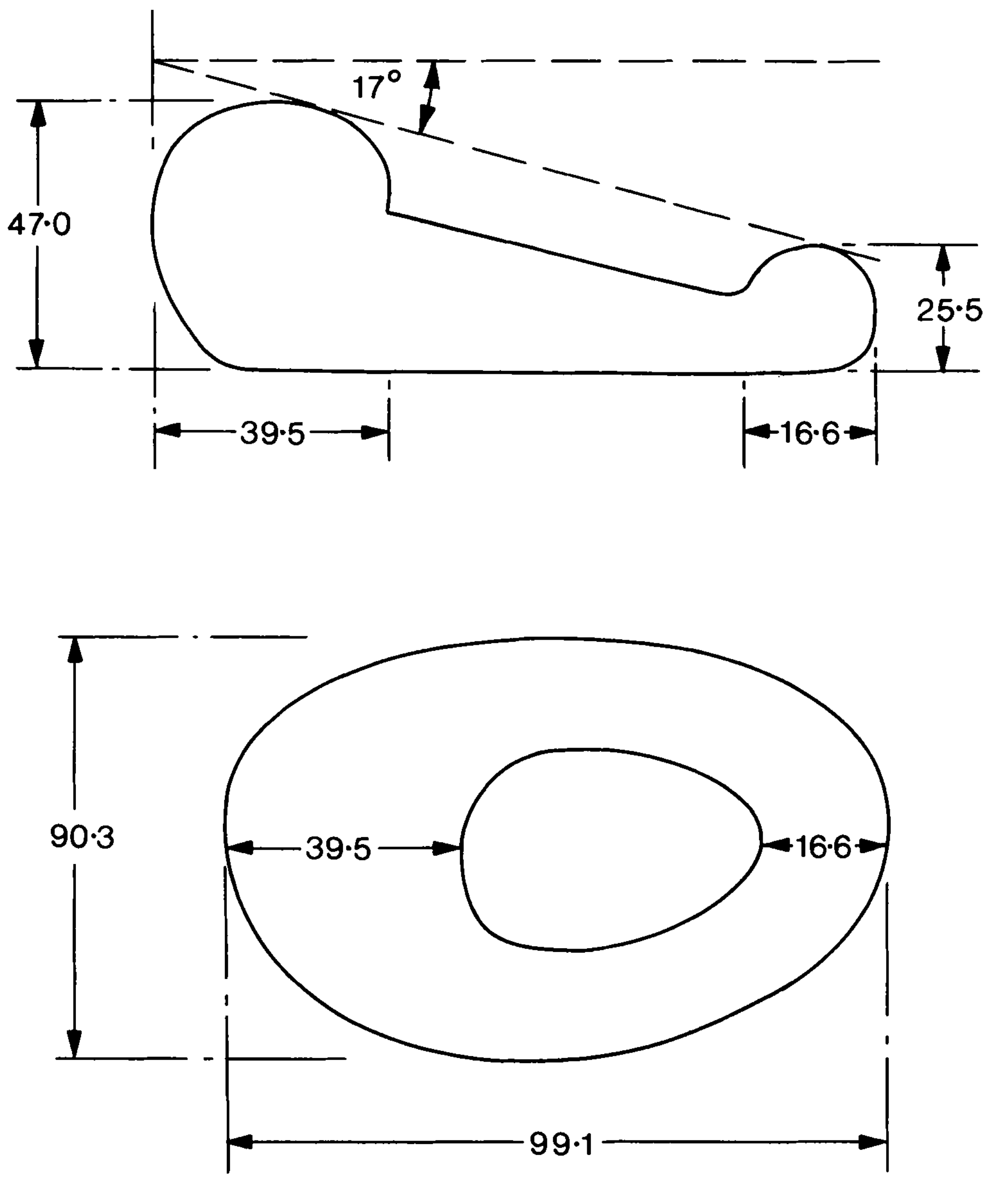
NO. 224

MICROATOLLS: REVIEW OF FORM, ORIGIN AND TERMINOLOGY

by D. R. Stoddart and T. P. Scoffin

Issued by
THE SMITHSONIAN INSTITUTION
Washington, D. C., U.S.A.

September 1979



Not to scale

Figure 1. Dimensions of inclined microatolls of *Goniastrea aspera* (cm), after Abe (1937).

MICROATOLLS: REVIEW OF FORM, ORIGIN AND TERMINOLOGY

by D. R. Stoddart[1] and T. P. Scoffin[2]

Perusal of much recent literature reveals wide differences in usage of terms referring to microatolls (in the sense of individual coral colonies) and small atoll-shaped reefs. Though many writers mention differences in interpretation of such features, there is no comprehensive recent summary of work on the subject, other than R. W. Fairbridge's article on microatolls in his *Encyclopaedia of Geomorphology* (1968). Work by the authors on microatolls during the Royal Society and Universities of Queensland Expedition to the northern Great Barrier Reef in 1973 (Scoffin and Stoddart, *in litt.*) emphasised the need for such a summary, which is provided in the present paper.

GENERAL DEFINITION

Early descriptions of microatolls were given by Darwin (1842, 6), Dana (1872; 1875, 72, 94), Semper (1880; 1889, 224-226), and Guppy (1886), using general names such as coral head or coral block. Thus Dana (1849, 39) described situations where "corals, when growing beneath the water, form solid hemispheres, or rounded hillocks; but on reaching the surface, the top dies, and enlargement takes place only on the sides. In this manner the hemisphere is finally changed to a broad cylinder with a flat top". Possibly the earliest description of this phenomenon was that of Chamisso (1821, 143), who noted that "species, which otherwise assume a spherical form, spread out in places where sand is carried, into flat surfaces, with a raised edge, because the sand kills the upper part, and they can only live and grow on the circumference".

