RECONNAISSANCE GEOLOGY OF THE GILBERT GROUP WESTERN KIRIBATI

Bruce Richmond[1]

SOPAC Technical Secretariat

May 1993

SOPAC Technical Report 77

[1]Current address: Branch of Pacific Marine Geology
United States Geological Survey
345 Middlefield Road MS99
Menlo Park
California 94025

Prepared for: South Pacific Applied Geoscience Commission (SOPAC)
Coastal Program

CONTENTS

LIST OF FIGURES AND TABLES

Figure

Table

SUMMARY

The Gilbert Islands comprise five reef islands and eleven atolls, essentially Holocene carbonate caps resting on a pre-Holocene reef developed on a NW-trending chain of mid-oceanic volcanoes. The windward reef front is typically a gently seaward-sloping terrace marked at its seaward margin by a steep drop-off to the reef slope and at its landward margin by abrupt, coral-algal buttresses. The reef platform, or atoll rim, extends from the reef crest to the first major break in slope in the atoll lagoon, or in the case of reef islands, the leeward reef crest. It is the substrate on which the atoll islets and reef islands rest, varying from an erosional hard-rock surface to a prograding surface built up by ocean to lagoon sediment transport and deposition.

The atoll rim islets and reef islands are a complex association of limestone and unconsolidated carbonate sediments. Most of limestones form basal platforms of cemented coral conglomerate characterised by complex morphology and internal structure, overlain by unconsolidated sands and gravels which make up most of the islet surfaces.

Coral gravel ramparts form extensive shore-parallel deposits produced by catastrophic events and composed mostly of coral debris from the reef front. Shore-parallel, high-level conglomerate platforms, almost certainly the cemented counterparts of coral ramparts, are prevalent features of the inner reef flat and merge with the shorelines of atoll islets and reef islands where they appear to form an armoured substrate supporting the islands. Shore-normal, high-level, coral conglomerate tongues appear to be formed by multiple events as indicated by repetition of obscure, coarsening-upward sequences. Beachrock conglomerates and sandstones mimic the sediment texture and bedding of the adjacent beaches and are limited to narrow, roughly shore-parallel exposures along both ocean and lagoon shorelines or to areas that have undergone significant erosion.

Most of these high-level deposits are water-laid and therefore represent sedimentation under conditions other than those produced by present day-to-day processes. The islands owe their origin to catastrophic events which produced many of the original limestone deposits and subsequent sediment veneers. Dated surficial limestones range between about 1500 and 3000 years B.P. in age and may represent an increase in storminess or

catastrophic events, a relative higher sea level position, or an increase in carbonate production rates at that time.

The high-level limestones, particularly the conglomerates, play a significant role in the recent development of the atoll islets and reef islands. Several distinctive shoreline configurations, including prominent shoreline re-entrants, are the result of the interaction between nearshore sediment transport and conglomerate tongues and platforms. Lateral spit progradation is one of the major processes responsible for islet growth, mainly at the end of islet chains or their lagoon margins. During periodic El Nino and Southern Oscillation (ENSO) episodes, the usual easterly trades are punctuated by strong westerlies forming waves that are important in the development of the islets and which can also result in significant shoreline change.

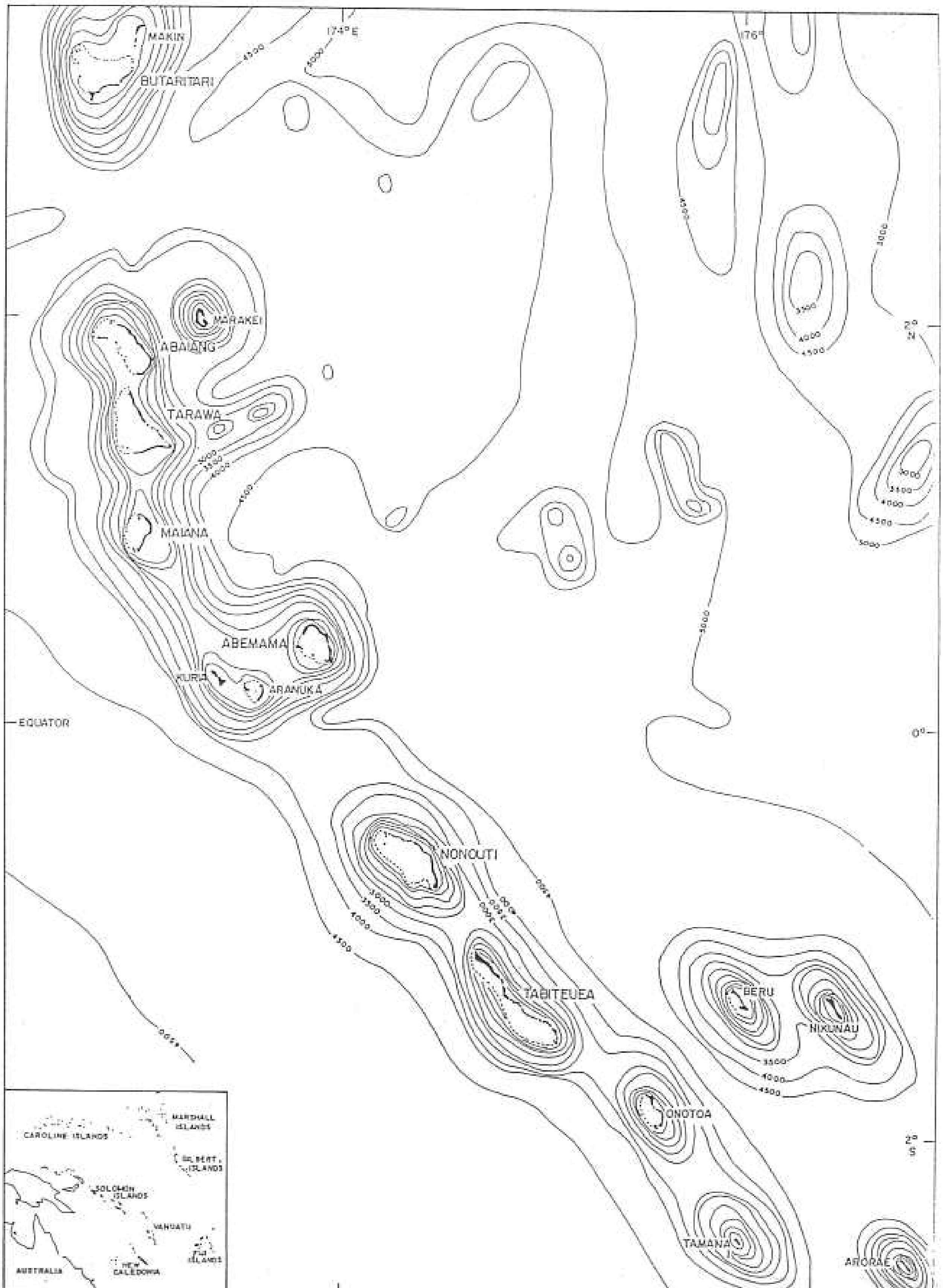
INTRODUCTION

The Gilbert Islands of Western Kiribati comprise five low-lying coral reef-islands and eleven atolls which straddle the equator just west of the International Date Line (Figure 1). During a SOPAC marine survey to determine the occurrence and distribution of precious black coral species, eight of these mid-oceanic islands were visited and the Holocene geology examined. The primary objectives of this survey were to inspect the surficial geology to decipher the recent (Holocene) development of the islands, principally focussing on morphology and sedimentology. Features related to former positions of relative sea level were of particular interest. Prior to the field studies, vertical aerial photographs of the islands were used to identify morphological features for later field checking. Although the visits lasted only one or two days, enough islands and their morphological features were examined for some generalisations to be made about their recent geologic developments.

CLIMATE

The islands are composed almost entirely of skeletal carbonate material, both in situ and detrital, and therefore their existence and form are sensitive to climate variations. The Gilbert Islands lie in the tropical zone where environmental conditions such as water clarity, temperature and organic productivity are favourable for vigorous coral growth. Air temperature averages around 28-30'C.

Moderate easterly tradewinds characterise the wind regime. However, during periodic El Nino and Southern Oscillation (ENSO) episodes there is a greater variation of wind patterns and the trades are punctuated by strong westerlies (Figure 2). Butaritari is usually much calmer than Tarawa. For the years 1970 to 1974 (Holmes 1976) the amount of time where the wind was Beaufort force 1 or less (>1.8 m/s) averaged 37% at Butaritari (range 18-58%) whereas at Tarawa the average was a much lower 8% (range 4 to 15%). The highest percentages of calms were coincident with an ENSO event in 1972. Under "normal" tradewind conditions there is a strong northeasterly component from about January through June, switching to southeasterly from July to December. The typical tradewind tends to be



PREPARED FROM D.O.S. 987: KIRIBATI WEST SHEET AND CCOP/SOPAC CHART 1: BATHYMETRY OF THE SOUTH WEST PACIFIC

Figure 1. Index map of the Gilbert Islands of Western Kiribati showing bathymetry of the seafloor. Contour interval is 500 m.

75%

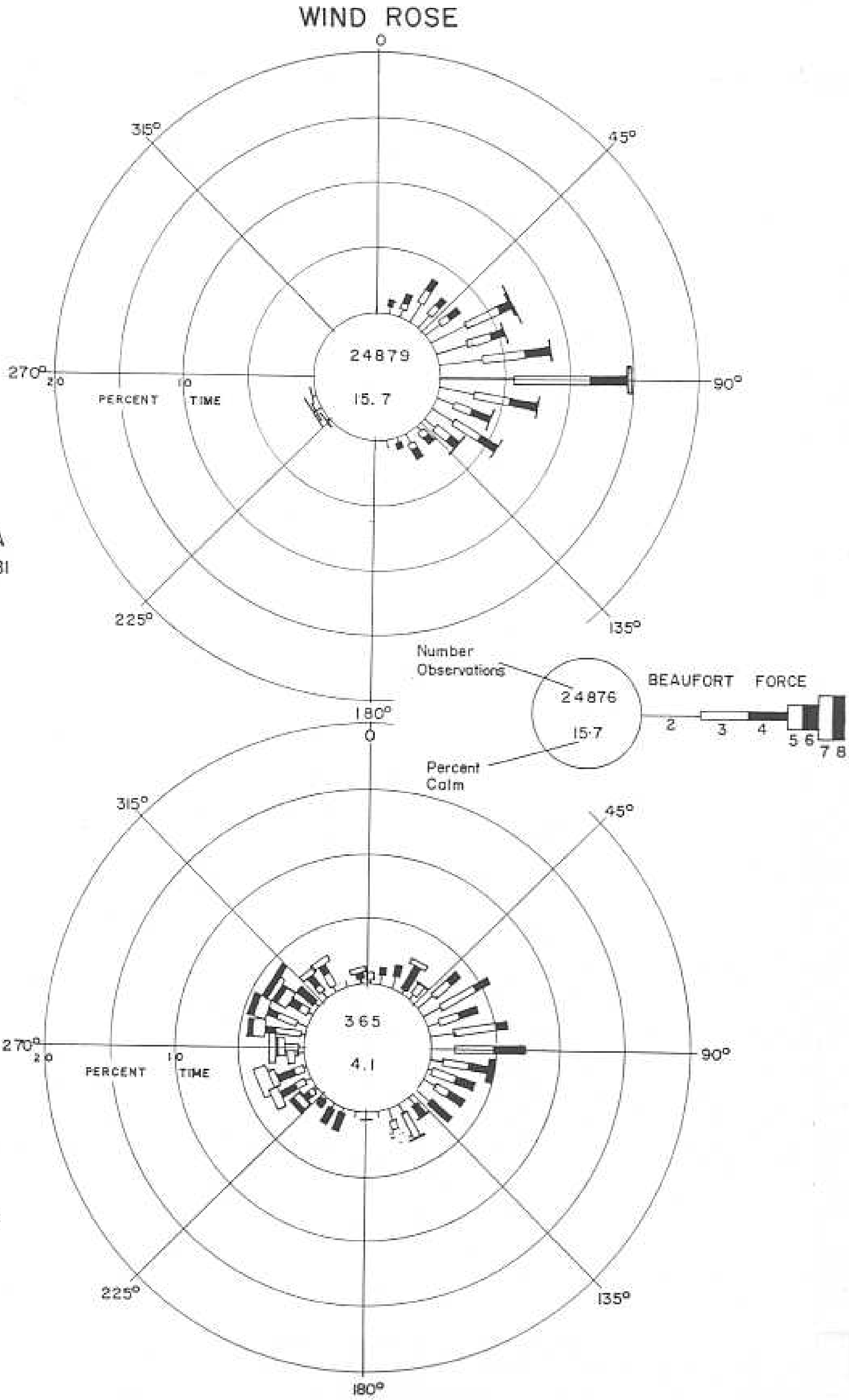


Figure 2. Wind roses for South Tarawa (from Carter, 1983). The 1978-1981 data are representative of "normal" tradewind conditions whereas 19892 is considered typical of westerly conditions associated with El Nino a southern Oscillation (ENSO) episodes.

relatively constant over a number of days whereas stronger winds (>/= Force 6, 11 m/s) persist for short periods, usually associated with the passage of storm fronts.

Wave data are virtually non-existent for the Gilbert Islands, but studies by the Holmes (1976) and Carter (1983) using hindcasting techniques from local wind data provide some information on locally generated waves. Figure 3 (from Carter 1983) depicts the predicted wave climate under 'normal' tradewind conditions and during an ENSO episode. During tradewind flow, as expected, waves are generated primarily from easterly directions with relatively short periods (>6 s) and low significant wave heights (>2 m). Greater variability in direction and an increase in period (>10 s) and significant wave height (>5 m) can be expected during ENSO episodes. Of particular interest is the potential for large waves from the west, normally the leeward side of the islands. The effect of long distance swell is not taken into account in the hindcasting procedures and at times will probably significantly influence the wave climate. The impact of the wind regime and wave climate on the morphology of the islands is discussed more fully in the section on island development.

Spring range of the semi-diurnal tides varies from a low of about 1.5 m at Beru to just over 2.2 m at Abaiang (Holmes 1976). Tide stage is important in determining where wave processes are active and in the generation of lagoonal currents.

Average rainfall varies from just over 1000 mm/yr at Tabiteuea to nearly 3100 mm/yr at Butaritari (Figure 4). Rainfall generally increases both north and south from approximately 1'20'south latitude and all of the islands are subject to drought, especially the southern islands.

Historical records show that tropical cyclones are rare for the Gilberts with only one recorded event this century (Sachet 1957). In late 1927 or early 1928, a cyclone did considerable damage to Butaritari and Little Makin. Recent cyclones have occurred further north at Jaluit Atoll (6'N), Marshall Islands (McKee 1959), and further south at Funafuti Atoll (8'S), Tuvalu (Baines and others 1974). In both instances, significant deposition of coarse gravel ridges occurred. Within the Gilberts, squalls accompanied by heavy rains and strong winds are more common.

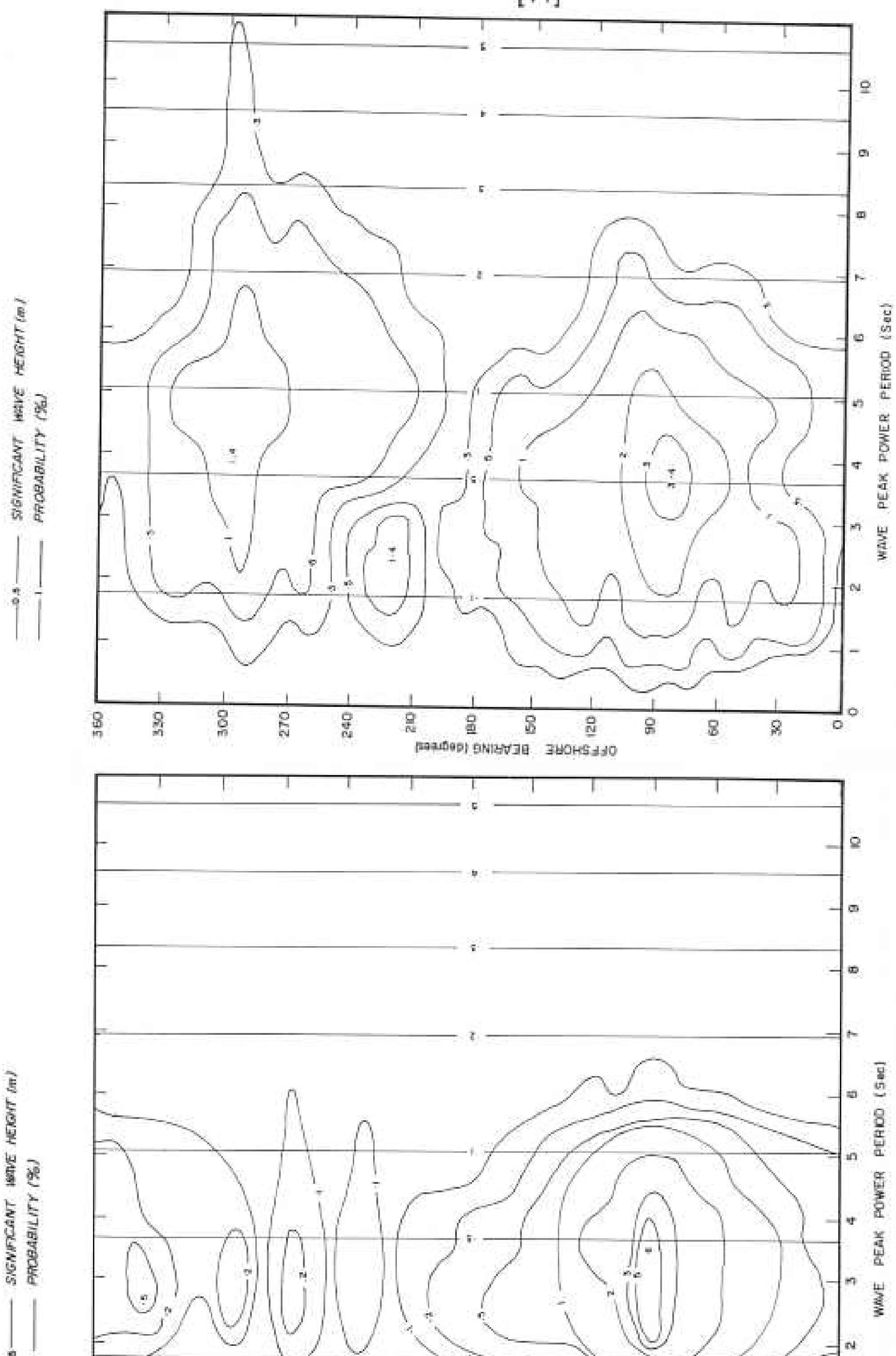


Figure 3. Offshore wave climate for South Tarawa during tradewind conditions (3a) and during ENSO episode (3b). Plots derived from hindcasting wind data presented in Figure 2 and therefgore do not provide information on swell generated outside the immediate area. (From Carter, 1983).

