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ATOLL RESEARCH BULLETIN

Terrestrial Sediments and Soils of the Northern Marshall Islands

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F. Raymond Fosberg and Dorothy Carroll

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THE PACIFIC SCIENCE BOARD

National Academy of Sciences—National Research Council

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past eighteen years.

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Terrestrial sediments and soils of the northern Marshall Islands[*]

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F. Raymond Fosberg and Dorothy Carroll

*/ Publication authorized by the Director, U. S. Geological Survey

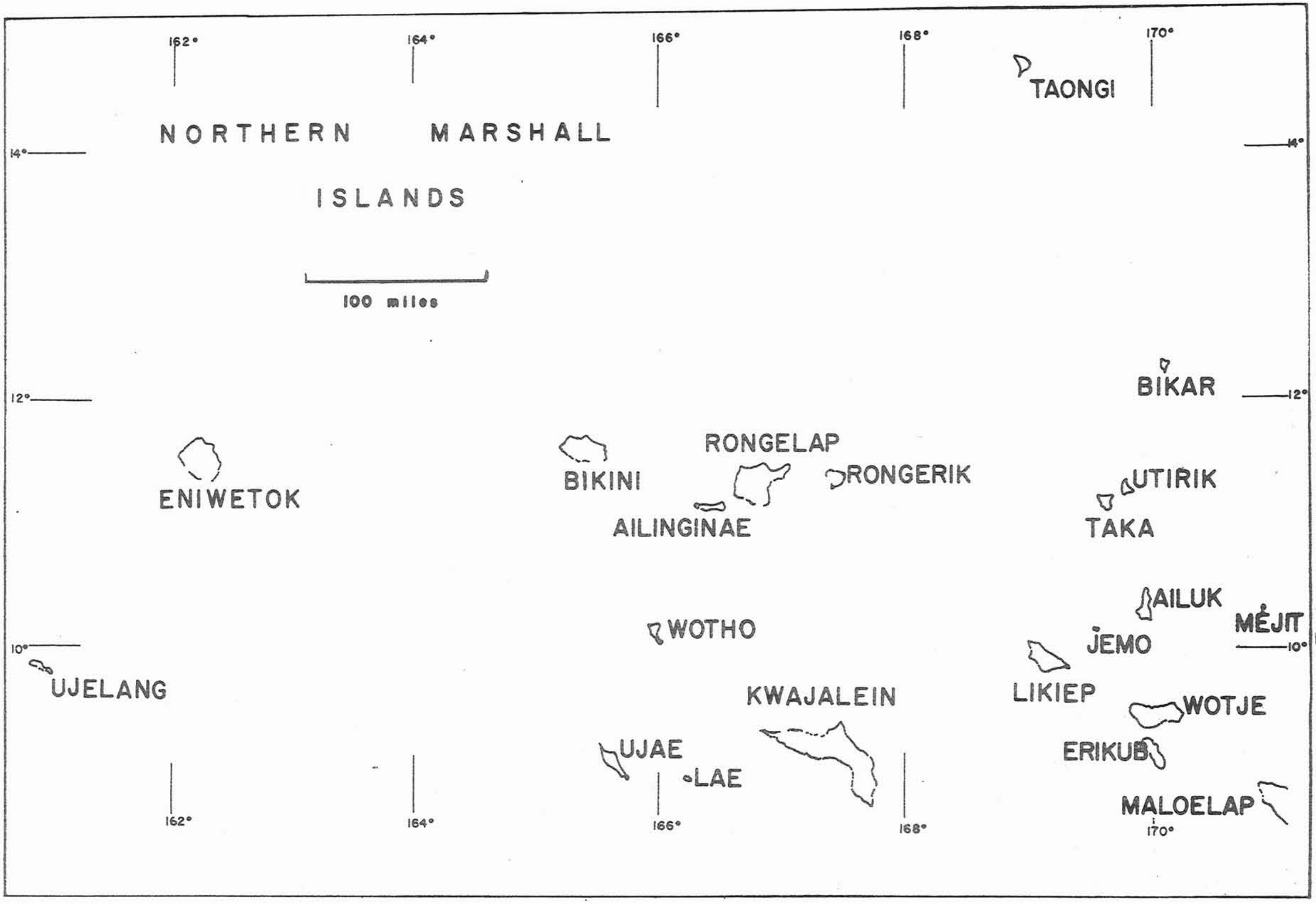

FIGURE 1. MAP OF THE NORTHERN MARSHALL ISLANDS

PREFACE

Parts of the information in this paper have been previously included in a U. S. Army Intelligence document (Fosberg and others, 1956) but are presented here in somewhat modified form to be generally available to the scientific public. The present paper was first written in 1954 for publication as a Professional Paper of the U. S. Geological Survey, under which auspices the work was done. Extended delay and the prospect of still more finally brought about the decision to publish it in the Atoll Research Bulletin, thus avoiding continued inaccessibility of the information. We apologize for the long delay, and for any failure to take into account literature published after the paper had reached its present form as well as later field work, the results of which have not yet been analyzed.

The U. S. Board on Geographic Names has, since the 1956 publication, issued decisions on Marshallese place names which take up different spellings for many of the islet names used in 1956, different names altogether for some, reverse the application of several names, and in at least one case (Jaboero and Jabwelo), adopt variants of the same name for two different islets in the same atoll (Bikar). In order to reduce confusion resulting from place names differing in the two reports, a complete list of the islets of all the atolls for which maps are provided in this paper is given in Appendix III, with parallel columns giving names adopted by the Board on Geographic Names and used in this paper, those used in the 1956 maps (Fosberg and others, 1956), and those from a manuscript list supplied by E. H. Bryan, Jr., of the B. P. Bishop Museum. These latter were compiled by Bryan in consultation with Dr. Leonard Mason of the University of Hawaii, and a number of Marshallese informants from most of the atolls concerned. It is hoped that this will make the present paper intelligible to those who have used the Army publication (Fosberg and others, 1956), as well as to Marshallese and others familiar with the names actually used in the islands.

The maps (figures 5-15) are adapted by change of islet names from originals prepared by F. Stearns MacNeil for the 1956 report (Fosberg and others 1956, figs. 2-13) which were there wrongly listed as based on Hydrographic Office charts. These maps were based on air photographs.

Grateful acknowledgment must be made to Prof. E. L. Stone, Jr., Dr. K. O. Emery, and Mr. Z. S. Altschuler who reviewed and made suggestions on an early draft of the manuscript, and many of whose suggestions have now been incorporated. The editorial criticism of the present manuscript by Miss Natalie Jones and by Mrs. Wenonah E. Berquist is greatly appreciated. The figures were redrafted by Miss Barbara Geyer. Great credit is due our several typists who have produced the several drafts of the manuscript, especially Mrs. Josephine Q. Barton, who did much of the final version, and to Mrs. Ann Chamberlain, who cut the stencils. J. Anthony Denson gave valuable advice and much help with improved prints of many of the photographs as did Norman Prime. Finally, we wish to thank Dr. Marie-Hélène Sachet, whose assistance with the manuscript at all stages has been indispensable.

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ABSTRACT

An investigation was made of surface geology, islet formation, sedimentation, and physical and chemical nature of loose sediments on atolls of the northern Marshall Islands.

Islets in their present form are of three types, based on origin and position: (1) formed by partial removal by planation of preexisting reef platform, leaving remnants around which sediments accumulate; (2) formed by accumulation and stabilization of detrital deposits on reef flats, and (3) formed by accumulation of detrital deposits locally within the lagoon, especially just inside channel mouths. Physiographic features of islets--erosion ramps, sand lobes, sand horns, sand aprons, tidal and storm beaches, rock shores, beachrock, marginal ridges, dunes, interior flats and depressions, parallel ridges, and blowdown mounds are described, and their principal organic components listed.

Mechanical analyses were made of samples of beach sands and soils. Size classes were correlated to some extent with faunal composition of the materials, small Foraminifera accounting for a large part of the 2-1 mm and 1-0.5 mm sizes. Larger fractions were made up of whole or broken corals, large fragments of algae, and large shells. Fractions smaller than 0.25 mm are mostly of broken unidentifiable fragments.

The frequency of the modes (or maximum grades) in the size distribution in the beach sands is as follows: 2 to 1 mm (-10 + 18 mesh), 21 percent, 1-0.5 mm (-18 + 35 mesh), 48 percent, and 0.5 -0.25 mm (-35 + 60 mesh), 17 percent. In none of the sands is there a primary mode in the + 0.125 mm, + 0.062 mm, or less than 0.062 mm fractions.

Determination of mineral composition of the sediments by X-ray diffraction shows a correlation of calcite:aragonite ratios with original biological composition rather than with degree of weathering. Considerable magnesium is present in the calcite, especially in sediments largely made up of algae, and in the middle size grades of the sediments.

Median grain diameter, sorting coefficient, and skewness were calculated for the samples. Size distributions, illustrated by histograms, show that the beaches are, in general, similar from islet to islet, even though the individual samples from a beach may vary. Beach materials do not become much smaller than 0.25 mm grain diameter, or else the smaller material is lost by winnowing by waves and currents. Skewness in most sands is positive, indicating admixture of coarse material and lack of fines.

The soils resemble beach materials in their mechanical analyses, but the texture range is enormously wider and the range in sorting is also wider. The soils are irregularly stratified, commonly with weak profile development, but with strata mostly representing stages or events in deposition. Most soils can be assigned to three previously described series, the Shioya, Arno Atoll, and Jemo, but certain highly organic soils could not be definitely assigned to series. These

series differ chemically in the amounts of organic matter in the A horizons and the presence or absence of a phosphatic B horizon. A_0 horizons and B horizons are found only in the Jemo series soils, usually correlated with the presence of Pisonia forest vegetation.

Chemical analyses show that vertical trends in the amounts of certain elements in the different layers are discernible: magnesium increases downward; calcium is lowest in layer 1 because of the higher organic content, and this is especially obvious in the Jemo series. Of the minor elements, iron, cobalt, nickel, molybdenum, and zinc are much higher in the raw humus layer of the Jemo series profiles, suggesting accumulation of these elements by the Pisonia tree in its tissues. Most of the metallic constituents, except calcium and magnesium, are present in extremely small amounts. Serious deficiencies in most mineral nutrients of plants, except calcium, magnesium, phosphorus, and possibly potassium, would be expected. These might be intensified, in some cases, by the strongly calcareous environment.

pH values are high in all layers except the raw humus layer of the Jemo soils where the pH ranges between 4 and 6.

INTRODUCTION

by F. R. Fosberg

In spite of the great amount of attention that has been paid to the geology of coral atolls, relatively little detailed information is available on the chemical and physical properties of the sediments which make up atoll islets, on their weathering, their origin, their stratigraphy, or the conditions under which they were laid down. The availability of a large series of samples representing sections down to the water table or to bedrock in the northern Marshall Islands, and of a considerable body of chemical and mechanical analyses of these samples has made it possible to remedy this deficiency to some extent. The study of this material has yielded a picture of the general nature of the sediments, but has also brought out certain problems which only further research will solve.

Field work

The material considered here was collected on a reconnaissance survey of the military geography of a number of the atolls in the northern part of the Marshall Islands, and this paper is a by-product of that investigation. This survey was carried out by a field party of the U.S. Geological Survey working for the Office of the Engineer, Headquarters, U.S. Army Forces, Far East, during 1951 and 1952. Most of the soil samples were collected by F. R. Fosberg; some were collected by Ted Arnow, hydrologist of the party, during the digging of wells. Beach sand samples were gathered by F. Stearns MacNeil and Charles G. Johnson, geologists. The sampling is admittedly inadequate because of the broad nature of the assignment and the fact that only minutes, hours, or at the most, parts of a few days, were available for work on soils of any given islet.

The circumstances of the survey (Fosberg, 1955) were such that it was possible to obtain a scattering of material from over a wide area but impossible to study any single atoll or islet in detail. Furthermore, lack of any previous soils work in this area made the sampling, especially in the earlier atolls visited, a random procedure rather than one designed to bring out any specific type of information or to investigate particular problems.

Laboratory work

After the samples collected had been brought in, described, and the soils assigned to previously known or to new atoll soil series, it was felt that for the purposes of the military geography report (Fosberg and others, 1956), more should be known about the physical properties of the sands and soils and that some chemical studies should be made in order to understand the severe agricultural limitations of these soils. A selection of samples was made that it was hoped would prove representative of the soils in the area studied. It was unfortunate, but unavoidable, that this selection had to be made before the problems regarding these soils were clearly formulated. Because of the unusual interest of the phosphatic materials a more complete representation of them was analyzed than of the other materials. The lower layers of all the types of soil profiles are poorly represented in the analyses. Organic carbon in less humic soils was not determined. Future work, on more critically selected complete profiles down to ground water in all the series, is much to be desired.

Previous studies

Studies have been made on various atolls as part of the Coral Atoll Program of the Pacific Science Board (Stone, 1951a, 1953, Cloud, 1952; Hatheway, 1953, 1957; Fosberg and Sachet, 1953; Newell, 1954b, 1956; Sachet, 1955; McKee, 1956, 1958; Fosberg, 1957b; Catala, 1957, McKee and others, 1959; Tracey and others, 1961), on Bikini and nearby atolls by the Crossroads Operation Survey and subsequent surveys (Emery, Tracey, and Ladd, 1954), and on Ulithi Atoll by Schlanger and Brookhart (1955). These, as well as the investigations reported here (also reported in Fosberg, 1954, 1957a; Fosberg and others, 1956), make it possible to know what to expect in the way of soil and sediment types, as well as areal and stratigraphic arrangements of sediments, and to define at least some of the problems which should be investigated. Certain earlier literature, especially the publications resulting from the expeditions that made the boring on Funafuti in 1896 (Sollas and others, 1904), those of Wentworth and Ladd (1931) on the Central Pacific Atolls, and those of Kuenen on East Indian Atolls (1933, 1950) also contribute important information. The paper by Ladd, Tracey, Wells, and Emery (1950) is of special significance in understanding the origin of the sediments with which we are dealing.*/

Land areas

The Marshall Islands comprise 31 atolls and single low islands scattered over an area nearly 700 miles from north to south and about the same distance from west to east, between 4°34' N. and 14°43' N. and 160°48' E. and 172°10' E. They form two very irregular, roughly parallel chains that trend northwest-southeast. The western chain is called Ralik, the eastern Radak. This arrangement, however, is difficult to discern on a map. Before reading further, the reader is urged to consult the section "Synonomy of place names" at the end of the report.

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*/ Since this paper reached its final form, a number of pertinent and important papers have appeared, such as Blumenstock, ed., 1961, Guilcher et al., 1965, Hoskin, 1963, McKee, 1959, Newell, 1960, Russell, 1962, 1963 and Stoddart, 1960, 1962a, 1962b, 1963, 1964, 1965. None of them, however, appear to necessitate serious modification of interpretations presented here, though not all these authors would agree completely with our interpretations.

The present paper is concerned only with those 21 atolls or islands lying north of 8°30' (fig. 1), hereafter referred to as the northern Marshall Islands. These are, from north to south and west to east, Taongi (Pokak), Bikar, Eniwetok, Bikini, Ailinginae, Rongelap, Rongerik, Taka, Utirik, Ujelang, Wotho, Likiep, Jemo, Ailuk, Mejit, Ujae, Lae, Kwajalein, Wotje, Erikub, and Maloelap, 21 in all. Maloelap could equally well be included in the Southern Marshalls. Observations were actually made and material collected for study on Taongi (Pokak), Bikar, Taka, Utirik, Ujelang, Wotho, Likiep, Jemo, Ailuk, Ujae, Lae, and Kwajalein. In addition, use has been made of certain observations, analyses, and collections made by the geologists of the Crossroads Survey in Eniwetok, Bikini, and nearby atolls in 1946.

The land on these atolls is nowhere much above sea-level, averaging between 4 and 10 feet above mean low tide. The highest elevations are beach ridges, piled up by storms, and sand dunes. The highest recorded elevation in the group is a sand hill or beach ridge on Likiep Atoll, variously said to be 25 to 37 feet high. These higher features are all composed of loose sediments. The consolidated platforms on which much of this loose material rests are mostly between mean low tide level and about 6 feet above, with a very few humps extending up a few feet more (only seen on Bwokwla (Bokla or South) Islet, Taongi (Pokak) Atoll). The relationship of the individual islets of an atoll to the underlying reef is shown diagrammatically in figure 2.

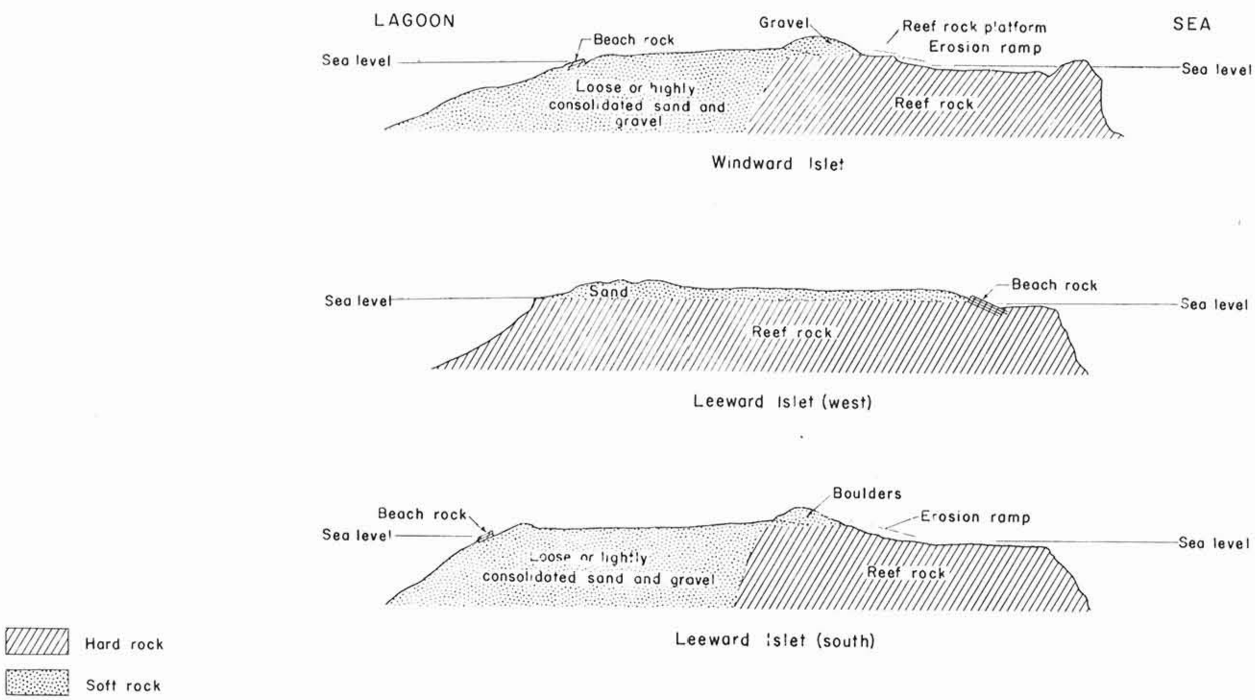
Climate

The climate of the northern Marshall Islands is tropical, with very little variation in temperature. The extreme variation is from about 68° F to 97° F, but most of the time the range is from 76° F to 87° F, with a mean of about 82° F. The sunlight is intense and the sky usually characterized by considerable scattered cumulus cloudiness. Really cloudy days are rare but do occur. The islands all lie in the trade-wind belt, with prevailing winds from the east to northeast, strongest in the winter and spring months. Calms, weak, variable winds or southeasterly winds may occur from June to September. Storms are likely to come from the south. Typhoons are rare but sometimes extremely severe and destructive. These, also, usually travel in a general northerly direction and rotate counterclockwise. Both typhoons and trade winds are of great importance in determining the topography of the islets and the nature and distribution of sediments.

Available moisture is of primary importance in the weathering and leaching of sediments, soil formation, and in determining the nature and luxuriance of vegetation. The islands are relatively dry, compared to the southern Marshall Islands and the Caroline Atolls. The rainfall decreases rapidly to the northward, with a total range from a recorded extreme of 149 inches to 25 inches or less, possibly almost no rain in very dry years in the northernmost of the atolls. The annual averages range from an estimated 40 inches in the north to a recorded 106 inches in the south. The rainfall is strongly seasonal, December to April being the driest months, June to November the wettest. The rainfall in any one atoll varies tremendously from year to year, even in corresponding months. The extreme annual figures recorded for Ujelang are a low of 52 and a high of 116 inches. Comparable figures for Kwajalein are 82 and 149 inches; for Eniwetok, 24 and 73 inches. It will be noted that none of these figures indicate a dry climate as understood in continental regions, but with the special soil conditions on atolls, the lower figures are correlated with an aspect of relative aridity in the landscape. The relative humidity is ordinarily fairly high, as might be expected from the proximity of the ocean, the lowest monthly mean recorded being 66 percent for noon readings on Eniwetok. In the more northerly atolls it doubtless reaches a lower figure than this occasionally.

Tides

Tidal data for coral atolls are generally unsatisfactory, as there are few stations and the lagoons with openings of different sizes introduce complications. In the U.S. Coast and Geodetic Survey tide tables for 1966 information for the Marshall Islands is calculated from predictions made for Kwajalein. There is no indication as to whether the observational data on which these predictions are based were collected in the lagoon or on the windward or leeward seaward coasts. Because of the peculiar geographic relations introduced by the difference in size and in number of openings into a lagoon, the tidal behavior, and especially the lag in tidal events inside compared with outside of the lagoon, will be highly variable from atoll to atoll. An extreme example may be cited, that of Taongi (Pokak), where the opening is so small that the tide level inside the lagoon never falls significantly below the level of the reef, though outside the spring tide range is 4.7 feet. Keeping in mind these reservations, data from the tables for 1966 show that the mean tide ranges, presumably outside the lagoons, in the northern Marshall Islands are from 2.7 to 3.7 feet, the spring ranges, 3.9 to 5.1 feet, the maximum difference in one day, 6.6 feet; the minimum difference between high and low, 0.0 foot, the minimum difference in one day, 0.0 foot. These figures are, of course, also subject to variation due to weather conditions both local and general, or even elsewhere in the Pacific. It is probable that careful studies would show that significant average figures for any given locality could be derived from the vertical distribution of certain sessile organisms in the intertidal zone, reflecting their capacity to endure exposure to air. Such studies are not, to the best of my knowledge, available yet in sufficient detail to be used.



2. Diagrammatic cross sections of islets on windward and leeward reefs of atolls showing positions of reef rock, unconsolidated materials, beach rock, rock platforms, and erosion ramps.

PART I: GEOLOGY

by F. R. Fosberg

The geology of these atolls has been described in several publications (Tracey, Ladd and Hoffmeister, 1948; Nugent, 1946; Emery, Tracey and Ladd, 1954; Fosberg and others, 1956, p. 74-132; and Fosberg, 1957 a). A summary of the geology follows.

Physiographically an atoll is the upper calcareous part of a broadly conical or irregularly pyramidal mountain mass rising from the floor to the surface of the ocean. Only the top of this is usually considered, geographically, and of this only the part which breaks the surface of the sea need be discussed here. Thus restricted, the northern Marshall Islands are a series of narrow platforms or reefs, usually irregularly ring-shaped or polygonal, commonly enclosing a shallow body of ocean water called a lagoon (pl. 1A). Of these platforms by far the largest areas lie at or just above or below tide level and are called the reef flat. The outer edge of this either falls off abruptly, as on leeward sides, or is elevated in the form of a low ridge, as on windward sides. The inner margins, where not occupied by islets, shelve off into the lagoon. The surface of the reef flat may be relatively smooth or locally quite rough or strewn with great boulders. Scattered along these platforms are areas that rise above high-tide level, called islets (perhaps a better term is the Polynesian word motu, but even this is not completely devoid of ambiguity) (pls. 1, 2). These islets, though forming only an infinitesimal part of the area and bulk of atolls, are in many respects the most interesting one, and that with which this report is principally concerned.

The entire structure of an atoll, except the deeply submerged part of the foundation, is made up of organic limestone sediments, either loose or variously consolidated. Deep borings on Bikini and Eniwetok have given much information on the nature of the sediments making up the part below sea level (Emery, Tracey, and Ladd, 1954; Ladd and others, 1953; Ladd and Schlanger, 1960.) These are mostly unconsolidated material, and extend downward to more than 4,000 feet below sea level. Some layers are consolidated or partly so. Most of the material resembles that deposited in the lagoon today. A few traces of carbonaceous material, with land plant pollen and fossil land and fresh-water shells, suggest that some of these sediments were once terrestrial and supported vegetation.

Origin of the reefs

Before considering the morphology and structure of the islets, themselves, it will be necessary to give brief attention to the origin and nature of the reefs and the materials of which they are composed. This is, in certain aspects, a highly controversial subject, and for more adequate treatment of it reference may be made to the publications cited above. The limestone is made up of the skeletons of lime-secreting animals and plants, mainly corals. Foraminifera, and those algae which possess hard skeletons (see p. 56-74). These animals and plants add to the rocky structure on which they grow in two different ways. Some of them are firmly attached and cemented onto the rock, adding by the growth of their skeletons to the material of the rock itself, either in the form of crusts or as outgrowths. Storm waves may break these off. Others are either free or loosely attached, becoming free when they die. The loose material so formed, as well as that resulting from breakage, accumulates on the reefs, on the islets, in the lagoons, and on the submarine outer slopes of the atolls. That on the islets comprises the sediments that are the subject of this report.

The firmly attached organisms are of many different shapes and grow together very abundantly in the warm seas of the tropics. Attaching themselves to each other, as well as to the rocks, their skeletons form a rigid latticework of limestone, which may be filled in either by growth or by deposit of loose sediments in the interstices. Most of the corals (pl. 3) are branched; often they are miniature treelike structures that are rather fragile and easily shattered or torn loose by storm waves (pl. 3A, B). Some of those exposed to direct wave action have more compact growth forms and are more resistant. By themselves, however, most of the corals would not be able to make the stable structure known as coral reefs. The function of cementing and binding these corals together into a massive rock is performed by certain of the calcareous algae (plants) (pls. 4, 5) and by certain colonial hydrozoans (Millepora) (animals) related to corals, which grow with no fixed or definite forms but which make a shapeless hard crust over the surfaces of the other animals, smothering them, filling in the holes and spaces between them, thus presenting a smoother and more resistant surface to the force of the waves. These binding organisms, especially the plants, thrive best in the roughest, most thoroughly aerated water. For this reason the firmest structures of the atolls are on the windward sides where the swells break continuously. Growth of reef-building organisms, generally, is faster on the outer edges of the reefs where waves break, thus building up these portions more rapidly than the more protected parts (pl. 5A, C). Usually the most perfect and most intricately branched coral skeletons may be found in quiet places, such as lagoons (pl. 3), or in water below the active turbulence zone on the outer slopes, where they are not smashed by heavy waves. However, the greatest amount of limy material is added on the outer edges of the reefs. This area is also the source of much of the fragmentary material which forms the sediments that fill large parts of the reef structure. It has been shown by the studies at Bikini (Ladd and others, 1950) that loose material detached from the reefs, especially on the windward sides, is carried by currents, waves and winds and deposited in various other parts of the atoll structure to form the sediments of which the atoll is largely composed. Any hole in the latticework, any protected pool or cavity, as well as the lagoon itself, tends to be filled in by this loose material. This debris may become cemented either by growth of such binding organisms as those mentioned above or by deposition of lime from the sea water, thus adding to the strength of the reef structure, or it may remain indefinitely as unconsolidated sediments protected from wave action by the surrounding rigid framework of the reefs.

It might well be supposed that these masses of limestone had grown up directly from their volcanic foundations until they reached the surface of the ocean. This cannot be true, however, because none of the important reef-building organisms can thrive in water too deep to permit a significant amount of light to reach them. The actual limits of growth of these organisms vary greatly, but there is certainly little material added below a depth of 300 feet, and the important addition is above 150 feet. These facts have been known for a long time and recent investigation has tended to confirm and amplify previous knowledge of these limitations. Therefore, it is clear that other principles must be involved in the presence of enormous masses of limestone below the limits of effective penetration of light into sea water. These principles have been the center of violent scientific controversy for more than a hundred years, and only the investigations of the last 20 years have brought matters to a point where a brief, reasonably convincing generalization can be made of the mode of origin of coral atolls.

There now seems little doubt that all reef growth took place in shallow water and that the volcanic foundations of the atolls have subsided with relation to sea level, the relative change in elevation being slow enough to allow upward growth to keep pace with the subsidence. In this way the zone of active growth would have remained within the levels where light was sufficient. Whether this relative change was due to actual subsidence of the volcanic islands or to worldwide changes in sea level is not certain, but it is probable that both took place. During the glacial periods, especially, there are known to have been considerable shifts of sea level and unquestionably these have had a profound effect on the present form of coral islands. It is believed, for example, that within the last few thousand years there has been a fall of approximately 6 feet (or 11 feet according to some authorities, especially Fairbridge , 1950, 1952) in sea level, leaving extensive areas of coral limestone reef rock above water. Remnants of these form much of the consolidated part of most of the islets on present-day atolls, the rest of it having eroded away since exposure took place.

The geology of the islets, themselves, may be treated in greater detail as these structures are largely made up of the sediments to be discussed in the present paper.

General features of islets

All the northern Marshall Atolls have some dry land in the form small islets (pls. 1, 2) scattered along the reef flats (pls. 6, 8). These range from tiny deposits of sand and gravel (pl.10) almost awash at high tide to flat expanses as much as several miles long and almost half a mile wide. Not counted as islets are the rubble tracts (pl. 9) and storm-cast boulders lying on the reef flat (pl. 5D), though some of them may be exposed even at high water. The islets are essentially portions of the reef which lie above the general level of the reef flat. The materials are the same and there is no real difference except that they are exposed above sea level.

The surface of most islets lies between 4 and 10 feet above mean tide level but practically no accurate measurements of heights are available, nor have all the islets in the northern Marshall Islands been visited. Areas denuded by storms may lie close to high-tide level or even lower. Some islets have central depressions with bottoms at or slightly above high-tide level. Dunes, beach ridges, and boulder ridges may rise 6 to 12 feet or rarely even as much as 25 feet or more above mean tide level. A boulder-capped ridge on the south coast of Lae Islet has an altitude of about 18 feet. The highest altitude in the Marshall Islands is believed to be a beach or dune ridge on the lagoon side of Labinwor Islet, Likiep, on the leeward side of the atoll. Some parts of this ridge are more than 25 feet above mean sea level.

The islets may be regarded as ephemeral from a geological standpoint. This is shown by such evidences as ancient shorelines, indicated by beachrock, which do not coincide with the outlines of present islets, striking differences between outlines observed at present from those on maps of early surveys, and the relatively youthful character of the vegetation on some islets. That they are reasonably stable from a human standpoint however, is shown by the fact that a distinctive human population has occupied them for many generations; many islets show a well-developed vegetation, as well as populations of land animals, some of the latter unknown anywhere else.

Types of islets

Examination of a large number of islets shows that they are of three principal kinds: (*a*) those having a remnant of emerged reef rock, a mass of reef rock not yet eroded away, as a core; (*b*) those that are simply an accumulation of limestone detritus on the present reef flat; and (*c*) islets within lagoons. Type (*a*) islets are the result of a general lowering of sea level in relation to the reefs. This lowering of sea level is considered to have started several thousand years ago. Type (*b*) islets can be observed at present in all stages of formation in the northern Marshall Islands (pls. 9, 10). The three types and variants of them will be discussed separately, as they differ in some important respects. Types (*a*) and (*b*) are illustrated in figures 3 and 4.

Islets with a remnant of emerged reef rock as a core

By far the greater number of islets on atolls in the northern Marshall Islands are essentially platforms of reef breccia or conglomerate standing above the present reef-flat surface, with associated accumulations of sand, gravel, and larger debris. Most windward islets are of this type, as well as those on south reefs. This type of islet (fig. 3) may be readily identified by the presence of a rock platform (pls. 11-13) above high-tide level, protruding from beneath the sandy or gravelly vegetation-covered part of the seaward side of the islet. The platform may extend beneath the loose material of the islet for as much as a third or even two-thirds the distance to the lagoon beach. More rarely it may extend all the way and protrude from under the sand at the top of the lagoon beach (pls. 11B, 12C). On the seaward sides of windward islets the platform may be of considerable extent (pl. 2A). It presents a rough pitted surface, blackened by the growth of microscopic algae. The rock of which it is composed is generally a highly consolidated reef conglomerate or breccia of unsorted, often very angular fragments, case-hardened by exposure to air. The highest rock surface observed, excepting the remnants of Bwokwla (Bokla) islet, Taongi (Pokak), was about 5 1/2 feet above mean low tide. Others were from 1 to 2 or more feet lower, having probably been eroded by slow solution by rain water. The pitting of these surfaces shows that this solution process is constantly taking place (pls. 14-16).

The suggestion has been made that some islets apparently of this type may really belong to the second type, the platform being simulated by subaerially consolidated sediments. This possibility is hard to eliminate unless reef material in growth position is found. It is by no means certain that such consolidation does actually take place under atoll conditions, but it is possible. Petrographic studies of the type of cementation and recrystallization involved might yield dependable criteria for distinguishing subaerial from intertidal and submarine consolidation, but we know of no such studies on atolls as yet. At present, degree of consolidation, indications of planation surfaces, and fossils of intertidal organisms in their characteristic growth habitats and positions are the best available criteria for concluding that the apparent platforms are of formerly submerged rock.

The edge of this platform may be more or less abrupt and ledgelike or it may slope. Commonly a ramplike slope of irregularly eroded rock, a few to many yards wide, extends from the edge or base of the ledge down to the reef flat just above low-tide level. There may be a transitional area of irregular or roughened rock slightly higher than the reef flat. The ramplike slope has been termed the erosion ramp (pls. 11A, 14A, B, D, 15, 16, 17B, D), as it is here that the active erosion of this elevated reef rock is taking place. Comparable erosion ramps may also be cut in beach rock (pl. 14A).

Several processes were observed which contribute to this erosion. Solution, by rain water and possibly by sea water also, is a factor, as is shown by the prevalence of the pitted surfaces characteristic of limestone erosion. The outlines of the animal skeletons of which the rock is composed are often left in relief. Solution basins (pls. 15, 17D, 20C) from about an inch to as much as a foot deep, with straight or slightly undercut sides, are commonly seen. An abundance of small mollusks (such as Nerita, Littorina) and other animals that feed on algae in the surface of the rock undoubtedly contribute to abrasion of the surface in this zone. Abrasion by rolling back and forth, or swirling in pot-holes, of gravel, pebbles, and even larger rocks by waves leaves noticeable effects (pl. 19C, D). A conspicuous process is the spalling off of slabs of rock (pl. 16) from a foot to as much as 6 feet across, presumably due to sudden chilling of sun-heated rock by the rise of water with the tide. Spall planes cut through coral fragments and interstitial material alike, leaving smooth surfaces (pl. 16B). The constantly moving water of even small lagoon waves tends to cut away weaker beds and areas in the limestone, often undermining stronger rock, which then may collapse (pl. 14A, B), contributing large angular fragments to the loose rubble mass lying on the reef flat or erosion ramp. Just how important this process is and just how much of it occurs in normal weather and how much in storms are hard to estimate, but a combination of storm and normal erosion of this sort unquestionably accounts for the removal of a sizeable volume of material. Much of this material may be identified in the rubble deposits around the peripheries of the islets. What is probably the most important process of all is the weakening and crumbling of rock in the intertidal zone that result from the activities of boring organisms, especially one or more species of sipunculid worms. In many localities a narrow band of rock on the erosion ramp was seen to be riddled with the burrows of these worms, usually with the animals still inside. How the sipunculids accomplish the boring is not known, as they do not have boring mouthparts. They may, of course, dissolve away the limestone by acid body secretions. Other worms, mollusks, echinoids, sponges, and blue-green algae were also observed to contribute to the disintegration and erosion of limestone by boring in this intertidal belt.

The total effect of all these processes is the removal of an enormous amount of rock, resulting in planation down to low-tide level, and the production of large quantities of sediments. The extent of present-day reef flats (pls. 1, 2, 6, 8, 9), frequently half a mile to a mile wide, is a measure of the planation that is thought to have taken place since the fall of sea level which happened several thousand years ago.

Locally, the erosion ramp may be covered by beaches (pls. 17, 18) of sand, gravel, or cobbles, or the beaches may be restricted to an area above the edge of the protruding rock platform. The ramp itself is commonly found on the seaward side of the islets and frequently extends along the channels between islets, but has only rarely been observed on the lagoon side by us. Deposits of any sort of material such as sand, gravel, boulders, unsorted rubble, or even large slabs (pl. 20D) may be piled on and around the hard rock core of the islet. They may even cover it completely, in which case the islet may be mistaken for type (b). The lagoon side of type (a) islets is usually built of sand or small gravel (pls. 17A, 18). Often there are evidences of successive deposits of sand in the form of beaches or ridges which have been added lagoonward.

There is a tendency for islets of this type on windward reefs to be strongly convex on the seaward side and somewhat concave on the lagoon side, with prominent angles on the lagoon corners. The islets may be widest in either direction but those elongated perpendicular to the trend of the reef have a tendency to broaden along the lagoon beach so that they are roughly T-shaped, with a narrow rock platform extending seaward from a bar of sand along the lagoon shore. Sand horns (fig. 3, pl. 2B) and sand lobes, spits extending from the inner corners, are common on islets on windward reefs. Sand aprons are broad deposits of material in shallow water just inside the reef, especially windward reefs.

Islets formed of accumulations of loose material on reef flats

Accumulation of sand, gravel, or unsorted material on the surface of the reef may result from any one of several causes or combinations of them: (1) Storms may deposit tracts of large boulders (pl. 9) on the reef, which are too heavy to be removed by ordinary wave action; later, smaller material may be piled around and among these; (2) The reef may be so wide that the force of normal waves is insufficient to carry loose material completely across and into the lagoon, and it may pile up on the reef; (3) The same thing may result from lagoon waves neutralizing sea waves, causing them to drop any loose materials they are carrying. Bars (pl. 10) formed in any of the above ways may become large enough to resist moderate storm waves which may then pile the material up above the high-tide level, or wind may also pile it up. These bars may become partially consolidated into beachrock (pls. 19, 20), which may survive even severe storms and serve to catch more loose material. Surfaces above high-tide level soon become colonized by plants (pl. 27B) the resulting vegetation further stabilizing the islets.

Regardless of how the loose material has become stabilized, these islets are essentially only piles of detritus on the flat surface of the reef. The core may or may not be of large boulders or consolidated material. Some islets which appear to be of this type may actually be of type (a), described above, but with the entire platform or remnants of it completely buried by loose material (fig. 4B).

Detrital islets may form on any part of the periphery of an atoll but are usually found on wider parts of the reef. Practically all islets on western reefs, many of those on southern reefs, and some on windward reefs may be so formed. They are of all sizes and shapes. Those on widened corners of atolls tend to be triangular or prolonged in the direction of the angle of the reef. Those on straight or gently curving reefs tend to be elongate in the direction of the length of the reef. Small bars tend to be crescent shaped, with the horns of the crescent downwind, or, rarely, concave toward the wind, but with the tips of the horns recurved in a downwind direction. Such small bars are frequently high around the periphery and depressed in the middle. Finer material is often removed from the surface by wind or waves, leaving a layer of loose gravel.

Islets of this sort, at least while small, are more vulnerable to the force of typhoons and lesser storms than those with a hard rock core. Storm waves, if severe enough, can move enormous quantities of loose material, even chunks. They may, on the other hand, add material either from the outer margin of the reef or from nearby islets, or occasionally, perhaps, from sand aprons in the lagoon.

Islets within the lagoon

In addition to the two main types a few islets exist within the lagoons, especially just inside the passes. Most of these (perhaps all) are composed entirely of sand accumulated on patch reefs at or just below the level of the lagoon water. The sand is piled up in low hillocks or dunes and may be well vegetated. Such islets occur in the lagoons of Likiep, Kwajalein, Wotje, and Eniwetok, and perhaps one on Rongelap would be in this class. Eniwetak islet in Kwajalein Lagoon, was the only one of this sort examined closely, and that during a very short visit only. It consists of a relatively small flat area of sand 6 or 8 feet above lagoon level, with steep sides, and with one corner at a lower level forming a terrace. It is bordered, at least on one side, by a fringing reef.

The origin of these lagoon islets is obscure. They may be simply of sand deposited on the reefs by wind, but this does not explain their being usually located just inside passes. It has been suggested (K. O. Emery, oral communication) that the sand may have been deposited by currents prior to the fall of sea level; if so, these islets are a special case of type (a).

Shores

Shores (the strips of land between mean low tide and the high-water mark of ordinary storm waves), may be divided into those predominantly of loose or unconsolidated materials, called beaches (pls. 17, 18), and those of hard or consolidated materials or rock. These are not sharply separated, as loose materials may be scattered or spread in various manners over rock shores, rock may be variously exposed by erosion of beaches, and beaches may even become consolidated to form beachrock. Generally, the two types and obvious combinations of them may be easily distinguished.

Beaches

Beaches are, within certain limits, continuously and locally variable and may be classified only arbitrarily. Furthermore, the same beach may change completely even during the course of a single storm. Therefore, it is possible to speak only in generalities and in terms of what may be reasonably expected in certain situations. As to topographic position, beaches are readily divided into tidal and storm beaches (pls. 11B, 17A), the tidal beaches lying between low-tide level and extreme high-tide mark, storm beaches lying above high tide. In texture both of these may be sand, pebble, cobble, or boulder beaches, any combination of these, or intermediate between them. Beaches commonly (but not universally) slope from the land toward the water, the nature and steepness of the slope being determined by the nature of the detrital material, the substratum on which it is lying, and a combination of all the forces of waves, currents, and winds which have acted upon it. The analysis of these forces is extremely difficult; formulation of it is not yet in a very advanced state and our data are not adequate for such detailed consideration.

Beaches exposed to the direct force of waves generated by the trade winds, or of frequent southerly storm waves and swells are generally much steeper than those on more sheltered coasts. Lagoon beaches generally are less steep than seaward beaches, except on leeward sides of large lagoons where strong waves may be generated. The slope is usually in the form of one or two shallow concave curves with a break at high-tide level. High sand or gravel beaches frequently have a sand terrace or berm (pl. 17A) at high-tide level between the storm and tidal parts of the beach.

Sand beaches (pl. 18A) may be found in any situation on either windward or leeward islets. However, they tend to be both more common and more extensive on lagoon shores than on seaward shores. On the lagoon shores of windward islets the sand is usually finer than on those of leeward islets, especially southern ones, where the beaches are frequently of gravel rather than sand. The sand particles of beaches on windward islets are generally much more angular than those of leeward ones, where they are worn and rounded. On islets with an exposed platform of rock there is frequently a storm beach above the rock platform. Where no rock platform is exposed, the beach commonly extends from the vegetation down to the reef flat, or erosion ramp, or on lagoon beaches down to the sand apron with which it merges. If there is a beachrock formation along the shore, there is more often than not a storm beach behind it, either continuous with the top of the beachrock or separated from it by a low escarpment or cuesta.

Pebble beaches (pls. 17A, 18B) are common along windward shores of windward islets. They also occur along the channel sides of all islets except those on the western reefs that consist mostly of sand; they are especially common on the lagoon shores of leeward islets on the south reefs. In texture pebble beaches vary from fine to coarse, where they merge with cobble or boulder beaches, and the particles may be well sorted or more rarely mixed in any proportion of sizes.

Sand and gravel beaches are commonly white to pinkish in color, particularly where the material is frequently disturbed and worked over by wind and waves. Where beaches are undisturbed for long periods of time, the color of storm beaches becomes progressively more grayish or even blackish, from the growth of microscopic algae on the upper surfaces of the particles.

Cobble or boulder beaches (pls. 13A, 17C, D) are commonly associated with storm deposits of coarse material (boulder or cobble ridges), hence are more frequently found on southern seaward shores; they may, however, be found in any position, though rarely on western leeward islets. The size of the fragments of rock varies but may be a foot or more in diameter. Cobble size, from 3 to 10 inches, is more common. At times a combination of a storm beach of boulders or cobbles with a tidal beach of sand or pebbles, or the reverse, may be encountered; more frequently both tidal and storm beaches are of material of similar texture. Generally, the smaller sizes tend to be less angular than large boulders, presumably because small pieces are more frequently rolled around. This, however, is by no means always so. Beaches of such coarse material occur rather rarely on lagoon shores except adjacent to deep passes on south reefs. Even on Taongi (Pokak) where there is a short beach ridge of cobbles along the lagoon shore of Sibylla islet, the beach below it is of sand.

Rock shores

Rock shores are of two types, those of slanting beds of beachrock (pls. 19A, B, 20A, B) and those of reef rock (pls. 11A, 12) in which the bedding is obscure or horizontal.

Beachrock shores (pls. 19A, B, 20A, B) may slope at the angle of the bedding planes, ranging from 5° to more than 30°, or may be truncated by erosion to a much gentler slope than the dip of the beds. Frequently, where there is a wide series of beds, these may be represented by a series of sharp parallel ridges at or just above high-tide level. Where beachrock is between tides it may be smooth from abrasion by wave-rolled gravel, pitted with large potholes (pl. 20C) and solution basins, or it may be cracked into large slabs or blocks (pls. 14C, 20D). These, as on the lagoon shore of Yeldo (Enejelto) islet on the east side of Wotho Atoll, may be thrown up into an irregular windrow on the storm beach above (pl. 20D). Near and especially above high-tide level the surface may be extremely rough and pitted (pl. 14A, B), almost honeycombed, from weathering by rainwater. Here, also, the surface is likely to be very dark or almost black from algal growth. To the casual observer these jagged blackened surfaces may suggest volcanic rock, which is not exposed on atolls.

Reefrock shores (pls. 11A, 12) are of two principal types, those where a platform of elevated reef protrudes from beneath the vegetation well above high-tide level, ending either in a ledge or an erosion ramp; and those where the rock has been eroded down to high-tide level or below. The latter type is commonly rather rough and may end in a low cliff if on the lagoon side, or merge into an erosion ramp on other sides of an islet. Both these types may commonly be partly covered by beach deposits. On Bwokwla islet, Taongi (Pokak) Atoll, the lagoon shore is a platform about 1 foot above high-tide level and is conspicuously undercut. An approach toward this condition may be seen on other lagoon shores of south reefs. Where a similar emerged platform protrudes onto a reef flat there always seems to be some development of an erosion ramp (pls. 11A, 15, 16). This may be broad, as much as 100 feet wide, and gently sloping, or as narrow as 3 to 4 feet and steep. Steep clifflike shores may also be found lining inter-islet channels where the islets are very close together, but still separated by water. Such a situation is to be seen between Anenlik (Enelik) and Jabwe islets, Ailuk Atoll.

Ledgelike shores frequently have their erosion ramps covered or partly covered by accumulations of coarse rubble. This is commonly in the nature of a mantle resting on the underlying rock, it is rarely banked up in the form of a beach. This may be seen most often near the seaward ends of passages between islets. The surface of the ramp is usually somewhat rough and pitted, sometimes extremely so. In other examples the roughness may be moderated by abrasion from wave-rolled gravel, as on some beachrock shores. The transition to the relatively smooth reef flat surface may be abrupt or gradual, in places marked by minor corrugations perpendicular to the waves. A good example of these corrugations is shown by Schlanger and Brookhart (1955, pl. 1). Elsewhere the edge of the ramp is irregular with many low spurs and reentrants.

Beachrock

A feature of atoll islets so common and conspicuous as to deserve special mention consists of narrow elongate beds of consolidated sand, gravel, or even larger material, dipping at the angle of inclination of a beach surface (pls. 19, 20). Such beds may consist of a single layer a few inches thick, or more commonly many such layers superimposed and dipping at the same angle. Owing to the small lateral extent of the single beds the actual vertical thickness or depth of such a series is very small. The total vertical dimension of the series is not more than the distance between mean high and low tides, except where such beds persist from an earlier higher sea level. In such cases, they may extend 1 or 2, or even 4 feet above mean high tide, and if recent beds have been added to the series, down to low-tide level. A continuous series of these beds may reach an extreme width of 20 yards or even more, but usually such a series is not more than 3 or 4 yards wide. The length is quite varied but may be as much as hundreds of yards.

Beachrock apparently forms beneath the surface of beaches and when first exposed by wind or wave action may be very weakly consolidated; the particles are cemented by a coating of aragonite needles. Exposure to air tends to harden the rock so that it may persist for a long period, as is shown by ancient beds now above high-tide level that must have been formed while sea level was higher than at present. This is undoubtedly a manifestation of the general phenomenon of "case-hardening" of exposed limestone, apparently due to recrystallization of calcite, which shows in some thin-sections of old, hardened beachrock.

Long strips of beachrock commonly occur around the peripheries of islets, usually sloping away from the islet, toward either lagoon or sea, in the manner of beaches of loose sand. However, locally the dip may be just the opposite of what would be expected, suggesting that the islet may not have always been in its present position. Such displacement of islets is also indicated by strips of beachrock found in the interior of islets and in various positions on otherwise denuded reef flats, between islets, or away from them altogether. On some reefs, such as that extending westward from Utirik Islet, Utirik Atoll, there may be a number of parallel series of beachrock beds, the seaward ones dipping seaward, those along the lagoon dipping lagoonward. It is thought that a typhoon may have removed most of the loose material from the reef flat here, leaving beachrock marking former shorelines of the islet. In places, especially near reef angles and the corners of islets, extremely complicated arrangements of beachrock may be exposed, indicating many shifts in former shorelines. A conspicuous example may be seen on the eastern point of Likiep Islet, Likiep Atoll.

Marginal ridges

Ridges (pls. 21, 22A, B) of unconsolidated limestone detritus are common just inside the margins of islets, especially along the seaward sides. The material varies in texture from fine sand, less than 0.5 mm in diameter, to cobbles and even boulders. The ridges may be interrupted or may extend continuously around an islet. Small islets are especially likely to have ridges all around them. The ridges are likely to be highest on the seaward side and the highest ones are on south shores.

These ridges may be normal beach ridges, piled up by waves, or by waves with the help of wind; they may be enormous masses of cobbles and boulders probably cast up by typhoons; or they may be dunes resulting from wind-blown sand caught by vegetation.

Beach ridges are the most common, existing at the tops of most beaches at least to some extent. They are commonly broad, low, and rounded in profile, seldom more than 2 to 4 feet above the general level of the islet surface. Where recent and not yet vegetated they may be narrow with sharp tops. Frequently they are double, the front crest sharp and narrow, the back one rounded and broad. In texture they generally correspond somewhat to the beaches that are in front of them, being sandy along most lagoon slopes except those on south reefs and frequently so along seaward slopes of windward islets. Along the lagoon side of islets on the south reef they tend to be of gravel, which often changes from coarse to fine from east to west along any particular islet, ending in sand at the west end. Gravel ridges as well as sand ridges may also be found along the seaward south shores of the islets where these are not occupied by storm deposits. The gravel is commonly rather rounded but may be angular in some situations. Many small sand and gravel bars are simple peripheral ridges surrounding bowl-shaped depressions.

The most conspicuous surface features of atoll islets are the enormous boulder ridges (pl. 22A, B), often termed "boulder ramparts", which occur on some islets of most atolls. These are beach ridges formed of large-size material. They are somewhat randomly distributed, being known from coasts facing in almost all directions, and from lagoon as well as seaward sides. They are, however, far more frequent along the seaward coasts of islets on the south reefs, and least frequent on lagoon coasts and on islets on west reefs. The texture of the material ranges up through cobble to boulder sizes (pl. 22). Different segments and layers in the same ridge often may be of very different average size and have abrupt boundaries between them. The highest known boulder ridge in the northern Marshall Islands is on the south coast of Lae Islet, Lae Atoll. It is about 18 feet high, with the upper several feet composed of huge boulders, a foot or more in diameter. Generally the size range of the material is much smaller than this and the height is between 5 and 10 feet. The rocks are frequently very angular and sharp and the upper layers may have relatively little finer material in the interstices. The profile of the ridges varies from narrow, with the seaward side rather steep, to broad, as much as 100 yards wide, with very gradual slopes. Where the ridge is wide a secondary ridge may frequently develop at its seaward margin, this one much sharper and with a steep seaward slope.

There is no sharp distinction between the boulder ridges and ordinary beach ridges. Their occurrence in a more or less random distribution, with a predominance on south reefs, and the energy requirements for moving and piling up such large fragments suggest that boulder ridges may be thrown up by typhoons, whereas ordinary beach ridges are probably formed by milder storms or ordinary high waves in rough weather.

Both beach ridges and boulder ridges in some situations occur in series, with more recent ones partly superimposed on the older, arranged from older to younger in either a seaward or lagoonward direction, starting from the interior of the islet. This arrangement is thought to result from successive heavy storms, each depositing a great mass of material. The vegetation on such a series may be observed to be more mature on the inner ridges, and the rocks may be more blackened. Islets may be enlarged by such deposition, especially on the lagoon side, but only where shallow water, a reef flat, or a sand apron exists along the original shore. Often the lagoonward third or more of an islet seems to have been built in this way, usually of smaller size material than that found in seaward beach ridges or boulder ridges.

Dunes, likewise, may be found in almost any situation, but they are most common along lagoon shores, especially on islets on west reefs and the west ends of those on south reefs. They are also found on the rare islets inside the lagoons. The dunes in the northern Marshall Islands are all small and are mostly stabilized by vegetation. It is likely that the vegetation is principally responsible for their formation by stopping the wind-driven sand and causing it to pile up among bushes and trees. The presence of pebbles and even some cobbles and boulders in many of these dune ridges shows that storm waves have frequently had a part in their construction.

Interiors of islets

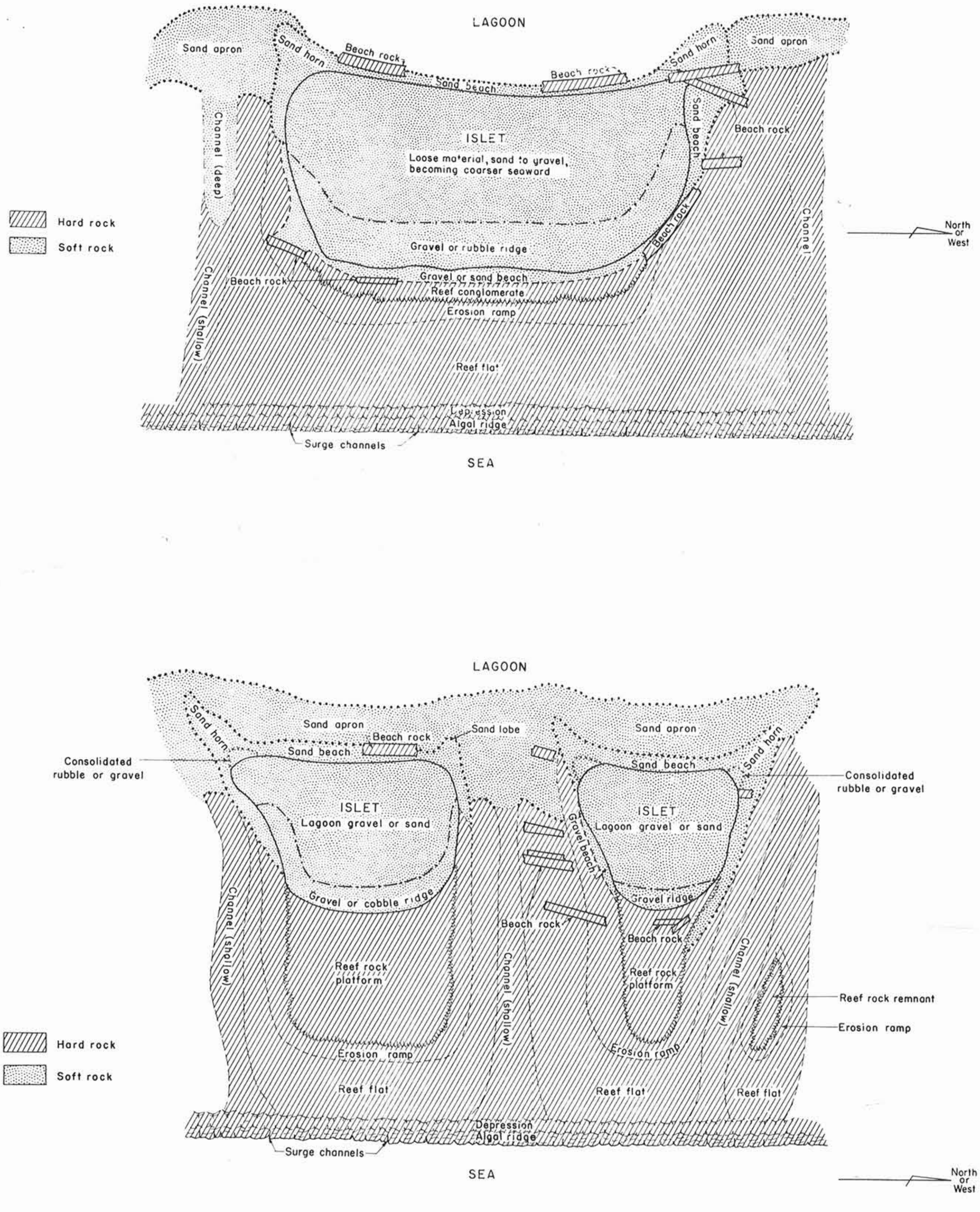
Inside the marginal ridge an islet may have little relief. It commonly shows an extremely slight slope upward from the lagoon side, with a surface of sand near the lagoon, becoming gradually coarser toward the sea. Boulders and blocks of reef rock, many of enormous size, are scattered over the surface of many islets inward from the seaward side to as much as 200 yards, or even more. These are more common where there is a well-developed boulder ridge along the seaward coast. The only apparent explanation is that they were carried inland by enormous typhoon waves. Their presence vividly illustrates the power of such waves, as the largest boulders must weigh tons. Occasionally there are areas, termed block fields, which are thickly covered with such boulders and large rubble, even to a depth of 1 to 4 feet. The narrow seaward parts of some windward islets may be composed entirely of coarse, loose rubble. The seaward sides of islets on south reefs may be covered by several feet of boulders and blocks, 6 inches to 3 feet in diameter, extending 200 feet or more back from the beach. This type of deposit usually but not always assumes the form of a broad low ridge, as described above under boulder ridges. Holes, loose blocks, and a tangle of vines may make footing here precarious.

Other topographic features may be found locally. Broad central depressions may occur. On Lado Islet, Likiep Atoll, there are at least two such broad depressions parallel with the long axis of the islet. On long islets there may be two different types of transverse depressions. One results from the filling in of the gap between two islets, uniting them into one, usually with some indication of the former separation in the form of an inward scallop of the seaward beach. The depression is commonly very gradual and slight. The other type apparently results from partial breaching of an islet by typhoon waves, which sweep the loose material into sea or lagoon. This type of depression is likely to be more abrupt, with sand, rock, or coarse rubble on the bottom. The appearance of a reasonably recent scour of this type may resemble that of a dry stream bed, though of course there are no streams on these islets. The inner ends of both these types of transverse depressions are often filled by a lagoon beach ridge of gravel or sand. Broad flat areas at lower levels than that of the rest of islets are usually either recently filled by wind or storm deposits, or are areas scoured by typhoon waves.

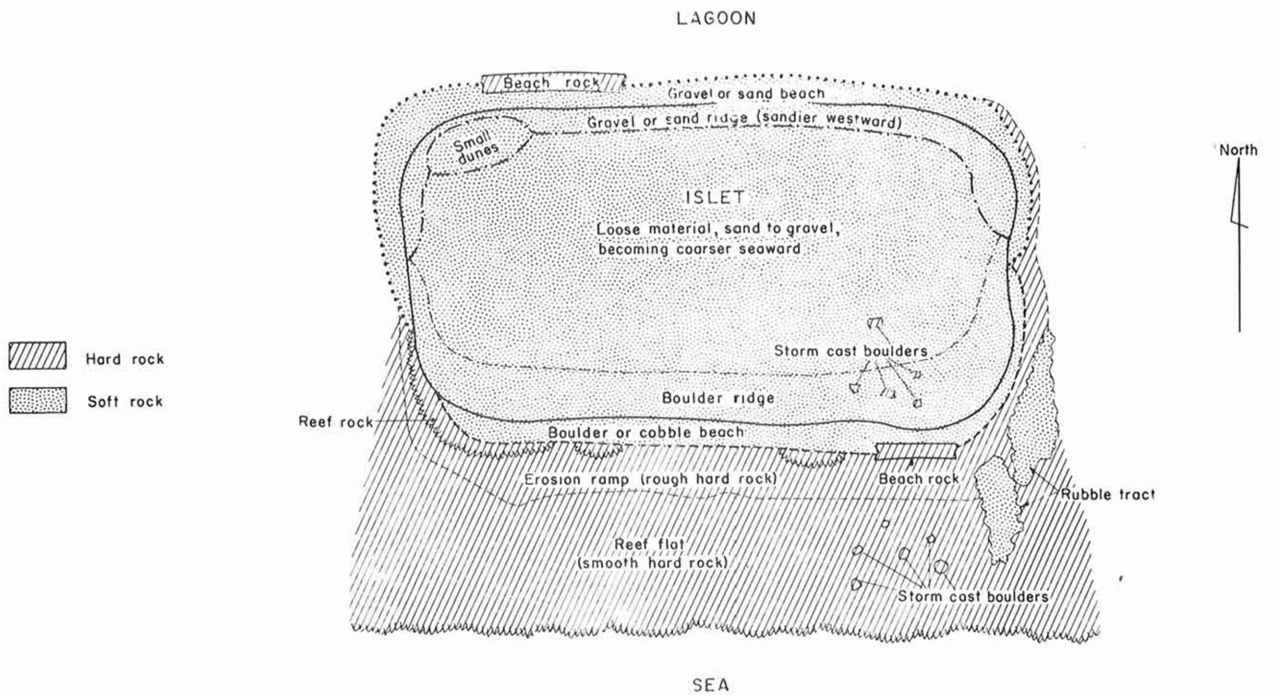
More abrupt, smaller, or irregularly winding depressions, from pond-like to trench-like, 3 to 6 feet deep, surrounded by piles of excavated sand and gravel, and usually with mucky soil in the bottom, are ancient taro pits dug by the inhabitants but abandoned many years ago. They are usually found near the centers of large islets or inward toward the lagoon. They are rarely found on atolls north of Ailuk. They are conspicuous on Wotho and Lae. Very rarely, small depressions are found containing tiny mangrove swamps. One such is found at the south end of Pigowak (Bekrak) Islet, Utirik Atoll, another on Jeltonet (Jeltoniej) Islet, Likiep Atoll.

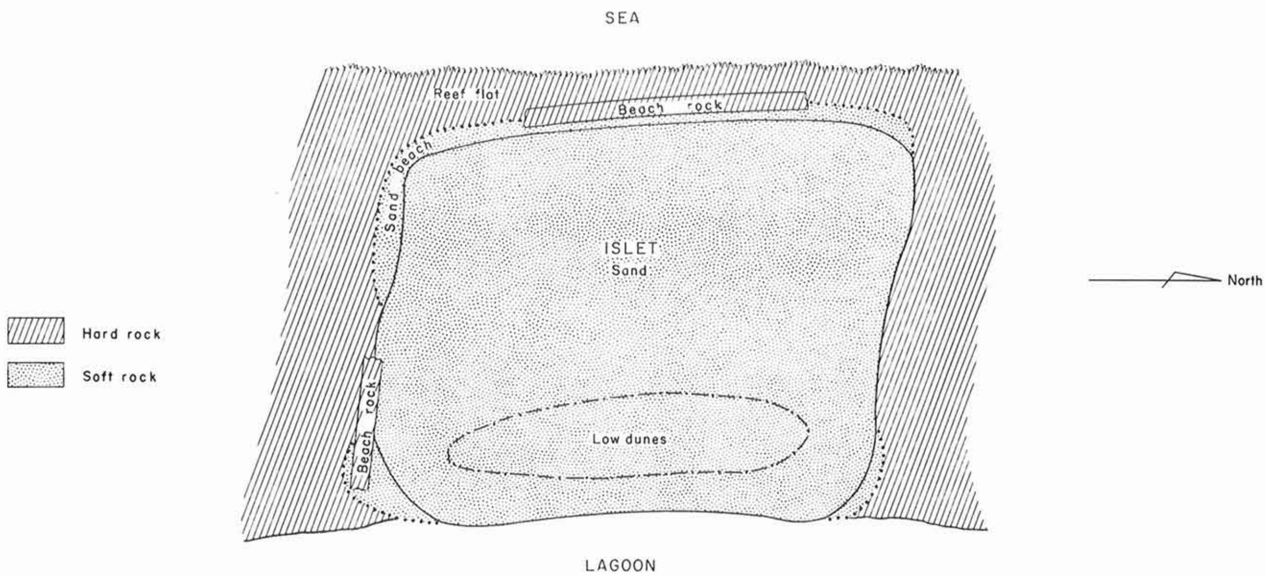
Islets composed, entirely or in their lagoonward parts, of successive beach ridges have a topography of alternate ridges and furrows parallel with the lagoon margin. At places, as near the north end of Taka Islet, Taka Atoll, there is what appears to be a storm deposit of small sharp rubble rising slightly above a general surface of sand or gravel, well inward from the beach. This may be the result of growth of the islet subsequent to deposition of the rubble.

In the interior of a number of islets, such as Utirik Islet, and several of those on Wotho Atoll, are rounded mounds, a few yards in diameter, of small sharp coral fragments. These mounds may rise 2 to 4 feet above the general level of the interior of the islet. There is generally little or no fine material in the interstices, at least in the surface layers. The origin of these mounds is not clear but they may result from the pushing up of rubble by the roots of trees, possibly accentuated by the blowing down of trees by storms. Stages in this process were observed on the islets of Wotho Atoll. They differ, however, from the tree-fall mounds observed in continental forests in that they commonly have no hollow alongside, of the sort regarded as characteristic of such features. It may be that there is some other explanation, entirely, for them.



3. Diagrams of typical windward islets showing position of surface features. A, single islet on reef flat; B, two small adjacent islets on reef flat.





4. Diagrams of typical leeward islets showing position of surface features. A, islet on south reef; B, islet on west reef.

Legends of plates

Plate 1. Aerial views of Lae and Ailuk Atolls.

A. Lae Atoll from the air, viewed from north. Photographed by D. B. Doan.

B. Ailuk Atoll, east reef with islets, from the air, viewed from south. Photograph by F. R. Fosberg.

Plate 2. Islets on reefs of Ailuk and Taka Atolls.

A. Islets on east reef of Ailuk Atoll, viewed from west, showing denuded platform seaward of islet, remnants of platform in channel, rubble tracts in channel, and coconut plantations protected by crescent-shaped windbreak of native vegetation.

B. Eluk islet, Taka Atoll, showing sand horns and beachrock.

Photographs by F. R. Fosberg.

Plate 3. A, B. Corals growing in lagoon, on reef inside Rua and Ebbetyu (Ebeju) islets, Ujae Atoll, depth 1-3 meters. Photos by F. R. Fosberg.

Plate 4. A, B. Surge channel through algal ridge, windward reef, Wotho islet, Wotho Atoll. The reef here is composed of colonies of several species of the algal genus *Porolithon*. Photos by F. Stearns MacNeil.

Plate 5. Windward reef features.

A, B, C. Algal ridge, windward reef opposite Lado islet, Likiep Atoll, composed mainly of several species of *Porolithon*. Photos by Fosberg.

D. Moat or back-ridge trough behind algal ridge, windward reef opposite Lojjairok (South Loj) islet, Kwajalein Atoll. Reef-flat and storm-cast boulders to left in distance. Photos by MacNeil.

Plate 6. Details of reef flats.

A. Detail of reef flat, at low tide, windward reef, Wotho islet, Wotho Atoll. Note small algal colonies and relatively smooth surface.

B. Detail of reef flat, at low tide, leeward reef, southwest of Ailuk islet, Ailuk Atoll.

Photos by MacNeil.

Plate 7. A, B. Outer margin of leeward reef and reef flat at low tide, southwest of Ailuk islet, Ailuk Atoll. Note absence of algal ridge and prevalence of corals. Photos by MacNeil.

Plate 8. Windward reef flat, Taka Atoll, near Lojrong (Lojiron) islet, at low tide, showing solution basins with raised rims. Photo by MacNeil.

Plate 9. Rubble tract on reef flat, windward reef, Ujelang Atoll. Photo by MacNeil.

Plate 10.
A. Crescent-shaped gravel bar on leeward reef east of Lotj (Loj) islet, Lae Atoll.
B. Seaward end of gravel bar, windward reef, Ujelang Atoll.
Photos by MacNeil.

Plate 11. Post-Pleistocene eroded reef platforms.
A. Post-Pleistocene reef platform with erosion ramp, Taka islet, Taka Atoll.
B. Lagoon beach, Taka islet, Taka Atoll, showing tidal beach, eroded post-Pleistocene reef platform, and storm beach.
Photos by MacNeil.

Plate 12. Exposure of post-Pleistocene reef platforms.
A. Ennimenetto islet, Ujelang Atoll.
B. Jabwe islet, Ailuk Atoll.
C. Lae islet, Lae Atoll, lagoon beach.
D. Lojjairok (South Loj) islet, Kwajalein Atoll.
Photos A, C, D by MacNeil; B by Fosberg.

Plate 13. A, B. Boulder beach and exposed post-Pleistocene rock platform with stack and perched boulder.
Photos by Fosberg.

Plate 14. Surfaces of erosion ramps.
A. Erosion ramp on Ulka (Ulika) islet, Ailuk Atoll, showing rough pitted surface and undercutting; storm beach in background.
B. Same, closeup, showing collapse of undercut limestone (width of foreground about 5 feet).
C. Beachrock on Yeldo (Enejelto) islet, Wotho Atoll, being undercut and quarried by waves (width of foreground about 8 feet).
D. Closeup of edge of erosion ramp, showing solution features, Ebbetyu (Ebeju) islet, Ujae Atoll.
Photos A, B, C by Fosberg; D by MacNeil.

Plate 15. Solution basins on erosion ramps.
A. Solution basins with overhanging rims, erosion ramp, Emejiwan (Enijwa) islet, Likiep Atoll. Photo by MacNeil.
B. Solution basins on erosion ramp, north end of Taka islet, Taka Atoll, showing chalky deposit in bottom. Photo by Fosberg.

Plate 16. Spalling off of erosion ramp surfaces.

A. Surface of erosion ramp, Erlie (Alle) islet, Ujae Atoll, showing spalled slab and spall plane. Photo by MacNeil.

B. Surface of erosion ramp north end of Taka islet, Taka Atoll, showing spall planes of different ages as indicated by different degrees of pitting and discoloration by algal growth. Area 2-3 square feet. Photo by Fosberg.

Plate 17. Gravel and boulder beaches.

A. Gravel beach on lagoon side of Bik islet, Ujae Atoll, showing terrace or berm.

B. Erosion ramp with small storm beach on left, Daisu(Raij) islet, Ujelang Atoll.

C. Boulder beach, Bock islet, Ujae Atoll.

D. Boulder beach, Ujae islet, Ujae Atoll, showing abraded erosion ramp.

Photos by MacNeil.

Plate 18. Sand and gravel beaches on lagoon side of islets.