---

1 Department of Geography, Cambridge University, Cambridge, England.

2 Grant Institute of Geology, University of Edinburgh, Edinburgh, Scotland.

(Manuscript received January 1974 -- Eds.)

Guppy (1886) spoke of "miniature atolls", Agassiz (1895) of "diminutive atolls", and Krempf (1927) of "dwarf atolls" ("atolls nains"). The term *micro-atoll* was first used by Krempf (1927, 13), but without concise definition. It was widely adopted and variously defined. Kuenen (1933, 64) used it for "a colony of corals" with "a raised rim, more or less completely surrounding a lower, dead surface". MacNeil (1954, 394) used it for "massive colonial corals growing peripherally in shallow areas and whose dead upper surface (sometimes made concave by solution) is exposed at low tide. Microatolls often form a pavement of closely spaced stepping stones". Such pavements have recently been termed "reef tables" by Fishelson (1973, 193). Most definitions of microatolls include elements of morphology, location, origin, and, rarely, internal structure.

CHARACTERISTICS

Most authors use microatoll "to designate a special type of growth of coral colonies" (Kuenen 1933, 90), not for ring-shaped assemblages of a variety of corals for which the word *faro* is more appropriate (Gardiner 1931, 19; MacNeil 1954, 399; Guilcher 1971, 77; Scheer 1972, 102). Typical microatolls comprise single colonies of massive corals ("monospecific microatolls" of Mergner and Scheer, 1974, 11), especially of *Porites,* usually round (though complexity of form is stressed by Kuenen 1933, 64), and with a flat or concave upper surface devoid of living polyps. Several authors have stressed the importance of a well-defined peripheral ridge of living coral several centimetres high and wide, surrounding the dead inner area (Krempf, 1927, 15); Semper (1899, 226) found this feature present only in larger colonies, and Pichon (1964, 135) found it generally absent in southwest Madagascar microatolls.

Most microatolls are found in pools on reef surfaces or on reef flats. Kuenen (1933, 65) stated that with respect to sea-level the surfaces of microatolls were higher on the windward than the leeward sides of reefs, and that exceptionally high microatolls could be found in ponded situations on reef-flats. Most microatolls described are up to 6 m in diameter. The general characteristics of microatolls may be derived from the following regional descriptions:

> *Cocos-Keeling Atoll.* "One large circular mass of *Madrepora* (with short branches), which measured 18 feet across and 2 feet in height, possessed a dead centre that was depressed 9 or 10 inches below the level of its living margin. ... An adjacent flat-topped mass of *Porites,* measuring 13 feet across, at the same condition of the tide presented an example of another miniature atoll. Its central portion was dead and hollowed out into a basin, which was occupied by a small pool of water" (Guppy 1886, 893).

Bikini Atoll. At Bikini, in the outer *Heliopora* zone of windward reefs, Emery et al. (1954, 28) describe microatolls in "1 to 4 feet of water at low tide ... large subcircular masses, 3 to 25 feet or even more in diameter, consisting largely of the blue alcyonarian, *Heliopora,* [and which] rise close to low-tide level. In the outer part of this zone the microatolls are formed mainly by the scleractinian coral, *Acropora palifera*. This zone is a part of the belt of microatolls. In these structures, as in true atolls, there is a concentration of living forms around the periphery, although live colonies, particularly *Heliopora* and algae, may be growing sporadically all over the structure. The *Acropora,* which apparently is not quite so hardy a form as the *Heliopora,* is concentrated around the edge of the microatoll, and most of the colonies are at a somewhat lower level than the Helioporas; at low tide the tips of many *Heliopora* colonies break water. The upward growth of the microatolls is definitely limited by low-tide level, but the growth around the rim of each structure is rich, and the masses appear to be expanding laterally in all directions. As they coalesce, they form a new reef surface — not so firm a surface as the pavement from which they grow but one that may become so eventually by continued organic growth and silting. Many of the dead Helioporas in the centers of the microatolls are covered by a film of sand very rich in Foraminifera".

Great Barrier Reef. "Typical of the reef flat is the microatoll which is formed by one of several species of coral that grow radially in the horizontal plane and produce a flat-topped mass that is circular in outline or consists of several merging circles. The top of the microatoll is encrusted by calcareous algae and the living coral survives mainly around the margins and outer face. The coral *Porites* forms the compact, purple and brown microatolls which are possibly the most common. The blue *Heliopora* and grey *Goniopora* are also responsible for compact microatolls, while more open structures, generally yellow and pale green in colour, are produced by certain branching species," e.g. at Heron Island (Maxwell 1968, 115). Earlier, fields of microatolls had been described forming "coral platforms" at Low Isles by Stephenson et al. (1931, 46-47): *"Montipora ramosa, Acropora hebes* and massive *Porites* ... exhibit a curious development connected with the shallowness of the water. They grow in a normal fashion until their tops project above the level of low water; they may then survive with projecting tips for a longer or shorter period; but sooner or later the projecting parts are killed, become infested by microphytic algae and sediment, and encrusted by nullipores (Melobesiae); so that ultimately the coral colonies are converted into flat-topped platforms, dead across the top and alive around the edges. This process may affect individual colonies or, if the growth has been dense so that fields of branching corals have been formed, it may convert a whole field into a platform. The general result of this is to create a bewildering maze of level platforms with pools between. ... The extent and composition of the platforms varies in different parts of the moat [at Low Isles]; massive

Porites becomes converted into platforms as readily as the branched species, though the details are a little different. Astraeid corals, especially species of *Favia,* are common among the platform-building forms ... and these also often develop dead flattened tops".

