GIBBSITE-RICH SOILS OF THE HAWAIIAN ISLANDS

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INTRODUCTION

Gibbsite, the trihydrate of aluminum oxide, has been identified in a number of Hawaiian soils. This identification has been based on the high content of alumina found by chemical analysis and reported by Hough and Byers (*4*), Hough *et al.* (*5*), and Sherman (*9, 10*). The further identifications of the mineral were made by thermal methods by Matsusaka (*7*) and by X-ray diffraction by Tamura *et al.* (*13*). Cline *et al.* (*1*) also recognized the alumina, which was high in content, as being a dominant mineral in the soils he classified into the Humic Latosol and Hydrol Humic Latosol groups. Sherman (*11*) pointed out in 1953 that some of our soils could be considered ferruginous bauxite. The recorrelation of the soils of East Kauai in 1955 and 1956 has led to the recognition of a new great soil group, the Aluminous Ferruginous Latosol, a soil having a high concentration of gibbsite.

The interest in the gibbsite-rich soils has increased due to the possibility of these soils having an alumina content which is sufficient to be considered a commercial source of bauxite ore. The present interest of aluminum companies would indicate a good likelihood that this is the case. It is the object of this report to reveal all the information which has been obtained from the soil mineralogical research on gibbsite-rich soils conducted by the Department of Agronomy and Soil Science of the Hawaii Agricultural Experiment Station. This report will include brief descriptions of these soils; their distribution; mode of occurrence; their mineral and chemical composition; and their genesis.

OCCURRENCE OF GIBBSITE IN HAWAIIAN SOILS

In general, free alumina in soils occurs as the mineral gibbsite, the trihydrate of aluminum oxide. Aluminum oxide also occurs as the free oxide in soils and as fixed aluminum, usually as the primary alumino-silicate minerals, the layered alumino-silicate clay minerals such as kaolinite, halloysite, montmorillonite, beidellite, allophane, micaceous minerals, and others. The occurrence of free aluminum oxide is usually limited to gibbsite, the trihydrate, with a few instances to the monohydrates, boehmite and diaspore. Such occurrences of all three of these oxides appear to be limited to the tropics, as a warm, moist climate appears to be essential to the development of alumina-rich soils and other weathered deposits rich in alumina.

The origin of bauxite deposits (alumina-rich deposits) has been considered for some time. Harder (*3*) states that several factors and conditions enter into the decomposition processes which develop bauxite and laterite. In our work in Hawaii, bauxite is considered the residual product of chemical weathering in which aluminum oxides (gibbsite, boehmite, or diaspore) occur in greater concentrations than iron oxide. If iron oxide is accumulated in preference to alumina, then the soil is considered a laterite or a ferruginous latosol. If alumina and iron oxide are accumulated at the same rate, then the soil is an aluminous ferruginous laterite or latosol or a ferruginous bauxite deposit. Harder has concluded that the principal conditions favoring optimum bauxitization (accumulation of the minerals gibbsite, boehmite, and diaspore) are as follows: (1) the presence of rocks with easily soluble minerals yielding residues rich in alumina; (2) effective rock porosity, enabling easy access and free circulation of water; (3) climate having a normal to abundant rainfall alternating with dry periods; (4) vegetation, including bacteria, advantageously distributed; (5) available source of appropriate solution and precipitation agencies; (6) a tropical or at least a warm climate; (7) low to moderate topographic relief, allowing free movement of the water table but a minimum of erosion; and, (8) long, quiet periods in earth geological history.

Goldman and Tracey (*2*) obtained similar conclusions from their studies of the Arkansas bauxites. Their conclusions were as follows: (1) Area has a climate which is more or less continuously moist and in which rainfall exceeds evaporation during the year; (2) Temperature exceeds 77° F., most of the time providing microflora which can destroy organic matter faster than it can be produced by the macroflora; (3) Relatively pure rain water acts on the aluminous rocks, particularly upon coarse-grain porous rocks that permit free circulation; (4) Rock is located in topographically high and well-drained place; (5) Rock is well above the permanent water table; and (6) All of these conditions must last for a considerable period of time.

Harder (*3*) has found that bauxite has developed on the following types of parent rock: (1) rocks rich in alkali-aluminum silicates, particularly the feldspathoids, with alkali feldspars, pyroxenes, amphiboles, and micas but no quartz; (2) residual products of weathering limestones; (3) hydrous aluminum silicate rocks such as sedimentary clays low in free quartz; (4) intermediate and basic rocks such as diorite, diabase, dolerite, and basalt which contain abundant calcium-aluminum and calcium-magnesium-iron silicates but with little or no quartz; and (5) by the intensive weathering of various moderately aluminous igneous, metamorphic, and sedimentary rocks such as granite, syenite, gneiss, schist, phyllite, slate, and shale containing more or less quartz.

The interesting point of both Harder's (*3*) and Goldman and Tracey's (*2*) observations is the fact that most of the conditions essential to the development of bauxite are present in Hawaii. Furthermore, the parent materials for our intensely weathering soils of the Islands are basalts, andesite, trachyte, and andesitic volcanic ash, all of which contain practically no quartz.

These are the materials in which one would expect bauxite to develop in the Islands.

Sherman (*9*) was the first to call attention to the possible accumulation of aluminum oxide in the soils of the high-rainfall regions of Hawaii. Figure 1 gives data which show an increase in alumina content as the rainfall increased in a series of soils developed on andesitic ash. This observation was further substantiated by Tanada's work (*16*) in which he showed that, as the annual rainfall increased from 30 to 200 inches, the kaolin decreased from 80 percent to less than 5 percent in the soil. The obvious conclusion is that the soils of the high-rainfall areas are made up of free oxides of aluminum, iron, and titanium.

The factors contributing to the genesis of alumina-rich laterites in the Hawaiian Islands were described by Sherman (*10*) in 1952. A sequence of soil formation having typical soil minerals was proposed in this report. It developed a hypothesis which showed that climate and age played the most important role of intensity factors of soil weathering and formation. Weathering under semiarid conditions would first develop montmorillonite and if base removal was sufficient, a kaolin clay would develop. Under moderate rainfall, but with prolonged dry seasons, kaolin clays would be the predominant mineral of the soil. Under moderate or heavy rainfall, with both definite rainy and dry seasons, the soils would be enriched in the oxides of iron and titanium. Under continuous moist conditions with good internal drainage, aluminum oxide would become the most stable oxide in the weathering mass. The report states: "The hydrated aluminum oxides that develop in the wet tropics are stabilized in concretions or water-stable aggregates as the soil ages in its weathering cycle. The hydrated aluminum oxides first combine to form granules. In periods of decreasing moisture content, the aggregates grow to appreciable size. These aggregates become partially dehydrated in periods of low rainfall; thus, conditions are developed for the formation of bauxite. The aggregates will contain the hydrated aluminum oxide. The growth of the aggregates can be of a concretionary type when conditions favor the mobile form of free aluminum oxides. The water-stable aggregates or concretions lead to the development of horizons which are porous.... In the Hawaiian Islands, soils having the porous horizons of water-stable aggregates are very common on the geologically older islands. On Kauai the stability of these aggregates is very great.... The porous condition of the horizon develops conditions that would favor the formation of bauxite."