A. Sand beach, lagoon side, Utirik islet, Utirik Atoll. Photo by Fosberg.

B. Gravel beach, lagoon side, Nelle islet, Ujelang Atoll. Photo by MacNeil.

Plate 19. Details of abraded beachrock.

A. Beachrock series on northwest corner of Emejiwan(Rikararu) islet, Likiep Atoll.

B. Beachrock cuesta at southwest corner of Emejiwan(Rikararu) islet, Likiep Atoll.

C. Abraded beachrock, Jemo island, showing abrasive agent.

D. Closeup of abraded beachrock on Jemo island, showing composition.

Photos A, B by MacNeil; C, D by Fosberg.

Plate 20. Details of beachrock.

A. Beachrock series, Rua islet, Ujae Atoll.

B. Beachrock showing anticline-like arrangement, dipping seaward (to right) and lagoonward (to left), Rua islet, Ujae Atoll.

C. Potholes in beachrock on lagoon beach, north end of Bokanaetok islet, Wotho Atoll.

D. Slabs of beachrock quarried by lagoon waves and piled up at top of beach, Yeldo (Enejelto) islet, Wotho Atoll.

Photos by Fosberg.

Plate 21. Beach ridges of pebbles and cobbles.

A. Beach ridge of pebbles, Ailuk islet, Ailuk Atoll. Photo by MacNeil.

B. Beach ridge of cobbles, Utirik islet, Utirik Atoll. Photo by Fosberg.

Plate 22. Details of boulder and cobble ridges and other coarse deposits.

A. Boulder ridge, south side, Sibylla islet, Taongi (Pokak) Atoll.

B. Details of mixture of boulders and cobbles, boulder ridge, Utirik islet, Utirik Atoll. Large boulder in lower right about 16 inches across.

C. Details of coarse gravel, with tern (*Procelsterna caerulea*) nesting, beach ridge on small bar between Jabwelo (Jaliklik) and Almani islets, Bikar Atoll.

D. Details of small gravel on flat, with young noddy tern (*Anous stolidus*), Daisu (Raij) islet, Ujelang Atoll.

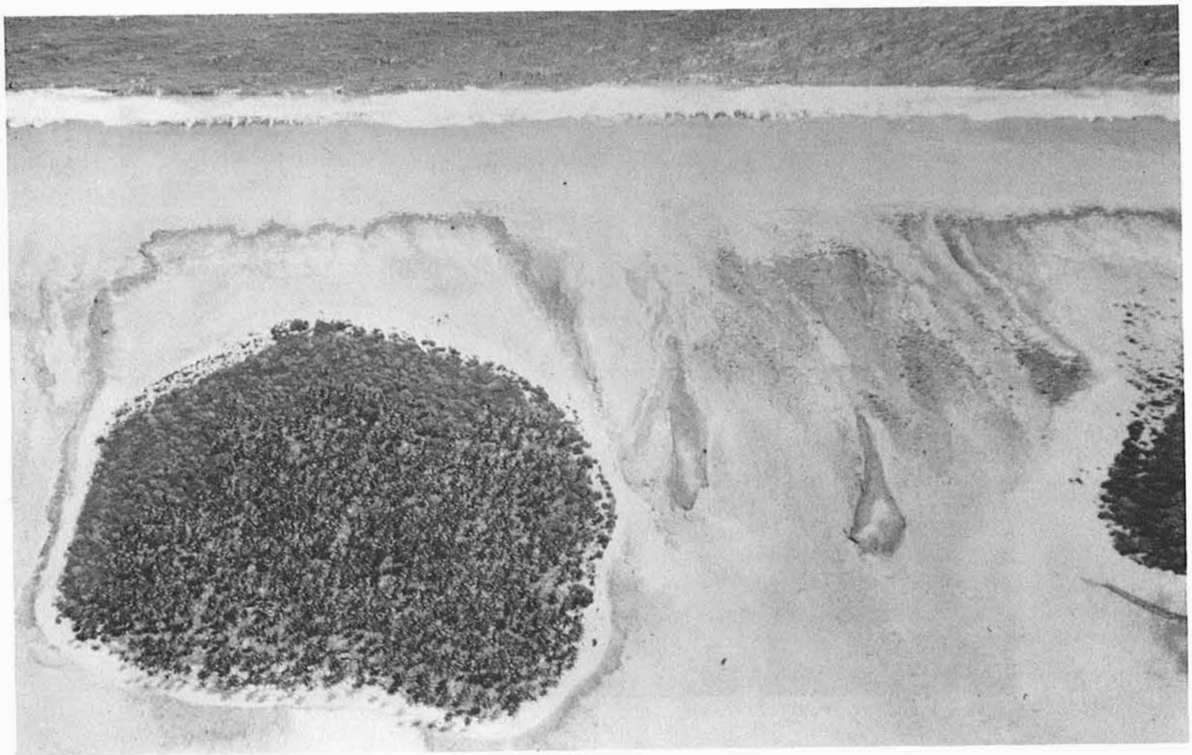
Photos A, B, C by Fosberg; D by MacNeil.

Plate 1

A

B

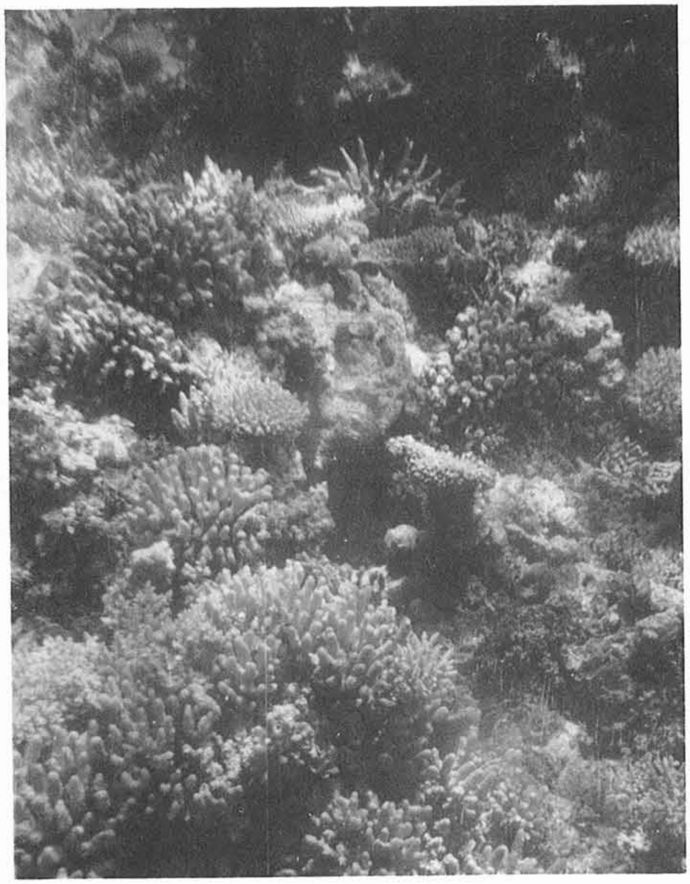
Plate 2



A

B

Plate 3



A

B

Plate 4

A

B

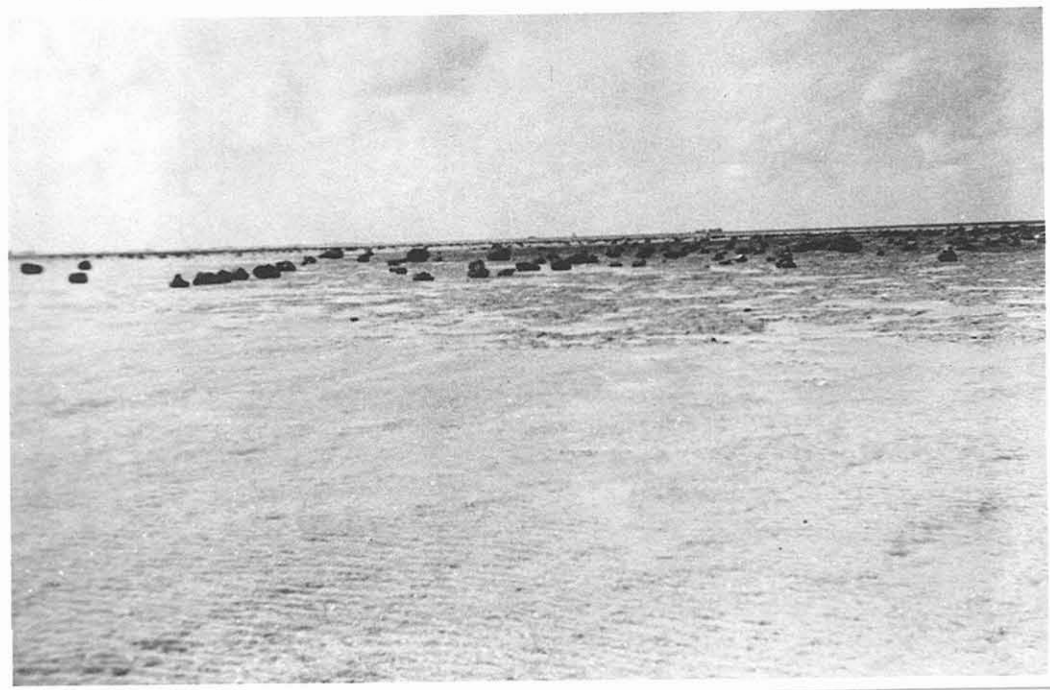
Plate 5

A

B

C

D



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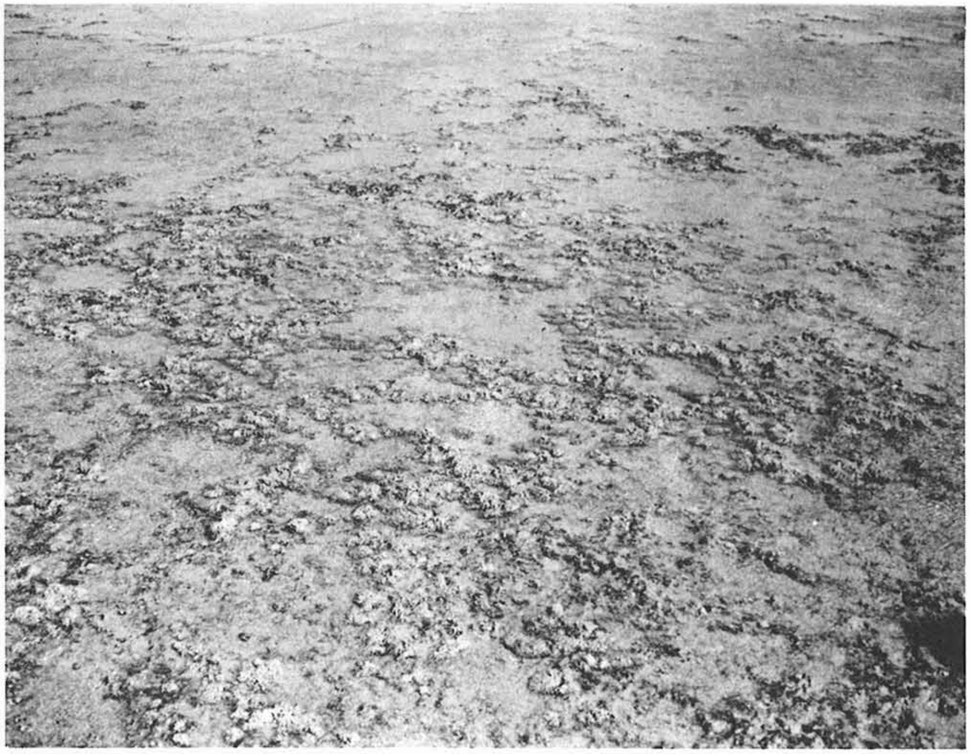


A

B

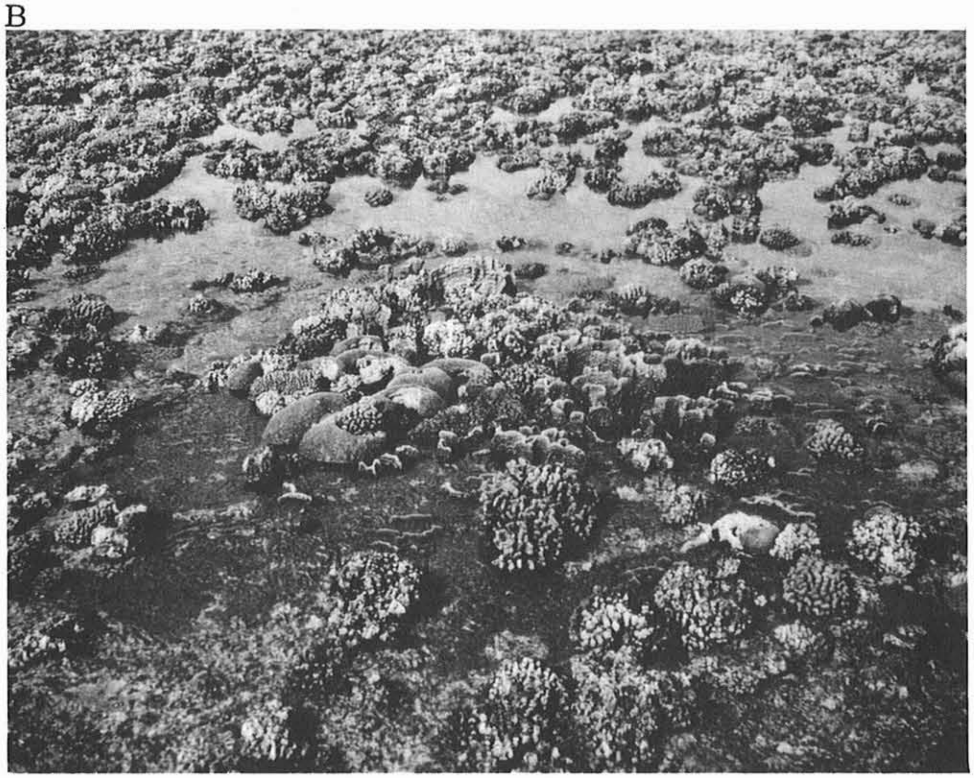


Plate 7

A

B

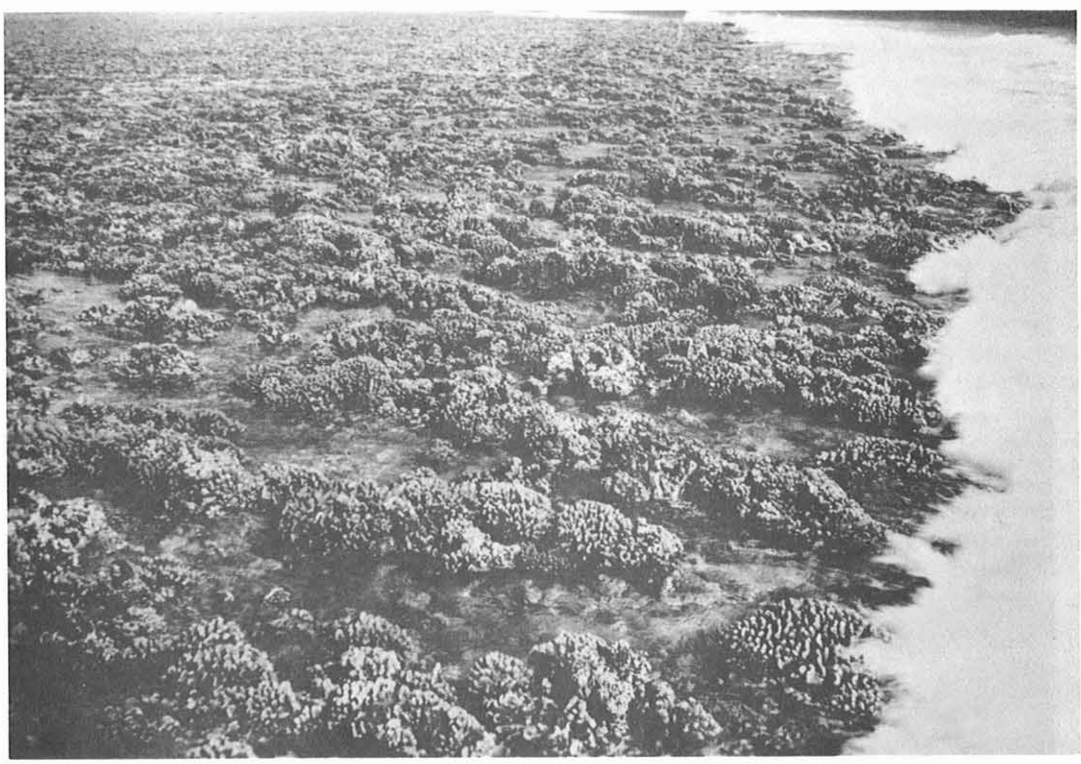


Plate 8

Plate 9

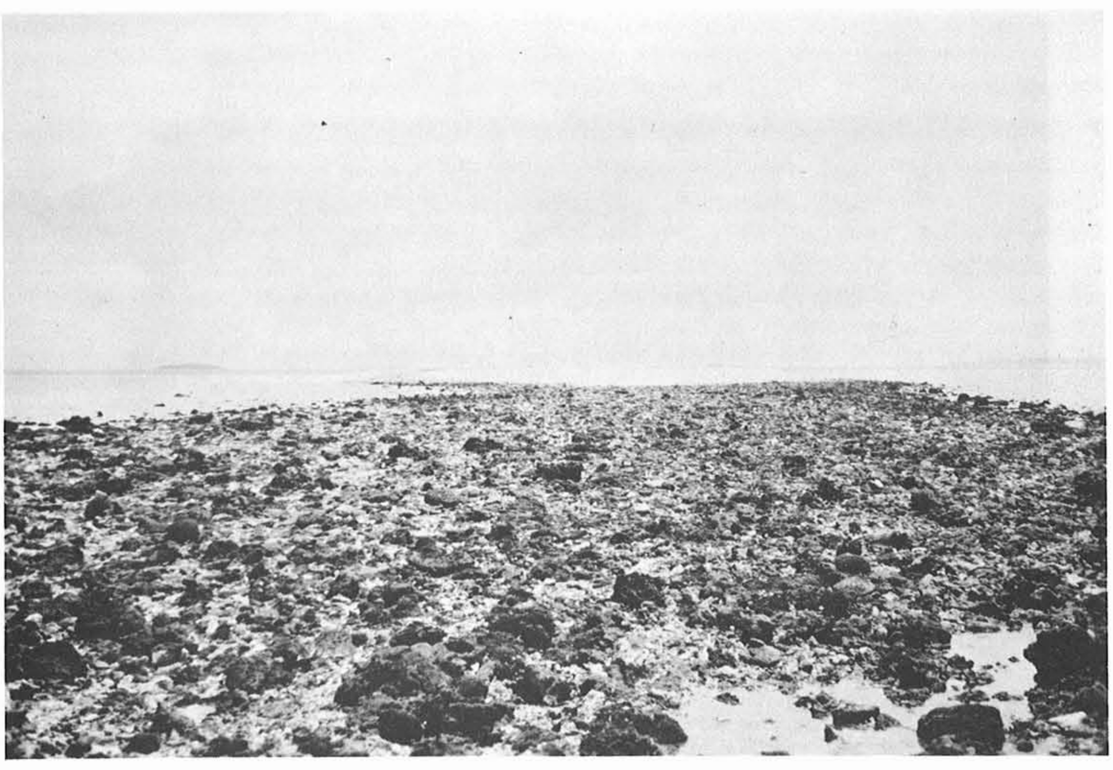


Plate 10

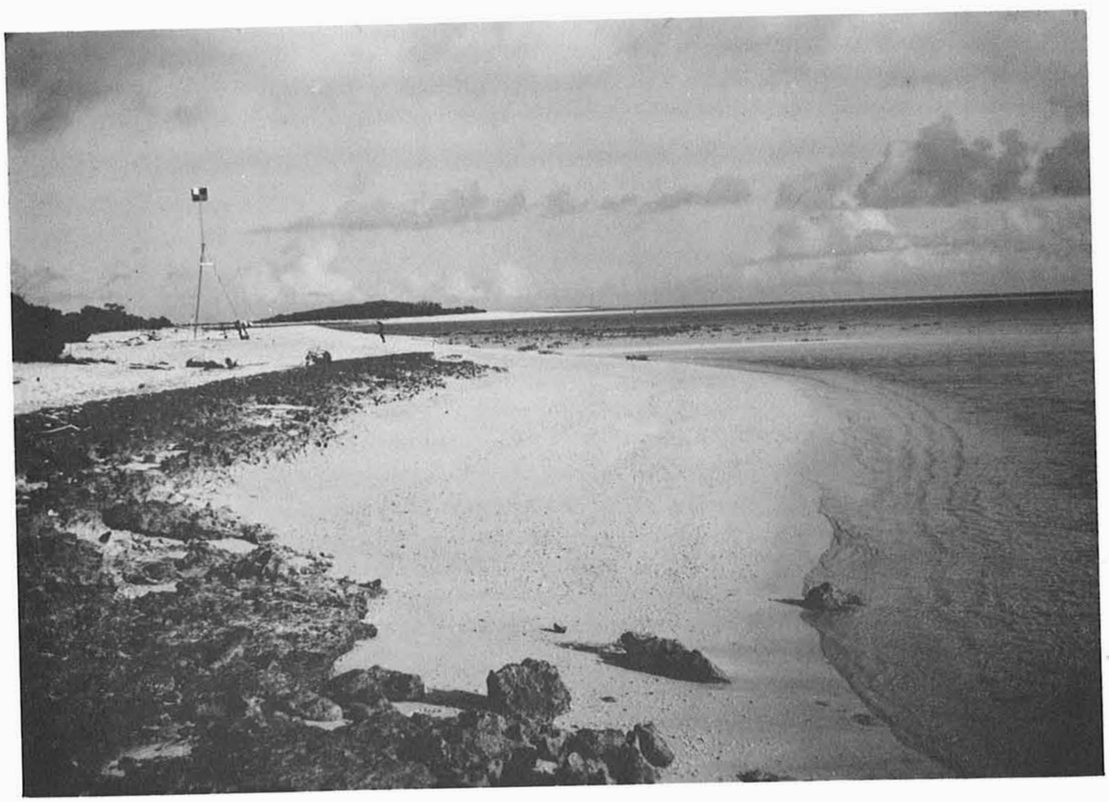
A

B

Plate 11

A

B



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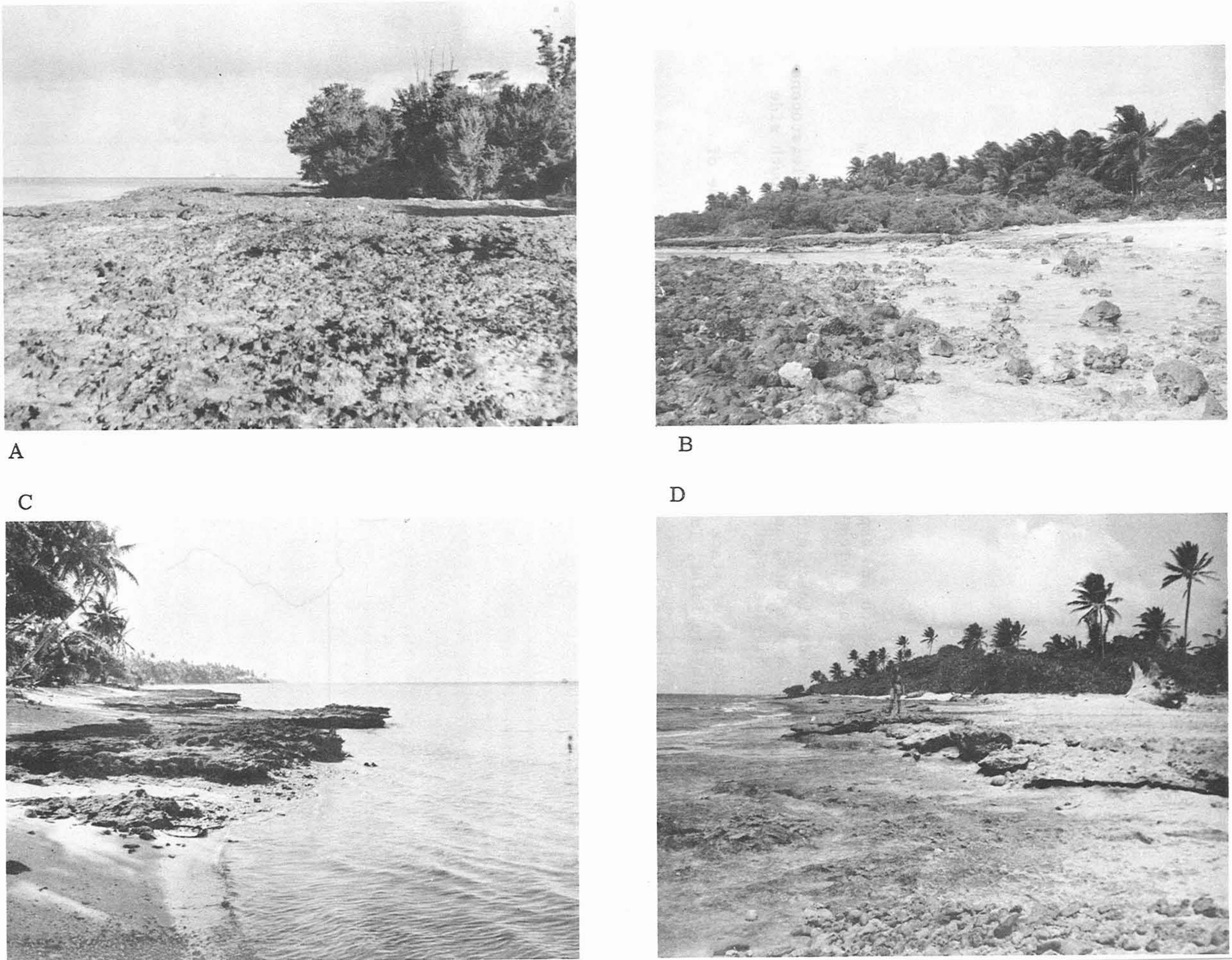


A B C D

Plate 13. Boulder beach and exposed post-Pleistocene rock platform with stack and perched boulder.

A. Boulder beach with protruding exposures of post-Pleistocene rock platform, and stack with perched boulder. South side of Sibylla islet, Taongi (Pokak) Atoll.

B. Closeup of stack with perched boulder, south side of Sibylla islet, Taongi (Pokak) Atoll.

Photos by Fosberg.

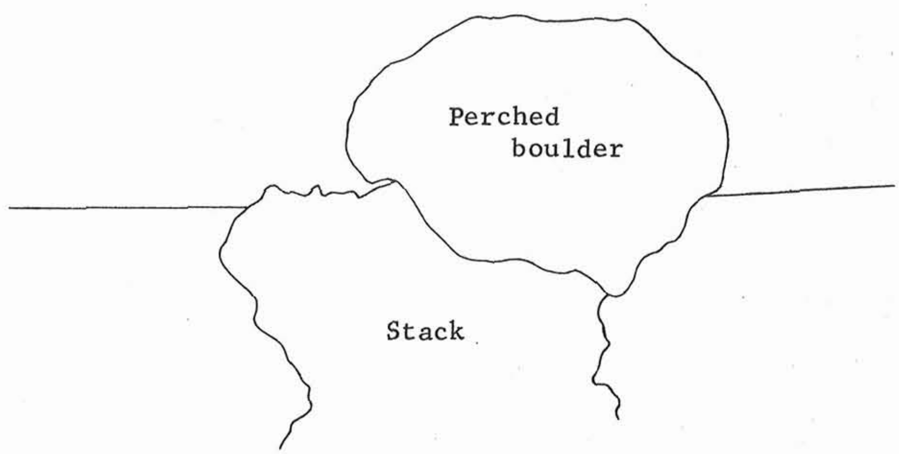
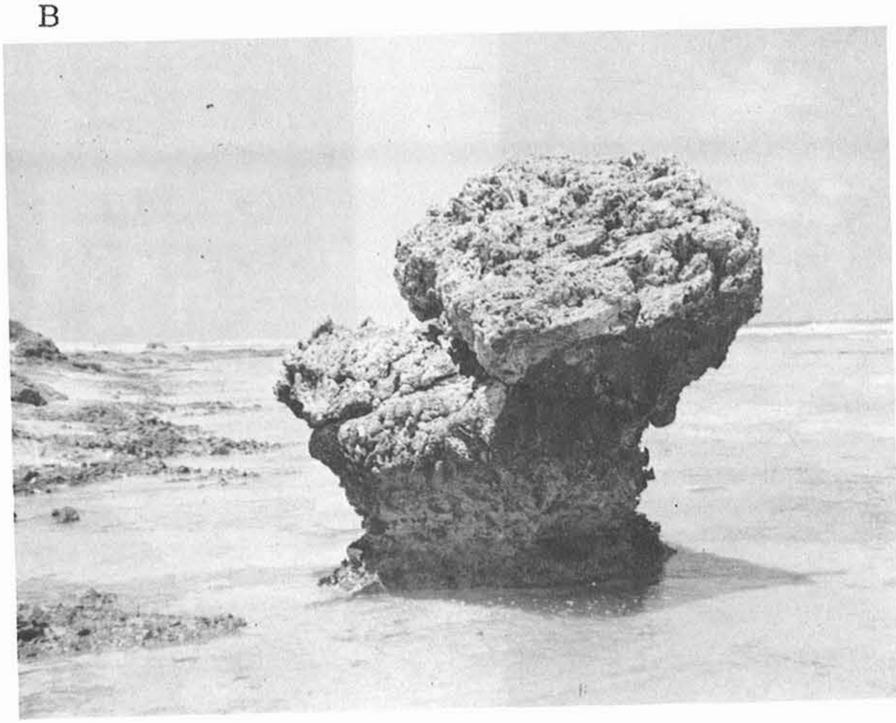


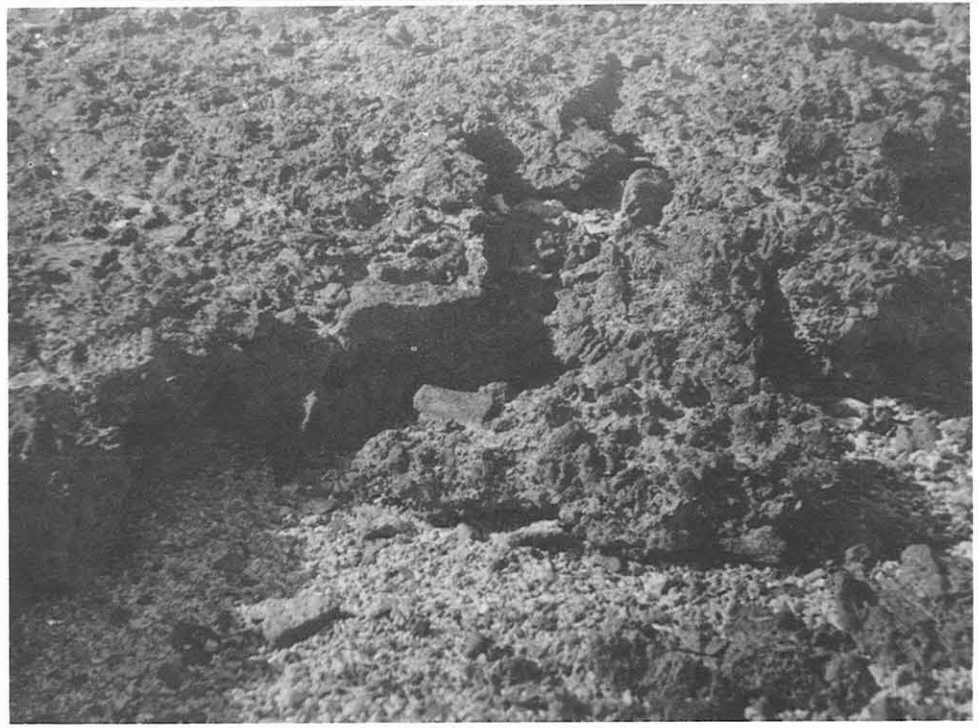
Plate 13

A

B

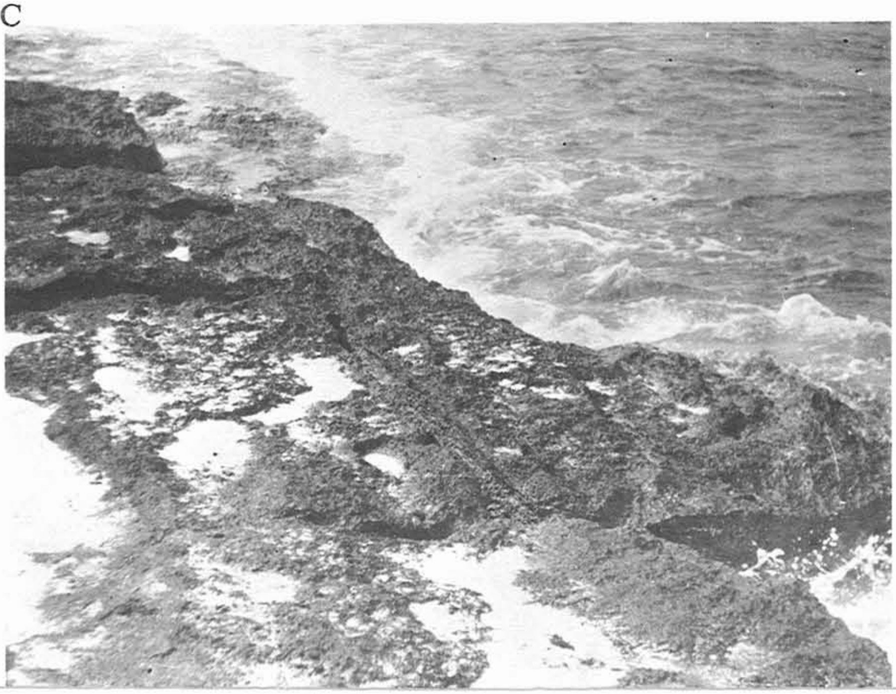


A

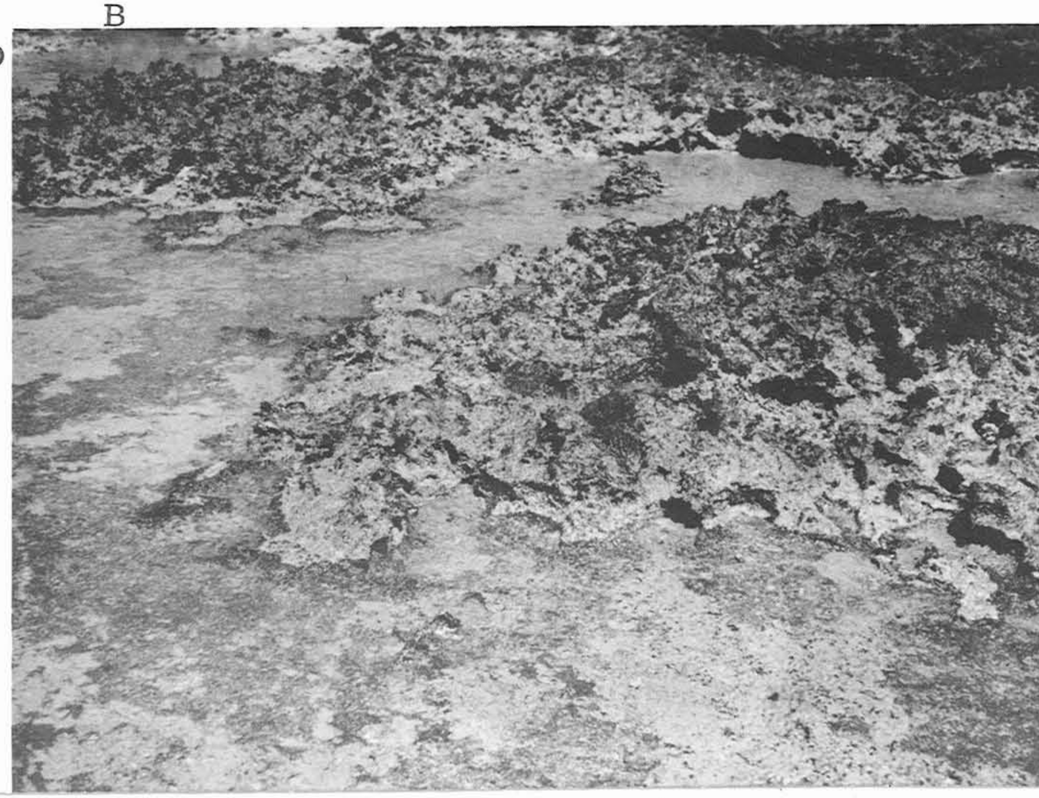


B

C



D



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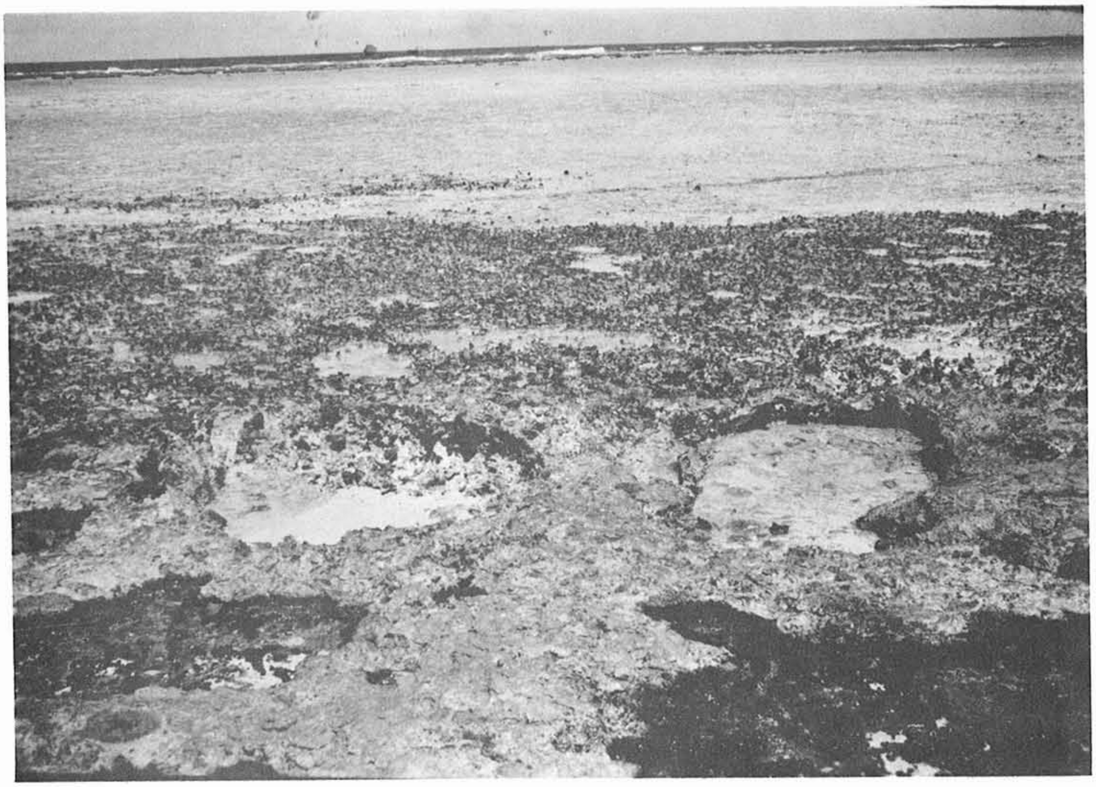


A

B

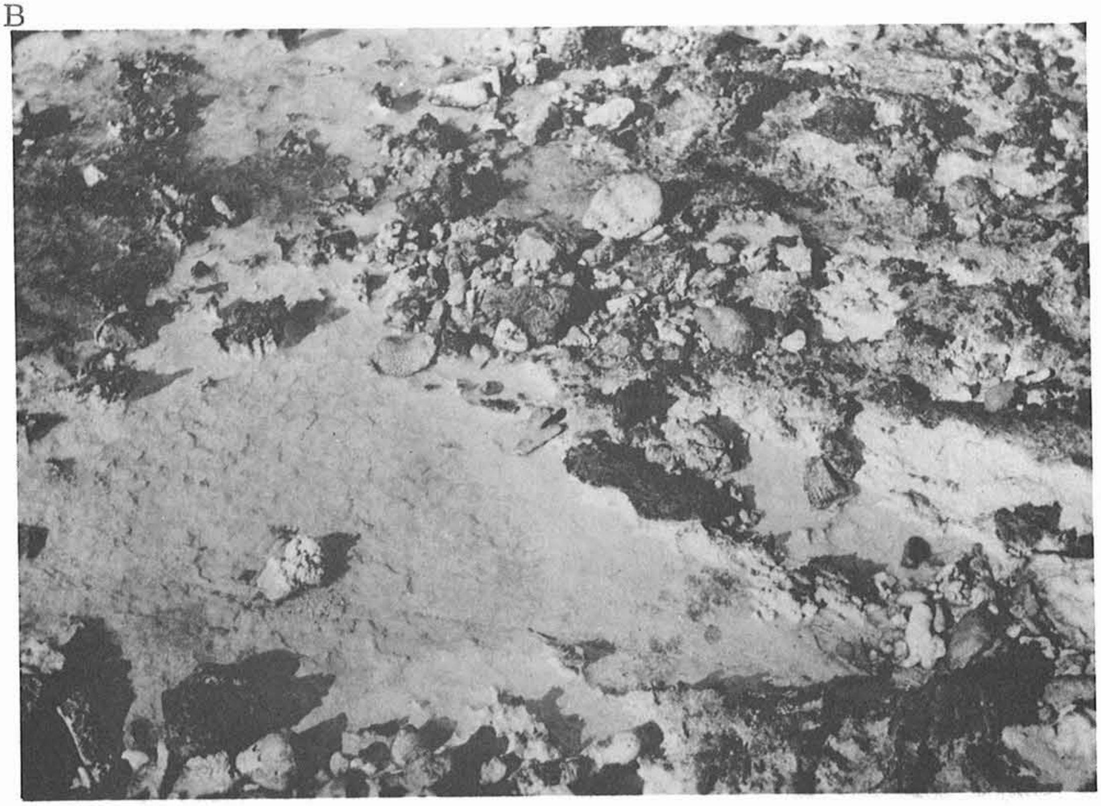
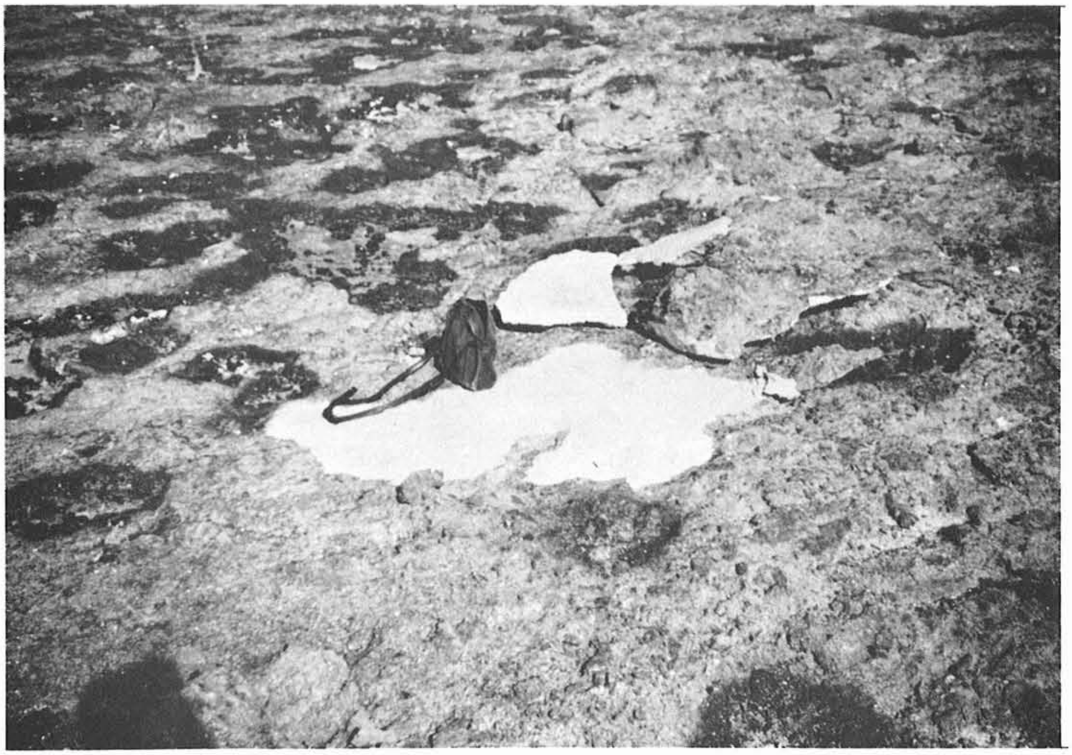


Plate 16



A

B

Plate 17

B

A

D

C

Plate 18

A

B

Plate 19

A

B

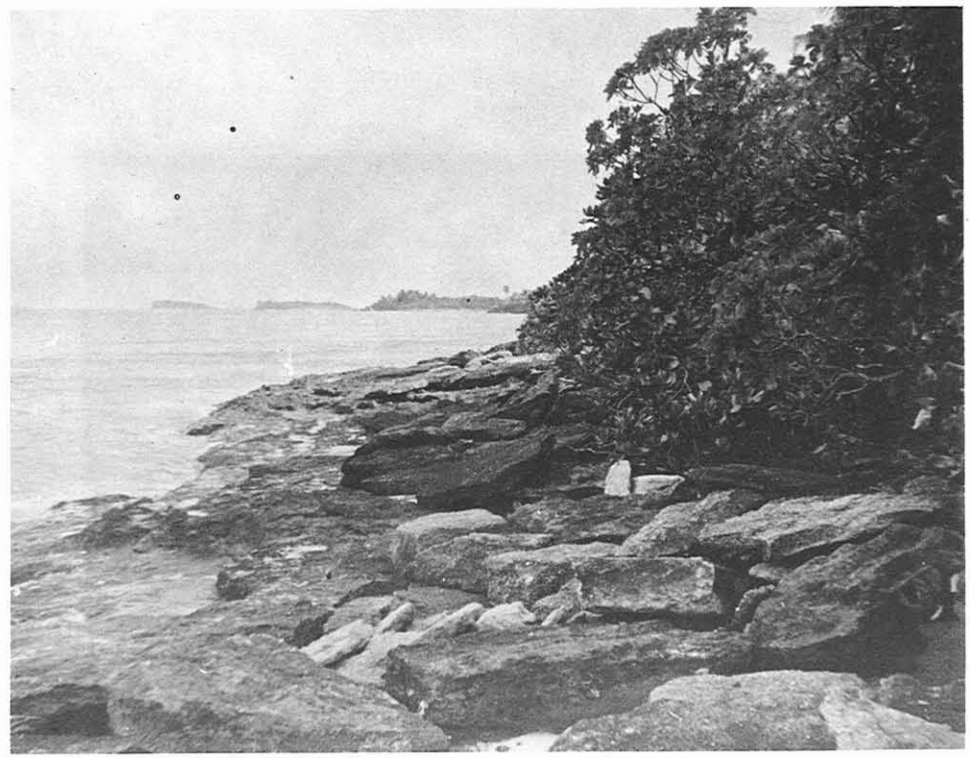
C

D

A

B

C



D

Plate 20

Plate 21

A

B

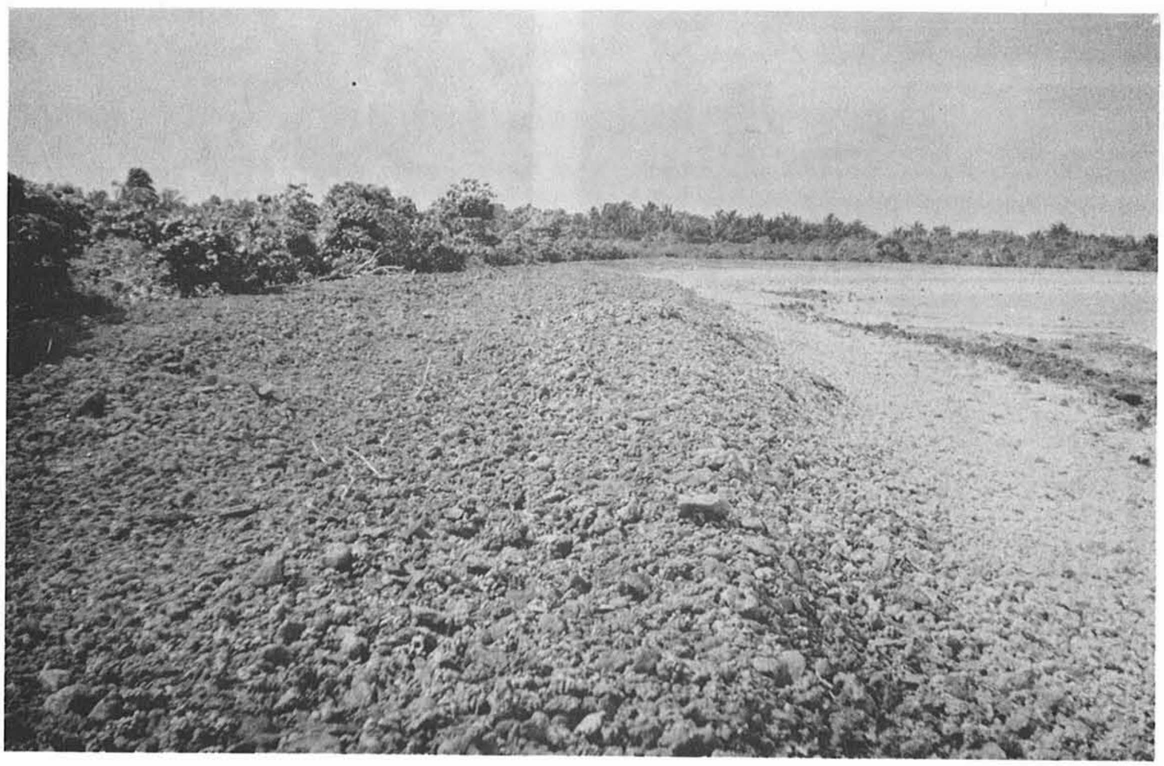
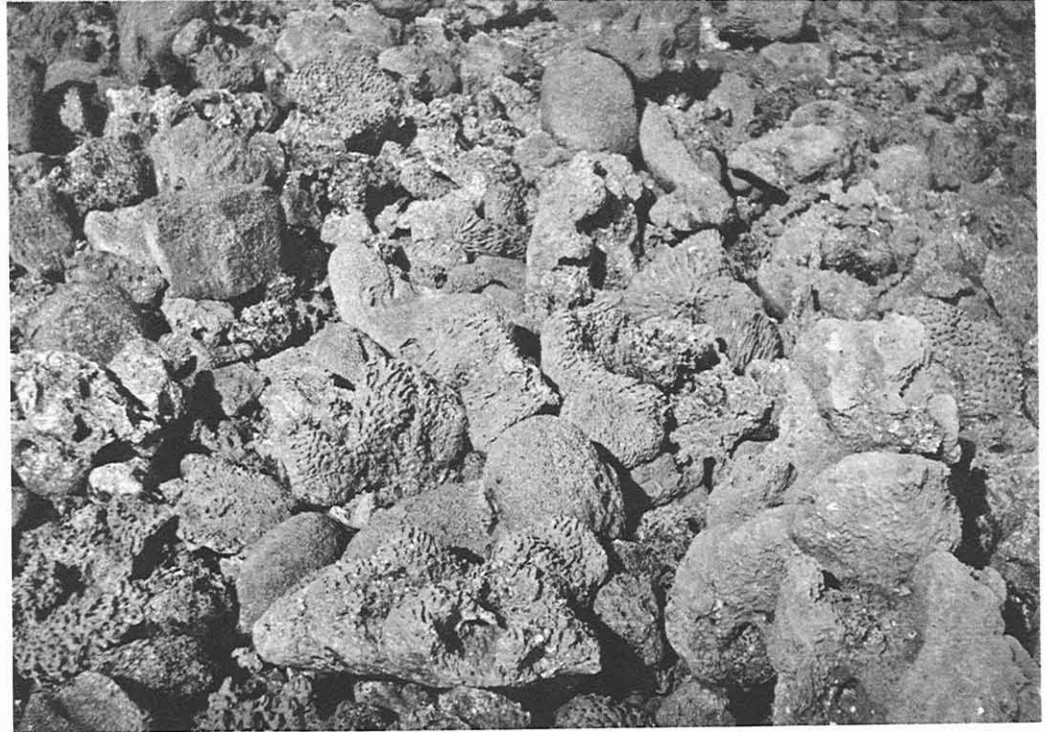


Plate 22



A ↑ C ↓ B ↑ D ↓

PART II: OTHER FEATURES

by F. R. Fosberg

Soils

The loose sediments piled above high-tide level on atoll islets are composed almost entirely of clastic limestone debris, mostly of organic origin and varying in size from the finest silt-size particles to enormous boulders many tons in weight (pl. 23B). This material is remarkably uniform in chemical nature but diverse in biological origin, comprising skeletons and fragments of skeletons of such lime-secreting organisms as corals, Foraminifera, mollusks, echinoids, and calcareous red and green algae, as well as all sizes of fragments of limestone consisting of such skeletons cemented together by recrystallized calcareous and phosphatic materials (pls. 28-31, 33). These are mixed in varied proportions without a regular pattern of distribution. The texture range is extremely wide and the range in sorting is far wider than that described above for the beach materials. They are irregularly stratified (pl. 25C), the strata mostly representing stages or events in the deposition of the material. There seems to be little regularity about the vertical or areal arrangement of different grades and mixtures of these sediments, although in general the lagoon sides of the islets are more likely to be sandy in texture, and the seaward sides are more often of coarse material (pls. 21-23). The sampling, unfortunately, scarcely represents the coarser range of these sediments. Previous descriptions of similar material have been given by Sollas and others (1904), David and Sweet (1904), Cloud (1952), Newell (1954a, 1954b, 1956), Fosberg (1954), Tercinier (1955), Schlanger and Brookhart (1955), McKee (1956, 1958), and Fosberg and others (1956).

The loose, unconsolidated materials on the atolls are the parent materials of the majority of the soils developed.

The soils on the islets fall into five principal types (Stone, 1951a, Fosberg, 1954):

1. Essentially unaltered sands and gravels.
2. Stony and very stony areas.
3. Shioya series.
4. Arno Atoll series.
5. Jemo series.

These are described in detail in Part IV.

Drainage

The material of the islets is generally so porous that drainage by percolation down through the ground is perfect and almost instantaneous. There is no running surface water, except during typhoons or tsunamis, when great sea waves may sweep across the islets. Normally there is no standing surface water except where depressions or taro pits extend down to below the maximum water table. An exception to this occurs on islets subjected to intensive military traffic, such as Kwajalein. Here the surface layers become so compacted and, apparently, so cemented as to become more or less impervious. Water puddles may stand in such areas as long as 24 hours after heavy rains.

Vegetation

Most of the original vegetation of the northern Marshall Islands has been replaced by coconut plantations. This is especially true on the larger islets. Only on Taongi (Pokak) (pl. 24A, B), Bikar, and Wotho Atolls was it possible to study considerable areas of apparently undisturbed vegetation; on Lae, Ujae, Ujelang, and Kwajalein Atolls smaller areas were studied (see Fosberg, 1953, 1955; Fosberg and others, 1956). As extensive reports on the vegetation are to be published elsewhere only a brief summary need be given here.

The coconut plantations (pl. 24C, D) range in density from almost complete cover in more moist areas to quite sparse in the dry northernmost atolls. The ground cover under the trees ranges from grass and other herbs to a thick tangle of bushes, vines, and trees, depending on the climate and on how diligently the weeds are kept cleared.

On the seaward sides of most islets a belt of thick scrub and scrub forest (pl. 2A) is left to protect the coconut trees from excessive wind and salt spray. On the windward side this tends to be very dense and to slope gradually to the beach. On more sheltered sides this belt tends to be narrower, taller, less dense, and with a more abrupt slope to the beach, both because trees grow closer to the beach and because shrubs and trees are less stunted by wind and salt spray.

On smaller islets, and on areas left undisturbed on larger ones, there are several types of forest--pure stands of giant soft-wooded Pisonia trees (pl. 25), of fantastic Pandanus, of umbrella-like Ochrosia, or mixed stands of these and several hardwood species. These forests commonly have dense canopies and little undergrowth. Around the edges a dense scrub fringe gives an appearance of impenetrability.

On sand spits, bars, and narrow places on islets a sparse scrub of pioneer species (pls. 26, 27) is found, grading into forest.

On very small or very rocky islets the woody vegetation may be low and dense, or of irregularly scattered trees and shrubs with patches of sparse bunchgrass and thin low scrub; rock flats may be completely bare of vegetation. Such aspects become more and more predominant as one goes northward in the Marshall Islands, until they characterize almost the entire vegetation of arid Taongi (Pokak) Atoll (pl. 24A, B).

Principal reef-forming animals and plants

Corals, by J. W. Wells

The reef building corals of the Marshall Islands include 52 genera of the Scleractinia, 2 genera of the Alcyonaria (Heliopora and Tubipora), and 1 hydrozoan genus (Millepora). The skeletons of all these are aragonitic, analyses showing $CaCO_3$, 98.05-99.71 percent; $MgCO_3$, 0.09-1.11 percent; and minute amounts of SiO_2, $(Al,Fe)_2O_3$, and traces of $CaSO_4$ and $Ca_3(PO_4)_2$. The texture of the skeleton ranges from porous or spongy in such rapidly growing forms as Acropora, Porites, and Montipora to relatively dense and solid in such relatively slow growers as Favia, Pocillopora, and Heliopora.

The protean scleractinian genus Acropora, with a bewildering array of species (298 named, but less than one-third valid), is easily the dominant coral everywhere on the Indo-Pacific reefs except in regions geographically peripheral to the reef zone. Judging from its frequency in reef rock and loose debris, it accounts in many places for three-quarters or even more of the mass. Locally, according to ecological controls, Acropora may be quantitatively secondary to a few other genera: on algal ridges to windward, Pocillopora commonly is almost the only scleractinian, followed by the hydrozoan Millepora. Behind the ridge, Acropora is dominant over those parts of the reef flat that do not "dry" at ordinary low tide. On many Indo-Pacific reef flats, but only rarely in the Marshall Islands, branching Montipora may be locally abundant even to virtual exclusion of other corals. Near shore, especially where the substratum is of shifting loose debris, Acropora diminishes and dominance is assumed by species of Porites or the alcyonarian "blue coral" Heliopora. Lagoon reefs are easily dominated to considerable depths by Acropora, except close to the shore. On Marshall Islands reefs the overall order of quantitative importance appears to be: Acropora, Porites, Pocillopora, and Heliopora, with Montipora, Astreopora, the faviid genera (as Favia, Favites, Platygyra, Goniastrea, Leptastrea, Cyphastrea, and Plesiastrea), and all others much in the minority.

Foraminifera, by Ruth Todd

Four species of Foraminifera are the chief representatives of this group of animals found in the sediments and soils of the northern Marshall Islands:

Calcarina spengleri (Gmelin)
Amphistegina madagascariensis D'Orbigny
Marginopora vertebralis Blainville
Homotrema rubrum (Lamarck)

In certain of the sands the four together comprise the bulk of the material and, in some places, Calcarina spengleri (Gmelin) alone accounts for most of it.

The entire skeletons of these four genera are composed of calcite. All are rather thick-walled forms with numerous interior chambers and consequently they are more resistant to abrasion on the beaches than are the smaller, thinner-walled and more fragile specimens of Foraminifera that comprise the remainder of the large foraminiferal fauna of the Marshall Islands.

So far as is known at present, Calcarina spengleri (Gmelin) lives only on the reef flat (Cushman, Todd, and Post, 1954, p. 364). Marginopora vertebralis Blainville lives both on the reef flat and in water of shallow to moderate depths inside and outside the atoll. The larger, thicker and more robust forms of this species are presumed to have lived on the reef flat or in shallow water. Homotrema rubrum (Lamarck) is an encrustation that occurs both on the reef flat and in water of probably only shallow depth.

Amphistegina madagascariensis D'Orbigny probably does not actually live on the reef at all, although it is found there in small quantities. Elsewhere, it is very abundant. It probably lives both inside and outside the atolls from shallow to moderate depths, with larger and thicker-walled specimens (such as those in the samples listed below) originating in the shallower parts of the lagoons.

Table 1 records the distribution of these major species in three groups of samples. Samples in (a) with mainly fresh and unworn specimens, indicate little transport from their place of origin; in (b) with worn and some polished specimens, indicate long transport and (or) prolonged abrasion; and in (c), with corroded specimens, may indicate attack by acid solutions.

Algae, by M. S. Doty

In tropical seas certain algae are major accumulators of the material that becomes deposited as calcareous sediment or rock to form the atolls and islands around and on igneous rock bases (Ladd and others, 1953). These algae dominate the atoll reefs and much of the lagoon bottom area. A readily available illustrated resume of these algae has been published by Johnson (1954). Fragments of algae broken from the reef patches and atoll reef edges by wave action or the browsing activities of such animals as the parrot fishes (Scaridae) or surgeon fishes (Acanthuridae) may wash into the lagoon where they contribute to its filling or accumulate as islands on reef tops. Calcareous algae, when ingested by animals such as these fishes, are defecated largely as fine sediment.

Quantitative relationships of four major constituents of present-day reefs are given in table 2. Among the red algae three or four genera are most conspicuous on the reefs of today, Porolithon, Goniolithon, Jania, and Amphiroa.

Table 1.--Foraminifera in various types of terrestrial sediments on atolls in the northern Marshall Islands

Analyst: Ruth Todd

(a) Samples containing fresh (unworn) Foraminifera

Foraminifera	14	18	53	57	60	75	76	92	105	112	126	129	139	156	253	275
Marginopora vertebralis	X	X	X	X	X	X	X	X	...	X	X	...	X	X	X	X
Amphistegina madagascariensis	X	X	X	...	X	X	X	X	...	...	X	...	X	...	X	X
Calcarina spengleri	...	...	X	X	X	X	X	...	X	X	X	X	X	...	X	X
Homotrema rubrum	...	...	...	...	X	...	...	X	...	X	X	...	...	X	X	...

(b) Samples containing worn Foraminifera

	22	25	29	34	36	44	70	72	96	104	110	115	116	120	122	132	150	166	251	254	255
Marginopora vertebralis	X	X	X	...	...	...	...	...	X	X	X	...	...	X	...	...	...	X	...	...	...
Amphistegina madagascariensis	X	X	...	X	...	...	X	...	X	X	X	X	X	X	X	X	X	X	X	...	...
Calcarina spengleri	X	X	X	X	X	X	X	X	...	X	X	X	...	X	X	X	X	...	...	X	X
Homotrema rubrum	X	...	...	...	...	X	X	...	...	X	...	X	...	...	...	X	...	X	...	...	X
							1/ p	p			p			p					p	p	p

(c) Samples containing corroded Foraminifera

	21	23	28	71	100	102	114
Marginopora vertebralis	...	...	X	...	X	X	X
Amphistegina madagascariensis	X	X	...	...	...	X	X
Calcarina spengleri	X	X	X	X	X	X	X

1/ polished specimens.

The genus Porolithon is the builder of sea edges of reefs, it is perhaps the principal organism making up the pink stony crusts and heads that may coalesce to form the buttresses and ridges of the reef margin. These buttresses and overhangs are, on occasion, broken off by storms and deposited inland or on the reef flat, often as huge and conspicuous reef boulders. Smaller fragments make up much of the island gravels and sand grains. It is to be noted that some of the huge chunks broken from the reef edge by storms become lodged in the grooves between the marginal reef buttresses and there, after being overgrown, contribute to the roofing-over of the inward ends of the grooves. In the central Pacific the material seen in such areas, often as a pink pavement, is perhaps 90 percent Porolithon onkodes.*/

Goniolithon, another of the lime-producing genera, is a dendritically branched alga of the more inward reef flats and passes between atoll islands. It does not form large detrital pieces, being friable, and is most notably a sand producer. Jania and Amphiroa are flexible jointed coralline algae that form patches of branches a few centimeters high and a millimeter or so in diameter. Upon breaking loose from their site of growth on the reef flats they die, and the soft parts of the joints decay leaving calcareous sediment or sand. This red algal detrital material around Johnston Island (Emery 1956, p. 1511) may be the principal lagoon-filling sediment. In many places a green alga, Halimeda, is the principal constituent of the sand that builds the islands, as in the Caribbean and Bermuda, or one of the principal constituents of lagoon sediments, as in the northern Marshall Islands atolls (Emery and others 1954, p. 58). Halimeda is composed of branches that are made up of heavily calcified, flat, waferlike segments. These segments persist as sand grains of a rather coarse kind after the death of the plant. While Halimeda does grow on reef flats, especially the broader and what we feel to be the older reef flats, it grows most conspicuously in the lagoons where it may densely cover the sides of the lagoon reefs and reef patches and form meadows on the shallower bottoms.

The chemical composition of these algae is shown on table 3. Further studies of chemical composition are reported by Clarke and Wheeler (1917), Lemoine (1911, p. 38-43), and Johnson (1954). The high magnesium content of the red algae is to be noted. This may be one of the sources of the dolomitizing magnesium salts in atoll areas. Whereas there are theories that certain phosphorites have arisen under marine conditions upon decay of marine organisms, from the very white color of young fossil material and the low P_2O_5 content, it is unlikely that these marine algae play such a role. Little is yet known of the biomass of these rocklike organisms. From the chemical analyses it is clear that they are mostly inorganic and thus could be regarded as mostly nonliving.

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*/ The oft-referred-to genus Lithothamnion is, virtually, not to be found on reef surfaces.

Table 2. - Quantitative relationships of the four major constituents of reefs

Constituents	Pearl and Hermes Reef [1]	Southeastern Florida [2]	Bahamas [2]	Murray Islands Australia [1]
Algae, calcareous	48.5	25.1	18.0	42.5
Mollusk	17.8	17.5	12.2	15.2
Coral, madreporarian	16.6	9.3	8.2	34.6
Foraminifera	6.3	9.0	17.3	4.1
Total (percent)	89.2	60.9	55.7	96.4
Constituent ratios				
Algae/coral	2.92	2.70	2.20	1.23
Algae/mollusk	2.72	1.43	1.47	2.79
Algae/Foraminifera	7.70	2.80	1.04	10.03
Mollusk/Foraminifera	2.82	1.94	.71	3.71
Mollusk/coral	1.07	1.88	1.49	.44
Coral/Foraminifera	2.64	1.01	.47	8.44

[1] Data from T. W. Vaughan, 1917.
[2] Data from Thorp, 1936, p. 52.

The results of Odum and Odum (1955) indicated that there is uniform concentration of chlorophyll (equivalent to between 0.05 and 0.10 gm/cm of Codium edule, dry weight) over the reef surface regardless of substratum, whether it be coralline crust, animal coral, or detrital. Sargent and Austin (1949) and Odum and Odum (1955) have shown that there may grow and be deposited as much as 1.4 to 1.6 cm of material per year over a reef surface. Under more ideal conditions growth may be much faster. For all practical purposes, reef surfaces are generally in equilibrium with as much material being removed by erosion as is deposited by the living organisms. Thus this increase of about 1.5 cm per year times the area involved can be used as a figure for calculating a maximum amount of material depositable as clastics that could become soil.

Table 3.--Partial chemical composition of some sediment-forming red algae as percent of dry weight

Sources: Clarke and Wheeler, 1917; Lemoine, 1911; Johnson, 1954

Algal species	CO_2 in ashed samples 1/	CO_2 in samples not ignited 1/	Organic matter	Moisture in air-dried samples	SiO_2	R_2O_3	CaO	MgO	SO_3	P_2O_5	SrO	Total
Porolithon	...	37.5	2/ 12.9	1.34	Tr	Tr	33.3	7.49	.68	1	1.03	94.2
onkodes	...	35.3	2/ 12.9	1.40	do.	do.	32.7	7.16	2.32	1	1.21	93.0
Porolithon	3.43	36.8	12.7	.67	do.	do.	34.0	7.64	1.03	.25	1.10	94.2
gardneri	2.96	37.4	11.8	.68	do.	do.	34.3	7.62	.28	.38	1.18	93.6
Porolithon	3.27	28.2	21.5	1.72	do.	do.	31.9	8.62	2.05	1	.97	96.0
aequinoctiale	2.88	28.4	21.0	1.54	do.	do.	31.9	8.46	1.84	1	1.10	94.2

1/ Determined by HCl titration. 2/ Loss in weight to 550° C.

Note: These percentages should not total 100 percent, as all the constituents were not determined. The figures for CO_2 in ashed samples should not be included in totals.

Legends of plates

Plate 23. Miscellaneous deposits.

A. Dunes on sand spit, south end of Enajelar islet, east side of Ailuk Atoll.

B. Large boulder in interior of Kamwome islet, Taongi (Pokak) Atoll, apparently carried some hundred meters inland by storm waves.

C. Mass of pumice pebbles on surface of ground, interior of south extension of Ebbetyu (Ebeju) islet, Ujae Atoll.

D. Top of broad boulder ridge, apparently piled up by typhoon, Utirik islet, Utirik Atoll.

Photos by Fosberg.

Plate 24. Types of vegetation on islets.

A. Lepturus grassland with shrubs of Sida fallax and scattered trees of Messerschmidia argentea, boulder covered with guano, on Shioya soil series, Kamwome islet, Taongi (Pokak) Atoll.

B. Sparse, half-dead Messerschmidia woodland on cobble flats, Kamwome islet, Taongi (Pokak) Atoll.

C. Coconut grove with thick undergrowth on cleared, disturbed Jemo soil, Jemo island.

D. Grassy opening in coconut grove on Shioya soil, Jemo island.

Photos by Fosberg.

Plate 25. Pisonia forest and forest soil.

A. Giant Pisonia grandis tree, Ebbetyu (Ebeju) islet, Ujae Atoll.

B. Pisonia forest with grassy ground cover, Jemo island.

C. Soil test pit in Pisonia forest on Bikar islet, Bikar Atoll, showing buried hardpan layer of Jemo soil series.

D. Pisonia forest, Bikar islet, Bikar Atoll, showing dark humus layer on the surface of the ground, Jemo soil series.

Photos by Fosberg.

Plate 26. Shore and sand-flat vegetation.

A. Mixed forest on stony soil, Bokerok islet, Ujae Atoll. Wave-cast log, probably Douglas fir from northwest America, in foreground.

B. Scrub forest of Pemphis acidula on rock platform surface, Jabwe islet, Ailuk Atoll.

C. Well-developed fringe of Scaevola scrub at top of gravel beach, leeward side, Kalo islet, Ujelang Atoll.

D. Darkening of bare coral sand by crust of blue-green algae, open areas on west end of Lae islet, Lae Atoll. This crust may contribute to the nitrogen supply of the soil.

Photos by Fosberg.

Plate 27. Pioneer vegetation.

