

C. 494

THE CHARACTERISTICS AND GENESIS OF THE AKAKA AND HILO SOILS
OF THE ISLAND OF HAWAII

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It is dedicated to my family without whose patience and understanding it could not have been completed.

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INTRODUCTION

During the last ten years there has been increasing interest throughout the world on the characterization of soils containing amorphous inorganic materials. This has been particularly true in those areas of the tropics, subtropics and even a few temperate areas having large areas of soils developed from volcanic ash. Most notable among these places are Japan, New Zealand, Indonesia, the Pacific Northwest of the United States, and Hawaii.

Hawaii is exceptionally well suited for this type of study because of the wide range of climatic conditions occurring over relatively short geographical distances. As a consequence, a complete range of soil development can be examined with rather uniform parent material influence.

This type of study has been largely accomplished on the volcanic ash soils of the drier areas in Hawaii, but the work in the perhumid rainforest and former rainforest areas is piecemeal at best.

Because of rapid weathering under conditions of high rainfall, volcanic ash quickly loses nearly all of its identifying characteristics as to its origin and age. Amorphous materials develop that reflect even minor differences in particle size, mineral content and moisture holding characteristics, but at the same time the causes of these differences are completely obliterated.

With continuing development these soils ultimately form ferruginous bauxites and/or bauxites as silica is removed. Then only is the amorphous character of these soils lost as hydrated oxides of iron and aluminum crystallize out, changing the nature of the soils completely.

The Hilo and Akaka soils are representative soils of a large part of the northeast coast of the Island of Hawaii that have formed under perhumid conditions from andesitic volcanic ash.

While geologically young, these soils have been so intensively weathered that they are approaching the stage of bauxitization and are therefore somewhat different than the other large areas of volcanic ash soils that have been reported in Hawaii and elsewhere.

With these factors in mind, eight profiles were described and sampled and characterized mineralogically, chemically and physically with the following objectives in view:

1. To determine the proper place of the Hilo and Akaka soil families in the new comprehensive system of soil classification the Seventh Approximation.
11. To establish the similarities and differences in the morphology and the genesis of the Hilo and Akaka soils.
111. To determine the nature of the allophane - amorphous hydrous oxide - gibbsite relationships in the Hilo and Akaka soils and the place of the soils on the continuum of weathering to bauxite.
- 1V. To relate the Hilo and Akaka soils to other soils of the world that have developed from volcanic ash.



Figure 1: Profile of Mauna Kea Mountain from Hilo Bay, Hawaii.

REVIEW OF LITERATURE

The Geologic Setting:

The Hilo and Akaka soils are found on the eastern slopes of Mauna Kea mountain on the island of Hawaii, the youngest and largest island of the Hawaiian Archipelago.

Mauna Kea is a volcanic dome covering 919 miles and reaching a height of 13,784 feet above sea level, Figure 1. The eastern coastal region has a drop of 500 feet per mile and is dissected by many narrow, deep erosional valleys.

The base rock of the mountain consists of two volcanic series. The older Hamakua Volcanic Series consists of olivine basalt with thin beds of vitric basaltic ash between some of the flows. Some andesite is also present in the upper members (Stearns, 1946). The second series is dominated by andesite and is designated as the Laupahoehoe Volcanic Series.

With the exception of the erosional valleys the eastern slope of Mauna Kea is nearly completely covered with weathered volcanic ash resting uncomfortably on the flow units.

There has been some question on the exact origin and character of the volcanic ash of the Hamakua coast due to this weathering and its effect on the diagnostic properties of ash.

Wentworth (1938) has stated that the production of numerous cones of fine pyroclastic material is commonly associated with the final stages of activity of a great volcanic dome.

This was true with Mauna Kea dome and the summit area has over a hundred cones ranging in size from a hundred feet high to nearly a thousand feet. These cones cover an area equivalent to 15 miles in diameter. In addition, there are a few cones on the lower slopes consisting of volcanics from the earlier Hamakua Volcanic Series. These cones include the small cones just outside of Hilo as well as the larger cones at Pepeekeo, (Figure 2a and b).



Figure 2a: Low lying cinder cone at Pepeekeo with Mauna Kea summit in background.



Figure 2b: Aerial view of cluster of cinder cones at Pepeekeo with Mauna Loa summit in background.

The ash associated with the summit cones was called the Waiau Formation by Wentworth (1938) to differentiate the Mauna Kea pyroclastic material from the more recent Pahala Ash covering a large portion of the southwestern section of the Island of Hawaii. The Waiau Formation takes its name from the small summit lake on Mauna Kea and the Pahala Ash from the town named Pahala in Kau.

The Waiau Formation includes the summit area material as well as the highly weathered and altered ash covering the Hamakua coastal area. A sub-designation was given to the weathered material, " yellow tuff phase " and the bedding of the weathered materials was attributed to rather gradual transitions in coarseness of the material as it was deposited. These differences are continuous and uniform over long distances parallel to the bedding and support the contention that the ash of the slopes of Mauna Kea originated from the summit cones.

Stearns (1946) proposed basically the same mode of formation and origin of the ash on Mauna Kea, but preferred to use the Pahala Ash designation for all the ash found on the south and east sides of the island of Hawaii.

The black ash of the upper slopes was found to be andesitic glass derived from the cones of the Laupahoehoe Volcanic Series on the summit. On the lower sections of the mountain both the ash and lapilli were found to be altered to palagonite, a yellowish-brown to orange colored, waxy, silica jel mineraloid. Late Pleistocene to early Upper Pleistocene age was given to the ash with the acknowledgement that the material in many sections has had contributions of pyroclastic material from Mauna Kea and Kilauea from its time of origin until present (Stearns, 1946).

In the Hamakua coast area the Pahala (Waiau) ash range in thickness from 10 to 15 feet at Hilo and thins to 5 to 6 feet thick at Ookala, 30 miles to the northwest. It thickens to over 20 feet at the 2,000 to 3,000 foot elevations above Hilo and is proportionately thicker above Ookala (MacDonald, 1945). In some areas there is evidence of ash of

different ages present but it is impossible to distinguish any differences in the weathered material on the lower eastern slopes (Stearns, 1946).

The pattern of thickness variation towards the northwest of Hilo has led Fraser (1960) to propose that the ash of the entire area surrounding Hilo and the Hamakua coast comes from Kilauea Volcano with only small contributions from the summit cones of Mauna Kea.

The Climatic Setting:

Although Hawaii's climate is influenced by the factors of geologic location in the Pacific Ocean, latitude, and the topography and elevation of the respective islands, only the last factor is of importance when characterizing soil in a specific location or area.

The Hamakua coast of the Island of Hawaii is situated on the windward eastern side of Mauna Kea mountain and receives from 100" of rainfall at Ookala up to 150" of rainfall per year at Hilo. These amounts increase as elevations are increased so that the annual rainfall approaches 300" at the 1,500 to 2,000 foot elevations above Hilo. Above this maximum the rainfall gradually tapers off to less than 20" at the summit of Mauna Kea. Much of the summit precipitation comes in the form of snowfall between the months of November and May.

This pattern of increase and subsequent decrease of rainfall with increasing elevation is common to the higher mountains in Hawaii. It is due to the splitting effect that the mountains have on the rain-bearing tradewinds (Cline, 1955) and a temperature inversion layer occurring at approximately 2500 feet above sea level (Swindale, 1964).

Temperatures in Hilo range from a lowest monthly mean of 70.4 °F to a highest monthly mean of 75.4 °F. Annual mean temperature is 72.8 °F. Day to night variations in Hilo are of the magnitude of 10°F.

Mean temperatures generally fall between 2.5 and 3.0 °F per 1,000 foot increase in elevation. At Lake Waiau, on the summit of Mauna Kea volcano, the nightly temperature falls below 32 °F without exception.

- During the Wisconsin glacial period a glacier of up to 250 feet thick covered the summit of Mauna Kea as shown by moraines and other signs of glaciation as far down as the 10,500 elevation (Stearns, 1946).

The prevailing winds on the Hamakua coast are northeasterly trade-winds but high altitude winds can be quite variable.

The rainfall pattern in the Hamakua coast is quite uniform, with no prolonged periods of dryness, although northwest of Ookala periodic late summer dry periods are known to occur.

The Weathering of Volcanic Ash:

Volcanic ash is classified geologically by its size, crystallinity, and composition (Wentworth, 1938).

- a. Grain size: 4 to $\frac{1}{2}$ mm - coarse ash
 less than $\frac{1}{2}$ mm - fine ash
- b. Crystallinity: lacks crystallinity - vitric
 mostly crystalline - crystalline
 mostly stony - lithic
- c. Composition: Named according to the rock name of corresponding chemical composition

These properties, along with that of porosity, contribute to the capacity factors of chemical weathering of volcanic ash.

The intensity factors such as climate, drainage, vegetation, and time affect the extent and rate of its weathering (Sherman, 1962).

Volcanic ash, possibly more rapidly than any other soil forming material, interacts through chemical weathering and biological forces to form the weathering product - volcanic ash soil.

Allophane Formation:

Mohr (1944) examined soils developed from vitric basic volcanic ash in Indonesia and found that the material is very easily attacked by weathering liquids. Under conditions of high rainfall and temperatures

above 25 °C hydralysis occurs very rapidly with the pH of the system stabilizing around a pH of 7.0. Under these conditions the silica goes into solution, iron forms a hydrated gel, potassium feldspar develops into a kaolinitic gel and calcium feldspar weathers to hydrated aluminum oxide.

This appears to correspond to the formation of palagonite, a silicate mineraloid gel of variable composition (Hart, 1929).

With continued weathering some of the silica freed from the system is removed and the kaolinitic gel, allophane, develops as a logical step in the weathering sequence of andesite ash (Hendricks, 1966).

Many proposals have been put forth on the formation of allophane, but to date no good definition has been given regarding the limits of its composition and character.

From Ross and Kerr's (1934) original work, allophane has been accepted as any mutual solution of silica, aluminum, and water, with minor amounts of bases. White (1953) broadened this to include all amorphous substances associated with clay minerals, a move that did not preclude non-silicate containing materials. Grim (1953) describes allophane simply as a random arranged tetrahedral silica and octohedral aluminum with variable water in solution rather than bonded water.

More recently, while little attention has been given to the chemical nature of allophane (Marshall, 1964), there is evidence to support limiting the term allophane to those amorphous arrangements of silica and alumina to silica/alumina mole ratios between 1 and 2 (Birrel and Fieldes, 1952; Swindale, 1965; and Yoshinaga, 1966). This range includes both soil and geologic allophanes, although some high aluminum allophanes have been reported with ratios below one (Tan, 1961; and Snetsinger, 1967).

Bates (1952, 1960, and 1962) found allophane to be an intermediate amorphous product in the breakdown of halloysite and in the formation of gibbsite in the weathering sequence:



The weathering conditions would determine whether an aluminum gel or allophane would form.

The sequence kaolinite to allophane to alunite was studied by Keller (1967) in Pennsylvanian shale due to silica removal by supergene sulfate weathering liquids, but the allophanes formed in non-volcanic ash materials are beyond the perview of this thesis.