It is clear from these descriptions that both massive (*Porites*) and branching (*Acropora*) scleractinian corals and also alcyonarians (*Heliopora*) commonly form microatolls. Wells (1957) lists six genera of massive scleractinians (*Favia, Favites, Platygyra, Cyphastrea, Goniastrea, Porites*) forming microatolls in the Marshall Islands, together with two species of branching corals (*Acropora palifera, A. brueggemanni*), and also *Heliopora.* Krempf (1927, 15) mentions *Porites, Acropora* and *Heliopora,* and also the hydrozoan *Millepora.* In Madagascar, Pichon (1964, 135) found *Porites somaliensis* Gravier to be the main former of microatolls up to 3 m in diameter, with smaller microatolls lacking a central depression built by species of *Acropora* and *Pavona,* and also *Turbinaria* sp. cf. *stephensoni* Crossland. At Alacran Reef, Gulf of Mexico, examination of 41 specimens of "atoll-shaped heads" and "atoll-shaped coral colonies" (the authors using the term microatoll for larger patch reefs) showed that nearly all species of massive corals found on the reef were represented, forming colonies 2-53 inches in diameter (Kornicker and Boyd 1962, 667). Microatolls are also described in the spicular skeletal material deposited in the tissues of the alcyonarian *Sclerophytum* in American Samoa (Cary 1931, 61).

In addition to "corals" *sensu lato* (Scleractinia, Hydrozoa, Alcyonaria), some authors consider that constructional features formed by other animals morphologically resemble microatolls to the extent of using the same term for them. Rock rims coated by the pelecypod *Brachyodontes erosus* at Point Peron, Western Australia, are termed microatolls by Fairbridge (1950, 52). Similar rock rims coated with tubes of serpulid worms at Bermuda have frequently been referred to as microatolls (Agassiz 1895; Krempf 1927; Fairbridge 1950). Constructions by vermetid gastropods are also so referred to by Krempf (1927) and by Safriel (1974). Coralline algal rims on reef flats and limestone terraces are termed microatolls at Cozumel, Yacatan, by Boyd, Kornicker and Rezak (1963), though where characteristically developed, e.g. in the western Pacific (Lister 1891; Stoddart 1969), they are not annular.

Microatolls have been described in the fossil scleractinian *Heliastraea reussana* Milne Edwards and Haime by Vasicek (1948), but reference to his figure shows that the typical microatoll form is not present in this lobate coral.

ORIGINS OF MICROATOLLS

A variety of modes of origin has been proposed for typical microatolls. Often these modes overlap in several particulars, but broadly three main explanations can be recognised.

(1) Low-water level control

Many authors have suggested that low-water level forms an upper growth limit for coral colonies; that when this is reached upward growth ceases and is replaced by lateral growth, leaving a dead, flat central area. Semper (1899, 224-226) described how up-growing small massive hemispherical colonies would be transformed to microatolls as their upper surfaces reached low-water level, and very similar explanations were given by Kuenen (1933, 64-65) and by Pichon (1964, 135-136). One of the earliest detailed accounts relating form of the corallum to measured water heights was that of Manton (1935, 300) at Low Isles, Great Barrier Reef. She states that: "The upper limit of coral growth is determined in the first place by the range of water level. In the Moat the height of the branched and massive coral platforms appears to be controlled by the permanent level of low water, and lies at 0.3 and 0.15 feet respectively above the latter. Outside the Boulder Tract and rampart coral growth starts at a lower level, just above datum [i.e. level of lowest low water springs] ..., so that corals are only exposed to the air intermittently at exceptionally low tides. No platforms are here formed with flat dead or living tops at a constant level since the water is continually changing, but over the level inshore part of Traverse II coral growth, except for *Acropora hebes*, is checked above 1.6 feet above datum. Massive corals with flat dead tops have been noted in other regions ... The distribution of such dead-topped corals on the traverses and on Low Isles generally, where they are found abundantly in Moats but rarely outside the Boulder Tract, even in regions where sediment is a limiting factor, and the direct correlation of the height of such colonies with low-water level, indicates that here water level and not sediment is the main factor responsible for such growth forms on Low Isles". This relationship is so close that the presence of microatolls in Pleistocene reefs has been used as an indicator of low-water spring tides (Braithwaite et al. 1973, 321).

More recently, Roy (1970, 12-13) has described microatolls, mainly of single colonies of *Porites compressa*, in Kaneohe Bay, Oahu, up to 20 ft in diameter, all rising to within a few inches of lower low water. He finds that the morphology of the microatolls is related to depth of surrounding water, though he does not discuss this relationship in his text (Table 1).

A tidal-level control could explain a flat, bevelled upper surface of the kind found by Pichon in Madagascar, but less easily the existence of a raised rim of living coral round the dead central area. Semper (1899) and Agassiz (1895, 258) both proposed that after growth ceased the central area was hollowed out by biological, chemical and mechanical erosion to form both the flat or concave centre and gullies and channels in it. Krempf (1927, 19) could find no evidence of such erosion: in Annam he found the central area sound, and often with small growing corals on it. Various conditions could form the specific cause of death at or near the sea-air interface. Fishelson (1973, 193) has suggested that exceptionally low tides, which may be aperiodic, could kill the upper surfaces of corals through emersion at Eilat in the Red Sea. In Bermuda Iams (1969, 70) has described several possibly pathological conditions leading to the disappearance of living polyps from otherwise healthy coral heads, and Garrett and Ducklow (1975) have described apparent evidence of disease from the same atoll. Once skeleton is exposed it is open to many processes of bioerosion, of which the activities of tridacnid clams are conspicuous on western Pacific microatolls (Figure 2 and 3).

Table 1. Relation of microatolls morphology to water depth, Kaneohe Bay, Oahu (source: Roy, 1970, table 3).

