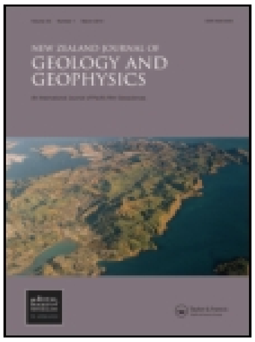

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EFFECT OF LATE HOLOCENE SEA-LEVEL FALL ON ATOLL DEVELOPMENT

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Abstract

A net fall of 2·4 m since 2760 yrs B.P., the local date for the Flandrian Transgression Maximum, has been of major importance in reef and atoll islet growth in the Gilbert and Ellice Islands. The islets have been built from sand taken from the shallow margins of the lagoonal floor as a direct result of this fall, and it may be no coincidence that the earliest Micronesian and Polynesian settlements date from about the sea level maximum. Later second-order transgressions have almost certainly been important in the development of zonation and increased width of the low-tide platform.

Introduction

Although the importance of marine transgression on the formation of atolls is widely acknowledged (Davis 1928), the effect of marine regression has been relatively neglected. However, it now seems reasonably certain that, for the western Pacific Atolls at least, sea level has fallen 2 or more metres in the last 3000 years or so (Buddemeier *et al.* 1975; Tracey & Ladd 1974; Schofield 1977), and this fall must have some bearing on the origin of atolls. Other factors influencing atoll growth are temperature, oxygen supply, and food supply, and their sum effect is shown by the increased width of coral reefs towards the equator (Fig. 1). These factors also affect sedimentary supply, particularly the infilling rate of lagoons where the sediment is almost wholly of local organic origin (Agadzanin *et al.* 1973).

Islet Building

There has been evidence accruing to support the belief of David & Sweet (1904), Gardiner (1931), Sewell (1933) and Emery *et al.* (1954) that a recent fall in sea level has been "the dominant cause of the formation of the islets of atolls". Quantitative and mineralogical studies show that the prograded coasts in the Auckland region of New Zealand are the result of the local net fall of 2 m in post-glacial times (Schofield 1967, 1975). Despite the incoming of some sediments from the hinterland, 95% or more of the prograded coastal sediment has been derived from the local sea floor in response to the net fall in sea level. This fall consisted of a number of fluctuations, during which the periods of sea-level rise promoted periods of coastal erosion, such as is occurring now, but because there has been a net fall, there has also been a net progradation. A parallel can be drawn with atoll islet development where, apart from cemented conglomeratic

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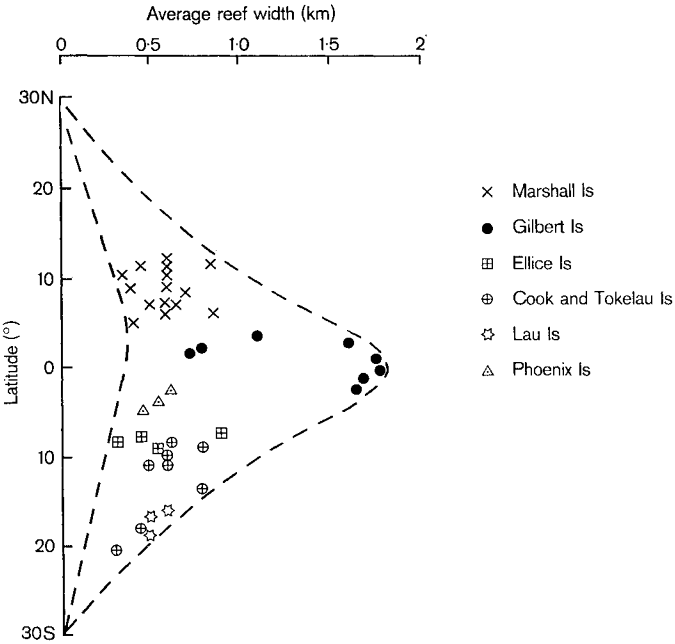

FIG. 1—Average coral reef width relative to latitudinal position.

ramparts on their oceanic side, the islets consist predominantly of sand. Although a fall in sea level may have led to some increase in the supply of atoll sediment from mechanical erosion of dead coral, the most likely source of sand would be from sediments formed in the shallow lagoonal margins—there is no similar source on the steep ocean wall of the reef.