In New Zealand, Fieldes and his co-workers have been studying the problem since 1952. They have found that volcanic glass goes quickly through the weathering stages to allophane (Fieldes and Swindale, 1954). With continuing silica removal kaolinite or gibbsite may form, but under conditions of silica addition and wetting and drying montmorin clays may develop. Two different types of allophane are commonly reported in New Zealand, allophane A and allophane B. An intermediate allophane is also recognized, AB.

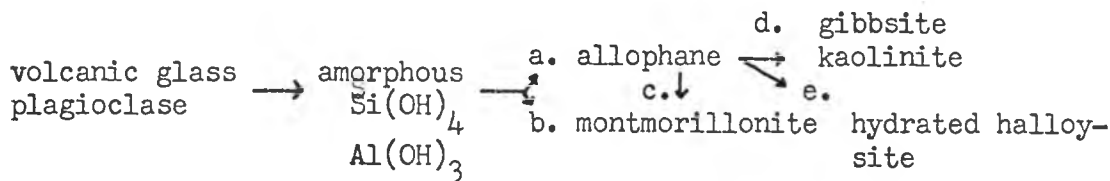
Allophane B is a fine grained mixture of discrete silica and aluminum. With continued wetting and drying this material increases in grain size and order. Still amorphous X-ray, this is allophane A. The sequence may then proceed through various stages of kaolinitic mineral formation such as; hydrated halloysite, halloysite, and under some conditions, kaolinite itself (Fieldes, 1954).

Hydrous feldspar, hydrous glasses, hydrogels and other amorphous materials are recognized as being in the allophanic weathering realm (Furkert and Fieldes, 1968).

Allophane is also considered to be an early weathering product in the volcanic ash soils of Japan (Sasaki, 1957). Plagioclase and vitric pumice break down to form silica, alumina, and iron oxide sols. The alumina sol can become gibbsite or by absorbing silica sol, in a weak acidic environment of pH 6 to 7, allophane. By releasing alumina or absorbing more silica sol the allophane becomes hydrated halloysite. The iron oxide sol in turn may form goethite.

Egawa (Japanese Ministry of Agri. and Forestry, 1964) has further refined this sequence from the work of his co-workers (Sudo, 1959;

Kanno, 1955 and 1962).



- where:
- a. indicates isoelectric co-precipitation
 - b. indicates base rich impeded drainage
 - c. indicates base rich, silica rich impeded drainage
 - d. indicates strong acid conditions with silica and bases absent and isolated silica reacts with gibbsite to form kaolin minerals
 - e. indicates silica rich, base poor water perculating through allophane to form hydrated halloysite

More recently (Miyauchi and Aomine, 1966) a relatively high alumina amorphous gel has been found in the Imogo soil in Japan. Taking its name from the soil name, imogolite has a silica, alumina mole ratio of near one. Wada (1967 and 1968), Yoshinaga (1968), and Kanno (1968) have since characterized it as being a precursor to allophane and have indicated that aluminum in 6 coordination would change to an average of 5 coordination upon dehydration, and be further changed to four coordination by dehydroxylation.

Kanno (1968) also found that the chain structured imogolite is best separated by acid dispersion while allophane is dispersed under alkali conditions.

In Hawaii it has become quite clear that the weathering of volcanic ash follows the sequence:

ionic system → amorphous system → cryptocrystalline system → crystalline clay

(Sherman, 1962, 1967).

After originally placing allophane at stage 11 of their numerical weathering sequence (Jackson and Sherman, 1953), Jackson (1968) and Sherman (1967) have both concluded that allophane should be placed at

stage 10 with the kaolin minerals on the weathering sequence. This recognizes the ability of allophane to weather to gibbsite (Sherman, 1958).

It has been proposed that a distinction should be made between sesquioxide allophane of relatively low silica to alumina mole ratio and halloysitic allophane with a chemical formula corresponding to the kaolin minerals (Jackson, 1965).

During the last few years the presence of allophane of various compositions has been reported throughout the world. Most of these occur in areas that have had some influence from volcanic ash.

Characteristics of allophane:

It has been well established that allophane and related amorphous hydrated oxides have a high reactivity in the soil. High cation exchange capacities, high phosphate fixing capacities, and marked changes due to dehydration have all been reported in conjunction with studies of allophane. In many cases it has been these phenomena along with the absence of crystalline clays that have led to the designation of allophane soils.

Amorphous soil clays with cation exchange capacities of over 100 mequivaleints per 100 grams soil have been reported (Fieldes, 1952; Rutherford, 1962; and Tan, 1965). Much of this cation exchange capacity is pH dependent (Tan, 1965; Fieldes, 1962; Hough, 1966; and Jackson, 1965 and 1968), and has led to the proposal for a semi-quantitative method of allophane determination, the cation exchange capacity delta value (Aomine and Jackson, 1959).

This value, the difference in cation exchange capacity determined at pH 7.0 of an acid pretreated sample and an alkali pretreated sample, can be used in mineral allocation as a measure of allophane content. The alkali pretreated sample has a net negative charge created by hydronium or proton release from the surface structure. This charge is measured at pH 7.0 as cation exchange. Pretreatment with acid buffered sodium

acetate completely restores the sites that had lost protons and eliminates a portion of the net charge as measured at pH 7.0 (Jackson, 1965).

The difference in measured cation exchange capacity of the sample pretreated in both ways is approximately 100 m.e. per 100 grams of soil for the sesquioxide allophane, but falls to 18 to 20 for the halloysitic allophanes (Jackson, 1965).

Charge characterization of allophane has been found difficult because of factors affecting its measured cation exchange capacity. Concentration of the leaching solutions, the nature of the saturating ion, and the strength and volume of the alcohol used have all contributed to nonreproducible results in some soils (Birrel and Gradwell, 1965).

The non-pH dependant or permanent charge of allophane is thought to be due to tetrahedrally coordinated aluminum (Fieldes, 1962; Swindale, 1965; and Hough, 1966). While 6 coordinated aluminum is neutral in charge, 4 coordinated aluminum has a negative charge. In synthetic silica and alumina systems, increasing the pH at the time of co-precipitation has been shown to increase both the cation exchange capacity and the tetrahedrally coordinated aluminum (Fripiat, 1964). Natural allophanes in Japan soils have been found to contain as high as 50 % tetrahedrally coordinated aluminum (Egawa, 1964).

This surface activity has been shown in some ways to correspond to the reactivity of amorphous aluminum silicate cracking catalysts used in the petroleum industry (Tamale, 1955 and Milliken, 1955).

The high buffering capacity shown by most allophanes can be attributed to the precipitation of $\text{Al}(\text{OH})_3$ from the exchange sites (Kanno, 1955).

Allophanes are also noted for their high water holding capacities, relationship with high humus contents in soils, and irreversibility of dehydration (Dames, 1955; Tan, 1965; Bates, 1962; and Sherman, 1958).

Many differentially soluble methods have been used for the separation and characterization of allophanes. Boiling carbonate (Jackson, 1958), oxalic acid and potassium oxalate (Harada, 1955), and 0.5 N

sodium hydroxide (Hashimoto and Jackson, 1960) have all met with some success.

The method of Hashimoto and Jackson is most promising at present, though the removal of silica and aluminum by it does not necessarily indicate the presence of allophane if gibbsite or other amorphous silica and aluminum materials are present in the sample (Hashimoto and Jackson, 1960) (Jenne, 1965).

Surface area measurements, electron diffraction studies, electron microscope studies, infrared adsorption, and moisture retention characteristics have also been used to characterize various allophanic materials from throughout the world (Fieldes, 1952 and 1955; Gradwell, 1954; Aomine, 1955 and 1968; Orchiston, 1959; Alonso, 1963; and Demumbrum, 1964).

Bauxite formation:

As weathering proceeds under conditions conducive to continued silica removal from volcanic ash, bauxitization can occur.

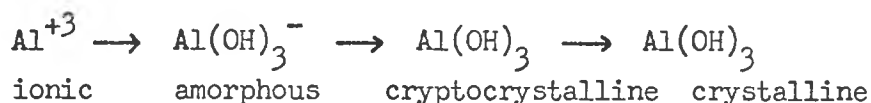
A delicate balance exists between the reactions involving the continued breakdown of allophane. If silica is present in the weathering solution, crystallization to halloysite can occur. If silica is absent or is being continuously removed, gibbsite may form (Jackson, 1968).

With fresh water, pH 6 to 6.5, silica is many times more soluble than aluminum so that in cases where water is abundant direct bauxitization may be the general rule (Keller, 1964). It results in crystalline products under wetting and drying, or as an amorphous hydrated alumina under continuously wet conditions (Sivarajasingham, 1962). Occurrence of direct bauxitization from feldspars has also been well documented (Abbott, 1958; Alexander, 1941; Edwards, 1955; Gordon, 1958; and Harrison, 1934).

Organic matter as well as sodium and potassium in solution tend to increase the solubility of silica in the process of weathering (Keller, 1965 and Ruxton, 1968). As a consequence, allophane and gibbsite or other hydrated oxides of aluminum can be found concurrently (Wada, 1966;

Besoain, 1964; and Glinka, 1927).

These hydrated aluminum oxides show a sequence of structural order similar to that found in allophane. Sherman has proposed the following scheme (Sherman, et al, 1967).



If silica enters into this reaction sequence at any point, resili-fication can occur, returning the system to the allophane - halloysite sequence explained earlier. This occurs at an H_4SiO_4 concentration in the weathering solution of 2 ppm. or above. Below this value kaolinite minerals would not be able to form and gibbsite or other aluminum hy-drated oxides would remain as a residual mineral (Garrels and Christ, 1965).

Weathering studies of the Hamakua coast area of Hawaii:

As early as 1898 the Hamakua coast area of the island of Hawaii gained recognition as being the site of extremely weathered volcanic ash soils. This weathering was attributed to the action of drainage waters high in sulfur dioxide originating from the surrounding sites of volcanic activity. Bauxite " of remarkable purity " (Maxwell, 1898) was found to exist in masses in the soil interlayered with material of markedly different color and composition.

Kelley (1915) and McGeorge (1917) worked with a few soil samples from the eastern coastal area of Mauna Kea, but took no special notice of the ash soils. Later, Richter (1931) and Dean (1937) took note of the high waterholding capacity, relatively high organic matter content, and irreversible drying of these soils.

In a review of the soils of Hawaii, Smith (1935) noticed the layering of the volcanic ash soils. He observed that bands of pumice or "scoria" (clinkery ash flows) were only partially weathered in the

"B" horizon of the soils, but that the breakdown of these bands was complete in the "C" horizon, (Figure 3). It was postulated that the lower layers had been subjected to a more prolonged effect of percolating groundwater because of the high porosity of the soils.

Later, more comprehensive and systematic studies were accomplished by Hough (1941) and Ayres (1943), but no special notice was taken of the distinctive layering of the soils formed from volcanic ash on the Hamakua coast.

It was then proposed that the hydrol humic latosols of the island of Hawaii (Cline, 1955) could develop distinctive stratification of the parent ash due to differential weathering that occurred very rapidly in the high rainfall, perhumid climate of the area (Sherman, 1949).