A. Low shrubs of *Pemphis acidula* on denuded rock platform surface, Jabanngit islet, Ailuk Atoll.

B. Young *Scaevola* and *Messerschmidia* plants colonizing gravel bar on south reef of Lae Atoll.

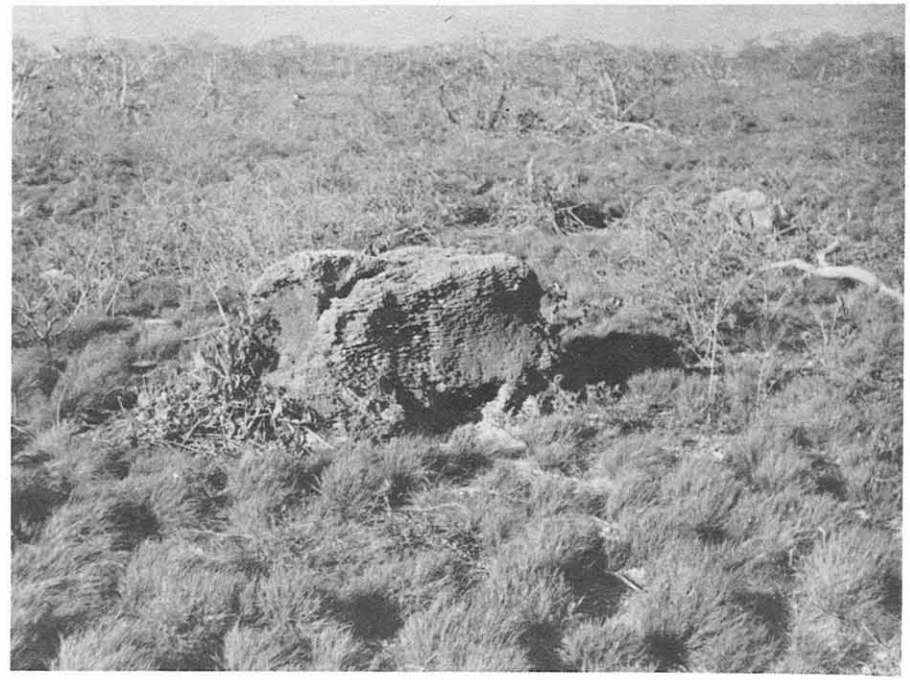
C. *Scaevola* and *Messerschmidia* colonizing gravel flat on Kabben islet, Wotho Atoll.

D. Young *Scaevola* plants colonizing upper part of gravel beach, lagoon side of Bwdije (Breje) islet, Taongi(Pokak) Atoll.

Photos by Fosberg.

Plate 23

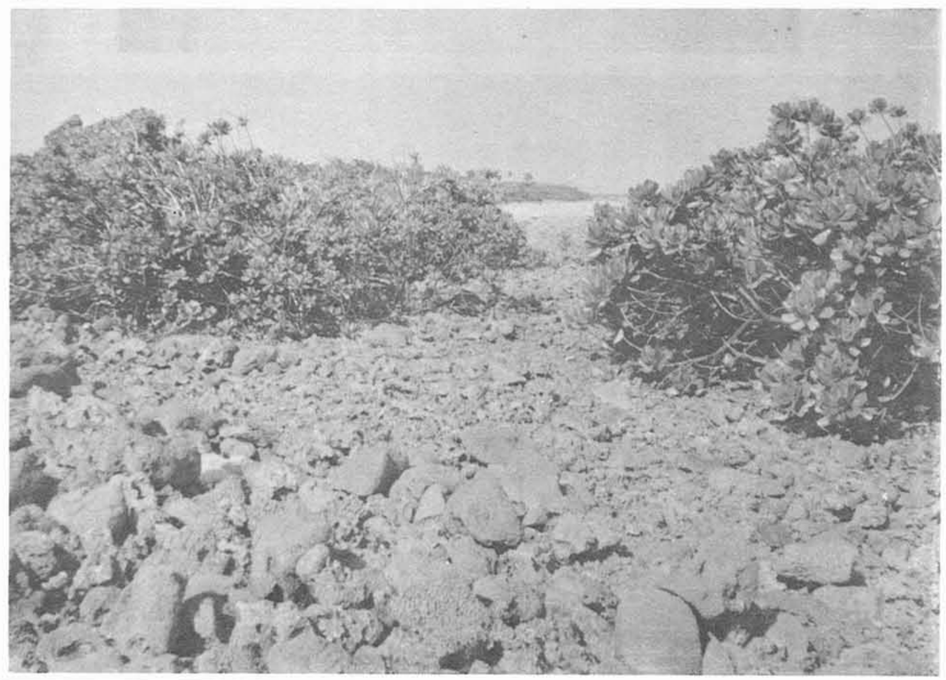
A



B

C

D



A

B

Plate 24

C

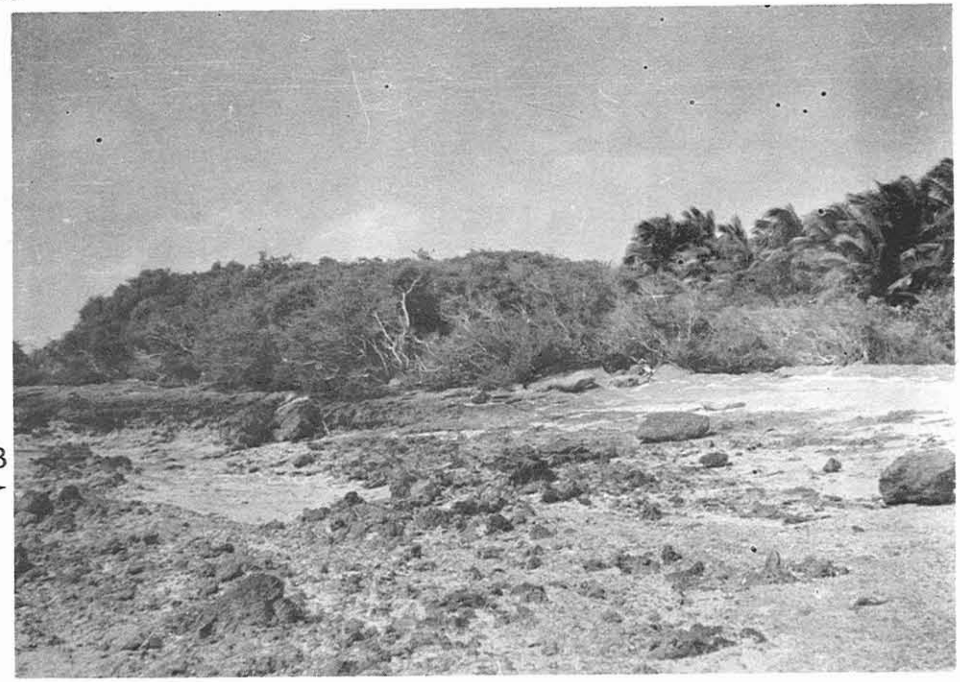
D

Plate 25

Plate 26

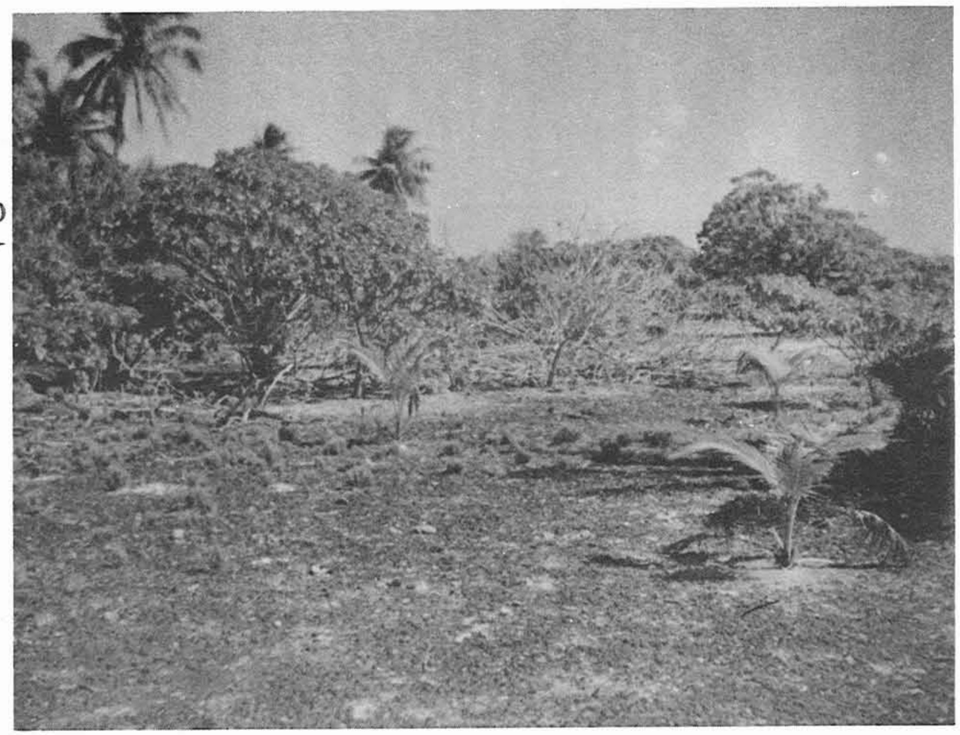
A

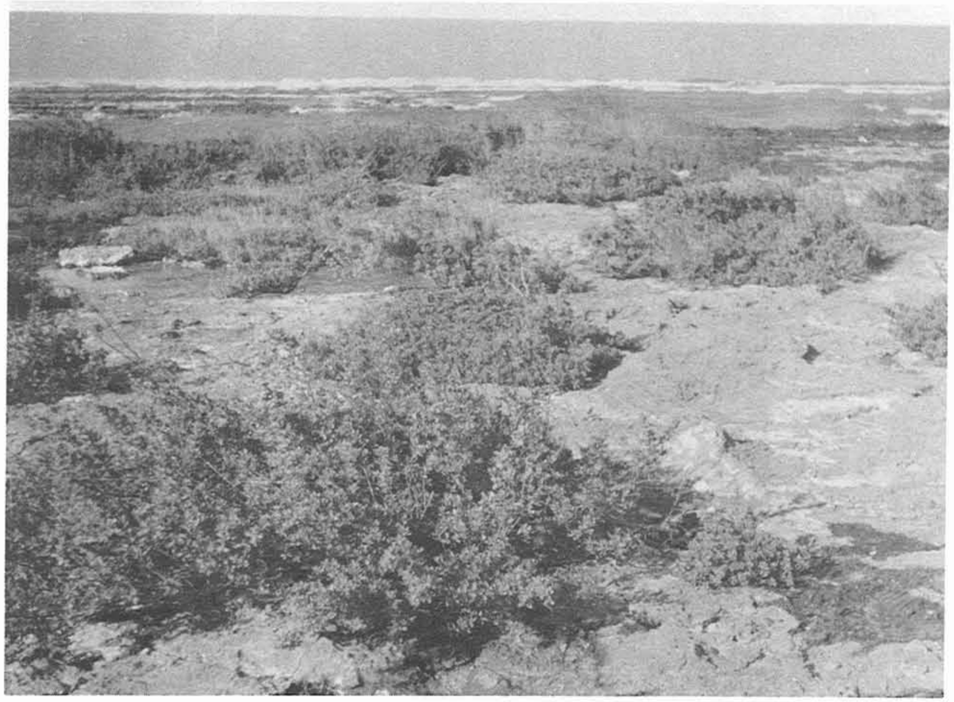
B



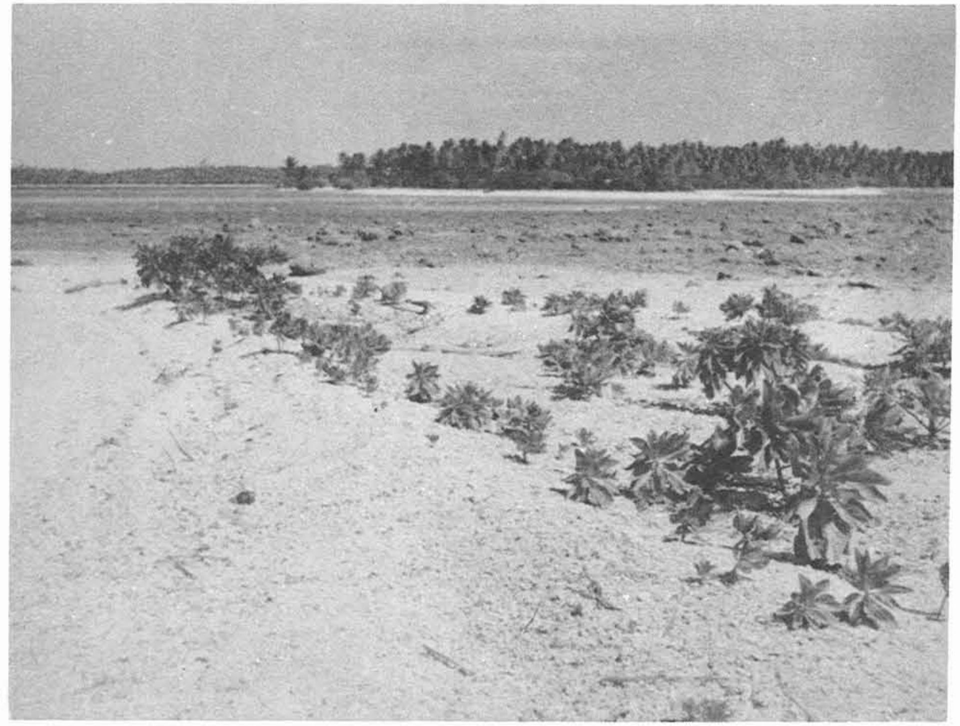
C

D





A



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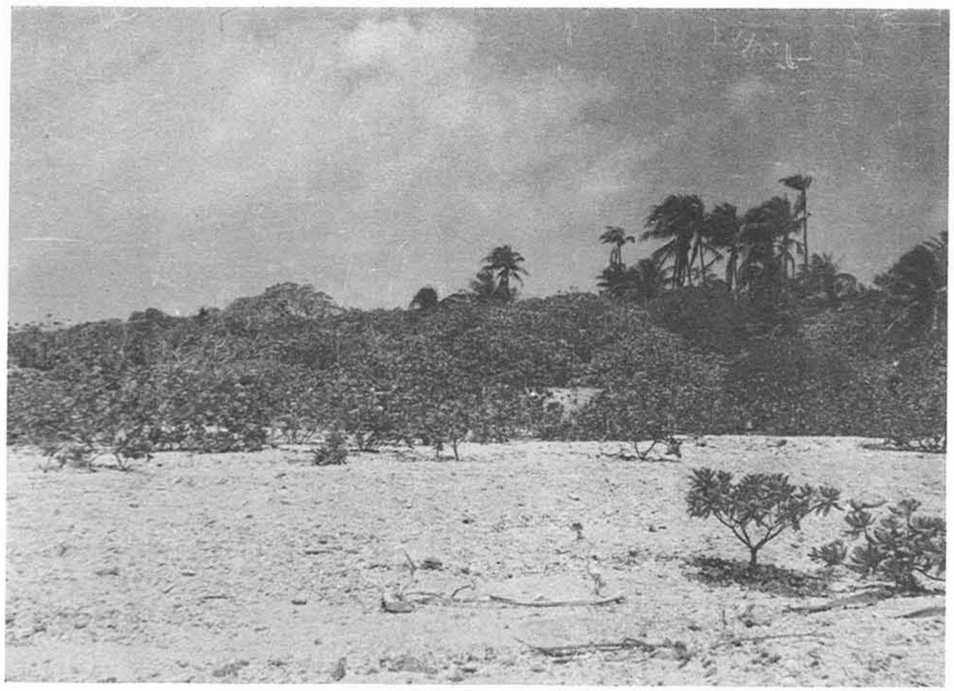
C



D

PART III: LABORATORY EXAMINATION OF UNCONSOLIDATED SEDIMENTS

by Dorothy Carroll

Unconsolidated calcareous material occurs on the beaches surrounding the islets on the atolls, and in the interiors of the islets as soils. Beach sands have been described from Bikini by Emery, Tracey, and Ladd (1954), Onotoa by Cloud (1952), Raroia by Byrne (in Newell, 1954b, 1956), Kapingamarangi by McKee (1958, 1959), and from various other Pacific Islands by Wentworth and Ladd (1931). The soils on Arno Atoll have been described by Stone (1951a,b), and on Bikini by Stone (in Emery and others, 1954). Fosberg (1954) gave a general description of the soils of the northern Marshall Islands and recognized a new soil type, the Jemo soil.

The materials present as beach sands together with larger fragments, solid reef materials, and organic matter, provide the parent material for the soils. The sands described here are representative of the finer rather than the coarser materials of the beaches.

The atolls from which beach sands were collected and described, and the number of samples from each atoll are: Ailuk 1, Bikar 15, Kwajalein 8, Lae 2, Likiep 2, Taka 4, Taongi (Pokak) 31, Ujae 2, Ujelang 8, Utirik 5, and Wotho 7, a total of 85 samples. The localities are listed in Appendix I and indicated on figures 5-15. A description of 28 of these samples is given in Appendix I.

The atolls from which soils were collected and described, and the number of samples from each atoll are: Ailuk 11, Bikar 26, Jemo 18, Kwajelein 5, Lae 12, Likiep 6, Taka 29, Taongi (Pokak) 15, Ujae 16, Ujelang 3, Utirik 22, and Wotho 23, a total of 186. When the samples were collected, a number of pits was dug through the soils so that material from different depths could be collected. Each vertical sequence of samples is referred to as a soil profile. The positions on the islets from which soil profiles were collected (except the Kwajalein profiles) are shown on figures 16, 17, and 18. Field descriptions of the analyzed soils are given in Appendix II. Unanalyzed soils are indicated by appropriate symbols on the maps in order to give a more adequate idea of the distribution of the several soils series within the islets.

Size distribution

To obtain the size distribution of the materials in the sands and soils, all the samples were sieved dry through a set of U.S. Standard Sieves to give grades as originally described by Wentworth (1922). The sizes and sieves are:

Size, mm	Descriptive term	Sieve No.*
above 16	Pebble	
16 - 8	Pebble	
8 - 4	Pebble	
4 - 2	Granule	5
2 - 1	Very coarse sand	9
1 - 0.5	Coarse sand	18
0.5 - 0.25	Medium sand	35
0.25 - 0.12	Fine sand	60
0.12 - 0.06	Very fine sand	120
less than 0.06	Silt	230

----
*Sieve through which sample passed; it was retained on the next finer sieve in the series.

In some samples the coarser material, generally coral fragments, was removed with a one-half inch (12.7 mm) or a one-quarter inch (6.35 mm) sieve before the finer grades were sieved.

The samples collected by F. Stearns MacNeil were sieved by him through sieves 3, 4, 9, 14 and 35, corresponding to openings of 6.35, 4.76, 2.0, 1.9, and 0.42 mm, respectively. These sieves do not correspond to those used for most of the samples, but are sufficiently close not to cause significant differences in the size distribution of the sands. MacNeil's material passing the 35 mesh sieve was not originally sieved into finer fractions, but as a number of these samples contained more than 50 percent by weight of smaller than 35 mesh grains, these were resieved to conform to the remainder of the samples.

Biotic composition

The beach sands and soils consist of reef organisms and those that lived in the lagoons. The original shape, size, and buoyancy of these organisms determine to some extent the size distribution, sorting, and general appearance of these materials. The admixture of organic matter with calcareous sands forms the soils of the atolls.

All the reef organisms, as described by Wells, Todd, and Doty (on pages 25-30) have characteristic sizes, shapes, and habits. Corals and algae of the reefs are massive. Large fragments are broken off by waves and carried to the shores of the islets. Halimeda in the lagoons breaks into fragments about one-half to one cm in length. The commonly occurring Foraminifera, Calcarina, Marginopora, and Amphistegina, range from about one-half to 2 mm in size, although some are smaller and a few larger. The detached spines of Calcarina spp. are generally unbroken in the finest fractions of the sand. Sea urchin spines are broken into all sizes from large to small fragments.

Each grade size of each sample of beach sand and of soil was examined under a binocular microscope to identify the kinds of organisms present. Estimates were made of the percentages of major constituents in each sample. The results were plotted as histograms combining the grain size and biotic composition.

The composition of the various grade sizes was found to be:

Size, mm	Faunal composition
Larger than 16, and 16 - 8	Large whole or broken corals; large fragments of algae; large shells
8 - 4	Coral, algae fragments, shells
4 - 2	Coral, algae fragments, shells
2 - 1	Foraminifera, broken coral, algae
1 - 0.5	Foraminifera, broken coral, algae
0.5 - .25	Few small Foraminifera, mostly broken pieces
0.25 - .12	Broken, unidentifiable fragments
0.12 - .06	Broken, unidentifiable fragments
Smaller than 0.06	Broken, unidentifiable fragments

The appearance of these materials is shown in Plates 28-30.

Mineralogic composition

by John C. Hathaway

The various size fractions of 19 samples from 6 soil profiles were examined by X-ray powder diffraction methods to determine their mineralogic composition, and to reveal any variations occurring amongst the different size grades as well as within the soil profiles.

A sample of each fraction was ground to pass a 230-mesh (0.06 mm) sieve and was packed into an aluminum sample holder. Care was taken to minimize the preferred orientation of the particles. An X-ray diffractogram was then made of each sample, and the amount of calcite and aragonite present determined by comparison of the intensity of the most strongly diffracted lines of the minerals. The interplanar spacing represented by the strongest calcite line, _d_ (104), was also measured for each sample. The results of the X-ray examinations are shown in figure 19, where the approximate amounts of calcite and aragonite in each size fraction are shown on histograms of the particle size distribution for the individual samples. There was found to be a variation in _d_ spacing of the strongest reflection of calcite (104) in the material of the size fractions. Inasmuch as the organic materials varied in chemical composition, some samples gave two strong _d_ (104) reflections for calcite.

The significance of the variation of the interplanar spacings in calcite is discussed by Chave (1952, 1954a, 1954b) and by Goldsmith, Graf, and Joensuu (1955). They have shown that decreases in the _d_ (104) spacing from those of pure calcite are the result of the smaller unit cell that occurs when magnesium substitutes for calcium in the calcite structure, and that the amount of magnesium can be correlated with the amount of shift in spacing position. Goldsmith, Graf, and Joensuu (1955) show this shift to amount to about 0.0029 Å per mol percent $MgCO_3$. Magnesium substitution has not been observed in aragonite.

In these Marshall Islands samples d (104) was measured to the nearest 0.01 Å, which represents increments of about 3.5 mol percent $MgCO_3$. The total variation in spacing found was 0.06 Å (2.98 to 3.04 Å), representing about 20 mol percent $MgCO_3$. Magnesium substitution increases upwards in the graphs (fig. 19). Conversion of mol percent to weight percent is made by using the following formula:

$$\text{Weight \% } MgCO_3 = \frac{84.33 \text{ X mol \% } MgCO_3}{84.33 \text{ X mol \% } MgCO_3 + 100.09\ (100\text{-mol \% } MgCO_3)}$$

Figure 20 shows the average particle size distribution for all the samples with the average amount of calcite and aragonite in each size grade. The number of samples in which a given type of material was dominant was determined for each grade size, and the percentage figure for the occurrence of the type is shown over each histogram block. At the top of the graph the average calcite d (104) spacing is given.

Figure 21 shows the aragonite content of the different grades as a percentage of the total amount of material in each size fraction.

A correlation between aragonite content and type of material is distinctly present in figure 19. Aragonite content is high in the coarse fraction where coral is the dominant constituent, and decreases considerably where algae and Foraminifera make up a large proportion of the smaller grade sizes. The rise in aragonite content in the 0.5-0.06 mm range reflects the presence of coral fragments mixed with fragments of Foraminifera and algae. The relative dearth of aragonite in the 2-0.5 mm grades as shown in figure 19 also suggests that the coral fragments are either less common or relatively unstable in this size. The low content of aragonite is possibly due to the relative instability of the mineral in fine particles. The wide range of composition shown by the extremes in the coarser fractions in figure 21 arises from the difficulty of sampling the large coral fragments representatively.

The calcite in these samples is high in magnesium as shown by the relatively low d (104) spacings. Calcite of more than one composition is present in 8 of the samples as revealed by double maxima in the region of the d (104) spacing. A distinct decrease in the amount of magnesium occurs in the less than 0.06 mm fraction of 16 of the samples. This is reflected in the upper curve of figure 20 showing the average d (104) spacings of the samples. A similar, although smaller, decrease occurs in the coarsest fraction. The calcite present may be the fine-grained material low in magnesium that occupies the many small cavities in the coarse coralline material. Algae in the coarse fractions tend to show high magnesium contents for most of the samples. Only in sample 62 (fig. 19) does a low-magnesium calcite occur where algae are important constituents, and there only as minor members of two types of calcite. An alternative possibility for the occurrence of low-magnesium calcite in the coarser fractions is the alteration of aragonitic materials to calcite. In this situation low-magnesium calcite should not be confined to the coarsest and finest fractions but should be found in the medium grades also, inasmuch as aragonite in the smaller fragments of coral might be expected to alter as readily as it does in the coarser fragments. However, "contamination" of fragments by fine-grained, magnesium-free calcite may be minor in the medium grades because the greater amount of working and washing that produced the fragments of these grades might tend to free the altered material. The liberated low-magnesium calcite would then appear in the finest fraction. If such alteration takes place it probably does so before deposition of the material in its present environment. Alteration in a soil profile would be expected to remove aragonite at the point of greatest weathering, presumably near the surface. In figure 22, all the profiles except 30 show increases of aragonite toward the surface, suggesting that alteration of aragonite to calcite is not important in the soil-forming processes in the soils studied. This, together with the erratic variations of mechanical composition at different depths in the profiles, suggests that depositional factors are more important in determining the calcite:aragonite ratio in these soils than is alteration of the materials in place. The depositional factor should be assessed in the light of the low rainfall that prevails in many of the areas from which soil samples were collected.

Analytical treatment of grain size distribution data

The data for grain-size distribution and biotic composition of all the beach sands were plotted as histograms, and the histogram for each sample is placed on the outline map of the atoll from which it was collected in figures 5-15. These histograms show the similarities and dissimilarities between samples collected from different positions on the same atoll and from the same geographic aspects on different atolls. Cumulative frequency curves were drawn for the data so that the median grain diameter, the sorting coefficient, and skewness could be calculated. Trask's (1932) sorting coefficient, $So=\sqrt{Q_3/Q_1}$, where Q_3 is the coarse quartile and Q_1 is the fine quartile of the distribution, and skewness, Q_3Q_1/Md^2 were used. The mean diameter for each sample of sand was calculated by a modification of a formula suggested by Folk and Ward (1957, p. 12), $M = \frac{\phi 16 + \phi 50 + \phi 84}{3}$. The modification consisted of using the grain diameter instead of the phi notation.

The skewness or asymmetry of the distribution curve of the grain-size distribution is also used to describe the samples. Skewness in sedimentary materials is not well understood, but it has been suggested by Krumbein and Tisdel (1940) that grain distributions with excess coarse grains (positive skewness) indicate disintegrating igneous rocks, whereas grain distributions with excess fine grains (negative skewness) indicate disintegrating sedimentary rocks. However, the size distribution in the Northern Marshall Islands beach sands is dependent on both the kinds of organisms present and on the sorting by waves and wind to which they have been subjected. The skewness figures for these sands are given to show the kind of distribution that occurs. The skewness is caused primarily by the presence of certain organisms; for example, a sand consisting almost entirely of one species of Foraminifera has perfect sorting and skewness. Skewness is, therefore, a measure of the organisms present as well as an indication of their slightly broken nature. The sands appear to have had their finest material washed out.

Size distribution of beach sands

The results of the mechanical analyses of the beach sand samples together with the median grain size, sorting coefficient, and skewness are given in Table 4.

The size distribution of the beach sands collected on the seaward and on the lagoon beaches of the various islets is similar to that found by Emery and others (1954, p. 38) on Bikini Atoll. The beaches are similar from islet to islet even though the individual samples collected on any beach may vary. In the size distribution of beach sands the frequency of the modes (or maximum grades) as shown in figure 23 is as follows:

Grain size, mm	Percent of total
2 - 1	21
1 - 0.5	48
0.5 - 0.25	17

In no sample of these beach sands is there a primary mode in the fractions finer than 60 mesh (0.25 mm). Secondary modes, indicating an admixture of different materials have a wider spread and include a few maxima in the 0.25-0.125 mm and the 0.125-0.06 mm grades. It has been observed that well-worn material does not seem to become much finer than 60 mesh (0.25 mm), indicating a lower limit for abrasive action to take place. Finer material has probably been winnowed out by waves and currents.

Size distribution of material in soils

The results of the mechanical analyses of the soil samples together with the median grain diameter, sorting coefficient, organic carbon, and pH of the soils, are given in table 5.

Physically the atoll soils resemble the beach materials. Mechanical analyses show that comparisons between the two can readily be made on this basis. It has been noted by Stone (1951a, p. 14) that many soil profiles are composite and consist of alternate layers of calcareous material and organic matter. The calcareous materials in which soils are developed are somewhat more heterogenous in size than the beach materials that were selectively collected as sands. The loose sediments piled above high-tide level on atoll islets range in size from the finest silt-size particles to enormous boulders of many tons in weight. Such material is similar to that in the beach sands but it also contains massive limestone composed of cemented skeletons of calcareous organisms. The soil materials are mixed in varying proportions with no very regular pattern in their distribution. The texture range is extremely wide, and the range in sorting is far wider than that described for the beach materials. The materials are irregularly stratified, the strata mostly representing stages or events in deposition. There seems to be little regularity about the vertical or areal arrangement of the different sizes and mixtures of these sediments, although in general the lagoon sides of the islets are more likely to be sandy in texture, whereas the soils from the seaward sides are more often of coarser material. The samples of soils collected represent the finer rather than the coarser parent materials.

One hundred and ten mechanical analyses were made of soil materials. Forty percent of the soils have the mode (or maximum grade) in the 1.0-0.5 mm grade, and 34 percent in the plus 8 mm grade; that is, such soils consist of large fragments of coral that have not been broken up either by abrasion or by solution. It is noteworthy that there is very little fine material, where present it consists of a mixture of fine organic matter and fine calcareous grains similar to those in the beach sands. Other soils consist of organic matter plus very coarse gravel; in some of these soils the organic matter is the most important constituent.

The size distribution of the soil material is given in table 5, where the grade sizes are the same as those used for the beach sands, so direct comparisons between the soils and beach sands can be made. In figures 24 to 28 the data are plotted as histograms, the samples being arranged in vertical sequence as they occurred in the field.

Sorting

The coefficient of sorting (So) (Trask, 1932) ranges from 1.0 to 2.76, with the majority of the samples, whether from seaward beaches or lagoon beaches, falling around 1.50. The sands are therefore considered well sorted by Trask's original definition. However, many naturally occurring disintegration products that have not been transported or winnowed by waves and wind have a sorting coefficient not much greater.

Sorting in these beach sands is due to two principal factors: (1), presence of calcareous organisms; and (2), movement of material on the beaches by waves, currents, wind, or any combination of these agents. The first factor brings in the size distribution in the sands, and it does not seem possible, until additional observations have been made on beach processes, to isolate either of these two factors. The histograms in figures 5 to 15, in which the major organic constituents are shown, indicate how the size distribution is in part dependent on the material that has been furnished by reef and lagoon organisms to the sands. Similarly, sands having the best sorting may consist entirely of one organism, as in the foraminiferal sands, or of completely comminuted fragments that have actually been sorted by waves and wind. Table 6 was prepared to assess the significance of the coefficients of sorting found in the sands.

In table 6 the constituents are listed as major constituents if any one makes up 50 percent or more of the sand. The "mixed assemblage" category indicates that the sand has two or more constituents neither of which is dominant. The column headed "none dominant" indicates that the sand consists of varying proportions of all the constituents. The columns headed "sorting caused by" are used to assess the principal factor in the sorting coefficient obtained from the sieve analyses.

Various categories may be recognized, as follows: If one kind of organism is dominant in a sand (Category A) then the sorting is considered to be due to the presence of that organism, although its presence may be due to selective transportation from its place of origin and to removal of other constituents originally present by winnowing; Category B contains sands in which there are two or more constituents of considerable importance, neither of which is dominant in weight percent of the sand; Category C (A plus B) contains sands in which a number of constituents may or may not be recognizable because of abrasion by reworking on a beach. In table 6 there are 21 sands in Category A, 16 in Category B, and 35 in Category C. The average sorting coefficient is:

Category A, 1.46 (range 1.10-2.60, median, 1.33)
Category B, 1.62 (range 1.10-2.02, median, 1.70)
Category C, 1.65 (range 1.00-2.65, median, 1.64)

The median figures for the sorting coefficient, 1.33, 1.70, and 1.64, respectively for the different categories indicate that the sands containing the highest percentage of one kind of organism have, on the whole, a more perfect sorting than those containing a variety of organisms, or those that are made up of comminuted fragments. However, the fact that some sands do contain only one kind of organism is a result of proximity to source of supply and of transportation conditions.

Skewness of the size distribution

In general the sands are skewed positively, that is, the asymmetry of the distribution curve (Sk) is caused by the admixture of coarse material. Seventeen (23 percent) of the sands have symmetrical distribution curves (Sk, 0), and there is only one sand that has a negative skewness (T30, table 6). One third of the sands that contain recognizable organisms as a major constituent have symmetrical distribution curves, whereas less than a quarter of the "mixed" sands (Category C) have symmetrical curves. As these sands all contain recognizable calcareous organisms, the skewness is considered to be caused primarily by them.

The skewness of the frequency curve for sands is reduced by the presence of one particular kind of organism; for example, Foraminifera that have a small range in size. _Calcarina spengleri_ has a diameter of between 1 and 2 mm, so a sand composed entirely of this Foraminifer will have Sk, 0 and So, 1.0. The presence of a concentration of any one type of organism that can take the place of individual mineral grains in making up a sand will have a similar effect.

Sufficient details concerning the localities where the samples were collected are not available, but a few suggestions can be made. Positive skewness occurs in more than three-quarters of the sands examined, irrespective of their situation on the seaward or lagoon side of the islands. Sample T30, from the southern seaward beach of Bwokwla islet, Taongi (Pokak) Atoll, is the only one that has negative skewness, indicating an admixture of fine material. T30 is a well sorted sand with So, 1.45; it has 80 percent of the grains between 1.0 and 0.5 mm in diameter, and these grains consist of comminuted fragments. The fact that most of the beaches examined do not contain extremely fine sand shows that such material, if it was formed from broken coral, algae, mollusks, and Foraminifera, has been transported out to sea.

The beach sands were grouped into those collected on the windward sides of the islets, and those from the lee sides. It was found that median, sorting coefficient, and skewness of the windward and lee beach material was:

	Median	Sorting coefficient	Skewness
Windward shore	1.27	1.66	+ 1.43
Leeward shore	.86	1.54	+ 1.07

Wear and rounding of grains

The beach materials are homogenous in composition but not in shape or in specific gravity. Mineralogically the organisms consist of calcite or aragonite. The hardness of calcite is 3; that of aragonite, 3.5-4. The specific gravity of calcite is 2.71; that of aragonite, 2.94. Most organisms have internal cavities and some, such as Foraminifera and Halimeda, have porous walls. This porosity reduces the specific gravity. Emery and others (1954, p. 65) give the following specific gravities for beach material on Bikini: coral, 2.51-2.62; Calcarina sp., 2.11-2.46; Marginopora sp., 2.10-2.31, Halimeda sp., debris, 2.47. The beach sand has a specific gravity of 2.57. In sea water the specific gravity of the constituents was lower, an average figure for Halimeda debris being 1.77, and for the sand, 1.79. The comminuted fragments have a higher specific gravity than the whole organisms because of removal of pore space. Coral fragments have the lowest porosity of the contributing material to beaches, and hence have the highest specific gravity.

The coarser fractions of the beach materials are generally rounded (pl. 28), but it is difficult to assess the amount of abrasion that has occurred because of the heterogenous original shapes. The constituents are described as rounded if original protuberances have been removed by abrasion, and if the grains have smooth, worn surfaces.

The original calcareous skeletons give the initial shape to the material in the same way that the presence of certain organisms influences sorting and skewness. The shapes are modified by abrasion, partly by grinding of one fragment on another, and partly by splitting and breaking. Pebbles and cobbles of rocks such as limestone, sandstone, and shale, when they become rounded by abrasion, always retain some features of their original shape, which in turn are conducive to the final shape (Raleigh, 1942). Some forms, the corals and algae, are massive, whereas others, the shells and Foraminifera, are hollow and will tend to be less abraded than the heavier, massive forms, when subjected to the same amount of wear. However, the massive forms are more susceptible to breakage, although shells and Foraminifera are abraded on a beach.

Five stages in the abrasion and rounding of the principal Foraminifer, Calcarina spengleri, in the sands of the Northern Marshall Islands, have been established as a result of observation. The forms are illustrated in Plate 31. The Calcarinas shown on Plate 31 E and F indicate that the sand in which they occur has been subjected to long-continued abrasion on a beach.

Stages in abrasion resulting in rounding are not as easily defined for the corals and algae, although in general the fragments considered to be well worn, particularly coral fragments, can be recognized by their lack of protuberances. These protuberances are commonly more massive than those of Calcarina sp., just as the corals themselves are originally broken into larger fragments than the Calcarina, which are concentrated in the 2-1 and 1-0.5 mm grades as shown in figures 5-15. The larger size of the coral and algae has two effects as far as abrasion is concerned: (1), such fragments cannot be transported as far as lighter fragments with the same current and wave activity; and (2), when washed up and down on a beach by waves they will, because of their weight and massive nature, be rubbed together more. In other words, once they reach a beach and remain in a wave zone their abrasion must be relatively rapid. Algae may differ from corals in abrasion effects, because some of the algae are originally smooth and rounded in appearance (except Halimeda sp., which is bladelike and hollow). Some calcareous algae are softer than coral. Hence, well-rounded algae may have undergone a lesser amount of abrasion than corals having irregularities of surface.

Shells both of pelecypods and gastropods are not a very prominent feature of these beach sands, but they too have been abraded and rounded, the pelecypods more than the gastropods, although the latter, being hollow and more buoyant, generally show more fracturing than rounding.

As both calcite and aragonite have good cleavage, one of the results of breaking up of the reef organisms may be the production of angular fragments. Halimeda sp., which consists of aragonite, breaks up into innumerable small laths of aragonite. Corals formed of aragonite may split into angular pieces, which can then be abraded by rolling.

Another feature exhibited by some of the beach sands is a high polish that has been attained, it is presumed, by long-sustained rolling abrasion in a wave zone. Such sands are generally well sorted and the elimination of very fine grains has allowed the larger fragments to rub one against another. Size is a factor in the production of this polish, as well sorted sands are more polished than those that contain both large and small grains. Plate 28 shows polish in some of the beach materials. Sample 115 (Fosberg) from Wotho is a very coarse sand that shows high polish.

Legends of plates

Plate 28. Beach sand, appearance of material in the 2-4 mm grade. Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by H. C. Starkey, U.S. Geological Survey.

Plate 29. Beach sand, appearance of material in the 1-2 mm grade. Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by Starkey, U.S. Geological Survey.

Plate 30. Beach sand, appearance of material in the 0.5-1 mm grade(A), 0.25-0.5 mm grade (B) and 0.12-0.25 mm grade (C). Sample 11, collected at mid-point of lagoon beach, Ninni islet, Kwajalein Atoll, by MacNeil. Photo by Starkey, U.S. Geological Survey.

Plate 31. <u>Calcarina</u> sp. showing various stages of abrasion in beach sands. Photo by Starkey, U.S. Geological Survey.

A. Spines intact, and the Foraminifer has not been abraded; this indicates little movement from site of origin. Specimen collected by J. I. Tracey, Jr., from reef flat at south end of Ifaluk islet, Ifaluk Atoll, Caroline Islands.

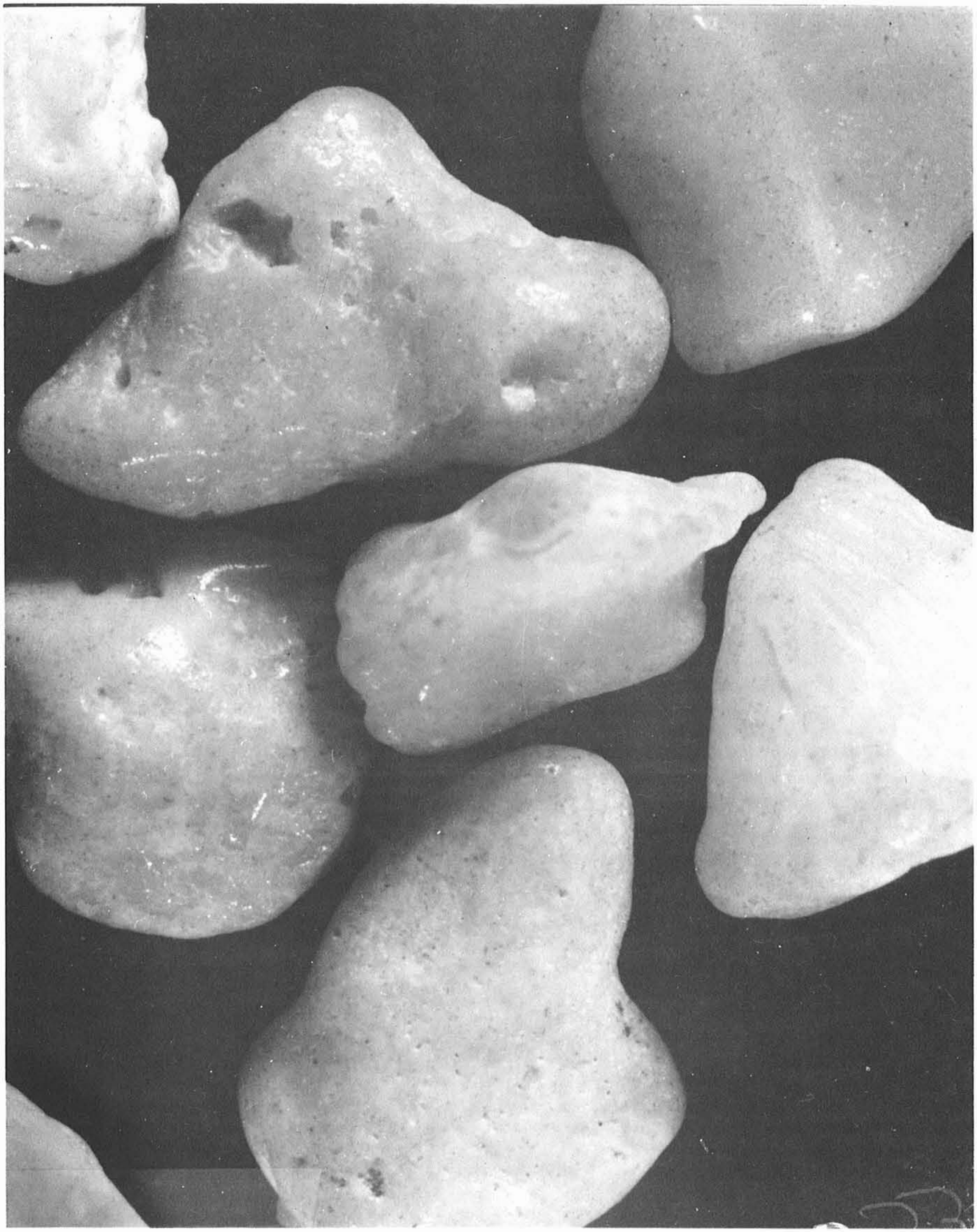
B. Many of the spines have been broken off. In beach sand from Taka Atoll (Tw 4), collected by MacNeil.

C. Nearly all the spines have been broken off, but a few still remain and are about one-half their original length. In beach sand from Taka Atoll (Tw 4) collected by MacNeil.

D. Only the stumps of the spines remain and there is some abrasion of the test of the Foraminifera. In beach sand from Taka Atoll (Tw 4) collected by MacNeil.

E. F. Only the test of the Foraminifer remains, and it is well polished; all the spines have been completely removed and the test has been reduced in size, but the chambers have not been exposed. In beach sand from Wotho Atoll collected by MacNeil.

Plate 28



1 mm.

Plate 29

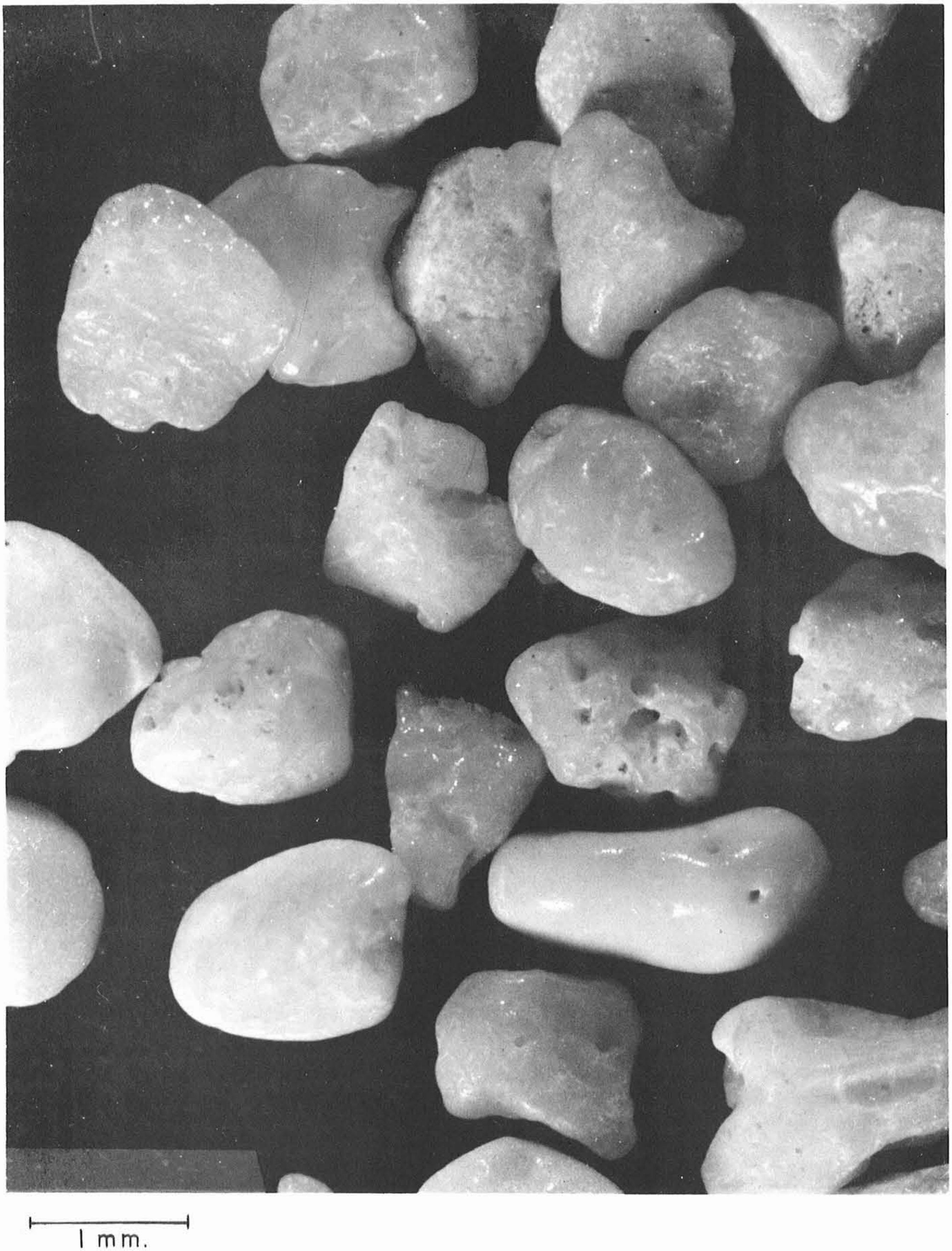
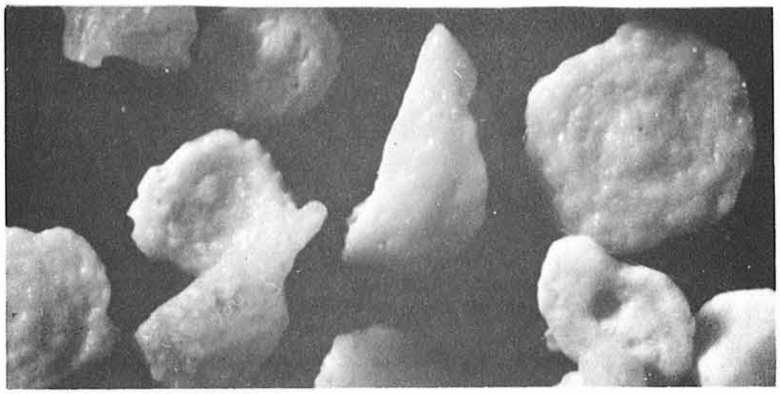
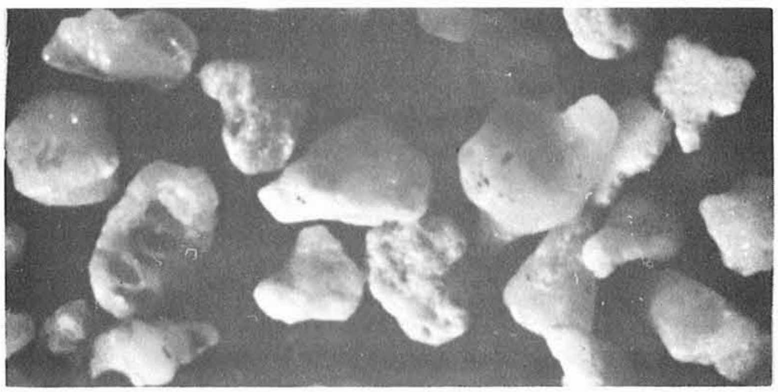


Plate 30

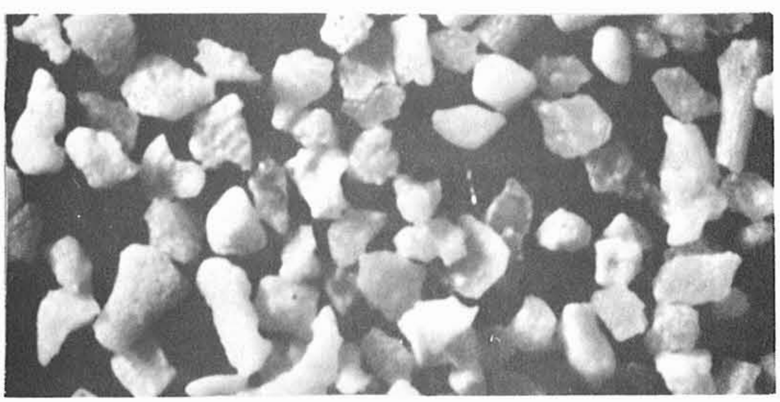
A



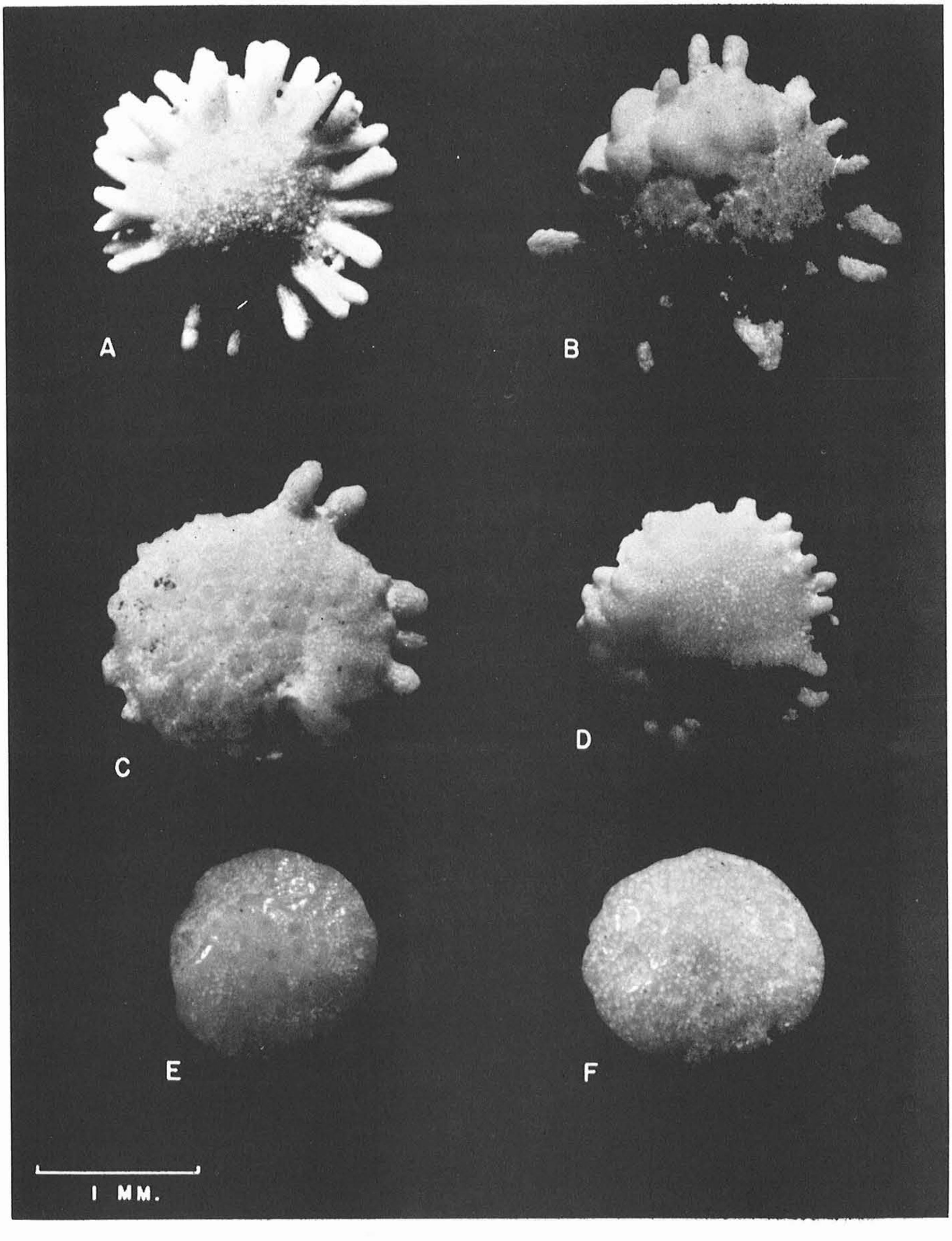
B



C



1 mm.


A
B
C
D
E
F
1 MM.

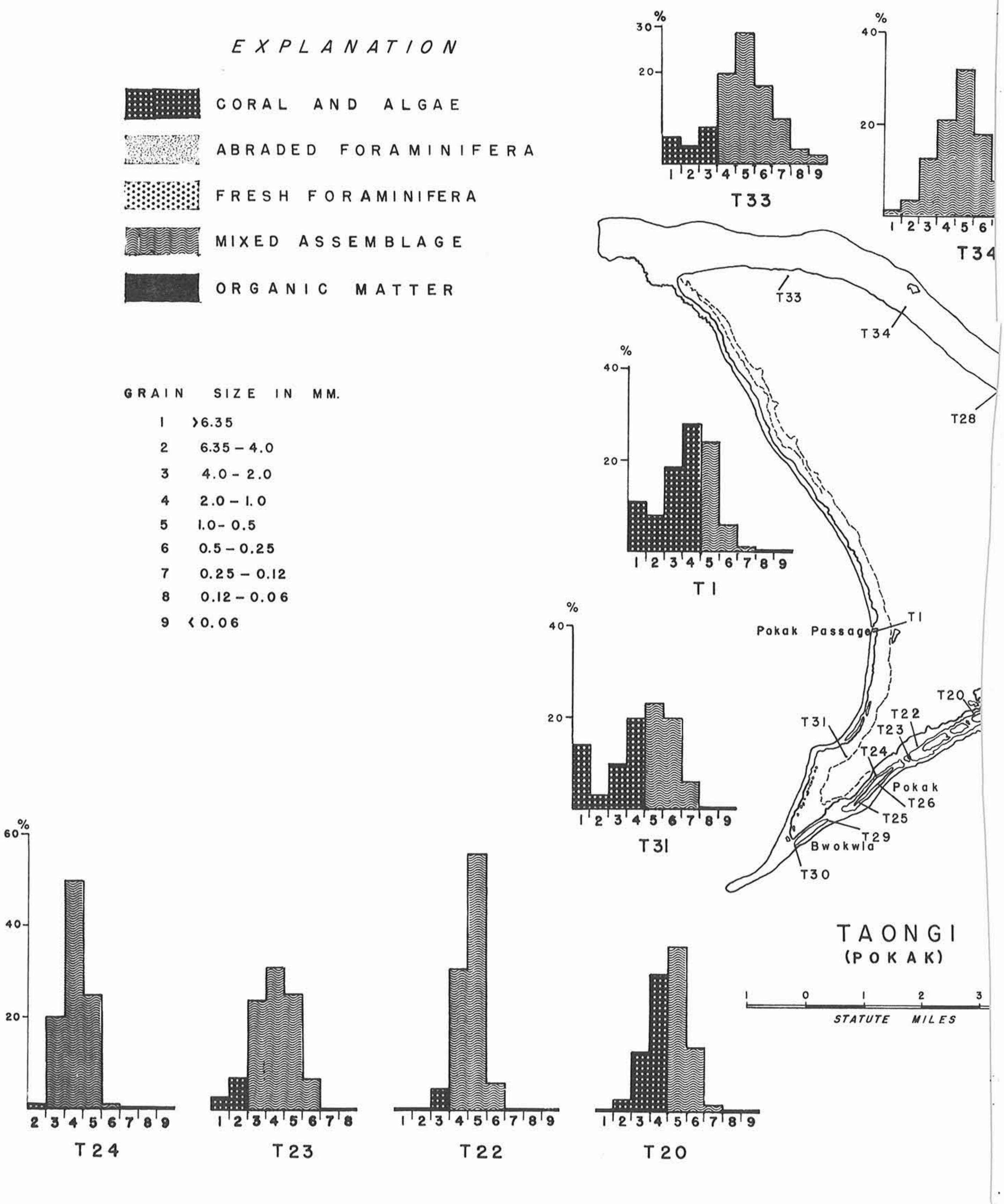

EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED ASSEMBLAGE
ORGANIC MATTER
GRAIN SIZE IN MM.
1 >6.35
2 6.35 – 4.0
3 4.0 - 2.0
4 2.0 – 1.0
5 1.0 - 0.5
6 0.5 – 0.25
7 0.25 – 0.12
8 0.12 – 0.06
9 <0.06
T33
T34
T1
T31
T24
T23
T22
T20
T28
T30
T29
T25
T26
Pokak Passage
Pokak
Bwokwla
TAONGI
(POKAK)
STATUTE MILES

FIGURE 5. TAO

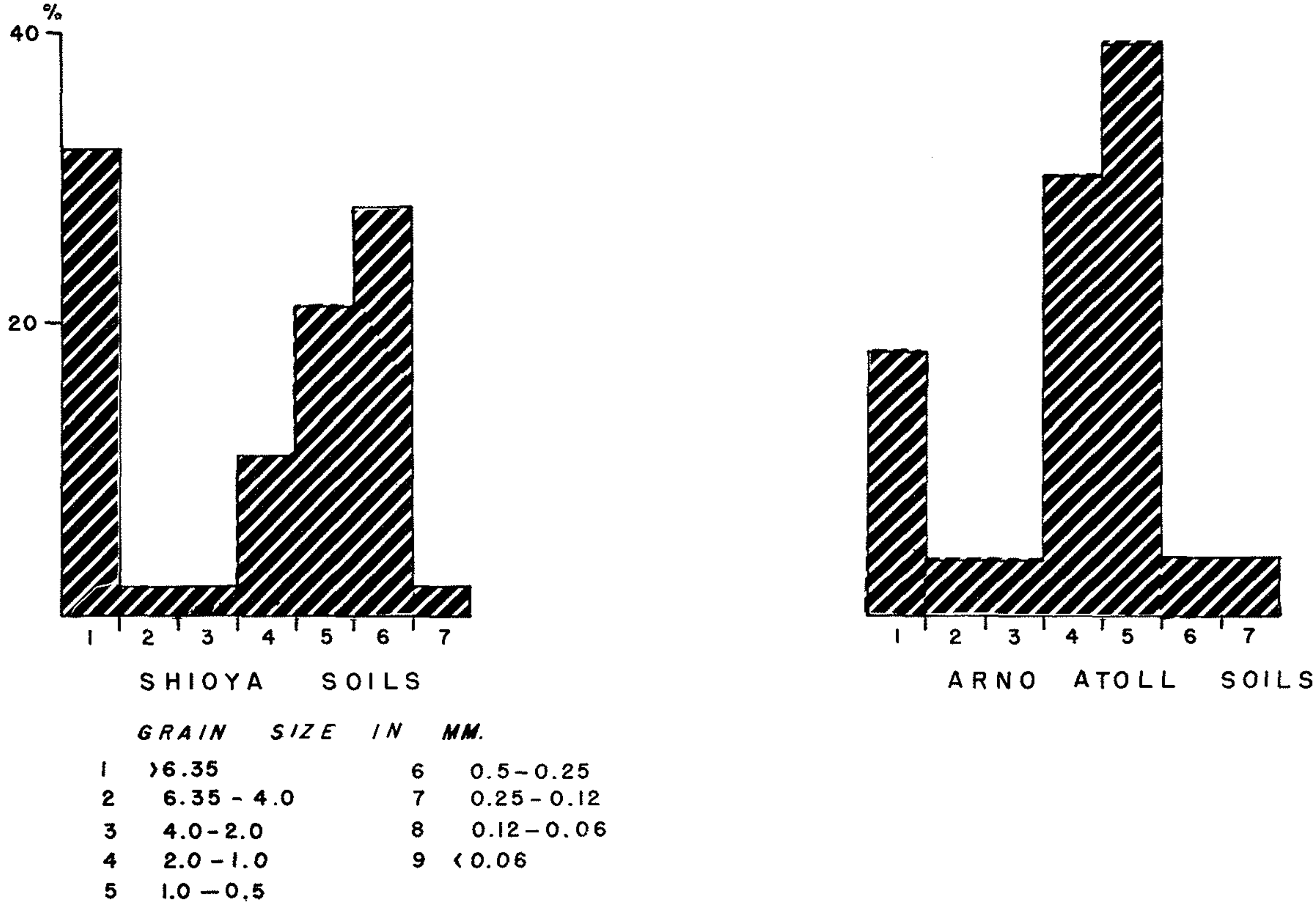


FIGURE 27. DISTRIBUTION OF THE MODES IN SHIOYA AND ARNO ATOLL SOILS

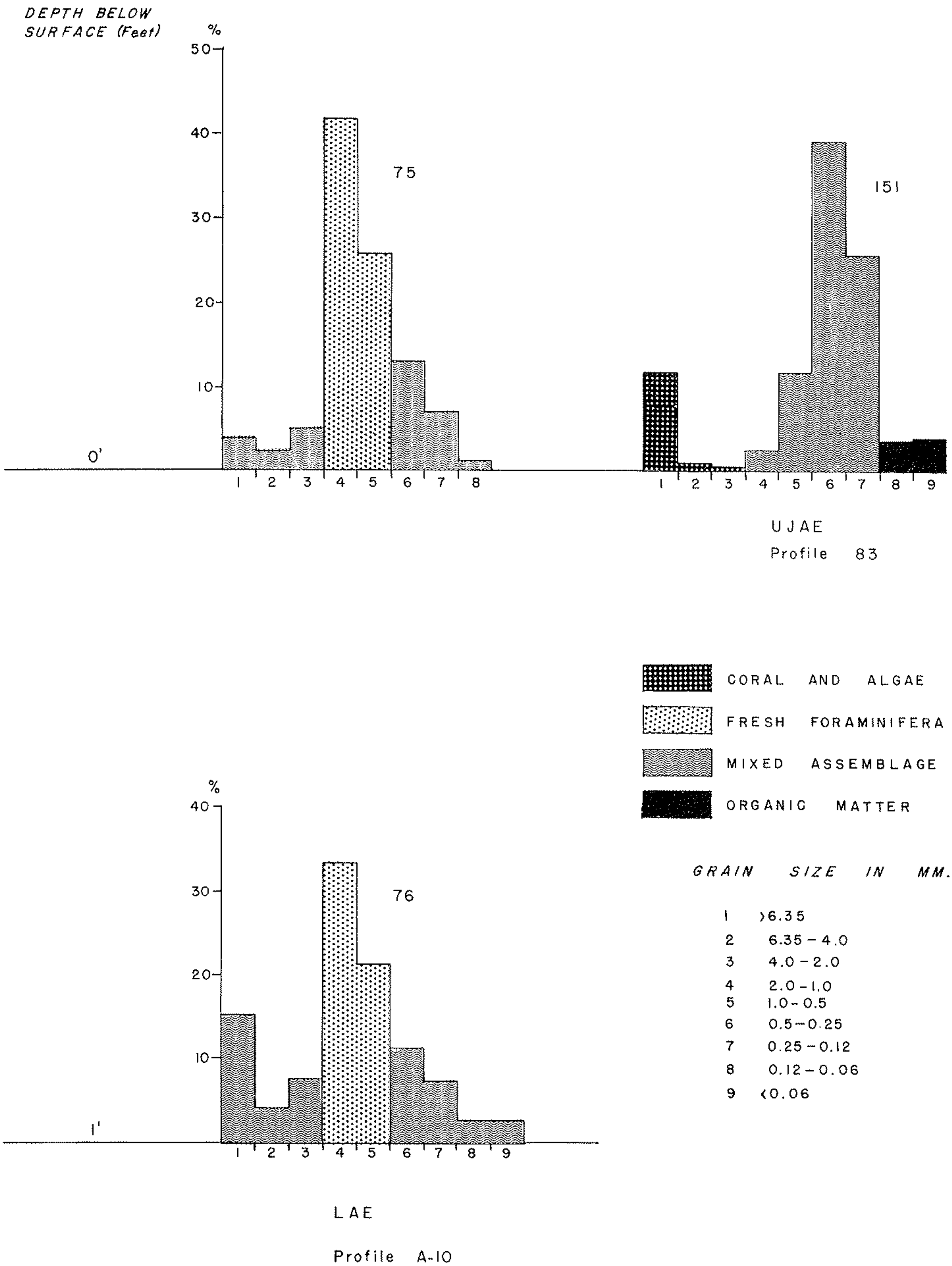


FIGURE 26. SIZE DISTRIBUTION AND COMPOSITION OF UNCLASSIFIED SOILS

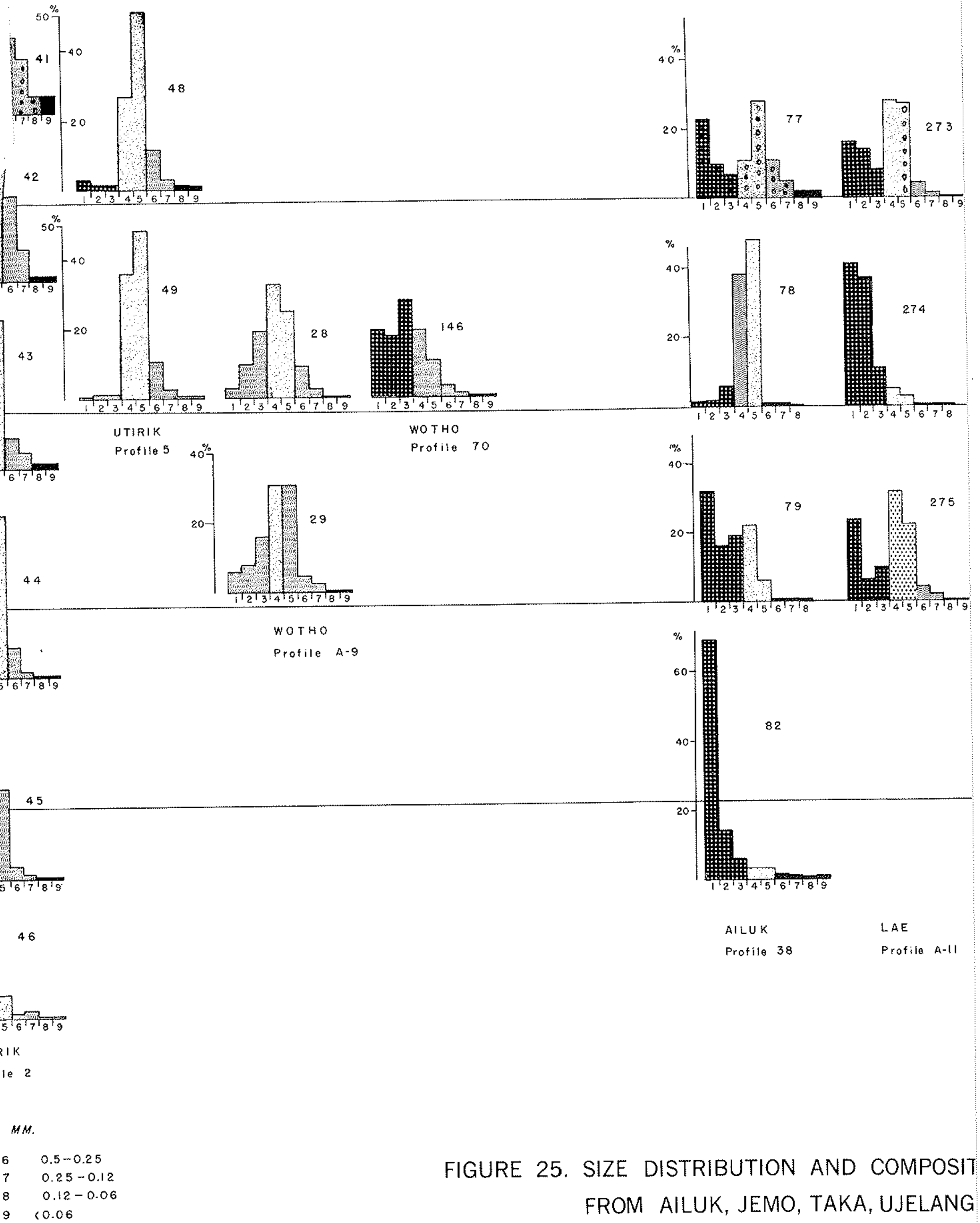
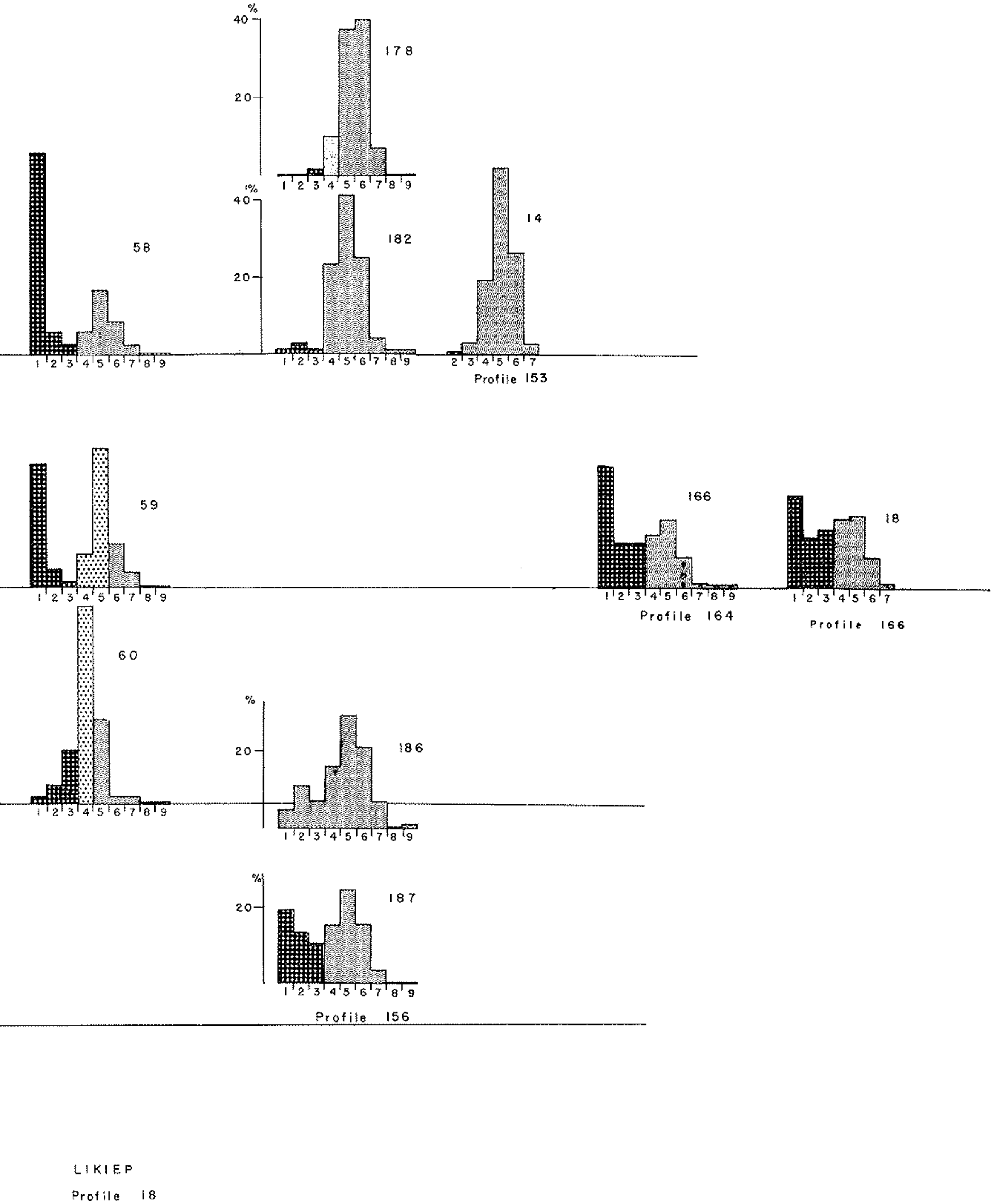
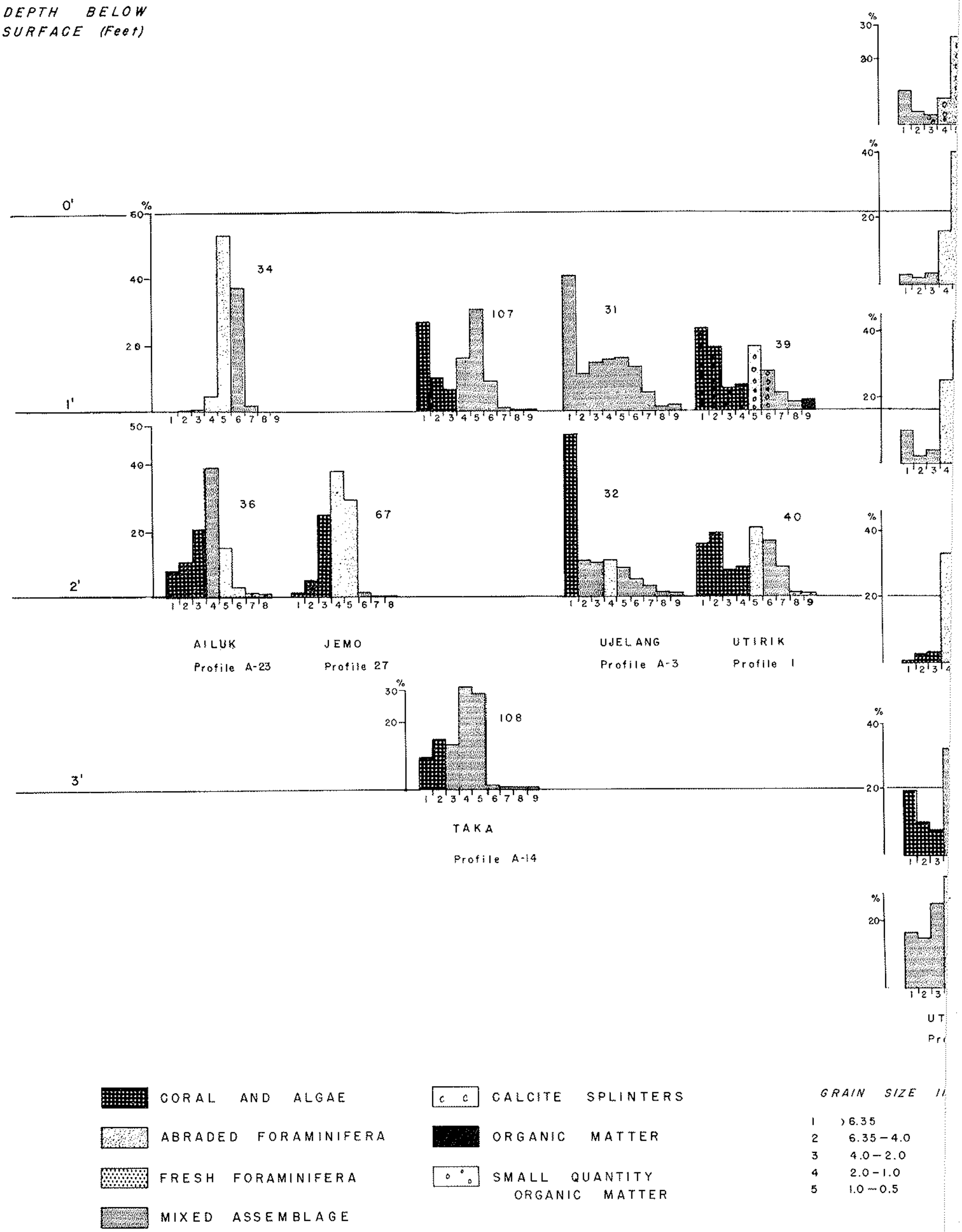
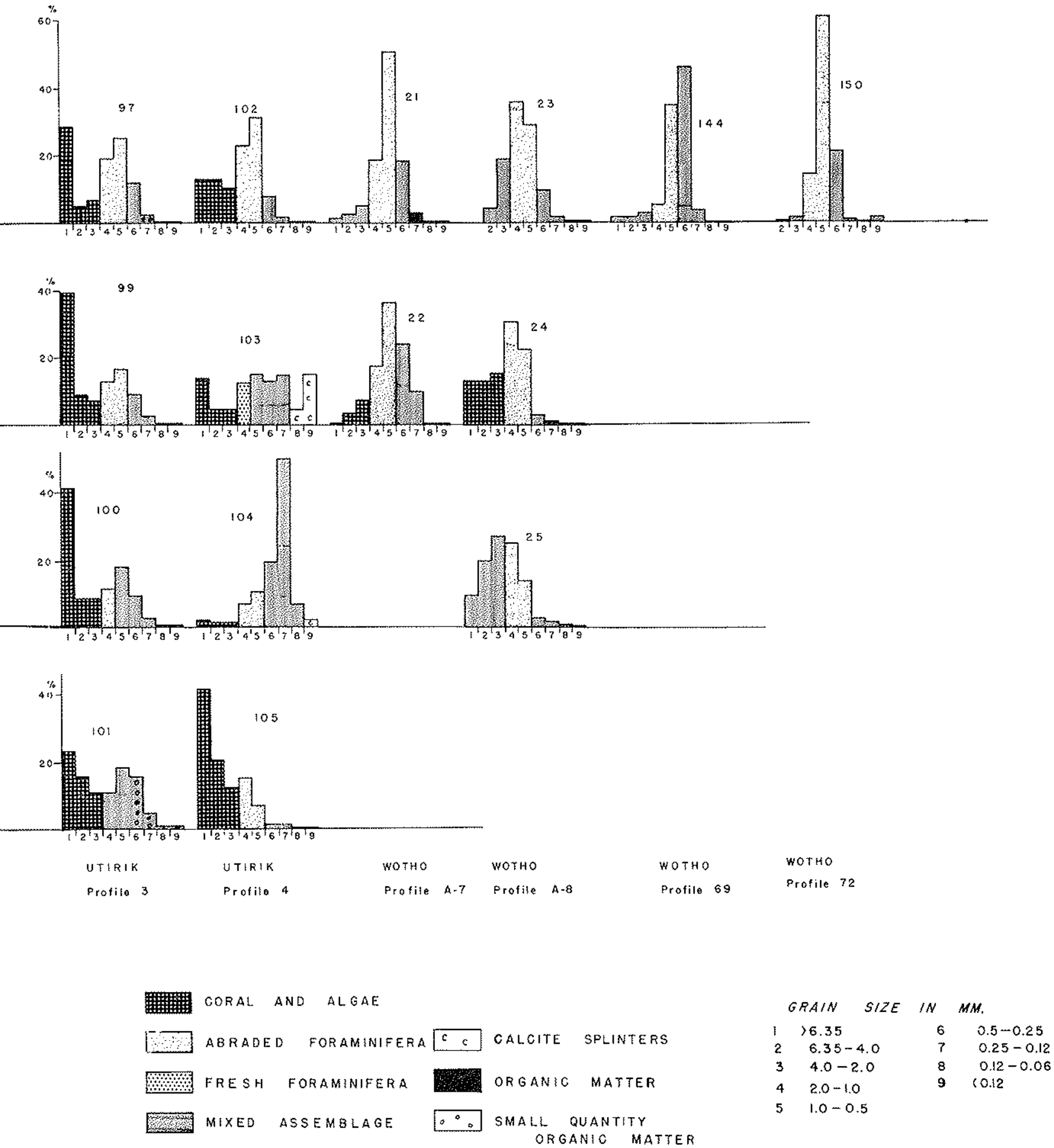