Tamura *et al.* (*14*) identified gibbsite in certain soils from West Maui by X-ray diffraction methods. He also identified gibbsite by the same method in soils of the Olinda family of East Maui. His work indicated the presence of 31 to 52 percent of gibbsite in this soil.

Matsusaka (*7*) identified gibbsite in a number of Hawaiian soils by differential thermal analysis. He was able to demonstrate that gibbsite content of Hawaiian soils increased with increase in annual rainfall. Under the same conditions kaolin decreased in these soils similar to data shown in figure 1.

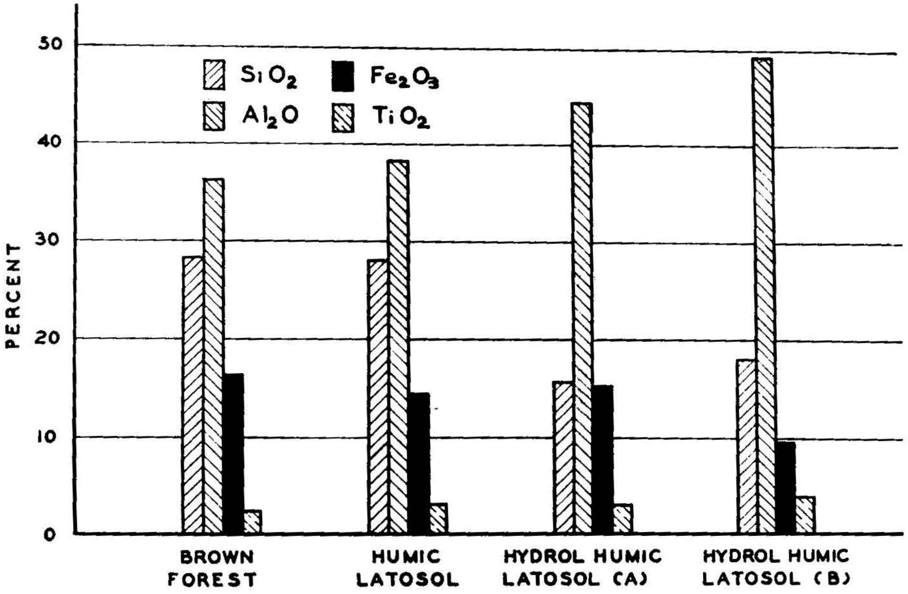

FIGURE 1. The effect of progressive increase in rainfall (left to right) in the chemical composition of soils developed on andesitic ash.

Tamura *et al.* (*13*) identified the allophane-gibbsite-iron oxide system in the soils of the Hydrol Humic Latosol group. These soils contained from 26 to 33 percent gibbsite in their mineral fraction as determined by X-ray methods. Matsusaka (*7*) has shown approximately the same values by differential thermal analysis.

Recently the chemical analysis and differential thermal analysis have been made of numerous aggregates, concretions, and mineral aggregates in Hawaiian soils and weathered rock. The analyses of these materials have given aluminum oxide contents ranging from 46 to 66 percent, which in terms of gibbsite is 70 to 100 percent. Most of the results of these studies will be published in the near future.

DISTRIBUTION AND OCCURRENCE OF GIBBSITE-RICH SOILS

The soils on the islands of Kauai, Maui, and Hawaii, which have a gibbsite content in excess of 10 percent, are shown in figures 2, 3, and 4. These soil areas are limited to those having a weathering depth in excess of 3 feet. Actually most of the soils included in this area have a weathering zone in excess of 10 feet. The soil solum plus weathered parent rock will approach an average of 20 feet for areas shown in these maps. Oahu has been omitted as the gibbsitic soils have not been fully explored. There are small areas of gibbsitic soils at the head of several of the wet valleys.

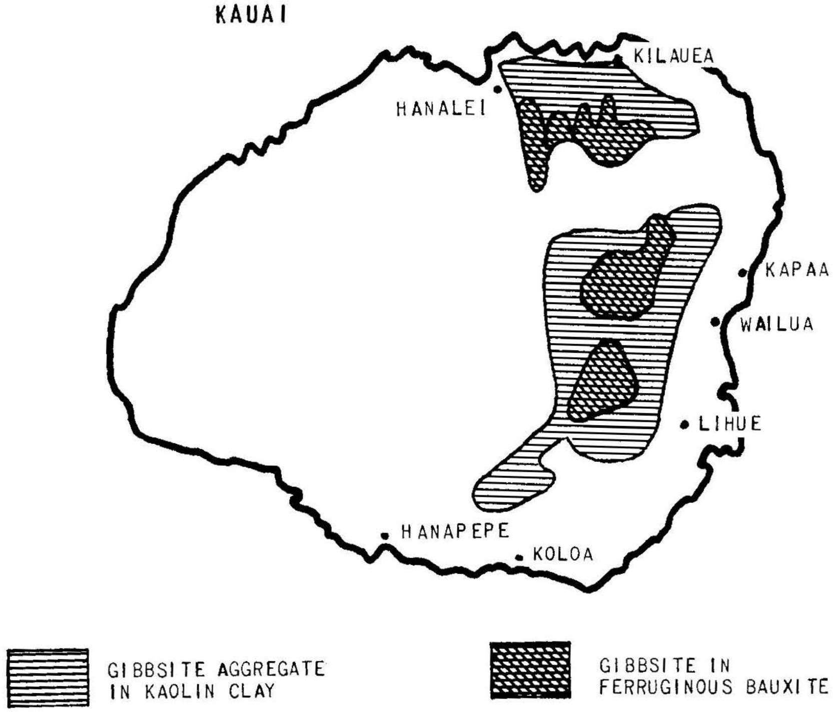

FIGURE 2. The general areas of gibbsite-rich soils occurring on island of Kauai.