This concept was affirmed and the pumice layers that had been described by Smith were identified as horizons of aluminum concentration, segregation and aggregation into gibbsite (Sherman, 1957). This gibbsite may be found in tube sheetlike forms when the soil is dried, but little evidence usually exists for gibbsite when the soil is in its field moist condition, (Figure 4a and b).

Dehydration has a very marked effect on both the physical and chemical properties of the Akaka and Hilo soils. Shrinkage and water loss is irreversible as is a large portion of the cation exchange capacity. Losses of up to 75% of the CEC are reported (Kanehiro, 1956), and the soils smear under pressure due to the thixotropic nature of the colloids present.

Because of their high aluminum content numerous studies of bauxite potential in the Hawaiian Islands have included these soils in their perview.

Variable average amounts of gibbsite from a few percent to 35% have been reported in these soils (Tamura, 1955; Sherman, 1958; Tenma, 1965 and Bates, 1960). Reports of the total alumina content also vary considerably. The ore content has been reported from 17 to 22% aluminum oxide (Sherman, 1958 and Irving, 1961) to 26 to 27%



Figure 3: Banding of gibbsite in Hilo soil .



Figure 4a; Closeup of gibbsite band.



Figure 4b; Aggregated gibbsite separated from gibbsite band.

(Calhoun, 1962).

Although low in grade, the 150 to 200 square miles of hydrol humic latosol has been shown to contain sufficient ore to support an aluminum industry if economic conditions were satisfactory. Benefication of the ore may be possible due to the separation of gibbsite into relatively pure aggregates upon drying (Sherman, 1958).

Low amounts of kaolin minerals may be present (Tanada, 1950; Dean, 1947; and Tamura, 1953). Larger amounts of mica, quartz, magnetite, maghemite, anatase and possibly lepidocrocite are also found (Tamura, 1953).

The present classification of the Akaka and Hilo soils:

The Akaka soil is classified under the U.S.D.A. Soil Classification System - the Seventh Approximation (1967) as a member of the thixotropic, isomesic family of typic hydrandepts and the Hilo soil as a member of the thixotropic isohyperthermic family of typic hydrandepts.

The hydrandepts belong to the inceptisol order of mineral soils having umbric or histic epipedons. The umbric epipedon is a dark colored, acid surface horizon that has less than 50% base saturation. The histic epipedon is a peaty, water saturated surface horizon found on some soils. Both the Hilo and Akaka soils have umbric epipedons, although some of the Akaka soils found in depressional areas could be expected to have histic surface horizons. They do not have horizons of iron and humus accumulations as are found in podzolic soils, and they should not contain horizons of low cation exchange capacity sesquioxide accumulations.

The order level of these soils is the andept soils. They are developed generally from volcanic ash or ash pumice and contain a high allophane content in their clay fractions or a high unweathered ash content in their sand and silt fractions, or both. Bulk density of the andepts are less than .85 grams per cubic centimeter in the surface or the elluviated subsurface and are moderately well drained to well drained.

The hydrandepts great group have clays that dehydrate irreversibly into gravel sized aggregates and have moderate to warm soil temperatures.

The typic subgroup designation of these soils indicates they are deep soils that follow the norm ~~from~~ the concept of the soils at the family level of classification the thixotropic designation indicates that the colloids are smeary or possess thixotropic properties. Isomesic and isohyperthermic indicate uniform year round temperatures that are moderate (59 to 72 °F) to warm (72 °F and above), respectively.

These are basically the properties that have been described in the soil survey of Hawaii (Cline, 1955) for the hydrol humic latosols, but put in terms of the present classification scheme.

THE SOIL SITES

The Hilo soil has been entirely devoted to sugar cane production for the past 100 years. It is situated on the lower slopes of Mauna Kea at elevations of from sea level to 2400 feet and covers 58,600 acres.

The Akaka soil is situated on higher elevations from 800 to 6000 feet. Because of dense cloud cover over most of the Akaka soil area and its depressing effect on sugar cane yields, it has been left largely to forest. The Akaka extends over 196,400 acres (Cline, 1956). Figure 5 show the extent of the two soils.

The dominant species in the rainforest areas is ohia lehua (Metrosideros collina), with some areas of native koa (Acacia koa) and introduced eucalyptus (Eucalyptus sp.). Guava (Psidium guayava), fern (Cyclosorus sp.), staghorn fern and treefern (Cibotium sp.) make up the ground cover throughout most of the forested area.

Previous to cultivation of sugar cane the lower slopes were covered with rainforest similar to that of the upper slopes at present (Ayres, 1943).

The following are detailed sample site descriptions.

Colors are according to the notation of Munsell and textures are apparent field textures. Sample locations of the eight profiles and the geology of the Hamakua coast are shown in Figure 6.



Figure 5: Topographic map showing extent of Akaka and Hilo soil areas in relation to the Northeast coast of Hawaii, (A, Akaka; H, Hilo).

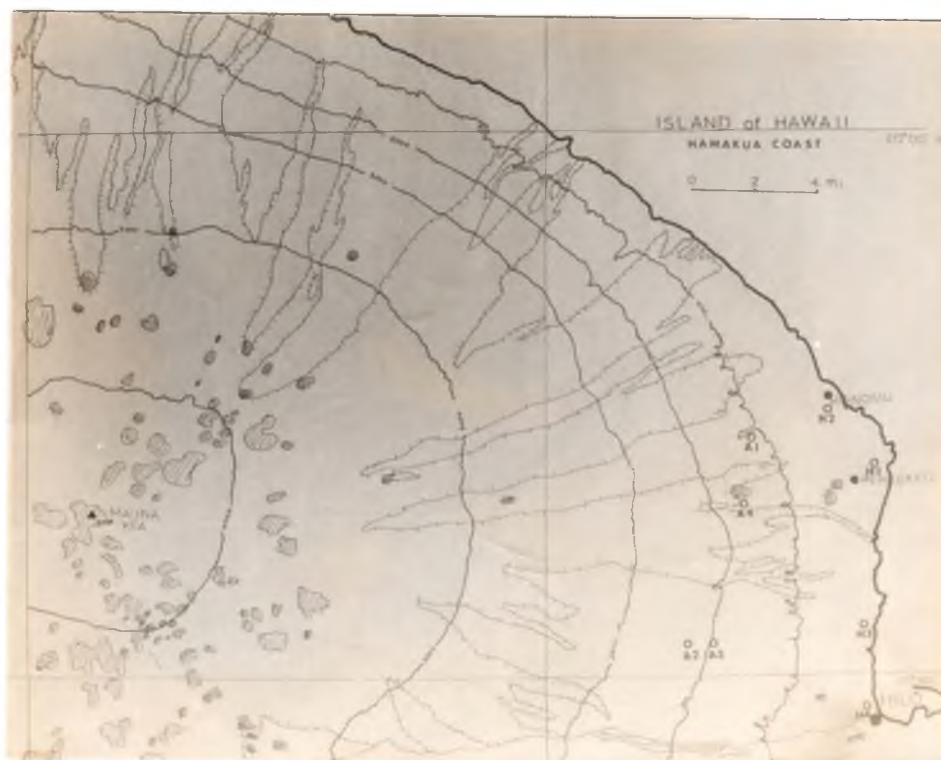






Figure 6: Geology of the eastern coast of Mauna Kea with sampling sites designated.

- | | | |
|--|-------|---|
| Hilo sites | ————— | H |
| Akaka sites | ————— | A |
| Laupahoehoe volcanic series | ————— |  |
| Laupahoehoe volcanic series cinder cones | ————— |  |
| Hamakua volcanic series | ————— |  |
| Hamakua volcanic series cinder cones | ————— |  |

Akaka soil sites and profile descriptions:

Site A-1:

Ap	0-13"	Dark brown (7.5YR 3/4) loam, friable when moist, slightly plastic when wet, with medium, moderately well developed granular structure, pH 4.6.
B2	13-20"	Yellowish red (5 YR 4/6) silty clay loam, friable when moist, plastic when wet, slightly smeary, with medium, moderate, subangular blocky structure, pH 5.1.
11 A1	20-28"	Red (2.5YR 4/6) silty clay loam, friable, slightly plastic when wet, moderately smeary, medium, moderate, subangular blocky, pH 5.1.
11 B2	28-36"	Strong brown (7.5YR 5/4-4/4) silty clay loam, friable, plastic, slightly smeary, with fine, weak subangular blocky structure, pH 4.9.
111 A1	36-47"	Strong brown (7.5YR 4/4) silty clay loam. Firm when moist, plastic, with fine, weak subangular blocky structure, pH 5.2.
111 B21	47-52"	Reddish brown (5YR 4/4) silty clay loam, moist friable, plastic when wet, slightly smeary, with moderately developed, medium subangular blocky structure, pH 5.2.
111 B22	52-59"	Dark brown (10YR 3/3) silty clay loam with moderate, medium subangular blocky structure. Friable when moist, plastic when wet, slightly smeary, pH 5.6.
111 B23	59-68"	Yellow red (5YR 4/6) clay loam, friable when moist, slightly plastic, moderately smeary, with weak, medium subangular blocky structure. Contain massive dark red (2.5YR 3/8) gritty clay loam inclusions with brownish yellow (10YR 6/8) gibbsite aggregates, pH 5.8.
1V A1	68-74"	Reddish brown (5YR 4/4) silty clay loam, friable when moist, slightly plastic, moderately smeary, medium, moderately subangular blocky structure, pH 5.6.
1V B21	74-83"	Reddish brown (5YR 4/5) silty clay loam, friable, slightly plastic, moderately smeary, weak, medium subangular blocky structure, pH 5.6.
1V B22	83-89"	Yellowish red (5YR 4/6) light clay loam, friable slightly sticky, moderately smeary, medium, moderate subangular blocky structure, pH 5.6.
1V B23	89-96"	Reddish brown (5YR 4/4) silty clay loam, firm,

Plastic, slightly smeary, with medium, well developed subangular blocky structure, pH 5.6.

V A1 96-106" Red (2.5YR 4/6) silty clay loam, firm, slightly sticky, moderately smeary, with weak, medium subangular blocky structure, pH 5.6.

Site A-1 is located approximately $\frac{1}{2}$ mile below the Akaka Falls State Park parking lot. The site is a convex slope on rolling topography at 1200 feet elevation just off the paved road to Akaka Falls.

Mean annual rainfall is 284 inches per year. The lithic contact is at 150 inches. Vegetation is sugar cane.

Site A-2:

A1	0-10"	Dark reddish brown (5YR 3/3) silty loam, slightly sticky when wet, with fine, moderately developed granular structure, pH 3.9.
B21	10-18"	Yellowish red (5YR 4/6) silty clay loam, slightly plastic when wet, moderately smeary, firm when moist, with fine, moderately strong subangular blocky structure, pH 5.1.
B22	18-26"	Reddish brown (5YR 4/4) silty loam, slightly plastic when wet, firm when moist, moderately smeary, with moderate, medium subangular blocky structure, pH 5.3.
B23	26-37"	Yellowish red (5YR 4/6) light silty clay loam, smeary, slightly plastic when wet, firm when moist, with medium, moderate subangular blocky structure, pH 5.7.
B24	37-42"	Dark brown (10YR 3/3) silt loam, friable when moist, slightly sticky, slightly smeary when wet, with weak, fine subangular blocky structure, pH 5.7.
11 A1	42-48"	Yellowish red (5YR 4/6) loam, sticky when wet, slightly smeary, with fine, moderate subangular blocky structure, pH 5.8.
11 B2	48-52"	Yellowish red (5YR 4/6) loam with massive inclusions of dark reddish brown (2.5YR 3/4) gritty loam. Slightly sticky when wet, friable when moist with massive structure, pH 5.9.