FIGURE 25. SIZE DISTRIBUTION AND COMPOSIT
FROM AILUK, JEMO, TAKA, UJELANG



TION OF THE ARNO ATOLL SERIES SOILS
, UTIRIK, AND WOTHO ATOLLS


DEPTH BELOW
SURFACE (Feet)
0'
1'
2'
3'
%
60
40
20
50
34
107
31
39
36
67
32
40
108
AILUK
Profile A-23
JEMO
Profile 27
UJELANG
Profile A-3
UTIRIK
Profile 1
TAKA
Profile A-14
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED ASSEMBLAGE
CALCITE SPLINTERS
ORGANIC MATTER
SMALL QUANTITY
ORGANIC MATTER
GRAIN SIZE
1 ›6.35
2 6.35 – 4.0
3 4.0 – 2.0
4 2.0 – 1.0
5 1.0 – 0.5



%
60
40
20
97
102
21
23
144
150
99
103
22
24
100
104
25
101
105
1 2 3 4 5 6 7 8 9
UTIRIK
Profile 3
UTIRIK
Profile 4
WOTHO
Profile A-7
WOTHO
Profile A-8
WOTHO
Profile 69
WOTHO
Profile 72
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED ASSEMBLAGE
CALCITE SPLINTERS
ORGANIC MATTER
SMALL QUANTITY ORGANIC MATTER
GRAIN SIZE IN MM.
1 >6.35
2 6.35 – 4.0
3 4.0 – 2.0
4 2.0 – 1.0
5 1.0 – 0.5
6 0.5 – 0.25
7 0.25 – 0.12
8 0.12 – 0.06
9 <0.12

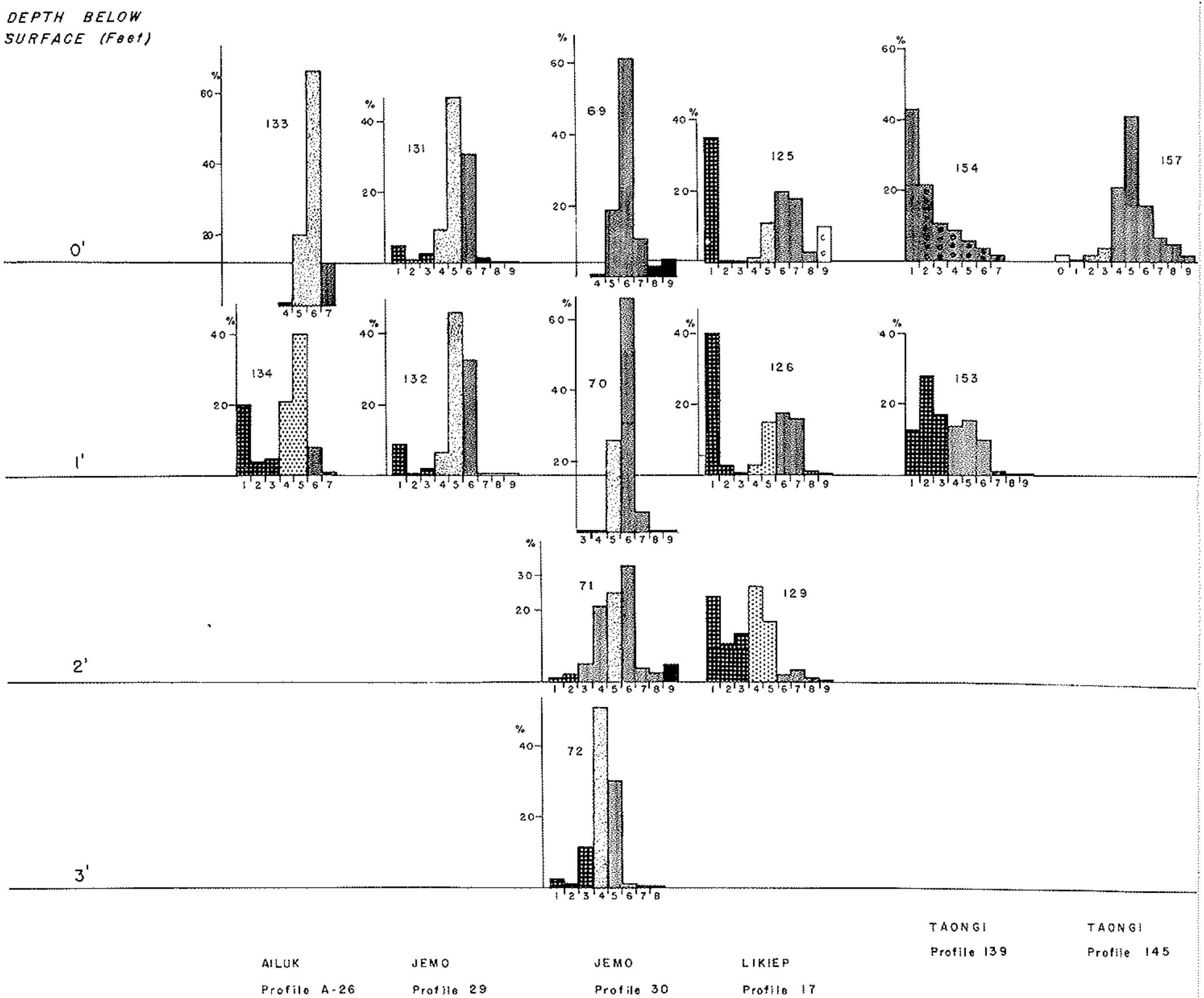
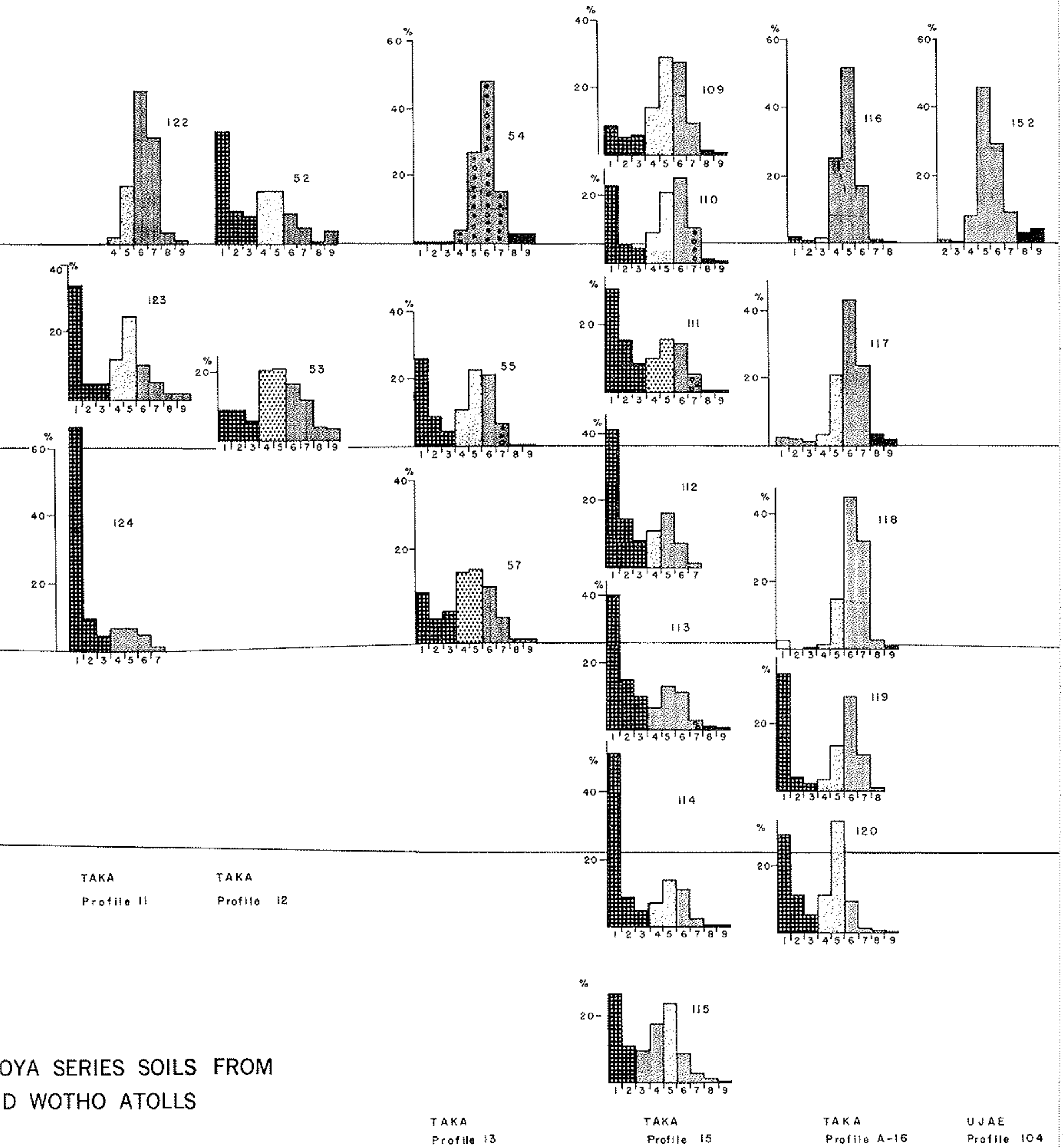
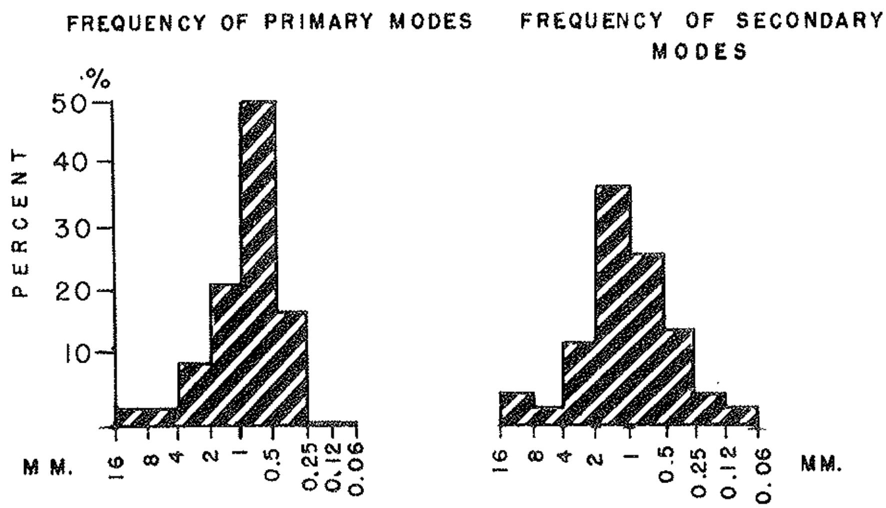


FIGURE 24. SIZE DISTRIBUTION AND COMPOSITION OF THE SHI
AILUK, JEMO, LIKIEP, TAONGI, TAKA, UJAE, UTIRIK, AN



OYA SERIES SOILS FROM
D WOTHO ATOLLS



	MEDIAN MM	SORTING COEFF.	SKEWNESS
SEAWARD BEACHES	1·27	1.66	1.43
LAGOON BEACHES	0.86	1.54	1.07

FIGURE 23. FREQUENCY OF PRIMARY AND SECONDARY MODES IN THE SIZE DISTRIBUTION OF ALL BEACH SANDS EXAMINED FROM THE NORTHERN MARSHALL ISLANDS

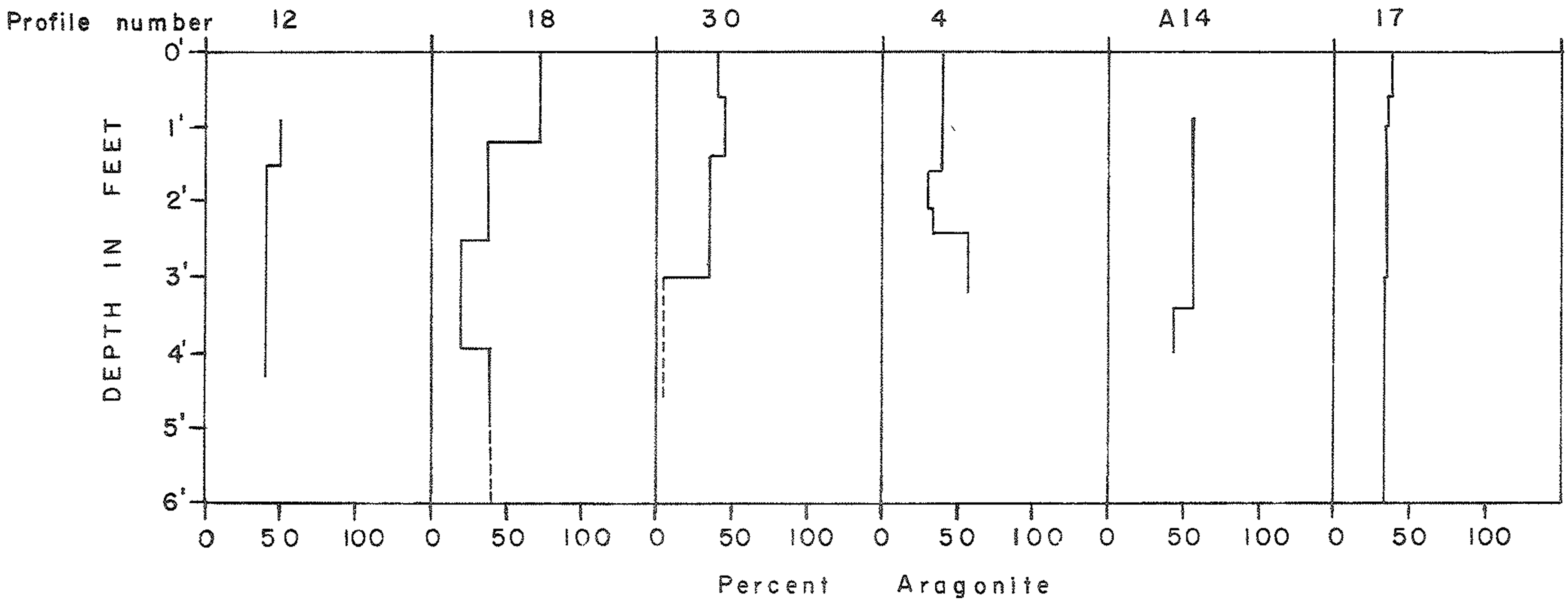


FIGURE 22. ARAGONITE CONTENT OF THE SOIL PROFILES SHOWN IN FIGURE 19

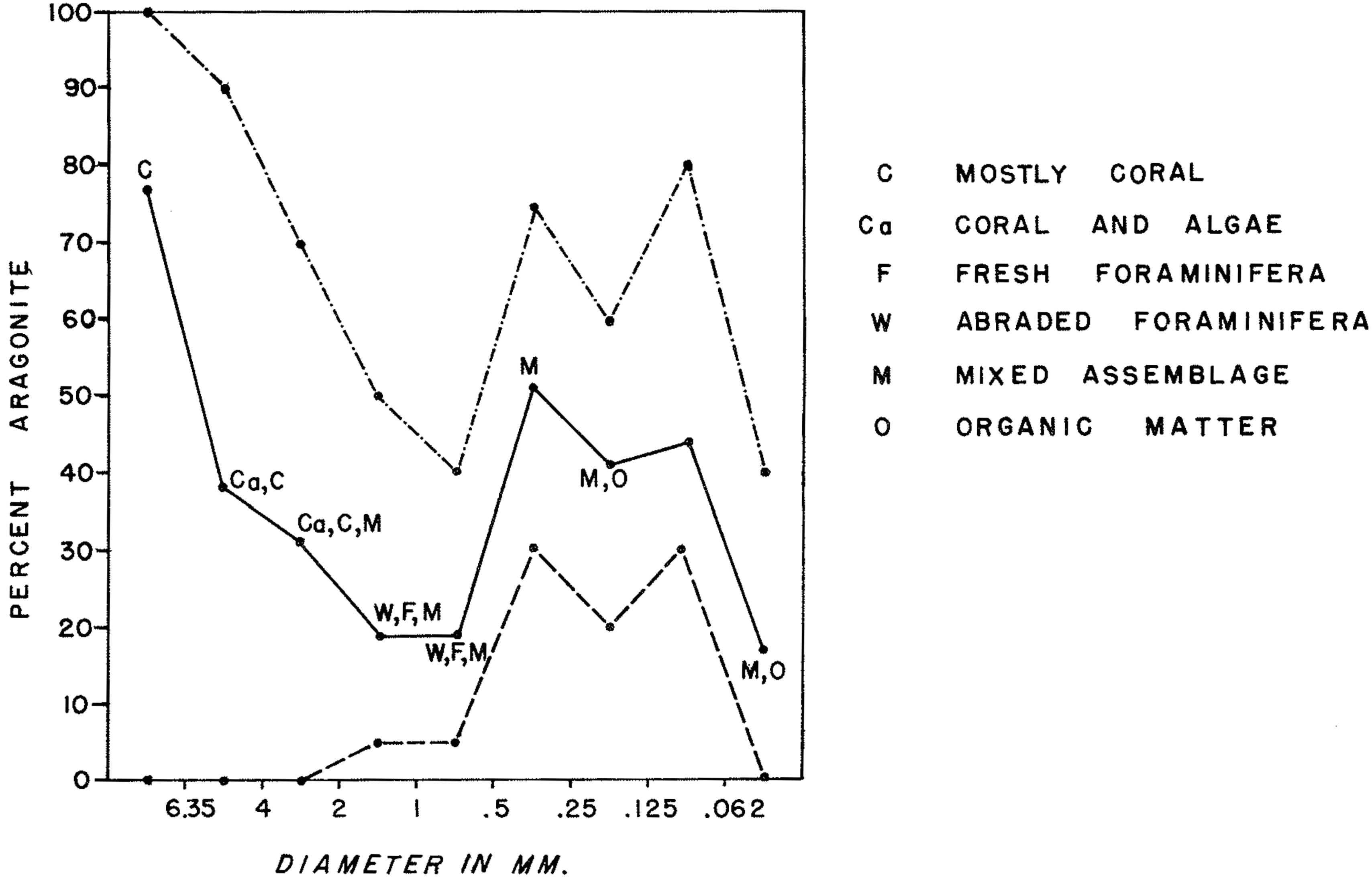
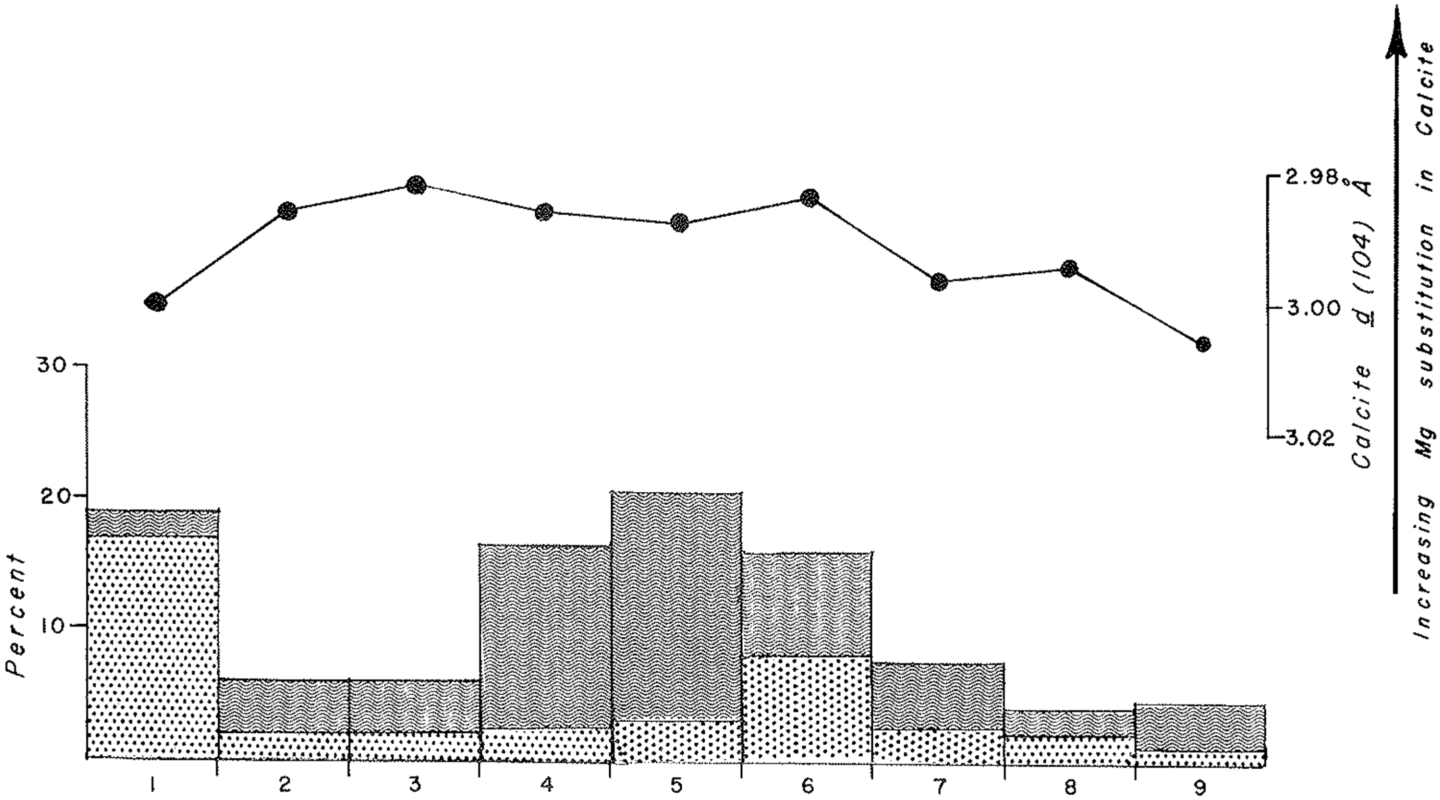


FIGURE 21. MAJOR CONSTITUENTS AND ARAGONITE IN THE VARIOUS GRAIN SIZES OF SOILS IN THE PROFILES DESCRIBED IN FIGURE 19



GRAIN SIZE IN MM.

Calcite

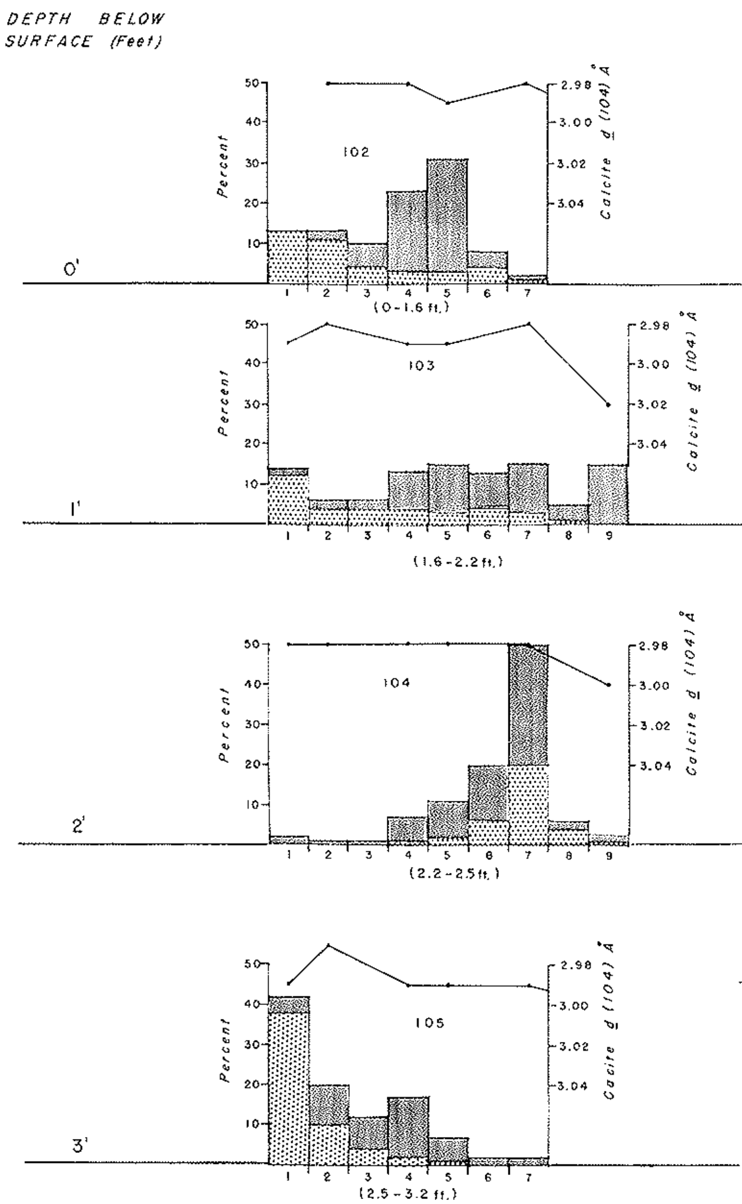
Aragonite

1	>6.35
2	6.35 – 4.0
3	4.0 – 2.0
4	2.0 – 1.0
5	1.0 – 0.5
6	0.5 – 0.25
7	0.25 – 0.12
8	0.12 – 0.06
9	<0.06

FIGURE 20. AVERAGE MINERALOGIC COMPOSITION OF SOIL PROFILES EXAMINED FROM THE ARNO ATOLL AND SHIOYA SOIL SERIES AS SHOWN IN FIGURE 19

UTIRIK

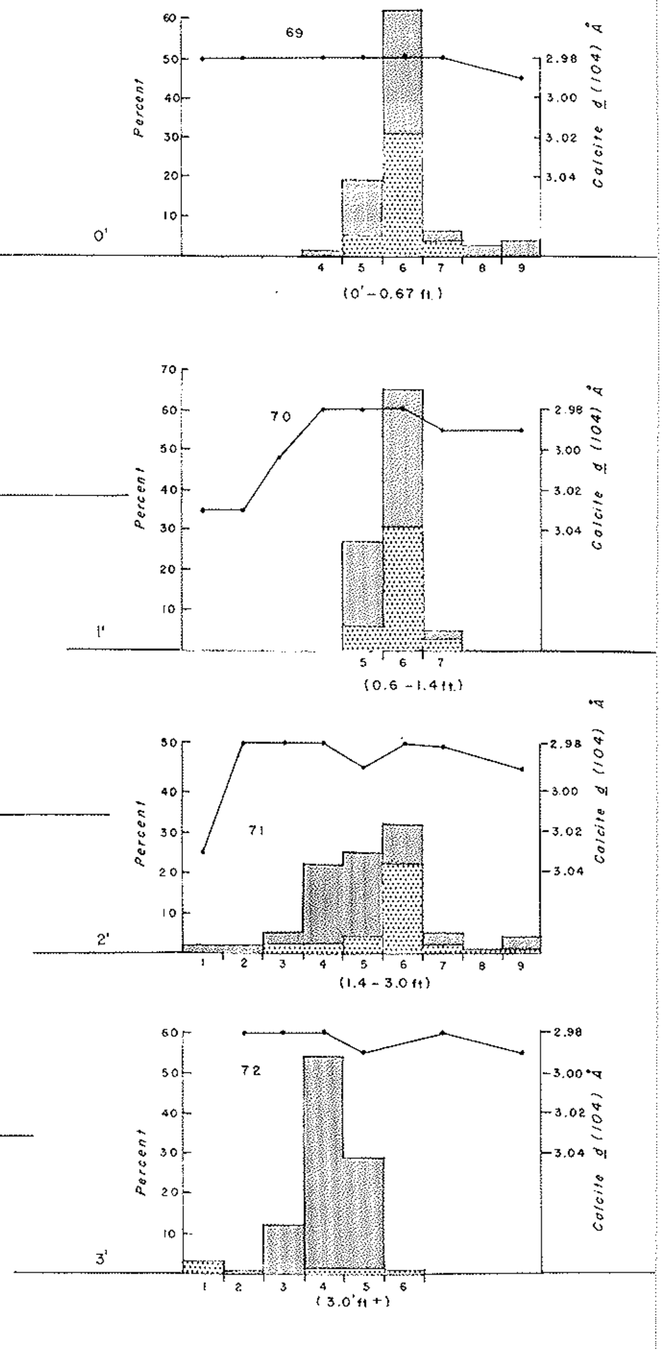
Profile 4



SHIOYA SERIES

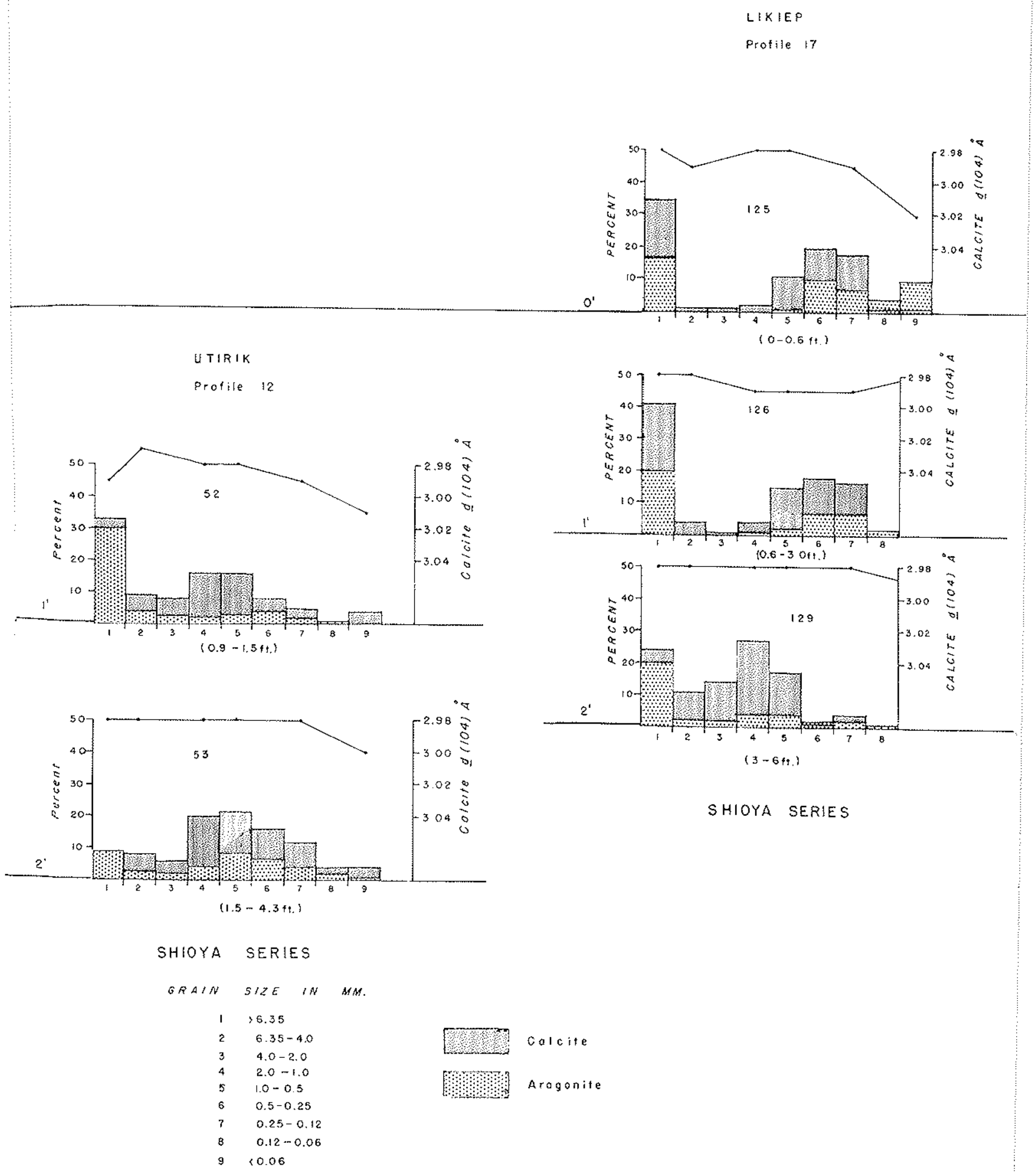
JEMO

Profile 30



SHIOYA SERIES

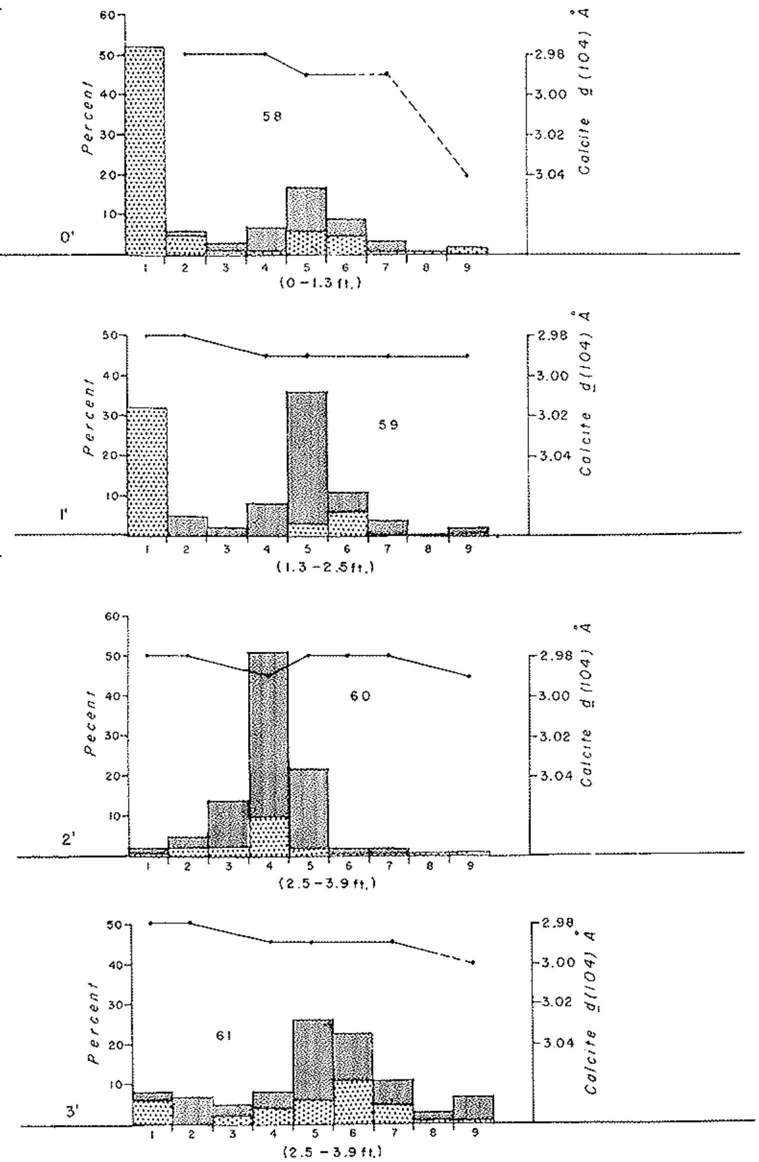
FIGURE



9. GRAIN SIZE DISTRIBUTION AND RELATIVE AMOUNTS OF CALCITE AND ARAGONITE IN SOILS ON UTIRIK, JEMO, LIKIEP, AND TAKA ATOLLS

LIKIEP

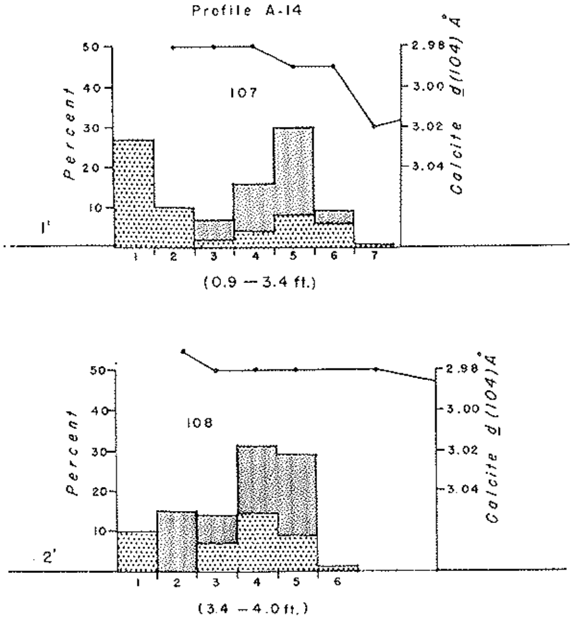
Profile 18



ARNO ATOLL SERIES

TAKA

Profile A-14



ARNO ATOLL SERIES

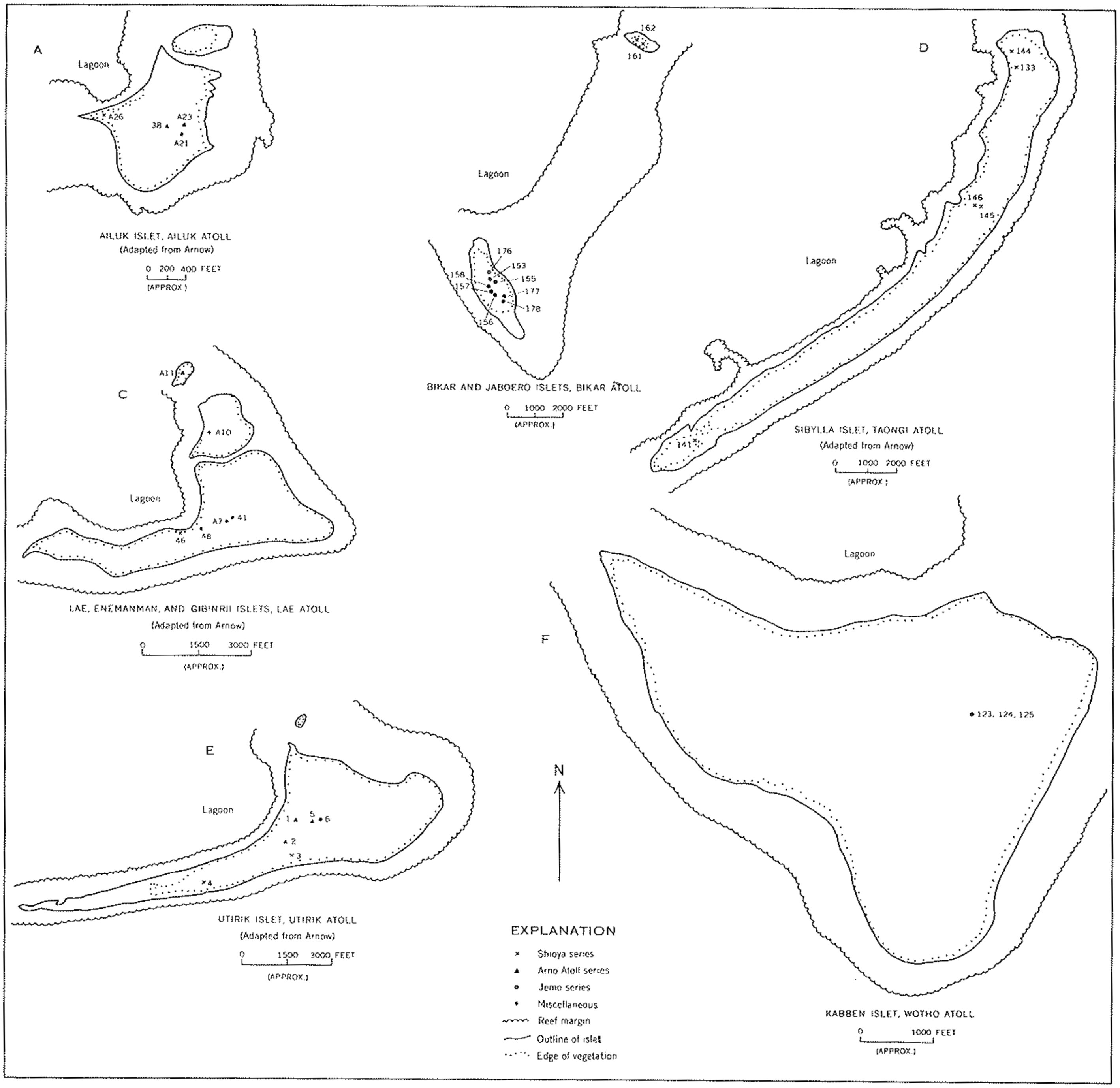


FIGURE 18. MAPS OF SOUTHEASTERN CORNER ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED

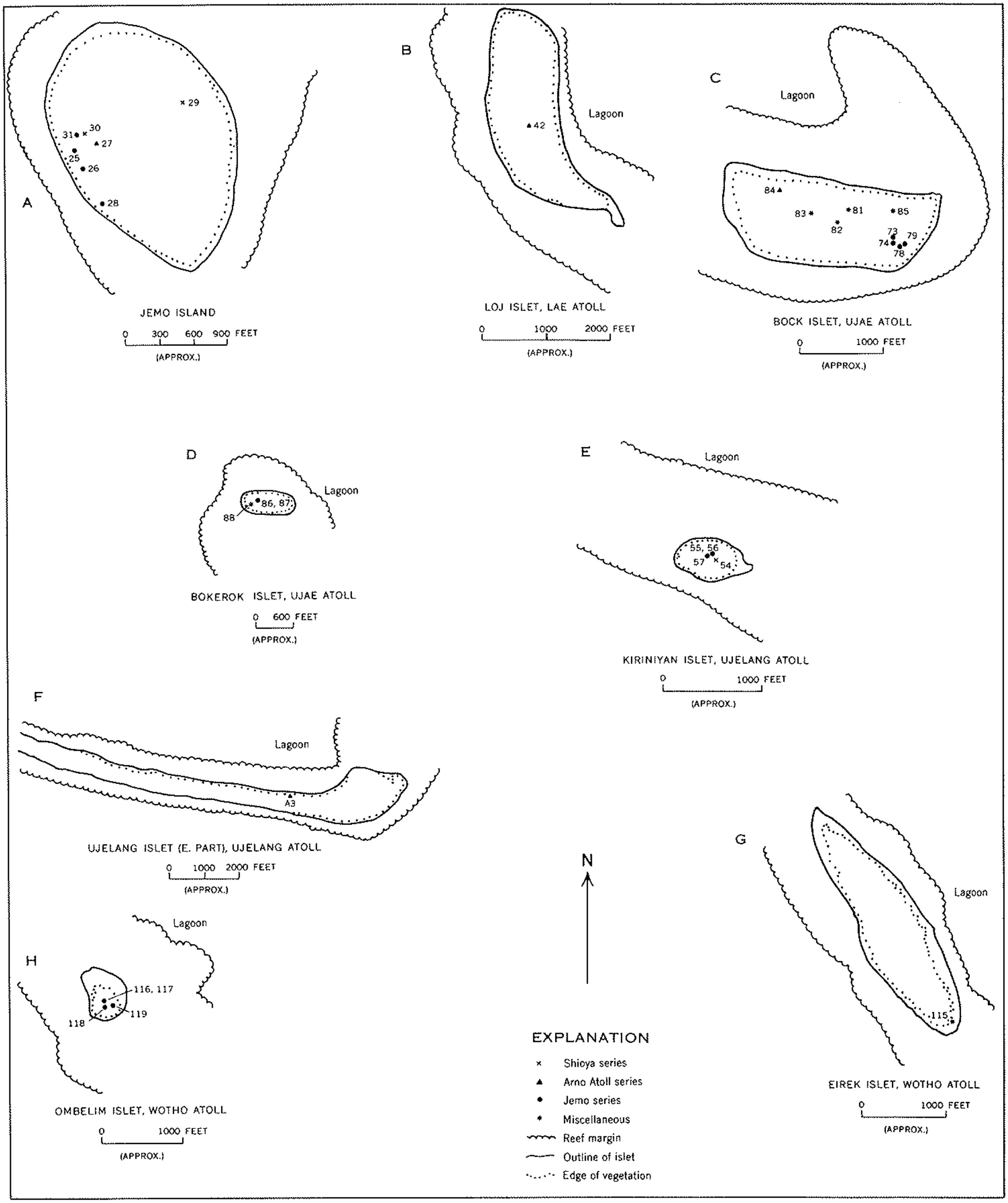


FIGURE 17. MAPS OF LEEWARD ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED

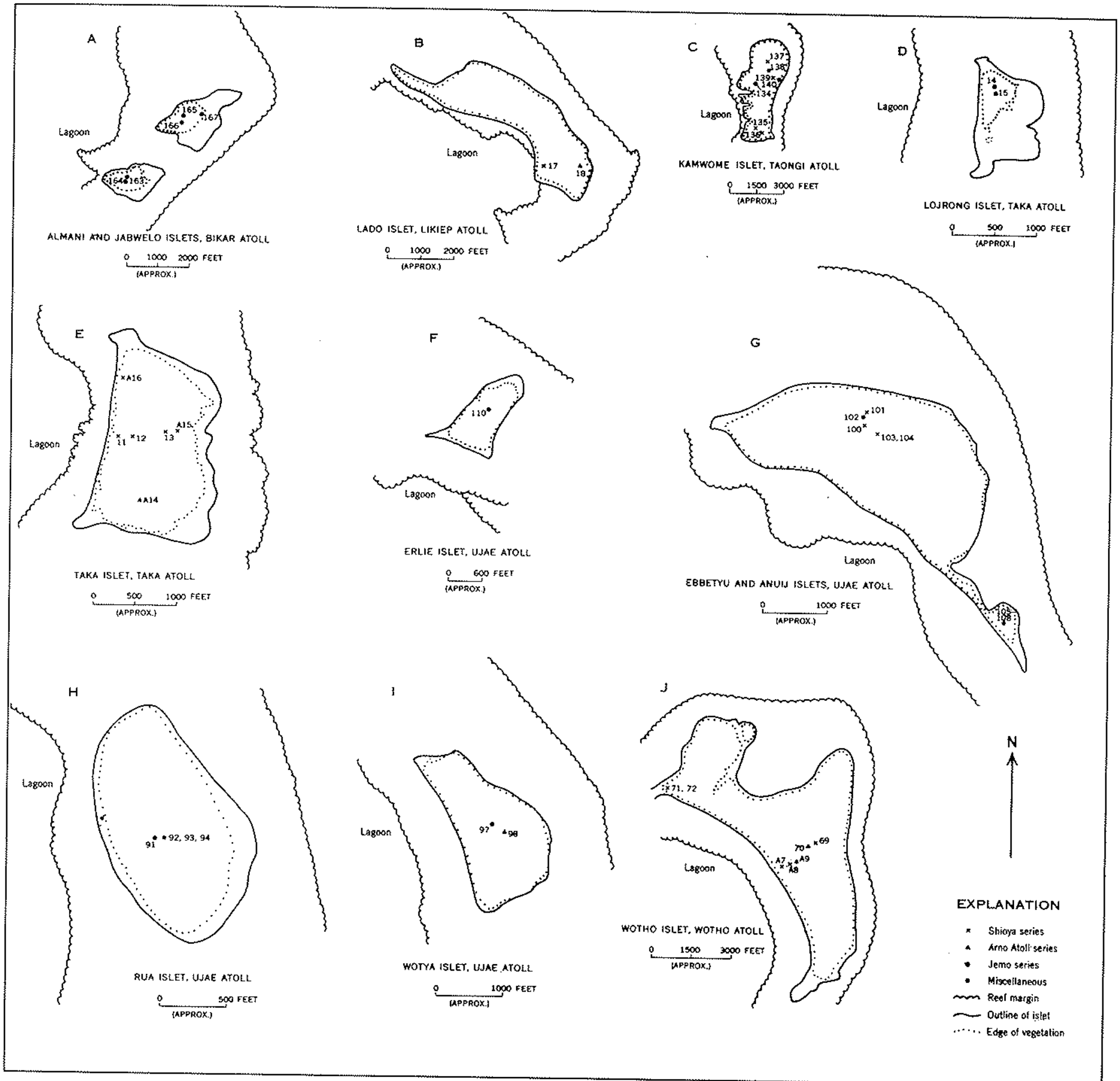


FIGURE 16. MAPS OF WINDWARD ISLETS SHOWING LOCATIONS FROM WHICH SOIL SAMPLES WERE COLLECTED

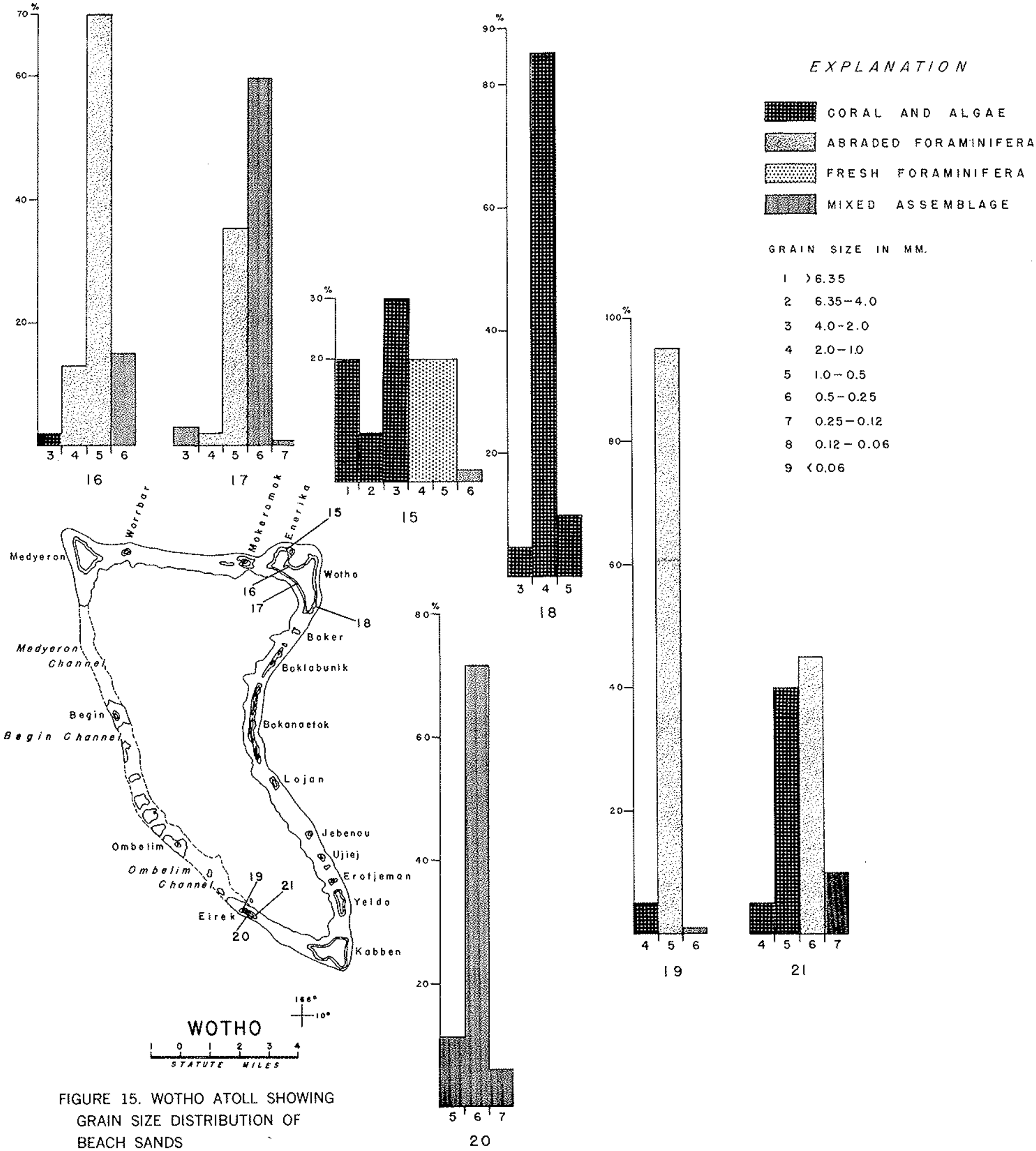


FIGURE 15. WOTHO ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

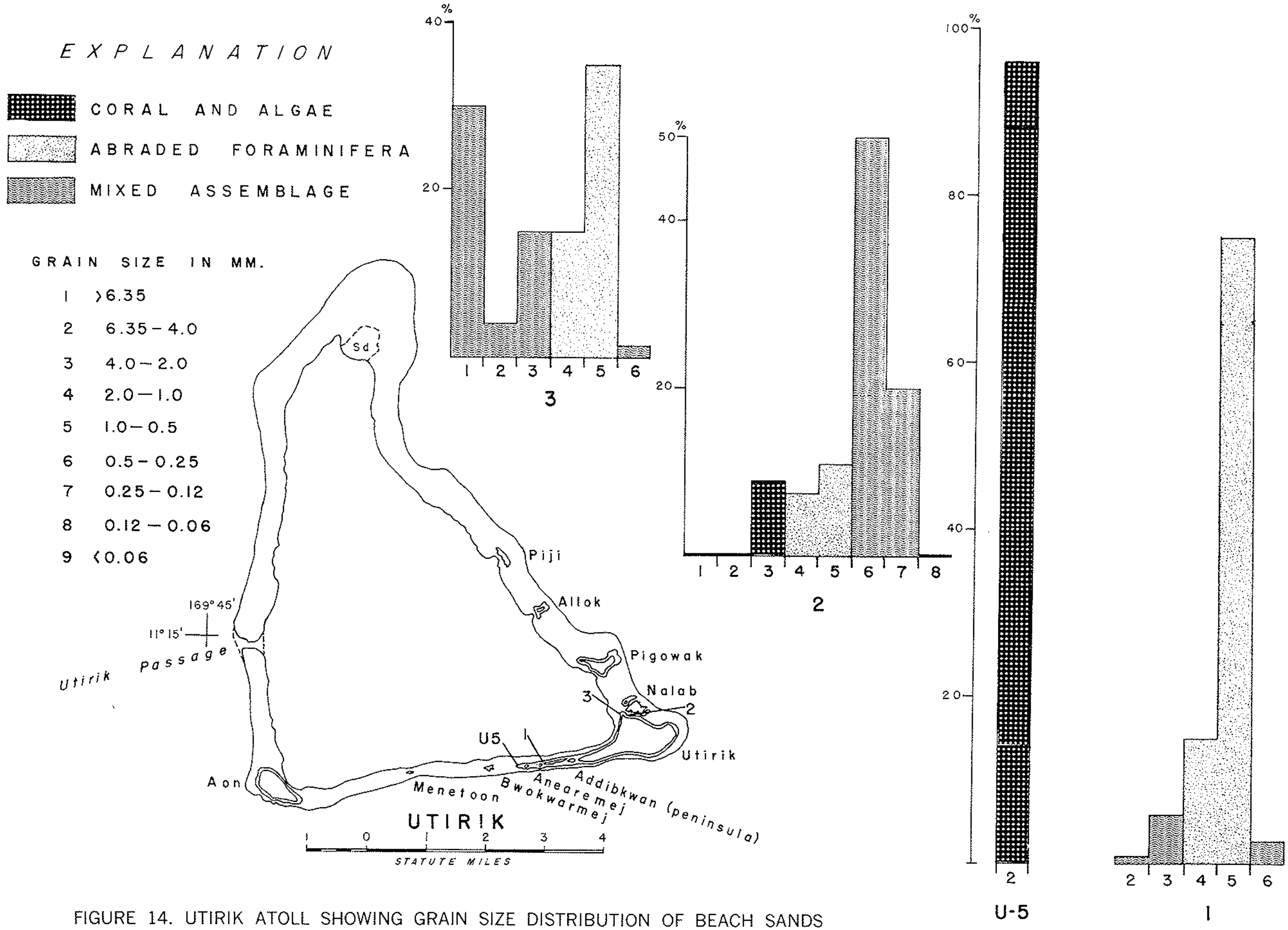


FIGURE 14. UTIRIK ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

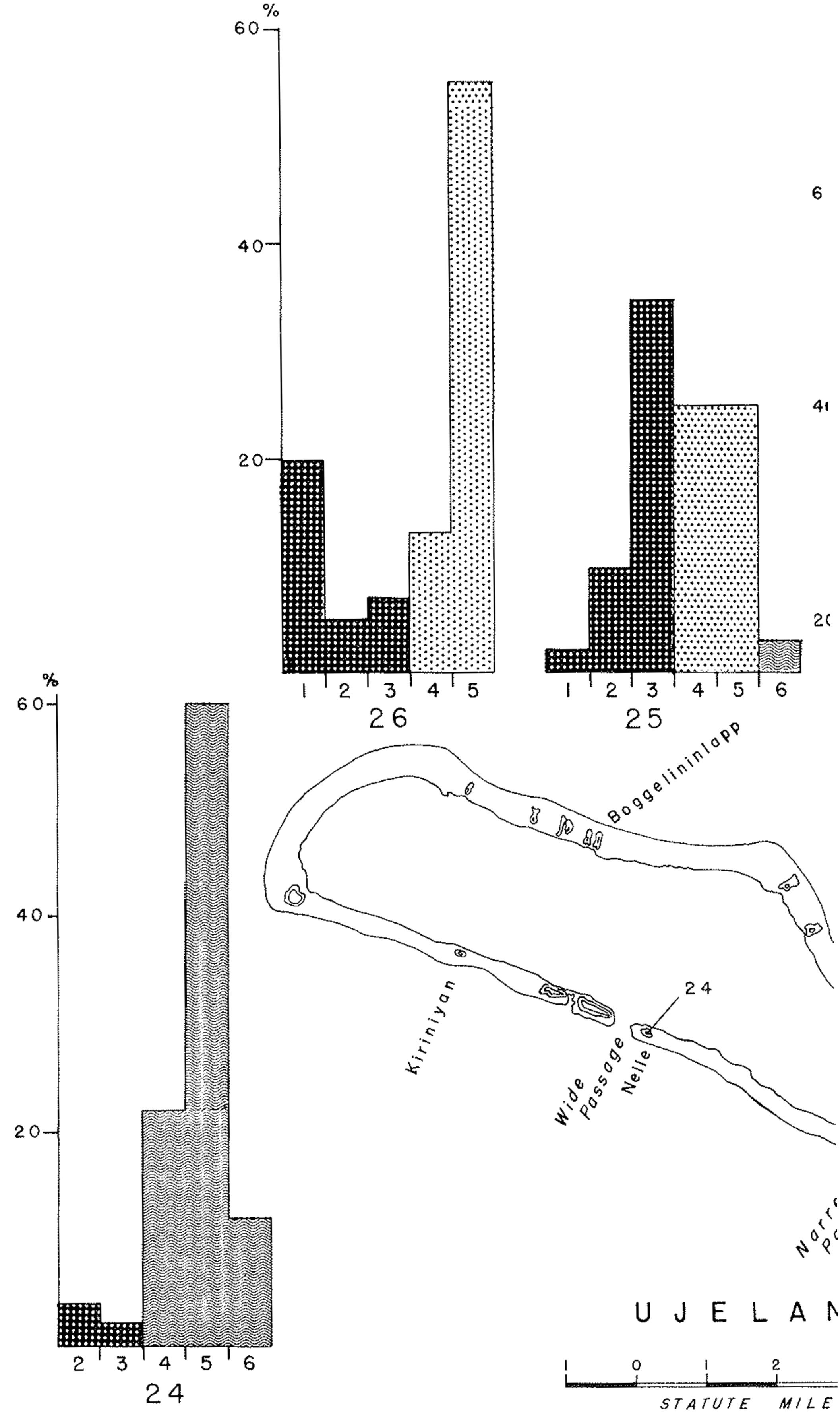
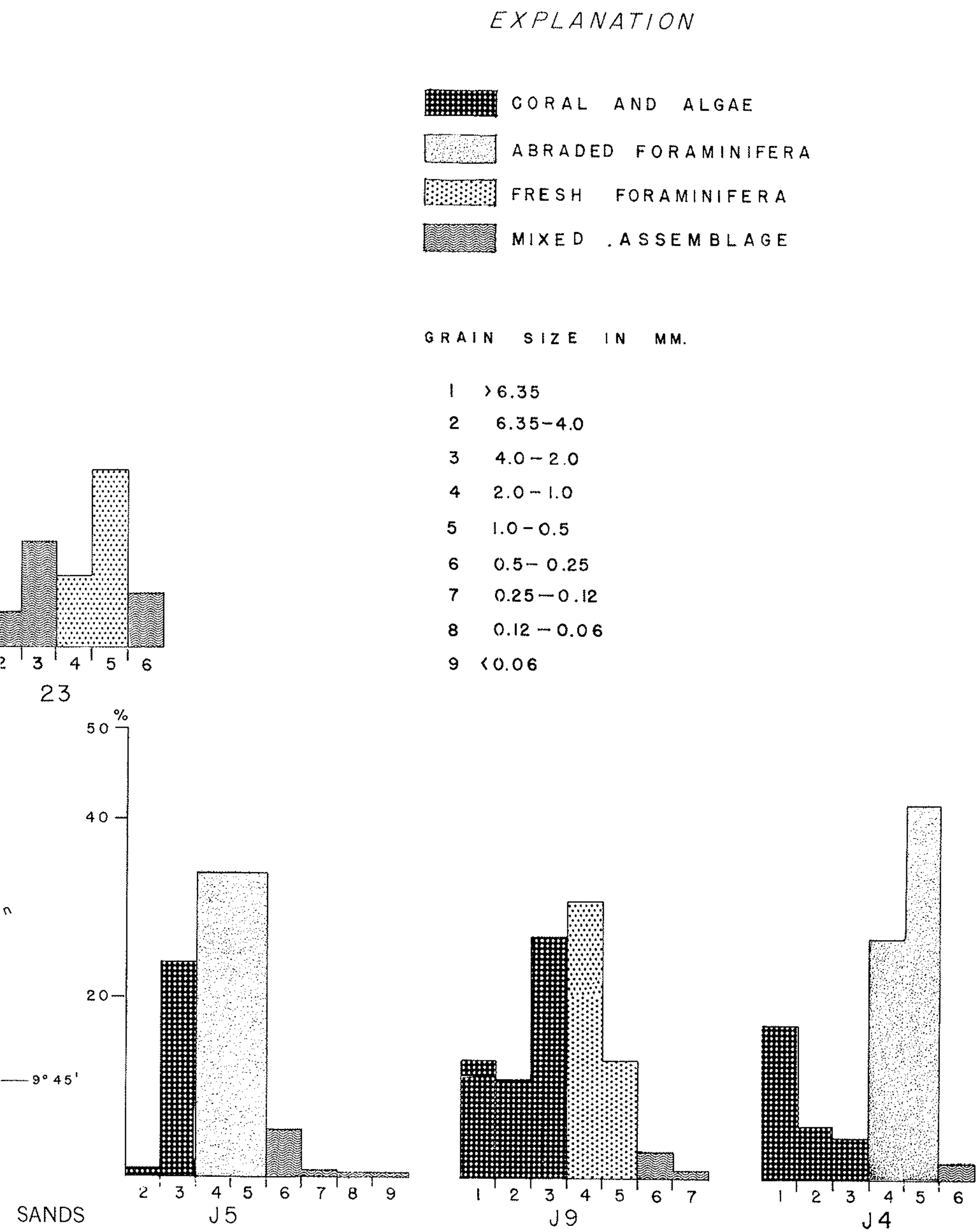