Samples from two Gilbert Island transects support a lagoonal sediment source. The Butaritari transect lay near the northern limits of the main village, Butaritari Islet, Butaritari Atoll. The Tarawa transect crosses Bikenibeu Islet near the east end of Bikenibeu Village, Tarawa Atoll. Sand from the ocean beaches in both transects (Table 1) has a moderate to high degree of sorting (sorting index 0·71 to 0·38—after McCammon 1962), the grains are highly polished, and the 0·6–1·2 mm size range consists of moderately rounded, equant grains of massive carbonate of indeterminate origin except for 5% of whole forams. The lagoonal sands are not polished; there is 45–63% whole forams in the 0·6–1·2 mm size fraction, and grain shape is highly irregular with shell ornamentation commonly preserved. The lack of polish and lesser degree of roundness in lagoonal sands compared with ocean sands is also noted by Weber & Woodhead (1972). In all islet samples, sorting is poor, the grains are unpolished, there is 38–93% whole forams in the 0·6–1·2 mm size range and grain shape is irregular. It would seem therefore that the islets have been mainly built from the lagoonal side.

TABLE 1—Lagoon beach, islet and ocean beach sediments

Locality	Median mm	Sorting	Whole Foram % 0·6–1·2 mm %	Whole Foram % distance*	0·21–0·30 mm Shell %†	0·21–0·30 mm Shape‡
TARAWA (Bikenibeu) TRANSECT						
Lagoon Beach	0·78	Poor	45	0	72	I
§+155 m islet	0·67	Poor	38	28	82	I
+195 m islet	0·64	Poor	38	35	83	I
+335 m islet	0·90	Poor	38	60	76	I
+390 m islet	0·81	Poor	56	70	54	I
Ocean beach (+555 m)	0·44	Good	2·5	100	4	E
BUTARITARI TRANSECT						
Lagoon beach	0·22	Good	63	0	82	I
§+52 m islet	0·45	Poor	48	14	89	I
+122 m islet	0·75	Poor	79	33	98	I
+162 m islet	0·62	Poor	68	40	88	I
+241 m islet	0·90	Poor	93	65	97	I
Ocean beach (+372 m)	0·49	Good	5	100	4	E

*Percentage distance from lagoonal beach towards ocean beach

†Shell refers to fragments either with ornamentation preserved and/or of a shape in which one axis is much shorter than the other two axes.

‡I, mainly irregular in shape; E, mainly equant in shape.

§Distance in metres from lagoon beach

It is interesting that samples furthest inland from the lagoonal beach (Table 1) and thus probably older than nearer lagoonal samples, tend to have higher percentages of whole forams in the 0·6–1·2 mm size range. This could be caused by different organic productivity rates or it could reflect greater amounts of transportation and wear of the younger, nearer lagoonal shore samples.

The sand sample collected 390 m from the lagoon and 165 m from the ocean (Tarawa Transect, Table 1) was sieved to produce two samples, 0·6–1·22 mm grain size with 56% whole forams (NZ3349) and 0·15–0·6 mm size range with 4·5% forams (NZ3351). It was thought that the sample with the greater amounts of comminuted material would have the oldest radiocarbon date. Both, however, yielded an identical date of 3660 ± 90 years B.P. ($T_{\frac{1}{2}}$ = 5730 years). Therefore, any apparent difference in age must lie within the limits of dating accuracy, i.e., an age difference of not more than 180 years. The age of 3660 years is almost certainly an average age for material that may have been stored on the floor of the lagoon before being transported shorewards to form part of the Bikenibeu Islet. As islet progradation would have been given greater impetus during periods of sea-level fall, the onshore deposition of the 3660 year old sand may not have taken place until some time after the maximum of the Flandrian Transgression, which locally (Schofield 1977) did not occur until about 2760

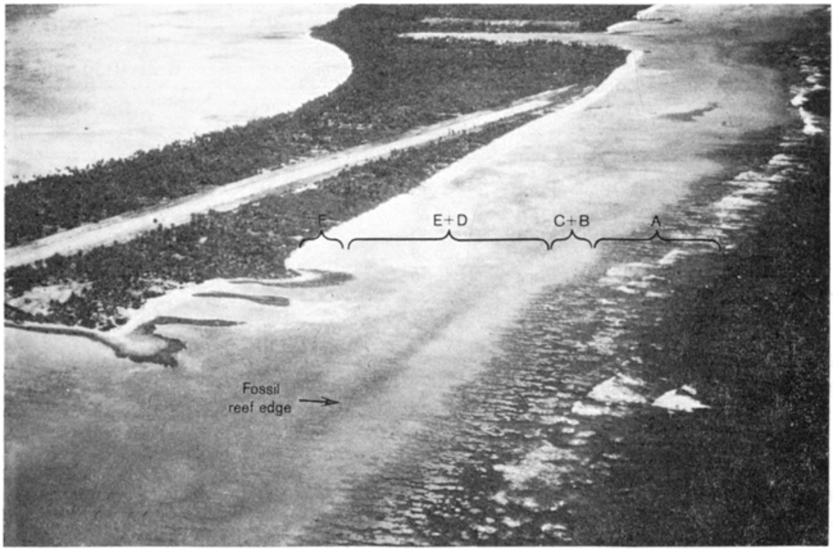

FIG. 2—Reef zonation east of Tabiteuea airstrip. For zone descriptions see text. Note the fossil saw-toothed edge in zone D; note also fossil "stone stripes", 1 m above local reef level, that project outwards from the coast, commonly from coastal promontories. These represent a +0·8 m sea level (Schofield 1977) and do not project beyond zone D.