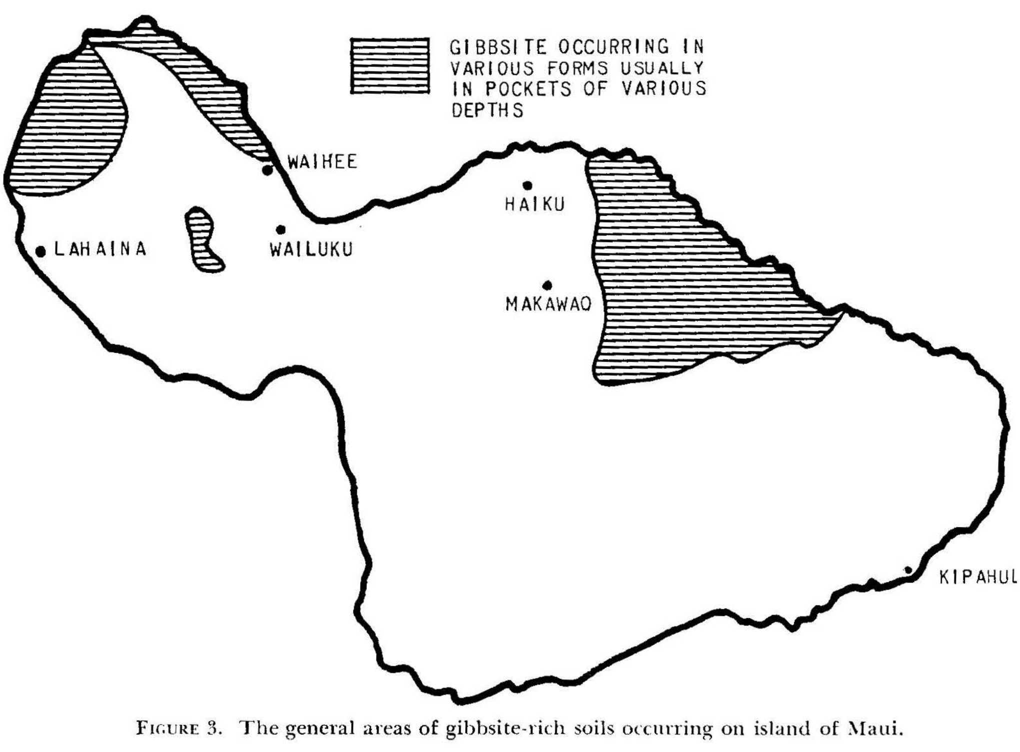

FIGURE 3. The general areas of gibbsite-rich soils occurring on island of Maui.

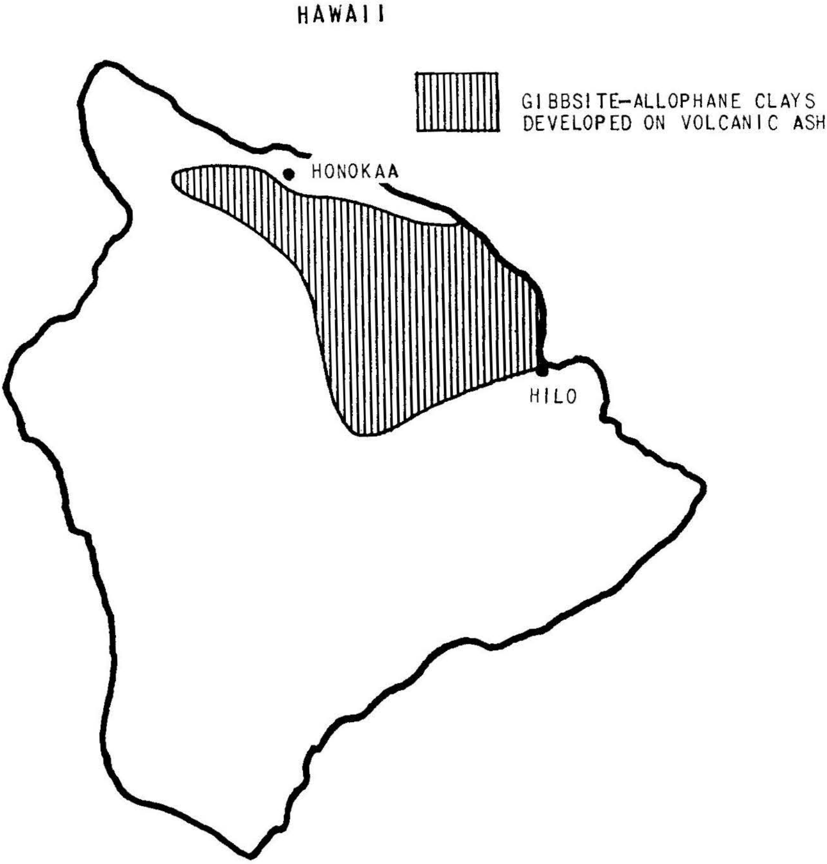

FIGURE 4. The general distribution of the gibbsite-allophane clays on island of Hawaii.

The soils shown in figures 2, 3, and 4 belong to the soil families and soil series shown in table 1. It should be pointed out that in many of these soils the aluminous ferruginous laterite is the parent material on which the soil is formed. The first observation of this fact was made during the first field exploration for extent of bauxite occurrence in 1955 by the author in company with bauxite geologists.

The deposits vary greatly in their chemical and mineralogical composition. The mode of genesis or deposition of their gibbsite has been different. Each major area will be described according to its properties.

KAUAI DEPOSITS

The deposits on the island of Kauai are limited to the Koloa volcanic flows and to the areas of these flows where the annual rainfall is in excess of 65 inches. The Koloa volcanic flows have produced gently sloping ridges radiating from its major crater, Kilohana Crater. The flows from this crater

TABLE 1. The soil series of the soil families of the various Hawaiian Great Soil groups which have more than 10 percent free alumina content

GREAT SOIL GROUP	SOIL FAMILY			SOIL SERIES		
	Name	Location found	Symbol in generalized map	Name	Location in islands	Mapping symbol in detailed map
Aluminous Ferruginous Latosol	Halii	Eastern half of Kauai	A-2	Halii	Eastern half of Kauai	Ho, Hm
Ferruginous Humic Latosol	Haiku	Eastern half of Kauai	T-3	Haiku	Eastern half of Kauai	Hc, Hd, He, Hf
	Puhi	Eastern half of Kauai	T-4	Puhi	Eastern half of Kauai	P2e, P2f, P2g
	Haiku	East Maui	T-3	Haiku Pauwela	East Maui	Ha, Hd, He, Hf, Pz, P2a
	Naiwa	West Maui	T-2	Naiwa Halawa	West Maui	Ne, Nf, Ng, Nh, Nk, Hh, Hi
Hydrol Humic Latosol	Akaka	Hawaii	K-8	Akaka	Hamakua Coast on Hawaii	Ac, Ad, Ae
	Hilo	Hawaii	K-6	Kaiwiki Hilo	Hamakua Coast on Hawaii	H2g, H2m, H2n, Kr
	Honokaa	Hawaii	K-7	Honokaa	Hamakua Coast on Hawaii	H2p, H2r, H2s, H2t, H2u, H2v
	Koolau	Kauai East Maui	K-3	Koolau	Above Hanalei Valley, Kauai	Kk2
Latosolic Brown Forest	Olinda	East Maui	F-4	Olinda	Maui	Og, Oh
Humic Latosol	Honolua	West Maui	A-2	Honolua	West Maui	H2x, H2y, H2z

