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Summary of Information on Atoll Soils

by
E. L. Stone, Jr.

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Our knowledge of atoll soils is still fragmentary and the following relates particularly to wet atolls, which have been more extensively studied than dry atolls. The nature of atoll soils is closely linked to the geological material on which they formed. These soils are extremely immature, usually having A-C profiles dominated by calcium and magnesium carbonates and with texture but little modified from that of the original material. This immaturity is in part a consequence of their limited age, which is presumably less than that of the xerothermic period, and of the continual disturbance by storms and typhoons. The frequent rejuvenation by storms is one of the major features of the land surface. Thus there has been little soil development in the usual sense, and the characteristics of the well-drained soils, in so far as they differ from geological materials, are due chiefly to organic matter accumulation and associated chemical changes.

I General: Despite immaturity, the differences in soils and physiography are sufficient to give rise to a variety of habitats. The expression of these in the vegetation, however, is in part concealed by the limited flora. This sometimes leads to a specious appearance of uniformity.

II Physical Nature of the Parent Material: The primary sources of land material are, of course, the reef organisms but in at least a few instances foreign material may occur. On Rose Atoll basalt has been found and pumice has been reported common on a number of atolls.

The mode of land formation has been treated more fully by geologists and need not be repeated here although it is obvious that particle size distribution and elevation of the land surface strongly influence subsequent soil development. Frequently materials deposited along the seaward shores are coarse-textured and porous. Consequently, as the data of Cox indicate, the ground water lens may have a lower head and greater salinity on the seaward side as contrasted with the lagoon shore, which is commonly composed of finer materials.

Although differences in texture of the deposits affect ground water movement and plant growth, all are sufficiently coarse to be freely pervious to air and water. The moisture holding capacity of the mineral soil is low, increasing the effect of rainfall distribution and ground water. Where fresh water is available at shallow depths textural considerations obviously do not have the significance for deep-rooted plants that they often have elsewhere. Furthermore, it is probable that the porosity of weathered coral and reef rock increases their moisture-holding capacity, as compared with that of solid fragments of similar size.

III Chemical Nature of the Parent Material: Analyses of the reef organisms, as by Clark and Wheeler, indicate that calcium carbonate, while predominant, is by no means the only compound of importance in their composition. Some of the Lithothamnion group may contain up to 25% magnesium carbonate and some of the Foraminifera up to 11%. Although phosphorus is generally low, some of the Crustacea may contain up to 27% calcium phosphate in their skeletons and there are appreciable amounts in some of the Alcyonarian corals. Nine samples of non-phosphatic subsoils from Arno contain from .01 to .02% phosphorus. Soluble potassium is found in moderate amounts whenever appreciable exchange capacity is present. Traces of most elements are of course to be expected by reason of their presence in sea water.

As a source of plant nutrients these materials have certain apparent advantages and disadvantages. The calcareous medium tends to be favorable for some nitrogen-fixing legumes and Azotobacter. However, it limits availability of certain nutrients such as iron, of which there is a conspicuous deficiency whenever organic matter content in the soil is low.

IV Soil Formation and Properties: These can not be considered apart from climatic influences, particularly those of rainfall. Not only the amount but the constancy of rainfall is of prime importance, with the effect of variation being more drastic the lesser the amount. The effects of variation are of particular consequence on narrow islands where the nature of the ground water lens is more readily affected by short droughts. Rainfall obviously affects the composition of the ground water and the rapidity of leaching of salts formed in the soil and those added by spray. To date conductivity measurements seldom show sufficient concentration of salts in the surface soil to be injurious to the plants, although these do not represent the temporary conditions that may result from flooding or heavy spray during severe storms.

Mere descriptions and analyses of a variety of profiles are often of limited value until the soils can be classified and arranged into an actual or inferred sequence related to time or developmental stages. Many of the data for well-drained soils on Arno and Onotoa can be described by such a sequence:

It is evident that the initial development of vegetation is somewhat analogous to lifting one's self by the bootstraps; plant growth is required to create organic matter which in turn supplies nitrogen, renders certain nutrients available, etc., to permit additional growth. In the early stages following colonization by hardy plants, each gain in amount of organic substance tends to favor greater and more diverse vegetational development. Ultimately the extent of this development is reflected in the soil profile. Thus a sequence may be observed extending from the wholly unaffected beach sand or boulder rampart of the island margins to the dark surface soils beneath the lush vegetation of the island interiors. Although in any one transect such a sequence is usually associated with time of development, other factors such as exposure, rainfall, groundwater, etc., surely influence the rate and presumably the maximum stage of development attainable. The conventional soil type designations employed tentatively on Arno can be used to designate various bands in this hypothetical developmental sequence on moist atolls. Figure 1 shows some features of profiles representing successive positions in such a sequence.

