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

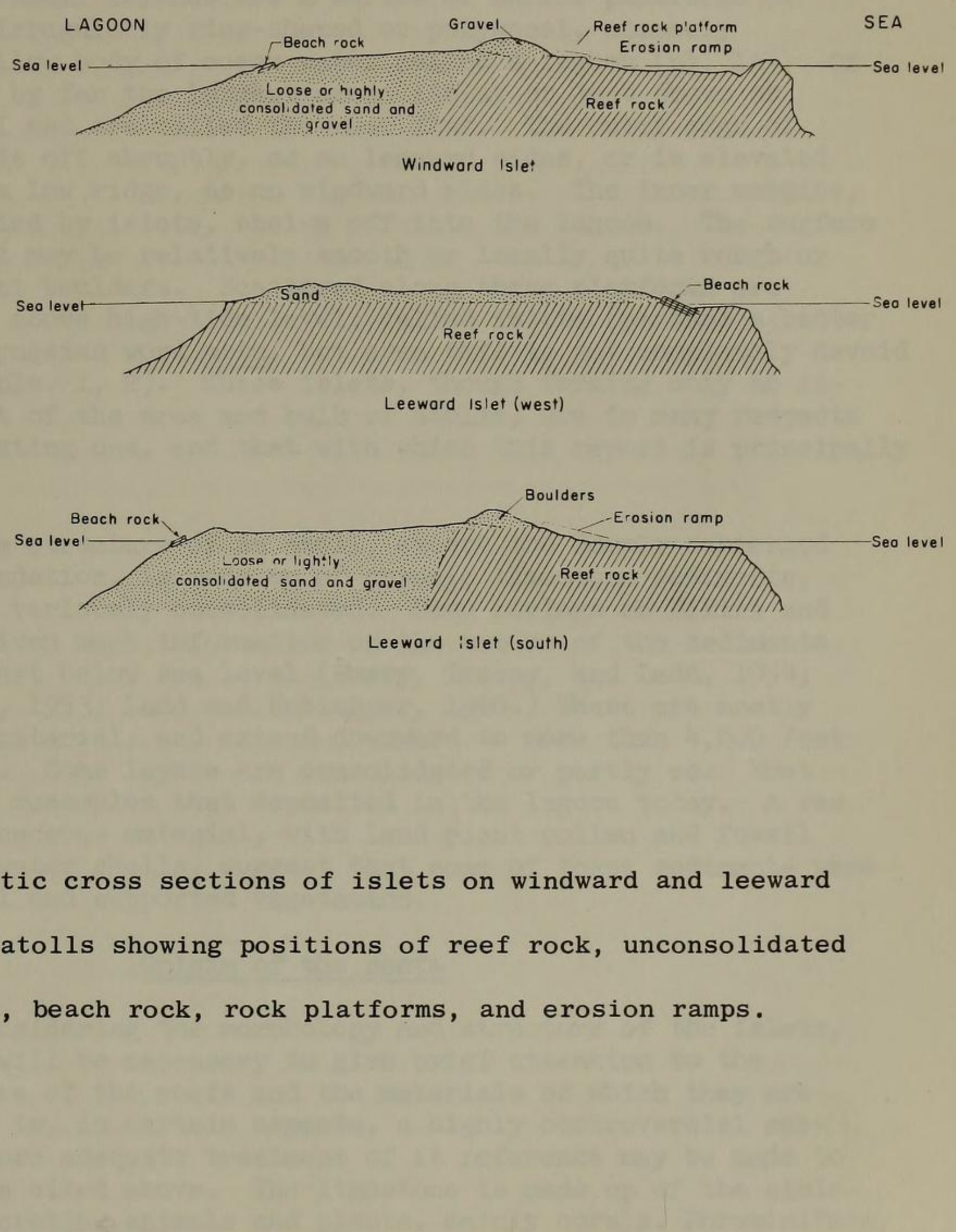
The climate of the northern Marshall Islands is tropical, with very little variation in temperature. The extreme variation is from about 68° F to 97° F, but most of the time the range is from 76° F to 87° F, with a mean of about 82° F. The sunlight is intense and the sky usually characterized by considerable 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.