swept through the Knudsen Gap and to the sea in the Koloa area; easterly through Puhi and to Nawiliwili Harbor and northerly and easterly on the lands of Lihue Plantation. Other major flows came from vents in the mountain range and descended southerly to the Wailua Game Refuge and the Wailua Homestead area with other flows extending into the Waipuhi and Kapaa areas. The northerly flows swept down the slope to the sea above Hanalei Valley and also the low lying lands of Kilauea Plantation. Several minor vents probably added their volcanic materials to these flows. These flows are briefly described by Macdonald *et al.* (*8*).

The Koloa volcanic series flows consist of rocks identified by Macdonald *et al.* (*8*) as melilite-nepheline basalt, melilite basalt, nepheline basalt, basanite, and other minor related types. These rocks are free of quartz and have a low silica content. They are porous, fine-grain rocks which are susceptible to rapid chemical decomposition. Chemical weathering has been exceedingly rapid due to the following reasons: (1) presence of easily soluble minerals due to relatively low combined silica content and the absence of quartz; (2) topographic position which makes greatest effective use of the heavy rainfall occurring at higher elevations of gently lying slopes which have a high infiltration rate of water with subsurface conditions favoring the lateral

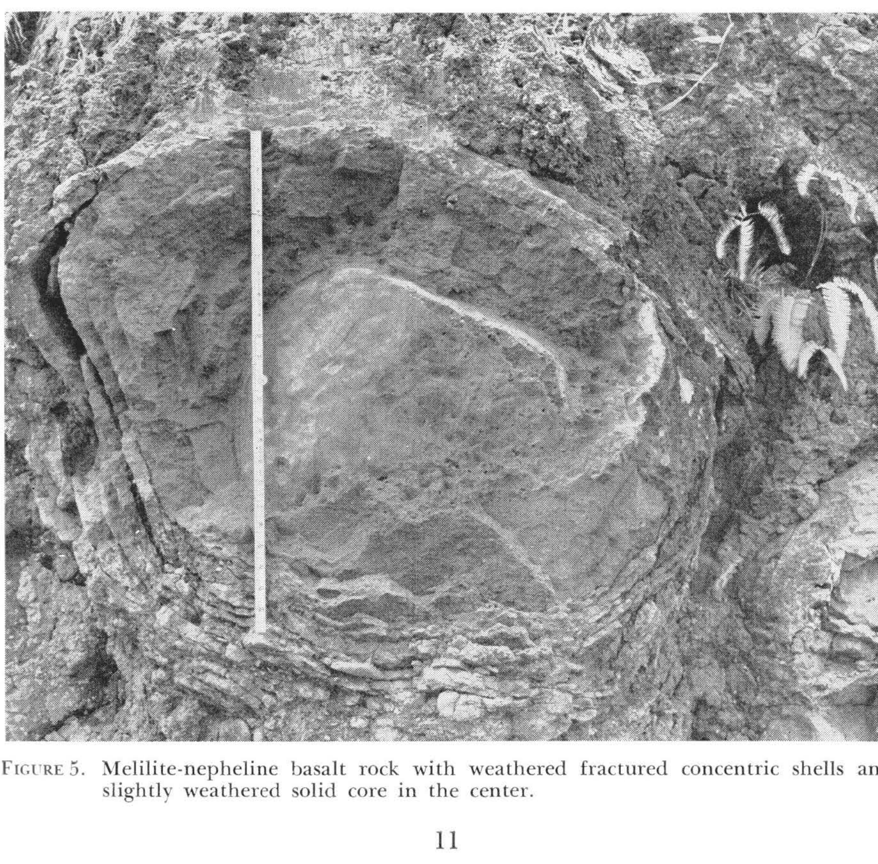

FIGURE 5. Melilite-nepheline basalt rock with weathered fractured concentric shells and slightly weathered solid core in the center.

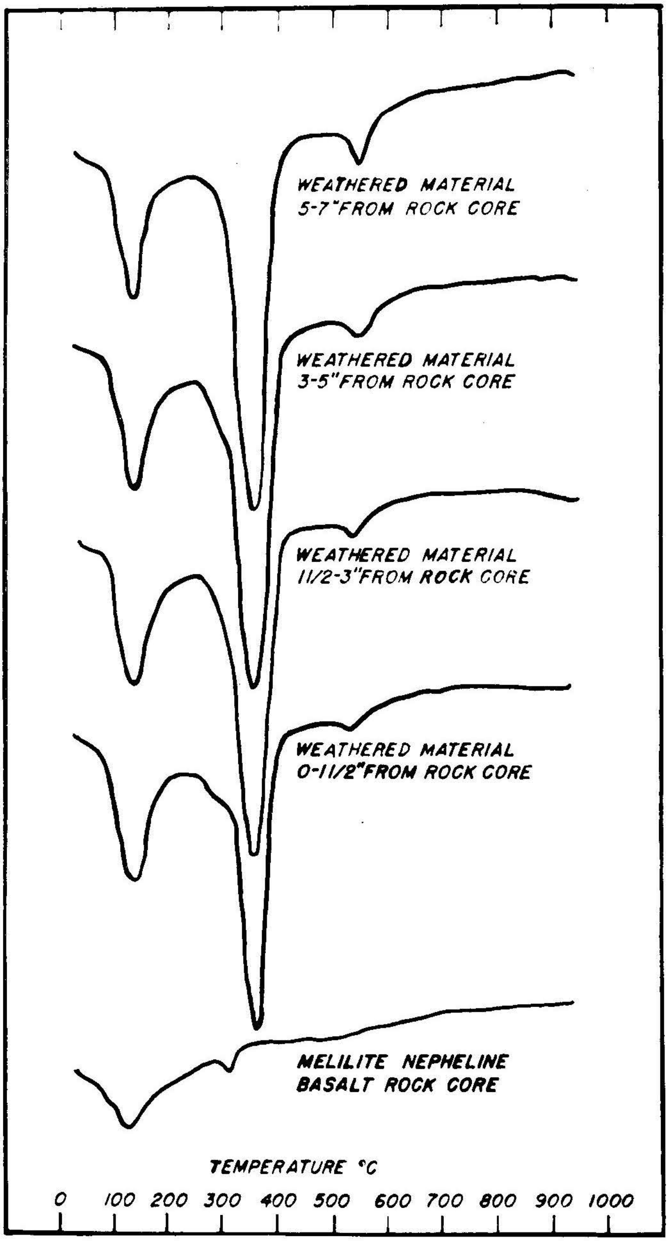

FIGURE 6. Differential thermal analysis of weathered melilite-nepheline basalt rock. Left endothermic peak indicates adsorbed water, second peak indicates hydrated sesqui-oxides, and the third weak peak indicates kaolin.

