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COMMENTS ON ATOLL PHOSPHATE ROCK

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Dr. K. A. Rodgers, in a series of previous articles (1987, 1989a, 1992), has gathered together what is known, published or previously unpublished, on the occurrence of terrestrial phosphate rock and phosphatic soil on the Tuvalu (Ellice) Archipelago of coral atolls in the central Pacific, (the southern extension of the Marshall-Gilbert Chain). These are typical low oceanic atolls, with no indication of any former connection with continental land or large islands. From his text and maps of the individual atolls it is evident that substantial areas of the "coral" sands and gravels that cover the surfaces of these atolls have been phosphatized by whatever process or processes. This is the most thorough treatment of phosphate occurrence on any non-elevated coral island group anywhere. It is of great value in demonstrating the existence and importance of what is a widespread geological and pedological phenomenon throughout the Indo-Pacific coral island region.

Rodgers' descriptions of the phosphatic material, though not always expressed in terms completely familiar to me, indicate that all or most of the phosphate in Tuvalu corresponds to what I have earlier (Fosberg, 1954, 1957; Fosberg and Carroll, 1965) termed atoll phosphate rock, phosphatic hard-pan, or the Jemo Soil Series. In the above cited papers, I presented a description of the bedded phosphatic rock or hard-pan found commonly on all but the driest low coral islands in the Indo-Pacific. To account for the origin and existence of this rock, I described a most interesting situation involving one of the (formerly) most common forest types on these islands, a practically pure stand forest of the large tree, Pisonia grandis R. Br. Under this forest, where its canopy is closed, and where there is little or no admixture of other tree species, is found a surface layer or horizon of "raw humus" similar to the "mor" of northern conifer forests, with an acidity of pH 6 to pH 4.5, or even lower. This occurrence of this type of "mor" is otherwise very uncommon at low elevations in the tropics. Pure stands of any tree species in the lowland tropics are also uncommon.

Sea-birds of several sorts tend to nest or roost gregariously in this forest, and where this happens, the surface of the humus layer is stained white by the bird droppings, or "guano". This is composed principally of finely comminuted fish-bones, largely a calcium phosphate mixture. Beneath such white patches is commonly found an uppermost layer of the coral-sand substrate cemented together, to varying degrees, by a bright brown phosphatic cement, giving a very characteristic brown surface abundantly speckled with white, the coarse sand or fine gravel carbonate particles. This hard-pan, when broken up, can be detected by being notably lighter in weight than similar fragments of lithified coral

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sand or gravel. These observations suggested a process where the fine phosphatic powder in the bird excrement was washed down into the porous acid raw-humus, acidified and dissolved, the solution percolating down until it reached the alkaline calcareous sand underlying the humus layer. It then, neutralized, precipitated out, forming a hardening deposit, holding the sand-particles together. All degrees of this lithification were observed, even involving small pebbles of carbonate, which tended to become friable under the influence of the acid percolate, where part of the carbonate may have been replaced by phosphate, rather than being washed off by the rain-water where no acid humus was present.

Since this phenomenon was first observed by me on Jemo Island, northern Marshalls, in 1951, I have, by watching for it in likely situations, seen it many times, in localities from Polynesia to the Seychelle Islands, and occasionally in places where no Pisonia remained. In such places, questioning the local people, I sometimes found that there had formerly been Pisonia. In one or two instances, questions as to where there had formerly been Pisonia, revealed unsuspected deposits of the speckled phosphatic rock, the surfaces weathered to a dull gray color.

The earliest case of the association of such phosphate, mis-called "guano", to come to my attention, was in a paper by Lipman and Taylor (1924), on Rose Atoll, where the material was collected by A.G. Mayor (Setchell, 1924) and studied by C.B. Lipman and J.K. Taylor. Lipman misinterpreted the nature of the phosphatic material, but there is little doubt that it belonged to what I have called the Jemo Soil Series.

In 1970 I spent a few days on Cousin Island, in the Seychelles, Western Indian Ocean (Fosberg, 1983). Over half of the 68 acre surface is a flat area, just about 2 m above sea-level, now planted with coconuts growing in holes excavated to 1 m depth. Examination of many of these holes and much of the flat surface showed this entire flat portion to be a continuous layer of brown, white speckled, rather soft rock, exactly like the atoll phosphate rock described from the Marshall Islands. Abundant young Pisonia grandis, sprouting after clearing of what must have been an imposing forest, suggests that this entire flat is a "beheaded" Jemo soil, the humus layer decomposed away after clearing. The only other occurrence of atoll phosphate comparable in thickness to this to come to my attention is a 5-foot-deep layer on Gaferut Island, Western Carolines, mentioned by Niering (1961).

Sea-birds have been observed nesting in large numbers in forests of other tree species than Pisonia, in bushes, and on the ground, on coral sand substrates. In no such situation has there been found a raw-humus layer, or any brown, white speckled rock. One exception to this was a description by Catala (1957) of a similar situation in the Gilbert Islands, where the trees were cited as Guettarda speciosa forests, but none with a raw-humus soil horizon. I can only assume that Catala, who is no botanist, mistakenly identified Pisonia as Guettarda.