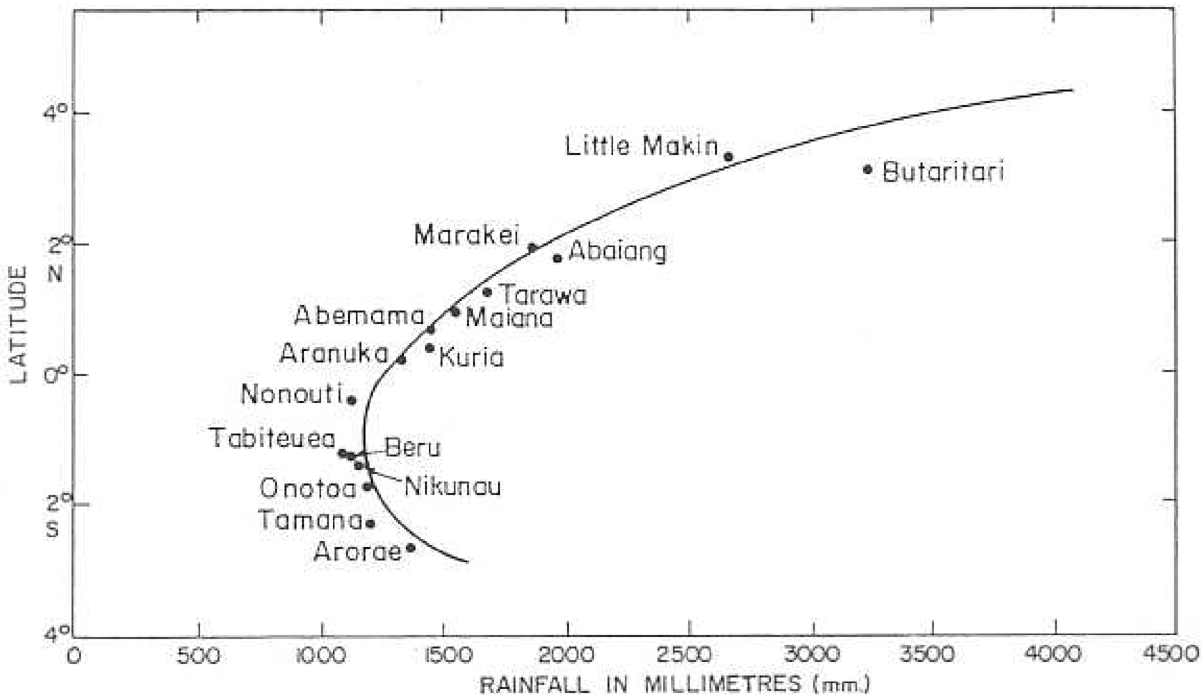


Figure 4. Variation of rainfall with latitude in the Gilbert Islands. Adapted from Amerson, 1969.

TECTONIC SETTING

The Gilbert Islands are carbonate reefs and atolls developed on mid-oceanic volcanoes forming a NW-trending chain. However, the Marshall, Gilbert, and Tuvalu chains lack many features characteristic of typical line island groups such as high volcanic islands or trench subduction (Scott and Rotondo 1983). Marakei and Abemama are slightly offset to the east of the chain and Beru and Nukunau are offset further to the east. The age of the nearby oceanic crust based on magnetic anomalies in Early Cretaceous (Mi1, 126 Ma) near Tabiteuea and Beru, and Late Jurassic (M20, 139 Ma) further north near Butaritari (Circum-Pacific Tectonic Map of the Pacific, in prep).

Deep drilling on nearby Pacific atolls has occurred at Bikini and Enewetok in the Marshalls (Emery and others 1954) and Funafuti, Tuvalu (David and Sweet 1904). A deep hole of 1412 m at Enewetok penetrated shallow-water limestone and forereef/outer slope deposits of Upper Eocene age before finally encountering olivine basalt (Ladd et al 1953). Shallow-water limestones were cored to a depth of 340 m at Funafuti and possibly include

Pliocene deposits (Emery and others 1954). Deep drilling of atolls essentially confirmed Darwin's hypothesis of thick, shallow-water limestone sequences deposited on subsiding volcanic basement.

MORPHOLOGY OF THE ISLANDS

The Gilbert Islands are composed of five reef islands and eleven atolls (Table 1) all of which are composed primarily of skeletal carbonate deposits. The reef islands (Little Makin, Kuria, Nikunau, Tamana, and Arorae) are distinguished by the lack of a significant lagoon and are essentially low-lying clastic carbonate buildups surrounded by a fringing reef. The reef islands tend to be slightly higher than the atoll islets, up to 5 m above sea level, which prompted Nugent (1946) to call Nikunau and Arorae uplifted. Little Makin has a central shallow depression connected to the sea by a small tidal channel and Nikunau contains central ponds which may be lagoon vestiges.

Atolls, islands with a lagoon and annular limestone rim, can be subdivided into fully or partially enclosed types. Marakei is the only enclosed atoll of the Gilberts. Except for two shallow reef flat channels the triangular shaped atoll has a continuous landmass around its rim. The remaining ten atolls, which are more representative of the classic Pacific type, can be sub-divided into those with shallow (<10 m) or deep (>10 m) lagoons. The shallow lagoon atolls are Aranuka, Maiana, Beru and Onotoa; the deep lagoon atolls are Butaritari, Abaiang, Tarawa, Abemama, Nonouti and Tabiteuea. The differences between island and lagoon characteristics do not necessarily represent a continuum in a progressive stage of development but instead may reflect variations of basement form and island growth. In other words, there does not appear to be a continuous north to south change indicative of greater age or development stage.

There are several gross features common to the atolls. Most of the atolls (and reef islands) are elongated in a NW orientation, which is also the trend of the submarine volcanic ridge that forms their basement, and therefore places the islands' long axis perpendicular or oblique to the predominate winds. Islet development on the reef rim is

Table 1. Geographic characteristics of Gilbert Islands.

	LAT*	LONG*	LAND AREA+ (km²)	LAGOON AREA (km²)	DEPTH # (m)	ISLAND TYPES
Little Makin	03°23'N	173°00'E	7.3	-	-	RI
Butaritari	03°10'N	172°50'E	40.6	191.7	33	A-DL
Marakei	02°00'N	173°18'E	10.2	19.6	?	A-EL
Abaiang	01°50'N	172°57'E	28.6	232.5	27	A-DL
Tarawa	01°28'N	173°00'E	20.0	343.6	24	A-DL
Maiana	00°56'N	173°01'E	26.9	98.4	7	A-SL
Abemama	00°25'N	173°53'E	17.0	132.4	26	A-DL
Kuria	00°15'N	173°23'E	12.9	-	-	RI
Aranuka	00°11'N	173°34'E	15.5	19.4	<110?	A-SL
Nonouti	00°39'S	174°21'E	24.3	370.4	26	A-DL
Beru	01°19'S	175°58'E	21.1	38.9	3	A-SL
Tabiteuea	01°20'S	174°48'E	49.2	365.2	27	A-DL
Nikunau	01°22'S	176°27'E	18.1	-	-	RI
Onotoa	01°52'S	175°32'E	13.5	54.4	<10?	A-SL
Tamana	02°30'S	175°58'E	5.2	-	-	RI
Arorae	02°38'S	176°49'E	13.0	-	-	RI
		TOTAL	329.4	2,196		

* approximate centroid position of land and lagoon

\+ adapted from Amerson, 1969

\# from nautical charts
RI = reef island; A-DL = atoll, deep lagoon; A-SL = atoll, shallow lagoon
A-EL = atoll, enclosed lagoon

dominantly on the windward margin. Deep reef passages are exclusively restricted to leeward margins.

A schematic diagram illustrating many of the morphological zones and features observed in the Gilberts is presented in Figure 5. The following is a brief description of the morphology and deposits from the windward to leeward margins.

Windward Reef

Reef Slope

The reef slope is essentially below the present limit of vigorous hermatypic coral growth - about 40 to 50 m depth. Although generally below the observation limits of the present study, in a few places the upper reef slope was observed to consist of reef-derived calcareous sediments mantling a steep slope. Emery and others (1954) found reef slopes of Marshall Group atolls to vary between 30" and 70" with a coarse to fine gradation in sediment texture downslopes. Blocks of reef-rock, however, occurred on the outer reef slope. The base of the islands merge with the deep seaflow at around 4500 m (Figure 1).

Reef Front

The reef front typically consists of a gently seaward-sloping terrace marked at its seaward margin by a steep drop-off to the reef slope and at its landward margin by abrupt, near-vertical walls of coral-algal buttresses (Figure 6a). The terrace is a roughly planar surface which may be incised by deep channels. Terrace surfaces, as observed by divers, consisted of small (<1 m high), massive, subcolumnar and hemispherical coral colonies. Sediments are typically angular, poorly sorted sand and gravel restricted to thin patches between coral colonies except where channels are present. In addition to the reef front terraces, which are generally less than 100 m wide, extensive submerged terrace platforms bordering many of the islands are common (Figure 6b). These terraces, which form submerged extensions of the islands along their general trend of elongation, lie in water depths of 10-40 m in areas of strong currents. Two types of terrace surface were observed: (i) a gently sloping, roughly planar surface with a dense cover of small coral colonies similar to the reef front terraces, and (ii) coral-algal ridges or knolls separated by sediment-floored, flat-bottomed channels similar in appearance to but of larger scale than spur and grooves. It is common for both types of morphology to occur on the same terrace. Islands which contain submerged terraces, and their approximate extension from the reef crest, include: NW Butaritari (2 km), W Maiana (5.5 km), NW Aranuka (5.5 km), N Nonouti (2 km), SE Tabiteuea (1 km), NW (1.5 km) and SE Beru (1 km), SE Nukunau (2.25 km), S Onotoa (2 km) and NW Arorae (2.715 km); these values are based on available nautical charts and vertical aerial photographs. Unfortunately, the limited echosounding of the present study precludes depth correlation between terraces. For the same reason, it is not known if the terrace rim shown in Figure 6b is a continuous or widespread feature although it is present on other terrace echosounder profiles.

Buttress Zones

Coral-algal buttress and spur and groove zones of the reef front were observed at only a few localities in this study but are well described at Tarawa (Zann 1982) and elsewhere (eg. Every and others 1954). Their distribution and morphology are primarily controlled by wave activity and they function as effective dissipators of wave energy (Munk and Sargent 1948). They are covered with compact and encrusting corals and coralline algae - commonly Lithothamnion species. Spur and groove zones are usually clearly visible on the aerial photographs (depending on sun angle) but no attempt was made to systematically map their characteristics. However, they are generally more prevalent and better developed on windward margins.

Reef Platform

The reef platform, or atoll rim, extends from the reef crest to the first major break in slope in the atoll lagoon, or in the case of reef islands, the leeward reef crest. It is the

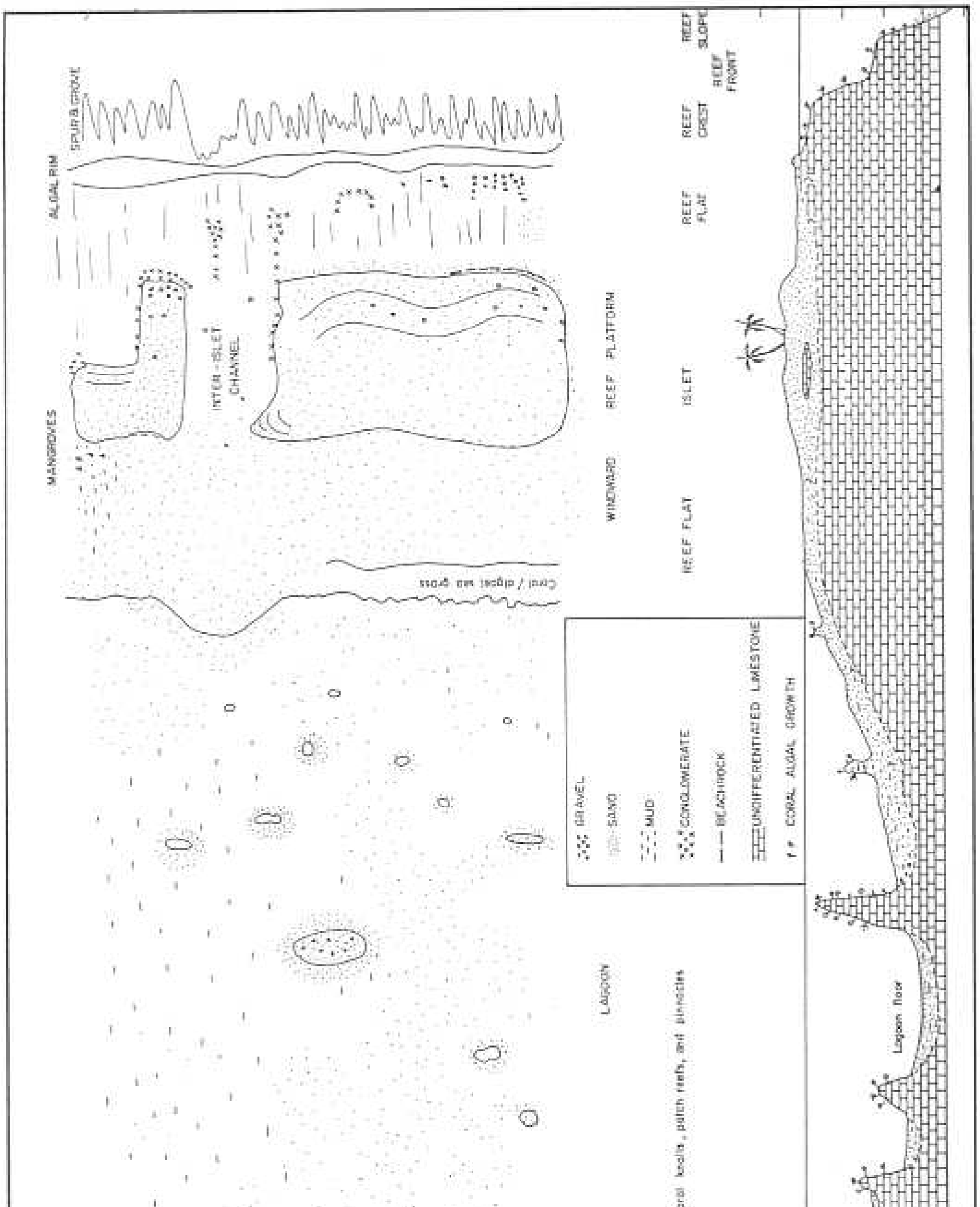


Figure 5. Schematic diagram illustrating atoll features of the Gilbert Islands. In reef islands and atolls with enclosed lagoons (e.g. Marakei), the leeward reef platform resembles the windward reef platform in character.

