PART IV: UNCONSOLIDATED SEDIMENTS CONSIDERED AS SOILS

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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

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*/ 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):

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

<u>Soil units and series--characteristics and chemistry</u>

Unaltered sand and gravel

"<u>Unaltered sand and gravel</u>, 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

Lepturus 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 Halimeda 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 Arno Atoll series (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_{00} horizon	6.0 - 5.5 inches	Loose twigs and leaves of *Pisonia grandis*, somewhat guano-stained.
A_0 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.

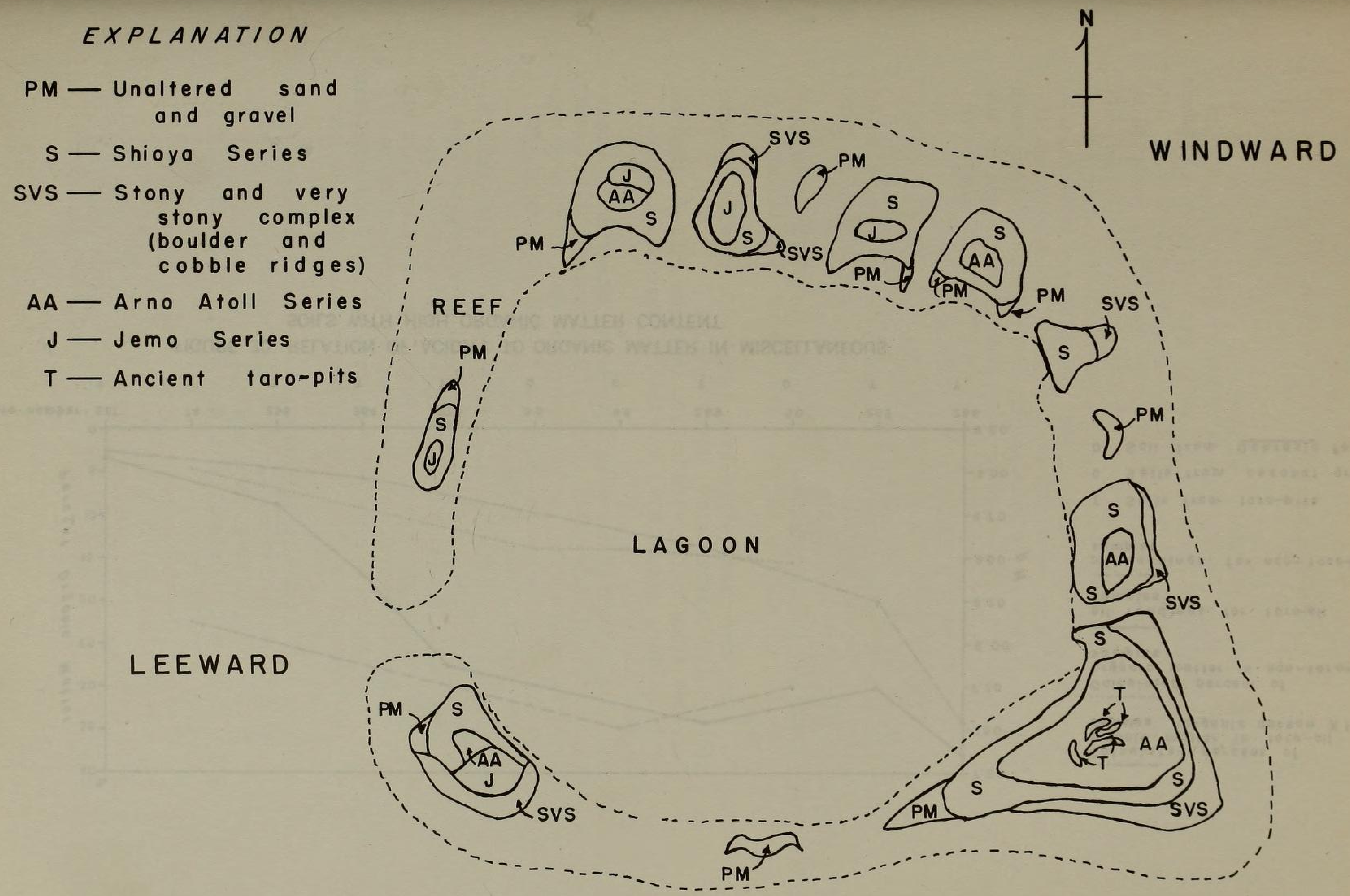


FIGURE 29. SCHEMATIC DIAGRAM OF A HYPOTHETICAL ATOLL SHOWING DISTRIBUTION OF SOIL TYPES

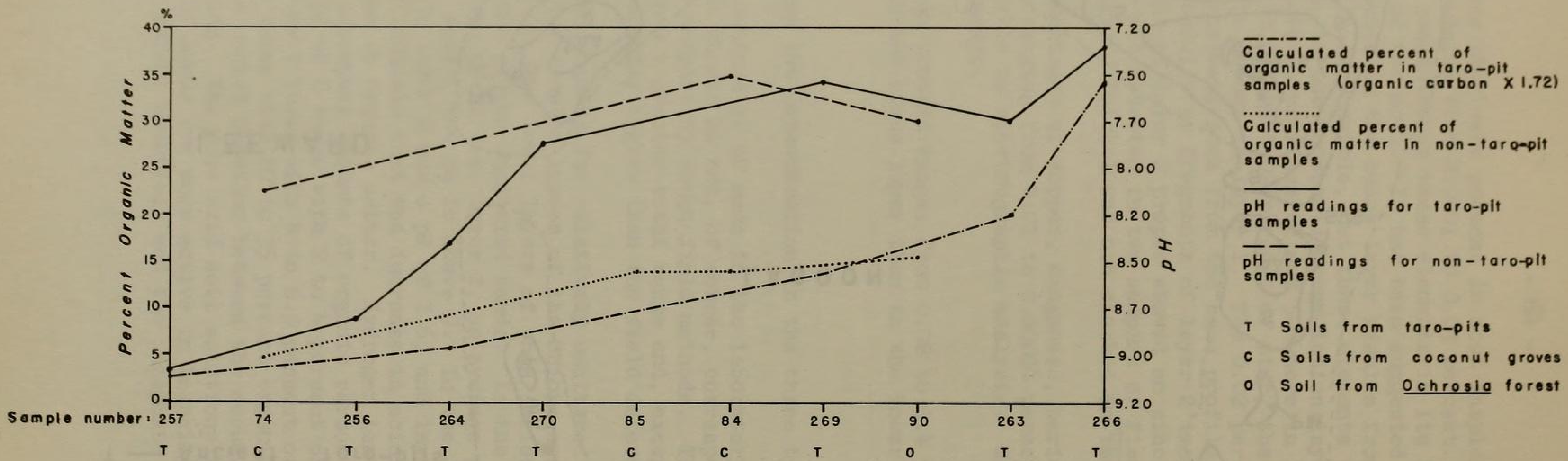


FIGURE 30. RELATION OF ACIDITY TO ORGANIC MATTER IN MISCELLANEOUS SOILS WITH HIGH ORGANIC MATTER CONTENT

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.