movement of water. The effectiveness of the water is enhanced by the fine-grain texture of the rock and its porosity which permits the free circulation of the percolating waters. The movement of water is from a continuous head and, while passing through the fine pores, aeration is kept to a minimum which favors the reduction of iron oxides and provides conditions for their leaching; (3) the chemical decomposition of the rocks is hastened by the organic acids added to the soil by the decomposition of the staghorn fern. The acidic nature of staghorn fern forest floors has been pointed out by Sherman and Kanehiro (*12*); and (4) a relatively long period of exposure to ideal conditions for chemical weathering processes which favors the rapid decomposition of silicates and the subsequent desilication of the weathering zone.

The rocks have weathered rapidly under these conditions with the first product of weathering being a laterite. While these rocks have weathered completely, they have retained their original shape and structure. The type of weathering is shown in figure 5, which shows an unweathered rock core in contact with the laterite with a knife edge, transitional weathering zone. This rock occurs near the reservoir of the Wailua Game Refuge. The hardening properties of the laterite give the rock the stability to retain its shape. If these weathered rocks are dried, they will become hard and when rewetted will break into hardened aggregates. When these rocks are wet, they can be cut easily by a knife or a spade.

The chemical analysis of these weathered rocks shown in figure 5 is given in table 2. The data show a very low silica content in the weathered materials ranging from a probable trace to little over 5 percent. The alumina content is high, ranging from 19 to 48 percent. The analysis of a number of samples from this area shows a range of aluminum oxide content ranging from 20 to 58 percent with a high proportion higher than 40 percent. All samples have a very low silica content.

TABLE 2. The chemical composition of ferruginous bauxites weathered directly from melilite-nepheline basalt from the Wailua Game Refuge, Kauai

SAMPLE	SiO_2 PERCENT	Al_2O_3 PERCENT	Fe_2O PERCENT	TiO_2 PERCENT	H_2O 110° C. PERCENT
1	4.0	48.5	26.0	3.1	17.3
2	4.7	47.0	25.1	3.3	17.5
3	5.5	46.3	28.7	3.6	17.9
4	4.4	45.8	28.0	4.1	17.6
5	2.1	41.2	36.1	5.0	16.8
6	1.9	43.1	36.0	5.8	16.7
7	2.0	39.3	37.0	5.5	16.3
8	2.4	39.3	36.5	6.5	16.7
9	2.1	19.2	60.8	5.5	14.1
10	0.0	36.2	38.6	6.0	16.8
11	0.0	44.3	28.7	4.5	19.7
12	0.0	43.7	31.0	5.0	22.2
13	0.4	41.7	32.5	4.1	18.9

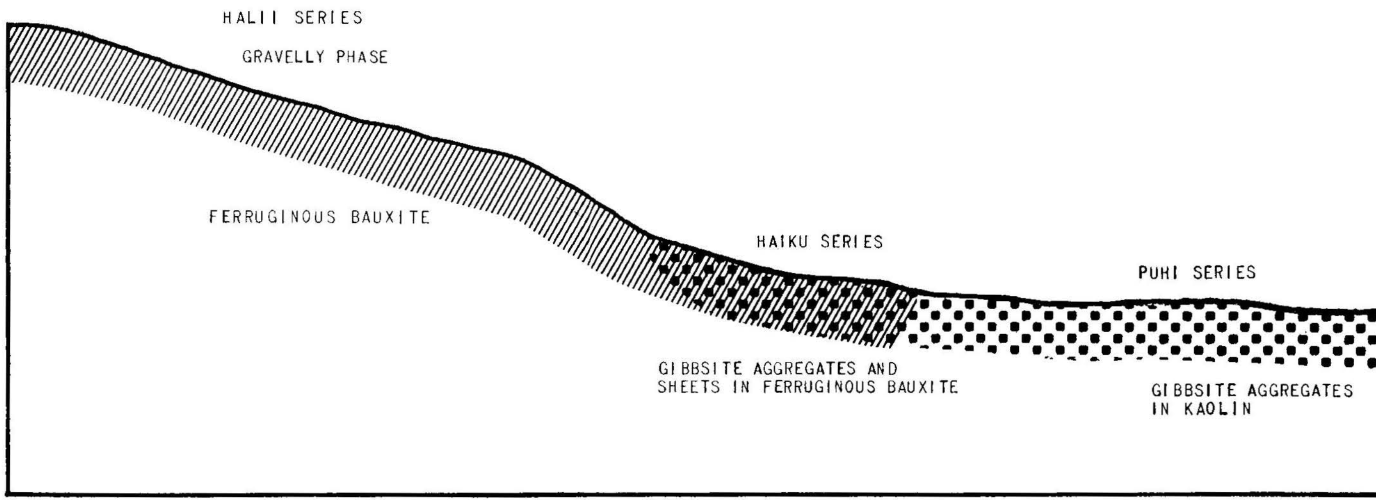

FIGURE 7. The relationship between soil series and the mineral composition of the bauxite soils.

The data obtained from differential thermal analysis are given in figure 6. The endothermic reaction between 350° C. and 360° C. is characteristic of gibbsite, the aluminum oxide mineral occurring in these deposits.

These slopes grade into more or less level land. In the soil and weathered rocks, there have been both the segregation of gibbsitic-ferruginous aggregates and the precipitation of gibbsite into layers, often called sheets. The latter is nearly pure gibbsite as is shown in the analysis given in table 3. The aluminum oxide of many of the white gibbsite layers approaches the theoretical pure gibbsite analysis of 66 percent. The slower movement of the circulating water has slowed the mobility of the soluble silica to a point where resilication of gibbsite occurs in the clay-sized particles. Thus, the kaolin content increases as the circulating water movement slows down and as water available for the weathering processes decreases with a lower rainfall. The resilication is probably facilitated by the increase in silica concentration in the circulating water due to evaporation during the increasing duration of dry periods. The schematic relationship is shown in figure 7.