111 A1	52-64"	Reddish brown (5YR 4/4) light silty clay loam, firm when moist, slightly sticky when wet, moderately smeary, with fine, moderate, subangular blocky structure, pH 5.8.
111 B21	64-69"	Yellowish red (5YR 4/6) silty loam, slightly sticky when wet, moderately smeary, with moderate, medium subangular blocky structure, pH 5.8.
111 B22	69-80"	Brown (7.5YR 4/4) silt loam. Slightly plastic when wet with massive structure, pH 5.4.
1V A1	80-90"	Reddish brown (5YR 4/4) silty clay loam, slightly plastic when wet, moderately smeary, with fine, moderate subangular blocky structure, pH 5.7.
1V B21	90-99"	Brown (7.5YR 4/2) silty clay loam, slightly plastic when wet, moderately smeary, with medium, moderate subangular blocky structure, pH 5.5.
1V B22	99-106"	Yellowish red (5YR 4/6) silty loam, slightly sticky when wet, moderately smeary, with fine, weak subangular blocky structure, pH 5.8.
V A1	106-116"	Brown (7.5YR 4/4) silty clay loam, slightly plastic when wet, moderately smeary, fine, moderate subangular blocky structure, pH 5.7.

Site A-2 is located at the upper end of Kaiwiki road 0.3 miles above site A-3 at an elevation of 2000 feet. It is located on a convex slope and rolling topography with a slope of 5 %. Roots and pores are common throughout the profile.

The lithic contact is greater than 180 inches. Rainfall is 300 inches per year. Native rainforest is the common vegetation.

Site A-3:

A1	0-16"	Dark brown (7.5YR 3/2) loam, friable when moist nonplastic, slightly smeary with fine moderately developed granular structure, pH 4.9.
B21	16-30"	Yellowish red (5YR 4/6) clay loam, friable when moist, plastic, slightly smeary with fine, moderate subangular blocky structure, pH 5.6.
B22	30-32"	Very dark grayish brown (10YR 3/2) loam, firm when moist, slightly plastic, moderately smeary,

		with medium, moderate subangular blocky structure, pH 5.7.
B23	32-48"	Yellowish red (5YR 4/6) silty clay loam, very firm when moist, plastic when wet, slightly smeary, with fine moderate subangular blocky structure, pH 5.7.
B24	48-56"	Dark brown (10YR 4/3) silty clay loam, firm, plastic, slightly smeary, with fine, moderate subangular blocky structure, pH 5.6.
11 A1	56-61"	Dark brown (7.5YR 4/2) silty clay loam, firm when moist, plastic, slightly smeary, with medium, moderate subangular blocky structure, pH 5.7.
11 B2	61-65"	Dark reddish brown (2.5YR 3/4) gritty silt loam, with darker reddish brown (2.5YR 2/4) gritty loam inclusions. Friable when moist, sticky when wet, smeary, with fine, weak subangular blocky structure, pH 5.9.
111 A1	65-72"	Dark brown (10YR 4/3) loam with dark grayish brown (10YR 4/2) inclusions. Slightly aticky, friable, moderately smeary, with medium, weak subangular blocky structure, pH 5.9.
111 B2	72-79"	Dark reddish brown (2.5YR 3/4) gritty silty clay loam with darker (2.5YR 2/4) gritty inclusions as in 11 B2, pH 5.8.
1V A1	79-90"	Dark reddish brown (5YR 3/4) clay loam, friable, slightly plastic, moderately smeary with fine, moderate subangular blocky structure, pH 6.0.

Site A-3 is located on Kaiwiki road at an elevation of 1719 feet where the road crosses Kaiwiki stream. Topography is rolling and the soil has numerous pores and roots throughout. The rainfall is 280 inches per year and the lithic contact is 150 to 170 inches. Vegetation consists of native rainforest.

Site A-4:

A1	0-6"	Dark brown (7.5YR 3/4) loam, friable, slightly plastic, slightly smeary, with fine weak subangular blocky structure, pH 4.4.
B21	6-17"	Dark grayish brown (10YR 3/3) loam, friable, slightly plastic, slightly smeary, with medium weak subangular blocky structure, pH 4.3.
B22	17-24"	Dark brown (7.5YR 3/4) loam, friable when moist,

		nonplastic, moderately smeary, with fine, weak subangular blocky structure, pH 4.3.
B23	24-29"	Brown (7.5YR 4/2) silt loam, friable, nonplastic, moderately smeary, with fine, weak subangular blocky structure, pH 5.2.
B24	29-33"	Brown (7.5YR 4/4) clay loam, firm, slightly plastic, slightly smeary, with medium, moderate subangular blocky structure, pH 5.5.
B25	33-36"	Very dark grayish brown (10YR 3/2) loam, friable when moist, slightly sticky, moderately smeary, with medium, weak subangular blocky structure, pH 5.8.
11 A1	36-42"	Yellowish red (5YR 4/6) silt loam, friable, nonplastic, smeary, with medium, moderate subangular blocky structure, pH 5.6.
111 A1	42-47"	Yellowish red (5YR 4/6) silt loam, friable, nonplastic, smeary, with medium, moderate subangular blocky structure, pH 5.6.
111 B21	47-56"	Reddish brown (5YR 4/4) silty clay loam, friable, slightly plastic, slightly smeary, with fine, moderate subangular blocky structure, pH 5.6.
111 B22	56-8-"	Brown (7.5YR 5/4) silty clay loam, firm when moist, slightly plastic, slightly smeary, with medium, moderate subangular blocky structure, pH 5.6.

Site A-4 is situated just inside the forest reserve area 4 miles due west of Pepeekeo at 1750 feet elevation. Annual rainfall is 260". The site is on a gently sloping area with good drainage. Roots and pores are common throughout. The lithic contact is over 120 inches. The vegetation is introduced eucalyptus forest.

Hilo soil sites and profile descriptions:

Site H-1:

Ap	0-15"	Dark brown (7.5YR 3/4) clay loam, friable when moist, plastic, with weak fine granular structure, pH 4.5.
B21	15-38"	Yellowish red (5YR 5/6) silty clay loam, firm, plastic, slightly smeary with medium strong subangular blocky structure, pH 6.0.
B22	38-60"	Dark brown (7.5YR 3/4) silty clay loam, firm, plastic, slightly smeary, with medium, weak subangular blocky structure, pH 6.0.
B23	60-62"	Dark red (2.5YR 3/6) silt loam, firm, slightly plastic, moderately smeary, with medium, strong subangular blocky structure, pH 6.0.
11 A1	62-65"	Reddish brown (5YR 4/4) silty clay loam, friable, plastic, with medium, moderate subangular blocky structure, pH 6.0.
11 B2	65-72"	Red (2.5YR 4/6) clay loam, friable, slightly sticky, smeary, with medium, weak granular structure, pH 6.3.
111 A1	72-77"	Strong brown (7.5YR 4/6) silty clay loam, firm, plastic, with medium, strong subangular blocky structure, pH 6.3.
111 B21	77-83"	Brown (7.5YR 4/4) silty clay loam, firm, slightly plastic, moderately smeary with medium, moderate subangular blocky structure, pH 6.0.
111 B22	83-85"	Dark reddish brown (5YR 3/4) clay loam, friable, slightly sticky, smeary, with medium, weak subangular blocky structure, pH 6.1.
1V A1	85-90"	Brown (7.5YR 4/4 - 3/4) silty clay loam, firm, slightly plastic, with medium, strong subangular blocky structure, pH 6.2.
1V B21	90-93"	Brown (7.5YR 4/4) silty clay loam, firm, plastic, with medium, moderate subangular blocky structure, pH 6.0.
1V B22	93-102"	Brown (7.5YR 4/2) silty clay loam, firm, plastic, with medium, weak subangular blocky structure, pH 6.0.
1V B23	102-110"	Brown (7.5YR 4/4 - 5/4) silty clay loam, firm, slightly sticky, non-smeary, medium, moderate subangular blocky structure, pH 5.5.

The H-1 site is located 9.4 miles north of Hilo off highway 19. It is adjacent to the main northern cane hall road to Pepeekeo mill about 0.2 mile below the highway at an elevation of 170 feet. Annual rainfall is 125 inches per year. The site is on slightly rolling topography with 3 % slope. Lithic contact is 110 inches. Roots and pores are common throughout.

Site H-2:

Ap	0-16"	Dark brown (10YR 4/3) clay loam, friable when moist, slightly plastic, medium, fine subangular blocky structure, pH 4.6.
B21	16-31"	Strong brown (7.5YR 5/6) clay loam, friable, slightly plastic, slightly smeary, with medium, moderate subangular blocky structure, pH 5.8.
B22	31-39"	Strong brown (7.5YR 4/6) silty clay loam, firm, slightly sticky, smeary, medium, moderate subangular blocky structure, pH 5.9.
11 A1	39-43"	Brown (7.5YR 4/4) silty clay, firm, plastic, slightly smeary, with medium, moderate subangular blocky structure, pH 6.1.
11 B21	43-46"	Brown (10YR 4/3) clay loam, firm when moist, slightly plastic, slightly smeary, medium, moderate subangular blocky structure, pH 6.2.
11 B22	46-49"	Brown (7.5YR 4/4) silty clay loam, friable, slightly plastic, slightly smeary, medium, moderate subangular blocky structure, pH 6.4.
111 A1	49-54"	Strong brown (7.5YR 4/6) silty clay loam, friable, plastic, with fine, moderate subangular blocky structure, pH 6.6.
111 B2	54-60"	Yellowish red (5YR 5/8) silty clay loam, friable, slightly plastic, with moderate, fine subangular blocky structure, pH 6.7.
1V A1	60-65"	Strong brown (7.5YR 4/6) silty clay loam, friable, slightly plastic, slightly smeary, with moderate, medium subangular blocky structure, pH 6.5.
1V B21	65-68"	Yellowish red (5YR 5/6) silty clay loam, friable when moist, plastic, slightly smeary, medium, moderate subangular blocky structure, pH 6.5.

1V B22	68-73"	Dark reddish brown (5YR 3/4) clay loam with inclusions of brown (7.5YR 5/4) clay loam, friable when moist, slightly plastic, slightly smeary, with fine, weak subangular blocky structure, pH 6.5.
1V B23	73-75"	Red (2.5YR 4/6) clay loam, friable, slightly smeary, slightly plastic, medium fine subangular blocky structure, pH 6.6.
V A1	75-95"	Strong brown (7.5YR 4/4 - 5/4) silty clay, friable when moist, plastic, medium, moderate subangular blocky structure, pH 6.3.