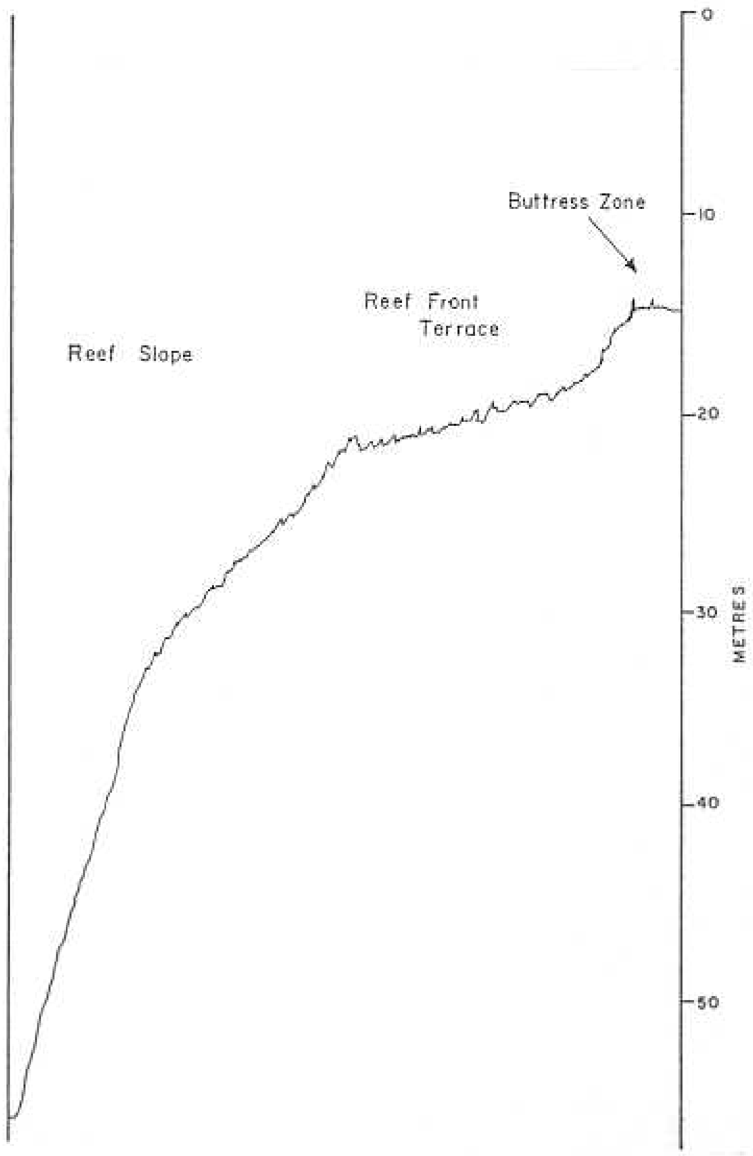


Figure 6a. Tracing of echosounder profile from south Tabiteuea windward reef margin showing the upper reef slope, reef front terrace, and buttress zone.

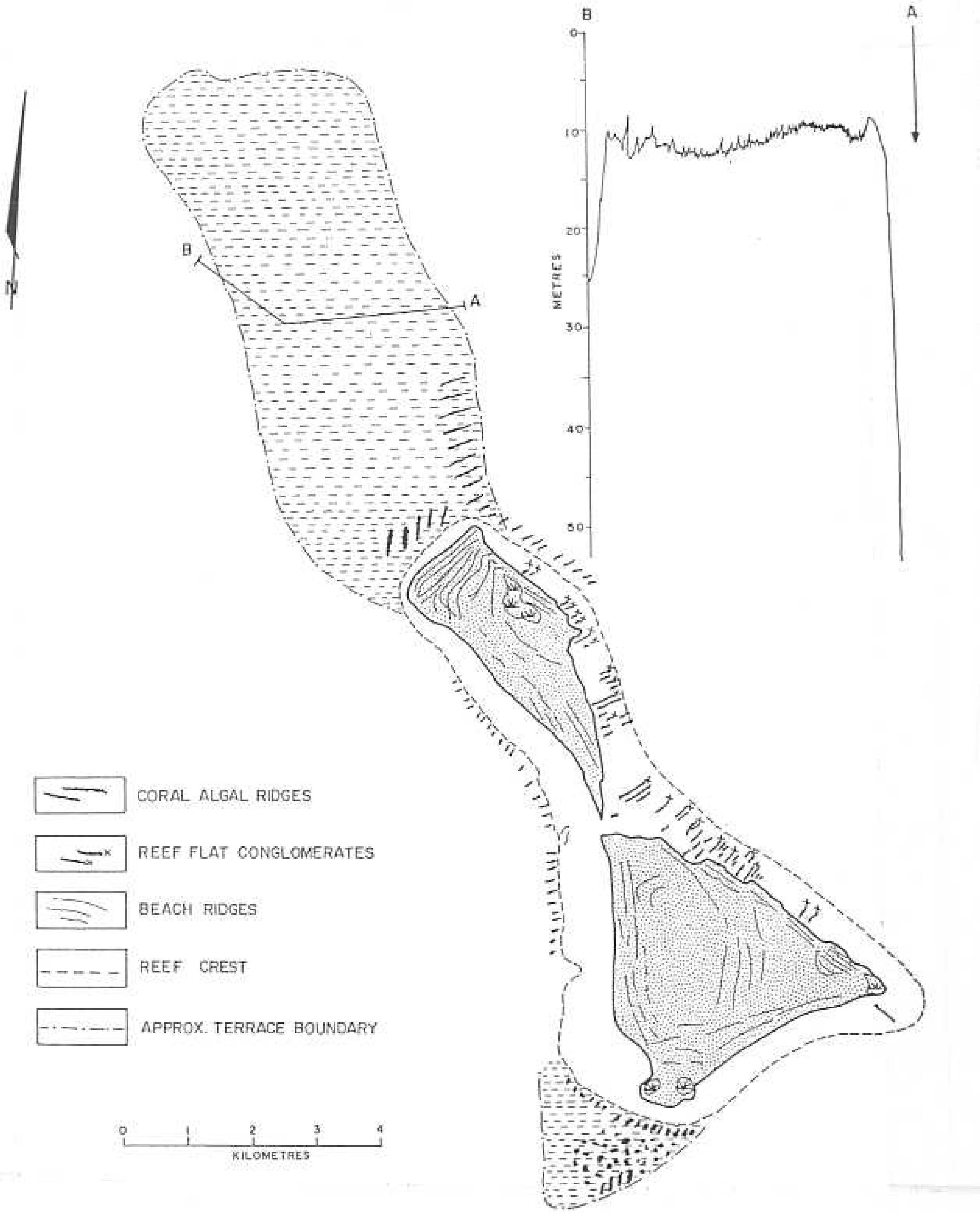


Figure 6b. Approximate distribution of extensive submerged terraces to the north and south of Kuria. A-B is an echosounder profile tracing across the terrace showing rim development and surface roughness, most of which is due to coral growth. Positioning was done by radar and compass fixes and is therefore only approximate.

substrate on which the atoll islets and reef islands rest, varying from an erosional hard-rock surface to a prograding depositional surface.

Reef Crest

The seaward limit of the reef platform is marked by a reef crest, commonly an algal rim (Figure 7a) on the windward coast. Pink, orange, or brown encrusting coralline algae grow upwards of 1 m above low water mark and are characteristic of high energy reefs as the algal rim requires constant moisture by wave spray. Surge channels commonly dissect the rim.

Reef Flat

The windward reef flat is a nearly horizontal surface overlain by a variety of unconsolidated and cemented deposits. Reef flats fronting land masses vary from less than 50 m wide at northern Little Makin to over 1 km wide at Western Kuria. Average widths vary from about 100 to 400 m, and the most common appearance is a boulder-strewn, algal-encrusted limestone platform (Figure 7b).

Gravel deposits have a variety of forms, from scattered individual clasts (Figure 7b) to dense tracts one or two layers thick, but the most striking are gravel ramparts which form extensive shore-parallel deposits (Figure 7c). Often asymmetrical in cross-section with a gentle seaward slope and a steeper landward slope, they are composed mostly of coral debris from the reef front. Stratification may or may not be apparent. Smaller ramparts of mostly branching corals are usually less than 0.5 m above the reef flat whereas the boulder ramparts may exceed 1 m in height. It has been well demonstrated that gravel ramparts are the product of catastrophic events such as cyclones (McKee, 1959; Baines and others 1974) and possibly tsunamis. Reworking imparts a convex seaward, concave landward plan view profile to the ramparts. Further working creates shore-normal gravel tongues which may extend for 100 m or more.

Sand deposits on the windward reef flat are generally restricted to thin veneers, patches, and the occasional bar (transverse or oblique). General observation indicates that the wider the reef flat, the greater the amount of finer (sand) sediments.

The most striking feature of the reef flats is high-level, shore-normal, coral-conglomerate tongues (Figure 7d and e), which are common features of all the islands visited and are clearly visible on aerial photographs. They exhibit a wide variety of configurations and structures but are typically much longer (up to several hundreds of metres) than they are wide (several tens of metres). Often marked by a broad (30-100 m) head at their seaward margin and a long narrow tail, they have been called hammerhead spits (Fairbridge 1968) and rockgrounds (Emery and others 1954). Their margins either gradually merge with the adjacent reef flat or more commonly form erosional (?) ledges up to 1 m or more in height. Clearly clastic in origin, some exhibit crude bedding and appear to be composed of multiple events as indicated by repetition of obscure, coarsening-upward sequences. Most of the conglomerate tongues we observed were well-cemented, with the upper surface usually solution etched and pitted. (Figures 7f-h). Their origin is somewhat problematical, primarily because of their shore-normal orientation, but they are most likely to be remnants of ramparts that have migrated landward. The conglomerate tongues commonly intersect the shoreline, the implication of which will be discussed below.

Extensive shore-parallel, high-level conglomerate platforms are prevalent features of the inner reef flat and merge with the shorelines of atoll islets and reef islands where they appear to form an armoured substrate supporting the islands. Similar in internal characteristics to the conglomerate tongues, they differ primarily in their shore-parallel orientation and tendency towards better sorting and definition of bedding. In general, clast size decreases landwards.

Other features of the reef flat include: shallow moated pools; microatolls and other small coral colonies; and large detrital reef blocks.

Figures 8a and b illustrate the main features of the reef platform and lagoon.

Figure 7a. Algal rim (pink coloured) onthe east coast of Butaritari at approximately mid-tide stage. The reef flat at this locality was an algal encrusted surface with scattered boulders and very little sand.

Figure 7b. Algal encrusted limestone reef flat with scattered boulders near Tebangetua, Maiana east coast). The boulders are composed almost entirely of single coral colonies.

Figure 7c. Reworked gravel (mostly boulder size) rampart on the east coast of Butaritari near Anontena. It possibly formed during the cyclone of 1927. Imbrication of clasts in a seaward direction by subsequent wave reworking. Sand and gravel clay is forming near crest of rampart. Lagoonward dipping cemented layers in lower right.

Figure 7d. Shore-normal coral-conglomerate tongue on the reef flat, Taboiaki, east coast Abemama. Note the bevelled edges which merge with the adjacent reef flat surface.

Figure 7e. Shore-normal coral-conglomerate tongue (Y-shaped) with erosional ledge margin that is nearly 1 m above the reef flat at its seaward end photograph taken at approximately mid-tide stage.

Figure 7f. High-level reef flat conglomerate remnant showing two coarsening upward sequences on the left-hand side of the outcrop. From Kariatebike, east coast of Abemama.

Figure 7g. High-level reef flat conglomerate remnant nearly 1.5 m, above boulder covered reef flat near Kariatebike, east coast Abemama.

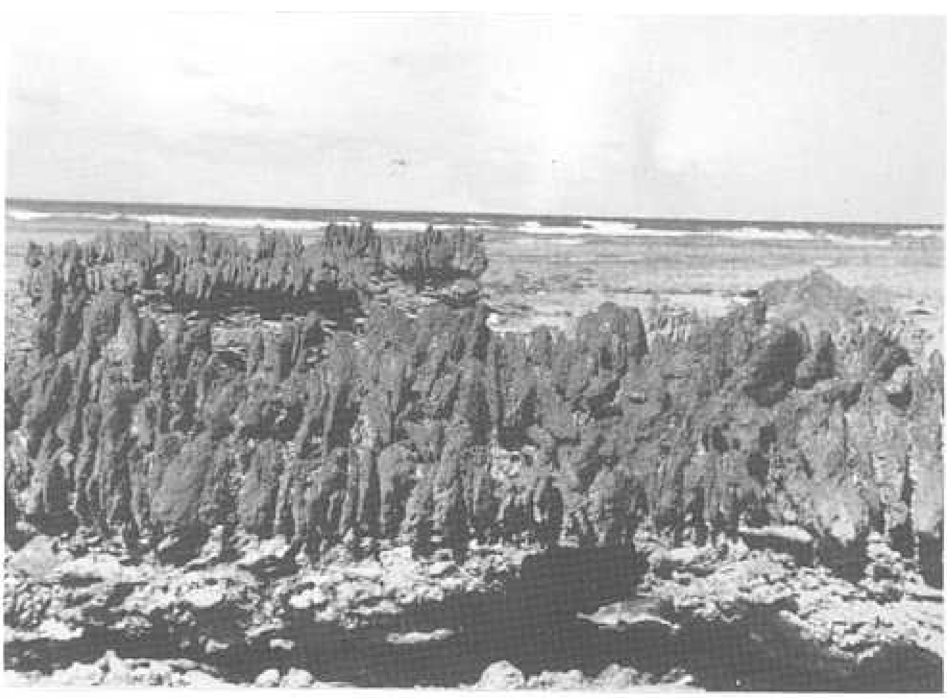


Figure 7h. High-level reef flat conglomerate remnants. The upper surface is composed of well-cemented platy coral fragments placed by man for use as a fish-trap. Age unknown.

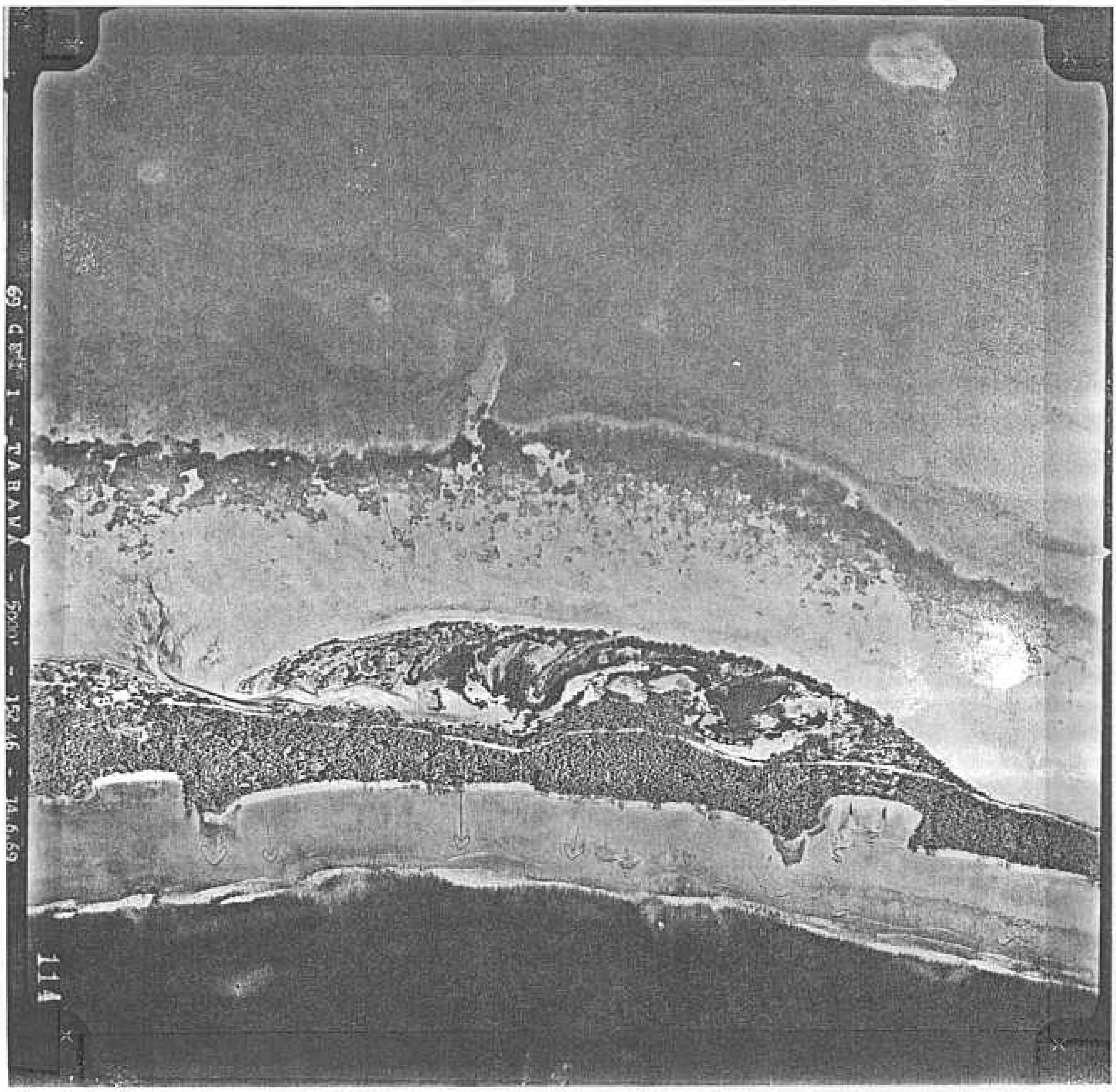


Figure 8a. Vertical aerial photograph of Eita, South Tarawa. Lands, Mines and Surveys Department, Fiji, June 1969, photograph.