TABLE 3. Chemical composition of bauxitic aggregates and gibbsitic sheets of Kauai soils

BAUXITIC MATERIALS	SiO_2 PERCENT	Al_2O_3 PERCENT	Fe_2O_3 PERCENT	TiO_2 PERCENT
Ferruginous bauxite aggregates from Puhi soil	6.5	43.3	28.7	4.2
Ferruginous bauxite aggregates from Haiku soil	4.1	46.0	28.0	3.0
Gibbsite sheet white layer	1.2	58.9	1.2	1.8
Gibbsite sheet gray brown layer	12.8	52.0	12.2	3.6

These observations are based on surface soils. The movement of water through the deeper substratum may be just as effective as on the slopes. Observations in a 25-foot cesspool in this area would indicate that weathering conditions favoring the enrichment of gibbsite do occur in the deep substratum.

In the Puhi soils, which are developed in areas of the lowest rainfall, there is evidence that iron oxide is accumulating more rapidly than gibbsite. This particularly is true in areas of the Kilauea Plantation and Waipuhi area near the Spaulding Monument. The data given in table 4 are obtained from the analysis of a Puhi soil on the main highway as it passes near Kilauea road to the mill. The data show a higher iron oxide content and a lower aluminum oxide content than the analysis shown by the wetter areas. The silica content of this soil is extremely low for this area.

The data presented in table 5 are obtained from the analysis of aggregates from the adjacent soils on Kilauea Plantation. The iron content of these aggregates is much higher than that found for aggregates on the steeper

TABLE 4. The chemical composition of a Puhi soil profile on Maui Road just east of road entering Kilauea Village, Kauai

DEPTH IN INCHES	OXIDE ANALYSIS IN PERCENT					
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	H_2O
0–5	0.7	18.6	43.7	7.6	0.2	19.9
5–10	0.5	18.6	41.1	6.8	0.1	20.8
10–12	3.6	19.7	45.0	8.5	0.2	21.0
12–20	0.5	21.3	43.1	7.9	0.1	23.2
20–35	5.7	25.8	45.5	8.1	0.3	16.0
35–40	7.0	21.4	44.1	8.3	0.3	17.6
40+	7.6	24.7	42.0	8.3	0.2	16.2

TABLE 5. The chemical composition of aggregates found in the graveled Haiku soils of the Kilauea Plantation, Kauai

MATERIAL	PORTION OF AGGREGATE	OXIDE ANALYSIS IN PERCENT			
		SiO_2	Al_2O_3	Fe_2O_3	TiO_2
Ferruginous aggregate #1	Outer coating	1.7	16.0	56.5	4.7
	Inner portion	0.4	27.0	43.8	6.9
Ferruginous aggregate #2	Outer coating	0.4	18.6	57.0	4.6
	Inner portion	1.1	26.2	44.1	5.0
Gibbsitic aggregate	Outer coating	2.0	35.6	40.5	4.2
	Inner portion	1.1	51.0	16.2	4.8

slopes. These aggregates have a low content of silica. The impervious coating of iron oxide of the surface will protect the gibbsite from resilication.

The greatest resilication of the gibbsite to kaolin minerals occurs in soils of the very high rainfall area where the internal drainage has been impeded so as to produce waterlogged conditions in the weathering system. The white clays in the mountains above Hanalei Valley are an excellent example. The clay-sized gibbsite has been resilicated to kaolin minerals. The waterlogged condition will reduce and remove the iron oxide. The precipitated gibbsite concretions, aggregates, and layers are nearly pure gibbsite since they contain 65 percent aluminum oxide. The swamp areas west of Kilohana Crater are kaolin clays except for pure gibbsite nodules and aggregates.

The material found in the Knudsen Gap is similar to Akaka soils on Hawaii, and the description of the Akaka soils will apply to the soils of Knudsen Gap.

MAUI DEPOSITS

An accurate description of the Maui deposits is very difficult. The indications are that the quality is very high, but certain physical conditions and their peculiar mode of occurrence make them less attractive than their aluminum oxide content would warrant. Each deposit will be described separately as these deposits do not have the uniformity of the Kauai deposits.

The first verified high concentration of gibbsite in the Islands was identified in the weathered trachyte parent rock of the Naiwa soils above Waihee, Maui. X-ray analysis of fractions of the material showed from 60 to 75 percent gibbsite. The author has explored the road cuts along the coastal road and has found bauxite deposits having a gibbsite content as high as 90 percent occurring in pockets in the road banks. The materials are very irregular and need to be explored in detail. Generally this area has been considered too irregular and too rocky for commercial recovery of the gibbsite even though small areas of it are the richest in the Islands.

The best prospect for bauxite on Maui is in the Haiku area beginning with the Libby, McNeill & Libby cannery at Pauwela and extending beyond Kailua and extending up the slopes of Haleakala, like a large slice of pie. The bauxite underlies a surface soil having a high content of titanium oxide. Most of it occurs as segregated hard aggregates having a high content of aluminum oxide, approximately 60 percent. In some areas it occurs in a pisolitic form, having been deposited in the gas bubble pores of the rock during the weathering process. After weathering, pisolites appear as white pearls in the clay soil. These pisolites have an average aluminum oxide content of 62 percent and amount to about 50 percent of the ore. These deposits are extremely deep in places, but in general do not exceed 10 feet in depth. The analysis of aggregates from the Haiku area is given in table 6. These data indicate that these aggregates are almost pure gibbsite.

TABLE 6. Chemical composition of gibbsite aggregates, pisolites, and pebbles from Haiku, Maui

MATERIAL	SiO_2 PERCENT	Al_2O_3 PERCENT	Fe_2O_3 PERCENT	TiO_2 PERCENT	LOSS ON IGNITION
White pebbles	0.8	64.8	0.8	0.1	34.4
White layer	3.8	57.7	2.8	0.2	23.3
Gray layer	12.9	46.2	18.7	0.6	20.8
Pisolites (average)	1.7	61.7	5.8	0.8	31.9

HAWAII DEPOSITS

The soils of the Hydrol Humic Latosol on the Hamakua Coast represent the largest area of gibbsite-containing soils in the Territory of Hawaii. The soils of the Akaka family cover over 300 square miles and will average 20 feet of highly weathered volcanic ash containing from 27 to 33 percent of gibbsite in their mineral fraction. The soils of the Hilo family have an equal content of gibbsite but are shallower than their closely related soil, the Akaka. The Honokaa soils are less weathered and the gibbsite content will be less. However, in an area above the village of Honokaa, these soils approach the same degree of development as found in the Akaka soils.