The H-2 site is located on the Hilo side of the road to Akaka Falls park on Hawaii Highway 19. Elevation is 150 feet and the rainfall is 140 inches per year. The vegetation is sugar cane. Lithic contact is at 110 inches. Roots and pores are common throughout.

Site H-3:

Ap	0-18"	Dark brown (7.5YR 3/3) clay loam, friable, medium, fine subangular blocky structure, pH 5.0.
B21	18-22"	Dark reddish brown (5YR 3/4) silty clay, friable when moist, plastic, slightly smeary, medium, fine subangular blocky structure, pH 5.7.
B22	22-30"	Dark brown (7.5YR 3/4) silty clay loam, friable when moist, plastic when wet, slightly smeary, moderate, fine subangular blocky structure, pH 6.1.
B23	30-40"	Reddish brown (5YR 4/4) silty clay loam, firm, plastic, slightly smeary, medium, moderate subangular blocky structure, pH 6.3.
11 A1	40-61"	Dark brown (7.5YR 3/4) silty clay loam, firm, plastic, moderately smeary, moderate, medium subangular blocky structure, pH 6.2.
11 B21	61-64"	Dark reddish brown (5YR 3/4) gritty silty clay loam, with dark brown (2.5YR 3/4) gritty loam inclusions. Slightly smeary, smeary, medium large subangular blocky structure, pH 6.3.
11 B22	64-68"	Dark brown (7.5YR 3/4) silty clay loam, plastic, medium, moderate subangular blocky structure, pH 6.2.
11 B23	68-73"	Yellowish red (5YR 4/6) silty loam, slightly

		plastic, slightly smeary, with moderate, medium subangular blocky structure, pH 6.4.
11 B23	73-77"	Dark reddish brown (2.5YR 3/5) silty clay loam, sticky, non-smeary, moderate, medium sized subangular blocky structure, pH 6.5.
111 A1	77-84"	Reddish brown (5YR 4/4) silty clay loam, plastic, moderate, medium subangular blocky structure, pH 6.3.
111 B2	84-87"	Red (2.5YR 4/6) clay loam, slightly plastic, with moderate, medium subangular blocky structure, pH 6.3.
1V A1	87-92"	Dark reddish brown (5YR 3/4) silty clay, non-plastic, smeary, fine granular structure, pH 6.4.
1V B21	92-96"	Dark reddish brown (2.5YR 3/4) gritty clay loam, non-plastic, slightly smeary, medium weak granular structure.
1V B21a	—	Brown (7.5YR 4/2) gritty clay loam inclusion in 1V B21.
1V B22	96-101"	Brown (7.5YR 4/3) silty clay, slightly sticky, slightly smeary, moderate, medium subangular blocky structure, pH 6.0.
1V B23	101-110"	Reddish brown (5YR 4/4) clay, plastic, non-smeary, moderate, medium subangular blocky structure, pH 6.3.

Site H-3 is located on the upper side of Hawaii Highway 19 between Onaamea and Hilo mills. Elevation is 200 feet and rainfall is 140 inches per annum. Pores and roots are common throughout and the lithic contact is 150 inches. Vegetation is sugar cane.

Site H-4:

Ap	0-8"	Dark brown (7.5YR 3/2) silty clay loam, friable when moist, plastic when wet, with fine, moderate granular structure, pH 5.6.
B21	8-11"	Reddish brown (5YR 4/4) silty clay, friable, plastic, with medium, moderate subangular blocky structure, pH 6.1.
B22	11-14"	Dark reddish brown (5YR 3/4) silty clay, friable, when moist, plastic, fine, weak sub-

		angular blocky structure, pH 6.2.
11 A1	14-23"	Dark brown (7.5YR 3/4) silty clay, friable, plastic, slightly smeary, medium, moderate subangular blocky structure, pH 6.2.
11 B21	23-27"	Dark reddish brown (5YR 3/4) silty clay, friable when moist, plastic when wet, slightly smeary, with moderate, medium subangular blocky structure, pH 6.1.
11 B22	27-34"	Brown (7.5YR 4/4) silty clay, friable, slightly plastic, medium, moderate subangular blocky structure, pH 6.3.
11 B23	34-36"	Dark red (2.5YR 3/6) silty clay loam, firm, fine, moderate subangular blocky structure, pH 6.2.
111 A1	36-40"	Dark reddish brown (5YR 3/4) silty clay, firm when moist, moderate, medium subangular blocky structure, pH 6.2.
111 B21	40-50"	Dark reddish brown (2.5YR 3/4) silty clay loam, friable when moist, with moderate, medium subangular blocky structure, pH 6.2.
111 B22	50-59"	Dark reddish brown (5YR 3/4) clay, friable when moist, fine, moderate subangular blocky structure, pH 6.2.
111 B23	59-61"	Dark reddish brown (2.5YR 3/4) silty clay, friable when moist, fine, weak subangular blocky structure, pH 6.1.
1V A1	61-70"	Dark reddish brown (5YR 3/4) clay, friable, fine, weak subangular blocky structure, pH 6.3.
1V B21	70-72"	Dark reddish brown (2.5YR 2/4) silty clay loam, friable, fine, medium subangular blocky structure, pH 6.1.
1V B22	72-74"	Very dark grayish brown (10YR 3/2) gritty clay loam, friable, non-plastic, medium, weak granular structure, pH 6.1.
1V B23	74-76"	Dark reddish brown (2.5YR 2/4) silty clay, friable, medium, moderate subangular blocky structure, pH 6.0.
V A1	76-86"	Dark reddish brown (2.5YR 2/5) silty clay, friable, medium, weak subangular blocky structure, pH 5.9.

Site H-4 is located south of Hilo mill on highway 19 at 100 feet elevation. Rainfall is 140 inches and the lithic contact is 150 inches.

METHODS

Sample selection and description:

Four profiles each of the Akaka and Hilo soil were chosen after careful study of the Hamakua Coast area and consultation with the Soil Conservation Service field staff.

At the time of collection a complete field description was taken according to the procedure of the U.S.D.A. Soil Conservation Service (Kellogg, 1951). The samples were placed in double plastic bags for shipment to the Manoa Campus of the University of Hawaii.

Sample preparation:

The freshly sampled field samples were gently pressed through a 10 mesh to the inch sieve and mixed thoroughly. They were then placed in quart screw cap glass jars with double plastic cover liners to prevent any drying from taking place.

Moisture determinations were taken initially and at intervals throughout the duration of the project to insure that no water loss had occurred. Samples were dried at between 100 and 110°C. The first samples dried were then ground to 100 mesh and stored in glass vials for subsequent analysis.

Unless noted otherwise, all sample analysis with the exception of the total silicate analysis was done on the field moist soil samples. All analysis with the exception of total silicate analysis was done in duplicate.

No particle size separation was attempted.

pH:

Soil pH was determined by glass electrode using a Beckman pH meter. Because of the high initial water content of the soil a 1 : 1 moist soil to water was used for both the H₂O and KCl pH determinations. All samples

were allowed to equilibrate at 25°C overnight.

The pH of selected samples was determined on the hydrated samples using a 1 : 5 soil to water ratio.

Organic matter:

Organic carbon was determined by the wet digestion Walkley and Black method (Piper, 1944). Organic carbon is oxidized by dichromate in the presence of concentrated sulphuric acid, which upon dilution provides the heat necessary for the oxidization of the organic matter contained in the soil.

A recovery factor of 77 % is used and the amount of organic matter is estimated by taking the amount of organic carbon and multiplying it by the factor 1.72.

Preliminary checks on the method using moist samples showed rather incomplete digestion and a failure of the aggregates to break up during the digestion process. Because of this, the 100 mesh oven dried sample was used for organic matter analysis.

Total nitrogen:

Total nitrogen was determined by the Kjeldahl method on the moist sample (Jackson, 1958).

Extractable iron oxide and associated H₂O:

Extractable iron oxide was determined by the method of Kilmer (1958). A 16 hour room temperature extraction with dithionate was modified to accomodate the larger amounts of iron oxides in tropical soils and the extraction time was lengthened to 24 hours. This was found necessary after preliminary studies showed additional iron being removed after the first 16 hours of extraction time. Longer times than 24 hours did not extract additional iron oxides.

The water associated with the extracted iron was calculated on the basis of loss of ignition of an organic matter free sample as compared to an organic matter free sample with its iron extracted. The value of 0.24 multiplied by the extracted oxide content was found on the average to give an approximation of the water content. The sum of the iron oxide and its associated water is equal to the $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ content of the soil.

Extractable phosphorus:

Phosphorus was extracted from the moist soil using 0.02 N sulphuric acid with 3 grams of ammonium sulfate per liter added. A 1:100 soil to extractant ratio was maintained and the extracted phosphorus was determined by the phosphomolybdate blue colorometric method (Jackson, 1958).

Total silicate analysis:

Loss on ignition was determined by weight loss on ignition of an oven dry, 100 mesh soil in platinum ware.

The samples were then fused with sodium carbonate (Kanehiro, 1965), and silica was determined gravimetrically on the double dehydrated silica from the fusion extract with hydrofluoric acid (Jackson, 1958).

Aluminum was determined gravimetrically by hydroxide precipitation after removing iron and titanium with cupferron (Jackson, 1958) and also by titration after complexing with EDTA (deLonguyen, 1958 and Swindale, 1961). Results of the two analysis agreed well.

Iron plus titanium was determined gravimetrically by cupferron separation and subsequent analysis of titanium by the colorimetric peroxide method (Jackson, 1958).

Calcium was determined by permanganate titration of the oxalate (Jackson, 1958).

The potassium iodate method was used to determine manganese.

Potassium was determined by flame photometer on a hydrofluoric acid digested sample. A few drops of sulfuric acid were added to the digest to prevent attack on the platinum crucible (Jackson, 1958).

Total phosphorus was determined on the HF digested sample using the vanadomolybdate yellow colorimetric method (Jackson, 1958).

Exchangeable cations:

Normal ammonium acetate adjusted to pH 7 was used to displace the exchangeable cations. Exchangeable calcium and magnesium were analysed for by atomic adsorption spectrophotometry following the procedures of the Beckmann Company. Lanthanum oxide was used to suppress interference in the calcium determination.

Exchangeable sodium and potassium were determined by flame photometry.

Cation exchange capacity:

Cation exchange capacities were determined using normal potassium acetate buffered at pH 7 to saturate the exchange complex. Samples were washed free of excess salts with alcohol and the potassium retained was replaced by ammonium ions added in normal ammonium acetate buffered at pH 7. The potassium released was determined by flame photometer (Swindale, 1952).

All saturation and washing was done with an International Model 11 centrifuge with Nalgene centrifuge tubes. A soil to extractant ratio of 1:20 was used. Mixing of the samples was accomplished by using a glass rod with a rubber disc attached to the end that would fit into the centrifuge tube. Gentle up and down movement mixed the hardest filter cake without fail and succeeded in thoroughly breaking down the structural aggregates in the samples so that complete exchange could be accomplished. Four washings with each of the reagents was used.

Routine care in keeping the soil extractant ratio and washing procedure constant gave reproducible results even when duplicates were run some days or weeks apart.