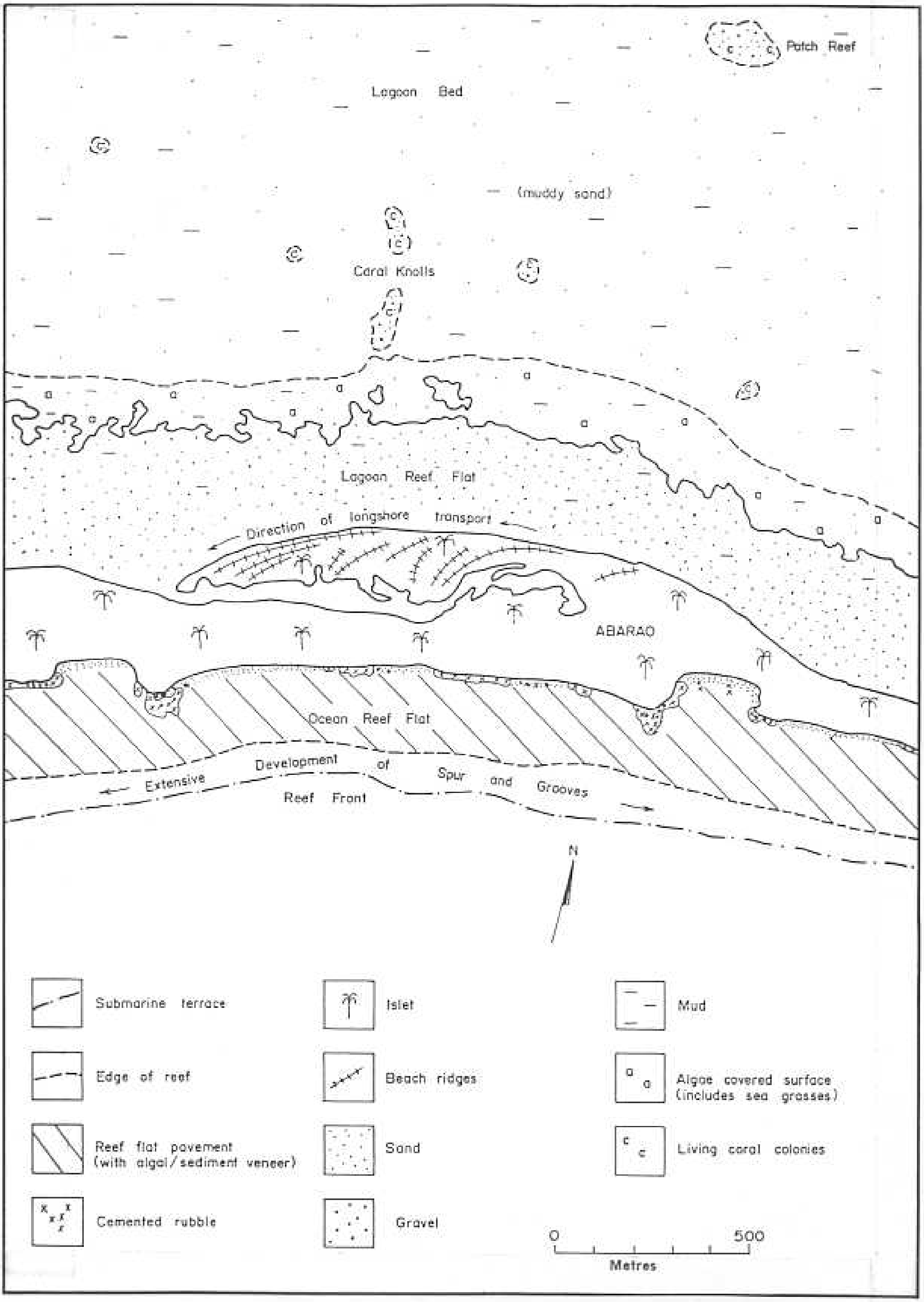


Figure 8b. Interpretation illustrating various features of the reef platform and lagoon.

Atoll Islets

Islets on atoll rims form primarily along the windward margins. Unlike the Marshall Islands, where islets are generally confined to convex seaward rim bends (Emery andothers 1954), Gilbert Island atoll islets are well-distributed along both convex and concave rim segments. A wide variety of islet shapes and sizes occur. Where continuous, the islets are long and narrow. Seaward islet shorelines consist of either sand or gravel beaches, beachrock, or high-level conglomerates (Figure 9). Beach textures range from medium sand to boulders and are moderately to poorly sorted. Beach slopes on South Tarawa average around 8" (Carter 1983). Composition is mainly skeletal remains of corals, Foraminifera, molluscs, and coraline algae. Size and composition tends to vary with exposure: steep gravelly coral beaches are typical of narrow reef flats and sharp convex bends at north and south atoll margins, while sands and gravelly sands with greater amounts of molluscs, foraminifera and coraline algae are characteristic of beaches adjacent to wide reef flats.

Lagoon beaches tend to be well to moderately sorted but exhibit greater grain angularity. Mono-component (e.g. small bivalves) beaches are common.

The most striking feature of the seaward shorelines are prominent shoreline re-entrants that in most cases can be related to the intersection of a reef flat conglomerate tongue with the shoreline or to a gap in a shoreline platform conglomerate. The shoreline re-entrants typically occur in complex associations (Figure 9) primarily due to different ages and trends of conglomerates and varying rates of sedimentation and erosion. Shoreline re-entrants are discussed more fully in the section on island development.

Beach ridges, recurved spits, ponds and flats are the main components of the islet surfaces (Figure 10). For the most part, the beach ridges are subtle features often more easily detected from aerial photographs than from the ground. They are best developed adjacent to narrow reef flats particularly on reef islands and leeward islets of atolls rims. Presumably they are formed by beach progradation, possibly during storm events as they are usually gravel-rich. Some islets, for example Takaeana, a leeward reef platform islet on Aranuka, exhibit a quasi-concentric growth of beach ridges. The interpretation of beach

Figure 9. PHOTOGRAPHS OF ISLAND SHORELINES. a. Platy-coral gravel beach face on the northern tip of Anikai, Tabiteaua.

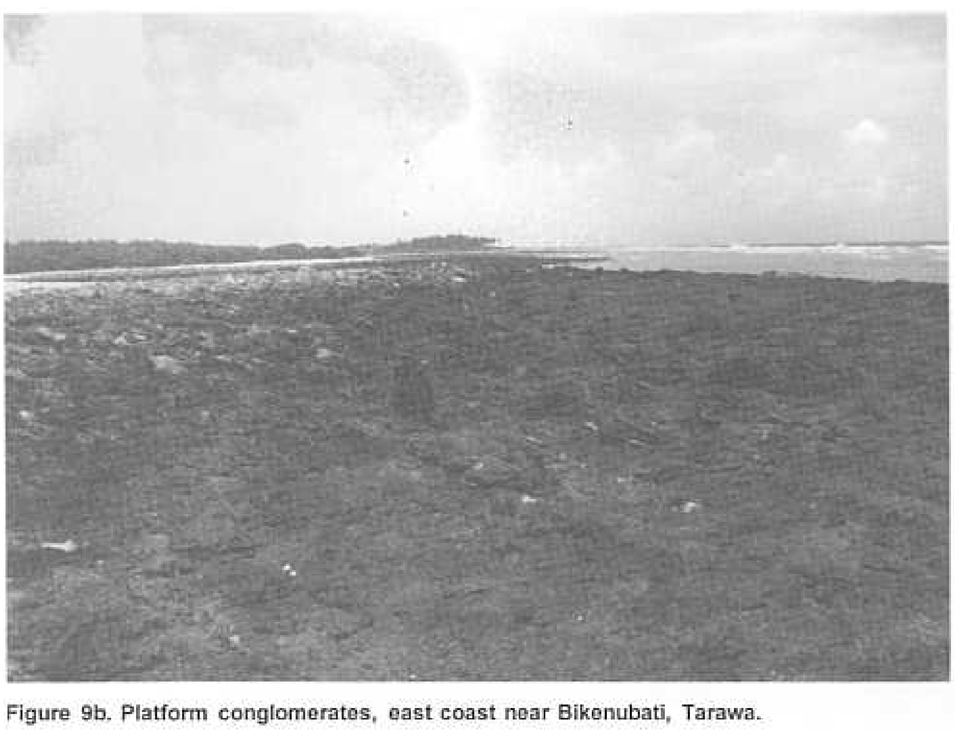


Figure 9b. Platform conglomerates, east coast near Bikenubati, Tarawa.

Figure 9c. Conglomerate tongues bordering islets (background) and inter-islet channels (foreground), Anikai, Tabieuea.

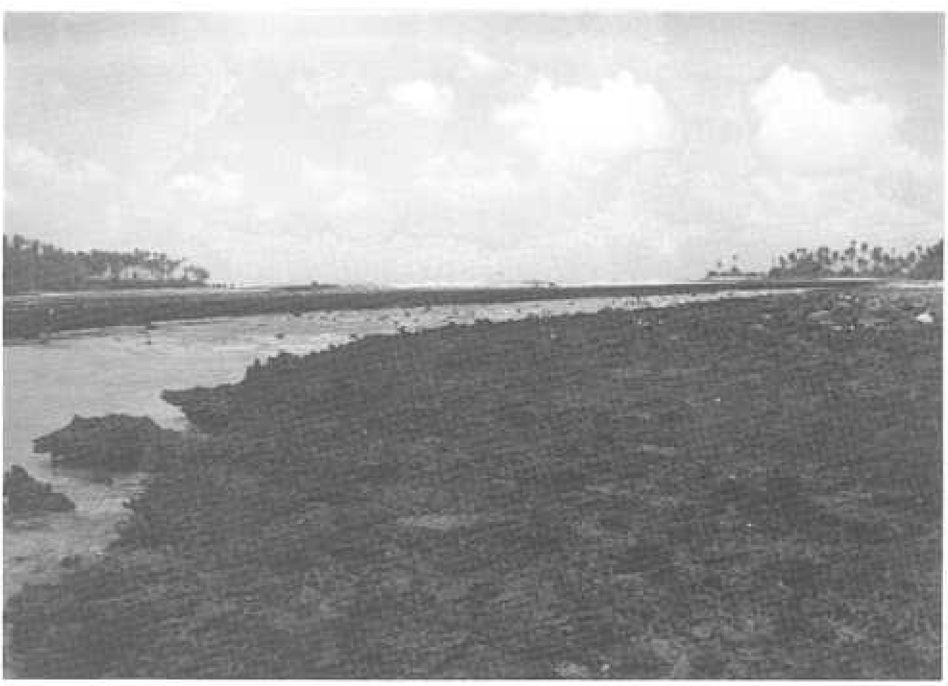


Figure 9d. Conglomerate tongues and inter-islet channel near Bikenubati, Tarawa. Photograph taken facing lagoonwards.

Figure 9e. Conglomerate lined shoreline reentrant looking seaward.

Figure 9f. Conglomerate lined shoreline reentrant looking landward. The head of the reentrant is a gently curved beach backed by beach ridges. The conglomerates are overlain by beach sands, and it is not known how far they extend inland. Near Taunibong, Tabiteuea.

Figure 9g. Conglomerate lined channel and conglomerate tongue mantled by loose sediments. Near Kapiatebike, Abemama.

Figure 9h. Sandy conglomerate (beachrock?) forming platform. Cross-bedding dips obliquely onshore. East coast near Tebangetug, Maiana.

Figure 10. PHOTOGRAPHS OF ISLET SURFACE FEATURES. a. Sand and gravel beach ridges with relief greater than 3 m. West Takeang, Aranuka.

Figure 10b. Coral gravel washover ridge on east coast of Butaritari north of Kenea.

Figure 10c. Nearly flat washover (?) surface composed of pebbly sand covered by dessicated algal mat. Eastern end of Takeang, Aranuka.

Figure 10d. Sand and gravel ridgeover 3m high blocking the mouth of a former shoreline reentrant (?) forming a brackish red-coloured pond (background), Teraereke, Abaiang.

Figure 10e. Lagoon recurved spit constricting an inter-islet channel near Manoku, Abemama.

Figure 10f. Former inter-islet channel that has been sealed bylagoonal spit growth and seaward beach ridge development, formikng a low-lying swampy area near Temangaua, Maiana.

Figure 10g. Lagoon # directed spit growth at the north end of Aranuka near Tetongo. Note curved bedding of the conglomerate in the foreground.

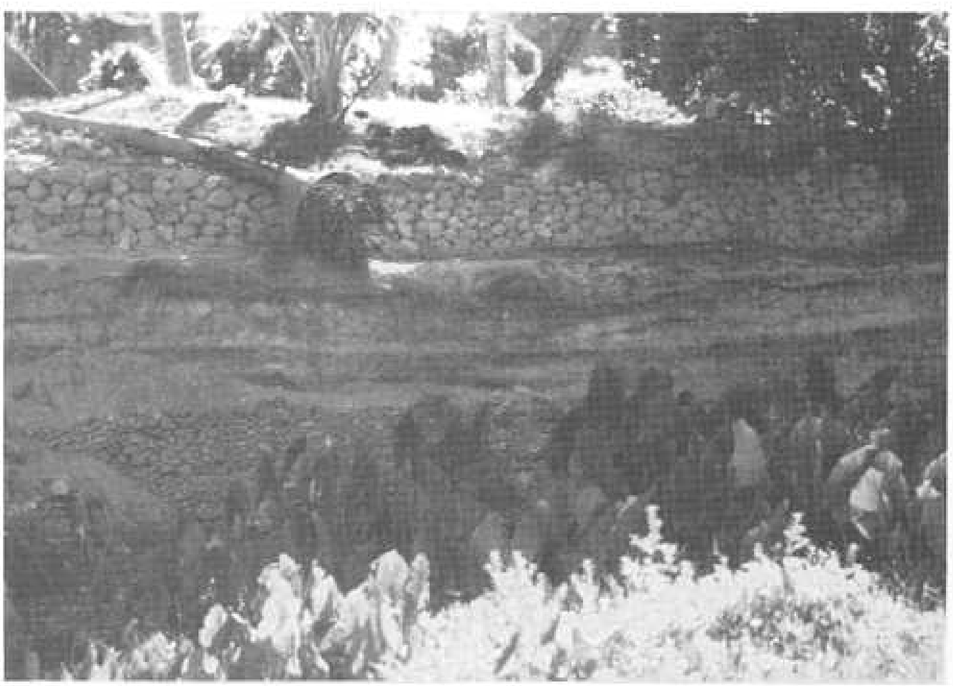


Figure 10h. Vertical exposure is a man-made babai pit showing alternating soil and sandy gravel zones, near Tebunginako, Abaiang.

ridges is complicated by the presence of babai pits - long, narrow ditches used for gardens - which resemble beach ridges when left unattended for long periods. Any pre-existing topographic variations, such as beach ridges, would be utilised in the construction of the gardens.

Spits are common features along lagoon shorelines, especially near inter-islet channels, at the ends of islet chains, and as lagoon-directed, seaward-produced growth at the ends of the atolls. Lagoonal spits typically contain a shore-detached ‘free’ end and extend the shoreline lagoonwards, often building out over washover lobes. As a general rule, spits developed at atoll ends prograde in a consistent direction while those in the central portions commonly show contrasting growth directions in close proximity, indicating bi-directional longshore transport.

Many islets and reef islands have ponds; most appear to be former shoreline indentations that have been separated from open water by either spit or beach ridge closure. Commonly algae rich (red or green), their depths vary from less than 1 m to several metres.

Extensive, low-lying, nearly-flat to gently undulating surfaces covered by sand and gravel sheets form much of the islets. Occasional lagoon-directed slip-faces, usually less than 1 m high, probably indicate storm washover.

Except in the babai pits, soil development is thin (>0.5 m), sparse, and low in nutrients and organic matter (Mason 1960). Rare vertical exposures typically show thin soil profiles alternating with sediments that were presumably deposited during washover events.

Lagoon Reef Flat

Whereas the seaward reef flat is primarily an erosional surface, the lagoon reef flat is typically a depositional surface built up by ocean to lagoon sediment transport and deposition (Figure 11). The sediments tend to be poorly sorted with small amounts of mud (no mud is present within oceanside sediments). Large areas may be covered by sea-grasses and/or algae and the sediments support a prolific burrowing infauna. Small coral

Figure 11. PHOTOGRAPHS OF LAGOONAL LEEWARD SHORELINE AND REEF FLAT FEATURES. a. Conglomerate exposed on lagoonal shoreline Karongoa, Tabiteuea.