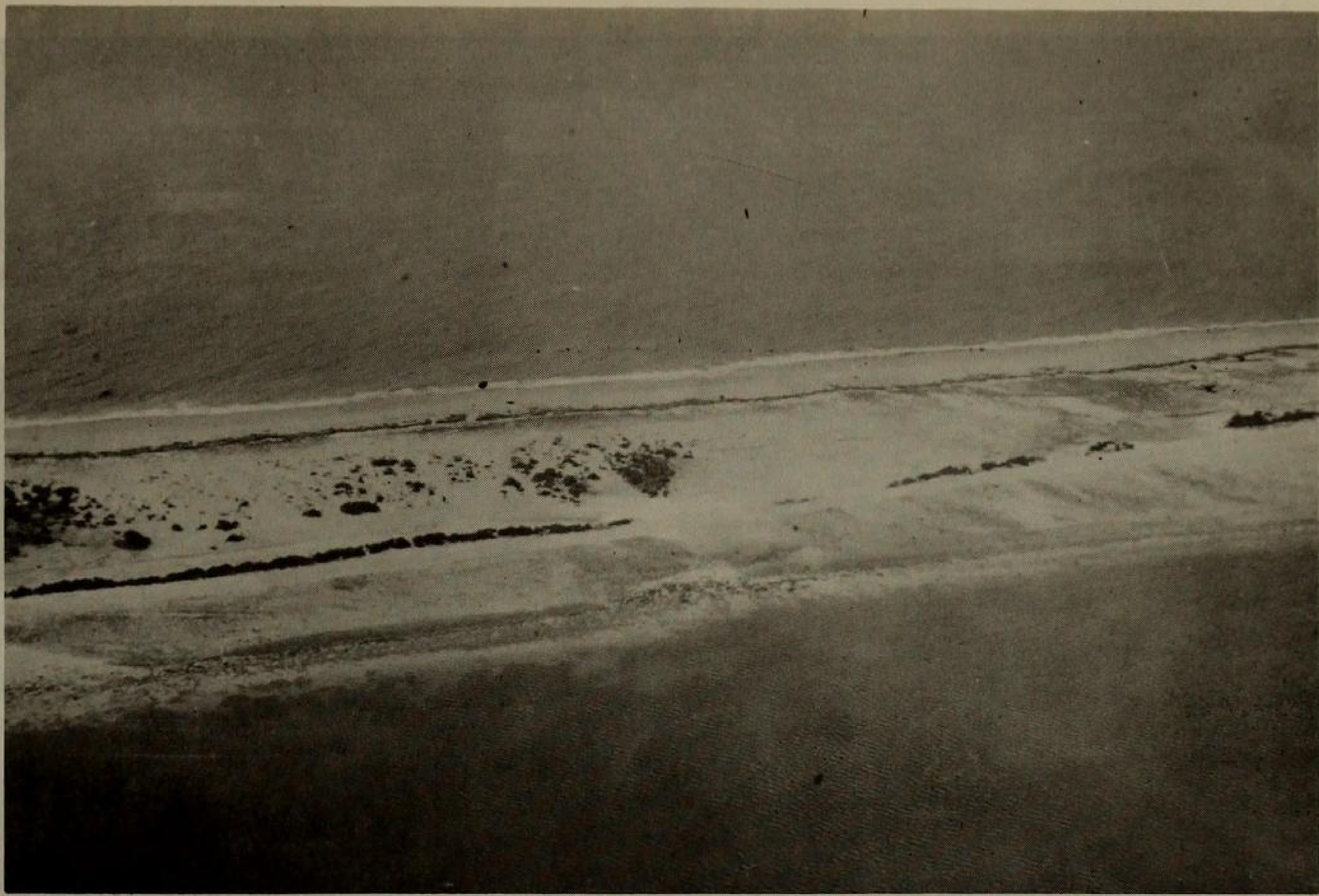
G, H. Foraminifera with additional firm calcium carbonate deposited on the original surface, sample 146, profile 70, Arno Atoll soil, Wotho islet, Wotho Atoll.