radiocarbon years B.P. In fact, the actual commencement of permanent islet growth may not have taken place until after this date, and it may be no coincidence that the earliest known settlements within Micronesia and Polynesia are of about this age, almost precisely 1000 B.C. (Green & Schofield, "Relative sea-level change as a factor in Polynesian migration"; in prep.).

REEF ZONATION CAUSED BY LATE HOLOCENE SEA-LEVEL FLUCTUATION

A fluctuating sea level is the most likely cause of the interesting reef zonation found on the windward reef at Bikini (Ladd *et al.* 1950; Emery *et al.* 1954) and observed at Tabiteuea (Fig. 2) This zonation is parallel to the present reef edge, and at Bikini consists of the following zones:

(A) An outer groove-and-spur zone or saw-toothed edge that extends to several metres below low tide and has a living algal ridge at its inner margin that may extend up to 1 m, but commonly less than 0·5 m, above low tide level. This inner algal ridge is kept alive to greater heights than the rest of zone A by constant spray from breakers, and, although it has a longitudinal form parallel to the coast, it is cut across, like the rest of zone A, by transverse grooves which provide direct access to water flowing out of zone B. These grooves are thought to result from upward organic growth in the intervening transverse ridges (Emery *et al.* 1954).

(B) Reef flat, rich in living coral, covered only by a few centimetres of water at low tide but with pools up to 0·6 m deep.

(C) A living *Heliopora* zone in which "the general surface of the reef flat is distinctly lower than the zones to seaward and is covered by" water to a depth of 0·3 to 1·2 m at low tide.

(D) The "main reef flat, a fairly level rock surface that is divided by what appears to be the margin of an older reef"—aerial photographs show that this margin has the same saw-toothed structure as the modern reef edge.

(E) An inner living *Heliopora* zone with *Porites* living near its inner edge.

(F) Modern beach.

Along the windward reef of Tabiteuea, east of the airstrip, all these zones are present although some are not as well developed as at Bikini. Zone A is well developed, its inner, longitudinal, algal ridge rising about 0·3 m above the level of maximum upward growth of coral found in pools in the area representing zones B and C which are not distinctly separated. The water level in these pools seems governed by low tide and the maximum upward growth of corals within them most likely represents the approximate position of low-water springs. In plan view, the saw-toothed nature of the outer edge of zone D is comparable in every way to its modern counterpart except that it is only really noticeable from the air (Fig. 2). It also differs in having no relief, i.e., the inner high belt of irregular algal growth is absent, as are the deep transverse grooves. The view from the air, however, suggests that such features were once present and hence that a combination of erosion of the high parts and infilling of the grooves has produced its present flat nature. This flat lies about 0·35 m above the limits of upward coral growth within the pools of zones B + C. Behind this flat, in zone E, the most noticeable form of living coral are the micro-atolls of *Porites*. These grow up to the level of water ponded by zone D and only a few centimetres below its general level, i.e., the *Porites* of zone D grow to a level that is 0·3 m above the limits of coral growth in zones B + C.

These zones seem to represent two distinct cycles of growth rather than a continuous outward growth of the reef flat, and are more easily explained by fluctuating changes in sea level than by a steady rise, fall, or stability of sea level. The earlier cycle is represented by zones D and E, when sea level was either rising to or was more or less stationary at some level above today's level—its present flat is equal in level to the local modern algal ridge, the counterpart of which was most likely present before being eroded to produce the present flat in zone D. Thus the level of the sea during the aggradational phase of zone D was almost certainly higher and probably more than 0·3 m higher, than its present level. The latest cycle is represented by zones A, B, and C, which were most likely formed as sea level fell to some unknown depth and then rose to its present position. During regression the exposure of zone D led to its decay and erosion; the longitudinal algal ridge and transverse saw-toothed ridges were planed off and the grooves infilled;

breakers formed further offshore, favouring the development of the longitudinal algal ridge at its present position where it persisted and still persists during the current world-wide transgressional period.

During the upward growth of zone A, local rates of back-reef breccia deposition (Schofield 1977) determine whether zones B and C persist or become infilled.

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