Figure 2 illustrates the inferred sequence from shore to interior and the effects associated with increasing organic matter content. In the synthetic transect the Onotoa profile appears to agree generally with those from Arno atoll.

The consideration of organic matter is almost inseparable from that of nitrogen since the two are linked in the soil with an OM/N ration of between 20:1 and 30:1. Apart from growth effects, in the absence of nitrogen additions of organic substance alone do not result in formation of "humus" and hence organic matter accumulation. The very considerable accumulations illustrated by Figure 2 direct attention to the sources of nitrogen. Apart from rainfall four are known: (1) Flotsam and dead marine organisms are presumably of significance only to the early stages of strand vegetation. (2) Legumes, <u>Sophora</u>, <u>Canavalia</u>, and <u>Vigna</u> are often common in the earlier stages of the sequence but only <u>Intsia</u> persists in quantity in the dense forest. (3) The contribution of nitrogen-fixing blue-green algae is unknown although certain terrestial algae are abundant. Azotobacter is common in certain Arno collections (Lochhead) and presumably would be favored by the highly organic calcareous substrate. (4) Observations suggest that sea-birds may add appreciable amounts of nitrogen to the land surface generally, apart from the marked guano or phosphate areas. High amounts of nitrogen and phosphorus found in sparsely vegetated areas on dry Canton Island are attributed to nesting birds (MacDaniels, Hatheway).

There are no systematic studies of organic matter decomposition but vigorous faunal activity by termites, snails, earthworms, crustacea, etc., (Usinger and LaRivers) rapidly reduce organic residues. Incorporation of organic matter may also be accomplished by grasses and the dense root mat of the coconut. Well-drained atoll soils seem to be marked by a sharply delimited zone of mixing, with slight organic staining of the deeper layers only in the older profiles. Darker layers occuring at depth usually indicate profile burial, as by dunes, typhoon debris, etc. Deep profiles may originate by continuous additions, as of wind-blown sand to a vegetated surface, and probably also in certain imperfectly drained situations.

As indicated by Figures 1 and 2, the depth of the organic layer tends to increase with age but the most marked effect is in percentage composition. Rather rough estimates indicate that the dark soils from Arno contain at least 2,000,000 lbs. organic matter per acre. It appears likely that a few centuries may have been required for such accumulation and there is no evidence of any rapid decline in the long occupied areas of Arno Island.

In non-saline atoll soils reaction commonly ranges between pH 7 and 9, with the higher values presumably influenced by magnesium carbonate. Moderate but consistent shifts in soil reaction are associated with the effects of organic matter. Species unsuited to an alkaline substrate may be favored further by localized pockets of organic matter, decaying wood, etc., of lower reaction. A slightly acid reaction also characterizes some peats.

Of the mineral nutrients phosphorus occupies a special position because of the probable significance of sea-birds in the phosphorus cycle of land areas, as well as in numerous localized accumulations. A possible role of phosphorus deficiency in the "laora" disturbance of coconut has been conjectured but evidence is as yet incomplete. An effect of copra cropping on phosphorus removal from the land has been suggested.

Fosberg's study of the ecological factors involved in phosphorus accumulation may solve a number of questions on phosphate "rock" and "hardpan", and perhaps on nitrogen accumulation in the dark soils also. In addition to their effects *in situ*, such deposits might well be reworked, notably enriching new beach materials.

Exchangeable (or extractable) potassium tends to increase with the exchange capacity of organic matter but it is markedly affected by leaching and by contact with salt water. Under dry conditions evaporation may concentrate potassium, as well as nitrate nitrogen, at the soil surface but the high values of such samples (e.g. Bikini) are not indicative of the entire soil.

Of the other plant nutrients calcium and magnesium are, of course, abundant, and little is known of the precise status of many "minor" elements. Iron deficiency is common in many plants, and symptoms on introduced plants suggest their susceptibility to other deficiencies.

Observations on soil organisms from Arno Atoll show appreciable numbers and the expected relationships between numbers and organic matter content. Determination of species and groups (Lochhead, Martin) indicate that the fungal and bacterial flora are cosmopolitan.

Losses from leaching can be assumed except on the driest atolls. Some recovery from the groundwater by vegetation is probable but is limited by the level of maximum evaporation, (presumably about 60") and the selectivity of plant roots. A continuing loss of calcium and magnesium carbonates is obvious but visible solution seems limited to the surface layers. Softening and reduction of large fragments is marked in the surface layers of the older soils.

Although the undisturbed well-drained type of profile is taken as a model, numerous exceptions and anomolies occur as a result of typhoons, shoreline activity, etc. Freshwater and mangrove peats, phosphate rock, exposed beach rock, etc. provide numerous specialized situations for vegetational development.