Sample pretreatment for cation exchange capacity experiment:

Pretreatment for the cation exchange capacity determinations included the moist samples untreated, dehydration at 100 - 110°C and ground to 100 mesh, peroxide treatment, and iron removal. The peroxide treated samples were found to contain less than 1 % organic matter. Analysis both before and after dehydration was done after washing the peroxide treated samples with water to remove extraneous salts.

Peroxide treated samples that had not been dehydrated were subjected to sodium dithionate - citrate - bicarbonate iron removal in preparation for determination of the cation exchange capacity delta value (Aomine and Jackson, 1959).

For determination of the cation exchange capacity delta value the organic matter free, iron oxide free samples were boiled for 5 minutes in 2 % sodium carbonate, washed with acetone, oven dried, weighed, and ground to 100 mesh.

Portions were then taken for boiling in normal sodium acetate buffered at pH 3.5 for 15 minutes. Similar portions were taken and boiled for 60 minutes in 2 % sodium carbonate. After these treatments the cation exchange capacity was determined by the previously outlined method using potassium as the exchanging cation. The resulting difference in cation exchange capacity between the acid (pH 3.5) and the carbonate treated sample is known as the cation exchange capacity delta value.

Cation exchange capacity was also determined on portions of the samples that had been readied for the delta value determinations but had not recieved the acid treatment or the hour long boiling in carbonate.

Finally, the exchange capacity of the moist samples with no pretreatment was determined with reagents Buffered at the average pH value of the samples analysed. In this case a pH of 5.6 was used.

X-ray diffraction analysis:

Random oriented powder samples of the samples that had been pre-

treated for the cation exchange capacity delta value determination were analysed using a Phillips - Norelco X-ray diffractometer with copper tube. Read-out was by chart at 2°2 θ per minute.

Differential thermal analysis:

Selected samples were analysed with the automatic D.T.A. apparatus manufactured by Stone. The CEC delta value samples were equilibrated at 52 % relative humidity and run from 30 to 1100°C at 10°C per minute using ignited alumina as reference.

Bulk density:

Bulk density as determined on paraffin coated clods. Apparent weight loss in water was corrected for the paraffin used and the weight per volume determined.

Particle density:

Particle density was determined on selected samples by picnometer after removing entrapped air from the sample by vacuum.

RESULTS

Morphology and soil pH:

The surfaces of both the Akaka and Hilo soils are dark brown to dark reddish brown with apparent field textures ranging from loam to silty loam in the Akaka soils to clay loam and silty clay loam in the cultivated Hilo soils.

These overlies sequences of dark brown to yellowish red subsoils and buried soils. No pattern could be found that conclusively related darker colors in the horizons with buried surface horizons. As a result, organic matter discontinuities were used to designate the buried soil sequences in both the Hilo and Akaka soils (Fig. 9 and 10).

When this criteria was used it was found that at the bottom of a sequence there is typically a reddish colored horizon that dehydrates to a yellowish red, very friable mixture of gibbsite aggregates and iron oxide. In many cases there is a darker colored horizon directly below this that can be seen to correspond to a buried "A" horizon.

The detailed descriptions have been presented earlier and show that this phenomenon is more common in the Hilo soils than the Akaka soils.

Figure 7 shows a typical Akaka profile. Horizons 11 B2 and 1V B22 are gibbsite horizons that show this distinctive dehydration. These are the "scoria" horizons of Smith (1935).

Figure 8 shows that B 23, 11 B2, and 111 B22 of the Hilo soil, site 1 also possesses these qualities. Also observable in the Hilo profile is a gray plastic clay that occurs as an upper weathered zone of the underlying basalt. This gray clay is common throughout the area of the Hilo and Akaka soils and is related to the weathered ash as a silica enriched zone promoting illite formation and serving as an impervious layer that promotes lateral drainage.

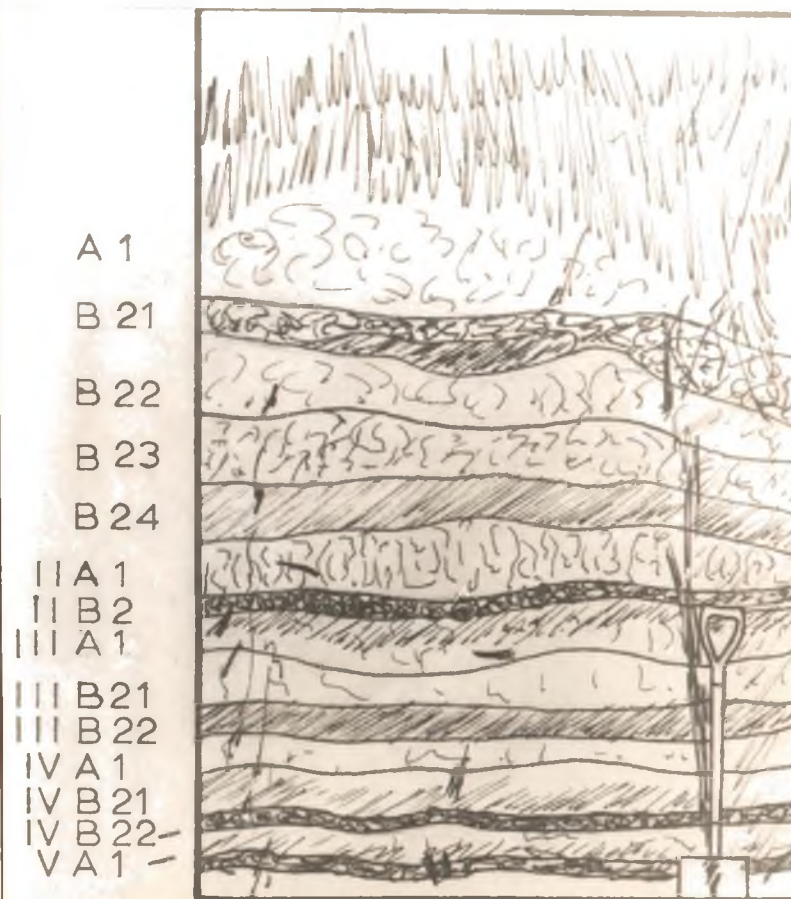


Figure 7: Profile of Akaka soil, site 2.

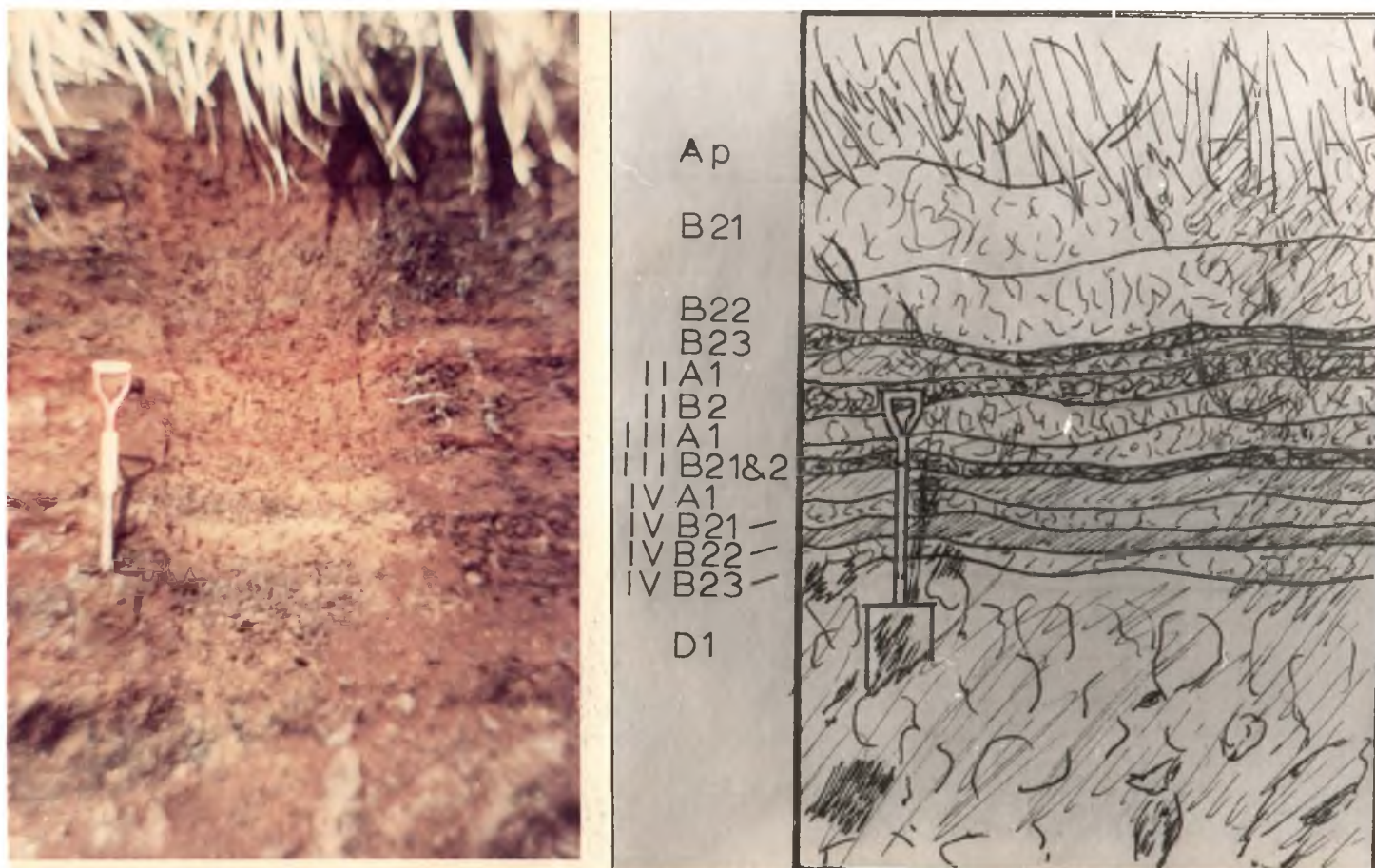


Figure 8: Profile of Milo soil, site 1.