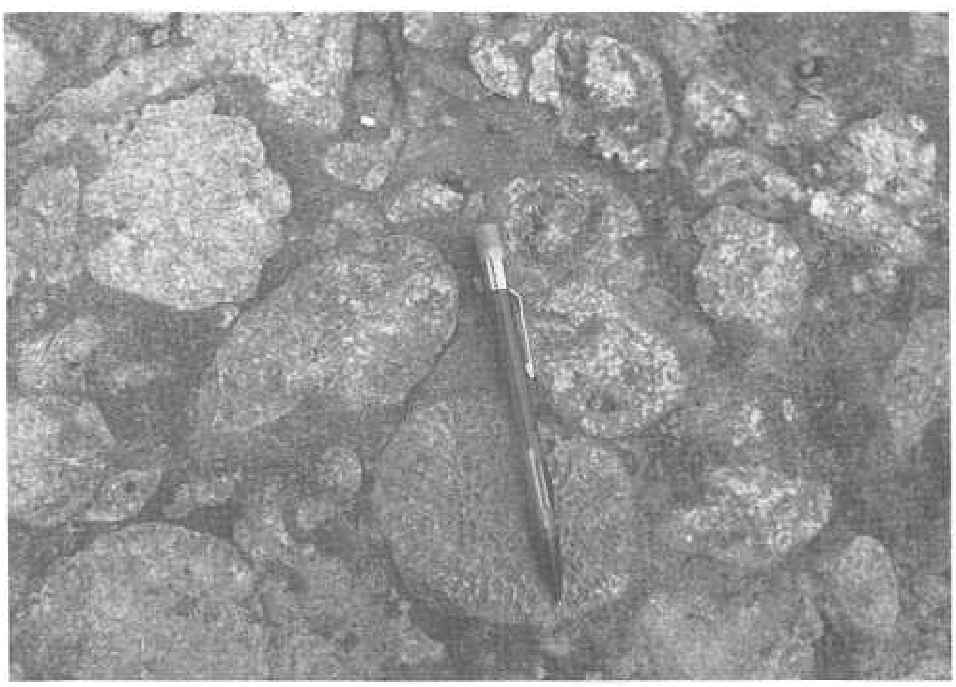


Figure 11b. Close-up of conglomerate in (a) showing rounded coral clasts and sandy matrix.

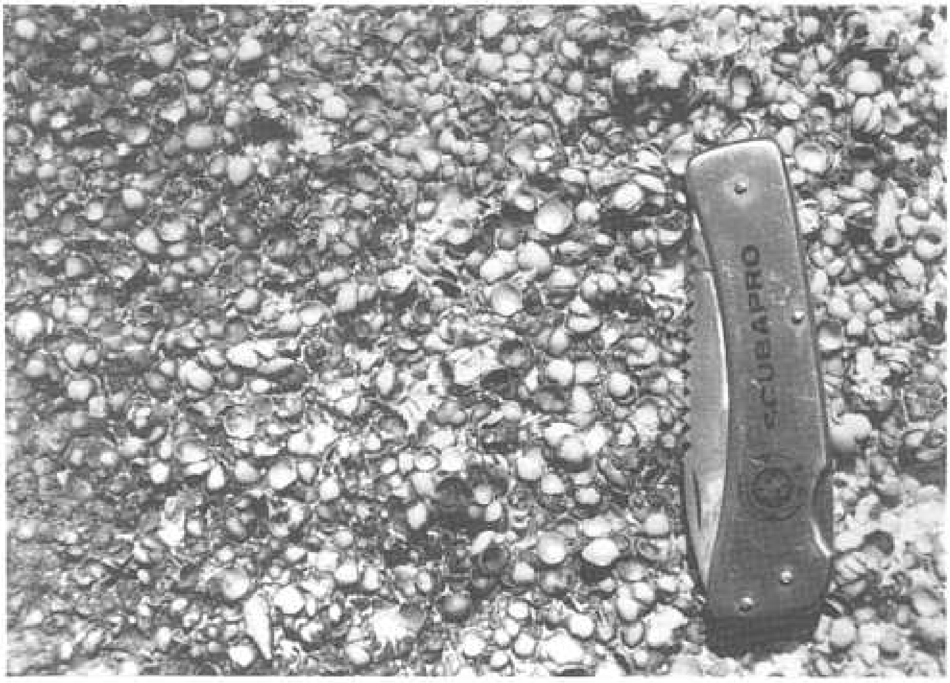


Figure 11c. Close-up of a cemented crust composed almost entirely of small bivalves. From a restricted lagoonal setting south of Manoku, Abemama.

Figure 11d. Lagoonal reef flat near Nea, Tarawa showing extensive algal mats (foreground), small tidal creek, and large (5-6 cm openings) crustacean burrows).

Figure 11e. Sandy tidal flat in the lee of a gravel rampart possibly built during a 1927 tropical cyclone, northern Little Makin.

Figure 11f. Lagoonward migrating foram-rich sand bar to the less of an inter-islet channe,l near Nea, Tarawa. The slip-face is about 40cm high.

Figure 11g. Coral blocks transported lagoonward over reef flat, near Aoutena, Butaritari.

Figure 11h. Mangrove on upper tidel (reef) flat near Tanaea, Tarawa.

colonies may be present near the slope break into the lagoon proper. The lagoon reef flat has low relief, slopes gently towards the lagoon, and is lower than the seaward reef flat - an average 0.45 m lower near Betio and Bairiki, Tarawa (Carter 1983). Clearly visible on aerial photographs but barely discernable on the ground are large (wavelength tens of metres), low-amplitude (heights 10-20 cm) sand waves. Sinuous to straight-crested, they form trains oriented parallel or oblique to the shoreline. Occasionally two intersecting trains may be present.

Extensive stands of mangroves are also typical of many lagoon reef flats.

Inter-islet Channels

Islets may be separated by narrow channels several tens of metres wide or by extensive expanses of reef flat up to several kilometers in width. Depths range from intertidal to shallow subtidal. Subtidal areas may contain small coral colonies. Sediments tend to be coarse and a wide variety of bars and channel patterns may be present. Transverse bars and sand bodies are best developed on extensive reef flat areas such as between Betio and Bairiki, Tarawa. Circulation and water flow is predominantly from windward to leeward due to wave set up at the reef. Tidal and lower frequency current reversals may occur however.

Lagoon

Atoll lagoons of the Gilbert Islands encompass a much larger area than the land masses (Table 1) but are not well described. In the Gilberts, lagoons vary from those that are fully enclosed as at Marakei, to poorly-defined, shallow expanses of water as at Nonouti and Tabiteuea. The deepest lagoon is at Butaritari, but at 33 m, it is shallower than atoll lagoons in the Marshall Islands or Tuvalu. It is not known whether the extensive terraces in the lagoons of the Marshall Islands are present in the Gilberts.

An echosounder traverse from a leeward passage to the inner lagoon at Abemama

(Figure 12) illustrates many typical lagoon features. One of the most prominent is a windward increase in bottom smoothness due to sediment blanketing. This implies significant reef to lagoon sediment transport. The deepest portion of Abemama is a smooth-floored central basin, slightly skewed towards the windward side. The sharp irregularities in the bottom are due to coral-algal reef growth forming coral knobs (height 1-3 m, width 1-5 m), patch reefs (height 3-6 m, width 5-50 m) and pinnacles (height 6-20 m, width 5-50 m; terminology after James 1983). Diving observations suggest an increase in live coral coverage of the bottom and a decrease in sediment coverage towards the leeward reef platform.

Deep reef passages are restricted to leeward lagoon margins. Usually, a sill is developed which separates the deep lagoon basins from the offshore reef slope. Where observed, the sill is a hard limestone substrate, often scoured or covered with encrusting and compact algae or corals. Sediment coverage is sparse in the main axis but large sediment-floored areas occur both lagoonward and seaward. Poorly sorted, gravelly coarse sands were sampled at several of these 'tidal delta' deposits.

Leeward Reef

The leeward reef platform is mostly shallow subtidal, but occasionally intertidal with isolated islets. However, some of the leeward reef islets may be quite sizeable. This zone was not closely examined in the present study and aerial photograph coverage was generally poor. Buttresses and spur and grooves do occur, but the reef crest generally lacks an algal rim.

SEDIMENT DISTRIBUTION

Tarawa is the only atoll in the Gilberts where appreciable surface sediment sampling has taken place, Figure 13 is a generalised surficial sediment distribution map for Tarawa based on over 200 samples from various sources (Burne 1983, Carter 1983, Gauss 1982,

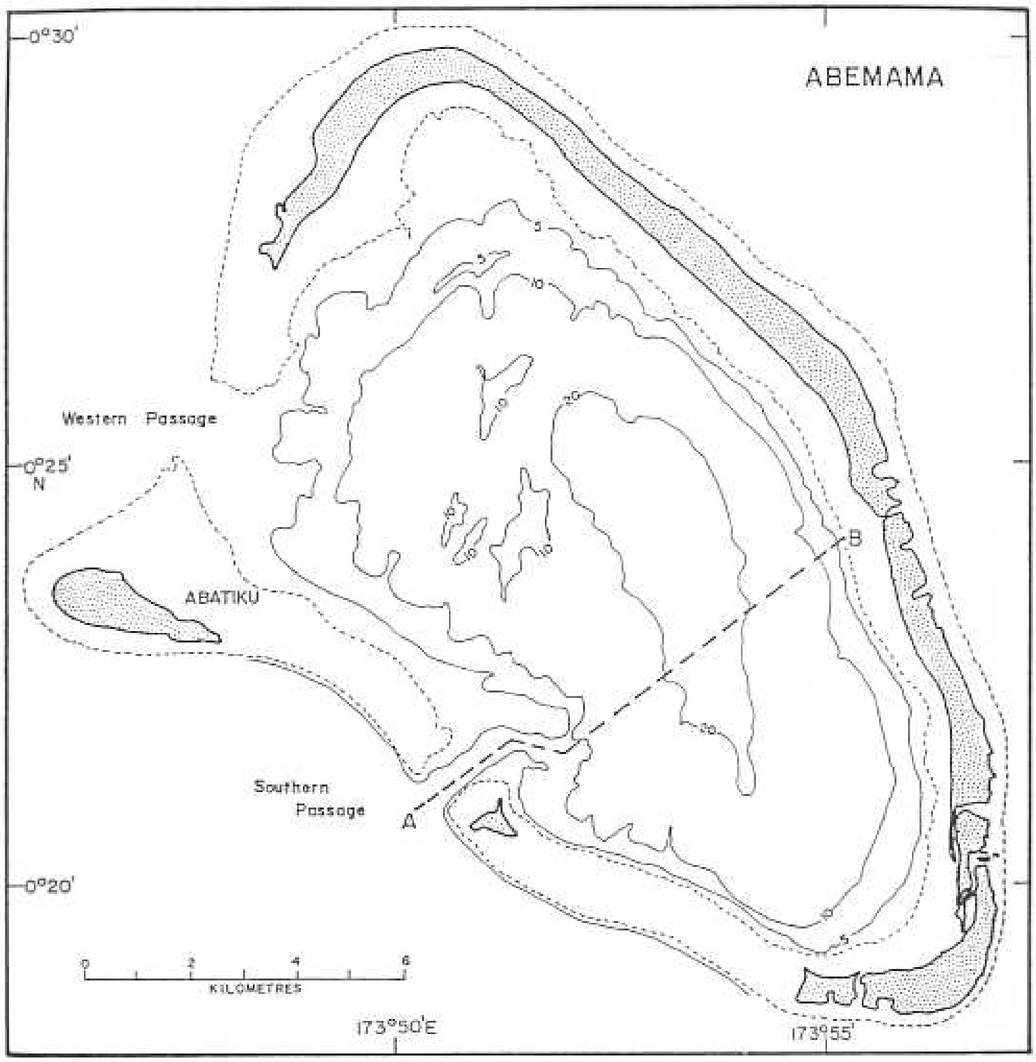


Figure 12. Bathymetry and echosounder profile from the lagoon at Abemama Atoll illustrating features typical of atoll lagoons of the Gilbert Islands. Note the smooth sediment-covered lagoon floor of the windward margin, deep central basin, and reef passages of the leeward margin. Somewhat a typical is the large islet, Abatiku, of the leeward reef platform. Echosounder trackline is approximate; contours are in metres and adapted from Admiralty Chart No. 743 (1963).

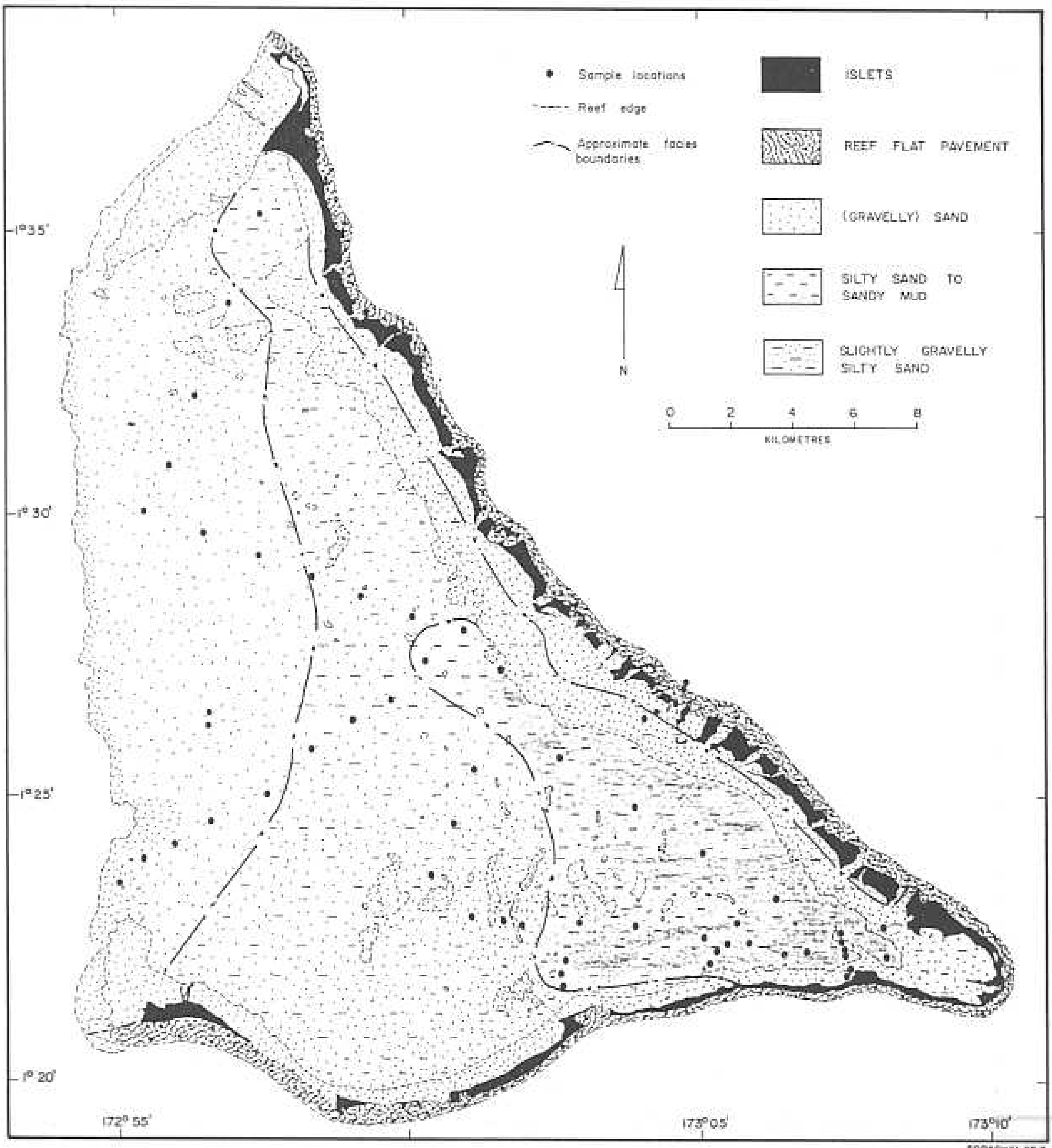


Figure 13. Generalised sediment distribution of Tarawa Atoll based on over 200 surface sediment samples from various sources (see text). Most of the samples are from south Tarawa.

Kiribati Government 1969 and 1981, Weber and Woodhead 1972, and the present study). The sediment distribution can be briefly summarised as follows:-

(a) The reef platform is dominated by sands and gravels. Sands comprise the bulk of the islet and lagoon reef flat deposits whereas gravels dominate the seaward reef flats and constitute a large percentage of some islets.

(b) Sediment thickness is variable; Marshall and Jacobson (1985) reported between 2 and 12 m of sediment on islets drilled in Tarawa. Many reef flats are rock surfaces with a patchy veneer of sediments, although unconsolidated material may underlie extensive areas.

(c) Within the lagoon, sediment texture varies primarily with depth and proximity to reefs. In deeper areas with few reefs, silty muds predominate while in shallow water near reefs, sands and gravels are common.

(d) The sediment composition is nearly pure skeletal carbonate. Coral and algal fragments are common near reefs, mollusc material can be significant within thicker substrates and on some beaches, while Foraminifera are ubiquitous (some beach deposits are almost entirely Foraminifera tests).

