Characteristics and Formation of Plinthite On Maui Island, Hawaii

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Introduction

The tropical rain forest of Winward Haleakala mountain on Maui Island, Hawaii, has a geologic and climatic setting distinctly different from any in the continental United States (1, 2). Weathering has been so intense here that the major soil forming factors are fully expressed in the morphology of the soil.

One of the more striking characteristics of the soils is the widespread incidence of indurated plinthite in the soil profile. Plinthite, as used herein, has been variously referred to as ironstone or laterite (3, 4). The name is derived from the Greek word **plinthos**, meaning brick. In nature it occurs in a hard state, or a soft state that will usually harden if exposed to drying conditions.

While there are conflicting names and theories of formation for this material there is general agreement that plinthite is high in iron oxides and aluminum, low in organic matter and silica, and that it occurs in a matrix of highly weathered material.

This study concerns an area located on windward Haleakala mountain at elevation of 2,300 to 5,300 feet with annual rainfall of 200 to 400 inches. The land surface has an overall seaward slope of 10 to 15 percent. Topography consists of sloping interfluves, ⅛ to ½ mile wide, separated by drainages and gulches deeply incised into basalt bedrock. While the character of the landscape is dominated by the basalt, thin deposits of volcanic ash are detectable in the soil profile in the wind shadows of steep slopes and in depressions.

Previous Investigations

The Hawaiian Planter's Record of September and October, 1909 contains the first recorded reference to distinctive features of the soils of this area. Dr. H. L. Lyons, working under the auspices of the Experiment Station of the Hawaiian Sugar Planters Association, made a detailed field study of the forest disease in the area, and evaluated several possible causative agents (5, 6).

The disease involved the dying out of large tracts of trees, and potential denuding of this water shed which was so vital as a source of irrigation water for sugar cane production. As reported by Dr. Lyons, apparently healthy trees sickened and died in a matter of weeks. This condition was most pronounced on the gently sloping interfluves; decreasing rapidly as the slopes became steeper. Few trees appeared to be affected on areas with slopes over 100 percent. Dr. Lyons further reports that the precise limitation of the disease by topographic features is most striking. In his words "One may travel up an interfluve for a couple of miles through a recently dead forest, but if he turns at any point toward the gulch he will come upon healthy trees at the crest of the steep slope near the gulch."

Possible causal agents investigated were parasitic fungi, insects, and harmful chemicals in the soil. Fungi were ruled out because so few could be found in the area, the disease seemed so closely controlled by topography, and that the same constitutional problems were produced in totally unrelated species of plants. Insects were also ruled out because of the small number present.

Chemical agents in the soil thus remained the most probable cause of the disease. The fact that below-ground portions of roots of diseased trees had turned a deep purple or black, and died, while above-ground brace roots were still natural functional tissue seemed indicative of chemical activity in the soil. In addition an oily appearing film was observed on the surface of standing water in the area, and attributed to soluble iron salts leached from the soil. It was also noted that hydrogen sulfide odors permeated the area.

From these observations it was hypothesized that with these soils high in ferric iron, sulfates, and organic matter, the high rainfall and stagnant water effectively excluded oxygen from the soil; thus inducing fermentation by anaerobic bacteria. This fermentation liberated toxic hydrogen sulfide which further acted to reduce ferric iron to ferrous iron which is also toxic. Chemical analyses published in the Hawaiian Planter's Record show a ferrous oxide content of 5.75 percent which is normally considered a prohibitive level for plant growth.

Recent Investigations

Since 1909, foresters of the Division of Land and Natural Resources, and irrigation engineers of the East Maui Irrigation Company have had a continuing interest in this Maui forest disease because of its potential effect on hydraulic characteristics of the watershed. However, the first known reference to the problem by soil scientists is contained in the soil survey of the Territory of Hawaii, published in 1955 (7). In this survey the author made note of the still active forest disease, and also recorded the first known observations of an ironstone sheet in certain soils of the rain forest area. These observations are fully confirmed in the current soil survey.

In the 1955 soil survey the observation was made that the ironstone sheet appeared to form at any point in the soil profile where very porous material overlay relatively less permeable substrata. However, recent observations indicate a great probability that the less permeable material overlay material of relatively high permeability.

Investigations made early in 1964 included the preparation of profile descriptions of representative soil types in the area. Descriptions of two such soil types are included below to illustrate the morphology of soils containing indurated plinthite as an ironstone sheet.

Amalu peaty clay

Elevation—4,200 feet

Rainfall—350 inches annually

Slope—8% Northeast

Horizon	Depth	Description
01	8-0 "	Black (5YR2/1) fibrous peat with matted roots; pH 3.9.
Ag	0-8 "	Mottled gray (10YR5/1) and dark gray (10YR4/1) clay which is massive but can be broken to weak angular blocky structure; firm, sticky, and plastic; many roots; common fine pores; slightly smeary under pressure; has rubbery feel; abrupt boundary; pH 4.2.
B2ir m	8-8¼"	Indurated plinthite in solid horizontal phase.
B3ir	8¼-32+"	Soft plinthite with fragments of hard plinthite in matrix of highly weathered basalt; halloysite and gibbsite in seams; many large pores.