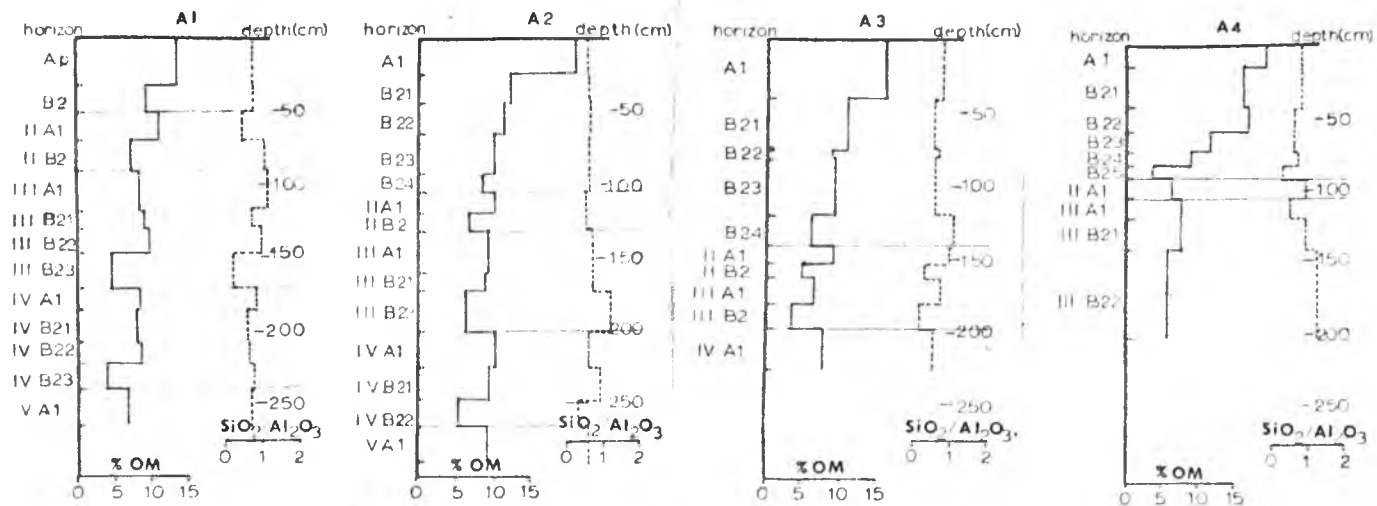


Figure 9: Schematic diagrams of organic matter contents and silica:alumina ratios of Akaka soils.

The Hilo profiles were sampled to this contact, but because of the relatively deeper material of the Akaka sites no attempt was made to sample to the lithic contact.

Surface horizons are considerably more acid in both the Akaka and Hilo soils than the subsoils immediately below them. This is due to the native fern vegetation and its acid humus formation as well as the heavy use of sulfate base fertilizers in the sugar cane culture in Hawaii. The soils show high pH even with great depths with the Hilo soil uniformly higher than the Akaka soil (Table 1). The average pH of the Akaka soil is near pH 5.6 while the average pH of the Hilo soil is 6.0.

When determined in normal, neutral KCl solution the pH of the surface horizons is normally higher than when determined in water. This phenomenon sometimes continues with depth in the Akaka soil but usually does not in the Hilo soil.

In this respect, it has been shown that on the dryer, higher elevations of the northeastern slopes of Mauna Kea the soil pH in water is normally higher than that found in normal KCl. This difference, called the delta pH, was correlated with rainfall, with the delta pH decreasing in value as rainfall increases. It was suggested that this difference in pH may be due to the replacement of OH^- by Cl^- proceeding at a faster rate than the replacement of H^+ by K^+ in the soils of higher rainfall. Delta pH was designated as pH in water minus pH in KCl (Loganathan, 1967).

More recently it has been proposed that the delta pH be defined as the pH in KCl minus the pH in water to take into account the net surface charge of the soil system. If the delta pH is negative, ie; pH in water is greater than in KCl, the soil is said to have a net negative charge. If pH in KCl is higher than the pH in water the charge is said to be positive. If there is no difference the system would be said to have a balanced charge. High oxide soils sometimes possess net positive charge and are thought to have higher anion exchange in proportion to cation exchange, (Mekaru, 1969).

Table 1 : pH, Δ pH, and effect of dehydration on pH of Akaka and Hilo Soils.

Soils and Horizon	Depth inches	pH H ₂ O	pH KCL	Δ pH (pH _{KCL} - pH _{H₂O})	pH (air dry)
<u>Akaka 2:</u>					
A1	0-10	3.92	4.27	.35	3.80
B21	10-18	5.07	5.30	.23	4.91
B22	18-26	5.33	5.42	.09	4.92
B23	26-37	5.71	5.58	-.13	5.69
B24	37-42	5.66	5.55	-.11	5.58
11 A1	42-48	5.75	5.54	-.21	5.59
11 B2	48-52	5.86	5.84	-.02	5.59
111 A1	52-64	5.76	5.67	-.09	5.55
111 B21	64-69	5.81	7.70	-.11	5.58
111 B22	69-80	5.43	5.39	-.04	5.25
1V A1	80-90	5.75	5.65	-.10	5.46
1V B21	90-99	5.51	5.53	.02	5.48
1V B22	99-106	5.76	5.83	.07	5.50
V A1	106-116	5.68	5.64	-.04	5.42
<u>Hilo 1:</u>					
Ap	0-15	4.46	4.86	.40	5.38
B21	15-38	6.01	5.98	-.03	5.75
B22	38-60	6.03	6.00	-.03	5.58
B23	60-62	6.02	6.01	-.01	5.80
11 A1	62-65	6.00	6.00	.00	5.77
11 B2	65-72	6.33	6.20	-.13	5.68
111 A1	72-77	6.33	6.04	-.29	5.54
111 B21	77-83	6.03	5.95	-.08	5.66
111 B22	83-85	6.08	6.03	-.05	5.82
1V A1	85-90	6.22	5.96	-.26	5.45
1V B21	90-93	6.00	5.75	-.25	5.40
1V B22	93-102	6.02	5.68	-.34	5.37
1V B23	102-110	5.46	5.31	-.15	5.38

Because of the combined error of the two pH determinations needed in the delta pH determination, differences of less than 0.1 pH unit should be disregarded. Only about half of the soil delta pH values could be considered significantly different from zero (Table 1).

The pH determined on air dried soils indicates a uniform lowering of pH that may be caused by dehydration of the amorphous gels contained in the soils.

Water, Organic Matter, Total Nitrogen content and C/N ratios:

Water held in the soil under field conditions ranged from as low as 62% on the oven dry basis for a Hilo soil surface, to over 400% in some of the Akaka subsoils (Tables 2 and 3). The averages were for site 1 of the Hilo soil, 176% and for site 2 of the Akaka, 377 %.

Even with high water contents the soils remain in a moderately well drained condition. Very few mottles, even in the Akaka soil were observed.

The organic matter discontinuities were used to differentiate buried sequence within the soils (Figures 9 and 10).

The surface soils had accumulations of organic matter of up to 20 % in the Akaka soils and up to 13.6 % in the Hilo soils. The average organic matter content for site 2 of the Akaka soil is 10.4 % and for site 1 of the Hilo soil 6.2 %.

When compared, there is a high correlation between the water content and organic matter content. When sites 1 and 2 of each soil are compared with the surface horizons deleted, the regression of % field moisture on organic matter has a coefficient of .882, which is highly significant. The regression formula is % water at field condition = $4.2 + 34.7 \text{ O.M. } \%$.

While not indicating a cause and effect, this relationship does indicate a possible common factor in the two properties of the soils. It is believed that the amorphous clay minerals can accumulate large amounts of organic matter due to clay-organic complexes (Broadbert, 1962).

Table 2: Field moisture, extractable iron oxides, O.M., N, C/N, Silica-alumina ratios and CEC of Akaka Soils.

Soil and Horizon	% H ₂ O	% Ext. Fe ₂ O ₃	% O.M.	% N	C/N	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	CEC
<u>Akaka 1:</u>							
Ap	119	24.5	13.7	.462	16.9	.78	66.9
B2	343	25.9	9.3	.308	17.5	.80	83.9
11 A1	429	25.9	11.0	.404	15.8	.53	97.5
11 B2	264	22.5	7.2	.320	13.1	1.06	67.0
111 A1	304	25.3	8.4	.309	15.9	1.12	84.0
111 B21	313	29.9	8.9	.360	14.4	.73	74.6
111 B22	324	21.9	9.3	.341	15.8	.89	95.1
111 B23	158	22.7	4.5	.162	16.0	.27	52.7
1V A1	359	26.4	8.3	.274	17.5	.79	79.2
1V B21	346	26.1	7.9	.292	15.8	.55	95.6
1V B22	365	24.7	8.5	.285	17.2	.58	99.2
1V B23	159	24.3	4.1	.151	15.9	.81	36.9
V A1	423	28.2	6.9	.371	10.8	.74	98.5
<u>Akaka 2:</u>							
A1	261	26.4	21.5	.741	16.9	.59	91.4
B21	385	21.6	12.6	.437	16.7	.62	68.0
B22	424	23.4	12.2	.379	18.7	.64	67.6
B23	424	24.5	10.6	.328	18.9	.65	88.4
B24	329	17.5	9.0	.134	24.8	.64	73.2
11 A1	432	25.6	10.3	.323	18.6	.57	53.8
11 B2	303	24.5	7.0	.191	21.5	.53	65.5
111 A1	424	25.3	9.5	.338	16.3	.72	81.7
111 B21	418	28.9	8.7	.247	20.6	.75	28.0
111 B22	295	25.8	6.5	.189	20.1	1.22	68.1
1V A1	421	29.6	10.2	.289	20.4	.58	31.3
1V B21	369	23.3	9.2	.211	25.1	.93	33.8
1V B22	230	22.8	5.3	.122	25.4	.33	28.6
V A1	492	22.9	9.1	.238	22.3	.60	35.4

Table 2: (continued) Field moisture, extractable iron oxides, O.M., N, C/N, silica-alumina ratios and CEC of Akaka soils.

Soil and Horizon	% H ₂ O	% Ext. Fe ₂ O ₃	% O.M.	% N	C/N	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	CEC
<u>Akaka 3:</u>							
A1	232	26.2	15.8	.536	17.2	.73	85.0
B21	399	24.8	10.8	.392	16.1	.54	86.5
B22	369	22.1	8.7	.315	16.2	.68	85.2
B23	394	25.0	8.9	.318	16.4	.59	107.7
B24	268	26.7	6.2	.185	19.5	1.08	63.5
11 A1	362	24.0	9.2	.210	25.2	.92	89.6
11 B2	177	25.0	5.0	.138	21.0	.30	59.2
111 A1	289	17.2	6.9	.233	16.7	.67	89.1
111 B2	143	21.6	3.4	.089	22.5	.19	42.9
1V A1	403	24.8	7.7	.226	19.9	.53	79.7
<u>Akaka 4:</u>							
A1	143	22.1	19.2	.636	17.6	.81	80.9
B21	115	23.7	16.0	.543	17.1	.82	63.8
B22	101	23.2	17.0	.568	17.4	.64	66.8
B23	156	23.8	11.9	.419	16.5	.63	65.9
B24	307	23.7	9.3	.246	22.0	.71	73.8
B25	165	14.9	4.2	.157	15.3	.36	52.6
11 A1	313	22.4	6.3	.262	14.1	.96	64.4
111 A1	452	25.8	7.8	.299	15.1	.50	78.4
111 B21	378	25.6	7.7	.246	18.3	.92	74.6
111 B22	288	23.7	6.3	.219	16.9	1.27	61.4

Table 3: Field moisture, extractable iron oxides, O.M., N, C/N, silica-alumina ratios and CEC of Hilo soils.