Depth of water on surrounding bottom (feet)	Microatoll morphology
1	No live coral on the rim: top dead, centre eroded nearly to the level of the surrounding bottom.
2	Part of the rim is live coral: top dead, centre partly eroded.
3	All of the rim is live coral: top dead, flat, not eroded.
4	All of the rim is live coral: some live coral on top, top tends to be domal rather than flat, not eroded.

(2) <u>Sedimentation leading to differential growth</u>

Wood Jones (1912, 107-109, 247-251) observed that coral colonies with dead upper surfaces were frequently found at Cocos-Keeling Atoll well below low-tide level. He proposed that the steady rain of sediment through the water led to accumulation on the flat upper surfaces of coral colonies, especially of massive hemispherical *Porites* colonies, the consequent death of living polyps, and the ultimate formation of an "atoll reef in miniature". Krempf (1927, 13) similarly observed deep microatolls in Annam. He argued that sedimentation on horizontal surfaces was aided by ectodermal mucus secretion trapping fine particles, though it is now usually held that mucus helps remove sediment from corals. This control was absent on vertical surfaces, which consequently grew faster, leaving a flat dead area within. An early stage in this process produced "umbilical" colonies, round with a central depression. Vasicek (1948) has pointed out that this process of control by sedimentation appears more applicable to massive than to branching and platy corals. He has also noted that the resulting differential growth of different parts of the skeleton should be clearly observed in skeletal structures.

Marshall and Orr (1931, 131) noted at Low Isles, Great Barrier Reef, that microatolls were formed near low tide level by both large-polyped *Favia* species and small-polyped *Porites* species, the former efficient sediment-removers and the latter not, and they concluded that microatolls were probably not therefore primarily caused by sedimentation. Other factors, such as growth form, could, however, affect the efficiency of sediment removal.

Interesting variations on normal microatoll form have also been described in shallow-water situations. In Iwayama Bay, Palau, Abe (1937, 253-256) described microatolls of *Goniastrea aspera* Verrill with inclined upper surfaces; such inclination was not found in *Porites somaliensis*. Figure 1 gives mean dimensions for 17 measured *Goniastrea* microatolls with inclined surfaces; Abe also gave data on 23 more colonies where the rim was incomplete because of the interruption of its narrower lower part. The mean orientation of the long axes of the complete microatolls was 117°, and the mean angle of inclination of the upper surface about 17°. These orientations are "to the direction of the upper stream at rising tide" (1937, 253); Abe believed that sediment in the current was probably an important control. Elsewhere, especially on shallow reef flats, sediment may accumulate to form conspicuous tails in the lee of microatolls, as near Gan, Addu Atoll, Maldive Islands (Stoddart et al., 1966, 19); both here, on *Porites,* and in the Gulf of Eilat on *Platygyra,* the dead upper surfaces of the microatolls are conspicuously colonised by the alga *Turbinaria* (Fishelson, 1973, fig. 3b).

(3) Food supply, currents, and differential growth

Some authors have suggested that as a coral grows, it will influence hydrologic conditions near it, and that in general currents and food supplies will be greater round the periphery than in the centre. Hence the margins will grow more rapidly than the centre and a microatoll form will result. This has been proposed for alcyonarian microatolls in Samoa (Cary 1931, 61) and for fossil corals by Vasicek (1948).

(4) Overgrowth on older coral colonies

Kornicker and Boyd (1962, 667-668, fig. 33) produced a novel explanation of microatoll development at Alacran Reef. Gulf of Mexico. Here microatolls "have developed principally (about 90 per cent) by peripheral growth around the rims of overturned coral heads; a few have formed after the central part of the dome was encrusted with calcareous algae that effectively stopped coral growth in that area but permitted continued growth around the edge. Atoll-shaped coral colonies formed on overturned heads have convex-downward bases. Specimens were collected that had evidently been turned over several times so that both top and bottom were atoll-shaped". Overgrowth on dead coral blocks, not necessarily overturned, to form microatolls was noted with *Porites* in Madagascar by Pichon (1964, 136), who also found it to be the sole mode of microatoll development in *Turbinaria*.

SUSCEPTIBILITY TO MICROATOLL FORMATION

Abe (1937) contributed important data on microatolls (termed by him "coral tables") at Iwayama Bay, Palau. He measured the depth from mean water level of the upper surfaces of microatolls and of round-topped colonies of three common species (*Porites somaliensis, Favia speciosa, Goniastrea planulata*) at three sites in the Bay (Stations 1 and 2 are reef margin sites, Station 3 a reef flat and pool site). His data are summarised in Table 2. The lowest tide recorded in 1935 was 100 cm below mean water level, though in such a topographic situation local variability must be considerable.

Table 2. Depth below mean water level of microatolls and hemispherical coral colonies at Iwayama Bay, Palau (from data in Abe 1937, 306-307)

	Microatolls				Hemispherical colonies			
	Mean depth	Minimum depth	Maximum depth	n	Mean depth	Minimum depth	Maximum depth	n
Porites somaliensis								
Station 1	101.9	86	124	25	122.8	106	144	12
Station 2	123.8	116	130	12	139.2	134	148	5
Station 3	115.3	108	124	21	-	-	-	-
Favia speciosa								
Station 1	96.5	78	114	4	126	-	-	1
Station 2	104	-	-	1	-	-	-	-
Goniastrea planulata								
Station 1	108	106	112	6	124	-	-	1

Depths in cm; depth of lowest low tide in 1935 100 cm.