FIGURE 13. UJELANG ATOLL SHOWING GRAIN


EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
FRESH FORAMINIFERA
MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35–4.0
3 4.0–2.0
4 2.0–1.0
5 1.0–0.5
6 0.5–0.25
7 0.25–0.12
8 0.12–0.06
9 <0.06
23
%
50
40
20
9° 45'
SANDS
J5
J9
J4

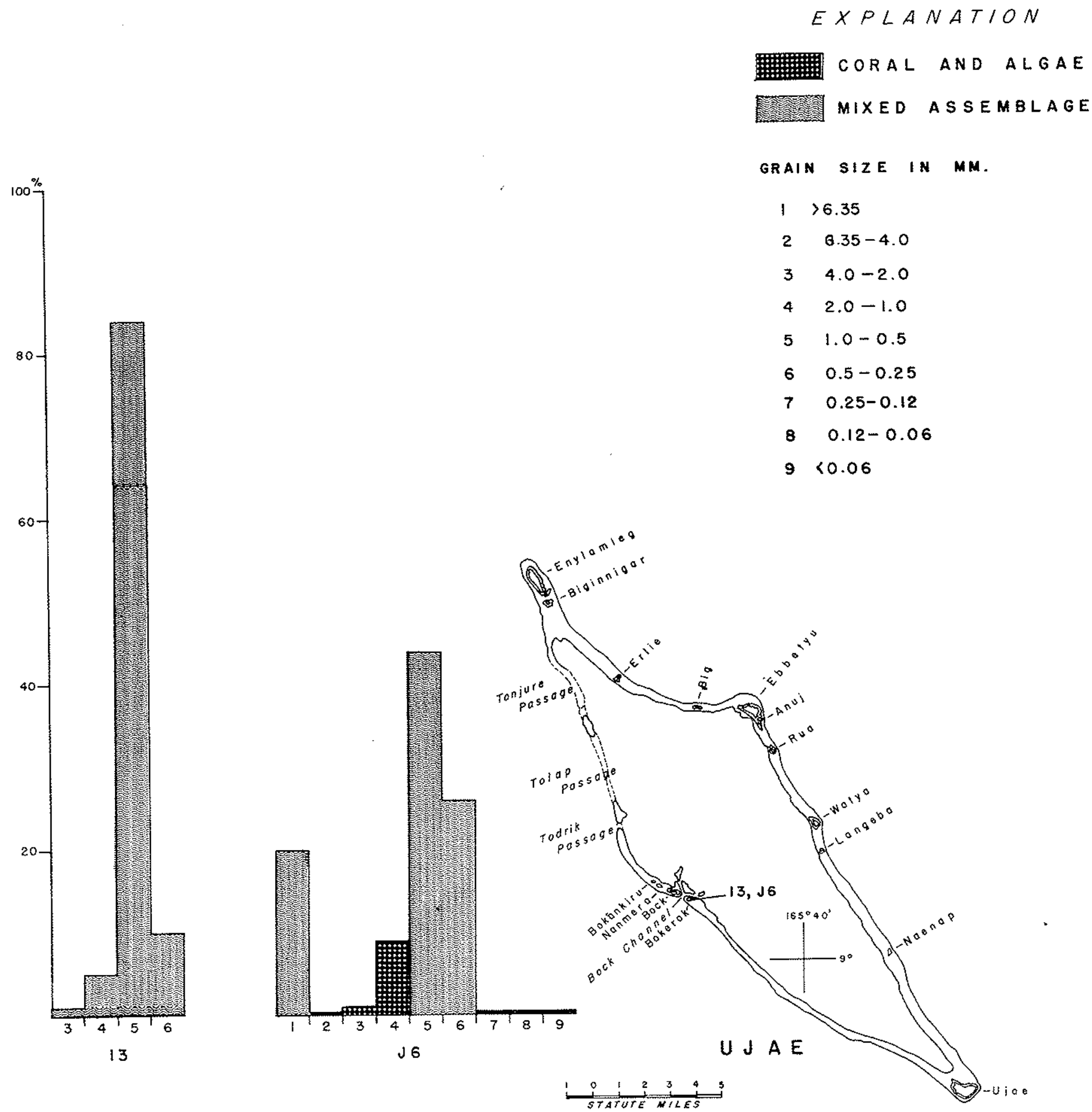


FIGURE 12. UJAE ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

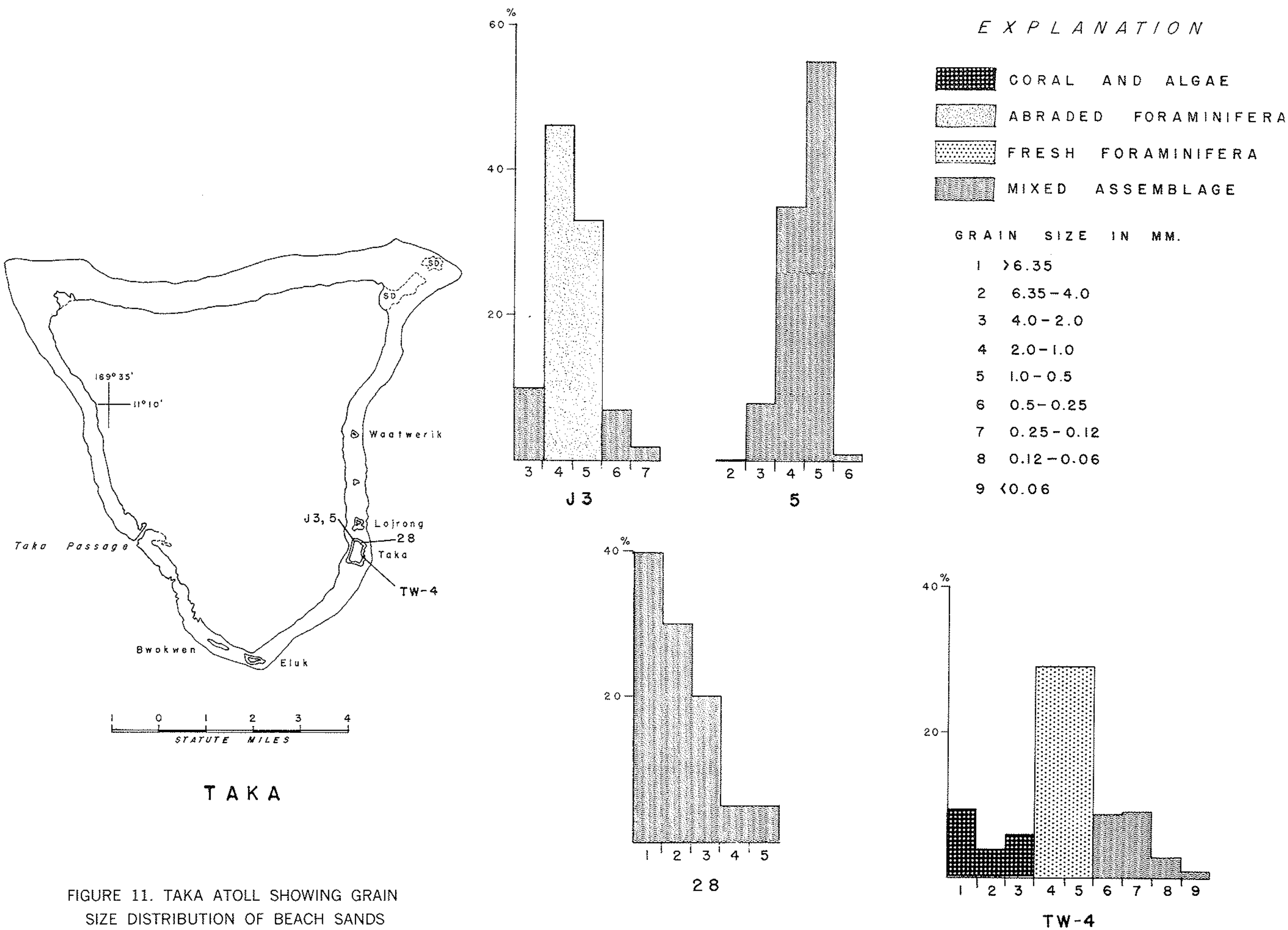


FIGURE 11. TAKA ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

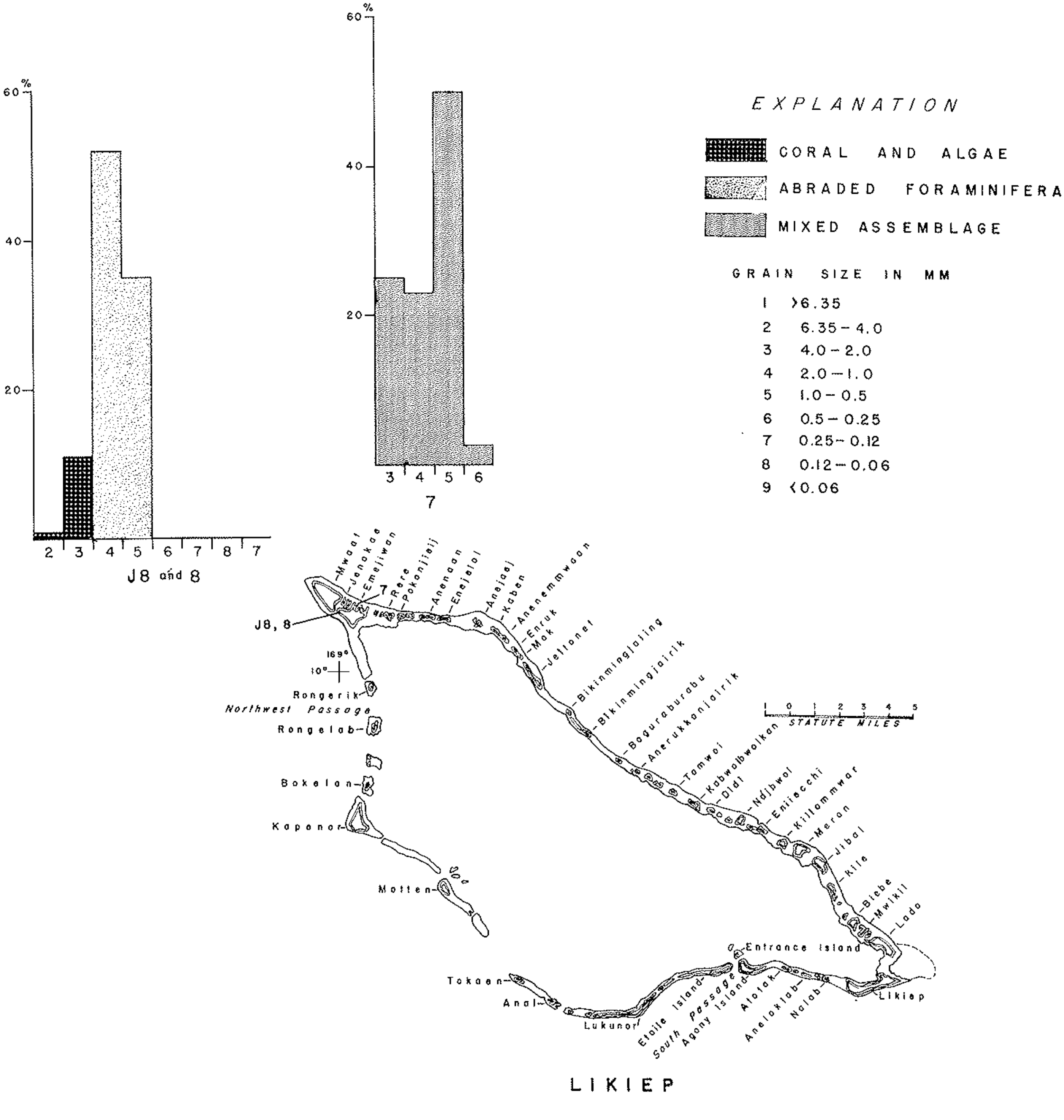


FIGURE 10. LIKIEP ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

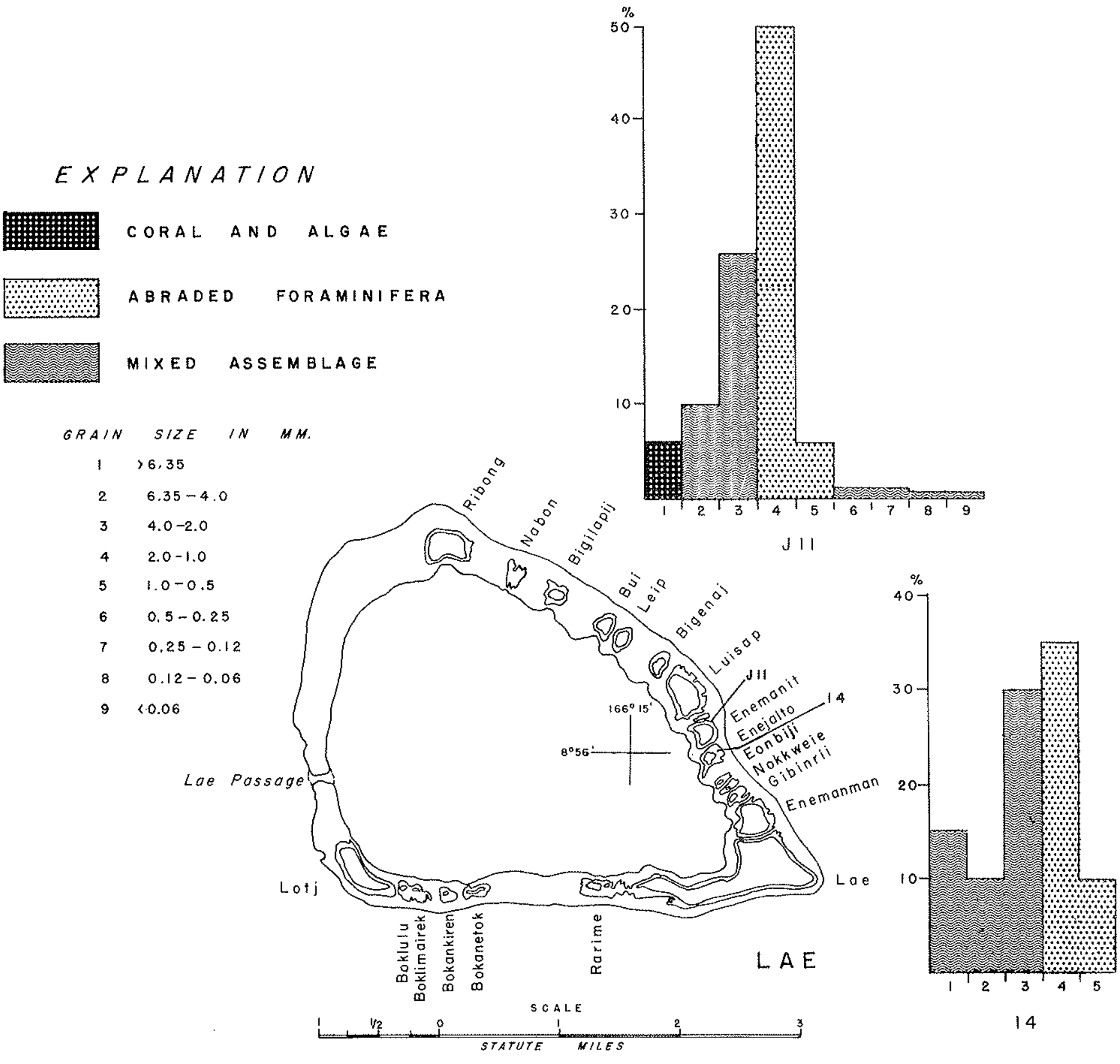
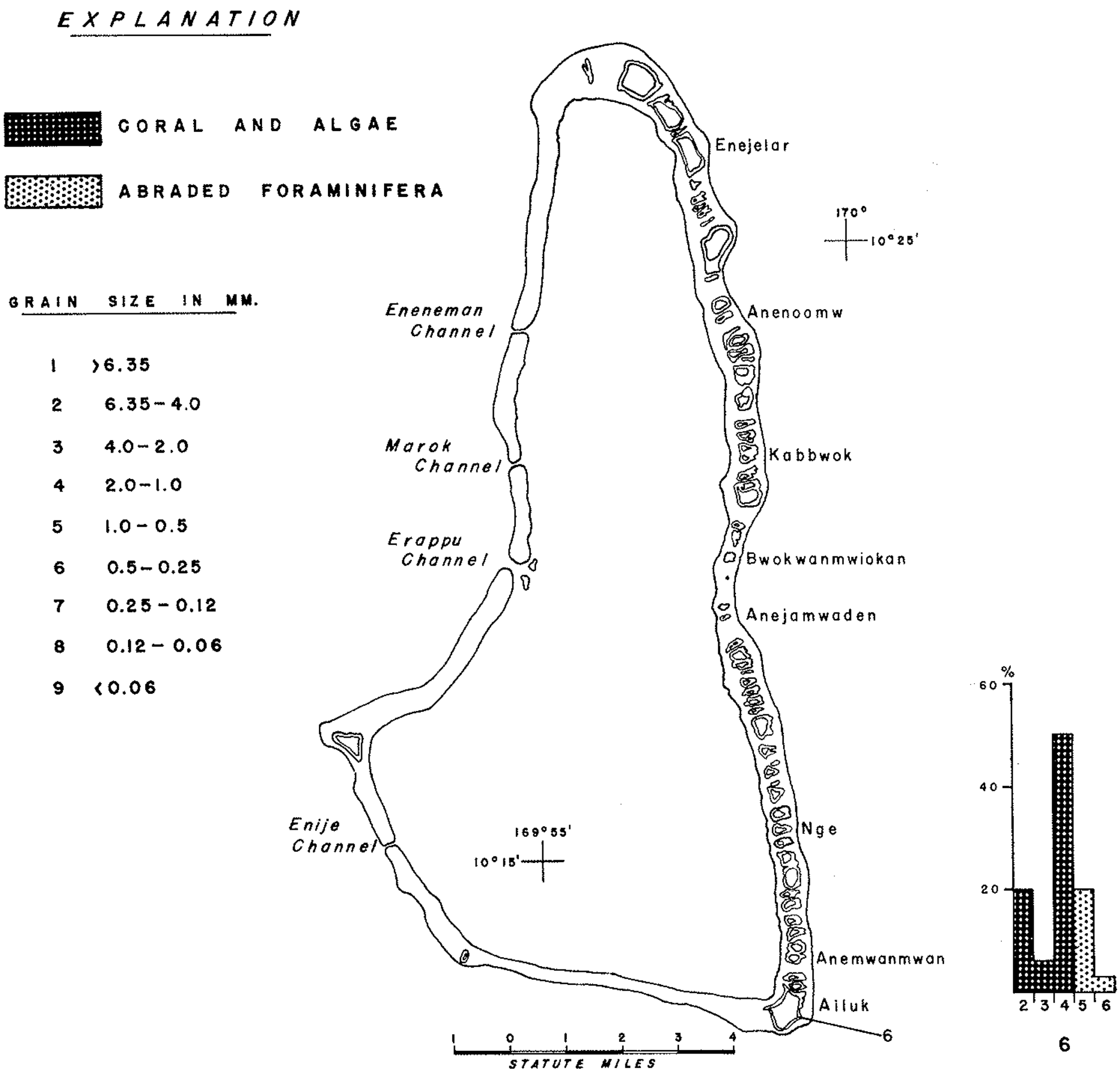


FIGURE 9. LAE ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS



AILUK

FIGURE 7. AILUK ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

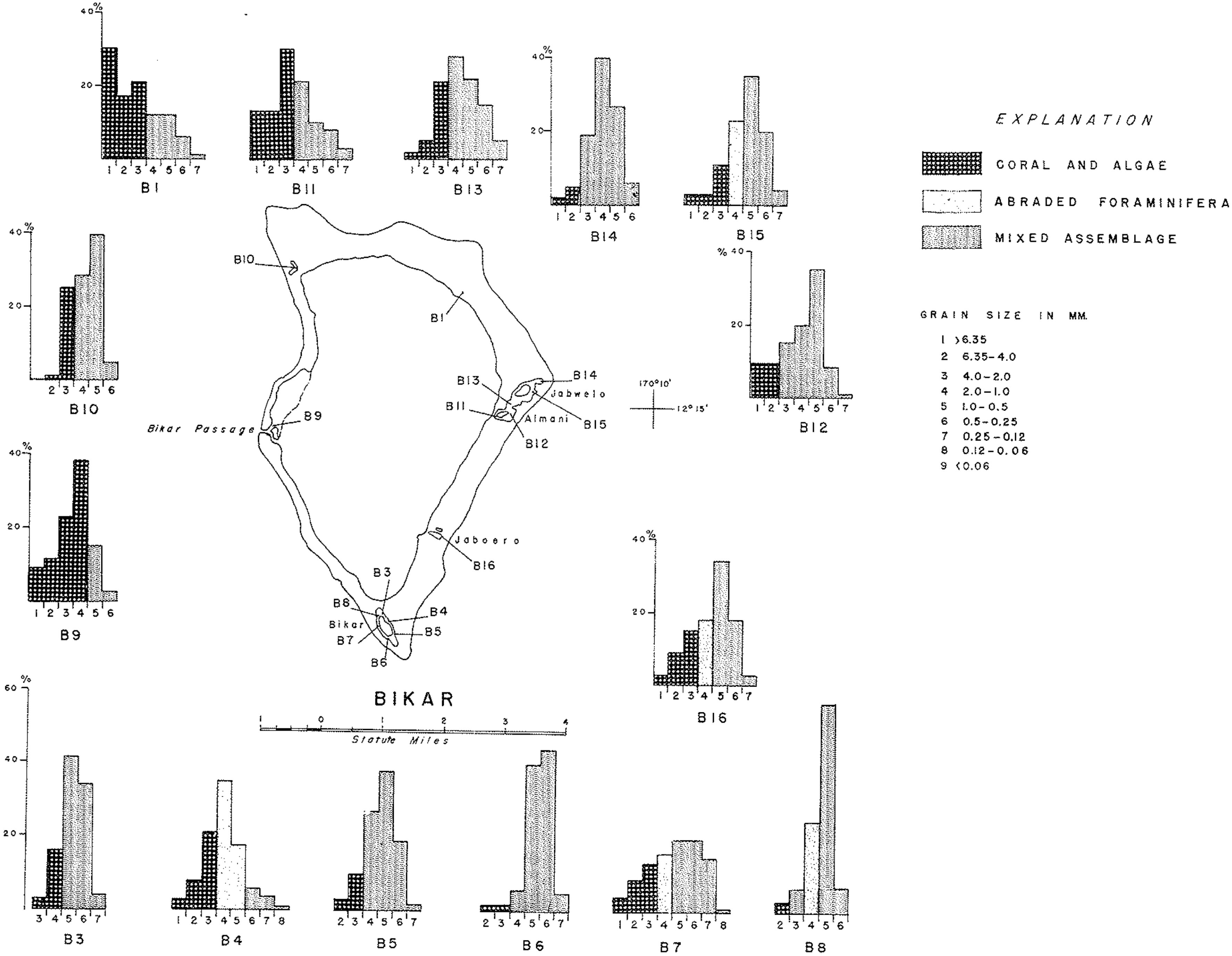


FIGURE 6. BIKAR ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS

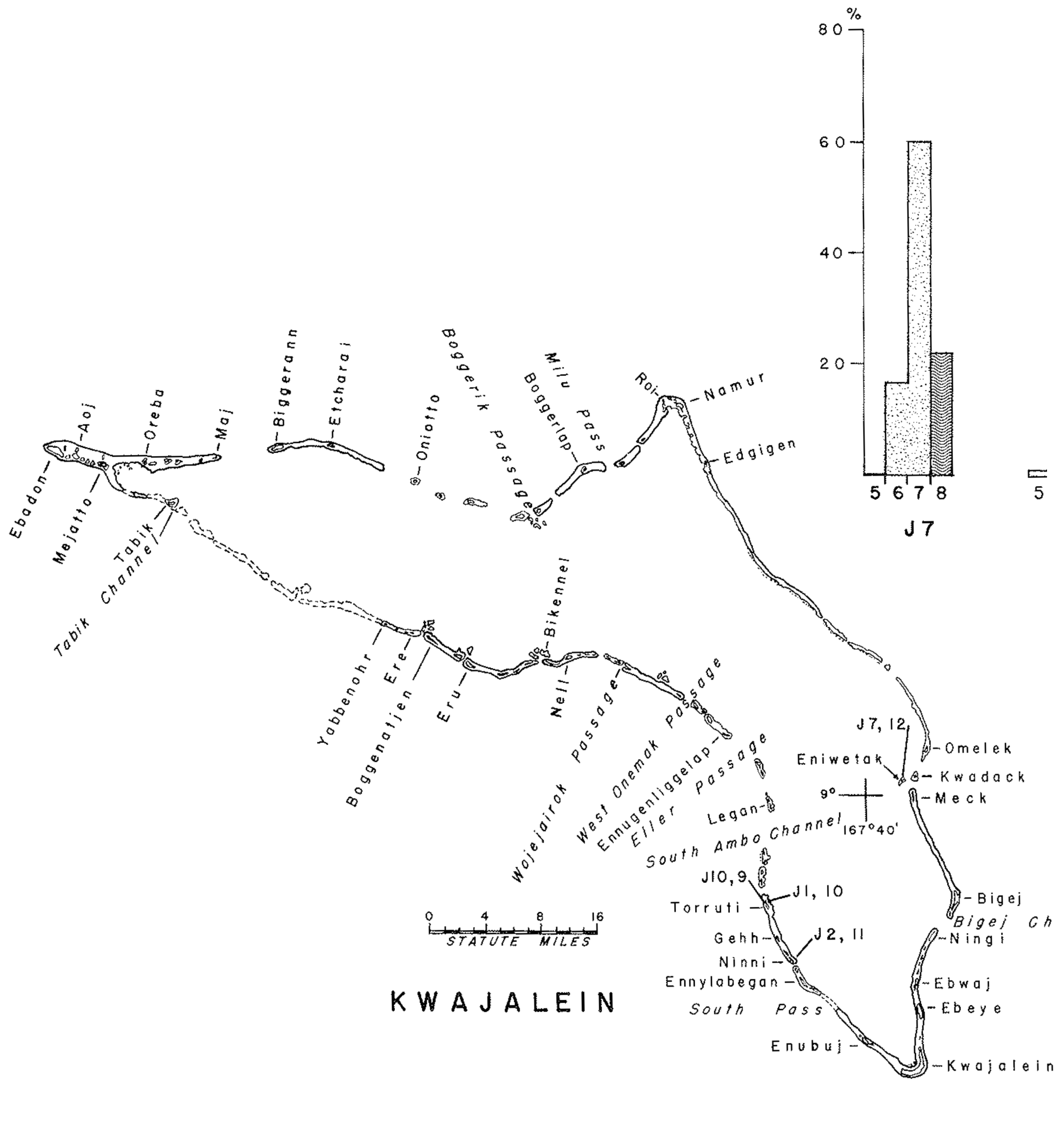
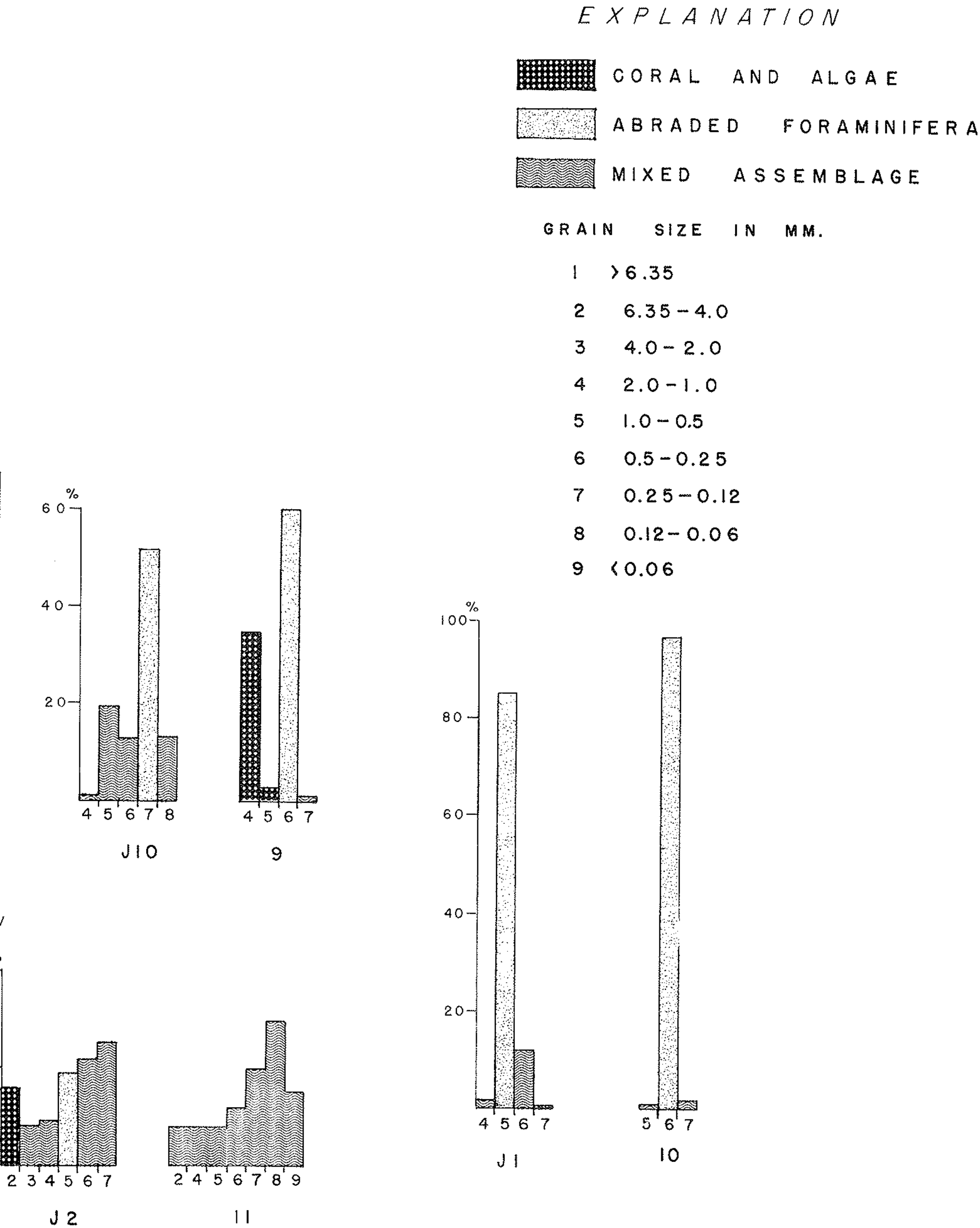
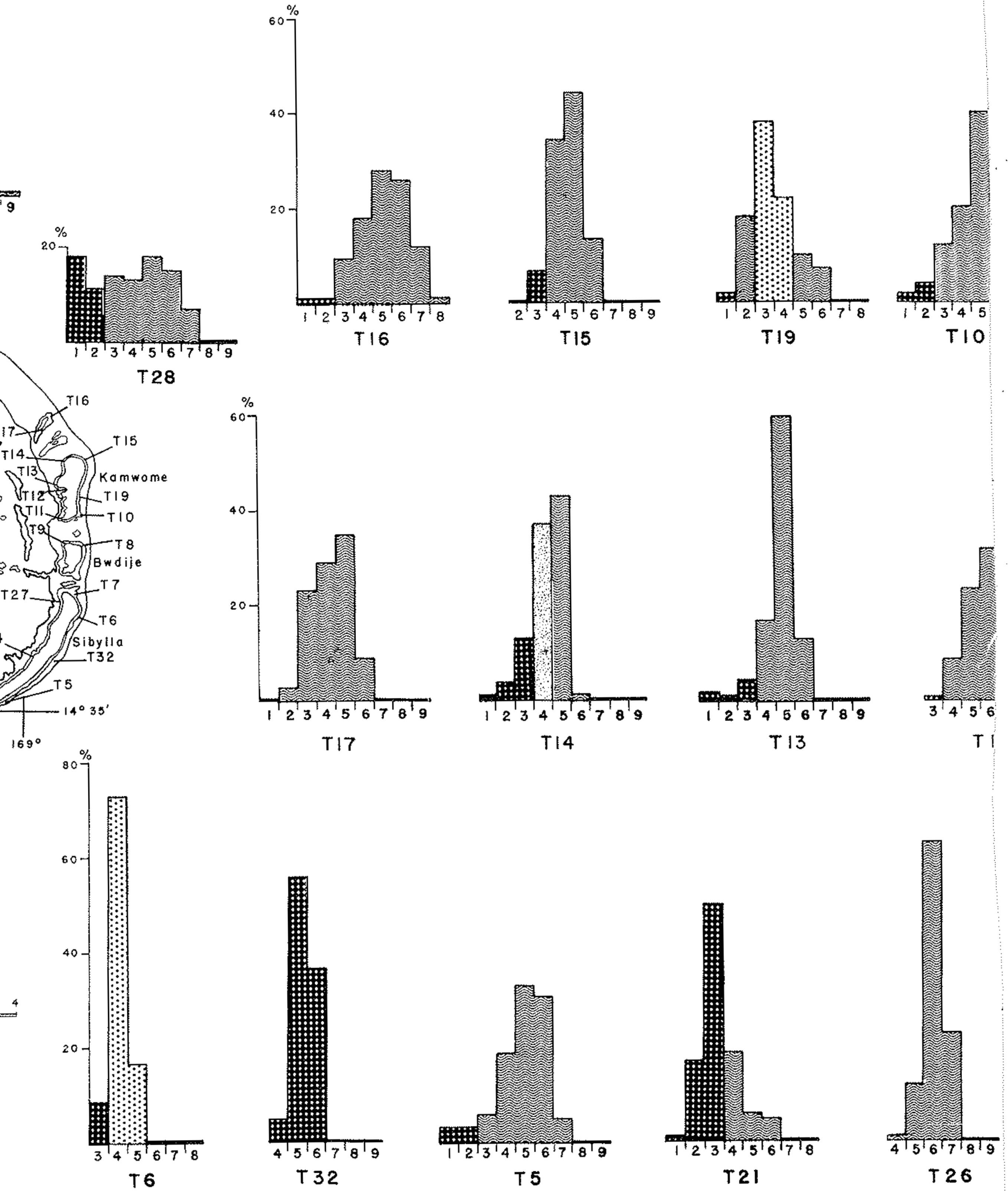
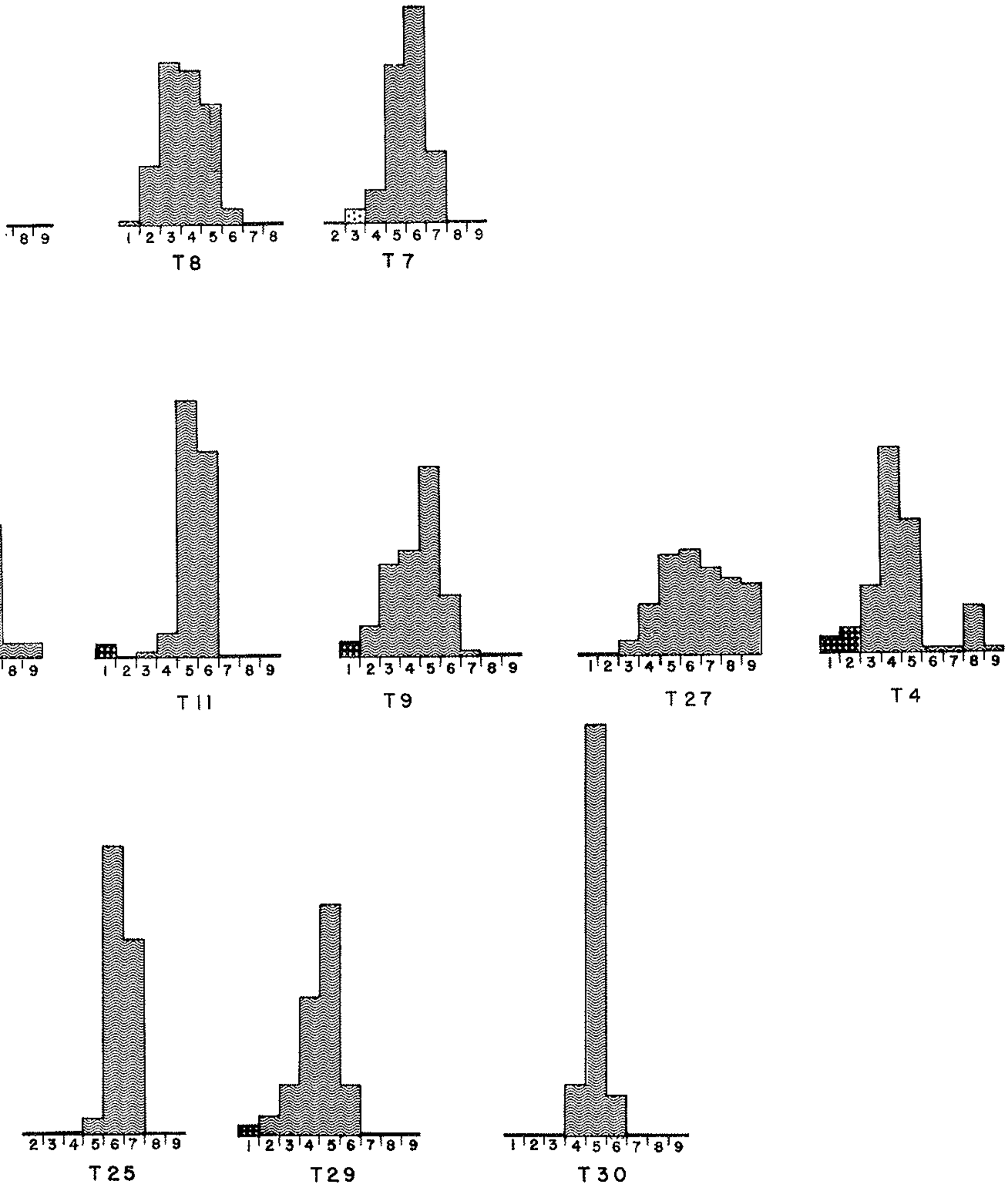


FIGURE 8. KWAJALEIN ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEACH SANDS


EXPLANATION
CORAL AND ALGAE
ABRADED FORAMINIFERA
MIXED ASSEMBLAGE
GRAIN SIZE IN MM.
1 >6.35
2 6.35 - 4.0
3 4.0 - 2.0
4 2.0 - 1.0
5 1.0 - 0.5
6 0.5 - 0.25
7 0.25 - 0.12
8 0.12 - 0.06
9 <0.06
%
60
40
20
4 5 6 7 8
J10
4 5 6 7
9
%
100
80
60
40
20
4 5 6 7
J1
5 6 7
10
2 3 4 5 6 7
J2
2 4 5 6 7 8 9
11



GI (POKAK) ATOLL SHOWING GRAIN SIZE DISTRIBUTION OF BEAC



SANDS

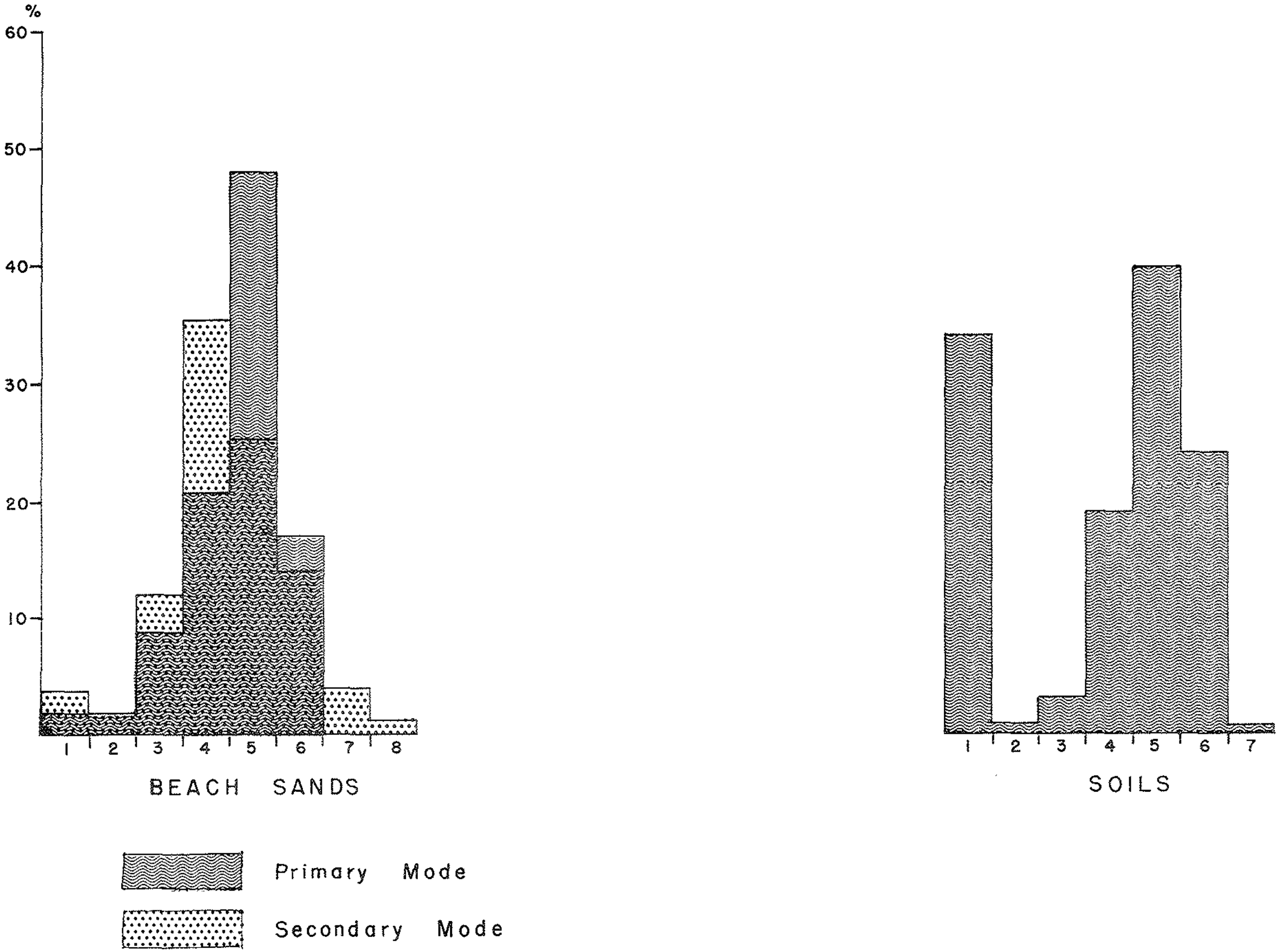


FIGURE 28. COMPARISON OF GRAIN SIZE DISTRIBUTION OF BEACH SANDS AND SOILS

Table 4.--Size distribution (percent by weight), median grain diameter, sorting coefficient, and skewness of beach sands from islets on various atolls in the northern Marshall Islands. (Situation of sample on islet is indicated by S, seaward, and L, lagoon).

Atoll and islet	Sample No.	Situation	Grain size (mm) +8.0	+4.0	+2.0	+1.0	+0.50	+0.25	+0.125	+0.062	<0.062	Median (mm)	Sorting coefficient	Skewness
Taongi: (Pokak) Atoll														
North	T 16	S	1.4	1.7	9.5	18.7	28.0	26.4	12.5	1.0	0.3	0.60	1.90	1.08
	T 17	L	.3	2.8	23.6	28.7	34.5	9.6	tr	tr	tr	1.15	1.67	1.06
Kamwome	T 15	S	.4	.8	6.7	34.4	43.9	13.2	.1	tr	tr	.90	1.38	.92
	T 19	S	1.3	2.1	18.6	37.8	22.2	10.2	7.0	.2	.1	1.10	1.67	.93
	T 10	S	1.9	4.0	12.4	20.6	39.6	21.1	.1	tr	tr	.80	1.70	1.17
	T 14	L	1.5	3.9	12.8	36.8	42.8	1.1	.6	tr	.1	1.10	1.52	.99
	T 13	L	2.0	1.6	4.6	16.9	60.2	13.6	.1	.3	.3	.78	1.26	.98
	T 12	L	-	tr	1.0	9.2	24.3	32.5	26.4	3.3	3.0	.37	1.73	.87
	T 11	L	2.4	.7	1.5	5.1	48.9	40.6	.3	tr	tr	.52	1.41	1.01
Bwdije	T 8	S	1.3	11.7	31.2	30.3	23.5	1.5	tr	tr	tr	1.60	1.80	.98
	T 9	L	2.8	6.4	18.3	21.3	37.0	12.0	1.4	.1	.2	.99	1.73	1.28
Sibylla	T 7	S	-	.7	2.4	6.5	33.3	42.0	14.2	.4	.1	.45	1.52	1.04
	T 6	S	-	-	9.3	73.0	17.1	.3	tr	tr	tr	1.30	1.22	.99
	T 32	S	-	tr	.3	5.1	56.5	37.4	.3	tr	tr	.58	1.14	1.06
	T 5	S	2.9	2.5	5.9	19.0	32.8	31.4	5.1	tr	tr	.66	1.73	1.10
	T 21	S	-	1.4	16.9	50.5	18.9	6.2	5.5	.2	tr	1.20	1.48	1.00
	T 27	L	.6	.3	2.6	9.5	19.5	20.3	17.0	15.5	14.3	.28	2.65	.71
	T 4	L	2.8	4.8	13.4	39.5	26.3	1.0	1.4	9.0	1.3	1.20	1.58	.90
	T 20	L	.4	2.5	13.4	30.2	36.8	14.6	1.7	tr	tr	.92	1.58	1.02
	T 22	L	.2	.6	5.0	31.3	56.3	5.1	.4	tr	tr	.81	1.34	1.00

Pokak	T 26	S	-	.2	.2	.9	12.6	62.7	22.8	.4	tr	.32	1.41	1.02
	T 25	S	-	.4	.2	.7	3.7	56.7	38.0	tr	tr	.27	1.30	1.03
	T 23	L	3.3	6.9	24.2	31.5	25.7	7.7	.3	tr	tr	1.40	1.90	.90
	T 24	L	.3	1.4	20.4	50.4	25.8	1.3	tr	tr	tr	1.30	1.41	1.05
Bwokwla	T 29	S	2.1	4.0	9.5	27.4	45.5	10.5	.7	tr	tr	.90	1.48	1.07
	T 30	S	.2	tr	.7	10.5	79.6	8.6	tr	-	-	.90	1.45	1.14
<u>Bikar Atoll</u>														
Jabwelo	B 14	S	2.3	4.8	19.0	40.1	26.7	6.0	.4	.1	.3	1.20	1.61	1.16
	B 15	S	2.7	3.3	10.8	22.7	35.6	19.6	4.5	.3	.1	.80	1.73	1.17
Almani	B 13	L	2.6	4.9	21.1	28.1	22.3	15.0	5.2	.4	tr	1.10	2.02	.81
	B 11	L	13.5	13.2	29.4	21.4	10.5	8.6	3.1	tr	tr	2.20	1.92	.93
	B 12	S	9.7	9.5	14.9	19.8	35.3	8.9	1.5	tr	tr	2.20	1.92	.93
Jaboero	B 16	S	2.9	8.9	14.8	17.8	34.2	17.9	2.9	tr	tr	.80	1.95	1.62
Bikar	B 4	S	2.3	8.2	21.1	35.7	17.6	5.9	4.2	1.6	.5	1.40	1.84	.93
	B 5	S	.4	3.1	10.1	27.0	37.7	19.2	2.2	tr	tr	.84	1.98	.60
	B 6	S	.4	2.0	1.8	6.1	39.8	44.4	5.0	tr	tr	.50	1.30	1.03
	B 7	S	3.6	9.0	13.5	16.4	19.7	20.3	15.1	1.5	.4	.80	2.51	1.08
	B 3	L	-	.4	3.0	16.4	41.2	34.1	4.5	tr	tr	.60	1.64	.83
	B 8	L	.7	3.1	6.5	24.9	57.5	6.8	.1	tr	tr	.79	1.34	1.07
<u>Ailuk Atoll</u>	6	S	20.0	6.0	50.0	20.0	3.0	1.0	-	-	-	2.60	1.45	1.27
<u>Kwajalein Atoll</u>														
Torrutj	9	S	.5	.5	35.0	3.0	60.0	1.0	-	-	-	.92	1.70	2.03
	J 10	S	-	1.7	19.6	13.2	52.4	12.7	tr	tr	tr	.74	1.79	1.61
	10	L	-	-	tr	1.0	97.0	2.0	-	-	-	.80	1.10	.89
	J 1	L	-	.1	.2	1.7	85.4	11.9	.5	tr	tr	.64	1.09	.98

Atoll and islet	Sample No.	Situation	Grain size (mm) +8.0	+4.0	+2.0	+1.0	+0.50	+0.25	+0.125	+0.062	<0.062	Median (mm)	Sorting coefficient	Skewness
Ninni	11	L	-	-	22.9	12.3	19.3	29.4	15.3	tr	-	.52	2.36	2.13
	J 2	L	.5	15.8	8.0	9.3	19.2	21.9	24.9	tr	tr	.54	2.76	1.63
Eniwetok	12	L	-	-	.7	1.5	17.4	67.4	12.5	tr	-	.36	1.26	.97
	J 7	L	-	tr	tr	.9	16.6	60.7	21.5	tr	tr	.35	1.26	.99
Lae Atoll														
Enejalto	14	S	15.0	10.0	30.0	35.0	10.0	tr	-	-	-	2.20	1.68	1.15
Enemanit	J 11	L	6.0	10.1	25.9	49.1	6.5	.9	.8	.2	.2			
Taka Atoll														
Taka	5	S	tr	.5	8.0	35.0	55.0	1.5	-	-	-	.96	1.18	1.06
	J 3	S	-	.3	9.7	46.6	33.5	7.3	2.2	tr	tr	1.00	1.26	.88
	28	S	40.0	30.0	20.0	5.0	5.0	tr	-	-	-	n.d.	n.d.	n.d.
	TW 4	L	9.0	3.9	5.7	29.2	29.2	8.6	9.2	3.2	1.5	.96	1.00	2.20
Likiep Atoll														
Emejiwan	J 8	S	-	1.3	10.9	52.6	35.0	.1	tr	tr	tr	1.05	1.26	1.06
	7	S	-	tr	25	23	50	2	-	-	-	1.0	1.55	1.64
Ujae Atoll														
Bokerok	13	L	tr	tr	1	5	84	10	-	-	-	.78	1.0	.83
	J 6	L	19.6	tr	1.2	9.0	43.8	25.8	.3	tr	tr	.68	1.70	1.45
Ujelang Atoll														
Ujelang	J 4	S	17.0	6.1	5.5	27.3	41.7	1.9	tr	tr	tr	1.10	1.87	2.08
	J 5	S	-	.8	24.3	34.2	34.2	5.2	.5	.1	.1	1.20	1.64	1.02
	J 9	S	13.2	11.0	26.8	31.3	13.7	2.8	.6	.1	tr	2.10	1.79	1.06

	23	L	50	4	12	8	20	6	-	-	-	n.d.	n.d.	n.d.
Nelle	24	L	tr	tr	2.5	2.5	40	55	-	-	-	.38	1.34	1.12
Maronlik	25	S	2.5	10	35	25	25	2.5	-	-	-	1.90	1.70	.73
	26	L	20	5	7	13	55	tr	-	-	-	.90	2.60	3.66
<u>Utirik Atoll</u>														
Utirik	2	L	-	-	9.2	7.5	10.5	52.5	19.4	.5	-	.35	1.41	1.14
	3	L	30	4	15	15	35	1	-	-	-	1.90	-	-
	1	L	-	1	6	15	75	3	-	-	-	.92	1.10	.90
	U 5	L	98.5	.6	tr	tr	tr	.5	.2	tr	tr	n.d.	n.d.	n.d.
<u>Wotho Atoll</u>														
Wotho	15	S	20	8	30	20	20	2	-	-	-	1.30	2.02	4.26
	16	S	tr	tr	2	13	70	15	-	-	-	.70	1.18	1.01
	17	L	-	-	2.5	2.0	35.0	59.4	.5	-	-	.44	1.26	.98
	18	S	tr	5	85	10	tr	-	-	-	-	2.50	1.10	1.03
Eirek	19	L	tr	-	tr	4	95	2	-	-	-	.78	1.05	.85
	21	L	tr	tr	5	40	45	10	-	-	-	.98	1.22	.82

Table 4.--<u>Size distribution (percent by weight), median grain diameter, sorting coefficient, and skewness of beach sands from islets on various atolls in the northern Marshall Islands. (Situation of sample on islet is indicated by S, seaward, and L, lagoon).</u>

Analysts, F. S. MacNeil, G. W. Chloe, Dorothy Carroll

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Atoll	Profile No.	Sample No.	Depth (feet)	Organic carbon (percent)	pH	Grain size (mm) >8.0	8.0-4.0	4.0-2.0	2.0-1.0	1.0-.5	.5-.25	.25-.12	.12-.06	<0.06	Median	Sorting coefficient	Skewness
Shioya soil series																	
Wotho	71	147	0-0.3	3.52	8.0	...	...	...	...	...	...	...	...	...	...	...	...
Wotho	72	148	0-0.3	2.53	8.0	...	...	...	...	...	...	...	...	...	...	...	...
		149	0.3-0.5	1.24	8.6	...	...	...	...	...	...	...	...	...	....	...	...
		150	0.5-1.8	...	...	...	.1	1.8	14.1	60.6	21.0	.6	.1	1.6	.66	1.30	.98
Ailuk	A26	133	0-1.0	...	...	...	...	.2	1.1	20.0	66.0	12.0	.6	.2	.37	1.22	.97
		134	1.0-4.0	...	...	20.5	4.0	5.5	21.0	39.9	8.0	.8	.2	.2	1.05	2.26	2.16
Taongi (Pokak)	141	156	0-0.08	1.05	8.8	...	...	...	...	...	...	...	...	...	...	...	...
Taongi (Pokak)	145	157	0-0.85	...	...	1.7	.6	2.4	4.1	21.1	41.3	15.8	7.3	5.6	.36	1.58	.95
Taongi (Pokak)	139	154	0-0.13	...	...	43.5	22.0	11.5	9.4	6.3	4.3	2.2	.6	.2	6.9	...	...
		153	0.13-1.1	...	...	13.4	28.0	17.1	13.9	15.7	10.1	1.6	.2	.2	2.8	2.6	.70
Likiep	17	125	0-0.6	...	...	35.0	.3	.4	1.7	11.0	19.6	18.3	3.4	10.3	.47	...	...
		126} 127}	0.6-3.0	...	...	40.8	3.3	1.3	3.4	15.2	17.7	16.9	1.3	.2	.90	...	...
		129} 130}	3.0-6.0	...	...	24.6	10.9	13.7	26.8	16.9	1.9	3.5	1.6	.3	1.9	...	...
Lae	46	138	0-0.3 or 0.9	...	...	12.4	3.7	3.2	4.6	18.4	32.6	17.6	3.1	4.4	.86	1.9	1.21
		139	0.3 or 0.9-6.0+	... ...	... ...	16.2	6.0	5.5	19.5	26.6	16.8	7.6	1.3	.7	.92	2.42	1.54

Jemo	29	131	0-0.5	...	...	5.5	1.1	2.5	9.2	47.2	31.6	1.3	.7	.8	.56	1.34	1.26
		132	0.5-2+	...	...	9.0	.8	2.2	7.4	46.4	33.6	.5	.1	.1	.60	1.34	1.09
Jemo	30	69	0-0.6	...	...	.4	...	.1	1.2	19.3	61.5	10.8	2.7	4.1	...	...	...
		70	0.6-1.4	...	...	.2	...	.1	.4	26.7	66.7	5.8	.2	.2	...	...	...
		71	1.4-3.0	...	...	1.7	1.8	5.5	21.6	25.0	32.5	4.6	2.3	4.7	...	...	...
		72, 73	3.0-?	...	...	2.5	1.1	11.9	53.7	29.3	1.5	.3	.2	.1	...	...	...
Utirik	3	97	0-1.3	...	...	28.8	5.1	7.0	19.5	25.2	12.0	2.5	.1	.1	1.3	...	...
		98	1.3-1.9	1.37	8.3				Coral fragments and organic matter								
		99	1.9-2.3	...	...	39.6	9.4	7.5	12.9	17.1	9.7	3.3	.4	.2	3.7	...	...
		100	2.3-3.0	...	...	40.9	8.6	8.5	11.6	18.0	9.4	2.4	.3	.3	3.7	...	...
		101	3.0-4.2	...	...	23.1	15.3	10.9	11.0	18.1	15.8	4.5	.7	.5	1.9	...	...
Utirik	4	102	0-1.6	...	...	13.0	12.7	10.3	22.9	31.0	7.9	1.8	.3	.3	1.2	2.5	2.2
		103	1.6-2.2	...	...	14.0	5.2	5.0	12.6	15.2	12.6	15.5	4.6	15.5	.54	...	...
		104	2.2-2.5	...	...	2.0	1.3	1.5	6.9	10.8	19.6	50.0	6.3	1.8	.22	1.73	.14
		105	2.5-3.2	...	...	41.8	20.3	12.1	15.3	7.2	1.4	1.5	.3	.2	6.6	...	...
Ujae	104	152	0-1.0	...	...	...	.9	.3	7.5	46.0	29.5	9.0	2.7	4.1	.52	1.41	.80
Ujae	103	121	0-1.0	5.23	8.14				25 percent over 2 mm								
Ujae	101	89	0-0.5	7.4	7.7				38 percent over 2 mm								
Ujae	100	88	0-0.5	6.7	7.6				30 percent over 2 mm								
Wotho	A8	23	0-1.4	...	...	.3	4.4	18.5	36.0	29.1	9.8	1.7	.2	.2	1.2	1.61	.95
		24	1.4-1.9	...	...	13.3	13.5	15.8	30.7	22.7	2.9	.9	.3	.2	1.6	2.12	1.6
		25	1.9- ?	...	...	9.5	19.7	27.1	24.9	13.8	2.4	1.9	.5	.2	2.2	2.0	1.2

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Wotho	A7	21	0-1.6	...	...	1.7	2.4	5.0	18.7	50.5	18.0	3.2	.4	.3	.72	1.41	1.14
		22	1.6- ?	...	...	.5	3.7	7.7	17.7	36.4	23.9	10.0	.2	.2	.70	1.73	.95
Wotho	69	141	0-1.0	...	...	40 percent over 2 mm											
		142															
		143		...	...	6 percent over 2 mm, earthy											
		144	1.0-3.0	...	...	2.1	2.1	3.0	5.8	35.2	46.5	4.4	.5	.4	.48	1.08	1.26
Taka	A15	109	0-0.3	...	...	8.2	5.2	6.0	13.9	29.1	27.0	9.0	1.1	.5	.66	1.95	1.15
		110	0-3-0.9	...	...	22.8	5.7	4.5	9.0	20.8	25.6	10.3	.8	.6	.74	4.35	4.73
		111	0.9-1.4	...	...	30.4	15.3	8.3	9.8	15.7	14.2	5.4	.5	.3	2.7	...	...
		112	1.4-1.8	...	...	41.2	14.2	8.2	11.2	16.1	7.7	1.2	.1	.1	5.4	...	...
		113	1.8-2.1	...	...	40.1	15.0	9.4	6.7	13.1	11.6	2.9	.7	.6	4.8	...	...
		114	2.1-3.1	...	...	50.5	8.9	5.0	7.4	14.2	11.1	2.4	.3	.2	...	...	...
		115	3.1-8.8	...	...	26.1	10.9	9.4	17.6	23.8	8.7	2.6	.8	.4	1.7	3.68	2.35
Taka	11	122	0-0.8	...	...	...	tr	tr	2.1	17.0	45.2	31.6	3.4	.6	.26	1.41	1.81
		123	0.8-1.5	...	...	34.1	4.8	5.0	12.0	24.4	10.4	5.0	2.0	2.4	...	...	...
		124	1.5-3.0	...	...	66.0	9.4	4.3	6.7	6.9	5.1	1.2	.2	.2	...	...	...
Taka	A16	116	0-0.5	...	...	...	1.7	.3	1.8	25.1	52.4	17.3	1.1	.3	.39	1.34	1.03
		117	0.5-1.2	...	...	2.5	2.0	1.2	3.2	20.4	43.0	23.2	2.8	1.7	.35	1.55	1.36
		118	1.2-1.9	...	...	2.5	tr	.27	1.7	14.7	45.0	32.3	3.0	.5	.27	1.38	1.26
		119	1.9-2.8	...	...	35.0	4.5	2.5	4.0	13.6	28.2	11.1	.8	.4	.80	...	...
		120	2.8-5.7	...	...	28.6	10.9	5.5	10.8	33.0	9.1	1.6	.4	.1	1.4	...	...

Taka	13	54	0-0.25	...	...	.5	.3	.5	3.8	26.5	47.4	15.3	3.0	2.8	.36	1.41	1.16
		55	0.25-2.0	...	...	25.9	8.8	4.5	10.3	22.0	20.2	7.3	.4	.6	.94	4.55	4.58
		56	2.0-2.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		57	2.5-4.4	...	...	14.9	7.5	9.4	20.9	21.4	16.3	7.6	.9	1.1	1.05	2.53	1.35
Arno Atoll soil series																	
Utirik	1	37	0-0.7	6.01	8.0	60 percent over 2 mm											
		38	0.7-1.1	3.2	8.1	57 percent over 2 mm											
		39	1.1-2.7	1.8	...	24.6	18.7	6.6	7.7	19.5	12.0	5.5	2.3	3.0	2.0	4.07	1.21
		40	2.7-4.0	...	...	16.1	19.3	8.1	8.8	20.3	16.7	8.5	1.2	.8	1.2	3.64	1.87
Utirik	2	41	0-0.2	...	8.3	10.2	3.8	2.9	7.9	26.5	22.1	16.1	5.3	5.3	.52	2.08	.85
		42	0.2-0.7	...	8.9	2.6	2.0	2.9	16.0	40.6	24.8	9.1	1.0	1.1	.68	1.58	.76
		43	0.7-1.8	...	8.8	9.8	2.2	3.9	25.3	43.4	8.8	4.5	1.1	.9	.86	1.53	1.13
		44			9.3	.7	2.9	3.8	33.6	46.7	9.3	2.3	.5	.5	.84	1.38	1.05
		45	1.8-7.0	...	...	19.2	9.9	7.4	32.1	25.9	3.2	1.3	.6	.6	1.35	2.55	2.64
		46	7.0-8 +	...	...	16.6	14.7	25.1	33.0	6.3	1.8	2.1	.4	.3	2.2	1.67	2.64
Utirik	5	47	0-0.7	3.49	7.9	...	...	...	...	...	...	...	...	...	...	...	...
		48	0.7-1.5	...	....	2.9	1.2	1.2	26.8	51.0	11.7	3.4	.9	.7	.68	1.38	1.33
		49	1.5-2.5	...	...	.3	.8	1.0	36.0	48.2	10.7	2.4	.4	.3	.86	1.31	.95
		50	2.5- ?	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ujelang	A3	30	0-1.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		31	1.5-2.4	...	...	20.5	11.0	14.5	15.9	16.2	13.5	5.5	1.3	1.8	1.65	...	...
		32	2.4- ?	...	...	48.7	10.5	10.0	10.9	9.0	5.8	3.2	.9	1.1	...	...	...
Taka	A14	106	0-0.9	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		107	0.9-3.4	...	...	26.6	9.9	6.6	15.9	30.6	8.9	.9	.2	.5	1.4	3.8	3.3

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

		108	3.4-4.0	...	...	9.7	15.2	13.8	30.8	28.6	1.2	.4	.3	.1	1.35	2.1	1.9
Wotho	70	145	0-1.0	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		146	1.0-1.7	...	...	19.2	17.8	28.0	19.1	10.2	3.7	1.2	.4	.5	2.7	2.16	1.26
Wotho	A9	27	0-1.0	3.47	7.8	...	...	...	...	...	...	...	...	...	...	...	...
		28	1.0-2.0	...	...	2.4	9.5	19.0	32.4	24.8	8.9	2.4	.4	.3	1.35	1.73	.96
		29	2.0-5.0	...	...	6.0	8.1	16.1	31.3	31.2	4.4	2.7	.2	.2	1.2	1.76	1.20
Ujae	84	86	0-0.5	4.9	7.5	...	...	...	...	...	...	...	...	...	...	...	...
Ujae	98	87	1/ Surface	7.6	7.3	...	...	...	...	...	...	...	...	...	...	...	...
Jemo	27	63	0-0.7	11.0	7.3	...	...	...	...	...	...	...	...	...	...	...	...
		64	0.7-1.1	5.0	7.5	...	...	...	...	...	...	...	...	...	...	...	...
		65	0.7-1.1	1.5	7.8	...	...	...	...	...	...	...	...	...	...	...	...
		66	1.1-2.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		67,68	2.4- ?	...	...	1.1	4.7	25.0	38.4	29.7	1.0	.3	.1	.1	1.3	1.64	1.04
Ailuk	A23	33	0-1.2	2.75	8.1				40 percent over 2 mm								
		34	1.2-1.7	...	...	.3	1.0	5.4	53.5	37.1	2.1	.3	.2	.2	.56	1.34	0.87
		35	1.7-2.4	2.1	8.3				63 percent over 2 mm								
		36	2.4-4.3	...	...	7.9	11.3	20.9	39.4	14.8	2.5	1.7	.7	.6	1.7	1.67	1.18
Ailuk	38	77	0.1.0	3.75	8.0	22.9	10.0	7.1	11.5	28.5	11.0	4.8	2.2	2.2	1.1	3.04	2.58

		78	1.0-1.8	...	...	2.1	1.9	6.0	38.4	47.7	1.2	1.2	.9	.6	.98	1.34	1.08
		79} 80}	1.8-2.7	...	...	32.0	16.1	18.9	22.2	6.6	1.4	1.3	.9	.7	3.7	...	...
		81	2.7-3.0	1.08	8.5	...	...	...	...	...	...	...	...	...	...	...	...
		82	3.0-3.74	...	...	69.6	14.2	6.1	3.6	3.2	1.6	.5	.4	.6	...	...	...
Likiep	18	58	0-1.3	...	...	52.5	6.1	2.7	6.5	17.2	8.9	3.1	1.4	1.6	...	...	...
		59	1.3-2.5	...	...	32.1	5.0	2.0	8.5	36.2	11.3	3.8	.6	.5	.94	4.0	5.70
		60} 61}	2.5-3.9+	...	...	2.0	5.0	14.0	51.2	21.8	2.1	2.4	.6	.7	1.2	1.41	1.12
Lae	A11	272	0-0.6	4.79	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		273	0.6-1.4	...	...	16.2	14.3	8.5	27.8	26.8	3.7	1.3	.5	.8	2.0	1.48	.74
		2/...	1.4-2.2	...	...	...	...	...	...	...	...	...	...	...	...	...	...
		274	2.2-2.5	...	...	41.4	37.6	11.3	5.5	2.6	.8	.4	.2	.2	7.0	...	...
		275	2.5-5.0	...	...	23.6	5.8	9.3	31.5	22.3	4.4	1.8	.5	.7	1.4	2.51	2.51
								Jemo soil series									
Jemo	26	4	3/1-0	33	3.8					Peaty, 3.7 percent coral fragments							
Jemo	25	1	3/0.5-0	17.68	5.2					Peaty, 9.6 percent coral fragments							
		2	0-0.3	...	...												
		3	0.3-1.5	2.12	...					Peaty, 61.3 percent coral fragments							
Bikar	156	176	3/0.15-0														
		177	0.0.1														
		178} 179}	0.1-0.6	...	...	.9	.5	1.8	10.5	37.6	40.5	7.2	.5	.5	.5	1.45	1.0
		182	1.2-2.5	...	...	1.2	2.7	1.4	23.3	41.0	24.7	4.4	.7	.8	.66	1.51	1.08
		186}	4.8-8.8	...	...	5.5	10.9	7.8	16.1	29.3	21.6	7.1	.6	1.4	.76	4.2	2.02
		187}	4.8-8.8	...	...	18.6	13.5	10.5	14.7	24.2	15.0	3.0	.2	.2	1.3	8.3	2.9

Table 5.--Grain-size distribution (percent by weight), and pH of soils in the northern Marshall Islands

[Analysts, P. D. Blackmon and Dorothy Carroll]

Bikar	153	12	[3/]0.1 to 0.15-0	31.4	4.5	...	...	...	...	...	...	...	...	...	...	...	...
		13	0-1.0	...	7.9	...	...	...	...	...	...	...	...	...	...	...	...
		14	1.0-1.2+	...	8.6	...	.6	2.7	19.3	47.7	26.6	2.8	.2	.2	.6	1.41	1.22
Bikar	166	15	[3/]0.4-0	30.9	4.8	...	...	...	...	...	...	...	...	...	...	...	...
		16	0-0.6	...	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		17	0-0.6	...	7.6	...	...	...	...	...	...	...	...	...	...	...	...
		18	0.6-1.0+	...	8.5	24.0	13.5	14.9	18.2	19.3	8.2	1.7	.2	.2	.9	3.4	.59
Bikar	165	19	[3/]0.7-0	30.9	5.3	...	...	...	...	...	...	...	...	...	...	...	...
		20	0-0.5	...	8.0	...	...	...	...	...	...	...	...	...	...	...	...
Bikar	164	166	0.25-0.6+	...	...	34.6	12.0	11.8	14.4	17.8	7.7	1.4	.2	.2	3.2	...	...
Miscellaneous soils																	
Lae	A7	266	0-0.5	19.8	7.3	...	...	...	...	...	...	...	...	...	...	...	...
		267	0.5-0.8	...	...	40.0	21.8	9.3	10.9	10.4	4.3	1.7	.8	1.1	1.6	2.09	2.24
		268	0.8-2.5	...	...	52.6	26.3	12.8	4.1	1.5	.8	.8	.5	.6	...	...	...
Lae	A10	74	0-0.5	2.6	8.1	...	...	...	...	...	...	...	...	...	...	...	...
		75	0.5-2.2	...	...	4.1	2.8	4.9	41.0	25.8	13.0	7.2	1.2	.7	2.0	1.41	.75
		76	2.2-3.8	...	...	13.0	3.9	6.8	32.9	20.9	11.0	7.0	2.3	2.3	1.15	1.79	.83
Lae	A8	269	0-0.5	8.17	7.5					12.5 percent over 2 mm							
		270	0.5-0.9	4.33	7.8					58.3 percent over 2 mm							

		271	0.9-1.5	...	...	5.6	5.2	9.5	22.4	44.4	8.1	2.6	.9	1.1	.88	1.61	1.24
Ujae	83	151	0-1.5	...	...	11.8	.9	.5	2.6	11.7	39.3	25.8	3.5	4.0	.32	1.67	1.09
Ujae	81	84	[3] 0.2 or 0.4-0	8.1	7.4					42 percent over 2 mm							
Ujae	102	90	0-1.0	9.4	7.7					31 percent over 2 mm							
Utirik	6	256	0-1.9	2.65	8.7					38 percent over 2 mm							
		257	1.9-2.5	1.45	9.0					30 percent over 2 mm							
		258	2.5-3.2+	...	...	25.0	9.9	8.3	9.4	13.1	8.6	8.1	5.8	11.9	1.2	6.25	1.44
Ujae	82	85	0-0.5	8.11	7.6					23 percent over 2 mm							
Taongi (Pokak)	138	[2] ...	0-0.1														
		[2] ...	0.1-0.3														
		155	0.3-0.8	...	...	21.4	7.0	6.4	8.9	18.6	22.6	8.8	3.1	3.3	.76	3.98	3.18
Ailuk	A21	263	0-0.9	11.67	7.7					45 percent over 2 mm							
		264	0.9-2.5	3.37	8.4					13.6 percent over 2 mm							
		265	2.5-3.0	...	...	24.6	12.3	9.6	9.7	23.7	10.8	5.6	1.7	2.1	1.5	3.31	1.65

[1] Thickness of layer not recorded.