Koolau silty clay
Elevation—2,500 feet
Rainfall—225 inches annually
Slope—7% Northeast

Horizon	Depth	Description
A1	0-3"	Dark grayish brown (2.5Y4/2) silty clay with few fine faint mottles of grayish brown (2.5Y5/2) and dark brown (10YR4/3); weak fine subangular blocky structure; friable, sticky, plastic, and slightly smeary; many roots, few fine pores; pH 4.0; clear boundary.
Ag	3-13"	Gray (2.5Y5/1) clay with common distinct mottles of olive brown (10YR5/4); massive; firm, very sticky and very plastic; few fine roots; common very fine, and few coarse pores; large pores have well developed metallic coatings on interior walls; has rubbery feel; pH 5.0; clear boundary.
B21g	13-19"	Light brownish gray (2.5Y6/2) and pale brown (10YR6/3) clay with few fine faint mottles of dark brown (7.5YR4/4); weak fine blocky structure; sticky and plastic; few roots; common fine pores; gritty feel due to plinthite nodules; pH 4.7; abrupt boundary.
B22ir m	19-19½"	Red, gray, and brown indurated plinthite in solid horizontal phase; abrupt boundary.
B3	19½-30"	Reddish yellow (7.5YR6/6) silty clay with many prominent mottles of yellowish red (5YR4/6), brown (7.5YR4/4), and black (N2/0); massive; common plinthite as segregated sharp edged particles, and as thin coatings on saprolite; plinthite content appears to decrease with depth; many medium and large pores; gradual boundary.
C	30-36+"	Gray, yellow, and black soft rock encasing hard cores (saprolite); vesicular.

All colors are for moist soil. Terminology according to Soil Survey Manual (8).

This indurated plinthite sheet is a dominating soil characteristic on slopes below 25 percent in areas with annual rainfall above 150 inches. At the minimal rainfall it commonly forms at depths of 18 to 24 inches below ground surface, while at rainfall above 300 inches it is seldom more than 15 inches below ground surface. When viewed through a 14X hand lens it can be seen that the horizons below the plinthite layer have significantly more medium and large pores than the upper horizons. The indurated plinthite (Bir m horizon) is characteristically less than ½ inch thick; can be penetrated by a spade only with difficulty; is exrtmeley dense; and serves as a complete barrier to air and water movement except where fractured.

Theory of Formation

In this area of high rainfall, low evaporation, and gentle slopes the soil surface is saturated at all times. This effectively excludes air from the soil and makes a favorable environment for production of hydrogen sulfide through anaerobic fermentation. The hydrogen sulfide reduces ferric iron to ferrous iron which is not only toxic, but mobile. Ferrous iron gradually migrates downward in percolating water until it approaches the interface between saturated surface material and more porous material below. At this interface re-oxidation and precipitation of the iron takes place as the downward moving solution momentarily resists entrance into larger voids of the material below, and comes into contact with oxygen diffusing upward through the porous basalt. Over long periods of time a solid sheet of precipitated iron has thus developed into indurated plinthite. It is suggested that the theory of formation advanced above is very similar to Bartelli's theory for the formation of Beta horizons in glacial outwash soils (9).

Literature Cited

1. Thorpe, J. 1941. Geographic Setting and Climate of the Hawaiian Islands. Climate and Man, U.S.D.A. Yearbook of Agriculture. pp. 225-226.
2. Stearns, Harold T, and Gordon A. Macdonald. 1942. Geology and Ground Water Resources of the Island of Maui, Hawaii. Bulletin No. 7, Division of Hydrography, Territory of Hawaii.
3. Alexander, L. T. and J. G. Cady. 1962. Genesis and Hardening of Laterite in Soils. Technical Bulletin 1282, U.S.D.A. Soil Conservation Service. 99 pp.
4. Sivarajasingham, S., L. T. Alexander, J. G. Cady, and M. G. Cline. 1962. Laterite. Advances in Agronomy. Volume 14.
5. The Hawaiian Planter's Record, Vol. 1, No. 3, September 1909. Experiment Station of the Hawaiian Sugar Planters Association.
6. The Hawaiian Planter's Record, Vol. 1, No. 4, October 1909. Experiment Station of the Hawaiian Sugar Planters Association.
7. Soil Survey —Territory of Hawaii. Series 1939, No. 5, U.S.D.A. Soil Conservation Service cooperation with the Hawaii Agricultural Experiment Station. pp. 387-389, 421-424.
8. Soil Survey Manual. 1951. U. S. Department of Agriculture Handbook No. 18.
9. HBaretlli, L. J., and R. T. Odell. 1960. Field Studies of a Clay-Enriched Horizon in the Lowest Part of the Solum of Some Brunizem and Gray-Brown Podzolic Soils in Illinois. Soil Sci. Soc. Am. Proc. **24**:388-390.