At Station 1, for which data are fullest, Abe found (1937, 305-309) considerable differences between species in the levels at which microatolls form. *Favia speciosa* formed microatolls at the highest level (mean depth 96.5 cm), then *Porites somaliensis* (mean 101.9) and deepest *Goniastrea planulata* (mean 108). These differences must reflect variations in tolerance between different species of the controlling factors. Abe also found that the same species formed microatolls at different depths at the three different stations. Thus *Porites somaliensis* microatolls are found at a mean depth of 102 cm at Station 1 (round colonies at 123 cm); at 124 cm at Station 2 (round colonies at 140 cm); and 115 cm at Station 3 (no round colonies). Abe felt that these differences could not be explained by tidal control alone. He noted the prevalence of muddy sediments at Station 2, and argued (1937, 313-314) that microatolls formed at lower levels at this station because of the amount of suspended mud in the water.

MICROATOLLS AT ABNORMALLY HIGH LEVELS

Mention has already been made of Kuenen's (1933, 65) observation of microatolls in ponded situation on reef flats in the East Indies, and such a situation is implicit in the records of microatoll growth and elevation on the surfaces of low wooded island-reefs of the Great Barrier Reef by Manton (1935, 300). In describing reef-top pools at Low Isles, Fairbridge and Teichert (1947, 4) state that "there is often active coral growth reaching several feet above the normal upper limit of such growth, a significant point for those who would use coral which has grown *in situ* as a datum for former sea-levels". The height data used by Fairbridge and Teichert are the same as those used by Manton, derived from the careful surveys by Spender (1930). Clearly, if such reef-top pools are drained then such abnormally high microatolls might be killed; such changes could result from hurricane modification of reef topography (Moorehouse 1936).

High-standing dead microatolls which might be referred either to growth in formerly existing pools or to growth when sea-level itself was higher than at present were first described in detail at Funafuti Atoll, Ellice Islands. Here Sollas (1904, 20-22) noted an area of *Porites* microatolls and *Heliopora* colonies within a mangrove swamp, at a level submerged by several feet at high water but emerged during much of the day. The corals themselves were partly covered by a cemented shingle rampart. The flat tops of the corals were ascribed to "an arrest of upward growth ... by the level of low water". Sollas proceeded to discuss the interpretation of these microatolls:

> "If it be admitted that the surface of the *Porites* clumps marks an ancient level of low water, then it obviously becomes a problem of extreme interest to compare this level with that of the existing sea. ... the summits of the *Porites* clumps now stand 1 foot 4 inches above mean tidal level, i.e., 4 feet 6 inches above low water at spring tides or 3 feet 9 inches above low water at neap tides. I therefore concluded that a

> change in sea-level in a negative direction to the extent of about 4 feet had occurred over the site of the Mangrove Swamp since the growth of its ancient reef" (1904, 22).

David and Sweet (1904, 67) placed the downward movement of the shoreline so indicated at "from 4½ to 6¼ feet". Elsewhere on Funafuti, however, Finckh (1904, 138-139) found living *Heliopora* colonies at unusually high levels in moated situations similar to those later found at Low Isles. Both *Heliopora* and *Porites* were found at the north end of Amatuku Island, Funafuti, growing in a pool at a height of 2 feet above low-water spring tide: "great care was exercised to determine the exact height of this coral growth, since it would seem to offer an explanation for the occurrence *in situ* of dead *Heliopora* considerably above low-water mark in the Mangrove Swamp and in other localities on the main island of Funafuti". David and Sweet (1904, 67), however, while accepting this observation, did not feel that modern growth in pools could account for the main areas of dead microatolls. It "may explain small heads above low water level, but not the *Heliopora* slightly above high water level ... nor *in situ* heads of *Porites* "in many cases over a foot, some ... 4 feet above high water. These immense heads could not have grown in land-locked reef pools, but must have flourished under the most favourable conditions, such as free access to food-bringing currents, etc., would provide".

The Funafuti situation is directly analogous to that found on the northern Great Barrier Reef in 1973, and there is some suggestion in the literature that abnormally high dead microatolls (though perhaps not characterised as such) are fairly widespread in the western Pacific e.g. in the Marshall Islands (Emery *et al.* 1954, Buddemeier *et al.* 1975, Tracey and Ladd 1974) and the Gilbert Islands (Cloud 1952).

PROBLEMS OF TERMINOLOGY

Microatoll mis-used for patch reefs

As described above the usage of the term "microatoll" as introduced by Krempf is relatively unambiguous. Unfortunately several recent authors have used the term for quite different kinds of features and hence produced confusion.

In the Bahamas, Newell and Rigby (1957, 36) used the term for "certain ring-shaped patch reefs ... in many areas nearly circular ... measuring 10 to 200 metres across. As viewed from a boat or from the air, the faros [*sic*] stand out as dark rings or fringes of gorgonians upon a rim of stony corals. The central area is more or less dead, slightly depressed, and covered with coral fragments". Newell (1954, 12) considers the use of the term microatoll for single coral colonies "not very appropriate" and suggests it be reserved for such ring-shaped patch reefs (cf. Newell *et al.* 1951, 23; Illing, 1954); he does not explain why microatoll in this redefined sense and faro are used synonymously.

Similarly, at Raroia Atoll, Tuamotu Archipelago, Doty and Morrison (1954, 52) speak of larger reef patches "progressively like microatolls in that the centre is more apt to be a pool a few feet deep and the edge a rim a few feet wide more or less complete and higher, just below low tide level". Kinsey and Domm (1974, 51) described "a very large number of patch reefs "at One Tree Island, Great Barrier Reef, "many taking the form of microatolls. These vary from about 3 m to 200 m in diameter and are characterised by being fully or nearly fully enclosed by living reef. The walls are usually vertical on the sides and 2-5 m thick. Within these enclosures the water depth, during the 5-6 hr low-tide slack water period, is typically 0.5-2 m and the bottom has sparse coral cover being predominantly sandy with some rubble". Similar features of comparable size had earlier been termed "miniature atolls" at Pearl and Hermes Reef, Leeward Hawaiian Islands, by Galtsoff (1933, 14).