[2] No sample.

[3] Depth of leaf litter or raw humus above the soil.

Atoll	Sample No.	Situation on atoll or islet	Sorting	Major constituents					Sorting caused by			Skewness		
				Corals, algae	Fresh Foraminifera	Worn Foraminifera	Mixed assemblage	None dominant	Organisms (Category A)	Agencies (Category B)	Both together (Category C)	Skewness (Sk)	Mean[1] (mm)	Sign of skewness
Taongi (Pokak)	T16	[2] S	1.90	...	...	...	...	+	...	+	...	1.08	0.88	+
Do	T15	S	1.38	...	...	...	+	...	...	...	+	.92	.97	+
Do	T19	S	1.67	...	+	...	...	...	+	...	...	.93	1.24	+
Do	T10	S	1.70	...	...	...	+	...	...	...	+	1.19	1.14	+
Do	T8	S	1.80	...	...	...	+	...	...	...	+	.98	2.08	+
Do	T7	S	1.52	...	...	...	+	...	...	...	+	1.04	.50	0
Do	T6	S	1.22	...	+	...	...	...	+	...	...	.99	1.30	0
Do	T32	S	1.14	+	...	...	...	...	+	...	...	1.06	.56	0
Do	T5	S	1.73	...	...	...	+	...	...	...	+	1.10	.86	+
Do	T21	S	1.48	+	...	...	...	...	+	...	...	1.00	1.36	+
Do	T26	S	1.41	...	...	...	+	...	...	...	+	1.02	1.01	+
Do	T25	S	1.30	...	...	...	+	...	...	...	+	1.03	.28	0
Do	T29	S	1.48	...	...	...	+	...	...	...	+	1.07	1.11	+
Do	T30	S	1.45	...	...	...	+	...	...	...	+	1.14	.77	-
Do	T17	[3] L	1.67	...	...	...	+	...	...	...	+	1.06	1.35	+
Do	T14	L	1.52	...	...	...	...	+	...	+	...	.99	1.29	+
Do	T13	L	1.26	...	...	...	+	...	...	...	+	.98	.93	+
Do	T12	L	1.73	...	...	...	+	...	...	...	+	.87	.44	+
Do	T11	L	1.41	...	...	...	+	...	...	...	+	1.01	.57	0
Do	T9	L	1.73	...	...	...	+	...	...	...	+	1.28	1.47	+
Do	T27	L	2.65	...	...	...	+	...	...	...	+	.71	.40	+
Do	T4	L	1.58	...	...	...	+	...	...	...	+	.90	1.30	+
Do	T20	L	1.58	...	...	...	...	+	...	+	...	1.02	1.10	+
Do	T22	L	1.34	...	...	...	+	...	...	...	+	1.00	.91	+
Do	T23	L	1.90	...	...	...	+	...	...	...	+	.90	1.73	+
Do	T24	L	1.41	...	...	...	+	...	...	...	+	1.05	1.42	+

Bikar	B14	S	1.61	...	...	...	+	...	...	...	+	1.16	1.47	+
Do	B15	S	1.73	...	...	...	...	+	...	+	...	1.17	1.09	+
Do	B12	S	1.92	...	...	...	+	...	...	...	+	.93	2.46	+
Do	B16	S	1.95	...	...	...	...	+	...	+	...	1.62	1.23	+
Do	B4	S	1.84	...	...	...	...	+	...	+	...	.93	1.78	+
Do	B5	S	1.98	...	...	...	+	...	...	...	+	.60	.98	+
Do	B6	S	1.30	...	...	...	+	...	...	...	+	1.03	.55	0
Do	B7	S	2.51	...	...	...	...	+	...	+	...	1.08	1.21	+
Do	B13	L	2.02	...	...	...	...	+	...	+	...	.81	1.47	+
Do	B11	L	1.92	...	...	...	...	+	...	+	...	.93	2.81	+
Do	B3	L	1.64	...	...	...	+	...	...	...	+	.83	.64	0
Do	B8	L	1.34	...	...	...	...	+	...	+	...	1.07	.91	+
Ailuk	6	S	1.45	+	...	...	...	...	+	...	...	1.27	[4]n.d.	+
Lae	14	S	1.68	...	...	...	+	...	...	...	+	1.15	3.80	+
Likiep	J8	S	1.26	...	...	+	...	...	+	...	...	1.06	1.18	+
Do	7	S	1.55	+	...	...	...	...	+	...	...	1.64	1.30	+
Kwajalein	9	S	1.70	...	...	...	...	+	...	+	...	2.03	1.37	+
Do	J10	S	1.79	...	...	+	...	...	+	...	...	1.61	1.28	+
Do	10	L	1.10	...	...	+	...	...	+	...	...	.89	.75	0
Do	J1	L	1.09	...	...	+	...	...	+	...	...	.98	.68	0
Do	11	L	2.36	...	...	...	+	...	...	...	+	2.13	.99	+
Do	J2	L	2.76	...	...	...	+	...	...	...	+	1.63	1.57	+
Do	12	L	1.26	...	...	...	+	...	...	...	+	.97	.39	0
Do	J7	L	1.26	...	...	+	...	...	+	...	...	.99	.36	0
Taka	5	S	1.18	...	...	...	+	...	...	...	+	1.06	1.06	+
Do	J3	S	1.26	...	...	+	...	...	+	...	...	.88	1.16	+
Do	28	S	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	n.d.

1/Mean grain size; 2/S, seaward beach; 3/L, lagoon beach; 4/n.d., not determined.

Table 6.--Coefficient of sorting of Marshall Islands beach sands in relation to major constituents and skewness of distribution

Analyst, Dorothy Carroll

Atoll	Sample No.	Situation on atoll or islet	Sorting	Major constituents: Corals, algae	Fresh Foraminifera	Worn Foraminifera	Mixed assemblage	None dominant	Sorting caused by: Organisms (Category A)	Agencies (Category B)	Both together (Category C)	Skewness: Skewness (Sk)	Mean[1] (mm)	Sign of skewness
Do	TW4	L	1.00	...	...	...	...	+	...	+	...	2.20	1.31	+
Ujae	J6	L	1.70	...	...	...	+	...	...	...	+	1.45	1.10	+
Do	13	L	1.00	...	...	...	+	...	...	...	+	.83	.72	0
Ujelang	J4	S	1.87	...	...	+	...	...	+	...	...	2.08	3.06	+
Do	J5	S	1.64	...	...	+	...	...	+	...	...	1.02	1.38	+
Do	J9	S	1.79	+	...	...	...	...	+	...	...	1.06	2.90	+
Do	25	S	1.70	...	...	...	...	+	...	+	...	.73	2.00	+
Do	23	L	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	+
Do	24	L	1.34	...	...	...	+	...	...	...	+	1.12	.45	+
Do	26	L	2.60	...	+	...	...	...	+	...	...	3.66	n.d.	+
Utirik	1	L	1.41	...	...	+	...	...	+	...	...	1.14	.93	+
Do	2	L	n.d.	...	...	...	+	...	...	...	+	n.d.	n.d.	n.d.
Do	3	L	1.10	...	...	...	...	+	...	+	...	.90	n.d.	+
Do	U5	L	n.d.	+	...	...	...	...	+	...	...	n.d.	7.26	n.d.
Wotho	15	S	2.02	+	...	...	...	...	+	...	...	4.26	n.d.	+
Do	16	S	1.18	...	...	+	...	...	+	...	...	1.01	.73	0
Do	18	S	1.10	+	...	...	...	...	+	...	...	1.03	2.60	+
Do	17	L	1.26	...	...	...	...	+	...	+	...	.98	.48	0
Do	19	L	1.05	...	...	+	...	...	+	...	...	.85	.77	0
Do	21	L	1.22	...	...	...	...	+	...	+	...	.82	.96	0

[1] Mean grain size; [2] S, seaward beach; [3] L, lagoon beach; [4] n.d., not determined.

Table 6.--Coefficient of sorting of Marshall Islands beach sands in relation to major constituents and skewness of distribution

Analyst, Dorothy Carroll

PART IV: UNCONSOLIDATED SEDIMENTS CONSIDERED AS SOILS

by F. R. Fosberg and Dorothy Carroll

The loose unconsolidated sediments are the parent materials of the majority of the soils that develop on atolls. In no place visited in this survey was any soil observed being developed by gradual alteration or weathering in place of consolidated materials, nor has any such soil been found described in the literature on coral atolls (unless breaking down of limestone in mangrove swamps, described for Indian Ocean atolls by Wharton (1883), is regarded as an exception).

A distinction must be made between these sediments, which are practically pure calcium carbonate, and such impure limestones as are laid down adjacent to high land from which they receive an increment of detrital clay and sand. From such impure limestones, soils which are either clayey or sandy will develop through removal of calcium carbonate from the rock. Such soils are common on the coral limestone portions of high complex islands such as the Marianas and Ryukyus. It has not been suggested that any atoll soils are of such a residual nature except by Lipman and Shelley (1924), who suggested that a considerable thickness of limestone has been dissolved away to produce the soil analyzed by them from Rose Island, Samoa. The inadequacy of the sample analyzed and the existence there of volcanic rock of uncertain origin make it futile to discuss this one exception until further study is made of the Rose Island soils.

General character of atoll soils

In general the soils found on coral atolls are pale to gray-brown or black, and sandy to very coarse in texture. Occasional loamy or sandy loam surface layers occur, and less commonly are present as buried horizons. The depth varies, but according to no obvious pattern. In most places sampled consolidated rock was encountered only below 1 meter depth or not at all in test holes dug to between 1 and 3 meters. The material is conspicuously stratified, but the beds of different textures do not commonly correspond well to true soil horizons, which are distinguished by color (as well as chemical, mineralogical, and textural) differences.

Since all these soils are very immature, the horizons are mostly weakly developed and tend to grade into one another rather than being sharply defined. Generally there are only an A1 horizon of varied thickness, darkened by humus, and a C horizon not much altered. In one special type of limited extent an Ao horizon of raw humus and a B horizon of phosphate are characteristic.

Usually the darker and presumably older soils are nearer the center of the islets, if present at all, whereas the lighter ones tend to be peripheral. Ridges of very coarse stony material are common, mostly on the seaward sides of islets. Muck soils of very limited extent are found in depressions and taro pits.

Previous descriptions

There have been various casual references to, and passing descriptions of, atoll soils in the past, as well as the brief analytical study and interpretation by Lipman and Shelly (1924), and a series of short descriptions of soils of the Pacific equatorial islands by Christophersen (1927). Effective study of atoll soils, however, scarcely began before 1950, when E. L. Stone, Jr., visited Arno Atoll, in the southern Marshall Islands, for the express purpose of making soil investigations. His preliminary report (1951a) described in detail fourteen soil types and discussed soil formation in terms of physical and biological factors, as well as the chemical properties and ecological relations of these soils. Two of the soil series recognized by Stone (1951a, p. 19-25), the Shioya and Arno Atoll, plus his "stony and very stony complex" have since been found to be very widespread and most of the soils studied in the present investigation are classified with them. During 1951, investigations were carried out in the Gilbert atolls by Catala and by Cloud, as well as the beginning of the present study in the northern Marshalls. A preliminary report by Cloud (1952), a review by Stone (1953), an extensive report by Catala (1957), and short studies by Fosberg (1954), and Fosberg and others (1956) resulted. These brought out some additional diversity, including low-lying soils with a compact clay-like subsoil in the Gilberts, and the description of the Jemo series of phosphate soils in the Marshalls. Investigations on Raroia, Tuamotus, by Newell in 1952 and on Kapingamarangi, Carolines, by McKee and Niering in 1954 (Newell, 1954a, b, 1956; McKee, 1956, 1958; Niering, 1956, 1963) showed that essentially the same types of soil occur in these islands as were previously described from the Marshalls. No phosphatic soils were found on Raroia, however. Tercinier (1955), describing soils of the low islands of French Oceania, recognized three soil types only, in addition to stony ridges corresponding to the "stony and very stony complex." Of these, the pinkish sandy and gravelly soils immediately behind the boulder ridge and the sandy and gravelly soils along the lagoon shore seem to fall into the Shioya Series, and his stony or stony-gravelly soils from the center of the atoll obviously correspond to rather poorly developed Arno Atoll Series soils.

Most of the above workers seem to be in essential agreement about most of the soil-forming processes, and their reports are drawn upon freely in the present interpretation of the situation in the northern Marshall Islands.

Soil-forming factors

According to Jenny (1941) there are five principal factors of soil formation: parent material, climate, biological activity, relief, and time. Many processes can be identified as contributing to or characterizing the interaction between these variable factors to form soils. Soil development, in most continental and high island areas, presupposes that the parent material is weatherable; that is, that it can be broken down chemically and mechanically to form the mass of material in which plants grow and which we term soil. This weathering goes on everywhere, but in areas where the parent material is of loose sediments it is not as essential as in places where soils must be derived from hard rock. Here in the coral atolls an acceptable distinction can scarcely be made between the loose unaltered sediments which make up the parent material and essentially similar materials which serve as a substratum for plant growth and which are then called soil. However, the alteration and diversification of these materials which have produced and now characterize the various soil types described by previous workers, and which are recognized and discussed below, are definitely the result of certain processes of soil formation. Therefore, they are properly termed soils, though they are very young and poorly developed soils. Especially important among the processes involved are the accumulation of organic material, and the leaching and deposition of mineral materials, particularly calcium carbonate and phosphate.

The soil-forming factors considered important by Jenny (1941) are discussed in their relation to atoll conditions in the northern Marshalls and to the soils that have developed on the atolls.

Parent material

The parent material has been described and commented upon above, (see p. 23), being loose calcareous sediments of varied texture. The degree of alteration varies with the soil concerned. Generally the particles in the blacker layers have become more weathered than corresponding particles in the paler material.

Climate

The features of the climate of the northern Marshalls (see p.5-6) that are of most significance in the formation of its soils would seem to be the consistently rather high temperatures and complete lack of frost, the amount and distribution of rainfall, the intensity and prevalence of winds from a particular direction, and the incidence of typhoons.

With temperatures ranging continuously between 68° and 95° F, the rate of production and addition of organic matter to the soil is high and the process is not seriously interrupted seasonally. However, the same high temperatures result in rapid and relatively complete decomposition of the organic matter, under most circumstances, and consequent slowness of humus accumulation in the soils. Lack of frost which seriously reduces the populations of decomposing agents in temperate climates and interrupts their activities, tends to accentuate this effect of the high temperatures, as compared with more northern climates.

The relatively high rainfall, tending to increase luxuriance in the vegetation, also brings about the addition of greater quantities of organic matter as well as, in some areas, providing a more favorable medium for some of the organisms responsible for decomposition of this material. It also brings about leaching of soluble constituents at a high rate, as well as the weathering of the particles. The effect of this leaching on accumulation of organic matter is not clear to us. A result that is of more than ordinary interest in the atoll environment is the removal of sea salt that would otherwise accumulate in large amounts from the spray which is carried onto the land by the wind. The large amount of rain also serves to balance the effect of diffusion of salt water into the soil from the surrounding ocean. All the effects ascribed to rainfall will theoretically decrease in intensity as one goes from south to north in the Marshall Islands, as the rainfall becomes less in that direction. Actually, such differences are hard to observe and scarcely show up in our data, as the number of analyses is very small and they were not made with these features in mind. However, the complete lack of dark soils on Taongi (Pokak) Atoll, the driest of the group and that with the sparsest vegetation, may be significant in this connection. The effects of seasonality of rainfall in the Marshall Islands are not apparent, probably because the increase in seasonality is roughly parallel with increased dryness, and the effects of the two would be hard to distinguish.

The only obvious effects of ordinary wind would be in the deposition of sand, carried from the beaches onto the land in the interior of the islets, and the carrying of salt spray in from the breaker zone at the edge of the reef on the windward side. The amount of sand deposition is obviously important, as indicated by the small dunes found here and there, especially piled around the bases of plants. Layers of pebble-free sand in soil profiles are probably to be ascribed to wind, as well as some of the sand in other layers, but so far we have usually not been able to distinguish this material from that deposited by water. The effects of salt spray on the vegetation are apparent in the windward-leeward asymmetry of the profile of the vegetation when viewed from a distance, in the greater development of halophytic features on the windward side, and in eccentric patterns of zonation of vegetation in islets. Whether there is a direct effect on the soil or only an indirect one through the vegetation is not clear.

The effect of typhoons on the soil pattern is gross but of the greatest importance. Plate 32 shows the effect of a typhoon on Utirik islet. The marks of such catastrophic events may be seen practically everywhere. Boulder ridges, classified as stony and very stony complex soils, are a striking feature of most atolls. Denuded areas, of bare rock with only pockets of soil are very common and probably the result of typhoon action. Most areas show soil profiles with buried A horizons. These are probably very largely the result of deposition of sheets of sand and gravel by typhoons. Effects of long duration from inundation by salt water, though they might be expected, have not been noted.

Biological activity

Biological activity will be treated in somewhat more detail, as it is essential for an understanding of the soil-forming processes. Plants and animals are both important.

The luxuriance of the vegetative cover reflects, in an accentuated fashion, the gradient of rainfall from south to north. In the more humid south the cover is very dense, thinning out gradually northward until in the much less rainy Taongi (Pokak) Atoll it presents a distinctly semi-arid aspect. This does not seem explainable on the rainfall figures alone, since the rainfall of Taongi is about that of the luxuriantly green eastern United States, but must depend on the almost perfect drainage combined with high temperatures. The vegetation of the northern Marshall Islands was briefly described on page 24, to which reference should be made.

The influence of biological factors has been described by Stone (1951a, p. 15-18), and the following paragraphs have been taken from his work.

"BIOLOGICAL FACTORS

"Organic Matter

"From previous paragraphs it is already apparent that living vegetation and its disintegrating products contribute greatly to the solution of calcium carbonate by their production of carbonic acid. Through penetration of roots this process may occur slowly even well within large pieces of porous coral. Baas-Becking has called attention to the abundance of algae which on Arno, as elsewhere on the moist tropics, mantle the surface of rocks and even the sand in open groves.

"Apart from the effects on solubility the organic matter itself is of great significance in soil formation. In the absence of the more profound changes that mark mature soils, the presence of organic matter is the principal feature characterizing the atoll soil. It is obviously the principal source of cation exchange capacity. Further, the accumulation of nitrogen parallels that of well decomposed organic matter ("humus") for there is a fixed carbon-nitrogen ratio of approximately 10 or 12 to 1.

"The breakdown of organic remains is carried on in large part by micro-organisms but earthworms are often abundant, and small snails locally so, in the darker soils. The earthworms are presumably significant agents in mixing the surface matter with mineral soil although root growth and decay provides another means of incorporation. Dead woody tissues are generally broken down by termites. In localized areas burrowing crabs accomplish very considerable mixing. Where excessive moisture prevents normal oxidation of organic materials these accumulate giving rise to peats and mucks ....

"Nitrogen Fixation

"Baas-Becking has stressed the possible role of algae as nitrogen fixers and from soil samples collected by him a new group of nitrogen bacteria, Beijerinckia, has been isolated by Derx. Azotobacter has not been reported in atoll soils but would be expected in this habitat. /Later found in Stone's samples by Lochhead, see Stone (1953), and by Stevenson (1953)./

"On Arno legumes are common and nodules were observed on Vigna marina, Sophora tomentosa and Canavalia sericea. On the latter they occur on the roots at some distance from the root crown and hence they may be easily missed. The Vigna seems particularly important for it forms thick masses in the open groves and extends aggressively onto sand beaches, old dwelling sites and burned areas. The two species of Canavalia, though less abundant, are vigorous vines in lightly shaded areas. Intsia bijuga is the only leguminous tree but its abundance in the original forest cannot be estimated accurately now.

"Seabirds

"Throughout the dry islands of the Pacific nesting seabirds have created guano deposits and highly nitrogenous soils. Under wet conditions such accumulations do not remain long but the numerous areas of phosphate rock are generally considered to have originated beneath such guano areas. As mentioned, the phosphate was precipitated as the insoluble calcium salt when carried into calcareous material beneath, whereas the soluble nitrates were washed away. The resulting product is usually well cemented although unconsolidated brown sands may occur with the rock. Phosphate rock, guano, and soils strongly influenced by guano occur only where large numbers of seabirds congregated for long periods. Even away from these areas, however, the birds must have a very considerable effect on the soil. They are common in small numbers on many islands where they roost and nest...; feeding along the beaches and at sea they are the only significant agents adding to the land from the fertility of the sea."

Another biological activity not to be underestimated is the boring activity of microscopic blue-green algae which seems general in any limestone surface exposed to air for a considerable length of time. So appreciable is the breakdown of limestone by this agency that Nesteroff (1956) regards it as accounting for the greater part of both intra- and supra-tidal erosion of limestone. These algae must also add organic matter and possibly also nitrogen to the soil.

Relief

The relief of the atolls is negligible, the highest point seen being only some 25 feet above mean sea level. Nevertheless, drainage is rapid. Actually, since drainage has little or no relation to relief, it should in these situations be considered a separate additional factor, distinct from relief. The relief is mainly the result of piling up of loose materials, rather than of erosion of elevated land. There seems to be little or no relation between slope and soil type, but where the bottoms of depressions approach the water table there are in most cases special soils, either peat or muck. The higher areas are generally either boulder ridges or sand dunes. On the boulder ridges the soil is classified as stony and very stony complex; on the dunes it is generally Shioya. However, these seem to be more depositional than related to relief.

Drainage

The drainage in the atoll soils is mostly either very good or extremely poor (see p. 23), the coarse texture permitting rapid percolation of water through most material that lies at all above the water table. The water table is essentially mean tide level and fluctuates slightly with tidal changes.

Two processes related to the good drainage above the water table are of general significance. One is the solution, and removal by leaching of solutes, that accompanies the movement of water over the surfaces of the particles. The other is the migration downward of any very finely divided material that exists in or is deposited on the upper layers. This probably accounts in part for the low proportion of finer inorganic fractions in these soils. Also important here may be sorting and removal during the deposition process, also probably an original deficiency of fines.

Time

The time factor is difficult to assess, as the actual age of a soil is seldom known. However, the fact that calcium carbonate has not been removed to any great extent, at least differentially, from the upper layers of these soils, even in some cases under the influence of water that has percolated through an acid peaty layer, is one indication that these soils are relatively young. The difference between the actual and theoretical calcium percentages is so small and so obscured by the varied magnesium percentages that it cannot be regarded as indicating much or perhaps any differential leaching of calcium carbonate in any particular layer. It is commonly found, too, that the calcareous remains of the various reef organisms are readily recognizable throughout the profiles and have not been strongly affected by solution. Foraminiferal tests from soils are shown in plate 33. The weathering exhibited by these tests shows that some solution does occur, but not enough to make them unrecognizable. The hardness of the ground water also indicates solution, but not the amount.

It seems fairly clear that the Shioya soils are very young, grading imperceptibly into almost completely unaltered parent sediments. Almost no organic matter has accumulated in these light-colored soils. They grade into the darker Arno Atoll series, with much higher organic content and also more weathering of calcareous particles. There is undoubtedly a greater time involved in the formation of the blacker soils, but what the actual or relative time figures are is at present impossible to say. The variable nature of the other factors involved makes it highly unlikely that there is anything like a linear relation between amount of organic matter and time. The clarification of this relationship would be of great interest but will undoubtedly require more information than is presently available. Perhaps radiocarbon determinations of the organic carbon at different levels may give some approach to an absolute time scale.

The thickness of phosphate layers in the Jemo soils and the degree of replacement of calcium carbonate by calcium phosphates is undoubtedly also related to time. Certain of the layers analyzed are completely altered to phosphorite, but differences in bird populations and in luxuriance of the *Pisonia* forests involved in the phosphate formation again suggest that no linear relation is possible.

Until the detailed chemistry of the percolating waters that carry out the leaching process is known it will not even be possible to say what theoretical rates of change in proportions of relatively insoluble substances are likely. All that can be said now is that the differences in amount of most of them found in our analyses are too small to be very useful in interpreting the effects of the time factor in the formation of atoll soils.

Composition

Atoll soils resemble the beach materials of the islets in grain size distribution and in chemical and mineralogical composition. The grain size distribution of the soils was given in table 5. Table 7 sets out the most prevalent grade sizes found in the principal types of soil. The relation between the size distribution in beach sands and soils is shown in figure 28.

Table 7.--Distribution of modal grade size of calcareous material in soil profiles as percentage of total samples sieved

Soil series	Grade size (mm)						
	+8.0	+4.0	+2.0	+1.0	+0.5	+0.25	+0.125
Shioya (46)*	32	2	2	11	21	28	2
Arno Atoll (23)	18	4	4	30	39	4	...
Jemo (7)	28	...	...	57	14	...	...
Miscellaneous (19)	42	...	...	26	21	10	...

*/ Number of samples sieved.

It has been observed by Stone (1951a, p. 14) that many soil profiles are composite and have layers of black organic material at different depths.

Chemically the parent materials consist almost exclusively of calcium carbonate with varying small amounts of magnesium carbonate, depending on the type of organisms present. Minor amounts of other

Table 8.--Chemical composition (in percent) of calcareous reef and lagoon constituents, and of composite sediment samples (from Emery, Tracey, and Ladd, 1954, table 11, p. 67)

Analysts: C. M. Warshaw (Nos. 1, 2, 5, 6, 7, 9); A. C. Vlisidis (Nos. 3, 4, 10, 11, 12, 13); W. W. Brannock (Sr determination); J. M. Axelrod (X-ray determination of minerals)

	Foraminifera		Halimeda		Calcareous red algae			Corals	Sediments				
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	0.20	0.12	0.50	0.14	0.18	0.24	0.10	0.06	0.12	0.16	0.20	0.20	0.20
$(Al,Fe)_2O_3$	.30	.22	.30	.34	.40	.46	.34	.06	.36	.28	.26	.28	.18
MgO	5.52	5.67	.32	.38	8.01	8.25	6.73	.24	4.95	1.32	2.26	.82	.54
CaO	46.90	47.86	54.51	53.25	42.20	41.85	42.91	53.08	47.78	52.28	50.31	52.84	52.64
SrO	.18	.16	.90	.87	.24	.24	.22	...	.28	.72	.46	.82	.73
CO_2	42.64	43.16	42.66	41.46	41.08	40.43	39.75	41.68	42.36	41.57	41.65	41.60	41.28
Acid-soluble SO_3	.32	.68	.16	.25	.70	.64	.70	(?)	.44	.34	.55	.29	.37
Acid-insoluble organic	.26	.16	...	.15	1.27	1.60	2.01		.28	.17	.21	.16	.32
Water-soluble organic	.45	.87	...	...	1.98	2.73	2.47	3.21	...	...	...	...	...
Water	.40	.50	.20	.30	1.53	1.48	1.52		.48	.28	.28	.24	.44
Total	97.17	99.40	99.55	97.14	97.59	97.92	96.75	98.33	97.05	87.12	96.18	97.25	96.70
Acid-insoluble inorganic	0.18	0.09	...	0.38	0.35	0.38	0.36	...	0.12	0.20	0.05	0.43	0.25
Minerals[1]	C	C	A	A + little C	C	C	C	A	C + little A	A + little C	A + C	A + little C	A + little C

[1] C, calcite; A, aragonite.

1. Picked Foraminifera (Calcarina spengleri). Lagoon beach, Bikini.
2. Picked Foraminifera (Marginopora vertebralis). Lagoon beach, Bikini.
3. Picked unweathered Halimeda segments.
4. Picked weathered Halimeda segments.
5. Lithophyllum (Porolithon) gardineri.
6. Lithophyllum craspedium.
7. Porolithon onkodes.
8. Average of 15 analyses of madreporarian reef corals (Clarke and Wheeler, 1917).
9. Coarse foraminiferal beach sand, Bikini (sample Bik. 3).
10. Fine beach sand, Bikini (sample Bik. 5).
11. Medium sand, lagoon, 69 feet, Bikini (sample Bik. 51)
12. Medium sand and Halimeda debris, lagoon, 108 feet, Bikini (sample Bik. 713).
13. Halimeda debris, lagoon, 156 feet, Bikini (sample Bik. 548).

constituents such as calcium phosphate, calcium sulfate, and aluminum and iron oxides may also be present. Table 8 gives the composition of some of these reef-forming organisms.

Mineralogically both forms of calcium carbonate, aragonite and calcite, are present, the quantities depending on the dominant organisms. In addition, there is secondary and local enrichment of phosphate in the form of the mineral apatite.

Classification of soils

Stone's classification of atoll soils, with certain alterations, serves very well for the northern Marshall Islands, as for most other atolls studied so far. This classification was adapted for the northern Marshall Islands by Fosberg (1954) from whom the following paragraph as well as the introductory paragraphs under each soil unit are quoted.

"Areally, four principal units are easily definable on the atolls. They are (a) essentially unaltered sands and gravels; (b) stony and very stony complex; (c) Shioya series; and (d) Arno Atoll series. In addition to these, the Jemo series is widely distributed, though much smaller in area. Minor units are the muck soil found in taro pits, mangrove peat, and one or two local types so far known only from Arno Atoll. Exposed limestone reef-rock or beach-rock is common, usually in narrow peripheral strips and on denuded areas on the windward sides of atolls. This rock can scarcely be considered a soil, though it often serves as a substratum for one species of tree--*Pemphis acidula*. Where there are small pockets of sand, *Portulaca* and *Lepturus* may also clothe some of these bare rock surfaces."*/

Only a rough generalization may be made of the areal distribution of these categories, but the accompanying schematic diagram of an atoll islet (fig. 29) will serve to illustrate the general pattern.

All the atoll soils are relatively immature, the Shioya series being little modified from the parent material, the Arno Atoll series more modified, and the Jemo series even more so. However, these three are not necessarily related in a linear developmental series. In terms of profile nomenclature the Shioya and Arno Atoll series are "A-C soils" with an A_1 horizon (zone of incorporated organic matter) and usually a narrow A_3 (transitional) horizon passing directly into the relatively unaltered material, the C horizon. As a group, these two series are a

*/ Subsequent observation by Fosberg in 1956 suggests the existence of still another soil series, as yet undescribed and inadequately studied, on two or more of the northern Marshall Islands not visited during the 1951-1952 survey. This seems to be associated with a vegetation made up principally of *Cordia subcordata* Lam. which is not extensively developed on the atolls visited in 1951-1952. It was observed on Ailinginae and Rongerik Atolls, but time was not available for careful profile description and collection of adequate samples.

tropical equivalent of the "humus-carbonate soils" of European workers (see Stone, 1951a, p. 19). The Jemo series, on the other hand, is an A-B-C soil with an A_{oo} (litter) horizon and an A_o (partly decomposed plant remains) lying directly on a B (deposition or accumulation) horizon, which in turn lies on the relatively unaltered material or C horizon.

In this investigation chemical analytical data are given for 54 profiles or partial profiles comprising 100 samples. These are distributed among different soil types as follows (the proportions representing the different series are accidental and bear no relation to the relative abundance of the series in the field):

Unaltered sands
  2 profiles comprising 2 samples.
Stony and very stony complex
  No samples.
Shioya series
  7 profiles comprising 13 samples.
Arno Atoll series
  10 profiles comprising 28 samples.
Jemo series
  27 profiles comprising 46 samples.
Miscellaneous
  8 profiles comprising 11 samples.

These six categories will be described individually, with the chemical features summarized in tables 9-14. This will be followed by discussions of atoll soil development and of the chemical characteristics of atoll soils. Locality and descriptive data for all profiles analyzed are presented in appendix II. Profiles sampled but not analyzed are mostly omitted from the appendix but their localities are indicated on figures 16-18.

Soil units and series--characteristics and chemistry

Unaltered sand and gravel

"Unaltered sand and gravel, made up commonly of foraminiferal tests and the pulverized or waterworn skeletons of other animals and calcareous algae, are of wide distribution. They occur as bars on the reefs, spits, and narrow places on the ends of islets, beaches, and areas of dunes, most frequently on the lagoon coasts. They are white to pink, or even orange-pink. A number of kinds of plants grow in such substrata with no apparent inconvenience" (Fosberg, 1954).

Representing this are two samples, 39 and 40, both from Ailuk Atoll. Sample 39 is from the center of an almost unvegetated sand-bar on the windward reef. Considerable local variation in texture was observed but was not represented in the sample, which was taken from one spot. Sample 40 is from the windward base of a sand dune on Enejelar islet. The material in both represents only the surface layer of the profile.

Chemical analyses of major constituents are presented in table 9. These analyses represent, at least in some measure, the parent material and thus can be used as a basis of comparison for soils which may have been chemically altered during soil formation. The soil has a pH of 9.4. There is very little difference in the percentages of the constituents analyzed in the two samples, and the average composition is as follows: Calcium, 36.6 percent; magnesium, 1.8 percent; sodium, 0.3 percent; potassium, 0.03 percent; phosphorus, 0.03 percent; total soluble salts, 0.15 percent of which only one-fourth is sodium chloride.

Stony and very stony complex

"The unit termed stony and very stony complex by Stone (7 /1951a/, pp. 29-31) is made up principally of the cobble- and boulder-ridges and boulder-flats, which are a common feature of most atolls, especially in areas visited by frequent storms. Most of them, but by no means all, are found on the seaward sides of islets, sporadically distributed, but with some preponderance on the sides from which the storm winds most often come. A few such ridges are found behind lagoon beaches. These areas are commonly 100 m or less in width, but some of them may be much wider. Sometimes a whole islet is of this nature. The material is mostly coarse angular or water-worn fragments, sometimes well sorted, often extremely heterogeneous in size. The interstices may be filled with sand and small gravel, they may be empty, or they may have a soil that is black, with a high organic content, near the surface. The boulders and cobbles are white, but wherever exposed they become gray to black, owing to microscopic blue-green algae in their surface layers. This stony ground supports a thick scrub or forest, in some places becoming tall and luxuriant. Coconuts may be planted here, but these are usually the last large areas to be planted. The /coconut/ trees seem to do well except where the climate is too dry, as in the extreme northern Marshalls, or where the land is too narrow. Narrow necks and points of land are apparently too saline for proper development of coconut trees" (Fosberg, 1954).

No analytical data are available for this unit.

Shioya series

"The Shioya series in the Marshall Islands consists of grayish brown sands or gravels, rarely loamy sands (or even silts), that are only slightly weathered and with a very low organic matter content. It was first described (6)/Stensland and others, 1949/ on Okinawa, Ryukyu Islands, for soils developed on emerged old beach deposits of calcareous sand; later the term was applied to similar soils on Saipan, and then by Stone (7 /1951a/, pp. 19-22) made to include soils of this nature from Arno Atoll. On atolls the Shioya lacks the considerable percentage of quartz sand found in some of the Shioya sand of Okinawa, but the difference is probably not significant. This is by far the commonest and most wide-spread soil found on coral atolls. It naturally supports most of the mixed forest, several other forests types, and the

<u>Lepturus</u> grassland vegetation characteristic of atolls" (Fosberg, 1954).

This is a well-drained alkaline soil formed principally on calcareous sands and gravels, largely but by no means always medium to fine grained. It is typically marginal on the islets, developed toward ocean and lagoon coasts and on the ends of the islets, much less so and tending to be replaced by the Arno Atoll soils in the central parts (fig. 29). There is a transition zone between Shioya and Arno Atoll series.

A characteristic profile of the Shioya loamy sand from Arno Atoll is described by Stone (1951a, p. 20) as follows:

0 - 7"	Friable loamy sand, dark gray (10YR-4/1) in color when moist, single-grained or weakly aggregated. pH 7.8.
7 - 8"	Transitional.
8 - 40"+	Single-grained loamy sand, pinkish white (7.5 YR-9/2), composed of Foraminifera and ground shells, coral and <u>Halimeda</u> fragments. pH 8.4.

Color names and notations are according to the Munsell system.

A Shioya gravelly loamy sand and a Shioya sand have also been recognized and described from Arno Atoll, southern Marshall Islands. They differ from the Shioya loamy sand principally in the size of the calcareous parent material.

Although these several textural types have been described from the southern Marshall Islands, and although much textural variation is apparent in the present material and from field observations, for the purposes of the present report no textural types have been distinguished. It is felt that a more thorough sampling would be necessary to give such classes meaning.

Shioya soils were observed on practically all islets of all atolls visited, and samples of soil from Shioya profiles were obtained from all of these atolls except Kwajalein (see maps of islets showing sample localities, figs. 16-18, and Appendix II, p. 101). These were not all analyzed but at least some chemical analytical information is available for 13 samples from 7 Shioya profiles. Unfortunately only three reasonably complete profiles are represented by these data (see table 9). Of these three profiles one is from Lado, Likiep Atoll and the other two are from Wotho, Wotho Atoll. In addition, samples of surface layers were partially analyzed from profiles from Taka, Taka Atoll.

Of the major constituents, calcium ranges between 33.7 and 37.8 percent, generally increasing somewhat downward. Magnesium ranges between 0.8 and 2.7 percent, consistently increasing downward in the profile. Sodium ranges between 0.18 and 0.31 percent. Potassium is constantly between 0.02 and 0.05 percent and phosphorus is similarly low, from 0.02 to 0.21 percent.

Probably because the islands are exposed constantly to the influence of spray blown in from the ocean, the total soluble salt content is high, ranging between 0.02 and 0.49 percent, on the basis of dry weight. Assuming a moisture content of at least 25 percent in the soils as they occur naturally, this would indicate salt concentrations in the soil solution ranging from about 0.1 to 2.0 percent, varying seasonally. Most of these concentrations, especially the higher ones, would probably have a severe limiting effect on plant growth and might well account, at least in part, for the impoverished flora of atolls, especially the drier ones, as has been suggested earlier (Fosberg, 1949). Curiously enough, the higher sodium chloride contents, calculated from the chloride percentages, are found to correspond to the lower range of total soluble salts. The correlations, however, are not very good and possibly little importance is to be attached to this phenomenon.

Few determinations of organic carbon were made for this series, as, in general, soils of this series are low in organic matter and there is no peaty layer. Hydrogen ion concentration ranges between pH 8.06 and 9.67, determinations made on stored material. The only pH below 8.3, normal for calcium carbonate solutions under ordinary conditions, is in a surface layer where organic matter would be expected to have some influence, though in small amount. Higher figures doubtless reflect the presence of magnesium carbonate. Samples 126 and 129, showing the highest magnesium content and the highest pH, contain about 20 percent and 50 percent respectively of fresh foraminiferal tests, some species of which contain a high proportion of magnesium carbonate (table 8).

Arno Atoll Series

"The <u>Arno Atoll series</u> (7 /Stone, 1951a/, pp. 22-25) is composed of black or dark brown (values 1-4 in Munsell system) loamy sands and sandy loams with usually some increment of gravel. The organic matter content is high /16 to 32 per cent in original analyses by Stone (7 /1951a/, table 2)/ for tropical soils. The origin of these soils is obscure and may well be different in various occurrences. In some atolls the soils of this series seem to be correlated in occurrence with a history of intensive human activity (Utirik, Ailuk, Arno?), but in others (Jemo) definitely not. These soils occur in fairly large patches in the interiors of sizeable islets. They usually support coconut plantations at present. Little is known of their original vegetation. In certain areas of this type (Arno, Ailuk) the coconut trees become unhealthy and die early, possibly as a result of nutrient deficiency (8 /Stone 1951b/, p. 11-12) brought about by overcropping of copra (dried coconut meat)" (Fosberg, 1954).

This is a well-drained, dark-colored, calcareous soil formed on old beach and dune sands under vegetation in the island interiors. A representative profile from Arno Atoll is described by Stone (1951a, p. 22) as follows:

0 - 11"	Highly organic, granular loamy sand or sandy loam, somewhat plastic when worked. Black when moist, very dark gray (10YR-3/1) when dry, heavily flecked with lighter sand particles. pH 7.5. Earthworms abundant.
11 - 13"	Abrupt transition from above to--
13 - 21"	Single-grained, light-gray loamy sand stained with organic matter, becoming white (10YR-8/2) at a depth of a few inches. pH 8.4.
21-54"+	Friable, pinkish white (7.5YR-9/2) limesand becoming coarser at 40 inches.

The above description is of the Arno Atoll loamy sand developed on sand-grade material. A similar soil from Arno Atoll with coarser parent material has been called the Arno Atoll gravelly loamy sand. Types based on texture have not been distinguished in the present report.

Soils interpreted as belonging to the Arno Atoll series were observed on Taka, Utirik, Ailuk, Jemo, Likiep, Ujelang, Wotho, Ujae, and Lae Atolls, and samples representing profiles or partial profiles were obtained from all these (see maps of islets showing sample localities, figs. 16-18, and Appendix II).

In the laboratory information was obtained on organic matter, pH, salinity, and general chemistry for 28 of these samples (see table 9) but the data by no means are complete for all the samples.

Of the major constituents, calcium ranges from 32.6 to 38 percent, the surface samples usually containing 2 to 4 percent less than those from the lower layers, as might be expected from the amounts of organic matter present in the upper layer. Profile 27, from Jemo, is exceptional in its very high organic matter and phosphorus and unusually low calcium. It is perhaps not correctly placed in this series, but further investigations on soils in similar situations, in close association with soils of the Jemo series, will be required to clarify the disposition of this somewhat anomalous profile. The magnesium content, from 0.5 to 2.8 percent, increases from the surface layer downward. Variation in magnesium content could be introduced by the varied proportions of different calcareous organisms with differing amounts of magnesium carbonate in their skeletons, but the consistent increase in magnesium from upper to lower layers could scarcely be due to this cause. Estimates of proportions of different organisms making up the different layers show no such regular increase downward of those organisms known to contain much magnesium carbonate. Such is Calcarina spengleri, one of the Foraminifera common in these sediments, which commonly has about 3.5 percent magnesium in solid solution in the calcite structure. For example, in profile 1, samples 39 and 40 have similar proportions of different organisms but differ (1.1 compared with 1.8 percent) in magnesium content. In profile 2, the upper layer, containing abundant worn Foraminifera, has only 0.9 percent magnesium;

in the fourth layer, sample 44 has a preponderance of worn Foraminifera with coral and algae, and 2.3 percent magnesium, whereas in 45, where the Foraminifera are negligible, but also with coral and algae, the magnesium content is also 2.3 percent. In profile 5, samples 48 and 49 each contain about 75 percent Foraminifera, with expected high percentages of magnesium 2.3 and 2.5, respectively. Original composition undoubtedly accounts for much of the variation, but the regular increase downward suggests that leaching of magnesium may have been more intense toward the surface. This would not be unexpected.

The surface layer contains from 0.14 to 2.00 percent phosphorus (omitting from consideration profile 27, which has enormously more) and the lower layers, 3 and 4, contain from 0.02 to 0.52 percent. Potassium ranges from 0.01 to 0.05 percent, excepting for sample 66, in profile 27, which has 0.07 percent.

Organic carbon in the surface layer ranges from 2.88 to 6.01 percent (excepting the anomalous profile 27), and falls off rapidly in the lower layers so far as can be determined from the rather few analyses and the lack of dark staining of the calcareous material. Carbon/nitrogen ratios range between 15 and 28 in the surface layers.

The hydrogen ion concentration is uniformly lowest in the surface layers, from pH 7.30 to 8.35, and consistently increases downward, to an extreme of 9.47 in sample 60 in profile 18. Total soluble salts range from 0.03 to 0.85 percent (except for profile 27, with higher percentages which may have resulted from accidental contamination by sea water). The soluble salts are mostly surprisingly high, considering that the samples come from the interiors of the islets.

Jemo series

This series, described by Fosberg as a result of observations in the Northern Marshall Islands, usually consists of "a layer of organic matter resting on a phosphatic hardpan underlain by loose, essentially unaltered or somewhat darkened lime-sand or gravel" (Fosberg, 1954, p. 101). This, or similar soils, has been observed on a number of central and western Pacific atolls and undoubtedly is what has been exploited as "guano" on many of the more moist atolls of the Pacific. The total area of these soils is not large, but they are of extreme ecologic and pedogenic interest.

A typical Jemo profile (from Fosberg, 1954, p. 104) may be described as follows, from an old Pisonia forest in the interior of Jabwelo (Jaliklik) islet, Bikar Atoll (profile 166 of present paper).

A_{oo} horizon	6.0 - 5.5 inches	Loose twigs and leaves of Pisonia grandis, somewhat guano-stained.
A_o horizon	5.5 - 0 inches	Dark-brown, fibrous or spongy raw humus. Transition to B horizon abrupt.

B horizon	0 - 6.0 inches	Brown salt-and-pepper appearance, very well consolidated. Transition to C horizon abrupt.
C horizon	6.0 +	Loose pale sand mixed with rubble; depth undetermined.

The essential feature of these soils is the existence of an A horizon of a dark-brown to black organic matter, similar to the "raw humus" or "mor" found under northern coniferous forests and on heath lands, spongy or peaty in texture and lacking visible mineral constituents. Usually this is directly underlain by a B horizon of indurated phosphatic hardpan, but in some variants this is absent or, rarely, replaced by nodular phosphatic material. Under this the material typically resembles a Shioya soil.

This soil series seems to be consistently associated with existing or former forests or groves of Pisonia grandis, a common atoll tree. Its existence is interpreted as a direct result of the coincidence of large colonies of fish-eating birds roosting or nesting in stands of Pisonia trees. The humus which accumulates under Pisonia trees is highly acid, at least compared with the ordinary calcareous soils, ranging from pH 4 to pH 6 in reaction. When the guano, largely composed of finely divided calcium phosphate from fish bones, is deposited on the surface of this humus layer and washed by rain down into this acid material, it goes into solution and is carried on down through the organic layer. The high phosphorus figures in the analyses of the organic layers for this series are fair evidence of this. When this acid phosphate solution percolates down into the layer of calcareous soil beneath, it is neutralized and the phosphate comes out of solution as a cement, stained brown by humus, which indurates the loose calcareous material. As the resulting hardpan is subject to further percolation by the acid phosphate the grains of calcium carbonate composing it are gradually replaced by calcium phosphate in the form of apatite. Thus for some samples the analyses correspond to almost pure apatite.

Soluble salts were only determined for five samples. Two of these, both from layer 1, contain more than 2 percent total soluble salts, but the content seems to be quite variable, as two others contain between 1 and 2 percent, and the fifth only a negligible amount. These few analyses could scarcely give an adequate picture, as even in the same place soluble salts might at one time be concentrated in the surface organic matter by nitrification and evaporation, and at another time they might be leached out by rain water and removed through the porous calcareous material in the lower horizons.

Amounts of calcium, magnesium, sodium, potassium, and phosphorus are available for five profiles, three from Bikar Atoll and two from Jemo (table 9). At the surface the amount of magnesium and calcium varies inversely with the amount of organic matter present. This is well illustrated by profiles 153 and 166 from Bikar and profile 25 from Jemo. The surface peaty layers of the two profiles from Bikar contain between 7 and 8 percent calcium with about 55 percent organic matter, whereas the surface layer of the profile from Jemo with only about 35 percent organic matter contains 16.5 percent calcium.

The magnesium content varies similarly, but this variation is in part due to the quantity of the different kinds of calcareous organisms present. Some data on chemical composition of the reef organisms forming these atolls are given on page 121 and tables 3 and 8. Magnesium content depends on the presence of organisms consisting of calcite rather than of aragonite.

The chemical data obtained for the Jemo soils include spectrographic determinations of the trace or minor elements in 31 samples representing 18 soil profiles. These were done in two series reported in different terms, one set including elements not determined in the other. For this reason two tables, 10 and 11, have been prepared to present these results, which have been recombined into a third (table 12) showing the range and frequency of occurrence of the minor elements.

Some of these elements are known to be essential for plant growth and the concentrations of some of them are surprisingly low, considering the luxuriance of the vegetation on these islands. It is clear that at least certain species of plants are adapted to securing their requirements of these elements from soil solutions of extremely low concentration. The most frequent of these minor elements are: boron, chromium, copper, manganese, strontium, iron, and barium. The least frequent are: silver, cobalt, molybdenum, and yttrium. Those with largest amounts are: iron, silicon, and strontium. Those with smallest amounts are silver and cobalt.

Miscellaneous soils

Analyses of the upper layers of a number of miscellaneous soils that do not fit well into any of the named soil series show unusually high content of organic matter, when compared with other northern Marshall Island soils except the Jemo series. Determinations of organic carbon and pH are presented in table 13. A rough correlation between amount of organic matter and acidity shows up in these analyses, and is illustrated by the curves in figure 30. It will be noted that the main deviation is in a soil from a coconut grove, where the organic matter is largely from decomposed coconut husks, leaves, and other trash. The acidity in these soils probably may be ascribed mostly to humic acids, but in the taro pits the soils also smell somewhat of hydrogen sulfide, so some of the acidity may come from hydrogen sulfide produced under anaerobic reducing conditions in the muck in these pits. This general correlation of organic matter and acidity, even in a calcareous environment, is in line with the similar relationships shown in the Arno Atoll and Jemo soils (table 9).

Summary of chemical information

From an examination of the tabulations of analytical results presented in tables 9 to 13, the following summaries were obtained. Certain marked trends are pointed out, but owing to the inadequacy of the sampling no special significance is necessarily to be attached to these. They do indicate areas where future investigations might profitably be concentrated. A summary of the chemical information is given in table 14. This, however, is of limited value except to suggest trends, as the layers are not strictly comparable.

Shioya soil profiles

Organic carbon is usually less than 3 percent (maximum 3.08 percent). Phosphorus is 0.2 percent or less, highest in layer 1 and about equal in layers 2 and 3. Averages for layers 1-3, respectively: 0.15; 0.03; 0.03 percent.

Potassium content is always low, 0.02 to 0.05 percent.

Magnesium content consistently increases downward. Averages for layers 1-3, respectively: 1.09; 1.6; 2.2 percent.

Calcium content shows no significant trends. It varies between 33.7 and 37.8 percent with almost this variation within layer 1. If the whole soil were calcium carbonate the percentage would be 40.

Total soluble salts range from 0.04 percent to 0.49 percent with no order nor preponderance nor discernible trends. Salinity in terms of chlorides converted to sodium chloride shows no definite trend except that high total soluble salts seem to show low salinity and low total soluble salts, high salinity. We have no explanation for this except the possibility that the high percentages of soluble salts may represent sulfates, lacking in the others, and that the salinity variations may be due to sea spray.

Arno Atoll soil profiles

Percentage of phosphorus is roughly related to percentage of organic carbon, but layers showing no black staining were not analyzed for organic carbon; these are presumably less than 1 percent. Phosphorus decreases downward except where there are evidences of buried A horizons, in which cases the phosphorus in the buried A layer is somewhat higher than the C horizon layer above it.

Except for profile 27, layer 1 varies between 0.13 percent and 2.0 percent phosphorus. Averages for layers 1-4, respectively, are: 0.63; 0.30; 0.15; 0.04 percent. Profile 38, which is in an area of Ailuk similar to the "laora" areas of Arno Atoll (Hatheway, 1953, p. 60; 1957, p. 1-3), shows 0.34 percent in layer 1, which is not especially low, but 0.04 percent in layer 3, which is quite low.

Organic carbon is quite variable in layer 1, 2.88 to 6.01 percent (or 11.0 percent in profile 27), and falls off in lower layers (so far as analyzed and assuming less than 1 percent for uncolored layers).

Calcium content is lower in layer 1, but not conspicuously except in profile 27, where it is 23.5 percent. In other layers it is between 35 and 37 percent (except in profile 27, where layer 2 shows 29 percent). The lower percentage of calcium in layer 1 is probably related to high organic content.

Magnesium content generally increases downward. Exceptions are sample 81, from layer 4 of an unusual silty material, where it is very low compared with layers analyzed above it; samples 49 and 50, layers 3 and 4, where the percentages are very close, 2.5 and 2.4 percent; and sample 39, where there seems to be less difference in appearance and color than is usual between the layers of the profile. Averages for layers 1-4, respectively, are 1.02, 1.75, 2.00, and 2.08 percent.

Potassium is uniformly low, ranging between 0.01 and 0.07 percent.

There seem to be no systematic relationships in the percentage of total soluble salts, in the salinities or in the percentage of sodium. Profile 27 shows generally a very high percent of total soluble salts and a very high salinity in all layers, but not a strikingly high percentage of sodium except in layer 2. From the percentage of sodium in layers 3 and 4 and the sodium chloride in total soluble salts, there must be chlorides other than sodium chloride present in quantities.

Examination of the figures for profile 27, from Jemo, shows that it is aberrant, chemically, in many respects. This profile is either unusually high or unusually low in every constituent for which there are figures in one or more layers, as is indicated in the comments in the above paragraphs. For this reason this profile was omitted in calculating table 14. These considerations, as well as the field relations, suggest that it would be best to exclude this soil from the Arno Atoll series. As it occurs on Jemo on land presumed to have formerly been occupied by Pisonia groves, and where pieces of phosphate rock are occasionally found, it is probable that this is a Jemo series soil modified by cultivation. It may be significant that the other Arno Atoll series profiles for which chemical data are available are all from inhabited islands. Those from Taka, which is uninhabited, were not analyzed chemically.

Jemo Soil profiles

Organic carbon in layer 1 ranges from 19.92 to 34.71 percent. Much less is present in the lower layers, but was only determined in one sample of layer 3 where 2.89 percent organic carbon was found.

Phosphorus is high, ranging from 1 to 6.8 percent in the raw humus layer (one sample had a lower figure), much higher in the hardpan layer, ranging from 3 to 13.4 percent, and generally lower in layer 3, except in one profile where the percentage is greater. The average phosphorus content in the hardpan is about 7.4 percent. The phosphorus figures determined by rapid chemical methods (Shapiro and Brannock, 1956) and by spectrographic methods differ markedly; for example, figures of 12 and 10 percent, 5 and 7.9 percent, respectively, were reported for the two sets of samples. For such percentages of phosphorus as are discussed here the rapid chemical analysis method is considered the more reliable.

Leaves of Pisonia growing in this soil on Bikar contained 0.2 percent phosphorus in dried, and 0.5 percent phosphorus in fresh leaves. These figures, however, may not be significant because of possible undetected spatterings of guano.

Calcium content in layers 2 to 4 is between 31.3 and 36.2 percent, which is generally about the content in the more or less unaltered parent material. However, where there are comparable figures in the same profile, that for layer 2 is slightly lower. Probably this would be due to a certain amount of leaching, but it could possibly reflect a somewhat lower calcium ratio in the mixture of phosphates compared with that in calcium carbonate. As the exact composition of the phosphate mixture is not known, this remains purely speculative. The surprising thing is the large amount of calcium, 2.5 to 16.5 percent, average 8.3 percent, in the humus layers. This must be in the form of calcium phosphate, as no carbonate is likely in view of the low pH. However, as the amounts of calcium only roughly parallel those of phosphorus, the variation may be accounted for by assuming variation in the composition of the mixtures of phosphates.

Potassium in layer 1 is substantially higher (0.06 to 0.28 percent, average 0.13 percent) than in the Shioya and Arno Atoll soils and almost twice that in layer 2 of the Jemo profiles. In general, potassium seems either to be accumulated in the humus layer or to be added in substantial amounts in the guano that is deposited on the surface.

Magnesium generally increases downward but not as regularly as in other soil types. In one profile there is no detectable magnesium in the humus layer. In the others magnesium ranges from 0.16 to 0.46 percent in this layer.

Sodium content shows no discernible trends. Total soluble salts range from 0.11 to 2.55 percent, but only a very few analyses were made. The proportion of sodium chloride is high in the humus layers with high total soluble salts, and lower where total soluble salts are low, but there is no systematic relationship. This is the reverse of the condition in the Shioya series.

Iron is present in small amounts, ranging from 0.002 to 0.02 percent in layers 2, 3, and 4, but in all profiles the percentage in layer 1 is much higher, ranging from 0.02 to 0.2 percent. This suggests that Pisonia trees possess the ability to concentrate iron in the humus layer of the soil.

The percentages of cobalt, nickel, molybdenum, and zinc show a distribution similar to that of iron but in a much more striking fashion. None of these, with two exceptions, were detected in layers

2 to 4, whereas they were present in most samples of the humus layer in amounts, ranging from 0.0001 to 0.03 percent. This suggests, again, that Pisonia concentrates these elements in its humus, enriching the upper layers of the soil. It has been suggested that this concentration of minor elements in the humus layer results from digested fish deposited as guano. This is possible, but these elements would probably then show up, also, in the phosphate accumulation layer. The two exceptions noted above were in profiles 26 and 50 where in layer 2 there were, respectively, 0.03 and 0.02 percent of zinc, the 0.03 percent being higher than the amount in layer 1. The 0.02 percent is in one of two analyses of phosphate rock from the same profile, this particular sample being of nodules or fragments of layer 2 included in the raw humus layer. The one of layer 2 proper showed no zinc. Cobalt, molybdenum, and zinc were not detected in two samples of Pisonia leaves which were ashed and analyzed (nickel was not checked in these).

The percentages of copper, manganese, barium, boron, and chromium were all low, ranging from 0.01 to 0.00004 percent, but they were always detectible by spectrographic analysis. No systematic relationships are apparent.

Strontium content ranges from 0.02 to 0.4 percent and is conspicuously lower in the humus layer than in the lower layers in all but one profile.

Hydrogen ion concentration in the three types of profiles

Determinations of pH made in the laboratory on samples which had been dried and stored do not, of course, correspond very well with those made on fresh samples by rough field methods. The laboratory determinations of pH show a greater total range and, except for those of the Jemo soils, are generally higher than the field determinations.

Available figures for relatively unaltered sands are well above pH 9, but in the surface layers of the Shioya series this figure drops to about pH 8.5. The lower layers of this series have pH readings similar to those of the unaltered sands. In the Arno Atoll series, layer 1 has an average pH of 7.9, layer 2, an average pH of 8.6, and in the lower layers, again, the pH is above 9. In the Jemo series the pH of layer 1 is 4.5, layer 2 has a pH of 7.6, and layer 3 has a pH of 8.3. These figures indicate that the increase in acidity is roughly related to the increase in organic matter. Hydrogen ion concentrations of about pH 9 seem to accompany amounts of organic carbon in soils of less than 2 percent, a pH of 8 those with 2 to 4 percent of organic carbon, pH readings of 6 or 7 those with 4 to 6.5 percent organic carbon, and pH of 3.8 to 5.3 those with 20 to 35 percent organic carbon. These figures clearly show a marked relation between the accumulation of organic matter and leaching. The more acid soil solutions resulting from the accumulation of humus are more active in leaching both the calcium carbonate in the parent materials and the phosphate added later.

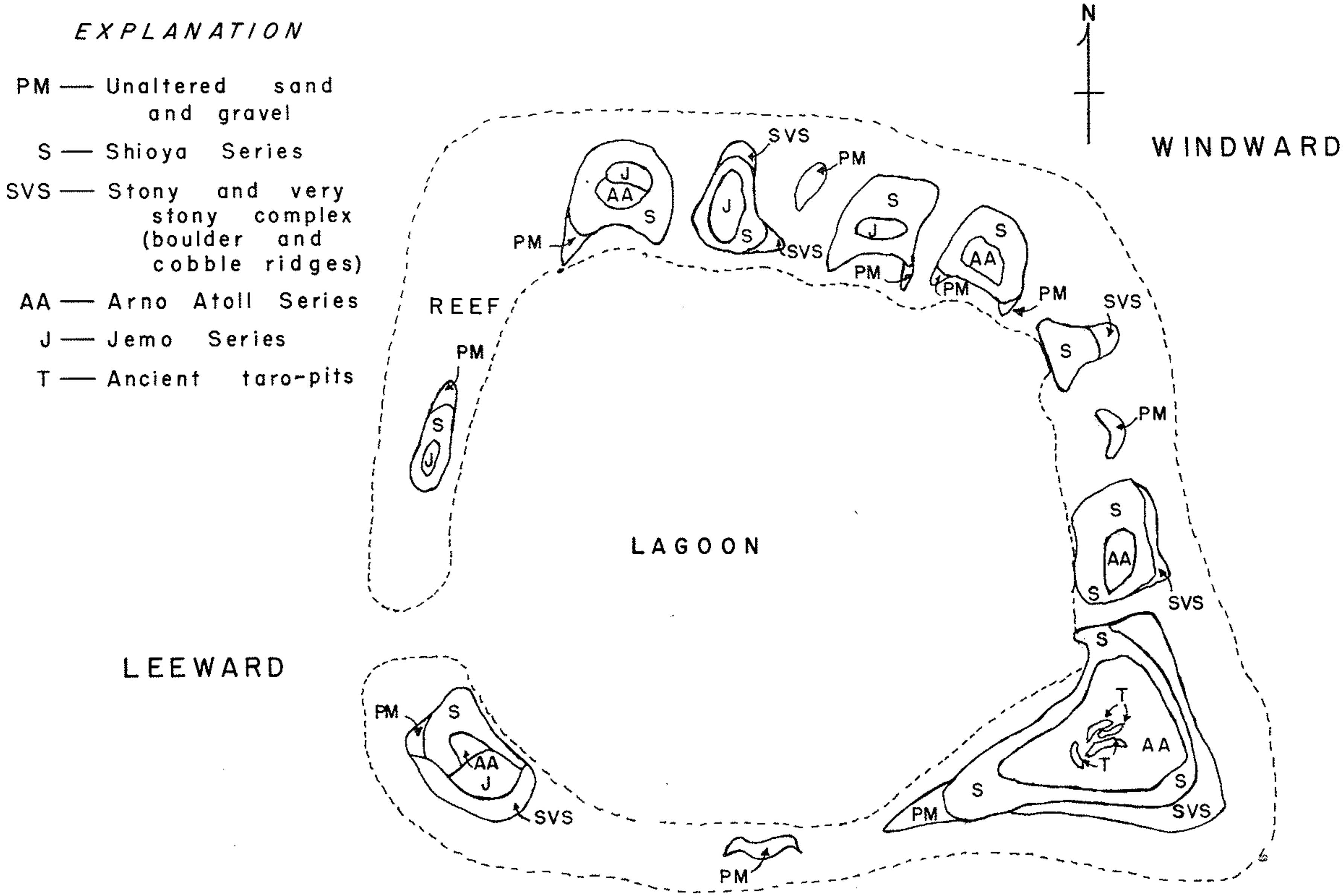


FIGURE 29. SCHEMATIC DIAGRAM OF A HYPOTHETICAL ATOLL SHOWING DISTRIBUTION OF SOIL TYPES

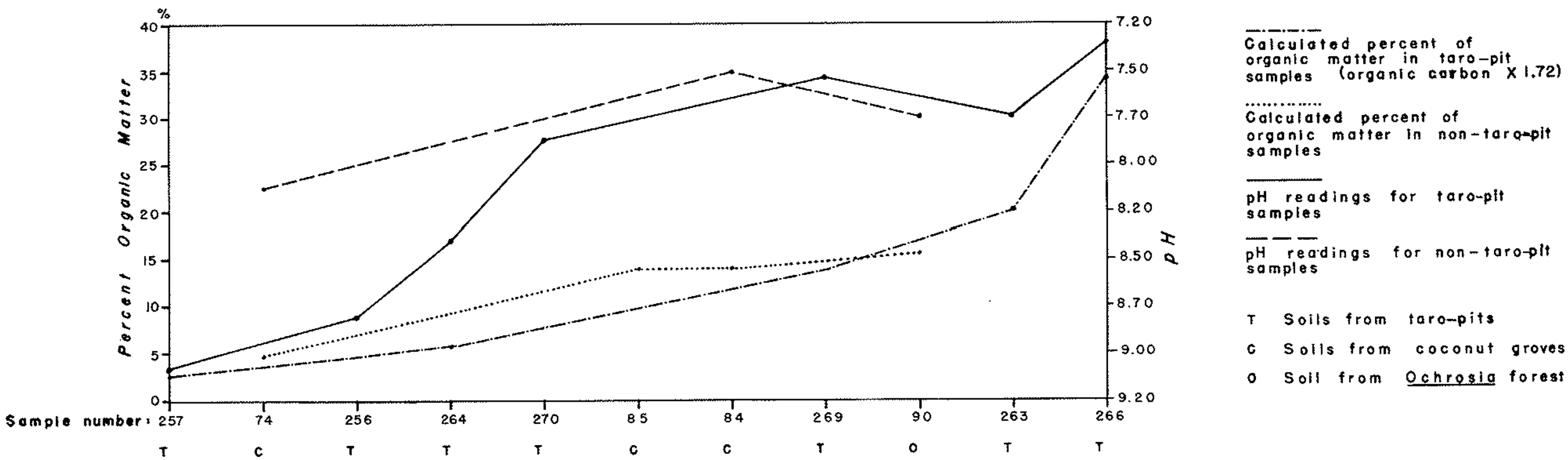


FIGURE 30. RELATION OF ACIDITY TO ORGANIC MATTER IN MISCELLANEOUS SOILS WITH HIGH ORGANIC MATTER CONTENT

Legends of plates

Plate 32. Effects of typhoon on Utirik islet.

A. Aerial view of western prolongation of Utirik islet, Utirik Atoll, swept clean of soil and vegetation by a typhoon many years ago, and again partially denuded in 1951. The boulder accumulation in the edge of the lagoon just below the dark line of vegetation was presumably swept from the land surface by the earlier typhoon. The faint darker lines in the right half of the land area are beachrock.

B. Closeup of an area in the left side of the area shown in A, being somewhat recolonized by vegetation. The coconut groves in the background were apparently protected by the broader parts of the islet from the severe effects shown in the narrow projection of the islet.

Photos by Fosberg.

Plate 33. Foraminifera in soils from the Marshall Islands. Examples of Foraminifera in various soils, showing changes due to organic matter and to removal of calcium carbonate.

A. Worn Calcarina from sample 131, profile 29, Shioya soil, Jemo island, showing slight adherence of organic matter (dark).

B. Corroded worn foraminifer from sample 48, profile 5, Arno Atoll soil, Utirik islet, Utirik Atoll.

C. Corroded foraminifer with broken chambers filled with organic matter, sample 204, profile 28, Jemo soil, Jemo island.

D. Foraminifer with dull, slightly earthy appearance, sample 48, profile 5, Arno Atoll soil, Utirik islet, Utirik Atoll.

E, F. Foraminifera with earthy appearance due to powdery calcium carbonate on the surface, sample 71, profile 30, Shioya soil, Jemo island.

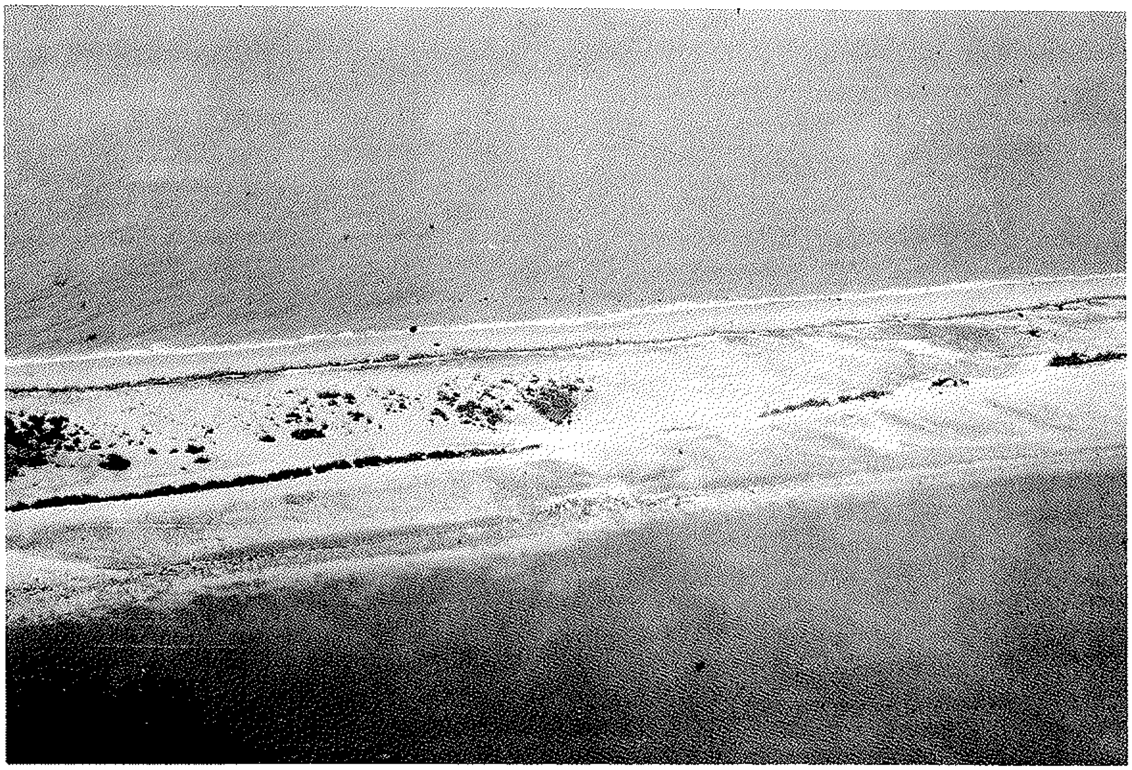
G, H. Foraminifera with additional firm calcium carbonate deposited on the original surface, sample 146, profile 70, Arno Atoll soil, Wotho islet, Wotho Atoll.