HOLOCENE ISLAND FORMATION

Age

Figure 14 and Table 2 give the locations, descriptions, and ages of limestones presented in Marshall and Jacobson (1985), and Schofield (1977). The oldest and deepest Holocene sample dated was from 13-14 m below the islet surface at Buariki, Tarawa and gave an age of 7750 years B.P. The shallowest exposure of pre-Holocene limestone, from Buariki, Tarawa was at 11 m depth. Dates of windward reef flat deposits from Tarawa, Abemama, Tabiteuea, and Butaritari ranged from 1570 to 2890 years B.P. The samples were collected between 0.9 and 2.4 m above low tide level. All available evidence suggests that the Gilbert Islands subaerial deposits are entirely Holocene in age. The islands are

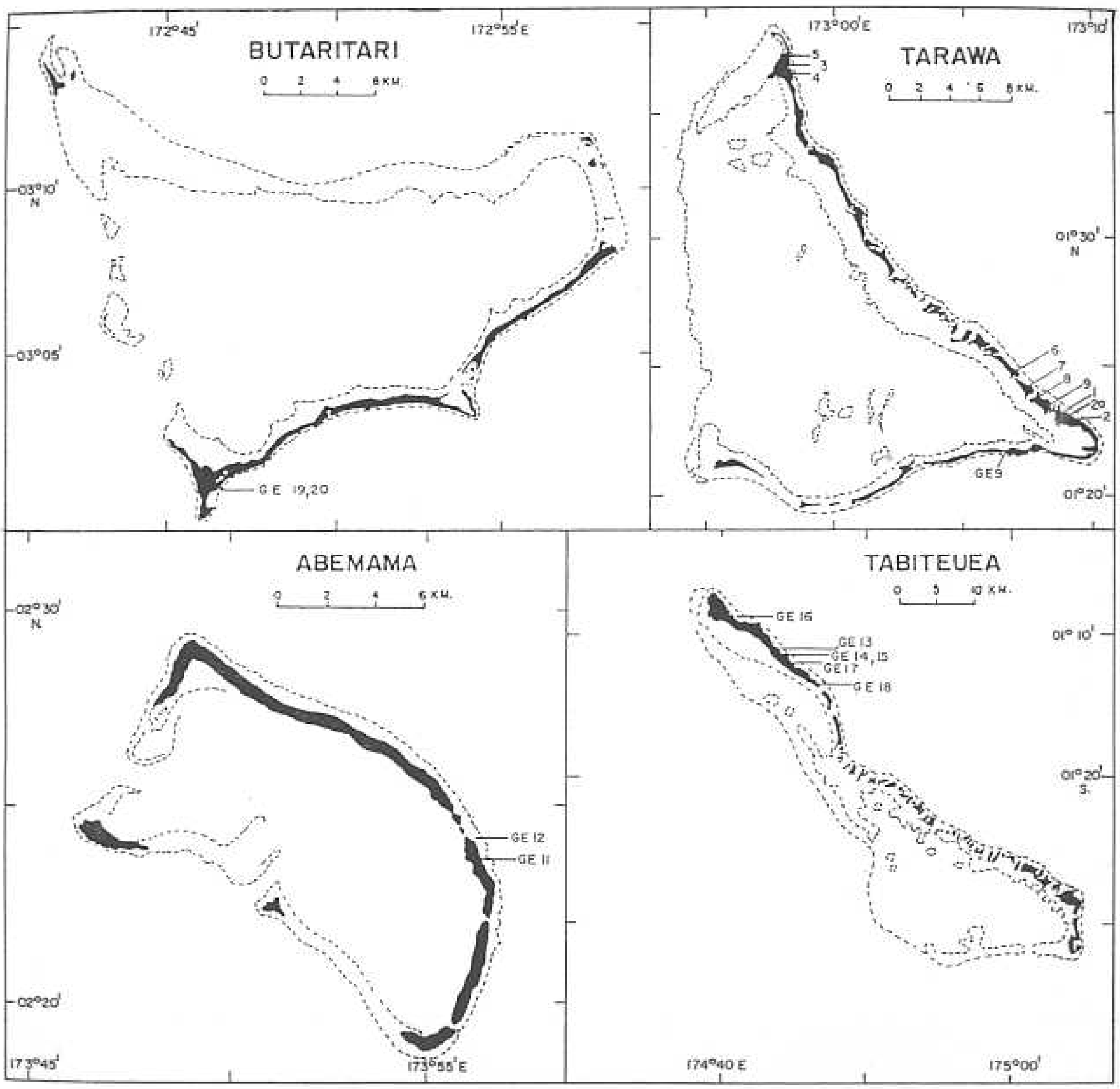


Figure 14. Location of 14°C samples described in Table 2. Note different scales used for each atoll. Samples prefixed by GE are from Schofield (1977) and locations are approximate; other samples are from Marshall and Jacobsen (1985).

Table 2a. Kiribati radiocarbon dates (Marshall and Jacobson, 1985).

LOCATION a	ID.NO. b	ELEVATION. C	LITHOLOGY	AGE (YEARS B.P.)
Bonriki, Tarawa	392 (1)	-11.0 to 11.6	coral	>30,000*
	393 (1)	-15.0 to 15.2	coral	>30,000
	413(2a)	-7.0	coral	6,600 +_ 130
	414(2a)	-11.5	coral	7,150 +_ 140
Buariki, Tarawa	294(3)	-10.5 to -11.0	coral	6,630 +_ 130
	395(3)	-11.5 to -12.0	coral	6,550 +_ 130
	396(3)	-17.0 to -17.8	coral	>30,000*
	403(5)	-4.2 to -4.8	coral	5,680+_120
	404(5)	-6.8 to -7.2	coral	6,140 +_120
	405(5)	-7.7 to -8.3	coral	6,500 +_ 120
	406(6)	-8.4 to -9.4	coral	6,700 +_ 120
	407(5)	-12.4 to -13.0	coral	7,170 +_130
	447(5)	-13.0 to -14.0	coral	7,540 - 150
	448(5)	-14.0 to -15.0	coral	7,750 +_150
Tabiteuea, Tarawa	416(6)	-5.2 to -5.8	coral	6,200 +_ 120
	449(6)	-6.4 to -7.2	coral	6,730 +_135
	450(6)	-8.4 to 9.0	coral	6,850 +_ 140
	451(6)	-9.6 to -10.6	coral	6,920 +_ 140
	452(6)	-11.4 to -12.4	coral	7,340 +_ 150
Abato, Tarawa	412(7)	-8.0	coral	6,500 +_130
Buota, Tarawa	415(8)	-11.0	coral	6,900 +_130
	417(9)	-10.0	coral	7,060 +_140
	453(9)	-10.5 to -11.0	coral	6,690 +_140
	454(9)	-11.5 to -12.0	coral	7,320 +_150
	455(9)	-15.5 to -16.0	coral	>30,000

a - Prefix by NSW for 14C Lab. code and no. Parentheses refer to drill hole number

b - Depth from surface; reduce by about 2 m to get mean sea level.

C - Undifferentiated coral samples, greater than 95% aragonite.

X - Directly below sample dated at 8,600 + 500 by uranium series

* - Dated at 125,000 +_ 9,000 by uranium series.

Table 2b. Kiribati radiocarbon dates (Schofield 1977).

LOCATION	ID.NO.	ELEVATION	LITHOLOGY	AGE (YEARS B.P.)
Bikenibeu, Tarawa	GE-9	+2.25	Tricadna near top of conglomerate	2,760+_70
Taboiaki, Abemama	GE-11	+1.95	Tricadna from back -reef conglomerate	1,570 +_50
	GE-12	+2.1		3,520 +_60
Anikai, Tabiteuea	GE-13	+1.5	Coral from older beach conglomerate	3,980+_70
	GE-14	+1.8	Tricadna from back -reef conglomerate	2,400+_70
	GE-15			2,230+_70
	GE-16	+1.3	In situ Heliopora from reef flat	1,320 + 50
	GE-17	+1.0	Coral boulder	2,890+_40
	GE-18	+0.9 to 1.1	Tricadna from shore -normal conglomerate	1,740+_50
Butaritari	GE-19	+2.4	Porites from bio-hermal reef rock	2,190 +_50
	GE-20	+2.4		2,140+_40

* Above low tide level which is approximately 0.60m below mean sea level (interpolated from Schofield, page 521).

essentially carbonate caps resting on a pre-Holocene (last interglacial) reef that exhibits diagenetic features characteristic of subaerial exposure (Marshall and Jacobson 1985). Marshall and Jacobson also determined that Holocene reef growth on Tarawa was initiated around 8,000 years ago with vertical accretion rates varying between about 5 to 8 m/1000 years. Sea level stabilised prior to 4,000 years ago. Although Schofield (1977) postulated that there have been several Holocene highstands of sea level the evidence is somewhat controversial. Most of the material dated by Schofield appears to be from cemented storm deposits having an uncertain exact relationship to a mean sea level position. In the present study we saw no widespread or abundant features indicative of higher Holocene sea level stands such as high-level reef flat surfaces, in situ corals or micro-atolls. More detailed work is necessary to correctly assess any variations in Holocene sea level position.

Influence of the Limestone

The atoll rim islets and reef islands are a complex association of limestone and unconsolidated carbonate sediments. Most of limestones form basal platforms of cemented coral conglomerate of catastrophic origin, subsequently reworked to varying degrees. Dated surficial limestones range between about 1500 and 3000 years B.P. in age and possibly represent an increase in storminess/catastrophic events at this time, or a relative higher sea level position, or perhaps an increase in carbonate production rates. Beachrock generally occurs as limited exposures close to modern beaches, often overlying conglomerate. Associated with and overlying the limestones are unconsolidated sands and gravels which make up most of the islet surfaces (and volume?). The vast majority of these deposits are water-laid and therefore represent sedimentation under conditions other than those produced by normal day-to-day processes. The islands clearly owe their origin to catastrophic events which produced many of the original limestone deposits and subsequent sediment veneers.

Of particular interest are the structural relationships and interactions between the high-level limestones and modem sedimentation patterns. Several distinctive shoreline configurations are the result of the interaction between nearshore sediment transport and conglomerate tongues and platforms. Shoreline re-entrants, composed of various associations of near right-angle shoreline bends, can be simplified into three common forms.

1. Step-like shoreline re-entrants (Figures 15a and 16a) form a series of convex seaward steps accompanied by a progressive widening of the reef flat (unless the reef edge is curving sharply in the same sense). The steps are created by the interruption of longshore transport by conglomerates effectively behaving as nearshore groins. A reduction in transported sediment 'downcoast' by trapping at the groins results in a successively recessed shoreline. Independent evidence, such as a preferred direction of nearby spit growth in some areas (for examples north and south Abemama) demonstrates a significant longshore component which is directionally consistent with sediment trapping at step-like re-entrants. In all cases however, a significant or persistent longshore component cannot be demonstrated independently. Step patterns could conceivably be the result of a single event such as a cyclone or tsunami.

2. Recessed re-entrants are box-like indentations of the shoreline (Figures 15b, 16). In some cases they can be related to inter-islet channel infilling (the process will be described more fully below). Another way of producing recessed re-entrants is to have a coastal segment or compartment (bordered by conglomerates) that has prograded at a lower rate than adjacent sections of coast, or conversely, has undergone selective erosion. In either case the flanking conglomerates exert control over local sediment transport pathways.

3. Promitory re-entrants (Figures 15c, 16c) are large mirror images of recessed re-entrants - a coastline segment protruding beyond the adjacent coastline.

In addition to shoreline re-entrants, there are other features dependent on interruption of sediment transport by limestones. Symmetrical shoreline protrusions or bulges often occur in the lee of reef flat conglomerates (Figure 15d) and resemble tombolos in appearance and presumably in their mode of formation. The conglomerates may or may not be shore-detached but in either case they create a zone of deposition.

Another common feature associated with high-level limestones are sand and gravel

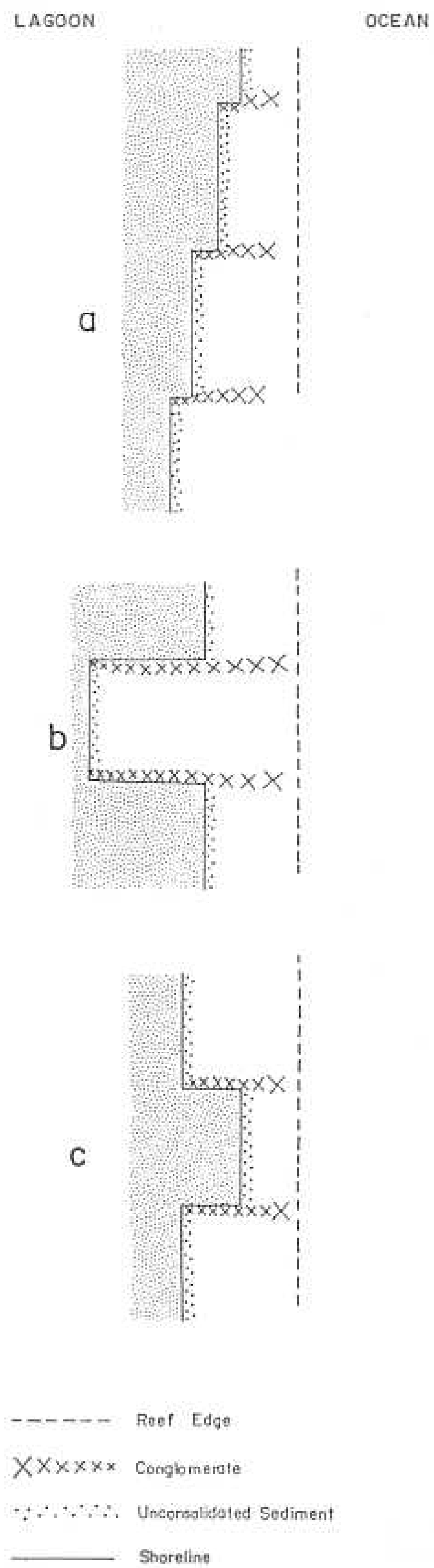


Figure 15. Schematic diagrams depicting the interaction between reef flat conglomerates and unconsolidated sediments and the formation of shoreline re-entrants. Conglomerate tongues are used in these examples, however similar features form adjacent to ramparts and/or conglomerate platforms. a. Step-like shoreline re-entrants where the loose-sediment beaches are progressively stepped-back from the reef crest at each intersection with a conglomerate tongue. Longshore drift in this case is from top to bottom; the conglomerates essentially function as rock groins.

Figure 15b. Recessed shoreline re-entrant bounded by conglomerate tongues. May be formed by infilling of an inter-islet channel, reduced deposition caused interception of sediment transport from conglomerates, or selective erosion.

Figure 15c. Promitory shoreline re-entrant bounded by conglomerate. Sediment transport into the area between conglomerates exceeds transport out of the area of the coastline is receding except in areas protected by conglomerates.

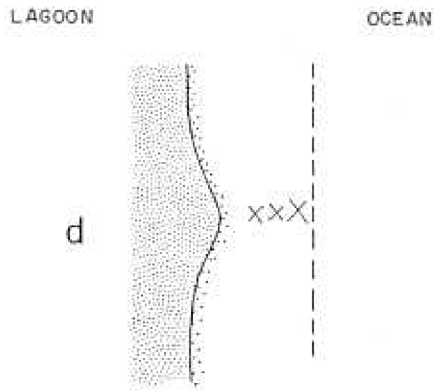


Figure 15d. Tombolo effect of conglomerate tongue or rampart on shoreline. Sheltering behind the reef flat obstruction causes deposition of longshore transported material. The conglomerates may be shore detached or intersect the shoreline in which case a true tombolo situation does not exist. However, this term is used here where symmetric deposition about the obstruction occurs.

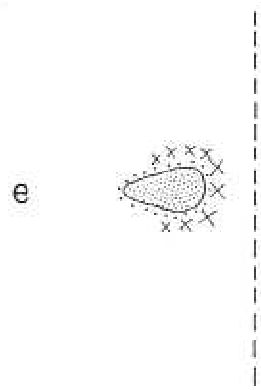


Figure 15e. Reef flat cay or proto-islet nucleated to a conglomerate - typically a rampart remnant. A complete spectrum of cay/islet types exist; cay generally referring to a non-vegeated or lightly vegetated subaerial accumulation of loosse debris (sand and gravel).

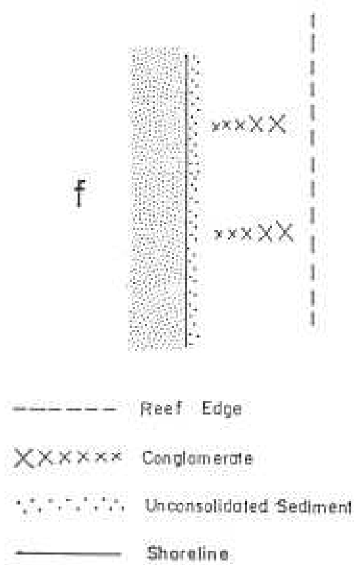


Figure 15f. No apparent effect on the shoreline. Field observbations suggest this is in due in part to low relief of the conglomerates.