Rodgers (1992), mentions Pisonia trees wherever they occur in connection with the phosphate deposits he describes. However, in only one place does he mention Pisonia as dominant in the plant cover, on Nui Atoll, quoting Woodroffe (1985). He discusses the problem in his section on geobotany, admitting that there may have been a Pisonia-

phosphate association in Tuvalu in the past, "man-induced changes make it impossible to recognize such a relationship today throughout most of the archipelago, or indeed to ascertain whether it was present in the virgin environment." He makes a considerable point of the nonoccurrence of Pisonia on five islands today, also of the lack of bird colonies associated with any known phosphate deposit in Tuvalu. One might expect 2000 years of human occupation to have obscured most evidences of natural conditions. He concludes in this section, as well as in his abstract, that "the presence or absence of Pisonia in the present day should not be taken as a geobotanical indicator." One can only agree with this, without argument.

However, he says nothing about whether the presence of atoll phosphate rock can be taken as an indicator of former Pisonia forests with colonies of roosting or nesting sea-birds. I have in a number of instances assumed that the presence of such rock, as for example, on Canton Island, Phoenix Group, a bed of weathered atoll phosphate rock, as a very good indicator of former Pisona forests, where none occur today. This I maintain even to the extent that a single well rounded, but unmistakable atoll phosphate pebble, collected by the late Wayne Gagné on Laysan Island, indicates to me than a Pisonia forest formerly existed on Laysan. Until recently, Pisonia grandis was not even considered to be a member of the Hawaiian flora, but recent collections from Pearl and Hermes Atoll, as well as two very old specimens in the Kew herbarium show that the species does occur in the Hawaiian group.

One further observation, just to round out this discussion, and to indicate the need for caution about sweeping generalizations, follows. That I can not insist, categorically that Pisonia grandis is essential for the formation of atoll phosphate rock is shown by the following. Samples collected by David Stoddart in 1961, on Lighthouse Reef, an atoll off Belize, where Pisonia grandis is not even known in the same hemisphere, do not seem to differ substantially from the atoll phosphates in the Pacific. And, in 1971, on Glover's Reef, another atoll off Belize, in the interior of Long Cay, in an area long ago cleared and planted to coconuts, I located an area of many square meters of a weathered, but when broken, bright orange brown white-speckled rock. The bed was not thick, but was firm (Stoddart, Fosberg, and Sachet, 1982). Later, on Northeast Cay, I found small boulders of similar rock in a pile of boulders, but none in place.

This Belize phosphate merits further study, but I have no doubt as to its nature. My only suggestion as to its origin is that Neea choriophylla Standl., a small tree related to the genus Pisonia, is fairly common to locally abundant on these Belize sand cays. I did not see it forming pure stands, but before the cays were cleared and changed to coconut plantations, such stands may have existed, and conceivably may have formed raw-humus horizons on the soil.

Finally, to give some idea of how much change has taken place in recent years on atolls throughout Polynesia, observations recorded in the voluminous reports of the U.S. Fisheries Commission Albatross cruises written by Alexander Agassiz (1903), show that around the beginning of the twentieth century Pisonia grandis forests were one of the commonest and most conspicuous forest types on coral islands throughout the areas of ocean visited by these expeditions. It would be surprising , indeed, if there were not "fossil" occurrences of atoll phosphate rock on almost any of the not-too-dry Pacific atolls.

Mention should be made of the very comprehensive review of Phosphate Rock on Coral Reef Islands, by Stoddart and Scoffin (1983). This surveys the nature, occurrence and petrology of phosphate rocks of a number of kinds, and undoubtedly of various origins, on coral islands both high and low. These authors discuss what I have called "atoll phosphate rock" along with several other forms of lithified phosphate under their heading "recent phosphate rock". They discuss these deposits at considerable length, but, in my opinion, do not clearly indicate whether rocks of one, several, or even many origins are discussed in their two sections headed "Recent phosphate rock" (pp. 376-378, and 380-382). Nowhere do they indicate that acidity is an essential factor in the process of formation, nor do they emphasize the bright brown color of the matrix or cement in which the white limestone grains are embedded. To me, the presence of acidity is essential for the solution of the comminuted fish-bones of the guano and its downward percolation through the soil. There also seems to be no other obvious origin for the bright orange-brown color of the cement than the brown raw-humus produced under the Pisonia forest. I would restrict the definition of atoll phosphate rock to occurrences where the matrix is brown and inclusions are white or pale calcareous particles, or their pseudomorphs in very altered examples.

With this restricted definition, I strongly maintain that such rock is an indicator of a practically pure stand of Pisonia grandis (or equivalent such as Neca) with nesting or roosting gregarious sea-birds, on "coral" sand or gravel. None of the other suggested processes of origin than that described above seems adequate, or necessary, to explain the origin and occurrence of the rock (or soil) under discussion.

Also, I would scarcely expect to find, on atolls as long and densely populated by humans as Tuvalu, more than casual persisting remnants of Pisonia vegetation. I have noted a strong inverse correlation of present-day seabird rookeries with human populations. Finally I have seen few, if any, uninhabited coral islands that do not have large or enormous colonies of fish-eating birds. Lack of birds, and only a few remnant occurrences of Pisonia grandis, are exactly what Rodgers describes for Tuvalu, where persisting beds of what seems to be typical atoll phosphate rock seem to be common. To me, this suggests that dense stands of Pisonia and vast numbers of seabirds were characteristic of the Tuvalu atolls in pre-human times.

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