The data obtained from Tamura *et al.* (*13*) are given in table 7, showing the chemical analysis of soils belonging to the Hilo and the Akaka families, and in table 8 showing the mineralogical analysis of the same soils. These mineralogical analyses show that these soils contain gibbsite, allophane, and goethite in appreciable quantities. It is of interest that the iron oxide mineral lepidocrocite has been identified tentatively in these soils. The gibbsite

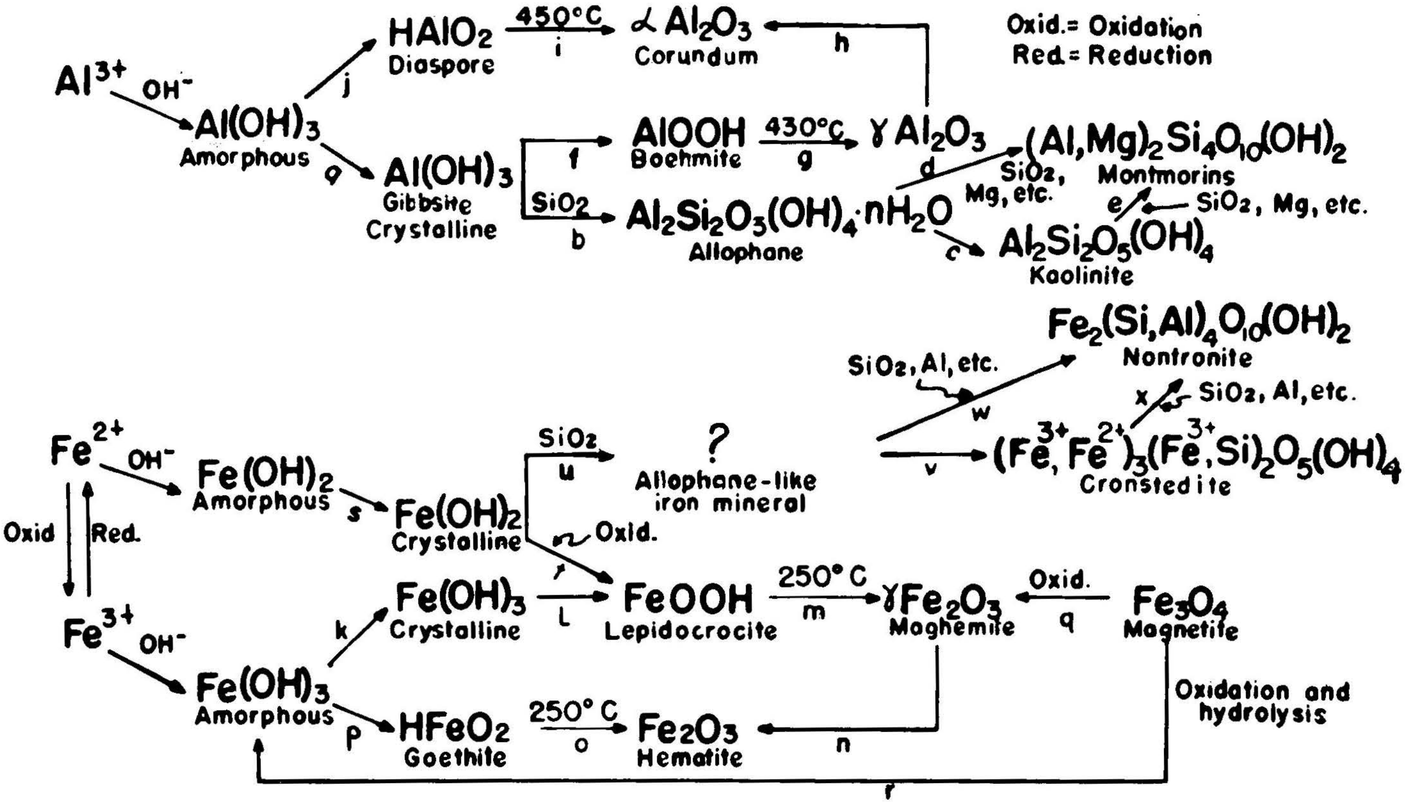

FIGURE 8. Structural and energy relationships of iron and aluminum oxides, hydroxides, and silicates (*15*).

TABLE 7. The chemical analysis of soil horizons of the Hilo and Akaka soils of the Hydrol Humic Latosol group. Tamura *et al.* (*13*)

SOIL FAMILY	HORIZON	SiO_2 PERCENT	Al_2O_3 PERCENT	Fe_2O_3 PERCENT	TiO_2 PERCENT	110°–400° C. H_2O PERCENT
Hilo	A*	14.6	22.1	32.9	6.8	15.7
	B_1*	16.7	24.2	29.7	7.7	15.1
	B_2*	13.0	20.8	37.1	6.8	15.6
Akaka	A	13.3	20.3	31.4	4.2	19.8
	B_1	12.9	26.8	26.7	6.4	18.6
	B_2	13.4	28.3	31.6	3.5	16.2

* A horizon represents the surface; B_1 represents a dark-colored horizon; and B_2 represents the light-colored horizon.

TABLE 8. Mineral composition of soil horizons of the Hilo and Akaka soils of the Hydrol Humic Latosol group. Tamura *et al.* (*13*)

SOIL FAMILY	HORIZON	MINERALS EXPRESSED IN PERCENT*									
		Qr	SiO_2	Mi	2 : 1	Kl	Allo	Gb	Ma	Gt	An
Hilo	A	2	5	7	0	0	16	27	18	12	7
	B_1	2	4	5	0	0	26	26	11	18	8
	B_2	2	4	10	0	0	15	25	6	34	7
Akaka	A	1	4	6	0	0	16	28	11	22	5
	B_1	0	4	3	0	0	23	29	19	10	7
	B_2	3	4	7	0	0	13	33	15	18	4

* Qr = quartz, SiO_2 = silica, Mi = mica, 2 : 1 = layered silicates related to montmorin type, Kl = kaolin, Allo = allophane, Gb = gibbsite, Ma = magnetite, Gt = goethite, and An = anatase.

content varies from 25 to 33 percent in these soils, which would be equal to 17 to 22 percent aluminum oxide. It is estimated that these soils would contain on this basis approximately 400,000,000 tons of aluminum oxide (table 9). Even so, these soils would be considered a very low grade ore.

A very important observation was made on these soils which may lead to methods of separation of the gibbsite. Mr. Norman Taylor, soil scientist from New Zealand, and the author observed that gibbsite would segregate on drying. This observation has been followed and it has been found that gibbsite segregates into light-colored aggregates, which contain from 62 to 64 percent aluminum oxide and a silica content of less than 1 percent. The separation of this material would give one of the highest grade ores known as it would approach pure gibbsite. After these findings, it was found that Dr. Tsuneo Tamura had observed the same phenomenon at the University of Wisconsin in 1951 and found that the light-colored aggregates contained from 90 to 100 percent gibbsite, while the dark-colored aggregates contained 25 percent gibbsite. This work was done by X-ray diffraction analysis.