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

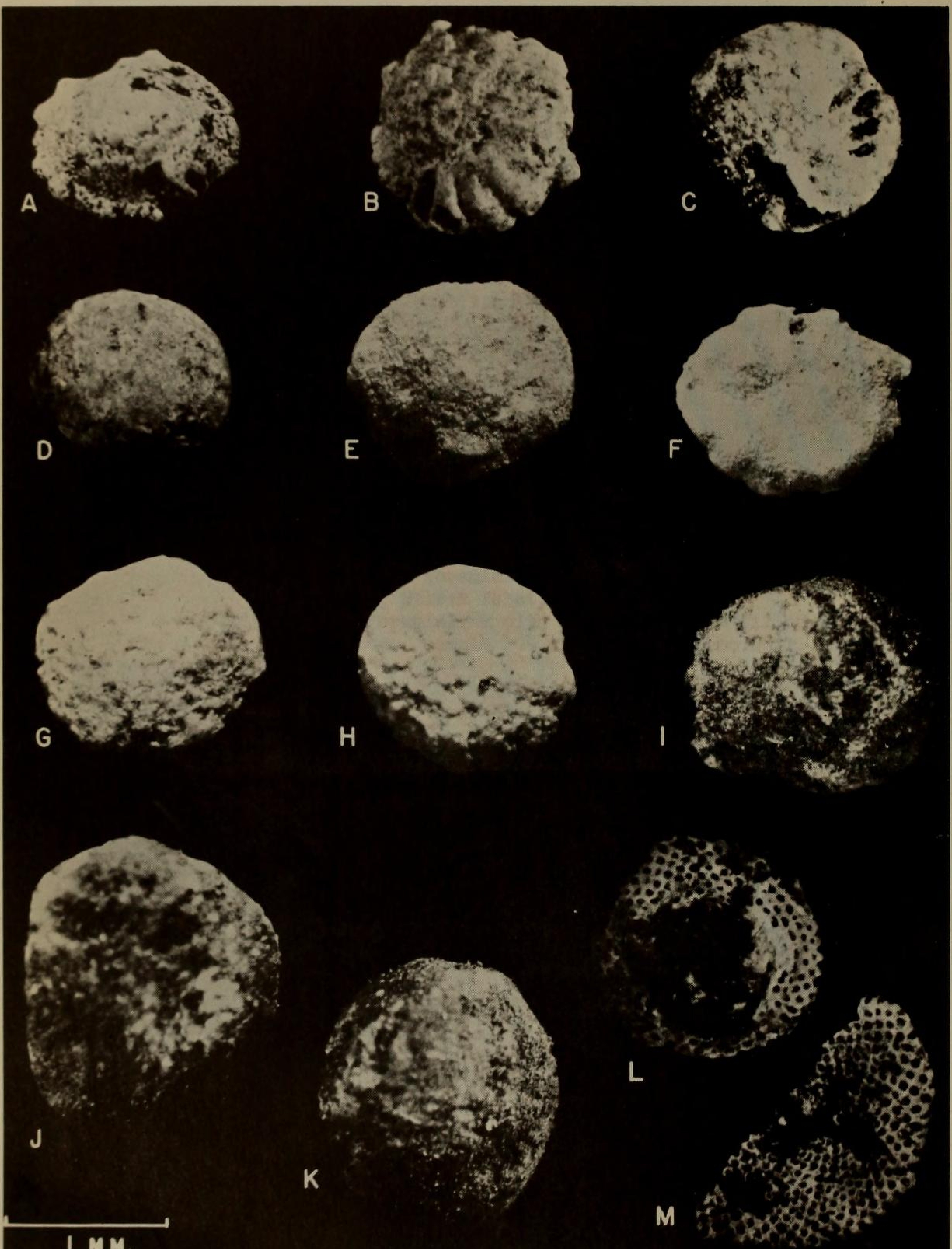


Table 9.--Major chemical constituents (in percent) and pH of northern Marshall Islands soils

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	[3]9.02
		do. 3			...	...	36.5	2.20	.30	.03	.03	.16	[3]1.21	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

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

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		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 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	28	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 *Ochrosia* forest.
Lae	A7	1 (266)	19.86	7.30	Taro pit.
	A8	1 ([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	2.4	35.5	1.09	.15	.25	.04	.17
Layer 2	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	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	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.