Students of atoll soils and ecology must add to their interest of vegetational succession a recognition of the frequent and drastic affects of catastrophe, of the influence of primitive man and his recent congeners, and of the self-limiting nature of many formative process.

The economic aspects of atoll soils are obvious, at least in outline. Within the limits set by climate, groundwater and exposure (as to spray) the productive capabilities and responsiveness of soils are set by texture, organic matter status, phosphate influences and perhaps by certain effects of age or history such as are associated with the "laora" disease. Many of these are subject to mapping, description or interpretation for use in any appraisal of atoll land productivity.

Figure 1.--Characteristics of Some Atoll Profiles

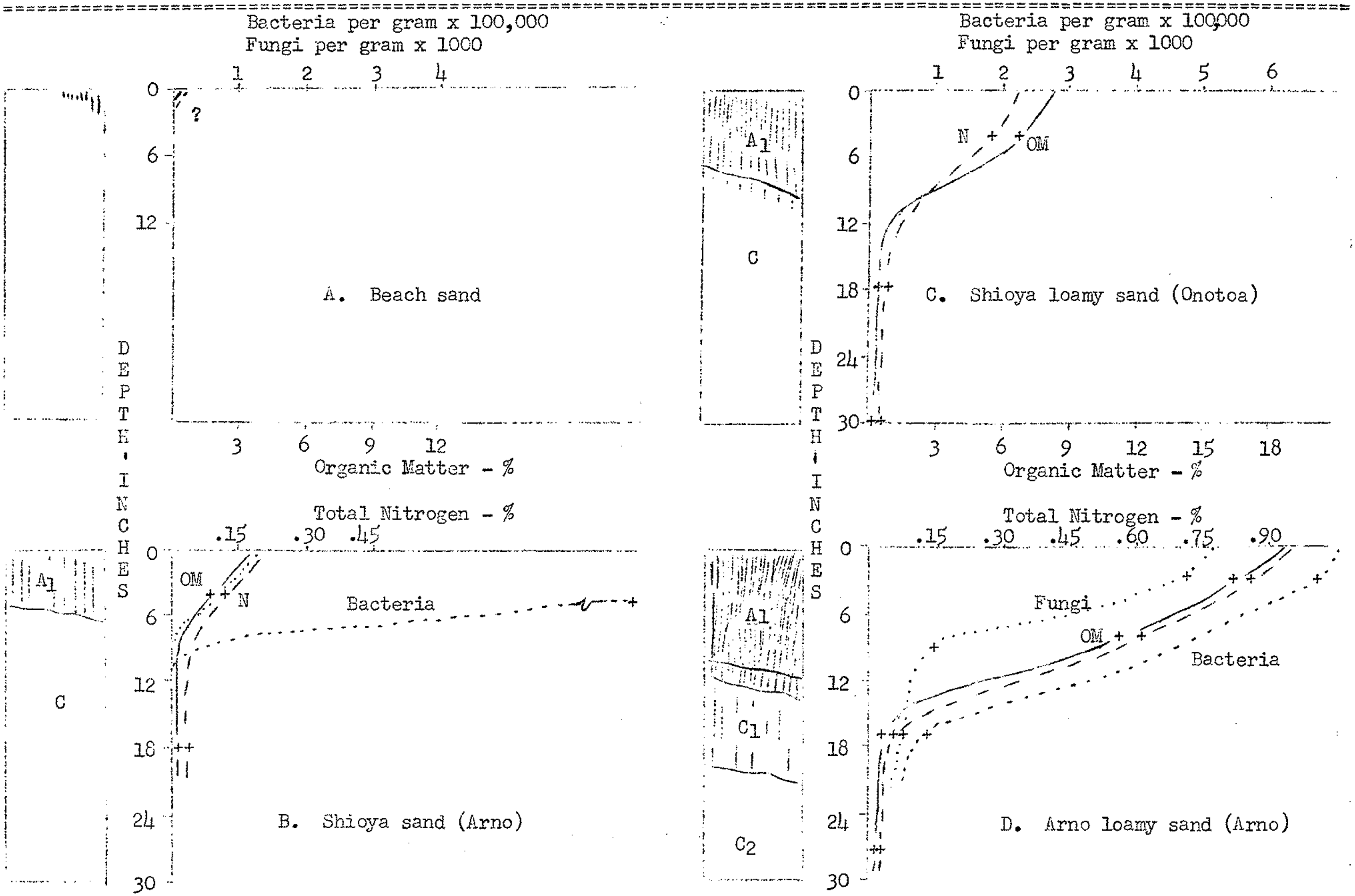

Figure 2.--Synthetic sequence of soil development and soil properties.