At Alacran Reef, Hoskin (1963, 27) used microatoll in an inclusive sense for "growths of massive corals which resemble a doughnut in shape. They range in size from single heads ... to very large and complex structures. ... The largest microatolls are called patch reefs ... [and] may be up to 20 feet in diameter". These Alacran reefs are also described by Kornicker and Boyd (1962, 658-659): "The upper surfaces of two microatolls about 2 miles north of Isla Perez were examined in detail. They rise within a few feet of the surface from a depth of about 40 feet, and their upper surfaces form circular areas 325 and 200 feet in diameter respectively. The water depths at the margins of these surfaces are typically about 5 feet to the base of the corals and 2½ feet to the tops of the corals. Between the outer edge and the central lagoon, depths are as shallow as 1½ feet to the coral tops and 3 feet to the base of the corals. The deeper parts of the lagoons are about 4½ feet beneath the surface. Beyond the outer edge of the larger microatoll, the slope is steep and was estimated at 30°. ... each of these microatolls could be mapped as a circular belt of massive corals enclosing a sand-bottom area and surrounded by sand bottom." These features are clearly quite different from classically-defined microatolls, and there seems no good reason for misusing this term to describe them.

Similar difficulties arise in new terminology proposed for lagoon patch reefs at Bermuda by Garrett *et al.* (1971, 650). These authors use "microatoll reef" for patch reefs which "resemble small atolls in possessing a growing perimeter and a sediment-filled interior". One example described measured 150 x 700 m, with an upper sandy surface 4 m deep; this they also term a "rough-topped mesa". A mesa reef is defined as a broad reef in the Bermuda lagoon bounded by steep slopes; further, "if the top is bowl-shaped and sandy, depth 4 m, the reef becomes a microatoll reef" (Garrett *et al.* 1971, 651). They also state that "continued lateral growth as well as coalescence of adjacent reefs results in poorer circulation for the central areas [of lagoon reefs], which die off; the reef is then a microatoll" (Garrett *et al.* 1971, 644). This misuses terms already well-defined and established in the literature, and it adds no precision to the features being described.

The need for a series of terms to differentiate members of a hierarchy of forms from microatoll *sensu stricto* to atoll was recognised by Scheer (1969, 1972). He proposed four terms: microatoll (classically defined as referring to individual colonies); mini-atoll; faro; and atoll. Mini-atoll is used for patch reefs in atoll lagoons with central depressions 2.5-3.5 m deep, comparable to the patch reefs described by Newell and by Doty and Morrison but termed by them microatolls. Scheer was quite clear that the term microatoll "should be reserved to the loaf-shaped, round coralla of the outer reef flat, whose upper parts are dead" (1972, 99-100). Faro refers to larger reefs of ring-shaped form, usually found round the margins of certain atolls in the Maldives instead of linear reefs (Gardiner 1903, 155; 1931, 19). The term is often restricted to peripheral reefs of atolls or outer reefs of barriers (Kuenen 1950, 426; MacNeil 1954, 393), in which sense it is close to the term "atollon" used by Guppy (1889, 472) and defined by Stamp (1961, 36), but it is also properly applied to ring-shaped patch reefs within atoll lagoons (MacNeil 1954, 399; Guilcher 1971, 77; Scheer 1972). "Bason-formed reef" of Darwin (1842, 106) and "lagoon atoll" of Davis (1928, 15) are obsolete versions of faro.

Cognate terms

Certain cognate terms have been introduced for features associated either with true microatolls *sensu* Krempf or for features improperly termed microatolls by some recent authors.

The dead central area or enclosed pool of true microatolls is termed a *microlagoon* by Vasicek (1948, 56) and by Boyd *et al.* (1963). *Micro-lagoon* is used for the larger patch reefs at Raroia, for "pool areas in the reef patch tops ... as a rule sand or sediment floored and a foot to a metre deep" (Doty and Morrison 1954, 52). Morrison (1954, 5) curiously uses micro-lagoon in a totally different sense, also at Raroia, for "brackish water lagoons ... [in] incomplete channels between islands [i.e. *hoa*] or small embayments close to the lagoon of the atoll, and more or less completely cut off from the salt water of the lagoon by sand barriers"; other terms, notably *barachois,* are available for this phenomenon (Bourne 1888, 442), and Morrison's usage is thus redundant as well as confusing. *Microatoll lagoon* is used by Garrett *et al.* (1971, 651) for the water up to 4 m deep over the wide sandy plain of their misnamed microatoll reefs.

In spite of the popularity of the term microatoll, there are few references to *microbarriers*. Fairbridge (1950, 345, fig. 4) applied this term to a submerged linear reef 1500-2000 ft seaward from the main reef rim on the south side of Pickersgill Reef, Great Barrier Reef; "patches of growing coral connect it with the main reef, but deep, rounded pools are left between".

REFERENCES

Agassiz, A. 1895. A visit to the Bermudas in March, 1894. *Bull. Mus. comp. Zool. Harvard Coll.* 26: 209-281.

Bourne, G. C. 1888. The atoll of Diego Garcia and the coral formations of the Indian Ocean. *Proc. Roy. Soc. Lond.* 43: 440-461.

Boyd, D. W., Kornicker, L. S. and Rezak, R. 1963. Coralline algal microatolls near Cozumel Island, Mexico. *Univ. Wyoming Dept. Geol. Contr. Geol.* 2(2): 105-108; abstract in *Geol. Soc. Am. Spec. Paper* 73: 120-121.

Braithwaite, C. J. R., Taylor, J. D., and Kennedy, W. J. 1973. The evolution of an atoll: the depositional and erosional history of Aldabra. *Phil. Trans. R. Soc. Lond.* B 266: 307-340.