I, J, K. Foraminifera coated with a mixture of flour-like calcium carbonate and fine-grained organic matter. I and K are from sample 204, profile 28, Jemo soil, Jemo island; J is from sample 110, profile A15, Shioya soil, Taka Atoll.

L, M. Worn and broken Marginopora showing intimate association with organic matter, sample 41, profile 2, Arno Atoll soil, Utirik islet, Utirik Atoll.

Photos by Starkey, U.S. Geological Survey, all X 30 (approx.).

Plate 32



A

B

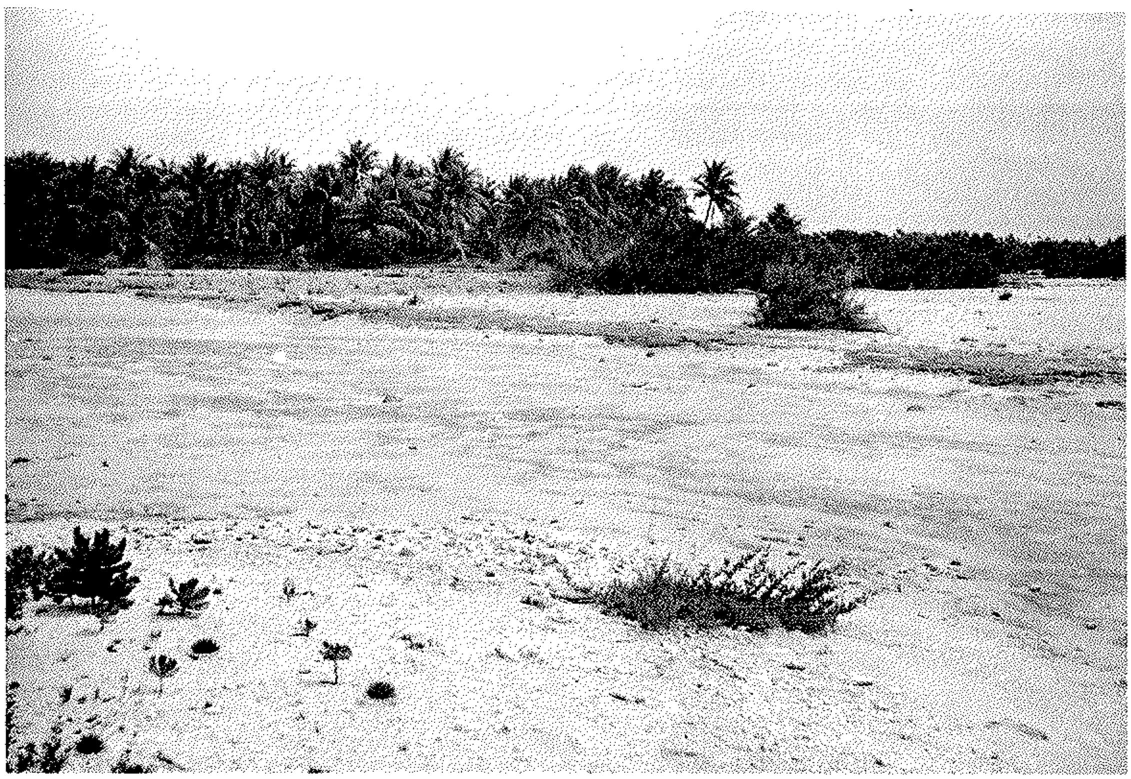


Plate 33

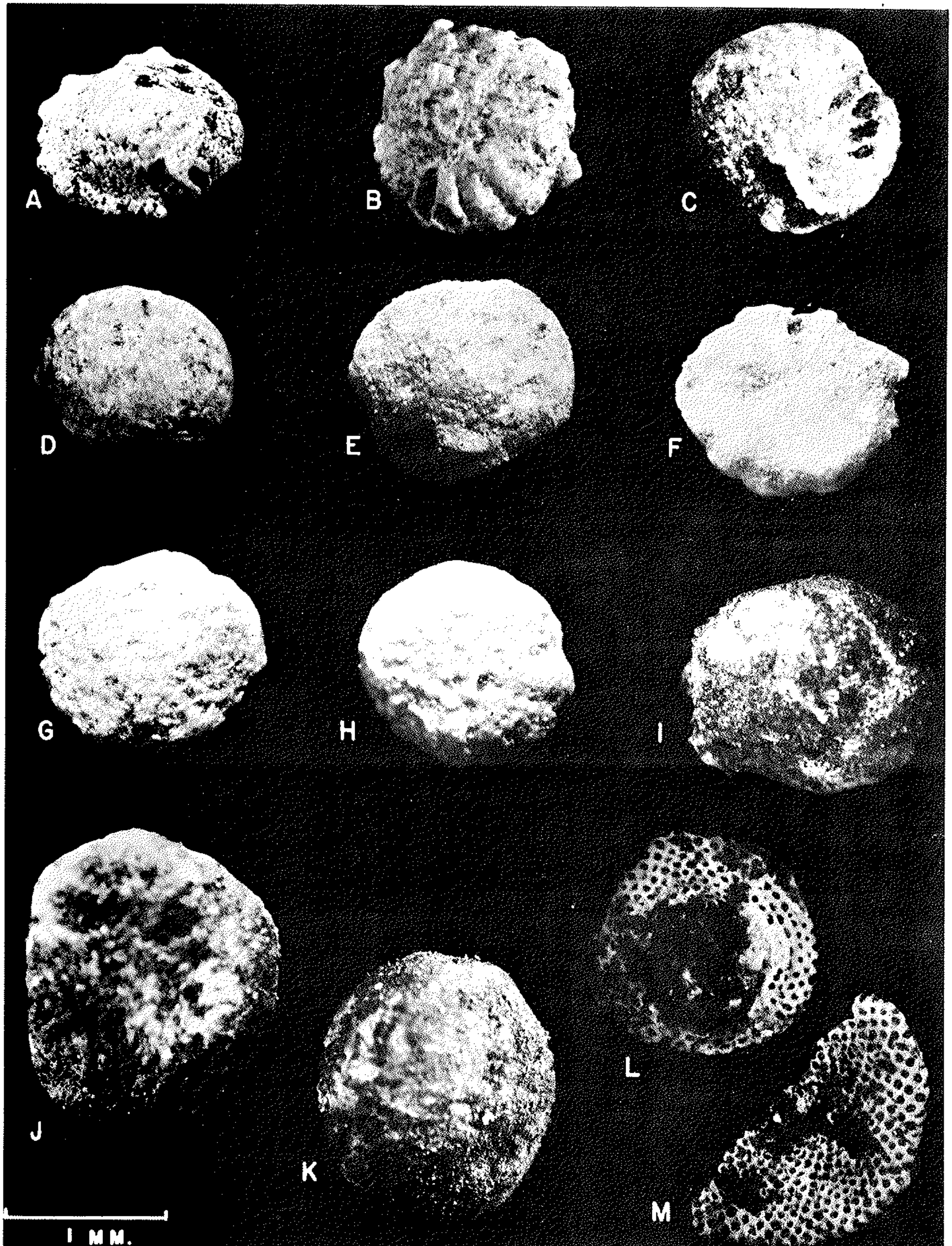


Table 9.--Major chemical constituents (in percent) and pH of northern Marshall Islands soils

Soil series or unit	Atoll	Profile No.	Layer No. (sample no.)	Depth (feet)	Organic carbon	Total N	Ca	Mg	Na	K	P	Total soluble salts[1]	NaCl in total soluble salts	pH
Unaltered sands	Ailuk	39	1 (252)	Surface	...	...	36.8	1.9	0.28	0.03	0.03	0.14	24.00	9.48
		40	1 (253)	do.	...	...	36.3	1.6	.31	.02	.03	.16	26.83	9.30
		Average for layer 1			...	...	36.6	1.8	.30	.03	.03	.15	25.42	9.39
Shioya series	Taka	11	1 (122)	0-0.8	...	...	...	...	...	...	...	.02	33.0	...
		12	1 (51)	0-0.9	...	...	...	...	...	...	...	.25	5.2	...
		13	1 (54)	0-0.25	...	...	...	...	...	...	...	.18	6.5	...
		A16	1 (116)	0-0.5	...	...	...	...	...	...	...	.04	24.5	...
	Likiep	17	1 (125)	0-0.6	...	...	36.2	1.3	.31	.03	.03	.12	25.5	8.97
			2 (126)	0.6-3.0	...	...	37.2	2.0	.31	.04	.02	.49	10.5	9.42
			3 (129)	3.0-6.0	...	...	35.6	2.7	.31	.03	.02	...	...	9.67
	Wotho	69	1 (141)	0-1.0	3.08	0.22	34.7	1.2	.26	.05	.20	.29	7.4	8.30
			1 (143)	0-1.0	1.58	...	37.5	.8	.27	.05	.21	.04	24.5	8.60
			2 (144)	1.0-3.0	...	...	37.8	1.4	.28	.03	.05	.12	60.94	...
		72	1 (148)	0-0.3	2.53	.22	33.7	1.1	.16	.03	.07	.09	33.0	8.06
			2 (149)	0.3-0.5	1.24	...	36.3	1.2	.18	.04	.03	.17	2.81	8.62
			3 (150)	0.5-1.8	...	...	37.3	1.7	.28	.03	.03	.24	1.21	...
		Average for layer 1			2.4	.22	35.5	1.09	.25	.04	.15	.17	20.0	[2]8.48
		do. 2			[3]1.24	...	37.1	1.60	.26	.04	.03	.27	24.22	9.02
		do. 3			...	...	36.5	2.20	.30	.03	.03	.16	[3]1.21	[3]9.67
Arno Atoll series	Utirik	1	1 (37)	0-0.7	6.01	.21	32.6	.49	.21	.03	2.0	.85	2.1	8.05
			2 (38)	0.7-1.1	3.20	...	35.5	.66	.21	.01	1.3	.50	3.0	8.16
			3 (39)	1.1-2.7	1.80	...	36.4	1.1	.21	.02	.52	.56	36.86	...
			4 (40)	2.7-4.0	...	...	37.2	1.8	.26	.02	.05	.56	55.82	...
		2	1 (41)	0-0.2	...	...	33.0	.90	.24	.02	.17	.24	15.6	8.30
			2 (42)	0.2-0.7	...	...	36.8	1.7	.30	.02	.06	.80	49.4	8.92
			3 (43)	0.7-1.8	1.25	...	36.9	1.8	.24	.02	.12	.12	6.08	8.87
			4 (44)	1.8-5.0	...	...	36.3	2.3	.30	.02	.03	.20	23.12	9.30
			4 (45)	1.8-5.0	...	...	36.0	2.3	.25	.02	.03	.28	15.72	...
		5	1 (47)	0-0.7	3.49	.13	34.6	1.1	.24	.02	.96	.50	4.6	7.98
			2 (48)	0.7-1.5	...	...	36.8	2.3	.30	.02	.08	.21	3.8	...
			3 (49)	1.5-2.5	...	...	36.2	2.5	.32	.02	.04	.24	4.64	...
			4 (50)	2.5-?	.24	...	36.3	2.4	.21	.02	.04	2.33	.07	9.20
	Ailuk	38	1 (77)	0-1.0	3.75	.17	35.0	.96	.23	.05	.34	.10	16.5	8.05
			3 (79)	1.8-2.7	...	...	36.1	1.8	.27	.05	.04	.36	33.5	...
			4 (81)	2.7-3.0	1.08	...	38.0	.58	.12	.05	.05	.06	19.3	8.52
	Jemo	27	1 (63)	0-0.7	11.0	.51	23.5	.39	.37	.05	9.9	1.15	72.8	7.30
			2 (64)	0.7-1.1	5.0	...	29.0	.49	.89	.05	8.5	1.75	88.3	7.57
			3 (66)	1.1-2.4	1.55	...	35.6	1.3	.37	.07	4.0	.53	73.5	7.85
			4 (67)	2.4-?	...	...	35.1	2.7	.36	.03	.31	.40	11.4	...
	Likiep	18	1 (58)	0-1.3	3.85	...	35.3	1.8	.24	.02	.14	.44	7.5	8.31
			2 (59)	1.3-2.5	...	...	35.9	2.0	.33	.02	.02	.16	16.73	8.80
			3 (60)	2.5-3.9+	...	...	36.1	2.8	.37	.02	.02	.08	29.97	9.47
	Ujelang	A3	1 (30)	0-1.5	4.1	...	...	...	...	...	...	...	...	...
	Lae	A11	1 (272)	0-0.6	...	...	...	...	...	...	...	...	...	8.11

Soil series or unit	Atoll	Profile No.	Layer No. (sample no.)	Depth (feet)	Organic carbon	Total N	Ca	Mg	Na	K	P	Total soluble salts[1]	NaCl in total soluble salts	pH
	Wotho	A9	1 (27)	0-1.0	3.47	...	...	...	...	...	...	...	...	...
		70	1 (145)	0-1.0	2.88	.19	35.5	.84	.31	.03	.18	.03	33.0	8.35
			2 (146)	1.0-1.7	...	...	37.1	2.1	.21	.03	.05	...	...	...
		Average for layer[4]	1		4.04	.17	34.2	1.02	.25	.03	.63	.47	13.2	7.88
		do.	2		[3]3.2	...	36.4	1.75	.27	.03	.30	.81	21.3	8.62
		do.	3		1.5	...	36.3	2.0	.28	.03	.15	.36	19.37	9.17
		do.	4		1.1	...	36.8	2.08	.23	.03	.04	.63	23.68	9.01
Jemo series	Bikar	153	1 (12)	[5]0.15-0	31.44	2.53	7.6	.22	.27	.28	3.1	...	...	4.57
			2 (13)	0-0.1	...	...	34.5	.97	.33	.08	4.4	...	...	7.92
			3 (14)	0.1-1.2	...	...	36.2	1.7	.33	.06	.54	...	...	8.64
		165	1 (19)	[5]0.7-0	30.87	1.95	9.0	.21	.34	.12	3.3	...	...	5.30
			2 (20)	0-0.5	...	...	34.8	1.1	.30	.06	5.2	...	...	8.07
		166	1 (15)	[5]0.4-0	30.87	2.45	7.9	.22	.28	.17	3.4	...	...	4.80
			2 (16)	0-0.1	...	...	34.4	1.7	.30	.08	3.0	...	...	8.10
			2 (17)	0-0.1	...	...	34.0	1.3	.31	.07	5.0	...	...	7.60
			3 (18)	0.1-1.2	...	...	35.0	2.1	.31	.03	.56	...	...	8.57
	Taka	A14	1 (106)	0-0.9	...	...	...	...	...	...	...	0.11	11.9	...
	Jemo	25	1 (1)	[5]0.5-0	19.92	1.64	16.5	.24	1.0	.06	6.8	2.10	78.0	5.17
			2 (2)	0-0.3	...	...	33.4	.48	.35	.05	7.7	...	...	7.71
			3 (3)	0.3-?	2.89	...	34.5	1.2	.61	.07	1.4	1.40	69.5	7.70
		26	1 (4)	[5]1.0-0	34.26	2.15	3.9	.46	.89	.10	1.0	2.55	69.0	3.80
			2 (5)	0-?	5.33	...	31.3	.26	.51	.07	13.2	...	...	6.60
		32	2 (6)	Exposed	...	...	36.2	.78	.33	.04	6.0	...	...	8.31
	Kwaja-lein	49	1 (7)	Surface	34.71	2.83	2.5	...	.25	.08	.48	1.00	28.0	4.10
			2 (8)	0-?	...	...	35.8	.33	.42	.06	4.0	...	...	8.22
		50	1 (11)	Surface	26.73	2.10	10.9	.16	.33	.07	4.2	...	...	4.08
			2 (10)	do.	6.41	...	31.8	.08	.33	.07	13.4	...	...	6.30
			2[6] (9)	do.	3.11	...	32.8	.10	.36	.11	12.0	...	...	6.90
		Average for layer	1		29.8	2.24	8.3	.25	.48	.13	3.2	1.44	46.7	4.55
		do.	2		[3]5.0	...	33.9	.71	.35	.07	7.4	...	...	7.57
		do.	3		[3]2.9	...	35.2	1.66	.42	.05	.8	[3]1.40	69.5	8.30

[1] Expressed as total weight of salts obtained by leaching with water.

[2] Empirical evidence indicates that when soils of different pH are mixed the resulting pH is close to an arithmetic average, even though this might not be expected from the expotential nature of pH numbers. It is felt, therefore, that the averages of the available pH determinations within layers and series may have some significance.

[3] Only one analysis.

[4] Profile 27 omitted from averages.

[5] Humus or A_0 layer is regarded as lying on the soil surface and depth is taken from the top of the mineral soil.

[6] Nodules from layer 2.

Table 9.--Major chemical constituents (in percent) and pH of northern Marshall Islands soils

Analysts, H. F. Phillips, K. E. White, P. L. D. Elmore, G. L. Otzelberger, and P. D. Blackmon

Table 10.--Occurrence of minor elements (in percent) in Jemo series soils

Analyst: Harry J. Rose. 0 in unit column indicates element below detection. All analyses were made on the ignited sample and corrected to the original sample weight.

Atoll	Profile No.	(Sample No.)	Cu	Mo	Zn	Mn	Co	Ni	Fe	Cr	Sr	Ba	B
Bikar	153	1 (12)	0.004	0	0	0.003	0	0.0002	0.03	0	0.03	0.0007	0.003
		2 (13)	.0004	0	0	.003	0	0	.005	.00009	.3	.001	.004
		3 (14)	.0002	0	0	.002	0	0	.002	.00008	.2	.0007	.002
	166	1 (15)	.004	.0008	.03	.003	.0003	.0004	.06	.00004	.06	.001	.002
		2 (16)	.0004	0	0	.003	0	0	.003	.00008	.2	.0009	.004
		2 (17)	.001	0	0	.004	0	0	.005	.00009	.3	.002	.005
		3 (18)	.0003	0	0	.003	0	0	.002	.0001	.1	.0005	.003
	165	1 (19)	.003	.0007	.01	.002	0	.0003	.03	.0001	.03	.0009	.002
		2 (20)	.001	0	0	.003	0	0	.003	.0001	.1	.001	.003
Jemo	25	1 (1)	.005	0	.03	.005	0	.0001	.07	.0002	.1	.002	.008
		2 (2)	.003	0	0	.003	0	0	.007	.0001	.1	.0009	.009
		3 (3)	.002	0	0	.003	0	0	.01	.0001	.3	.0009	.01
	26	1 (4)	.002	.0003	.004	.002	.0002	.0002	.04	.0001	.02	.0008	.004
		2 (5)	.003	0	.03	.006	0	0	.01	.0002	.1	.002	.01
	32	2 (6)	.0001	0	0	.005	0	0	.01	.0002	.2	.0009	.006
Kwajalein	49	1 (7)	.001	.0003	.007	.001	.0001	.0002	.02	.0001	.02	.0003	.004
		2 (8)	.002	0	0	.002	0	0	.007	.0002	.2	.0008	.009
	50	1 (11)	.005	.001	.03	.005	.0003	.0007	.2	.0006	.05	.0008	.001
		2 (10)	.002	0	0	.01	0	0	.02	.0005	.4	.002	.003
		2 (9)	.0009	0	0	.005	0	0	.008	.0003	.2	.002	.004
Averages for layers		1	.0031	.0004	.016	.003	.0001	.0003	.067	.00016	.04	.0009	.007
		2	.0015	0	.006	.004	0	0	.008	.00019	.21	.0014	.006
		3	.0008	0	0	.003	0	0	.005	.0009	.2	.0007	.005

Table 11.--Spectrographic determinations of minor elements in the Jemo series soils

Analysts: Helen Worthing and Katherine V. Hazel

Atoll	Profile No.	Layer No. (Sample No.)	0.X %	0.0X %	0.00X %	0.000X %
Bikar	153	1(12)		Fe, Sr	Cu, Mn, B	Ni, Cr, Ba
		2(13)	Sr		Mn, Fe, Ba, B	Cu, Cr
		3(14)	P, Sr		Mn, Fe, B	Cu, Cr, Ba
Bikar	166	1(15)	Sr	Zn, Fe, Sr	Cu, Mn, Ba, B	Mo, Co, Ni, Cr
		2(16)			Mn, Fe, B	Cu, Cr, Ba
		2(17)	Sr		Cu, Mn, Fe, Ba, B	Cr
		3(18)	Sr, P		Mn, Fe, B	Cu, Cr, Ba
Bikar	165	1(19)		Zn, Fe, Sr	Cu, Mn, B	Mo, Ni, Cr, Ba
		2(20)	Sr	Ba, B	Cu, Mn, Fe	Cr
Bikar	163	2(161)		Fe, Sr, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
Bikar	157	2(163)		Fe, Sr, B, Si	Cu, Cr, Ba, Al	Mn, V, Y, Ti
Bikar	164	2(165)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
Bikar	156	2(177)	Sr	B, Si	Cu, Fe, Cr, Ba, Al, V, Y	Mn, Ti
		3(180)	Sr	Fe, B, Si, Al	Cu, Cr	Mn, Ba, V, Ti
		3(181)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, V, Ti
		6(183)	Sr, Fe	Cu, Zn, B, Si, Al	Mn, Cr, Ba, V, Ti	Y, Ag
		6(184)	Sr	Cu, Fe, B, Si, Al	Zn, Mn, Cr, Ba	V, Ti
Bikar	177	2(229)	Sr	Zn, Fe, Si	Cu, Cr, Ba, B, Al	Mn, V
Bikar	156	6(227)	Sr	Si, Al, B, Fe	Zn, Cu, Ba, Cr, Ti, V	Mn
Bikar	158	2(159)		Sr, Si, Fe, B, Zn	Al, Cu, Ba, Cr, V	Mn, Ti
Bikar	174	3(169)		Sr, Fe, Si, Al, Zn	B, Cu, Cr	Ba, Mn, Ti, V
Bikar	176	2(172)	Si, Sr	Fe, Al, B	Cu, Ba, Cr	Mn, Ti, V
Bikar	178	2(173)		Si, Sr, Fe, Al, B	Ba, Cu, Cr	Mn, Ti, V
		2(174)	Sr	Fe, Si, Al, B	Cu, Ba, Cr, Mn	V, Ti
		2(175)	Sr	B, Fe, Si, Al	Ba, Cr, Cu	Mn, V

Table 11.--Spectrographic determinations of minor elements in the Jemo series soils--Continued

Atoll	Profile No.	Layer No. (Sample No.)	0.0X %	0.0X %	0.00X %	0.000X %
Jemo	23	2(203)		Fe, Sr, B, Si, Al	Cu, Cr, Ba	Mn, V, Ti
Jemo	25	1(1)	Sr	Zn, Fe, Ba, B	Cu, Mn	Ni, Cr
		2(2)	Sr		Cu, Mn, Fe, B	Cr, Ba
		3(3)	Sr	Fe, B	Cu, Mn	Cr, Ba
Jemo	26	1(4)		Fe, Sr	Cu, Zn, Mn, B	Mo, Co, Ni, Cr, Ba
		2(5)	Sr	Zn, Fe, B	Cu, Mn, Ba	Cr
Jemo	32	2(6)	Mg, Na Sr	K, Fe	Cu, Mn, B	Cr, Ba
Ujae	110	2(191)	Sr	Fe, Si, Al	Cu, Cr, Ba, B, V, Ti	Zn
Ujae	73	2(211)	Sr	Fe, Si, Al	Cu, Cr, Ba, B, V, Y	Mn, Ti
Ujae	74	2(213)	Sr, Si	Fe, Al	Cu, Zn, Cr, Ba, B, V, Ti	Mn
Ujae	79	2(217)	Sr	Fe, B, Si, Al	Cu, Cr, Ba, V, Ti	Mn
Ujae	97	2(225)	Sr	Fe, B, Si, Al	Cu, Mn, Cr, Ba, Ti	V
Wotho	117	2(193)		Ni, Fe, Sr, Si	Cu, Cr, B, Al, V	Mn, Ba, Ti
Wotho	118	2(195)	Sr	Fe, B, Si	Cu, Cr, Ba, Al	Mn, Y, Ti
Wotho	119	2?(189)	Sr	Si, B, Fe	Al, Ba, Cr, Cu, Ti, V	Mn
Kwajalein	49	1(7)	Na, P	Fe, Sr	Cu, Zn, Mn, B	Mo, Co, Ni, Cr, Ba
		2(8)	Mg, Na Sr	K	Cu, Mn, Fe, B	Cr, Ba
Kwajalein	50	1(11)	Mg, Na, Fe	K, Zn, Sr	Cu, Mo, Mn, B	Co, Ni, Cr, Ba
		2(10)	Na, Sr	Mg, K, Zn, Mn, Fe	Cu, Ba, B	Cr
		2(9)	Mg, Na, Sr, K		Mn, Fe, Ba, B	Cu, Cr

Table 12.--Ranges in amounts of minor elements in samples of soil materials from the Jemo soil series on Bikar, Jemo, Ujae, Kwajalein and Wotho Atolls.

For elements above double line, determinations were made on 45 samples; for those below lines, on 25 samples.

Element	Range (percent)	Frequently (number of times found)	Total
Boron	0.0X, 0.00X	23, 22	45
Barium	.0X, .00X, .000X	1, 28, 15	44
Cobalt	.000X	4	4
Chromium	.00X, .000X	17, 28	45
Copper	.0X, .00X, .000X	2, 5, 38	45
Iron	.X, .0X, .00X	2, 33, 10	45
Manganese	.0X, .00X, .000X	1, 23, 20	44
Molybdenum	.00X, .000X	1, 4	5
Nickel	.0X, .000X	1, 27	23
Strontium	.X, .0X	32, 13	45
Zinc	.0X, .00X, .000X	10, 5, 1	16
Aluminum	.0X, .00X	13, 9	22
Silicon	.X, .0X	1, 24	25
Silver	.000X	1	1
Titanium	.00X, .000X	5, 16	21
Vanadium	.00X, .000X	10, 14	24
Yttrium	.00X, .000X	2, 3	5

Table 13.--Organic carbon (percent) and pH of certain highly organic soils

Atoll	Profile	Layer No. (Sample No.)	Organic carbon (percent)	pH	Situation
Utirik	6	1 (256)	2.65	8.76	Taro pit.
		2 (257)	1.45	9.03	
Ailuk	A21	1 (263)	11.67	7.68	Taro pit.
		2 (264)	3.37	8.37	
Ujae	81	1 (84)	8.12	7.45	Surface soil on rubble in coconut grove where trash has decomposed for a long time.
	82	1 (85)	8.11	7.58	Bottom of depression in coconut grove.
	102	1 (90)	9.40	7.70	Thin surface layer in <u>Ochrosia</u> forest.
Lae	A7	1 (266)	19.86	7.30	Taro pit.
	A8	1 (2[illegible])	8.17	7.52	Taro pit.
		2 ([illegible])	4.33	7.82	
	A10	1 (74)	2.59	8.09	Coconut grove.

Table 14.--Major chemical constituents (average percentages) and pH[1] of samples from Arno Atoll, Shioya, and Jemo series soils collected from atolls in the northern Marshall Islands

Soils	pH	Organic carbon (percent)	Calcium (percent	Magnesium (percent)	Phosphorus[2] (percent)	Sodium (percent)	Potassium (percent)	Soluble (percent)
UNALTERED SANDS (parent material)	9.39	...	36.6	1.8	0.03	0.30	0.03	0.15
SHIOYA SERIES								
Layer 1	8.48	[3]2.4	35.5	1.09	.15	.25	.04	.17
Layer 2	[3]9.02	[3]1.2	37.1	1.60	.03	.26	.04	.27
Layer 3	[3]9.67	...	36.5	2.20	.03	.30	.03	.16
ARNO ATOLL SERIES[4]								
Layer 1	7.88	[3]4.04	34.2	1.02	.63	.25	.03	.47
Layer 2	8.62	[3]3.2	36.4	1.75	.30	.27	.03	.81
Layer 3	9.17	1.5	36.3	2.00	.15	.28	.03	.36
Layer 4	9.01	1.1	36.8	2.08	.04	.23	.03	.63
JEMO SERIES								
Layer 1	4.55	29.8	8.3	.25	3.2	.48	.13	1.44
Layer 2	7.57	[3]5.0	33.9	.71	7.4	.35	.07	...
Layer 3	8.30	[3]2.9	35.2	1.66	.8	.42	.05	[3]1.40

1/ See explanation in footnote 2 on table 9.
2/ Averages of rapid chemical method determinations only.
3/ Single determination.
4/ Profile 27 omitted from averages.

SUMMARY AND CONCLUSIONS

This investigation has shown that the islets on the atoll reefs of the northern Marshall Islands are mainly accumulations of calcareous debris, generally formed around erosion remnants of former slightly higher reef platforms, more rarely without such stabilizing cores. Their surface features conform sufficiently to a few patterns that their descriptions may be generalized and consistent terms applied to their common features. On the basis of their origin and position three types of islets are recognized--outer reef islets of detritus accumulated around a solid erosion remnant of a higher platform; outer reef islets composed of detrital accumulations without such a core; and islets built of detritus within lagoons.

The calcareous materials are either freshly derived or reworked skeletons or fragments of skeletons of marine plants and animals, or fragments of consolidated masses of such skeletons, and are mineralogically mixtures of calcite and aragonite. Most of the calcite is a more or less magnesian calcite. The characteristics, both physical and chemical, of the sediments are determined in large measure by the organisms of which they are principally composed. These characteristics, especially the physical ones, are modified both by the amount of weathering and abrasion they have been subjected to and by their position on the islet, either as constantly moving beach materials or as relatively stable deposits within the islets.

The interior deposits, considered as soils, are mostly referable to three previously recognized soil series, of which the Shioya and Arno Atoll series are almost entirely calcareous, differing principally in the amount of organic matter in their upper layers or A horizons. The Jemo series is highly phosphatic, with a raw humus A_0 horizon and a consolidated B horizon of phosphate rock. Chemically the Shioya soils are deficient in almost every plant nutrient element except calcium. The Arno Atoll series is more suitable for plant growth but is deficient in most elements. The Jemo soil has an abundance of phosphorus and has, in its A_0 horizon, more of most other essential elements than is general in atoll soils, though the quantities are even so extraordinarily small. The distribution of various elements through the profiles shows certain systematic trends. Interpretation of these is difficult at present and in most respects must await further data. Deficiencies of most nutrient cations, including some of the essential trace elements, are evident in all the soils studied. The ability of certain species of plants to grow in spite of these deficiencies, and the complete failure of others, is noteworthy. The process of phosphatization and hardpan formation in the Jemo series is fairly well understood, being dependent on the coincidence of guano from seabirds and acid humus from Pisonia trees. The chemistry and ecology of the formation of the Arno Atoll series is not well understood.

Further research should perhaps take the form of detailed mapping of the occurrence of the several soil types on selected islets in atolls with different climates and where as much as possible of the original vegetation remains. Correlation with vegetation patterns should be attempted. Further and more detailed chemical studies might profitably be made on selected profiles in the several series. An attempt should be made to find the origin of the indicated trends in occurrence of minor elements and to determine the fertility relations of the soils as substrata for plant growth. Attention should also be paid to the weathering processes going on in these sediments under different climatic conditions. The role of microscopic blue-green algae both in weathering and nitrogen fixation should be determined, as well as their contribution to the accumulation of organic matter. Finally, an investigation to determine relative and absolute ages of layers in the sections would be of great interest in relation to soil formation, climatic history and sea-level changes.

REFERENCES

Blumenstock, D. I., ed., 1961. A report on typhoon effects upon Jaluit Atoll. Atoll Research Bull. 75: 1-105.

Catala, R. L. A., 1957. Report on the Gilbert Islands: some aspects of human ecology. Atoll Research Bull. 59: 1-187.

Chave, K. E., 1952. A solid solution between calcite and dolomite. Jour. Geology 60: 190-192.

----------, 1954a. Aspects of the biogeochemistry of magnesium. I. Calcareous marine organisms. Jour. Geology 62: 266-283.

----------, 1954b. Aspects of the biogeochemistry of magnesium: II. Calcareous sediments and rocks. Jour. Geology 62: 587-599.

Christophersen, E., 1927. Vegetation of the Pacific Equatorial Islands. B. P. Bishop Mus. Bull. 44: 1-79.

Clarke, F. W., and Wheeler, W. C., 1917. The inorganic constituents of marine invertebrates. U.S. Geol. Survey Prof. Paper 102: 1-56.

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

Cushman, J. A., Todd, Ruth, and Post, R. J., 1954. Bikini and nearby atolls, Part 2, Oceanography (biologic). Recent Foraminifera of the Marshall Islands. U.S. Geol. Survey Prof. Paper 260-H: 319-384.

David, T. W. E., and Sweet, G., 1904. The geology of Funafuti, in W. J. Sollas and others, The Atoll of Funafuti, p. 61-124. Royal Soc. London, Rept. Coral Reef Comm. of the Royal Soc., London.

Emery, K. O., 1956. Marine geology of Johnston Island and its surrounding shallows, Central Pacific Ocean. Geol. Soc. America Bull. 67: 1905-1520.

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

Fairbridge, R. W., 1950. The geology and geomorphology of Point Peron, Western Australia. Royal Soc. Western Australia Jour. 34: 35-72.

----------, 1952. Marine erosion. Pacific Sci. Cong., 7th, Proc. 3: 347-358.

Folk, R. L., and Ward, W. C., 1957. Brazos River bar: A study in the significance of grain size parameters. Jour. Sed. Petrology 27: 3-26.

Fosberg, F. R., 1949. Atoll vegetation and salinity: Pacific Science 3: 89-92.

----------, 1953. Vegetation of Central Pacific atolls, a brief summary. Atoll Research Bull. 23: 1-26.

----------, 1954. Soils of the northern Marshall atolls with special reference to the Jemo series. Soil Sci. 78: 99-107.

----------, 1955. Northern Marshall Islands Expedition, 1951-1952. Narrative. Atoll Research Bull. 38: 1-36.

----------, 1957a. Some geological processes at work on coral atolls. New York Acad. Sci. Trans. II, 19: 411-422.

----------, 1957b. The Maldive Islands, Indian Ocean. Atoll Research Bull. 58: 1-37.

Fosberg, F. R., Arnow, T., and MacNeil, F. S., 1956. Military geography of the Northern Marshalls. Intelligence Div. Office of the Engineer, Headquarters, U.S. Army Forces Far East and 8th U.S. Army, 320 p.

Fosberg, F. R., and Sachet, M.-H., 1953. Handbook for atoll research (second preliminary edition). Atoll Research Bull. 17: 1-129.

Goldsmith, J. R., Graf, D. L., and Joensuu, O. I., 1955. The occurrence of magnesium calcites in nature. Geochim. et Cosmochim. Acta, 7: 212-230.

Guilcher, A., Berthois, L., Le Calvez, Y., Battistini, R., and Crosnier, A., 1965. Les récifs coralliens et le lagon de l'Ile Mayotte (Archipel des Comores, Océan Indien). Mémoires ORSTOM 11: 1-210.

Hatheway, W. H., 1953. The land vegetation of Arno Atoll, Marshall Islands. Atoll Research Bull. 16: 1-68.

----------, 1957. Agricultural notes on the Southern Marshall Islands, 1952. Atoll Research Bull. 55: 1-9.

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

Jenny, H., 1941. Factors of soil formation. New York, McGraw-Hill Book Co., 281 p.

Johnson, J. Harlan, 1954. An introduction to the study of rock building algae and algal limestones. Colorado School Mines Quart. 49 (2): 1-117.

Krumbein, W. C., and Garrells, R. M., 1952. Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials. Jour. Geology 60: 1-33.

Krumbein, W. C., and Tisdel, F. W., 1940. Size distribution of source rocks of sediments. Am. Jour. Sci. 238: 296-305.

Kuenen, Ph. H., 1933. Geology of coral reefs. Snellius Exped. 5 (2): 1-125.

----------, 1950. Marine geology. New York, John Wiley and Sons, Inc., 568 p.

Ladd, H. S., 1953. Drilling on Bikini Atoll, Marshall Islands. Internat. Geol. Cong., 18th, London, 1948, Rept., pt. 8: 38-43.

Ladd, H. S., Ingerson, E., Townsend, R. C., Russell, M., and Stephenson, H. Kirk, 1953. Drilling on Eniwetok Atoll, Marshall Islands. Am. Assoc. Petroleum Geologists Bull. 37: 2257-2280.

Ladd, H. S., and Schlanger, S. O., 1960. Drilling operations on Eniwetok Atoll. U.S. Geol. Survey Prof. Paper 260-Y: 863-903.

Ladd, H. S., Tracey, J. I., Jr., Wells, J. W., and Emery, K. O., 1950. Organic growth and sedimentation on an atoll. Jour. Geology 58: 410-425.

Lemoine, Mme. Paul, 1911. Structure anatomique des Mélobésiées. Annales Inst. Océanographique, Paris 2 (2): 1-213.

Lipman, C. B., and Shelley, P. E., 1924. Studies on the origin of the soil of Rose Islet. Carnegie Inst. Washington Pub., 340: 203-208.

McKee, E. D., 1956, Geology of Kapingamarangi Atoll, Caroline Islands. Atoll Research Bull. 50: 1-38.

----------, 1958. Geology of Kapingamarangi Atoll, Caroline Islands. Geol. Soc. America Bull. 69: 241-278.

----------, 1959. Storm sediments on a Pacific atoll. Jour. Sed. Petrol. 29: 354-364.

McKee, E. D., Chronic, John, and Leopold, E. B., 1959. Sedimentary belts in lagoon of Kapingamarangi Atoll. Am. Assoc. Petroleum Geologists Bull. 43: 501-562.

Nestéroff, W. D., 1956. Erosion et cimentation des calcaires dans les eaux tropicales [abs.]. Internat. Geol. Cong., 20th, Mexico City 1956, Resumenes de los Trabajos Presentados, p. 267.

Newell, N. D., 1954a. Expedition to Raroia, Tuamotus. Atoll Research Bull. 31: 1-21.

Newell, N. D., 1954b. Reefs and sedimentary processes of Raroia. Atoll Research Bull. 36: 1-35.

----------, 1956. Geological reconnaissance of Raroia (Kon Tiki) Atoll, Tuamotu Archipelago. Am. Mus. Nat. History Bull. 109: 311-372.

----------, 1960. Marine planation of tropical limestone islands. Science 132(3420): 144-145.

Niering, W. A., 1956. Bioecology of Kapingamarangi Atoll, Caroline Islands: Terrestrial aspects. Atoll Research Bull. 49: 1-32.

----------, 1963. Terrestrial ecology of Kapingamarangi Atoll, Caroline Islands. Ecol. Mon. 33: 131-160.

Nugent, L. E., Jr., 1946. Coral reefs in the Gilbert, Marshall, and Caroline Islands. Geol. Soc. America Bull. 57: 735-780.

Odum, H. T., and Odum, E. P., 1955. Trophic structure and productivity of a windward coral reef community on Eniwetok Atoll. Ecol. Mon. 25: 291-319.

Raleigh, Lord, 1942. The ultimate shape of pebbles, natural and artificial. Royal Soc. London Proc., ser. A, 181: 107-118.

Russell, R. J., 1962. Origin of beach rock. Zeitschr. f. Geomorphol. 3: 227-236.

----------, 1963. Beach rock. Jour. Trop. Geogr. 17: 24-27.

Sachet, M.-H., 1955. Pumice and other extraneous volcanic materials on coral atolls. Atoll Research Bull. 37: 1-27.

Sargent, M. C., and Austin, T. S., 1949. Organic productivity of an atoll. Am. Geophys. Union Trans. 30: 245-249.

Schlanger, S. O., and Brookhart, J. W., 1955. Geology and water resources of Falalop Island, Ulithi Atoll. Am. Jour. Sci. 253: 553-573.

Shapiro, Leonard, and Brannock, W. W., 1962. Rapid analysis of silicate rocks. U.S. Geol. Survey Bull. 1144-A: 56 p.

Sollas, W. J., and others, 1904. The Atoll of Funafuti. Royal Soc. London, Rept. of the Coral Reef Comm., London, 428 p.

Stensland, C. H., and others, 1949. Soils of Okinawa: Map 1:50,000, sheet 7 of 11, 64th Engineer Battalion, base topographic, U.S. Army, Corps of Engineers, Far Eastern Command.

Stevenson, I. L., 1953. Microbiological examination of soils of Arno Atoll. Soil Sci. 75: 225-231.

Stoddart, D. R., 1960. The reefs and sand cays of British Honduras: in, The Cambridge Expedition to British Honduras 1959-60, General Report, p. 16-33.

----------, 1962a. Physiographic studies on the British Honduras reefs and cays. Geogr. Jour. 128: 161-171.

----------, 1962b. Three Caribbean atolls. Atoll Research Bull. 87: 1-151.

----------, 1963. Effects of Hurricane Hattie on the British Honduras reefs and cays, October 30-31, 1961. Atoll Research Bull. 95: 1-142.

----------, 1964. Storm conditions and vegetation in equilibrium of reef islands. IXth Conf. on Coastal Engineering paper 5.7: 1-4.

Stoddart, D. R., and Cann, J. R., 1965. Nature and origin of beach rock. Jour. Sed. Petrology 35: 243-247.

Stone, E. L., Jr., 1951a. The soils of Arno Atoll, Marshall Islands. Atoll Research Bull. 5: 1-56.

----------, 1951b. The agriculture of Arno Atoll, Marshall Islands. Atoll Research Bull. 6: 1-46.

----------, 1953. Summary of information of atoll soils. Atoll Research Bull. 22: 1-6.

Tercinier, G., 1955. Rapport d'une mission aux Etablissements français de l'Océanie. Fascicule I. Etude des sols--leurs propriétés et vocations. Inst. français d'Océanie, Nouméa, 1-129.

Thorp, E. M., 1936. The sediments of the Pearl and Hermes Reef. Jour. Sed. Petrology 6: 109-118.

Tracey, J. I., Jr., Abbott, D. P., and Arnow, T., 1961. Natural history of Ifaluk Atoll: Physical environment. B. P. Bishop Mus. Bull. 222: 1-75.

Tracey, J. I., Jr., Ladd, H. S., and Hoffmeister, J. E., 1948. Reefs of Bikini, Marshall Islands. Geol. Soc. America Bull. 59: 861-878.

Trask, P. D., 1932. Origin and environment of source sediments of petroleum. Am. Petroleum Inst., Houston, Tex., Gulf Publishing Co., 323 p.

Vaughan, T. W., 1917. Chemical and organic deposits of the sea. Geol. Soc. America Bull. 28: 933-944.

Wentworth, C. K., 1922. A scale of grade and class terms for clastic sediments. Jour. Geology 37: 507-522.

Wentworth, C. K., 1931. The mechanical composition of sediments in graphic form. Univ. Iowa Studies in Natural History 14 (3): 1-127.

Wentworth, C. K., and Ladd, H. S., 1931. Pacific Island sediments. Univ. Iowa Studies in Natural History 13 (2): 1-47.

Wharton, W. J. L., 1883. Mangrove as a destructive agent. Nature 29: 76-77.

APPENDIX I

<u>Data for beach sand samples collected by</u>

<u>Charles G. Johnson and F. Stearns MacNeil</u>

1. Samples collected by Charles G. Johnson

Taongi (Pokak) Atoll (fig. 5)

T-1. Sand from small pit in reef 25 feet south of passage, on lagoon side. Pit about 3 inches deep, sand on bottom about 3 inches deep.

T-4. Beach sand from about mean tide level on the lagoon side near the middle of Sibylla islet.

T-5. Beach sand from the windward side and south of the middle of Sibylla islet. Sample was taken well above high-tide level.

T-6. Beach sand from above high-tide level on the windward side and north end of Sibylla islet.

T-7. Beach sand from the east end of the pass at the north end of Sibylla islet.

T-8. Beach sand from the windward side and north end of Ewdije (Breje) islet.

T-9. Beach sand from the lagoon side and north end of Ewdije (Breje) islet.

T-10. Beach sand from the windward side and south end of Kamwome islet. Sample from above high-tide level.

T-11. Beach sand from lagoon side and south end of Kamwome islet.

T-12. Beach sand from the head of a small reentrant on the lagoon side of Kamwome islet.

T-13. Beach sand at the mouth of the north side of a small reentrant on the lagoon side of Kamwome islet. This reentrant is the same as that of T-12.

T-14. Beach sand from the lagoon side and north end of Kamwome islet.

T-15. Beach sand from the windward side and north end of Kamwome islet.

T-16. Beach sand from the windward side of North islet.

T-17. Beach sand from the lagoon side of North islet.

T-19. Beach sand from the windward side and near the middle of Kamwome islet.

T-20. Beach sand from the lagoon side on south end of Sibylla islet.

T-21. Beach sand from the seaward side on south end of Sibylla islet.

T-22. Beach sand from the lagoon side and south end of an unnamed island north of Pokak islet.

T-23. Sand from the middle of a channel halfway between an unnamed island and Pokak islet.

T-24. Beach sand from the lagoon side and near the north end of Pokak islet.

T-25. Beach sand from the seaward side and near the south end of Pokak islet.

T-26. Beach sand from the seaward side and near the middle of Pokak islet.

T-27. Fine sand from the lagoon about 100 feet offshore of Pokak islet.

T-28. Sand from a pit in a small lagoonal reef on the windward side of atoll. Triangulation Station No. 5 is located on this reef. This sample was taken by one of the boatmen.

T-29. Beach sand from the seaward side and northeast end of Bwokwla islet.

T-30. Beach sand from the seaward side and southwest end of Bwokwla islet.

T-31. Sand from a pit in a small reef on the leeward side and south end of atoll. This sample smelled of hydrogen sulfide. Triangulation Station No. 12 is located on this reef.

T-32. Beach sand from the windward side and near the middle of Sibylla islet.

T-33. Sand from a small pit in a lagoonal reef on the windward side and north end of atoll. Triangulation Station No. 9 is located on this reef.

T-34. Sand from a small pit in a lagoon reef on the edge of the windward reef in the northern part of atoll. Triangulation Station No. 7 is located on this reef.

Bikar Atoll (fig. 6)

B-1 Sand bar at Survey Station No. 4, northeast part of lagoon.

B-3 Sand at north end, east side of Bikar islet.

B-4 Sand at middle of east side of Bikar islet.

B-5 Sand at south end, east side of Bikar islet.

B-6 Sand at south end, west side of Bikar islet.

B-7 Sand at middle of west side of Bikar islet.

B-8 Sand at north end, west side, Bikar islet.

B-9 Sand from leeward reef on north side of passage into lagoon.

B-10 Sand bar on northwest corner of atoll.

B-11 Sand from lagoon side of Almani (Alemeni) islet.

B-11 Sand from windward (southeast) side of Almani (Alemeni) islet.

B-13 Sand bar on lagoon side south of Jabwelo (Jalliklik) islet.

B-14 Sand from hole in bored platform, windward side, north of Jabwelo (Jalliklik) islet.

B-15 Sand from north end, windward side, Jabwelo (Jalliklik) islet.

B-16 Sand from reef side of Jaboero islet.

2. Samples collected by F. Stearns MacNeil

Locality (figs. 7-15)

Number

1. Lagoon beach of elongate western extension of Utirik islet, Utirik Atoll.

2. Tidal swirl pool along inter-island passage near north tip of Utirik islet.

3. Sand horn at north lagoon corner of Utirik islet.

4. High on beach at north tip of Utirik islet.

5. Beach sand near northwest corner of Taka islet, Taka Atoll, on inter-island passage side.

6. Seaward windward beach, Ailuk islet, Ailuk Atoll.

7. Seaward beach at west corner of peninsula off northeastern side of Emejiwan islet, Likiep Atoll.

8. Beach at northwest corner of Emejiwan islet, Likiep Atoll.

9. Seaward beach of Torrutj islet, Kwajalein Atoll.

10. Lagoon beach of Torrutj islet, Kwajalein Atoll.

11. Lagoon beach, Ninni islet, Kwajalein Atoll. About mid-point of lagoon beach.

12. Western tip of Eniwetak islet, Kwajalein Atoll.

13. Lagoon beach, Bokerok islet, Ujae Atoll.

14. Northeast corner of Enejalto islet, Lae Atoll, seaward side.

15. Seaward beach of northwest prong of Wotho islet, Wotho Atoll, just west of dry sand passage separating Wotho and Enerikon islets.

16. Beach at head of large cove on north side of Wotho islet, Wotho Atoll.

17. Lagoon beach, Wotho islet.

18. Seaward beach near south end of Wotho islet.

19. Lagoon beach near northwest of Eirek islet, Wotho Atoll.

20. Top of dune behind lagoon beach of Eirek islet, Wotho Atoll.

Number	Locality, continued
21.	Lagoon beach near southeast end of Eirck islet, Wotho Atoll.
22.	Bottom sample at end of lobe extending into lagoon at west end of Raej islet, Ujelang Atoll.
23.	Sand accumulation at lagoon side of what is either an indurated rubble flat or the remnant of a raised reef flat near east end of Ujelang Atoll.
24.	Lagoon beach of Helle islet, Ujelang Atoll.
25.	Sand from irregularities on raised rock platform on seaward side of Maronlik islet, Ujelang Atoll.
26.	Beach along west side of Maronlik islet, Ujelang Atoll.
28.	Rock platform at north seaward corner of Taka islet, Taka Atoll.
J-1	Lagoon beach, Torrutj islet, Kwajalein Atoll.
J-2	Lagoon beach, Ninni islet, Kwajalein Atoll.
J-3	Beach sand northwest side Taka islet, passage side.
J-4	Beach, west side of point 8, Ujelang islet, Ujelang Atoll.
J-5	Sand on seaward rock platform, point 3, Ujelang islet.
J-6	Beach sand Bokerok islet, Ujae Atoll.
J-7	Beach, Eniwetak islet, Kwajalein Atoll.
J-8	Beach sand northwest corner Emijewan islet, Likiep Atoll.
J-9	Sand on seaward rock platform, point 3, Ujelang islet.
J-10	Seaward beach Torrutj islet, Kwajalein Atoll.
J-11	Northeast corner Enemanit islet, Lae Atoll.
TW-4	Taka No. 3 dug hole
U-5	Utirik islet, out on spit.

Description of samples 1 to 23:

Sample 1

Lagoon beach of elongate western extension of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from lagoon beach of narrow western extension, about 2 miles from eastern end, on the southern reef, extending nearly E-W, lagoon beach facing north.

Other data: The western tip of the islet was denuded by a typhoon years ago and the unconsolidated materials washed into the lagoon. The present high-beach ridge on the lagoon side probably represents repiling of some of the finer material.

Character:	Size (mesh*/)	Percent	
	3	0)	
	4	1)	coarse
	9	6)	
	14	15)	medium
	35	75)	
	less than 35	3	fine

*/ Sieve openings: 3, 6.35 mm; 4, 4.76 mm; 9, 2.00 mm; 14, 1.19 mm; 35, 0.42 mm.

Fragments moderately to much worn with an occasional sharp fragment. Larger pieces (4 and 9 mesh) are whole shells of mollusks, pieces of coral and coralline algae, and orbitoids. Most orbitoids seem less worn than do other constituents. Two smaller screens (14 and 35 mesh) held about half worn fragments of corals and algae and about half worn Baculogypsina and Calcarina and a few scattered orbitoids, and echinoderm and mollusk fragments. Material passing through 35-mesh screen more angular than larger sizes, consisting of fragments of algae, corals, Foraminifera, mollusks, echinoids, etc., some fresh small Foraminifera and embryonic gastropods and calcareous spicules.

Remarks: Freshness of orbitoids, mollusks, and some smaller Foraminifera indicates recent addition. Calcareous crusts on many coral and algae fragments similar to that on material from dug holes suggests much of material was derived from unconsolidated island sediments by typhoon mentioned above.

Sample 2

Tidal swirl pool along inter-island passage near north tip of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from ripple-marked (high) tidal swirl pool along edge of inter-island spillway a few feet behind sand horn at lagoon corner. Reef at this point trends about NW-SE. Spillway develops behind several disconnected remnants of an indurated rubble track. Beach behind swirl pool faces NNE. Point about 1 mile from east end of island.

Other Data: Material in swirl pool is agitated at each tide with a general movement toward the sand horn. Probably much of material worked lagoonward along beach.

Character:	Size (mesh)	Percent	
	3	0.5)	
	4	.5)	coarse
	9	2)	
	14	2)	medium
	35	25)	
	less than 35	70	fine*/

*/ Fine fraction was resieved to conform to the Wentworth Scale

Larger fragments, mainly coral and algal, moderately to well worn, shells worn to fresh. Medium particles about half Foraminifera and half coral and algal and other fragments, worn to angular; spiny Foraminifera with most of spines partly or wholly broken off but with discs little worn, smaller Foraminifera and most orbitoids little worn or fresh. Finer particles slightly worn to angular, consisting of a few very small Foraminifera, embryonic gastropods, calcareous spicules, and fragments of other Foraminifera, corals, algae, etc.

Remarks: No evidence of calcareous crusting. All materials apparently freshly derived, much of it having moved lagoonward along sides of passage from seaward beaches. A large percentage of mollusks and orbitoids and some other forams recently added.

Sample 3

Sand horn at north lagoon corner of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from about halfway out on long low horn exposed only at low tide. Horn about 1 mile from windward (E) end of island. Sample from 150 to 200 feet out on horn. Horn oriented about W by N.

Other data: The present horn is more elongate and located more in line with the passage beach than with the more prominently bent horn on the 1944 photos which is oriented with the lagoon beach, curving lagoonward towards the end.

Character:	Size (mesh)	Percent	
	3	30)	
	4	4)	coarse
	9	15)	
	14	15)	medium
	35	35)	
	less than 35	1	fine

The larger fragments, mainly corals, algae and mollusca are moderately to well worn. The medium-sized particles, about 60 percent forams and 40 percent other, are worn to angular, the spiny Foraminifera with spines mostly broken off but discs not worn, and the orbitoids and small mollusk shells not perceptibly worn. The fine fragments are mostly sharp and angular, consisting of fragments of Foraminifera, corals, algae, etc., with some calcareous spicules.

Remarks: Presumably the fines are winnowed out rapidly here, and carried into the lagoon. At the same time there is a larger amount of coarse- to gravel-sized material accumulating.

Sample 4

High on beach at north tip of Utirik islet.

Atoll position: Islet at southeastern corner of atoll. Sample from highest part of beach at extreme north corner. Located about 1 mile from seaward (E) end of island.

Other data: Coarse material piled at top of beach to a depth of about 2 inches. Beneath it is a layer of medium fine to fine sand of undetermined thickness. Only a few scattered medium to coarse fragments in fine sand.

Character:

	Size (mesh)	Percent
surface layer - all more than 3		
substratum:	4	Trace
	9	Trace
	14	Trace
	35	20
less than	35	80

Material of surface layer consists mainly of worn coral fragments as much as 1 1/2 inches in longest dimension with a few pieces of coralline algae and mollusk shells.

Material of substratum consists mainly of angular fragments of corals, algae, Foraminifera, and mollusks with occasional whole specimens of smaller Foraminifera, embryonic gastropods and calcareous spicules.

Remarks: The nearly complete absence of intermediate-sized particles suggests entirely different causes for the deposition of the two layers. The lower fine zone is similar to fine material in the tidal swirl nearby, although which was derived from the other is difficult to say. The coarse upper zone is probably a high wave cast zone, probably with the fines winnowed out and perhaps settling out.

Sample 5

Beach sand near northwest corner of Taka islet on inter-island passage side.

Atoll position: Islet at southeast side of atoll. Reef to north of islet trends N-S, and to south of islet trends about NE-SW. Beach where sample was taken is between 0.2 and 0.3 mile from seaward edge and faces about due north or N. by E.

Other Data: A great many echinoid tests were strewn along the beach.

Character:

	Size (mesh)	Percent	
	3	Trace	
	4	0.5)	coarse
	9	8)	
	14	35)	medium
	35	55)	
less than	35	1.5	fine

Larger fragments moderately worn with a few fresh angular fragments, and a few fresh mollusk shells, consisting of fragments of corals, algae, echinoids, mollusks and some orbitoids. Medium-sized particles more angular, contains about 40 percent spined forams with spines mostly broken off but discs not worn, and about 60 percent coral, algal, mollusk, and other fragments and numerous fresh orbitoids and small gastropod shells. Fine particles angular or with only one side rounded, indicating breaking from larger rounded particles--consisting of fragments of coral, algae, mollusk shells, Foraminifera, etc.

Sample 6

Seaward windward beach, Ailuk islet.

Atoll position: Islet located at southeast corner of atoll. Sample from seaward beach at about center of eastward-facing stretch. Windward reef trends approximately N-S. South-facing reef trends nearly E-W. Beach 100 yards from reef edge.

Other data: The sand forms crescent-shaped beaches between projections of beach rock and raised reef rock. The materials are washed directly toward the beach from the reef flat and marginal zone, much of it being moved across the reef from one minor irregularity or depression to the next and finally to the beach.

Character:

	Size (mesh)	Percent	
	3	20)	coarse
	4	6)	
	9	50)	
	14	20)	medium
	35	3)	
less than	35	1	fine

Most materials fresh, angular and unworn, although occasional pieces are well rounded. Coarser sizes made up of corals, algae, mollusks, echinoid spines and plates and orbitoids with a small percentage of crustacean fragments. Medium-sized material more than half spiny forams and orbitoids, the remainder algae and other fragments. Only occasional coral fragments are present. Fine material consisting of fragments of algae, corals (?), Foraminifera, calcareous spicules and numerous transparent fibers not seen in more worn sands.

Remarks: All of this material is very little worn and close to its source. Most coral fragments are large, very little having been broken down. The fine material consists of a high percentage of originally small organisms or small structures of organisms. Many of the gastropods have well-preserved protoconchs.

Sample 7

Seaward beach at west corner of peninsula off northeastern side of Emejiwan islet, Likiep.

Atoll position: Innermost of two islets located on lagoonless projection of reef at northwest end of atoll. Samples from seaward (windward) beach at end of wedge-shaped peninsula and situated behind a tract of raised reef. Beach faces nearly north and is about 150 yards from reef edge.

Other data: The beach is worked by waves only at high high tides and during storms. Ordinary tides do not cover the raised reef platform.

Character:

	Size (mesh)	Percent	
	3	0)	
	4	Tr)	coarse
	8	25)	
	14	23)	medium
	35	50)	
less than	35	2	fine

Larger sizes consist of moderately to well-worn fragments of calcareous algae, corals, hydrocorallines, echinoids and mollusks. Medium-sized particles include worn pieces of coralline algae and less worn segments of Halimeda, together with less worn to fresh orbitoids, spiny and other Foraminifera and small mollusks. There is also a scattering of worm tubes and fragments of precious coral. Fragments of anthozoan corals are a minor constituent. The fine material consists of little worn fragments of all the above plus a larger amount of small Foraminifera and some calcareous spicules. Moderately abundant shreds of plant material are included. Some very fine (-100 mesh ?) material is included.

Remarks: Much of this material is freshly derived as shown by good preservation of spines on Foraminifera and the excellent preservation of orbitoids and some mollusks. Other algal and coralline fragments are much worn and presumably have been on the beach for a considerable period. The possibility of two histogram peaks, one for worn and one for fresh material is suggested. It is possible that some material is secondarily reworked from unconsolidated sand deposits which once covered the raised flats. Pockets of sand on the raised flat show the step-by-step movement of new materials beachward.

Sample 8

Beach at northwest corner of Emejiwan islet, Likiep.

Atoll position: Islet is the innermost of two located on a projection of the reef beyond the end of the lagoon. The northwestern tip of the island is in line with the leeward beach (there being no lagoon here), and about 100 yds. from the windward reef edge.

Other data: All sediment trains and erosional features indicate movement of sand across the reef flat from the windward edge and windward beaches to the leeward beaches and leeward reef flats.

Character:	Size (mesh)	Percent	
	3	0)	
	4	Tr)	coarse
	9	10)	
	14	40)	medium
	35	50)	
	less than 35	Tr.	fine

The materials are nearly identical in preservation and composition to those of sample 7, the main difference being the concentration of medium-sized particles.

Remarks: This material is obviously derived from the windward side. The nearly identical preservation suggests quick trans-reef movement by tidal currents. The preservation of materials here should be comparable to that at the lagoon corners of islands bordering the lagoon, the leeward beach here corresponding to lagoon beaches elsewhere.

Sample 9

Seaward beach of Torrutj islet, Kwajalein.

Atoll position: Islet located on leeward side of southern projection of atoll. Reef at this point trends nearly N-S.

Other data: The lagoon is more than 20 miles wide at this place, curving and becoming wider to the north. There is no reef alined in a windward direction along which sands could be moved by waves. The leeward reef bends far to the west above this point, and the southern tip of the atoll lies about 25 miles to the southeast.

Character:

Size (mesh)	Percent	
3	0.5)	
4	.5)	coarse
9	35)	
14	3)	medium
35	60)	
less than 35	1	fine

Grains well worn with somewhat more angular particles among the fine and medium sizes. Coarser particles are predominantly coral and coralline algae with minor amounts of molluscan fragments. The coarse medium size contains about 30 percent coral and coralline algae fragments, and about 20 percent highly worn Foraminifera, whereas in the finer medium size worn and polished Foraminifera made up about 50 percent of the particles. The fine material consists of rounded to angular fragments of corals, coralline algae and forams, and an occasional fresh small foram. A few calcareous spicules are present, but they are much worn.

Remarks: There is a rarity of orbitoids and orbitoidal fragments in the sample which seems unusual if the material came originally from the windward reefs. However, there is an abundance of coralline algae which is rare on the leeward reefs, but a major constituent of the windward reef on both the growing edge and the detrital sediments. Spiny forams which flourish on the windward reef flat, and form a major part of the sands are highly worn and polished, and not a single specimen having spines was found. The discs are worn and polished, many or most of the pimples being worn off. The evidence is strong that most of the materials originated on the windward reefs.

Sample 10

Lagoon beach of Torrutj islet, Kwajalein.

Atoll position: Islet located leeward side of southern projection of atoll. Reef at this point trends nearly N-S.

Other data: See sample 9. Sand on the lagoon beach has been piled steeply, exposing layers of gentler dips with incipient lithification.

Character:

Size (mesh)	Percent	
3	0)	
4	0)	coarse
9	Tr.)	
14	1)	medium
35	97)	
less than 35	2	fine

Most of the particles are worn and polished with only an occasional freshly broken particle or unworn forcm. Scattered coarse particles are coral or algal fragments (Porolithon) and aggregates of poorly consolidated medium grains, probably broken-up beach rock. Medium textured material consists of worn forams (Calcarina, Amphistegina, and Marginopora) and about an equal amount of coral and algal (Porolithon) fragments, and scattered specks of red encrusting forams (Fomotrema, etc.,), shell and echinoid fragments. The fines consist of finer fragments of the above with a few worn calcareous spicules and embryonic gastropods.

Remarks: The highly worn state of most materials suggests that the rate of addition of products of the leeward reef is very slow. A scattering of fresh specimens of Amphistegina, a species living in the lagoon, together with abundant worn Calcarina, and Marginopora and Porolithon fragments, which are added to lagoon sediments in abundance from the windward reef, suggests that a good part of the leeward sands are reworked lagoon sediments.

Sample 11

Lagoon beach Ninni islet, Kwajalein. About mid-point of lagoon beach.

Atoll position: Islet located on leeward side of southern arm of atoll. Reef at this point trends nearly NW-SE.

Other data: Fine, medium, and coarse zones are sharply separated on the beach--mixed evenly to form this composite sample.

Character: Sample mixed by hand to contain supposedly equal parts of fine, medium, and coarse zones; divided by screening into:

Size (mesh)	Percent	
3	10)	coarse
4	10)	
9	10)	
14	5)	medium
35	25)	
less than 35	40	fine*/

*/ Fines were sieved to conform to the Wentworth Scale.

Coarse material consists of worn and polished pieces of corals, algae (Porolithon), mollusks, and a few echinoid spines and crustacean fragments. The medium-textured material consists of smaller, frequently more angular pieces of the above, and in addition moderately to highly worn and polished forams (Calcarina and Amphistegina) and a few specimens of each that are less worn, fragments of Marginopora and numerous ruby specks of encrusting forams (Homotrema). A few scattered worn Heterostegina are also present. The fines contain somewhat more angular fragments of all the above but with a surprisingly small percentage of foraminiferal fragments.

Remarks: Here again is a surprisingly large amount of algal material (Porolithon) suggesting that the windward reef was the main source of the material.

Sample 12

Western tip of Eniwetak islet, Kwajalein.

Atoll position: The islet, which is about a quarter of a mile long, lies within the lagoon, about one mile inside a passage near the mid-point of the eastern side of the atoll. The reef bends in towards the passage at this point, trending away from the passage in northeasterly and southeasterly directions.

Other data: The reef around the island has mainly coral growing on it. The northeastern shore is a coarse boulder beach composed entirely of boulders of beachrock--no coral heads as on the seaward boulder ramparts.

Character:	Size (mesh)	Percent	
	3	0)	
	4	Tr.)	coarse
	9	Tr.)	
	14	Tr.)	medium
	35	30)	
	less than 35	70	fine*/

*/ Fines were sieved to conform to the Wentworth Scale.

The material is mostly fine medium to fine. Particles are worn and polished and consist mainly of corals, algae (Porolithon) and mollusks. The fine-medium-sized fraction consists of about 30 to 40 percent worn forams, mainly Calcarina and with lesser amounts of Amphistegina and broken Marginopora. The finer material consists of slightly more angular fragments of the above. Many ruby-colored specks of Homotrema are present in both fine and fine medium sizes.

Remarks: The materials here are worn and polished like the sands of the leeward reef. There seemed to be no evidence of any foram-laden algal mats on the narrow reef flat of the island, and presumably the forams were derived mostly from the windward reef of the atoll. There are also no growths of coralline algae along the island reef, suggesting that these too came from the windward reef, presumably via the lagoon. The nearly equal amounts of wear and polish on the coral and other fragments make it likely that all materials have had a more or less common origin and mode of transportation. Although this island is close to the windward reef its sands are more like the sands of the leeward beaches than the windward beaches, either on the seaward or lagoon sides. The similarity of the sands strongly suggest that they were derived from the lagoon.

Sample 13

Lagoon beach, Bokerok islet, Ujae Atoll.

Atoll position: Islet located on southeast side of Bock Channel which is at about mid-point of the leeward side of the atoll. The reef trends about NW-SE at this point.

Other data: Numerous coral knolls and reefs occur in the lagoon inside the channel. The sandy beach was developed only on the lagoon side and for a few feet around the sides of the island where it terminated steeply and abruptly. The remainder of the island beach is coarse rubble and bare raised reef rock.

Character:

Size (mesh)	Percent	
3	Tr.)	
4	Tr.)	coarse
9	1)	
14	5)	medium
35	84)	
less than 35	10	fine

The coarse screen retained only some fresh gastropod shells and some fragments of a poorly consolidated beach rock. The other coarse sizes were composed of rounded to angular pieces of coral, coralline algae (Porolithon), poorly consolidated beach rock, and 20 to 30 percent of Halimeda fragments, mostly broken. The medium sizes consist of worn to angular fragments of the same materials and in addition fragments of Marginopora, echinoid spines, mollusks, and medium to much worn specimens of Calcarina and Amphistegina. Scattered fragments of red Homotrema are also present. The Foraminifera make up only about 20 to 25 percent of the medium sizes. The fine material is made up of worn to subangular fragments of all the above.

Remarks: This sand is somewhat more angular than some other sands on the leeward islands. This may indicate that some was derived from the nearby knolls, or that it has not been on the beach for a very long period--the latter possibility may be supported by the rather restricted distribution of the sand on the island. The abundance of Halimeda fragments suggests here again that the sand was obtained from the lagoon sediments.

Sample 14

Northeast corner of Enejalto islet, Lae. Seaward side.

Atoll position: Islet located about one-fourth the distance from Lae islet on windward (northeast-facing) reef, the reef trending about NW-SE. The sample came from a broad seaward-facing horn on the seaward corner of the islet.

Other data: This unusual horn is apparently due to a short stretch of lagoonward-dipping beachrock on the seaward side of the island.

Character:	Size (mesh)	Percent	
	3	15)	
	4	10)	coarse
	9	30)	
	14	35)	medium
	35	10)	
	less than 35	Tr.	fine

The coarser material consists of unworn to moderately worn mollusk shells, and fragments of corals, coralline algae (Porolithon), hydrocorallines, echinoid spines, etc. The finer size (9 mesh) contains numerous well-preserved gastropods, Marginopora and Halimeda segments. The medium-sized material contains 60 to 70 percent well-preserved Calcarina, about 20 percent mixed Marginopora, small mollusks, and Homotrema fragments, and the remainder mixed fragments of coral, algae, echinoids, crustacea, etc. Numerous Volunlina occur in the 35-mesh sample. The fine material contains broken fragments of materials in the coarser sizes, and some shreds and filaments of broken up noncalcareous algae.

Remarks: This material, as might be expected, is close to the source of clastics, and relatively unworn. The rather large amount of Halimeda segments is unusual for a windward reef, but it was observed at other places that the outer moat locally supports prolific Halimeda colonies. The possibility that some Halimeda might have been derived from the lagoon by storm waves is suggested by the seaward point of this horn-like bar and the apparent lack of sand at the lagoon corner of the island--as if it had been washed seaward. This is contradicted by the virtual absence of highly worn Foraminifera which might be expected in lagoon-derived sediments--unless, of course, they were derived from the comparatively fresh sand lobes along the edge of the lagoon reef.

Sample 15

Seaward beach of northwest prong of Wotho islet, just west of dry sand passage separating Wotho and Enerikon islets.

Atoll position: Islet located at northeast corner of atoll, the beach facing north or a little east where the sample was taken.

Other data: This beach is partly in the lee of Enerikon islet.

Character:

	Size (mesh)	Percent	
	3	20)	
	4	8)	coarse
	9	30)	
	14	20)	medium
	35	20)	
	less than 35	2	fine

The larger sizes consist mainly of little-worn corals, coralline algae (Porolithon), hydrocorals, mollusks, worm tubes, and a few large forams (Marginopora) and Halimeda. There is also a generous red sprinkling of organ coral (Tubipora) fragments and Homotrema, both loose and encrusting other organisms. The medium sizes consist of fully 90 percent unworn Foraminifera, mainly Calcarina and Marginopora with scattered Amphistegina and Heterostegina. The remaining 10 percent is composed of small mollusks, bryozoan fragments, and fragments of materials in the coarser sizes. The 35-mesh screen held a slightly higher percentage of angular detrital material and fewer Foraminifera than the 14-mesh screen. Numerous Volunlina are present in the 35-mesh material. The fine material consists mainly of angular fragments of above materials and in addition a scattering of small Foraminifera (miliolids and cymbaloporids), fragments of needle-thick echinoid spines, calcareous spicules, etc.

Remarks: All materials appear virtually unworn, showing clearly their nearness to their source, but the little amount of beach erosion in their present position. The latter may be due in part to the semi-protection of Enerikon islet. Organ pipe coral is more abundant here than usual.

Sample 16

Beach at head of large cove on north side of Wotho islet.