In figure 8 is given a schematic system of the form of aluminum oxide and iron oxide found in weathered products as developed by Tamura and Jackson (*15*). These data show the structural and energy relationships in the genesis of various oxides of aluminum and iron. The utilization of this scheme is important in the development of methods of separation of gibbsite from the allophane and iron oxides. The physico-chemical properties of each oxide including its surface chemical reactions are being used in the development of the beneficiation processes for the commercial development of these mineral ores as a source of aluminum oxide. Several of the iron oxides are magnetic. These oxides develop their magnetic properties upon dehydration. Since iron oxide and aluminum oxide are in different aggregates, this may provide a means of separation.

TONNAGE ESTIMATES OF ALUMINA

The gibbsite-rich soil of the Hawaiian Islands occurs in area in excess of 330 square miles. While these deposits would be generally considered low grade ores, the potential tonnage of recoverable alumina is very substantial due to size and the depth of the area and to the very low silica content. The estimated tonnage of aluminum oxide in these soils is shown in table 9.

TABLE 9. The tonnage estimates of total alumina in the Hawaiian deposits and basic figures used in arriving at estimates

ISLAND	AREA IN SQUARE MILES	WEIGHT OF ORE TONS/ACRE FOOT	ESTIMATED AVERAGE DEPTH FEET	ESTIMATED AVERAGE PERCENT ALUMINUM OXIDE	CALCULATED TONNAGE OF ALUMINUM OXIDE
Kauai	15	1000*	30	33.3	96,000,000
Maui	15	1000*	20	40.0	77,000,000
Hawaii	300	500*	20	20.0	384,000,000
TOTAL	330	—	—	—	557,000,000

* Assumed bulk density of deposit for Maui and Kauai is 0.7 and for Hawaii deposit, 0.35.

The estimation of the tonnage of alumina is difficult due to the lack of well-established data for the average composition of deposits and the depth of deposits. There is a need for the estimated tonnage in order that the public may have some idea as to the magnitude of the deposits. The estimates in table 9 are based on the best information that can be derived from data obtained from our soil investigations in soil formation and rock weathering. The greatest assumption lies in the estimated average depth of the deposits. The data on depths are very scattered and thus these estimates should be re-evaluated when better figures are obtained. The other data used in the calculations are very conservative. The bulk densities are reasonably low. The average alumina content is accurate for Hawaii, reasonably accurate for Maui, and somewhat low for Kauai. The area used in making the estimate is low for Hawaii and reasonably correct for Kauai and Maui. *The tonnage estimates should not be considered the estimate of commercial ore.* There are many problems in the development of these deposits which must be solved before this ore can be considered commercial. These tonnage estimates are to be considered in terms of a *potential resource.* It may take a number of years before an economic method can be worked out to separate the gibbsite from the clay of the Hawaii deposit. The estimated tonnage of this deposit is sufficient to encourage mining companies to work out processes of recovering this alumina.

The total tonnage of alumina would give the United States a very substantial reserve as has been pointed out in the report by Magill (*6*). All of the ore except small areas in the Wailua Game Refuge and Kilohana Crater areas will require beneficiation. Cost of beneficiation in the Hawaiian Islands will be expensive. This cost will be partially offset by the low silica content of the resulting concentrate. On the other hand, beneficiation of the deposits on the island of Hawaii will require the development of new procedures adapted to this ore.

The Hawaiian gibbsite-rich soils generally occur in areas which have a low agricultural potential. Economic crops have been grown in these areas but only after heavy applications of fertilizers. Even with heavy applications of fertilizers the yields do not approach the yields of the better agricultural lands. This led to a high cost of production and thus these areas have become areas of subsistence farming. There are some areas where the surface soil is of substantially better quality; as for example, some of the sugar cane fields of the Grove Farm and Lihue Plantation on Kauai. Likewise, the soils of the Hilo family support a large acreage of sugar cane. These soils have been omitted from all tonnage estimates because mining would not be considered the best use of these lands.

THE PROBLEMS OF BAUXITE MINING

The commercial development of an alumina recovery industry from these gibbsite-rich soils will present a number of problems to the Territory of Hawaii. The deposits lie at the very surface so that strip mining methods will have to be used. In addition much of the ore will have to be upgraded before it can be shipped to the alumina plants either in the Islands or on the Mainland. Most of the upgrading will be by wet screening which presents further problems of controlling the wastes. The industry may build alumina plants in the Islands, and if this is done, there will be the problem of disposal of the "Red Mud," the waste product of the Bayer Process which would be the method used to recover the Hawaiian alumina. Also, the deposits occur in the high-rainfall areas on the windward slopes of the Islands. All of these areas are at a higher elevation than the productive soils of the lowlands. Much of the irrigation water is collected from the streams flowing between the fingering ridges on which the gibbsitic soils are located. The watershed must be protected as well as drainage systems. Lastly, the soils must be restored after the mining operations to their former use or to an approved new use.

The area of ore required to supply alumina for a Bayer Process plant will be relatively small. The average plant in the Pacific Northwest produces about 100,000 tons of metal. If we assume that an operating Bayer Process plant will produce alumina for an aluminum metal plant of this size, the area can be calculated as follows: It takes 2 pounds of alumina to make a pound of metal, and in this example it means our Bayer Process plant must have a capacity of 200,000 tons of alumina. If we assume that our deposit weighs 1,000 tons per acre-foot and that it contains 33 percent free alumina and is 30 feet in depth, it will yield approximately 10,000 tons per acre of extractable alumina by the Bayer Process. Accordingly, it will take about 20 acres of ore to supply the annual requirement of this plant. This example gives some idea as to the magnitude of the mining operation.

The Territory of Hawaii must face these problems of strip mining operations. Conservation practices must be developed which will provide protection of all the natural resources. It would be poor economy which would reap the immediate profit to find that we have lost our greatest resources, water and land.

SUMMARY

The Hawaiian Islands have substantial acreage of soil which can be considered a commercial source of a large tonnage of alumina. The tonnage of potentially available alumina exceeds a half billion tons. The greater portion would require special beneficiation processes which probably are not economical at this moment. They do, however, represent a sizeable reserve which the Nation could draw upon in a time of need.

The alumina occurs generally as aggregates of gibbsite varying in size from fine sand to aggregates of several inches in diameter. These aggregates occur in both ferruginous and kaolinitic clays. In general, these aggregates have an alumina content in excess of 50 percent; thus, it is possible to upgrade this material to a high quality product.

The mining of these soils for their gibbsite would be a strip mining process and thus the Territory should plan to develop conservation practices which would protect the soil and the watersheds.

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