Buddemeier, R. W., Smith, S. V., and Kinzie, R. A. 1975. Holocene windward reef-flat history, Enewetak Atoll. *Bull. geol. Soc. Am.* 86: 1581-1584.

Cary, L. R. 1931. Studies on the coral reefs of Tutuila, American Samoa, with especial reference to the Alcyonaria. *Papers Tortugas Lab.* 27: 53-98.

Chamisso, A. von. 1821. Remarks and opinions of the naturalist of the expedition. In O. von Kotzebue: *A voyage of discovery into the South Sea and Beering's Straits, for the purpose of exploring a north-east passage, undertaken in the years 1815-1818* (London: Longman, Hurst, Rees, Orme and Brown, 3 vols.), II, 349-433; III, 1-318.

Cloud, P. E., Jr. 1952. Preliminary report on geology and marine environments of Onotoa Atoll, Gilbert Islands. *Atoll Res. Bull.* 12: 1-73.

Dana, J. D. 1849. *Geology (United States Exploring Expedition. During the years 1838, 1839, 1840, 1841, 1842. Under the command of Charles Wilkes, U.S.N. Vol. X).* Philadelphia: C. Sherman. viii, 756 pp.

Dana, J. D. 1872. *Corals and coral islands.* New York. English edition, London: Sampson Low, Marston, Low and Searle (1875), 348 pp.

Darwin, C. R. 1842. *The structure and distribution of coral reefs.* London: Smith, Elder and Co. 214 pp.

David, T. W. Edgeworth and Sweet, G. 1904. The geology of Funafuti. In *The atoll of Funafuti* (London: The Royal Society), 61-124.

Davis, W. M. 1928. The coral reef problem. *Am. Geog. Soc. Spec. Pub.* 9: 1-596.

Doty, M. S. and Morrison, J. P. E. 1954. Interrelationships of the organisms on Raroia aside from man. *Atoll Res. Bull.* 35: 1-61.

Emery, K. O., Tracey, J. I., Jr., and Ladd, H. S. 1954. Geology of Bikini and nearby atolls. *U.S. Geol. Surv. Prof. Paper* 260-A: 1-265.

Fairbridge, R. W. 1950a. The geology and geomorphology of Point Peron, Western Australia. *J. Roy. Soc. W. Austr.* 34: 35-72.

Fairbridge, R. W. 1950b. Recent and Pleistocene coral reefs of Australia. *J. Geol.* 58: 330-401.

Fairbridge, R. W. 1968. Microatoll. In R. W. Fairbridge: *The Encyclopedia of Geomorphology* (New York: Reinhold Book Corp.), 701-705.

Fairbridge, R. W. and Teichert, C. 1947. The rampart system at Low Isles, 1928-45. *Rept. Gt. Barr. Reef. Comm.* 6: 1-16.

Finckh, A. E. 1904. Biology of the reef-forming organisms at Funafuti Atoll. In *The atoll of Funafuti* (London: The Royal Society), 125-150.

Fishelson, L. 1973. Ecological and biological phenomena influencing coral-species composition on the reef tables at Eilat (Gulf of Aqaba, Red Sea). *Mar. Biol., Berlin,* 19: 183-196.

Galtsoff, P. H. 1933. Pearl and Hermes Reef, Hawaii, hydrographical and biological observations. *Bull. Bernice P. Bishop Mus.* 107: 1-49.

Gardiner, J. S. 1903. The Maldive and Laccadive Groups, with notes on other coral formations in the Indian Ocean. In J. S. Gardiner, ed.: *The Fauna and Geography of the Maldive and Laccadive Archipelagoes* (Cambridge: University Press), 1: 12-50, 146-183, 313-346, 376-423.

Gardiner, J. S. 1931. *Coral reefs and atolls*. London: Macmillan. 181 pp.

Garrett, P. and Ducklow, H. 1975. Coral diseases in Bermuda. *Nature, Lond.* 253: 349-350.

Garrett, P., Smith, D. L., Wilson, A. O. and Patriquin, D. 1971. Physiography, ecology, and sediments of two Bermuda patch reefs. *J. Geol.* 79: 647-668.

Guilcher, A. 1971. Mayotte barrier reef and lagoon, Comoro Islands, as compared with other barrier reefs, atolls and lagoons in the world. *Symp. Zool. Soc. Lond.* 28: 65-86.

Guppy, H. B. 1886. Notes on the character and mode of formation of the coral reefs of the Solomon Islands, being the results of observations made in 1882-84, by H. B. Guppy, M.B., F.G.S., during the surveying cruise of H.M.S. Lark. *Proc. Roy. Soc. Edinb.* 13: 857-904.

Guppy, H. B. 1889. The Cocos-Keeling Islands. *Scott. Geog. Mag.* 5: 281-297, 457-474, 569-588.

Hoskin, C. M. 1963. Recent carbonate sedimentation of Alacran Reef, Yucatan, Mexico. *Nat. Acad. Sci.-Nat. Res. Coun. Pub.* 1089: 1-160.

Iams, W. J. 1969. New methods of studying the growth rates of reef-building organisms. *Spec. Publ. Bermuda Biol. Stn. Res.* 2: 65-76.

Illing, L. V. 1954. Bahamian calcareous sands. *Bull. Am. Ass. Petrol. Geol.* 38: 1-94.

Kinsey, D. W. and Domm, A. 1974. Effects of fertilization on a coral reef environment — primary production studies. *Proc. 2nd Int. Coral Reef Symp.* 1: 49-66.

Kornicker, L. S. and Boyd, D. W. 1962. Shallow-water geology and environments of Alacran Reef complex, Campeche Bank, Mexico. *Bull. Am. Ass. Petrol. Geol.* 46: 640-673.