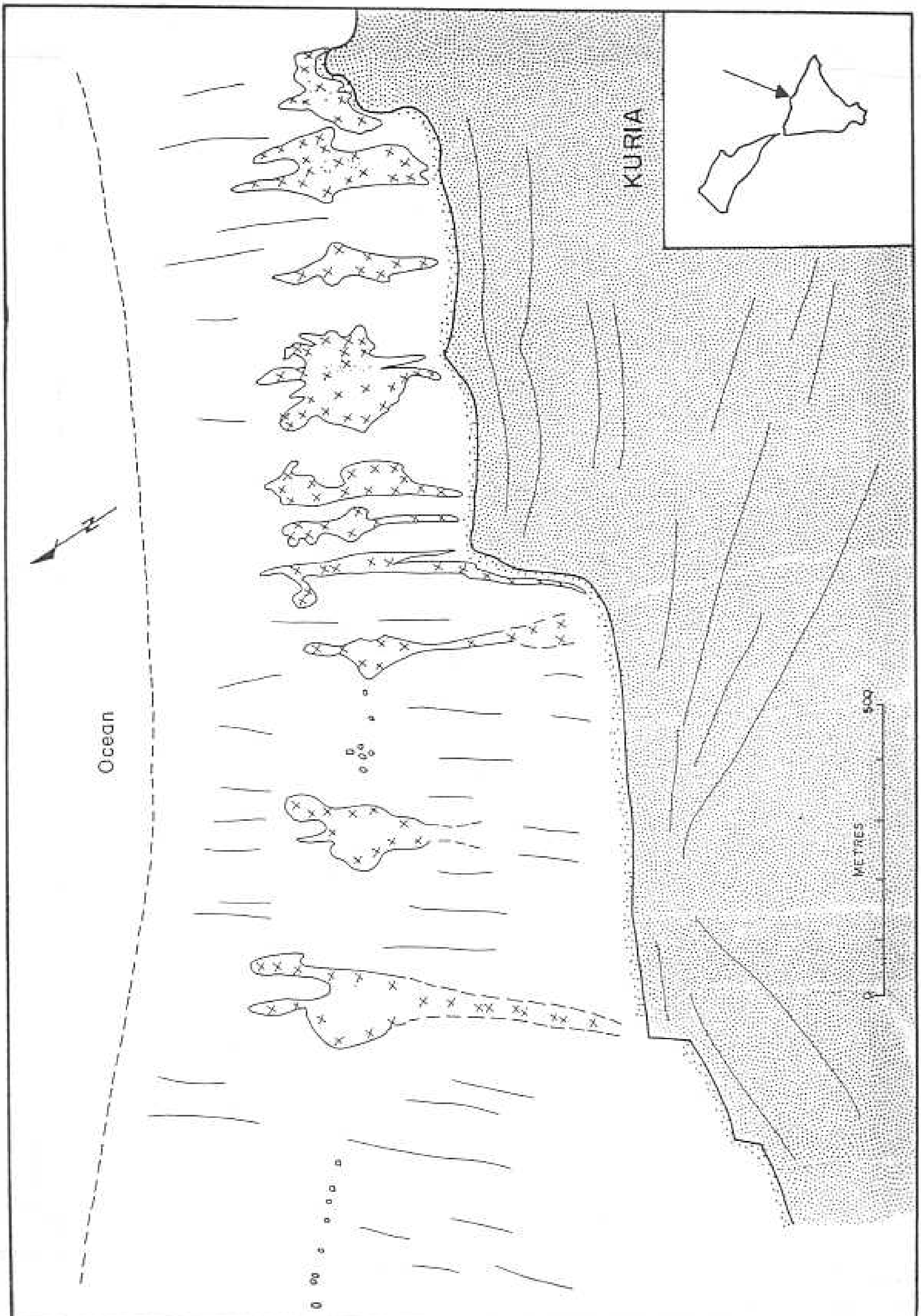


Figure 16. SKETCHES FROM LANDS, MINES AND SURVEYS DEPARTMENT, FIJI, 1969 AERIAL PHOTOGRAPHS ILLUSTRATING SHORELINE RE-ENTRANTS. a. Northeast facing coastline of the reef island Kuria showing step-like shoreline re-entrants. Net longshore movement is presumably from right to left (SE to NW). Note that the seaward margines of the conglomerate tongues are approximately equidistant from the reef margin.

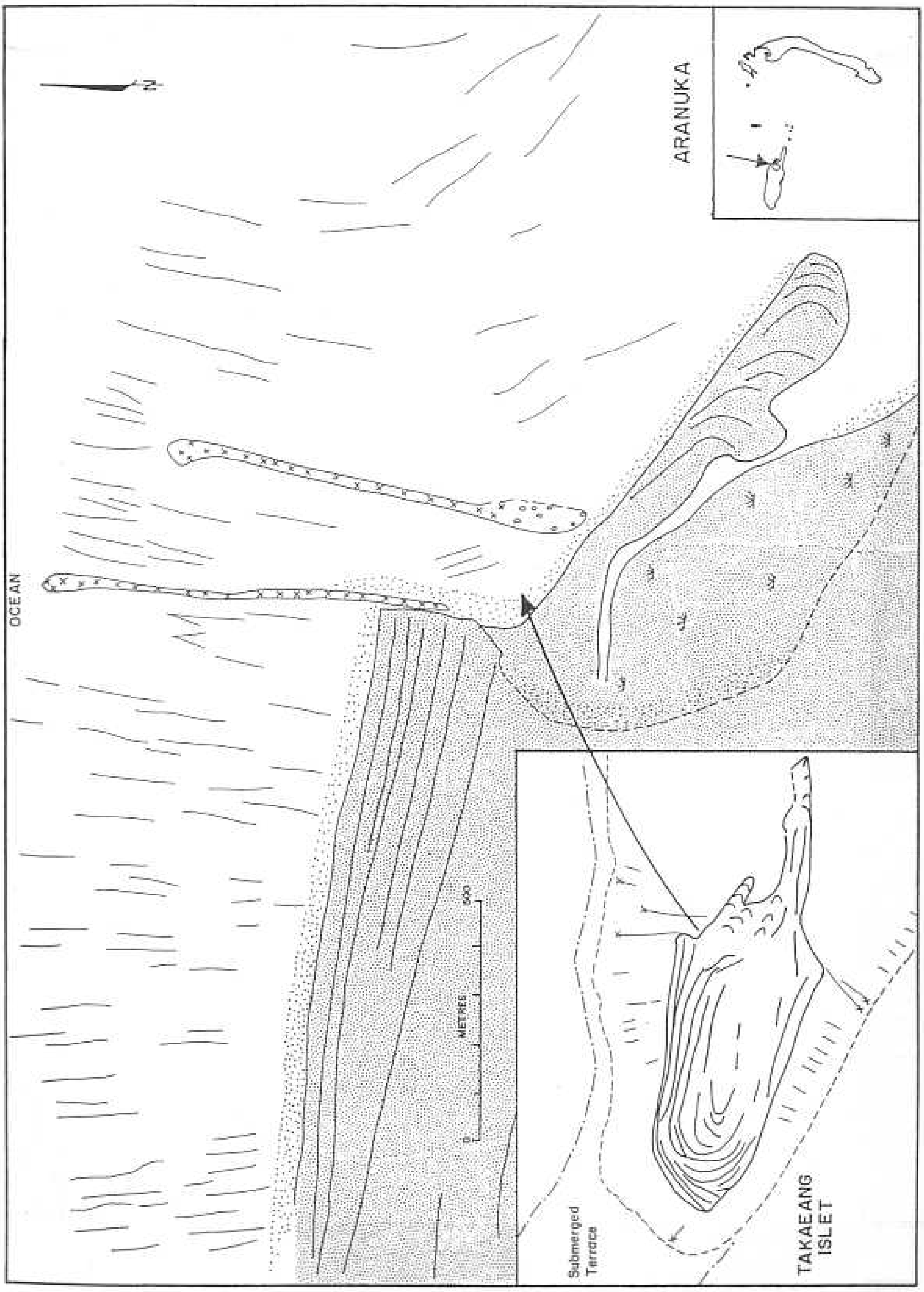


Figure 16b. North facing coastline of Takaeng Islet, Aranuka. This leeward reef islet has single large step like shoreline re-entrant that clearly demonstrates the "groin effect" of a pronounced conglomerate tongue. Numerous beach ridges have developed on the updrift flank, spit growth indicates a predominate left to right (E to W) transport direction. The large inset shows the quasi-concentric beach ridge development and spit progradation.

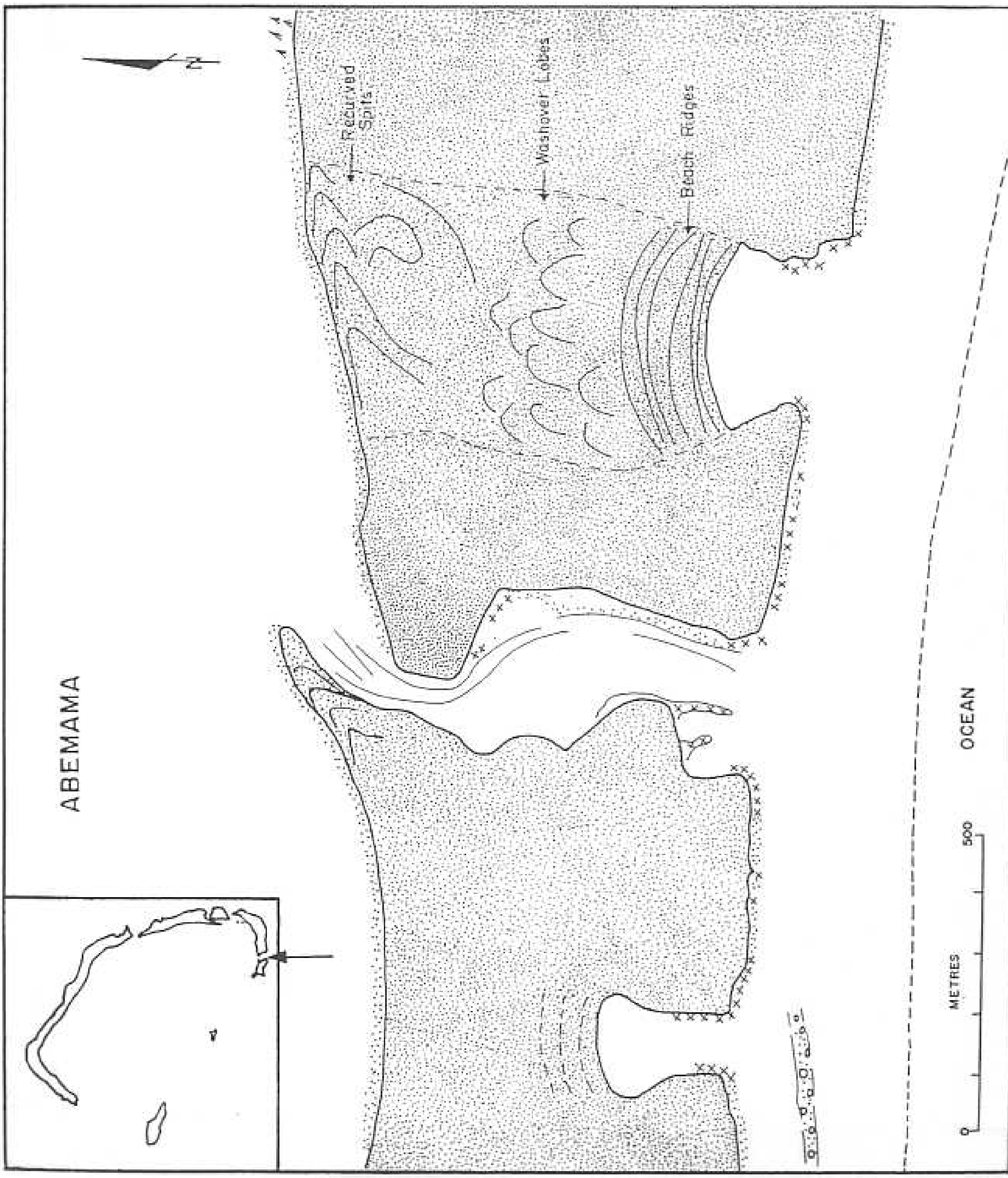


Figure 16c. Recessed shoreline re-entrants near Kenna, in southern Abemama. The re-entrant margins are bounded by platform conglomerates. The right side (eastern) re-entrant probably represents an infilled inter-islet channel similar to the channel in the center which is presently undergoing blockage by lagoon spit growth to the right (east). It is not clear from the aerial photographs how the left-side (western) re-entrant formed.

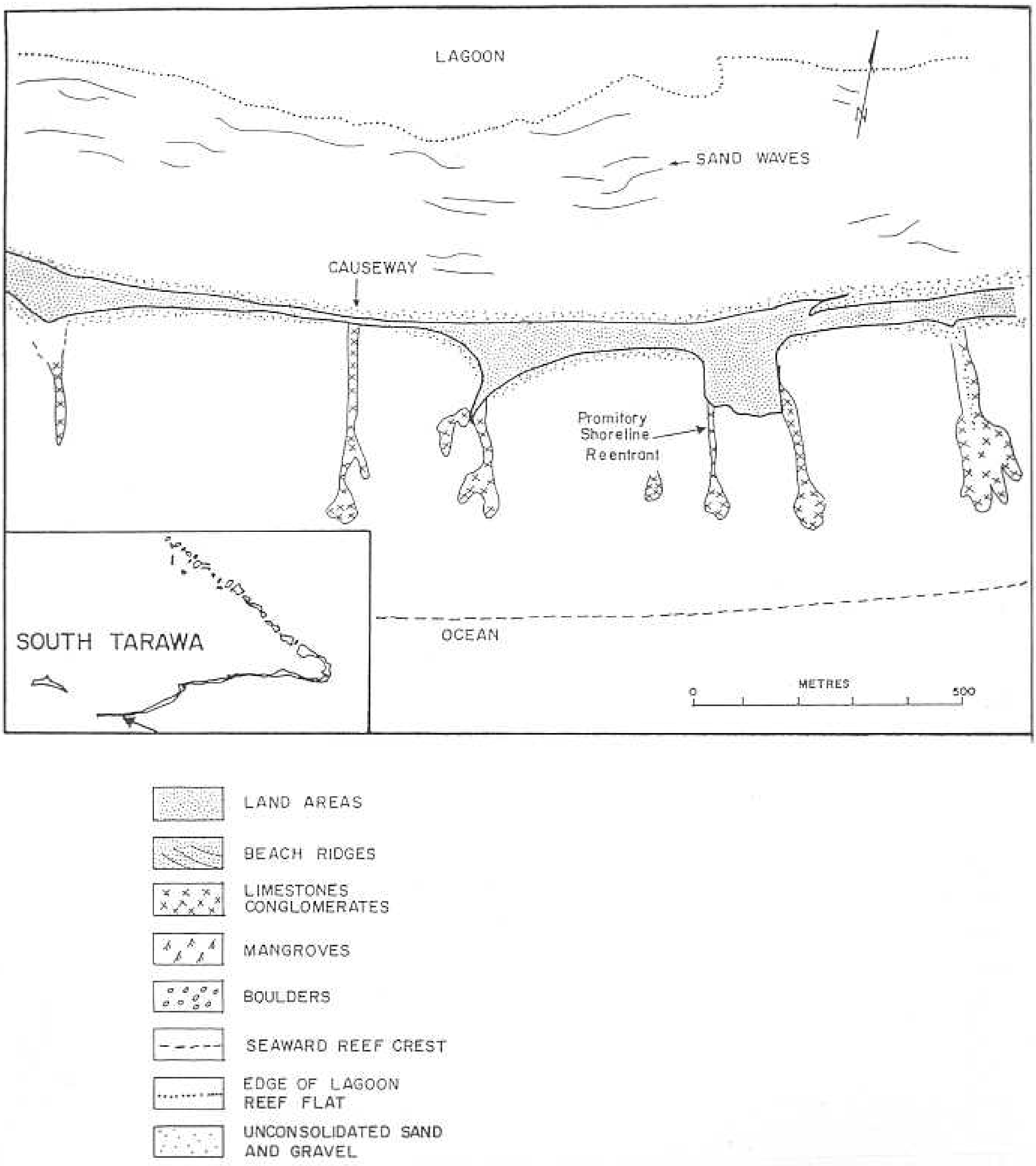


Figure 16d. South facing coastline at Nanikai, Tarawa displaying a promitory type shoreline re-entrant sandwiched between two conglomerate tongues. Asymetric deposition on the right-hand side (eastern) of other conglomerate tongues indicates a right to left (E to W) dominance of littoral transport, although significant reversals probably occur.