Atoll position: Islet located at northeast corner of atoll. The cove opens along the north side of the island and the prevailing wind affects it obliquely.

Other data: Fine material is concentrated at the southwest corner of the cove, where this sample was taken. The sand becomes increasingly coarser towards the east end of the head of the cove. The cove head is filling in, and appears to be an incomplete stage in the building of one large island from two smaller ones. The area behind the cove is not underlain by a raised rock flat whereas the larger areas on either side are.

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	Tr.)	coarse
	9	2)	
	14	13)	medium
	35	70)	
	less than 35	15	fine

The coarser fragments consist of fresh to moderately worn coral, coralline algae (Porolithon), mollusks, echinoid spines, and Marginopora with attached and detached Homotrema. The medium sizes contain moderately worn fragments of the above and an abundance of Marginopora, Calcarina, and Amphistegina. Most of the forams are fairly fresh, but most of the spines are broken off the Calcarina. The fine material is composed of little worn fragments of the above plus small forams (miliolids and cymbaloporids), embryonic gastropods, fragments of needle-sized echinoid spines and calcareous spicules. A few pelagic Foraminifera are present (Tretomphalus).

Remarks: This material is on the whole quite fresh, but somewhat more beach worn than nearby sample 15.

Sample 17

Lagoon beach, Wotho islet.

Atoll position: Islet at northeast corner of atoll. The point at which the sample was taken lies directly opposite the large cove on the seaward side, and in line with a bare scour scar that extends nearly to the lagoon beach. The lagoon beach at this point is nearly in the full lee, trending nearly NW-SE.

Other data: Water pours across the island at this point during major storms, and some of the sand here may have been derived from the large seaward cove by being washed directly across rather than having washed around the corners of the island.

Character:	Size (mesh)	Percent	
	3	shells)	
	4	shells)	coarse
	9	shells + Tr.)	
	14	Tr.)	medium
	35	75)	
	less than 35	25	fine*/

*/ Fines were sieved to conform to the Wentworth Scale.

Shells of a small, smooth-ribbed cardiid make up almost all of the coarser material. A few worn corals, coralline algae (Porolithon), Halimeda, and small gastropods make up about 20 percent of the 9-mesh screenings. The medium-sized material is mostly smaller than 14 mesh, the 14-mesh material being composed mainly of small Marginopora and coral and algal fragments, with a few fragments of Homotrema. The coarser medium-sized particles are about 10 percent coral and algal fragments, and about 30 percent moderately worn Calcarina, Amphistegina and small Marginopora, with a scattering of both fairly fresh and highly worn specimens. The fine siftings consist of unrecognizable moderately worn to angular fragments of corals, algae, Foraminifera, and some fresh miliolids and cymbaloporids, calcareous spicules, small echinoid spines, and red to pink fragments of Homotrema and organ pipe coral (Tubipora).

Remarks: This material is definitely more worn than the material on the seaward side (samples 15 and 16). The abundant cardiid, which lives in the lagoon suggests derivation of some of the sand from the lagoon beach, probably during summer storms.

Sample 18

Seaward beach near south end of Motho islet.

Atoll position: Islet at northeast corner of atoll. Sample from southern end of long stretch of beach (about 200 ft N of the north end of the southernmost stretch of exposed rock platform). The beach and reef edge trend nearly N-S at this point.

Other data: (none given)

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	5)	coarse
	9	85)	
	14	10)	
	35	Tr.)	medium
	less than 35	0	fine

The coarse material is composed of well-worn and polished coral, coralline algae (Lithothamnion), mollusks, echinoid and Halimeda material with a scattering of less worn or fresh Marginopora. The medium-textured material is similar, but with a higher percentage of Marginopora on the 14-mesh screen, and on the 35-mesh screen a few comparatively fresh specimens of Calcarina. The 35-mesh material is mostly angular. No fine material is present.

Remarks: This material is very much worn and polished for the windward reef. The amount of wear is probably due to slow movement along the long stretch of beach, and possibly entrapment behind the rock platform at the end, resulting in long wear on the same beach. The fines seem to have completely escaped. Quite fresh Calcarina in the medium sizes indicates that fresh material is still being added, nevertheless.

Sample 19

Lagoon beach near northwest of Eirek islet, Wotho.

Atoll position: The islet is located on the leeward reef in the southwestern part of the atoll. The reef trends NW-SE at this point. The sample is from the intertidal zone near the west end of the lagoon beach.

Other data: A large dune ridge rises directly behind the beach.

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	nil)	coarse
	9	Tr.)	
	14	4)	medium
	35	95)	
	less than 35	1	fine

The scattered coarse pieces present are worn corals, coralline algae (Porolithon), Halimeda, mollusks, etc. The medium sizes contain smaller worn fragments of the same and worn forams, mostly Calcarina. The material on the 35-mesh screen consists of about 50 percent worn and polished Calcarina and scattered Amphistegina, some of which are fairly fresh. Occasional unworn but spineless Calcarina can be seen. The fine material is comparatively unworn and mostly angular, apparently recently broken. A few small forams are present.

Sample 20

Top of dune behind lagoon beach of Eirek islet, Wotho.

Atoll position: Same as sample 19. Dune located directly behind beach.

Other data: The dune is about 9 to 10 feet higher than the inner edge of the beach and is partly healed over with vegetation. Numerous trees grow along its sides and crest although there is no mat of grass or other small vegetation covering it.

Character:	Size (mesh)	Percent	
	3	0)	
	4	0)	coarse
	9	0)	
	14	0)	medium
	35	30)	
	less than 35	70	fine*/

*/ Fines were sieved to conform to the Wentworth Scale.

No materials were held by the 14 mesh and coarser screens except a few pieces of carbonaceous material. The finer medium textured material consists of polished to dull, angular to highly worn fragments of corals, calcareous algae, mollusks, Marginopora, etc., and worn to moderately fresh smaller Foraminifera, mainly small specimens of Calcarina and Amphistegina. A minor amount of purplish to reddish material is present, some of which are echinoid spine fragments and Homotrema and some of which may be alcyonarian, either organ pipe coral (Tubipora) or precious coral (Corallium). The fine material consists of smaller fragments of the above, and occasional whole minute forams, probably miliolids or cymbaloporids.

Remarks: The low percentage of fine material in the beach sand and the concentration of fines in the dune suggests that the dune material was largely winnowed from the adjacent beach. Most of the material of the beach and dune is distributed between the fine-medium and fine sizes.

Sample 21

Lagoon beach near south end of Eirek islet, Wotho.

Atoll position: Same as samples 19 and 20. Sample from broad lagoon beach near eastern end of island.

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	Tr.)	coarse
	9	5)	
	14	40)	medium
	35	45)	
	less than 35	10	fine

Materials of coarse and medium sizes highly worn and polished. The coarse materials are fragments of coral and calcareous algae (mostly Halimeda with a few scattered fragments of Porolithon), and mollusk shells. The medium sizes contain similar materials with a scattering of highly worn Foraminifera (Calcarina and Amphistegina) on the 14-mesh screen, and 50 percent or more on the 35-mesh screen. A few Amphistegina appear to be quite fresh. There is also a scattering of purplish or reddish echinoid spine fragments, Homotrema or alcyonarians. The fine material is more angular and mostly unpolished, in contrast to the larger sizes. In addition to the constituents of the larger sizes, there are a few fresh small Foraminifera (miliolids and cymbaloporids) and some calcareous spicules.

Remarks: The materials here are coarser than at the west end of the beach. The abundant Halimeda indicates that much of the material is derived from the lagoon. The high degree of wear may indicate a rather long period of working on the leeward reef, and may in part reflect a long process of transportation from its ultimate place of origin along the windward reef. The finer sizes appear to have moved to the westward, and the finest to have been blown landward to form a dune.

Sample 22

Bottom sample at end of lobe extending into lagoon at west end of Raej islet, Ujelang.

Atoll position: Islet located on windward reef about 3 miles from east end of atoll. The reef at this point trends generally WNW-ESE.

Other data: Sample taken by dredging at a depth of about 25 feet at inner side of sand lobe on lagoon reef. The lobe is located just west of Raej islet, and projects lagoonward about 100 feet beyond the normal margin of the lagoon beach. The reef at this point is nearly half a mile wide.

Character:	Size (mesh)	Percent	
	3	1)	
	4	1)	coarse
	9	10)	
	14	35)	
	35	50)	medium
	less than 35	3	fine

The coarse sizes contain fragments of corals, coralline algae (Porolithon), Halimeda, Marginopora and mollusks. Few fragments show much sign of recent wear although some edges are well rounded. A crust of dead bryozoans, worms, Homotrema, and other organisms covers some fragments, and on some there is an irregular encrustation of white amorphous material. The medium-sized material consists largely of the tests of Calcarina, Amphistegina, and Marginopora, some of which are encrusted with a small amount of white amorphous material. The spines of the Calcarina are mostly broken, but otherwise there is little wear. About 20 percent of the material on the 14- and 35-mesh screens consists of coral, calcareous algae (Porolithon and Halimeda), echinoid, Homotrema, mollusk, and other fragments. The fine material is composed of fragments of the above plus a scattering of small Foraminifera (miliolids and cymbaloporids), needle-thick echinoid spines and embryonic gastropods.

Remarks: This lobe and others like it form opposite trans-reef spillways and points where sediments crossing the reef are funnelled into a narrow area. It is surprising that the spines on the Calcarina should be more broken than those on specimens collected from some of the seaward beaches, and it probably indicates that their transportation is either violent or very slow with the particles moving along the bottom of the reef flat and spillways the entire distance. The very fresh materials collected from some seaward beaches, or along the sides of islands, are for the most part high on the beaches. They were probably wafted high on the beaches by storm waves, and remained above high-tide level with very little subsequent working.

Sample 23

Sand accumulation at lagoon side of what is either an indurated rubble flat or the remainder of a raised reef flat, Bokanwor, near the east end of Ujelang Atoll.

Atoll position: The jagged flat is located at the eastern end of the reef. The reef at this point bends gently from its more northwesterly trend west of here to a more southerly trend to the easternmost tip of Ujelang islet.

Other data: The reef at this place is nearly half a mile wide. The point at which the sample was taken lies about 1,200 feet from the seaward edge, and about 200 feet lagoonward from the irregular promontory. The rough flat is submerged at high tide. Behind it is an accumulation of sand and gravel which is trapped in the lee of the irregular promontory, and which thins lagoonward.

Character:

Size (mesh)	Percent	
3	50)	
4	4)	coarse
9	12)	
14	3)	
35	20)	medium
less than 35	6	fine

The coarse sizes are pieces of coral and coralline algae (Porolithon) and mollusk shells, with a scattering of Halimeda segments. Well-preserved Homotrema and Carpenteria encrust many of the fragments. The fragments range from little worn to well worn and many of them are darkened by surface growths of algae. The medium sizes contain smaller fragments of the same materials, and about 50 percent Foraminifera, mainly Calcarina, Amphistegina, and Marginopora. Many of the Calcarina have spines intact. As with the coarser material, many particles are dark owing to a growth of minute algae on their surface. The fines contain fragments of the same materials with a scattering of minute Foraminifera (miliolids and cymbaloporids) and calcareous spicules.

Remarks: The materials at this place are covered with every tide. The lack of wear, which is emphasized by the algal growth on many particles, is probably due to the semiprotection of the deposit from agitation by the raised indurated flat to the seaward. A small amount of white sand can be seen extending lagoonward as a sediment train on air photographs.

Sample 24

Lagoon beach of Helle islet, Ujelang.

Atoll position: Islet located at east side of wide pass on leeward side of atoll, just a little west of the center of the leeward reef.

Other data: Coarser material occurs on the eastern seaward corner of the islet than elsewhere. The material in the intertidal zone along the lagoon beach is mostly fine.

Character:	Size (mesh)	Percent	
	3	Tr.)	
	4	Tr.)	coarse
	9	2.5)	
	14	2.5)	medium
	35	40)	
	less than 35	55	fine*/

*/ Fines were sieved to conform to the Wentworth Scale.

Coarser fragments are much worn pieces of coral, algae (Porolithon) and Halimeda), mollusk shells and echinoid spines. The medium-sized material consists of the same, plus a small percentage of foraminifera (Calcarina, Amphistegina, and Marginopora). The Calcarina are much worn, but some of the Amphistegina are quite fresh. The fine material consists of angular fragments for the most part. In addition to the constituents found in the coarser sizes, there are a few calcareous spicules.

Remarks: The freshness of some Amphistegina suggests that they were derived from the lagoon. The angular character of most of the fines is of interest here as on other leeward reefs. Whether this indicates that the fines are the result of local recent breaking of larger fragments, or whether it means that abrasion of the finer sizes does not take place at the same rate as the larger sizes is difficult to say. At any rate, there does not appear to be any indication of breakage on larger fragments, all of which are well worn. The most likely explanation is that the fines were washed up on the lagoon beach from the lagoon as angular fragments.

Sample 25

Sand from irregularities on raised rock platform on seaward side of Maronlik islet, Ujelang.

Atoll position: Islet located on windward (northeast-facing) reef on eastern third of atoll.

Other data: Sample from one of many sand-filled irregularities on rock platform extending seaward from islet. The spot is located about 100 feet from the seaward tip of the islet and about 700 feet from the outer reef margin.

Character:

	Size (mesh)	Percent	
	3	2.5)	
	4	10)	coarse
	9	35)	
	14	25)	medium
	35	25)	
less than	35	2.5	fine

The coarser materials are mainly fragments of corals and coralline algae (Porolithon) with occasional echinoid spines, mollusk or Halimeda segments. The fragments are moderately worn, but many are darkened by a surface growth of algae, showing a minimum of active wear. Small colonies of Homotrema are attached to the fragments. The medium sizes are made up of similar materials, less worn, for the most part, than the coarse material, and contains in addition about 50 percent little worn to fresh Calcarina and Amphistegina with a scattering of small Marginopora. The spines on most of the Calcarina are unbroken. The fines are composed of mostly angular fragments of the above and in addition there are a few small forams (miliolids and cymbaloporids) and calcareous spicules.

Remarks: The sand and gravel in the pockets on the raised platform is little more than wetted at high tide, only occasional waves welling on to the platform and sending little streams along its natural irregularities. These find the minor depressions and fill or partly fill them, and the water eventually disappears within the porosity of the rocks. There is, therefore, very little abrasion of materials in the pockets, and they are agitated and moved beachward only during rough weather or storms when waves sweep entirely across the platform. This probably accounts for the freshness of the Foraminifera and the algal coats on some of the other fragments.

The February 1945 photos show a broad sand beach around the seaward end of this island and an elongate sand spur extending seaward along the center of the raised flat. In 1952 the sand spur had largely disappeared, only occasional pocket fillings remaining, and sand was absent from the seaward tip of the island. A medium-textured boulder beach was partially exposed.

Sample 26

Beach along west side of Maronlik islet, Ujelang.

Atoll position: Same as sample 25.

Other data: Sample from beach facing reef along west side of island. The broad seaward beach and the elongate spur extending seaward from it along the center of the raised rock flat, shown on the 1945 photos, appears to have been redistributed along the sides of the island. There is some indication, particularly from the sharpness of the lagoon beaches and the spurs extending seaward on the 1945 photos, that a storm prior to 1945 steepened the lagoon beaches, and moved island beach sands seawards, producing the seaward-pointing spurs. A subsequent storm removed the spurs and moved materials seaward again along the sides of the island. Bars at the lagoon corners extending along the reef, or possibly deflected a little seawards, were deflected strongly lagoonwards and distributed more thinly across the lagoon beach.

Character:	Size (mesh)	Percent	
	3	20)	
	4	5)	coarse
	9	7)	
	14	13)	medium
	35	55)	
	less than 35	Tr.	fine

The coarse material consists of fresh to moderately worn pieces of coral, coralline algae (Porolithon), echinoid spines, and both whole and fragmented shells of mollusks, Marginopora, and Halimeda segments. Homotrema encrusts some of the algal fragments. The medium-textured material contains, in addition, about 60 percent moderately fresh Calcarina and a few Amphistegina. Although the Calcarina show little sign of disc wear, most specimens have the spines broken off. The fines contain numerous small forams (miliolids), fine echinoid spine fragments, and an abundance of calcareous spicules.

Remarks: For the most part the materials here are cleaner and look less worn than the material in the pockets on the rock flat to the seaward. However, the Calcarina in the sample from the rock flat have better preserved spines than the beach specimens.

Sample 28

Rock platform at north seaward corner of Taka islet, Taka Atoll.

Atoll position: Islet at southeast corner of atoll. Sample from pocket of gravel lodged behind a strip of abandoned beach rock.

Character:	Size (mesh)	Percent	
	3	40)	
	4	30)	coarse
	9	20)	
	14	5)	
	35	5)	medium
less than	35	Tr.	fine

Coarse material consists of moderately fresh fragments of coral, coralline algae (*Porolithon*), echinoids, mollusks, and *Marginopora*, and *Halimeda* segments. There is some darkening, probably due to algae growing on the surface. The medium sizes contain similar fragments and in addition there is 10 percent *Calcarina* and *Amphistegina* ranging from slightly worn to well preserved. There is some darkening due to algae on most particles, even the completely spined *Calcarina*. The fines contain fragments of the same materials plus a scattering of minute Foraminifera (miliolids and cymbaloporids) and calcareous spines.

APPENDIX II

Field descriptions of soil profiles or sedimentary sections

Because of a general dearth of descriptive data on atoll soils it seems desirable to record all information on the material reported in this paper just as it was written down in the field, in the form of descriptions of profiles or partial profiles. These do not correspond exactly, in certain respects, to ordinary soil profiles, as the layering is as much due to depositional phenomena, in other words, stratification, as to soil horizon development. The profiles might equally well be called sedimentary sections. However, there is in all cases some evidence of horizon development. In the Shioya and Arno Atoll series, layer 1 corresponds to an A_1 horizon and the lower layers to a C horizon. In the Jemo series, layer 1 is an A_0 horizon, layer 2, a B horizon, and the lower layers, a C horizon.

Color determinations were made under field conditions, ordinarily on somewhat moist samples, in most cases (except on Taongi (Pokak) and Bikar Atolls) by direct comparison with a Munsell color chart. Information on structure is only given if it is not the loose single-grain structure normally observed in these soils. Consistence, likewise, is not commonly mentioned, as it seems to lack significance in most of these sandy soils.

Certain of the profiles described were not analyzed, but are included here to provide a fuller basis for the generalized series descriptions.

SHIOYA SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 4			Utirik, Utirik islet, SW. corner of islet, nearer outer than inner beach (fig. 18, E).	Flat ground in open coconut grove, grassy with some bushes.
102	1	0-1.6		Reddish-gray (5YR-5/2) with some fine black (5YR-3/1), varying blotches of light-reddish-brown (5YR-6/3). Sand with irregular coral fragments.
103	2	1.6-2.2		Pinkish-gray (5YR-6/2) loamy sand with some gravel.
104	3	2.2-2.5		Pink (5YR-8/3) fine sand with some coarser particles.
105	4	2.5-3.2		Mixed pinkish grays averaging about 5YR-7/2. Gravel with some coarse sand.
No sample	5	3.2 +		Reef rock.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 3			Utirik, Utirik islet, S. of village near ocean beach (fig. 18, E).	Flat ground in open grassy coconut grove.
97	1	0-1.3		Salt and pepper pinkish (5YR-8/2, 5/1, 3/1 averaging 6/2) loose sand with irregular coral fragments.
98	2	1.3-1.9		Dark gray (10YR-3/2) loose sand with irregular coral fragments.
99	3	1.9-2.3		Pale gray-pink (5YR-8/2), loose sand with irregular coral fragments.
100	4	2.3-3.0		Pale gray-pink (5YR-8/2), darkened a little at top, loose sand with irregular coral fragments.
101	5	3.0-4.2 +		Gray (5YR-5/1) becoming lighter downward, irregularly mottled or splotched with pink (5YR-8/2-8/3). Sandy rubble with irregular coral fragments.

Then coral fragments became so numerous and hard-packed that digging became impractical. Large cobbles and even a few boulders were scattered through this entire profile.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A8 (Arnow)			Wotho, Wotho islet, 500 ft from lagoon beach (fig. 16, J).	Flat ground in coconut grove with grassy undergrowth.
23	1	0-1.4		Dark-brown (7.5YR-3/2) to brown (7.5YR-5/2). Sand, coarse to very coarse, and silt.
24	2	1.4-1.9		Very dark brown (10YR-2/2) and 10YR-7/3 mixed). Very coarse sand with small pebbles and silt covering many of the larger particles.
25	3	1.9-?		Very pale brown (10YR-8/3). Fine to coarse sand, few Foraminifera, some pebbles.
Water table		3.2		

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A7 (Arnow)			Wotho, Wotho islet, 210 ft. in from lagoon beach (fig. 18, J).	Flat ground in coconut grove.
21	1	0-1.6		Dark-brown (7.5YR-3/2) to brown (7.5YR-5/2). Coarse to very coarse sand, loamy in upper 6 inches.
22	2	1.6-?		Very pale brown (10YR-8/3). Medium to coarse sand, about 10 percent Foraminifera.
Water table		2.8		

Compact, walls stand up without caving, but easy to dig through.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 69			Wotho, Wotho islet, near center of islet (fig. 18, J).	Flat ground in *Ochrosia* forest.
141, 142, 143	1 Transition abrupt	0-1.0		Dark-gray (10YR-4/1), fine rubble varying to fine sandy loam, somewhat compact but friable.
144	2	1.0-3.0		Very pale brown (10YR-8/4) sand.
Profile 71 (partial)			Wotho, Wotho islet, on west point of islet (fig. 18, J).	Flat ground in scrub vegetation under young coconut trees.
147	1	0-0.1		Light-brownish silt (10YR-6/2), pisolites about 2-3 millimeters diameter.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 72			Wotho, Wotho islet, on west point of islet (fig. 18, J).	Flat ground in *Scaevola* scrub in sparse coconut plantation.
148	1	0-0.3		Gray to gray-brown (10YR-5/1-5/2), loosely pisolitic, silty.
149	2	0.3-0.5		Light-gray-brown (10YR-6/2) silt, compact, but fluffy when crushed.
150	3	0.5-1.8 +		Pink (7.5YR-8/2-8/4) loose sand.
Profile A26 (Arnow)			Ailuk, Ailuk islet, southwest corner (fig. 18, A).	Vegetated sand spit.
133	1	0-1.0		(10YR-8/1) light-gray-medium sand.
134	2	1.0-4.0		Coarse to very coarse sand with pebbles and small cobbles.
Profile 139			Taongi (Pokak), Kamwome islet, well inland from sea (fig. 16, C).	Middle of broad low ridge of small gravel with sparse *Messerschmidia* forest. 10YR-5/2, 10YR-3/1 + 7/2.
154	1	0-0.13		10YR-7/2, 7/3, 4/2 + 2.5Y-4.0. Darkened by organic material, small gravel.
153	2	0.13-1.1		Pale, small gravel.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 141 (partial)			Taongi (Pokak), Sibylla islet (fig. 18, D).	Shallow depression in open place, with algal film.
156	1	0-0.08		White (2.5Y-9/1-9/2) silt.
no sample	2	0.08-0.57		Sand.
Profile 144 (partial)			Taongi (Pokak), Sibylla islet, NE. end, 300 feet from lagoon beach (fig. 18, D).	Flat ground, Scaevola scrub vegetation.
no sample	1	0-1.5		Sand, slightly darkened at surface, otherwise light brown.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 145			Taongi (Pokak), Sibylla islet, about in center 1 mile from N. end of islet (fig. 18, D).	Flat ground, surface of small gravel strewn with boulders, in sparse *Messerschmidia* scrub.
157	1	0-0.85		Gray-brown (10YR-6/1-7/2) darkened somewhat at surface. Medium coarse sand with some coral fragments.
No sample	2	0.85-1.15		Very pale. Very fine sand with some coral fragments.
No sample	3	1.15-1.85		Gray-brown. Fine rubble.
No sample	4	1.85-2.75		Gray brown. Coarse rubble.
No sample	5	2.75-4.1		Light-pinkish. Fine rubble with some coarse fragments.
Water table		4.2		
No sample	6	4.1-5.4 +		Whitish. Semi-indurated rubble, interstices filled with very fine material.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 146			Taongi (Pokak), Sibylla islet, toward lagoon, about 1 mile from north end of islet (fig. 18, D).	Open flat ground, shearwater rookery with holes 1-1.5 meters apart, herbaceous vegetation mainly *Portulaca*.
No sample	1	0-0.03		White surface crust, strengthened by algae.
No sample	2	0.03-1.8		Light-gray-brown. Fine sand, standing up well when cut by shovel, even when dry.
No sample	3	1.8-3.2		Light-brown. Coarse rubble.
No sample	4	3.2-4.8 +		White rubble, mostly rather fine but with some large fragments, and fine claylike material between fragments.
Water table		4.5		

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 11			Taka, Taka islet, 300 feet from lagoon beach (fig. 16, E).	Flat ground in grassy opening in sparse coconut grove.
122	1	0-0.8		Whitish-pink, (7.5YR-8/2) slightly stained with organic matter in top 0.15 feet, coarse sand.
	Changing abruptly			
123	2	0.8-1.5		Salt and pepper mixture of dark-brown (7.5YR-3/2) and pinkish-gray (7.5YR-6/2) very sandy loam.
	Changing over space of 0.1			
124	3	1.5-3.0		Salt and pepper mixture averaging brown to pinkish-gray (7.5YR-3/2-6/2) sandy gravel with water-worn fragments.
	Changing abruptly			
no sample	4	3.0-?		Coarse angular rubble mixed with much sand.
no sample	5	?-?		Rock with sloping surface (beach rock?).

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 12			Taka, Taka islet, central part of islet (fig. 16, E).	Flat ground in grassy opening in mixed scrub vegetation.
51	1	0-0.9		Dark-brown (7.5YR-3/2) larger particles as light as 7.5YR-5/2-6/2, darker at top, loam sand, fluffier and with more organic matter toward top.
	Changing gradually			
52	2	0.9-1.5		Pinkish-gray (7.5YR-6/2) sand mixed with fine silt fairly compact, easily crumbled.
	Changing gradually			
53	3	1.5-4.3		Pink (7.5YR-7/4) sand to small gravel, occasional larger fragments.
no sample	4	4.3-?		Indurated limesand or beachrock.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 13			Taka, Taka islet, central part of islet (fig. 16, E).	Flat ground with Scaevola scrub vegetation.
54	1	0-0.25		Very dark gray (5YR-3/1) loamy sand.
	Changing abruptly			
55	2	0.25-2.0		Reddish gray (5YR-5/2) to pinkish gray (5YR-6/2-7/2) sand with some small gravel.
	Changing abruptly			
56	3	2.0-2.5		Pinkish gray (5YR-7/2) gravel with fine sand or silt.
	Changing abruptly			
57	4	2.5-4.4		Very pale brown (10YR-8/4) coarse sand with some gravel, changing to sand and large fragments in bottom 8 inches or so.
no sample	5	4.4-?		Consolidated fine gravel.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A15 (Arnow)			Taka, Taka islet, 400 feet in from outer beach (fig. 16, E).	Flat ground in clearing in mixed scrub forest.
109	1	0-0.3		Very dark gray (10YR-3/1) and very pale brown (10YR-8/3), medium sand and loam.
110	2	0.3-0.9		Gray brown (10YR-5/2), medium to fine sand.
111	3	0.9-1.4		Dark gray brown (10YR-4/2) pebbles.
112	4	1.4-1.8		Light gray (10YR-7/2), medium to fine sand.
113	5	1.8-2.1		Dark gray brown (10YR-4/2), coarse to medium sand and pebbles.
114	6	2.1-3.1		Light brown gray (10YR-6/2), coarse to medium sand and pebbles.
115	7	3.1-8.8 +		Very pale brown (10YR-8/4), fine to coarse sand with occasional small cobbles, becoming indurated in lower 3 feet.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A16 (Arnow)			Taka, Taka islet, 75 feet from lagoon beach (fig. 16, E).	Flat ground in coconut grove.
116	1	0-0.5		Very pale brown (10YR-8/3) fine to medium sand.
117	2	0.5-1.2		Gray brown (10YR-5/2) fine to very fine sand, occasional pebbles.
118	3	1.2-1.9		Very pale brown (10YR-8/3) fine to medium sand.
119	4	1.9-2.8		Light brown gray (10YR-6/2) fine to medium sand, occasional cobbles.
120	5	2.8-5.7		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size.
Water table		5.7		

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 29			Jemo Island (fig. 17, A).	Flat ground with low forest of *Scaevola* and *Messerschmidia*.
131	1	0-0.5		10YR-7/2, 7.5YR-7/2 salt and pepper averaging pale brown (10YR-6/3), lighter downward, sand, some rocks.
	Changing gradually			
132	2	0.5-2 +		Sand with pebbles and cobbles.
Profile 30			Jemo Island, near east side (fig. 17, A).	Flat open area with scattered *Scaevola* bushes.
69	1	0-0.6		Salt and pepper from very dark gray-brown (10YR-3/2) to pale brown (10YR-6/3) loamy sand.
	Changing gradually			
70	2	0.6-1.4		Very pale brown (10YR-7/3-8/3) sand.
	Changing rather abruptly			
71	3	1.4-3.0		Very dark gray-brown (10YR-3/2) including some lighter grains, general effect gray brown (10YR-4/2); lighter below first 0.5 feet, also coarser, compact but very crumbly.
72, 73	4	3.0-?		Pink (7.5YR-8/4) coarse sand with some gravel.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 103 (partial)			Ujae, Ebbetyu islet near lagoon beach (fig. 16, G).	Flat ground in coconut plantation, unburned.
121	1	0-1		Gray (10YR-4/1-4/2) sand.
Profile 104 (partial)			Ujae, Ebbetyu islet, near lagoon beach (fig. 16, G).	Flat ground in coconut plantation where pile of trash has been burned.
152	1	0-1		Gray brown.
Profile 101 (partial)			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground in *Ochrosia* forest.
89	1	0-0.5		Dark gray-brown (10YR-3/1-3/2).
no sample	2	0.5-?		Rubble.
Profile 100 (partial)			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground under *Pisonia* tree.
88	1	0-0.5		Gray-brown (10YR-3/2-4/1).
no sample	2	0.5-?		Rubble.

SHIOYA SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 17			Likiep, Lado islet, 221 feet E. of lagoon beach, 175 feet N. of south beach (fig. 16, B).	Flat ground in sparse coconut grove with thin herbaceous vegetation, barren in aspect.
125	1	0-0.6		Reddish gray (5YR-5/2) fine sand, pebbly at surface, much pebbly coral in layer.
126, 127	2	0.6-3.0		Pinkish white to pink (5YR-8/2-8/3), some lenses stained slightly grayish, sand with many water-worn pebbles and cobbles arranged in lenses or horizontally.
129, 130	3	3.0-6		White to pink (5YR-8/1-8/3) fine gravel with pebbles up to several inches across.
Water table		3.9-5.5 or lower (tidal fluctuation)		
Profile 46			Lae, Lae islet, in village 20 feet from high-tide mark on lagoon beach (fig. 18, C).	Flat ground under large breadfruit tree.
138	1	0-0.3 or 0.9		Gray (2.5Y-5/0) compact sand.
139	2	0.3 or 0.9-6.0 +		Light pinkish coarse sand.

ARNO ATOLL SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 1			Utirik, Utirik islet just E. of village (fig. 16, E).	Flat ground in open grassy coconut grove.
37	1	0-0.7		Black (10YR-2/1) flecked with pale, coarse irregular gravelly sand, some fine material.
38	2	0.7-1.1		Black (10YR-2/2) thickly flecked with pale sand.
39	3	1.1-2.7		Black (10YR-3/1) mottled with gray, coarse irregularly gravelly sand.
40	4	2.7-4 +		Very pale brown (10YR-7/3-8/3) sand.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 2			Utirik, Utirik islet, center of islet S. of village (fig. 16a, E).	Flat ground in open grassy patch in coconut grove.
41	1	0-0.2		Black (10YR-2/1) thickly flecked with light brown, coarse foraminiferal sand.
42	2	0.2-0.7		Salt-pepper brown (10YR-4/2-4/3) becoming lighter downward, coarse foraminiferal sand.
43	3	0.7-1.8		Black 1YR-2/1-4/1 coarse foraminiferal sand.
44, 45	4	1.8-7		Pinkish mottled with gray, gray (5YR-6/2) to pink (5YR-8/3) coarse foraminiferal sand, loose to hard-caked (below 5 feet).
46	5	7-8 +		Small gravel.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 5			Utirik, Utirik islet, near center of islet E. of village (fig. 16, E).	Flat ground in sparse coconut grove, herbaceous vegetation knee-high.
47	1	0-0.7		Black (10YR-2/2) loamy sand with a few small coral fragments.
48	2	0.7-1.5		Gray pink (7.5YR-6/4) blotched with a salt and pepper mixture (10YR-3/1 and 6/2) appearing gray, coarse sand.
	Changing gradually			
49	3	1.5-2.5		Pink (7.5YR-8/4) blotched above with gray (as in layer 2), foraminiferal sand.
50	4	2.5 +		Pink, consolidated small gravel, easily shattered.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A3 (Arnow)			Ujelang, Ujelang islet, 80 feet from lagoon beach (fig. 17, F).	Flat ground in coconut grove.
30	1	0-1.5		Very dark brown (10YR-2/2) loamy mixture of pebbles, sand and silt, some clay, occasional cobbles.
31	2	1.5-2.4		Light gray (10YR-7/2) loamy mixture of pebbles, sand and silt, some cobbles and boulders, silt forms coating around larger particles; rather compact.
32	3	2.4 +		White (10YR-8/1) rubble of boulders, cobbles, pebbles, sand and silt, compact and hardpan-like, friable when broken loose.
Profile A14			Taka, Taka islet, 540 feet in from lagoon beach (fig. 16, E).	Flat ground in *Pisonia* grove.
106	1	0-0.9		Black (10YR-2/1) with white grains, sand and clayey loam.
107	2	0.9-3.4		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size.
108	3	3.4-4		Very pale brown (10YR-8/4) coarse to very coarse sand with larger fragments up to cobble size, somewhat indurated.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A23 (Arnow)			Ailuk, Ailuk islet (fig. 18, E).	Flat ground in grassy coconut grove.
33	1	0-1.2		Very dark gray (7YR-3/0) loam and sand with pebbles and cobbles, mostly water worn.
34	2	1.2-1.7		Very pale brown (10YR-7/3) medium to coarse sand.
35	3	1.7-2.4		Dark gray (10YR-4/1) compact silt and medium sand, occasional larger particles.
36	4	2.4-4.3		Very pale brown (10YR-8/3) coarse to very coarse sand with pebbles and cobbles; pockets of silt and with clay acting as binder in lower 1.5 feet where it is indurated.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 38			Ailuk, Ailuk islet, near village (fig. 18, A).	Flat ground in open coconut grove, most trees dead or dying ("laora" disease?).
77	1	0-1.0		Black (5YR-2/1) sandy loam with some small gravel.
	Changing abruptly			
78	2	1.0-1.8		Pink (7.5YR-7/4) with a few black spots, foraminiferal sand.
	Changing abruptly			
79, 80	3	1.8-2.7		Pink (7.5YR-7/4) fine gravel, compact.
81	4	2.7-3.0		Very pale brown (10YR-7/3) silt, compact, slightly plastic when worked between fingers.
82	5	3.0-3.7 +		Very pale brown (10YR-7/3-8/4) small gravel with some larger fragments, poorly consolidated, shatters easily.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile All (Arnow)			Lae, Gibinrii islet, in center of islet, 120 feet from lagoon beach (fig. 18, C).	Flat ground in coconut grove.
272	1	0-0.6		Very dark brown (10YR-2/2) loam or loamy sand.
273	2	0.6-1.4		Pinkish gray (7.5YR-6/2) very coarse sand, mostly Foraminifera, occasional pebbles.
no sample	3	1.4-1.7		Pebbles and some loam.
no sample	4	1.7-2.2		Pebbles and some loam.
274	5	2.2-2.5		Gray (10YR-6/1) water-worn pebbles.
275	6	2.5-5		Reddish yellow (7.5YR-8/6) and very pale brown (10YR-8/3) very coarse sand, strongly indurated at 3.5 feet below which are alternating hard and soft zones.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 18			Likiep, Lado islet, back of seaward ridge (fig. 16, B).	Broad depression in grassy coconut grove.
58	1	0-1.3		Black to dark reddish brown or very dark gray (5YR-2/1-3/1) coarse sand and silt with much coarse gravel.
	Changing gradually			
59	2	1.3-2.5		Pink (7.5YR-8/4) coarse foraminiferal sand with coral fragments as much as several inches.
	Changing gradually			
60, 61	3	2.5-3.9 +		Fine gravel.
Water table		3.5		
Profile A9 (Arnow)			Wotho, Wotho islet, 650 feet from lagoon beach (fig. 16, J).	Flat ground in cleared area overgrown by *Wedelia*.
27	1	0-1.0		Very dark brown (10YR-2/2) mixture of silt, sand and small pebbles.
28	2	1.0-2.0		Light brown gray (10YR-6/2) coarse to very coarse sand and pebbles.
29	3	2.0-5.0		Very pale brown (10YR-8/4) sand and pebbles, semi-indurated.
no sample	4	5.0-?		Solid reef rock.

ARNO ATOLL SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 70			Wotho, Wotho islet, center of islet (fig. 16, J).	Flat ground on boundary between coconut plantation and *Ochrosia* forest.
145	1	0-1.0		Dark gray (10YR-4/1) fine powdery loam varied in places with small lenses of light-colored sand.
	Changing somewhat gradually			
146	2	1.0-1.7 +		Light brownish-gray (10YR-6/2-7/2) very compact fine rubble.
Profile 84			Ujae, Bock islet, near lagoon (fig. 17, C).	Flat ground in coconut plantation.
86	1	0-0.5		Black (10YR-2/1) silt mixed with lighter grains of sand and fine rubble.
no sample	2	0.5 +		Rubble.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 27			Jemo Island (fig. 17, A).	Flat ground in dense coconut grove, herbaceous ground cover.
63	1	0-0.7		Black (10YR-2/1) silt with some gravel.
64, 65	2	0.7-1.1		Black with conspicuous white grains, mixture of silt and rubbly fragments.
66	3	1.1-2.4		Salt and pepper mixture of dark gray (10YR-4/1) and light brown gray (10YR-6/2) loamy sand.
67, 68	4	2.4-?		Very pale brown (10YR-8/3) very coarse sand.
Profile 98 (partial)			Ujae, Wotya islet (fig. 16, I).	Flat ground in *Ochrosia* forest.
87	1	surface (thickness not recorded)		Dark brown (7.5YR-3/2) crumbly fine material with some fine fragments.
	Changing abruptly			
no sample	2			Loose rubble.

JEMO SERIES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 123-125 (partial)			Wotho, Kabben islet, near center of eastern half of islet (fig. 18, F).	Flat ground under large *Pisonia* trees.
196, 197	1	0.5(or 0.2)-0		Black to brown raw humus.
198, 199	2	0-0.5		Blackish loose crumbly soil with much rubble.
Profile 118 (partial)			Wotho, Ombelim islet (fig. 17, H).	Flat ground in *Pisonia* forest, covered by dry leaves.
194	1	0.1-0		Black raw humus with hard black surface.
195	2	0-0.2		Partially cemented sand.
no sample	3	0.2 +		Sand.
Profile 116-117 (partial)			Wotho, Ombelim islet (fig. 17, H).	Flat ground in *Pisonia* forest, covered by dry leaves.
192	1	0.3(to 0.2)-0		Raw humus.
193	2	0-0.2		Partially cemented sand.
no sample	3	0.2 +		Sand.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 110 (partial)			Ujae, Erlie islet (fig. 16, F).	Flat ground in *Pisonia* grove.
190	1	0.5(to 0.25)-0		Raw humus, surface bumpy, hardened and cracked polygonally.
191	2	0-0.1(to 0.15)		Partially consolidated material.
no sample	3	0.1(to 0.15) +		Coral rubble.
Profile 97 (partial)			Ujae, Wotya islet (fig. 16, I).	Flat ground in *Pisonia* grove.
224	1	0.25(to 0.1)-0		Dark reddish brown (5YR-3/1-3/2) mottled with light grayish flecks and patches, raw humus; 4 Truog tests: pH 4.5-5.
225	2	0-0.1		Mottled dark brown and light partially consolidated material, hard but crumbling between fingers; 2 Truog tests: pH 6.0(1), 8.0(1).
no sample	3	0.1 +		Rubble of small pebbles.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 86-87 (partial)			Ujae, Bokerok islet (fig. 17, D).	In *Pisonia* grove on boulder flat.
218, 220	1	0.3-0		Raw humus.
219, 221	2	0-?		Weakly consolidated sand (219); partially altered pebbles (221).
no sample		0-?		Boulders.
Profile 91 (partial)			Ujae, Rua islet (fig. 16, H).	In *Pisonia*-*Terminalia* grove.
222	1	0.4-0		Raw humus; 8 Truog tests: pH 5.5-6.5.
223	2	0 +		Hardpan of consolidated sand.
Profile 73 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
210	1	0.2(to 0.4)-0		Raw humus.
211				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0+		Rubble.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 74 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
212	1	0.4(to 0.2)-0		Raw humus.
213				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0 +		Rubble.
Profile 78 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
214	1	0.4(to 0.2)-0		Raw humus; Truog test: pH 5.
215				Pebbles, softened and ocher-like on outside, embedded in lower layers of raw humus.
no sample	2	0 +		Rubble.
Profile 79 (partial)			Ujae, Bock islet (fig. 17, C).	Flat ground in *Pisonia* forest.
216, 217	1	0.5-0		Light-brown raw humus with included pebbles, these altered and ocherlike externally. Truog test of pebbles: pH 8.
no sample	2	0 +		Rubble.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 15			Taka, Lojrong islet (fig. 16, D).	Flat ground in *Pisonia* grove.
201	1	0.25-0		Black to dark-brown raw humus with Foraminifera and coral fragments; Truog test: pH 8.0.
no sample	2	0 +		Coral gravel.
Profile 14			Taka, Lojrong islet (fig. 16, D).	Flat ground in *Pisonia* grove.
200	1	0.25(to 0.15)-0		Tough, compact dark-brown raw humus; 2 Truog tests: pH 5.5(1), 6.0(1).
no sample	2	0 +		Coral gravel.
Profile 134			Taongi (Pokak), Kamwome islet (fig. 16, C).	Flat ground in *Pisonia* clump, closely strewn with *Cardium* shells.
no sample	1	0.1-0		Poorly formed raw humus.
Do.	2	0-0.9		Brown fine sand.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 28			Jemo island, west side (fig. 17, A).	Flat ground in grassy *Pisonia* grove.
202	1	0.4-0		Very dark brown (10YR-2/2) raw humus, tough but friable when crushed firmly. 2 Truog tests: pH 5.0(2).
203	2	0-0.3		Variable light and brown, averaging yellowish brown (10YR-6/4) coarse sand, weakly cemented, crumbling between fingers.
204	3	0.3-?		Very dark gray-brown (10YR-3/2) with light grains, loamy sand.
Profile 26			Jemo island, west side (fig. 17, A).	Flat ground in *Pisonia* grove.
4	1	1-0		Dark-reddish brown (5YR-2/2-3/2) raw humus; 3 Truog tests: pH 4.5(3).
5	2	0-?		Very dark brown matrix (10YR-2/2) with white grains, coarse rubble of fragments of cemented material.
Profile 31 (partial)			Jemo Island, west side (fig. 17, A)	Flat ground in coconut grove.
205	2	surface		Exposed surface layer.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 32 (partial)			Jemo island, west side (fig. 17, A).	Flat ground in coconut grove.
6	2	surface		Exposed surface layer.
Profile 25			Jemo island, west side (fig. 17, A).	Flat ground in *Pisonia* grove.
1	1	0.5-0		Dark-reddish-brown (5YR-2/3-2/2) fine raw humus; Truog test: pH 6.5.
2	2	0-0.3		Matrix very dark brown (10YR-3/2) grains white (10YR-8/2), cemented coarse sand.
3	3	0.3-1.5 +		Very dark brown (10YR-2/2) with tiny white grains, sandy loam with gravel, more rubbly downward.
Profile 177 (partial)			Bikar, Bikar islet (fig. 18, B).	Flat ground in *Pisonia* forest.
228	1	0.5-0		Raw humus.
229	2	0-0.25		Consolidated layer.

These separated by a thin deposit of yellow-brown earthy material.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 156			Bikar, Bikar islet (fig. 18, B).	Flat ground, covered by litter, in *Pisonia* forest.
176	1	0.15-0		Very dark brown raw humus; 12 Truog tests: pH 4.5(2), 5.0(3), 5.5(1), 6.0(6).
177	2	0-0.1		Pale sand with dark brown cement; consolidated.
178, 179	3	0.1-0.6		Gray brown, streaks stained dark brown, finely and irregularly bedded sand.
180, 181	4	0.6-1.2		Dark gray brown, with (consolidated) layers of brown; sand with irregular consolidated layers.
182	5	1.2-2.5		Darker gray loose sand with brown lumps of cemented sand and thin layers of slightly darker material.
183, 184	6	2.5-3.9		Very dark brownish gray to brown, earthy, powdery, sandy, to consolidated (consolidated portion with dark-brown cement).
185	7	3.9-4.5-4.8		Pinkish ashy gray changing downward to pale brown, sand, compact above to loose below.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 156 (cont'd)				
186, 187	8	4.8-8.8		Pale-gray-brown, gravel layers humus stained; series of thin beds of alternating sand and small gravel, sand layers 2-3 inches thick, gravel thinner, all loose but gravel more compact than sand.
188	9	8.8 +		Hard rock.
Profile 153			Bikar, Bikar islet (fig. 18, B).	Flat ground, covered by litter, in *Pisonia* forest.
12	1	0.15(to 0.1)-0		Very dark brown raw humus.
13	2	0-0.1		Brown and pale salt-and-pepper consolidated layer.
14	3	0.1-1.2 +		Light-brown sand.
Profile 166			Bikar, Jabwelo islet (fig. 16, A).	Flat ground in *Pisonia* forest.
15	1	0.4-0		Dark-brown raw humus.
16, 17	2	0-0.6		Hardpan.
18	3	0.6-1 +		Pale sand and rubble.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 164			Bikar, Almani islet (fig. 16, A).	Flat ground in *Pisonia* forest.
164	1	0.4-0		Very dark brown raw humus.
165	2	0-0.25		Cemented sand.
166	3	0.25-0.6 +		Pale brown sand.
Profile 163 (partial)			Bikar, Almani islet (fig. 16, A).	Flat ground in *Pisonia* forest.
160	1	0.5-0		Loose dark brown raw humus.
161	2	0-0.5 +		Cemented sand.
Profile 165 (partial)			Bikar, Jabwelo islet (fig. 16, A).	Flat ground in *Pisonia* forest.
19	1	0.7-0		Dark-brown raw humus.
20	2	0-0.5		Cemented sand, very hard.
Profile 157 (partial)			Bikar, Bikar islet, near east side (fig. 18, B).	Flat ground in *Pisonia* forest.
162	1	0.16-0		Raw humus.
163	2	0-?		Cemented sand.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 158 (partial)			Bikar, Bikar islet, near center (fig. 18, B).	Flat ground in *Pisonia* forest.
158	1	0.2-0		Raw humus; 13 Truog tests: pH 5.0(3), 5.4(2), 5.6(1), 6.0(2), 6.5(5).
159	2	0 +		Cemented sand.
Profile 49 (partial)			Kwajalein, Eniwetak islet.	Flat ground in *Pisonia* forest.
7	1	0.5(to 0.3)-0		Raw humus.
8	2	0 +		Cemented layer.
Profile 50			Kwajalein, Eniwetak islet.	Flat ground in *Pisonia* forest.
9				Nodules of cemented material on surface.
11	1	0.5-0		Raw humus.
10				Nodules of cemented material embedded in humus layer.
Profile 55, 56 (partial)			Ujelang, Kiriniyan islet, in interior (fig. 17, E).	Flat ground in *Pisonia* grove.
207	1	0.1-0		Raw humus.
208	2	0-?		Coarse sand.

JEMO SERIES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 57 (partial)			Ujelang, Kiriniyan islet, in interior (fig. 17, E).	Flat ground in *Pisonia* grove.
209	1	0.1-0		Raw humus.
no sample	2	0-?		Loose rubble.

MISCELLANEOUS PROFILES

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A7 (Arnow)			Lae, Lae islet (fig. 18, C).	In taro pit.
266	1	0-0.5		Very dark brown (10YR-2/2) silt with occasional sand particles.
267	2	0.5-0.8		Very pale brown (10YR-7/3) and dark gray (10YR-4/1) silt and coarse to very coarse sand.
268	3	0.8-2.5		Very pale brown (10YR-7/4), coarse to very coarse sand and pebbles.
Profile A8 (Arnow)			Lae, Lae islet, near lagoon beach (fig. 18, C).	Taro patch.
269	1	0-0.5		Very dark gray (5YR-3/1) slimy jellylike silt with occasional sand particles.
270	2	0.5-0.9		Very dark brown (10YR-2/2) silt with fine to medium sand and occasional coral pebbles.
271	3	0.9-1.5		Very pale brown (10YR-8/4) coarse to very coarse, sand with some pebbles.

Water table at about 1 foot.

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A10 (Arnow)			Lae, Enemanman islet, 225 feet from lagoon beach (fig. 18, C).	Flat ground in coconut grove.
74	1	0-0.5		Dark-brown (7.5YR-3/2) loamy mixture of silt and coarse to very coarse sand (largely Foraminifera).
75	2	0.5-2.2		Pinkish-gray (7.5YR-6/2) sand with occasional pebbles (mostly Foraminifera).
76	3	2.2-3.8		Reddish yellow (7.5YR-8/6) and very pale brown (10YR-8/3), very coarse sand, largely Foraminifera and mollusk shell fragments.
Water table		3.5		
Profile 83			Ujae, Bock islet, near center of west part of islet (fig. 17, C).	Flat ground in coconut plantation.
151	1	0-1.5		Dark-gray (7.5YR-3/2), fine sand.
no sample	2	1.5 +		Rubble.

MISCELLANEOUS PROFILES (Continued)

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 81 (partial)			Ujae, Bock islet, interior (fig. 17, C).	Flat ground in coconut grove where coconut trash has decomposed.
84	1	0.4(to 0.2)-0		Black (10YR-2/1) humus with light sand grains.
no sample	2	0-?		Loose rubble.
Profile 82 (partial)			Ujae, Bock islet, interior (fig. 17, C).	Bottom of small depression 1 meter deep in coconut grove.
85	1	0-0.5		Dark-brown (7.5YR-3/2) plastic mucky material, highly humic.
no sample	2	0.5-?		Loose rubble.
Profile 102			Ujae, Ebbetyu islet (fig. 16, G).	Flat ground in *Ochrosia* forest.
90	1	0-0.1		Black (10YR-3/1).

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile 6			Utirik, Utirik islet, east of village (fig. 18, E).	Abandoned taro pit, filled with *Clerodendrum* thicket.
256	1	0-1.9		Black (10YR-2/1-2/2) mucky loam with some coarse sand; plastic when worked.
257	2	1.9-2.5		Gray (10YR-4/1) thickly flecked with pale brown (10YR-7/3), sticky silty sand with much coral gravel.
258	3	2.5-3.2 +		Pale brown (10YR-7/3), hard, firmly packed rubble with some sand.

Water table at about 3 feet, water with strong hydrogen sulfide odor, and a peculiar sweet taste, rose to 2.3 feet in 2¼ hours. Taro pit bottom perhaps 6 feet below level of surrounding area.

Profile no. & sample no.	Layer	Depth (feet)	Locality	Description
Profile A21 (Arnow)			Ailuk, Ailuk islet, not far from outer beach (fig. 18, A).	Depression (old taro pit?) in coconut grove, ground covered with *Clerodendrum*.
263	1	0-0.9		Very dark brown (10YR-2/2), compact silt with some medium to coarse sand.
	Changing gradually			
264	2	0.9-2.5		Dark gray (10YR-4/1), compact slippery silt with numerous medium to coarse sand particles.
Water table at 2.2 feet at 11:00 a.m., January 27, 1951.				
265	3	2.5-3		Very pale brown (10YR-8/3), coarse to very coarse sand.
Profile 138			Taongi (Pokak), north end Kamwome islet (fig. 16, C).	Guano deposit in bird rookery.
sample lost	1	0-0.1		Guano--gray, firm, somewhat greasy. pH 5.5-6 (field determination with Truog indicator kit).
sample lost	2	0.1-0.3		Loosely caked earthy material, gray-brown, somewhat greasy, pH 7.
155	3	0.3-1.8		Loose gray-brown sand, pH 8.
no sample	4	0.8		Rubble.

Index to soil profiles in Appendix II

Profiles collected by Ted Arnow

Profiles collected by F. R. Fosberg

APPENDIX III

Synonymy of place names

Since many of the place names used in this paper, in accordance with decisions issued by the U.S. Board on Geographic Names, differ from those used by Fosberg and others (1956) and especially from those commonly used by people in the Marshall Islands, the following lists have been prepared. The left-hand list contains all names used on maps in the present paper and are approved by the Board on Geographic Names. The center list is of the corresponding names used in 1956. The right-hand list is somewhat modified from a list supplied by E. H. Bryan, Jr., of names obtained from Marshallese informants. In all cases the names on a single line apply to the same islet or other feature. Where several spellings were listed by Bryan one has been selected and the others placed in parentheses. Blanks indicate that there is no name in the particular list for the feature indicated on the line.

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Taongi Atoll	Taongi Atoll	Pokak
North Island	North	---
Kamwome	Kamome	---
Bwdije	Breje	Breje
Sibylla	Sibylla	---
Pokak	Pokak	Pokak
---	---	Bokdik
Bwokwla	Boklā	Boklā
Pokak Pass	Pokak Pass	---
Bikar Atoll	Bikar Atoll	Bikar
Jabwelo	Jaboerukku-tō	Jalliklik (Jenilklik)
Almani	Arumeni-tō	Almeni
Jaboero	Jaboerukku-tō (changed in Errata to Jaboero-tō)	Jaboero
Bikar	Bikar	Bikar
Bikar Passage	Bikar Pass	---
Ailuk Atoll	Ailuk Atoll	Ailuk
Kapen	Kapen	Kapen
Enijabro	Enijabrok	Enijabrok
Amwo	Amo	Amo
Enejelar	Enejelar	Enejelar
Jeloklap	Jeloklap	Jeloklap
Enenpao	Enenpao	Enenpao
Bikonmenlok	Bikommenlok (2 small islets)	Bikõnmenlok
Enekelik	Enekelik	Enekelik
Bigen	Bigen	Bikon

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Ailuk Atoll (continued)		
Bwinejrak	Binejrak	Binejrak
Eneneman	Enemen	Enenemman
Anenoomw	Enen-om	Enen-om
---	---	Ajatak
Ajeleb	Ajeleb	Ajillep
Ajiddik	Ajirrik	Ajirrik
Anearmij	Enearmij	Enearmij
Anekinge	Enenkone	Enenkone
Abta	Ebta	Ebta
Jabta	Jebta	Jebta
Kabbwok	Kabbok	Kabbok
Mwalok	Malok	Malok
Aliet	Aliej	Aliej
Allirik	Allirok	Allirok
Bwokwanmwiokan	Bokanmweokan	Bokanmweokan
Jerongkan	Jirongkan	Jirongkan
Aneanij	Mutōkin	Mutōkin
Anejamwaden	Enejomaren	Enejōmaren
Baojan	Baojen	Baojen
Luujrik	Lujirok	Lujirōk
Bokrak	Bōkrak	Bōkrak
Biklab	Bōklap	Bōklap
Anine	Enine	Enine
Bio	Bieo	Bieo
Bererjan	Bererjan	Bwerōrkan
Ni	Ni	Ni
Tabu	Tabu	Tabu
Konnon	Kōnwon	Kōnwon
Jobeik	Jabeik	Jebeik
Nge	Ne	Nge
Anenkora	Enenkōra	Enenkōra
Ulika	Ulika	Ulika
Jibanngit	---	Jabanngit
Maribw	Maruppu-tō	Marib
Marme	Marme	Marme
Anenkinge	Enenkōnge	Enenkōnge
Aneaudik	Eneaurik	Eneaurik
Miemwa	Miemwa	Mienwa
Eneao	Eneao	Eneao
Anemwanmwan	Enemōnmong	Enemōnmong
Jabwe	Jabbwi	Jabbwi
Anenlik	Enellik	Enellik
Ailuk	Ailuk	Ailuk
Enije	Enije	Eneje
Enije Channel	Enije Channel	Toweje
Agulwe	Agulue	Akulwe
Erappu Channel	Erappu-suidō	Tolap
Marok Channel	Marok Channel	Ton Maluk
Eneneman Channel	Eneneman Channel	Ton Eneman

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll	Kwajalein Atoll	Kwajlen
Ebadon	Ebadon	Ebaten
Bokan	Bokan	Bokan
Aoj	Aoj	Aoj
---	---	Enenak (Elenak)
Enealo	Eneao	Eneao (Enealo)
Bikrik	Bikrik	Bikrik
Nennar	Nennar	Nennar
---	---	Tabta
Jein	Jein	Jein
Mejatto	Mejatto	Mejetto
Oreba	Oreba	Keko
Bokliplip	Bokliplip	Bokliplip
Geiga	Geiga	Enejebro
Marsugalt	Marsugalt	Malik (Boklap)
Bok	Bok	Bok
Maj	Maj	Maj (Mai)
Biggerann	Biggerann	Arbwa
Elcharai	Etcharai	Ejjela (Ejjellā)
Morenkul	Morenkul	Morenkul (Mōrōnkul)
Oniotto	Oniotto	Onwot (Wōnwōt)
Biggarenn	Biggarenn	Bikram (Bekram)
Bigi	Bigi	Bikren
Bokkumaruchi	Bokmaruj	Bokmaruj
Boggerik Passage	Boggerik Pass	---
Boggerik	Boggerik	Errob (Errop)
Boggerlap	Boggerlap	Boklab (Boklap)
Mellu Pass	Mellu Pass	Milu /pass/
Drenaenae (sand bank inside pass)	Drenaenae	Drenaenae
Mellu	Mellu	Milu
North Pass	North Pass	---
Ennuebing	Ennuebing	Enibing (Enebin)
Roi	Roi	Ruot
Namur	Namur	Nimur
Ennugarret	Ennugarret	Enekoran (Enekōren)
---	---	Bokanlabirka
Ennumennet	Ennumennet	Enemanet
---	---	Bikenwot
Ennubirr	Ennubirr	Enebōn
Bogeri	Boker	Boker
---	---	Bokabelbel
Obella	Obella	Obel (Wobel)
Begeraburappu	?	---
Edgigen	Edgigen	Ajkan
Debuu	Debuu	Tubwuj

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll (continued)		
Edjell	Edjell	Ejel
Gagen	Gagen	Kowakkan
---	---	Tahemujokan (Tokāmujken)
Gellinam	Gellinam	Kirenen
Omelek	Omelek	Komle
Kwadack	Kwadack	Kwateb (Kuatab)
Eniwetak	Eniwetak	Eniwetak
Meck	Meck	Meik
Bigej	Bigej	Bikej
Bigej Channel	Bigej Channel	Bikej [pass]
Ningi	Ningi	Ngenge
Gugegwe	Nōngejokenen	Nōngejōkenen
Ebwaj	Ebwaj	Ebwaj (Ebwoj) (3 islets above form Gugegwe)
---	---	Bijinkur
Loi	Loi	Lojjaiong (N. Loi)
Lojjairok	Lojjairok	Lojjāirok (S. Loi)
Ebeye	Ebeye	Ebeye (Ebeje, Ebeja)
Ebjapik	Ebjapik	Ebjapik (Ebja drik)
Worbab	Worbāb	Worbāb
Kwajalein	Kwajalein	Kwajlen Jittaken (N arm) Jittoen (SW curve)
Enubuj	Enubuj	Enebuoj (Enibuōj)
South Pass	South Pass	---
Ennylabegan	Ennylabegan	Enelapkan
Gea	Gea	Kio (Kiio)
Gea Pass	Gea (Kio) Channel	Kio (Kiio) [pass]
Ninni	Ninni	Nini
Gehh	Gehh	Kā
Torrutj	Torrutj	Bok
---	Tongle	Tongle (Tengle)
---	Tarwoj	Tarwoj (Tarwojion, Tarwōjirōk)
Mann	Mann	Man
Jokouj	---	Jokouj (Jokouij)
South Ambo Channel	South Ambo Channel	---

Names used in this paper	Names used in Military Geography of the Northern Marshalls, 1956	Names used by Marshallese
Kwajalein Atoll (continued)		
Legan	Legan	Amboirok and Amboiōng (2 islets joined)
Ambo Channel	Ambo Channel	---
Eller	Eller	Ellep (Alep)
Eller Passage	Eller Pass	---
Ennugenliggelap	Ennugenliggelap	Enekanliklal (Enekanliklōl)
Burle	Burle	Murle
Onemak East Passage	East Onemak Pass	---
Labo	Labo	Labo
Onemak	Onemak	Onmak
Onemak West Passage	West Onemak Pass	---
Illeginni	Illeginni	Likijjine (Likijinā)
Wojejairok	Ujajiirukku-tō	Wojejairok (Wojejārirok)
Wojejairok Pass	Ujajiirukku Pass	---
Wojejaiong	Wojejaiong	Wojejāiōng
Jiee	---	Jā
---	---	Rebweiu (Drebwin)
---	---	Jerak
Nell	Nell	Nel (Nōl)
Nell Passage	Nell Pass	---
Bikennel	Bikennel	Bikennel
Ennumet	Ennumet	Enmat
---	---	Bokālum (Bokaliom)
---	---	Enero (Enuero)
Jakeru	Jakeru	Enejore
Gurer	Gurer	Jakrout
Eru	Eru	Ero
Gegibu	Gegibu	Kurōr
Boggenatjen	Kijin-bwi	Kijin-bwi
Ere	Ele	Ele
Bokanaujjor	Boggenatjen	Bokanaujjor
Lobon	Ere	Lobon (Lobwom)
Yabbenohr	Yabbenohr	Jabōnwōr (Japōnwōr)
Tabik Channel	Tabik Channel	---
Tabik	Tabik	Jabok
Lae Atoll	Lae Atoll	Lae
Ribong	Ribong	Ribon (Ribūn)
Nabon	Nabōn	Nabōn
Bigilapij	Bigilapij	Bikelabet (Bikelabot)
Bui	Bui	Bwi (Bwe)
Leip	Reipu	Lep (Leep)
Bigenaj	Bikenaj	Bikenaj

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Lae Atoll (continued)		
Luisap	Luisap	Lwejap (Loejap)
Enemanit	Enemanet	Enejelto (Enijeldu, Enejaltou)
Enejalto	Enejelto	Enemanet
Eonbiji	Eonbeje	Eonbeje
Nokkweie	Nokkweie	Nokkweie
Gibinrii	Gibinrii-tō	Enen-bao (Arkarek)
Enemanman	Enemanman	Enemanman (Enemōnmōn)
Lae	Lae	Lae
Rarime	Rarime	Rama, Drame
Bokanaetok	Bokanaetok	Bokanaetok (Bokanatok)
Bokankiren	Bokankiren	Bokankiren
Boklimairek	Boklimairik	Boklimairik
Boklulu	Boklulu	Boklulu
Lotj	Lotj	Loj
Lae Pass	Lae Pass	---
Likiep Atoll	Likiep Atoll	Likiep
Mwaat	Mat	Mat
Jenokae	Senegai	Senegai
Malle	Melle	Melle
Emejiwan	Rikuraru-tō	Emijwe
Rere	Rere	Rere
Pokonjieij	Pokonjieij	Pokonjieij
Aej	Aij	Aij
Kekeron	Kekeron	Kekeron
Kidenkan	Kerenegan	---
Anenaan	Eninōn	Eninōn
Enejelol	Enejelōl	Enejelōl
Anejaej	Enejeij	Enejeij
Kaben	Kaben	Kaben
Anenemmwaan	Eneneman	Eneneman
Enruk	Enruk	Enruk
Mak	Mak	Mak
Jeltonet	Jeltonet	Jeltoniej
Bikinmingjaiing	Bikirkirjeiōng	Bikirkirjeiōng
Bikinmingjairik	Bikirkirjeirok	Bikirkirjeirōk
Boguraburabu	Boguraburabu	Boklaplap
Anerukkanjaiing	Enerukanjeiōng	Enerukonjeiong
Anerukkanjairik	Enerukanjeirōk	Enerukonjeirok
Kijjen	Kojjen	Kojjen
Tamwol	Tamōl	Tamōl
Kabwolbwolkan	Kabelbelkan	Kabelbelkan
Didi	Riri	Riri
Bwokwankowak	Bokankowak	Bokankowak
Najbwol	Najbol	Najbol
Eniiecchi	Eniiecchi	Eniej
Killommwar	Melemmar	Melemmar

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Likiep Atoll (continued)		
Meron	Meron	Melang
Jibal	Jebal	Jebal
Kile	Kōle	Kōle
Anekira	Enekura	Enekura
Anearmej	Enearmij	Enearmij
Biebe	Biebe	Biebe
Mwikil	Mukil	Mukil
---	---	Aujarej
Lado	Lado	Lato
Likiep	Likiep	Likiep
Nalab	Nalap	Nalap
Nadik	Narik	Narik
Anenanuun	Enenuan	Enenuan
Aneloklab	Enenloklab	Enenloklap
Biketokeak	Biketōkāk	Biketōkāk
Biketolong	Biketolon	Biketolon
Atotak	Atolak	Atolak
Agony	Agony	Aekōne
South Pass	South Pass	---
Entrance Island (inside pass)	Entrance Island	---
Etoile	Etoile	Eotōle
Lukunor	Lukunor	Lukōnwōr
Anal	Anel	Anel
Tokaen	Tōkaen	Tōkaen
Matten	Matten	Matten
Kapenor	Kapenor	Kabinwōr (Kabinwōd)
Bokelan	Bokelan	Boklang
Rongelab	Rongelap	Ronglap
Northwest Passage	Northwest Pass	---
Rongerik	Rongerik	Rongrik
Taka Atoll	Taka Atoll	Taka
---	---	Bok (coral patch)
Waatwerik	Watourikku-tō	Elluk (Allok)
Lojrong	Lojiron	Lojiron
Taka	Taka	Tōke
Eluk	Eluk	Watwerok (Waitwerok, Wotwerok)
Bwokwen	Boken	Boken
Taka Passage	Taka Pass	Tōke [pass]
---	---	Jōjakikikan [pass]
Ujae Atoll	Ujae Atoll	Ujae
Enylamieg	Enylamieg	Enelamōj
Biginnigar	Biginnigar	Bikenkar (Bokōnkar)
Erlie	Erlie	Alle (Arle)

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Ujae Atoll (continued)		
---	---	Bokarik (Bok)
Bik	Bikku-tō	Bik (Bok)
Ebbetyu	Ebbetyu	Ebeju (Ebāju)
---	---	Letko (reef to west)
Anuij	Anuij	Anuij (Anus)
Rua	Rua	Ruōt
Wotya	Wotya	Wojia (Wōjjak)
Langeba	Langeba	Lōngba (Langba)
Naenlap	Naenlap	Naenlap
Ujae	Ujae	Ujae
Bokerok	Bokerok	Bokerok (Bōkārok)
Bock Channel	Bock Channel	Bok /pass/
Bock	Bock	Bok
---	---	Latarbōn (reef patch inside channel)
Nanmera	Nanmera	Nanmera
Bokankiru	Bokankiru	Bokankiru
Todrik Pass	Todrik Pass	Todrik (To Rik)
Tolap Pass	Tolap Pass	Tolap
Tonjure Pass	Tonjure Pass	Tonjure
Ujelang Atoll	Ujelang Atoll	Ujelang
Pyokon	Pyokon	Bikom
---	---	Bok (sand spit)
Boggelininlapp	Boggelininlapp	Bokōnenellap
Seroko	Seroko	Jerko
Pokon	Pokon	Bokan (Bokanjuakak)
Bokanibop	Bokanibop	Bokanibwiebiong
Bokanibwiebirok	Bokanibwiebirok	Bokanibwiebirok
Kilagen	Kilagen	Kiloken
---	---	Bokanjoio
Bokankemej	Bokankemej	Bokankemej
Bokanalap	Bokanalap	Bokanalap
Maronlik	Maronlik	Madromedik
Maron	Maron	Madron
Enetobal	Morina	Enetobal
Daisu	Daisu	Raej
Bokanwor	Bokanwōr	Bokan wōr
Ujelang	Ujelang	Ujelang
---	---	Enekonge
Eneraj	Eneraj	Eneraj
Burle	Burle	Bieto
Narrow Pass	Narrow Pass	---
Nelle	Romu	Nelle
Wide Pass	Wide Pass	---
Einmlapp	Einmlapp	Enellap (Einmlapp)

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Ujelang Atoll (continued)		
Ennimenetto	Ennimenetto	Enimoni (Enemanet)
Kiriniyan	Kiriniyan	Kiriniyan (Kirenen)
Kalo	Kalo	Kalo
Utirik Atoll	Uterik Atoll	Wutrok
---	---	Emijwa (sand bank)
Piji	Pije	Bike
Allok	Elluk	Elluk (Allok)
Pigowak	Pigowak	Bekrak (Bekrōk)
Nalab	Nalep	Nalap
---	---	Najā
Utirik	Uterik	Wutrok
Addibkwan (peninsula)	Adropkan	Adropkan /peninsula/
Anearemej	Eneormij	Eneormij
Bwokwarmej	Bokarmij	Bokarmij
Menetoon	Ajanen	Ajanen
Aon	Aon	Aōn (Awan)
---	---	Kōbbar
---	---	Rereti
Utirik Passage	Uterik Pass	---
---	---	Likkirukan
---	---	Korikrikloken
---	---	Bukilaen
---	---	Borankwet (the 4 above are small patches on the W reef)
Wotho Atoll	Wotho Atoll	Wotto
Medyeron	Medyeron	Mejurwōn (Majurwon)
Worrbar	Worrbar	Enebarbar
Mokeromok	Mokeromok	Eneobnāk
Enerikan	Enerikan	Enerikan
Wotho	Wotho	Wotto
		Jitninean (N part of Wotto)
		Jitrokean (S peninsula of Wotto)
Boker	Boker	Boker
Boklabunlik	Boklabunlik	Boklabunlik (Enedrik Kan)
Bokanaetok	Bokanaetok	Bokanaetok (Bokōnaetok)
Lojan	Lojan	Lojwa
Jebenau	Jebenau	Jibnao (Jibnau)
Uditj	Editj	Utiej (Wutiej)

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Wotho Atoll (continued)		
Erotjeman	Erotjeman	Iroijeman
Yeldo	Yeldo	Enejelto
Kabben	Kabben	Kaben
Eirek	Eirek	Eneairik (Eneaidrik)
Ombelim Channel	Ombelim Channel	Ombelim (Anbwilen) [pass]
Ombelim	Ombelim	Ombelim (Anbwilen)
Begin Channel	Begin Channel	Biken (Bikien) [pass]
Begin	Begin	Biken (Bikien)
Medyeron Channel	Medyeron Channel	Mejurwon (Majurwon) [pass]