Krempf, A. 1927. La forme des récifs coralliens et le régime des vents alternants. *Mém. Trav. Serv. Océanogr. Peche Indochine,* 2: 1-33.

Kuenen, P. H. 1933. Geology of coral reefs. *Sci. Repts. Snellius Exped. Ned. East Indies,* 5(2): 1-126.

Lister, J. J. 1891. The geology of the Tonga Islands. *Quart. J. Geol. Soc. Lond.* 47: 590-617.

McNeil, F. S. 1954. Organic reefs and banks and associated detrital sediments. *Am. J. Sci.* 252: 385-401.

Manton, S. M. 1935. Ecological surveys of coral reefs. *Sci. Rept. Gt. Barr. Reef Exped.* 1928-29, 3: 273-312.

Marshall, S. M. and Orr, A. P. 1931. Sedimentation on Low Isles reef and its relation to coral growth. *Sci. Rept. Gt. Barr. Reef Exped.* 1928-29, 1: 93-133.

Maxwell, W. G. H. 1968. *Atlas of the Great Barrier Reef.* Amsterdam: Elsevier. 258 pp.

Mergner, H. and Scheer, G. 1974. The physiographic zonation and the ecological conditions of some south Indian and Ceylon coral reefs. *Proc. 2nd Int. Coral Reef Symp.* 2: 3-30.

Moorhouse, F. W. 1936. The cyclone of 1934 and its effect on Low Isles, with special observations on Porites. *Rept. Gt. Barr. Reef Comm.* 4: 37-44.

Morrison, J. P. E. 1954. Animal ecology of Raroia Atoll, Tuamotus. I. Ecological notes on the mollusks and other animals of Raroia. II. Notes on the birds of Raroia. *Atoll Res. Bull.* 34: 1-26.

Newell, N. D. 1954. Expedition to Raroia, Tuamotus. *Atoll Res. Bull.* 31: 1-23.

Newell, N. D. and Rigby, J. K. 1957. Geological studies on the Great Bahama Bank. *Spec. Publs. Soc. Econ. Palaeontol. Miner., Tulsa,* 5: 15-72.

Newell, N. D., Rigby, J. K., Whiteman, A. J., and Bradley, J. S. 1951. Shoal-water geology and environments, eastern Andros Islands, Bahamas. *Bull. Am. Mus. nat. Hist.* 97: 1-30.

Pichon, M. 1964. Contribution à l 'étude de la répartition des Madréporaires sur le récif de Tuléar. *Rec. Trav. Stat. mar. Endoume-Marseille,* fasc. hors-série, 2: 79-203.

Roy, K. J. 1970. Change in bathymetric configuration, Kaneohe Bay, Oahu, 1882-1969. *Hawaii Institute of Geophysics, Rept.* HIG-70-15, 26 pp.

Safriel, U. N. 1974. Vermetid gastropods and intertidal reefs in Israel and Bermuda. *Science, N.Y.* 186: 1113-1115.

Scheer, G. 1969. Investigations of coral reefs in the Maldive Islands with notes on lagoon patch reefs and the method of coral sociology. *Abstr. Symp. Corals and Coral Reefs, Mandapam Camp.*

Scheer, G. 1972. Investigations of coral reefs in the Maldive Islands with notes on lagoon patch reefs and the method of coral sociology. *Proc. Symp. Corals and Coral Reefs 1969* (Marine Biological Assoc. India): 87-120.

Scoffin, T. P. and Stoddart, D. R. in litt. Nature and significance of micro-atolls. *Phil. Trans. R. Soc. Lond.*

Semper, C. 1880. *Die natürlichen Existenzbedingungen der Thiere.* Leipzig. 2 vols.

Semper, C. 1899. *The natural conditions of existence as they affect animal life.* London: Kegan Paul, Trench, Trübner and Co. 5th edition. 472 pp. (First English edition 1881).

Sollas, W. J. 1904. Narrative of the expedition in 1896. In *The atoll of Funafuti* (London: The Royal Society), 1-28.

Spender, M. A. 1930. Island-reefs of the Queensland coast. *Geogrl J.* 76: 194-214, 273-297.

Stamp, L. D., ed. 1961. *A glossary of geographical terms.* London: Longmans. 539 pp.

Stephenson, T. A., Stephenson, A., Tandy, G., and Spender, M. A. 1931. The structure and ecology of Low Isles and other reefs. *Sci. Rept. Gt. Barr. Reef Exped. 1928-29,* 3: 17-112.

Stoddart, D. R. 1969. Geomorphology of the Solomon Islands coral reefs. *Phil. Trans. Roy. Soc. Lond.* B 255: 355-382.

Stoddart, D. R., Davies, P. S., and Keith, A. C. 1966. Geomorphology of Addu Atoll. *Atoll Res. Bull.* 116: 13-41.

Tracey, J. I., Jr., and Ladd, H. S. 1974. Quaternary history of Eniwetok and Bikini Atolls, Marshall Islands. *Proc. 2nd Int. Coral Reef Symp.* 2: 537-550.

Vasicek, M. 1948. Theorie o vzniku mikroatolu (Theories of the origin of microatolls). *Sbornik Ceskoslovenske Spolmocti Zool.* 55: 50-58.

Wells, J. W. 1957. Coral reefs. *Mem. Geol. Soc. Am.* 67(1): 609-631.

Wood-Jones, F. 1912. *Coral and atolls: a history and description of the Keeling-Cocos Islands, with an account of their fauna and flora, and a discussion of the method of development and transformation of coral structures in general.* London: L. Reeve and Co. 392 pp.

Zaneveld, J. S. 1957. Micro-atolls in the Netherlands Antilles. *Rep. Inter-Isl. Mar. Biol. Conf.* (Univ. Pto Rico Inst. Mar. Biol.): 18-19.