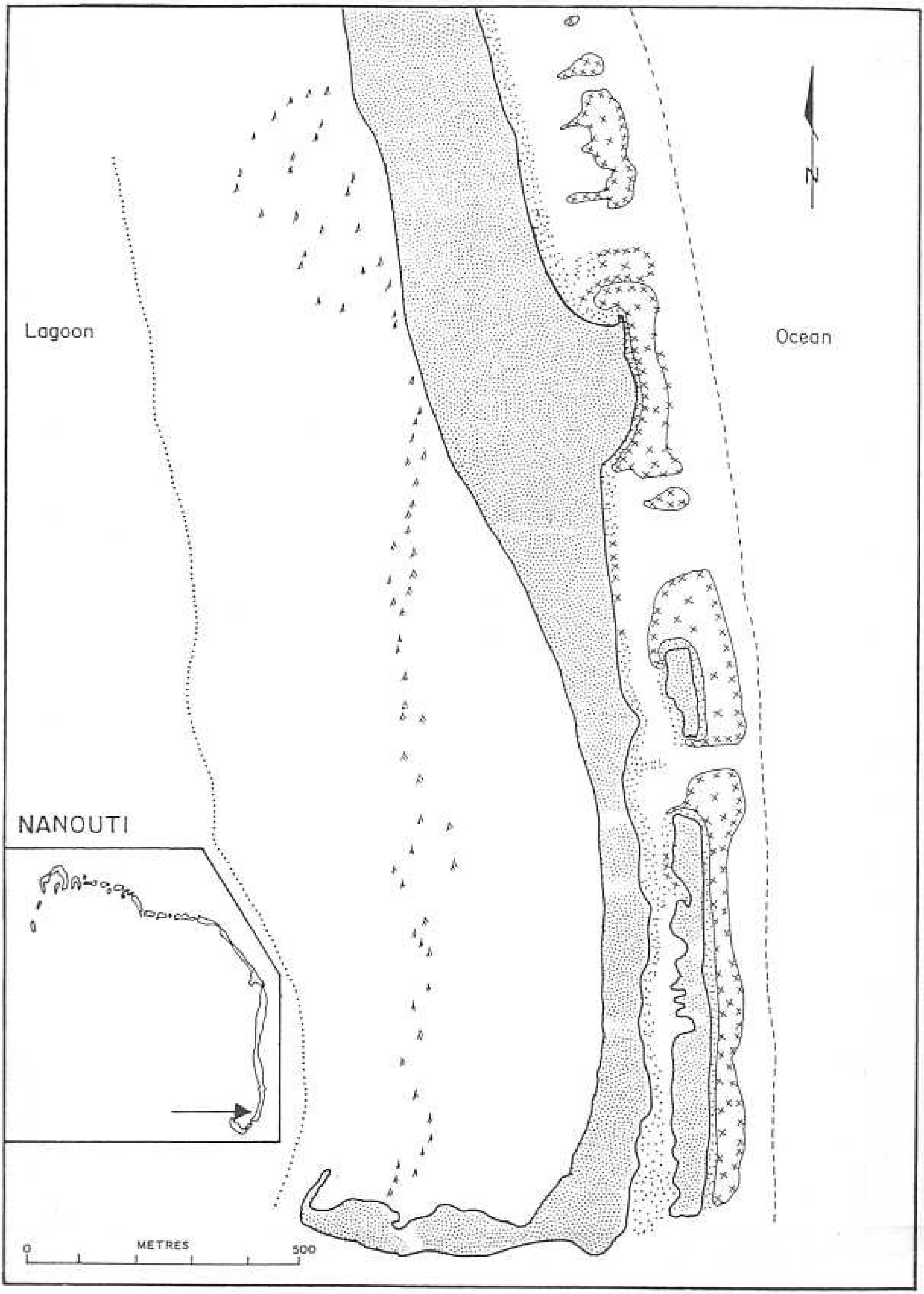


Figure 16e. Reef flat cays nucleated to rampart conglomerate at South Taboiaki, Nonouti. Ramparts to the top (north) appear to be in transition to conglomerate tongues.

51

clays (Figure 15e). The limestones act as a nucleus for these incipient islets which often support a sparse vegetation cover.

Not all high-level reef flat limestones appear to affect the shoreline. Many have caused no apparent offsets, buildups, or recesses. Although clearly visible on aerial photographs, ground-level observations suggest that in order for the limestones to significantly affect sediment transport they must be of sufficient vertical relief.

The high-level limestones, and in particular the conglomerates, play a significant role in the recent development of the atoll islets and reef islands. Although very complex morphology and internal features characterise the conglomerates, their general properties can be summarised as follows:

(a) Conglomerate tongues are shore-normal limestones that may extend from the outer seaward reef flat to the inner reef flat, island shorelines, or channel margins. Where continuous with channel margin conglomerates, there is usually a reduction in clast size and increase in clast rounding, sand matrix, and internal bedding away from the ocean. Possible mechanisms responsible for the formation of the conglomerate tongues include:

(i) Differential migration rates of reef flat rampart segments resulting in elongated gravel tracts which eventually become cemented, or (ii) channel margin gravels that are cemented in a fashion similar to beachrock formation. Gravel highs probably become focal points for continued deposition; the low areas would be maintained as channels for cross-shore water circulation.

(b) Shore-parallel conglomerates (platform conglomerates) are typically composed of angular coral rubble, contain variable amounts of sand matrix, and rarely exhibit bedding structures - perhaps they would best be described as coral breccias. They are almost certainly cemented counterparts of coral ramparts deposited during catastrophic events. As would be expected, there are numerous gradations between these first two conglomerate types.

(c) Beachrock conglomerates (and sandstones) occur along both ocean and lagoon shorelines and are usually easy to recognise because the sediment texture and bedding typically mimics those of the adjacent beaches. Except in areas that have undergone significant erosion, the beachrock is limited to narrow, roughly shore-parallel exposures.

Spit Development on Atoll Islets

Lateral spit progradation is one of the major processes responsible for islet growth. Spit locations are principally at the ends of islet chains or at the lagoonal margins of inter-islet chains or channels. Less commonly they protrude from continuous lagoon shorelines.

Spit development at the ends of islet chains occurs both from the ocean and lagoon sides (Figure 17) and are best developed where the atoll reef makes a sharp, convex-seaward bend. These are typically areas containing large reef flat exposures open to wave attack from many different directions. Spit development is often so profuse that large intertidal areas are cutoff from intensive water circulation. Continued vertical accretion leads to supertidal flat development.

Lagoonal spits are common along margins of inter-islet channels. Sequential channel closure precipitated by progressive spit enlargement appears to be an on-going phenomenon. A sequence of events, deduced from aerial photograph interpretation, is as follows (Figure 18):

(a) An open inter-islet channel acts as a conduit for primarily ocean-to-lagoon transfer of water and sediment. Protruding sediment lobes are typical in shallow lagoons.

(b) Sediment is dispersed along the lagoon coastline mostly by wave action. Beach progradation and incipient spit development occurs.

(c) Spit enlargement reduces the efficiency of the channel, resulting in increased deposition both from ocean and lagoon.

(d) Eventual channel closure by lagoonal spit growth, and beach ridge and washover sedimentation from the oceanside, may result in an essentially smooth continuous shore on both sides of the islet.

Lagoonal spits also occur along continuous islet shorelines presently unaffected by channels. Inter-tidal flats are often enclosed by spits, forming swampy lowlands if the distal spit end becomes attached to the shore. Inside the lagoon, shoreline spits in close proximity may grow in opposite directions indicating variable directions of longshore drift.

The abundant lagoonal spit development stresses the importance of westerly conditions in the development of the islets. The prevailing easterly tradewinds generally create offshore breezes which results in small waves and calm conditions along lagoonal shorelines of the windward rim islets. During ENSO episodes when there is a significant increase in westerly winds the lagoonal wave climate is markedly altered. Long lagoonal fetches (10-20 km) and semi-continuous leeward reef rims can result in appreciable wave heights (upwards of 2 m). Oblique approach of the waves is common and is conducive to the generation of longshore currents. Significant amounts of shoreline change have been documented for south Tarawa during a recent ENSO episode (Howorth 1983).

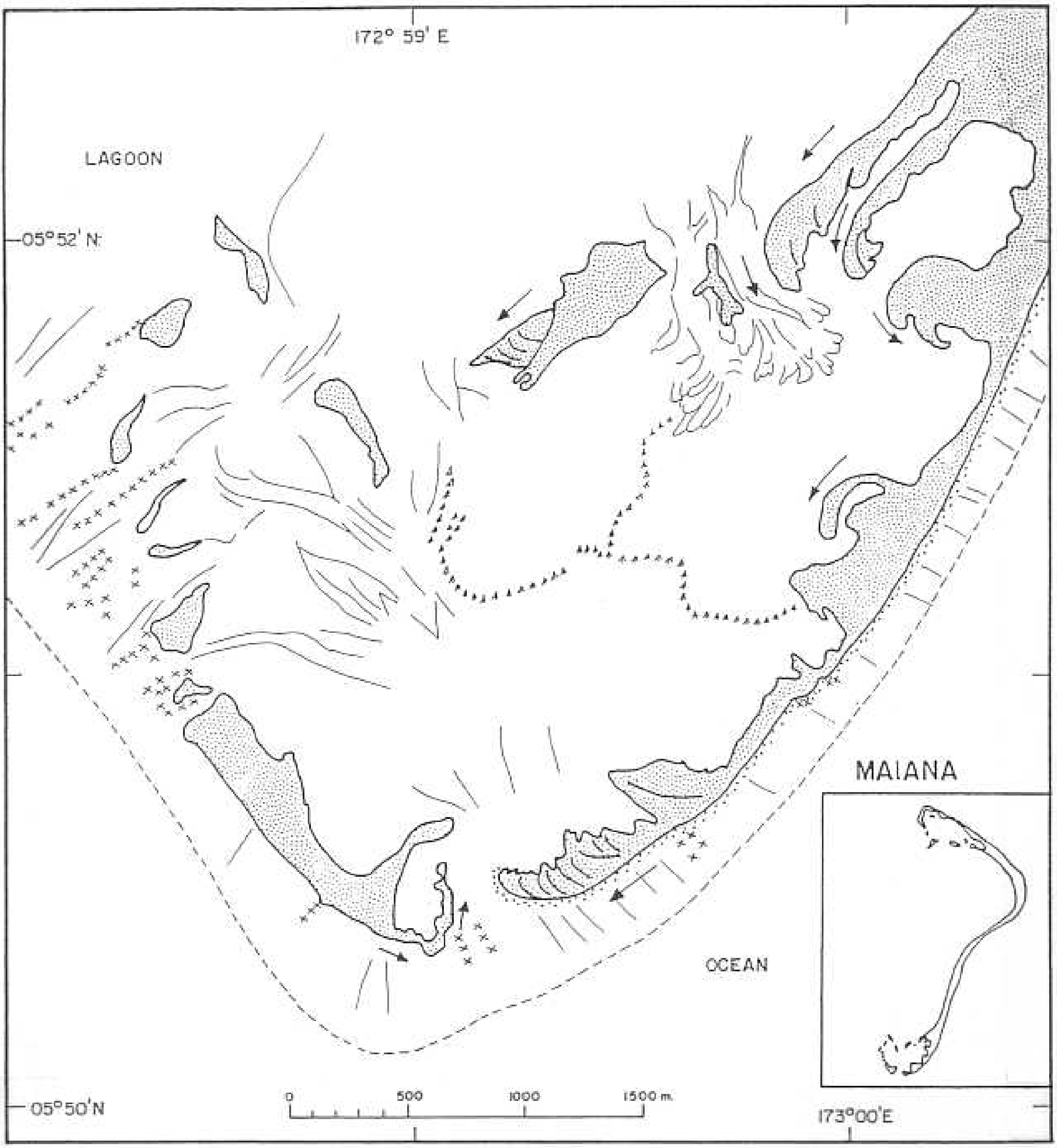


Figure 17. Sketch of South Maiana illustrating recurred spit growth along ocean and lagoon shorelines. Arrows indicate directions of longshore drift based upon spit progradation. Redrawn from Lands, Mines and Surveys Department, Fiji, June 1969 aerial photographs.

48%

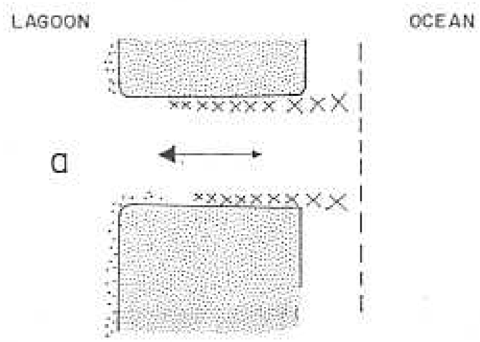


Figure 18. Schematic diagram illustrating the closure and infilling of an inter-islet channel. a. Inter-islet channel in wihc flow into lagoon dominates over a seaward return flow primarily due to wave set-up at the reef crest during onshore (tradewind) conditions. In many cases a sediment lobe protrudes into the lagoon.

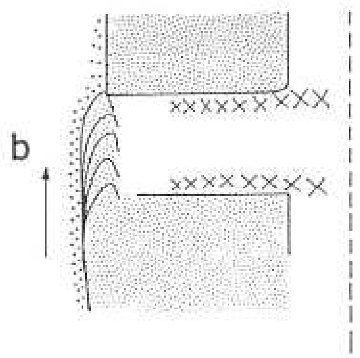


Figure 18b. Redistribution of sediment, both lagoonal and oceanic derived along the lagoon shoreline often forms recurved spits across the channels. Continued spit progradation results in complete channel closure.

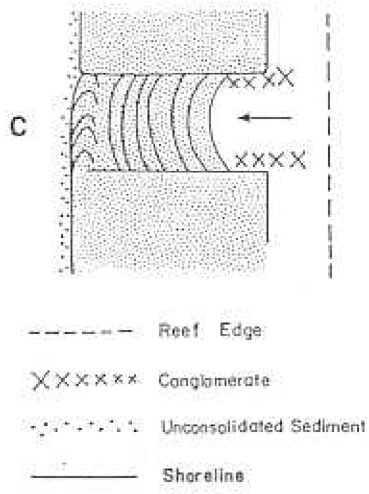


Figure 18c. Coincident with spit growth, deposition within the channel of primarily seaward derived sediment, eventually creates a series of prograding beach ridges.

REFERENCES

Baines, G.B.K., Beveridge, P.J., and Maragos, J.E., 1974. Storms and island building at Funafuti Atoll, Ellice Islands. Proceedings Second International Coral Reef Symposium 2: 485-496.

Burne, R.V. 1983. Origin and transportation of beach sand, Betio-Bairiki, Tarawa, Kiribati- July 1983. SOPAC Cruise Report 81 (Draft).

Carter, R., 1983. Coastal erosion in Kiribati, 10-13 January 1983. CCOP/SOPAC Cruise Report 76.

David, T.W.E., and Sweet, G., 1904. The geology of Funafuti. Rept. of Coral Reef Comm., Royal Society, London, pp. 61-124.

Emery, K.O., Tracey, J.I., and Ladd, H.S., 1954. Geology of Bikini and nearby atolls: Part 1, Geology. US Geological Survey Professional Paper 260-A.

Fairbridge, R.W. 1968. The Encyclopedia of Geomorphology. Encyclopedia of Earth Science Series, Volume III. Stroudsburg, Pennsylvania. Dowden, Huchinson and Ross.

Gauss, G.A. 1982. Nearshore surveys, Tarawa, Kiribati, 5 November - 23 December 1981. CCOP/SOPAC Cruise Report 63.

Holmes, D.W. 1976. Gilbert Islands: land reclamation, causeway construction and sea defences. Hydraulics Research Station, Wallingford, UK. Report EX727.

Howorth, R., 1983. Coastal erosion in Kiribati; visit to South Tarawa 23 August to 8 September 1983. CCOP/SOPAC Technical Report 31.

James, N.P. 1983. Reef Environment, in Scholle, P.A., Bebout,D.G., More, C.H. (eds) Cabonate Reef Environments. American Association of Petroleum Geologists Memoir 33.

Ladd H.S., Ingerson E., Townsend R.D., Russell M., and H.K. Stephenson, 1953: Drilling on Eniwetok atoll, Marshall Islands. Bulletin of American Association of Petroleum Geologists 37: 2257-2280.

McKee, E.D., 1959. Storm sediments on a Pacific atoll. Journal of Sedimentary Petrology 29: 354-364.

Mason, R.R. 1960. Some aspects of agriculture on Tarawa Atoll, Gilbert Islands. Atoll Research Bulletin 73.

Marshall, J.F. and Jacobson, G., 1985. Holocene growth of a mid-Pacific atoll: Tarawa, Kiribati. Coral Reefs 4: 11-17.

Munk, W.H., Sargent, C. 1948. Adjustment of Bikini Atoll to ocean waves. Transactions of the American Geophysical Union 29: 855-860.

Sachet, M.H., 1957. Climate and meteorology of the Gilbert Islands. Atoll Research Bulletin 60.

Schofield, J.C., 1977. Effect of Late Holocene sea-level fall on atoll development. New Zealand Journal of Geology and Geophysics 20: 531-536.

Scott, G.A.J., Rotondo, G.M. 1983. A model for the development of types of atolls and volcanic islands on the Pacific lithospheric plate. Atoll Research Bulletin 260.

Weber, J.N. and Woodhead, P.M.J., 1972. Carbonate lagoon and beach sediments of Tarawa Atoll, Gilbert Islands. Atoll Research Bulletin 157: 1-21.

Zann, L.P. 1982. The marine ecology of Betio Island, Tarawa atoll, Republic of Kiribati. CCOP/SOPAC Technical Report 23.