Soil and Horizon	% H ₂ O	% Ext. Fe ₂ O ₃	% O.M.	% N	C/N	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	CEC
<u>Hilo 1:</u>							
Ap	69	22.9	12.9	.338	22.1	.69	42.8
B21	219	23.0	7.6	.321	13.7	.54	44.8
B22	193	23.7	5.5	.164	19.5	.76	37.9
B23	185	23.8	4.8	.108	25.9	.32	47.5
11 A1	246	24.3	6.0	.160	21.9	.39	58.0
11 B2	128	24.8	2.4	.118	11.9	.15	23.0
111 A1	203	26.0	5.0	.169	17.2	.55	49.2
111 B21	258	23.6	5.4	.189	16.4	.41	40.2
111 B22	155	25.9	2.9	.090	18.9	.10	16.8
1V A1	303	26.1	5.6	.173	19.1	.65	41.6
1V B21	203	21.0	4.0	.138	16.7	.78	31.0
1V B22	146	19.5	3.6	.135	15.6	.97	22.1
1V B23	91	31.5	2.1	.112	10.7	1.46	16.6
<u>Hilo 2:</u>							
Ap	67	25.8	13.6	.533	18.2	.89	53.9
B21	183	21.6	7.6	.315	14.0	.63	53.2
B22	183	23.1	6.1	.256	13.7	.94	45.5
11 A1	198	23.2	7.2	.254	16.5	.48	61.6
11 B21	200	19.6	5.6	.195	16.9	.48	42.5
11 B22	159	22.0	4.4	.150	17.3	.29	37.9
111 A1	222	22.3	5.3	.178	17.4	.41	50.2
111 B2	141	24.0	3.0	.108	15.7	.25	36.5
1V A1	187	25.5	4.0	.179	12.8	.48	40.0
1V B21	195	23.2	4.2	.178	13.5	.38	36.1
1V B22	179	22.9	3.5	.122	16.4	.27	35.1
1V B23	108	21.9	2.0	.097	12.4	.18	21.5
V A1	107	23.6	2.3	.154	8.4	1.44	27.4

Table 3: (continued) Field moisture, extractable iron oxides, O.M., N, C/N, silica-alumina ratios and CEC of Hilo soils.

Soil and Horizon	% H ₂ O	% Ext. Fe ₂ O ₃	% O.M.	% N	C/N	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	CEC
<u>Hilo 3:</u>							
Ap	62	23.5	11.6	.461	14.5	.62	45.8
B21	187	23.5	6.9	.308	13.0	.72	61.6
B22	170	21.6	5.2	.213	14.1	.55	56.9
B23	185	24.3	4.4	.159	16.4	.67	55.9
11 A1	236	22.9	5.4	.217	14.2	.70	86.1
11 B21	136	22.3	2.6	.108	13.9	.27	32.6
11 B22	185	23.5	2.7	.127	12.6	.31	48.2
11 B23	156	24.1	2.4	.070	20.0	.26	34.6
11 B24	93	24.6	1.1	.056	10.7	.15	22.8
111 A1	150	32.5	2.4	.118	11.9	.91	35.2
111 B2	135	25.1	2.0	.084	14.3	.41	30.6
1V A1	172	26.1	2.2	.101	12.9	.57	25.9
1V B21	126	26.1	1.6	.071	12.7	.35	20.8
1V B21a	93	25.4	2.0	.050	24.0	.35	13.4
1V B22	151	27.4	1.7	.090	11.1	.64	37.7
1V B23	129	24.7	0.9	.115	4.3	1.25	33.0
<u>Hilo 4:</u>							
Ap	107	23.7	8.9	.362	14.4	.59	50.6
B21	160	24.0	3.9	.187	12.3	.57	57.0
B22	151	25.4	2.5	.151	9.9	.65	29.7
11 A1	185	24.3	4.0	.212	10.8	.83	38.8
11 B21	222	23.6	4.5	.184	14.1	.73	44.5
11 B22	211	21.8	4.0	.183	12.6	.63	52.3
11 B23	148	25.2	2.6	.121	12.4	.49	43.7
111 A1	186	23.9	2.8	.156	10.3	.51	25.6
111 B21	110	26.7	2.4	.060	23.3	.26	17.4
111 B23	126	26.9	1.3	.054	14.7	.27	16.2
1V A1	199	26.7	1.7	.125	8.0	.36	20.3
1V B21	124	27.7	0.9	.051	9.8	.18	13.5
1V B22	93	28.0	0.8	.053	9.4	.28	10.5
1V B23	107	28.6	0.7	.054	7.4	.36	14.3
V A1	143	26.0	1.8	.122	8.2	.85	19.9

Humic versus fluvic organic clays may also affect the movement of iron on aluminum in volcanic ash soils. It has been proposed that aluminum moves in predominantly fluvic acid combinations and iron in humic acid combinations (Tan, 1966).

Nitrogen contents of the Hilo and Akaka soils are uniformly low and are correlated very highly with the organic matter contents. A simple correlation coefficient of $r = .958$ exists and is very highly significant.

The carbon : nitrogen ratio ranges between 10 and 25 with a few below 10. The average C/N ratio for all the soils is 16.0. The trend of increasing carbon with increasing nitrogen and increasing C/N ratio with increasing rainfall (Blomberg, 1959) is evident in the data presented here (Tables 2 and 3).

It is evident from the very significant correlation between C/N and water held at field conditions of $r = .354$.

Total Silicate Analysis :

The result of the total silicate analysis are given in tables 4 and 5. The failure to total 100 % is due predominantly to the irregular loss of water at 100 - 110 °C.

This causes the base for calculation to fluctuate widely as well as giving a plus or minus 5 % error in the loss on ignition determination.

Schematic diagrams for the silica : alumina ratios of each site are presented in Figure 9 and 10. The ratios range from .10 to 1.50 in the whole soil.

In all the Akaka profiles studied the lowest horizon of the top, unburied soil sequence shows an increase of silica : alumina ratio. This occurs to a somewhat less extent on the top sequence of the Hilo soils. Field evidence indicates the presence of a tuff layer in soil sites not collected and could account for less weathering in that

Table 4 : Total silicate analysis of Akaka soils.

Soil and Horizon	Depth "	LOI %	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	TiO ₂ %	CaO %	K ₂ O %	MnO %	P ₂ O ₅ %
<u>Akaka 1:</u>										
Ap	0-13	31.4	10.5	22.6	28.3	4.0	—	.32	—	.08
B2	13-20	28.8	12.0	25.4	32.9	3.8	—	.46	—	.05
11 A1	20-28	32.2	7.7	24.5	29.4	5.1	—	.28	—	.05
11 B2	28-36	23.5	15.5	24.9	28.7	5.7	—	.78	—	.04
111 A1	36-47	25.5	14.4	21.8	32.2	5.0	—	.64	—	.05
111 B21	47-52	26.7	9.5	22.0	34.3	5.2	—	.43	—	.04
111 B22	52-59	25.2	14.0	26.8	29.4	5.5	—	.46	—	.05
111 B23	59-68	26.3	5.7	35.4	28.6	3.9	—	.08	—	.04
1V A1	68-74	25.7	12.0	25.8	32.9	5.3	—	.46	—	.04
1V B21	74-83	26.8	8.7	26.7	31.3	5.5	—	.19	—	.05
1V B22	83-89	27.6	9.3	27.2	28.2	5.4	—	.17	—	.05
1V B23	89-96	21.2	11.7	24.3	34.8	5.6	—	.63	—	.03
V A1	96-106	25.8	9.5	21.7	34.4	5.9	—	.30	—	.05
<u>Akaka 2:</u>										
A1	0-10	39.7	7.7	22.0	26.9	5.4	1.18	.30	.17	.04
B21	10-18	32.4	10.3	28.3	25.7	5.1	1.08	.27	.25	.04
B22	18-26	31.4	10.9	28.7	26.6	5.1	.94	.69	.27	.06
B23	26-37	29.8	10.6	27.7	24.8	5.4	.95	.27	.23	.04
B24	37-42	28.8	11.5	30.2	25.4	5.2	.94	.21	.28	.04
11 A1	42-48	31.1	10.7	31.6	30.3	5.2	.67	.32	.23	.03
11 B2	48-52	26.6	9.5	30.5	27.4	4.9	1.06	.12	.17	.03
111 A1	52-64	27.9	11.4	26.6	30.6	5.6	.76	.36	.25	.04
111 B21	64-69	26.4	10.3	23.2	33.4	6.0	1.15	.20	.23	.04
111 B22	69-80	20.3	18.1	25.2	32.8	7.2	.86	.93	.24	.03
1V A1	80-90	30.8	8.3	24.3	34.7	6.2	.90	.29	.21	.04
1V B21	90-99	27.9	13.7	25.1	29.4	5.5	.87	.48	.14	.05
1V B22	99-106	27.7	5.6	29.0	27.8	3.8	.77	.08	.37	.05
V A1	106-116	28.4	10.1	28.5	32.7	5.7	.56	.22	.46	.05

Table 4 : (continued) Total silicate analysis of Akaka soils.

Soil and Horizon	Depth "	LOI %	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	TiO ₂ %	CaO %	K ₂ O %	MnO %	P ₂ O ₅ %
<u>Akaka 3:</u>										
A1	0-16	32.9	9.8	22.7	30.5	5.2	—	.24	.39	.04
B21	16-30	31.4	9.6	29.7	28.9	5.2	—	.27	.26	.03
B22	30-32	28.8	12.1	30.1	25.6	5.2	—	.34	.21	.03
B23	32-48	30.1	9.9	28.1	26.2	5.5	—	.31	trace	.03
B24	48-56	22.9	15.5	24.3	27.0	6.7	—	.68	.19	.02
11 A1	56-61	27.0	13.8	25.4	25.9	5.5	—	.38	.24	.04
11 B2	61-65	28.2	6.3	34.8	24.9	5.3	—	.04	.21	.03
111 A1	65-72	26.3	12.0	30.5	24.0	4.8	—	.18	.25	.05
111 B2	72-79	27.6	4.5	39.1	21.9	4.5	—	.03	.15	.02
1V A1	79-90	28.6	9.2	29.5	22.5	5.4	—	.16	.21	.03
<u>Akaka 4:</u>										
A1	0-6	37.3	10.5	21.5	26.0	5.3	.67	.40	.19	.05
B21	6-17	33.6	10.8	22.3	27.0	5.4	1.05	.40	.18	.05
B22	17-24	34.0	9.2	24.4	27.0	5.2	.64	.36	.15	.06
B23	24-29	30.1	10.8	29.1	26.6	5.9	.60	.35	.20	.05
B24	29-33	28.9	12.0	28.4	27.9	5.6	.51	.45	.23	.04
B25	33-36	23.3	8.8	41.7	21.5	6.0	.64	.13	.29	.06
11 A1	36-42	24.5	16.6	29.3	24.9	5.3	.54	.60	.24	.03
111 A1	42-47	28.6	8.6	29.3	28.7	5.6	.41	.30	.27	.04
111 B21	47-56	26.5	12.9	23.7	31.1	5.9	.40	.64	.25	.04
111 B22	56-80	22.1	17.8	23.8	32.0	6.9	.62	.84	.17	.04

Table 5: Total silicate analysis of Hilo soils.

Soil and Horizon	Depth "	LOI %	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	TiO ₂ %	CaO %	K ₂ O %	MnO %	P ₂ O ₅ %
<u>Hilo 1:</u>										
Ap	0-15	32.9	10.6	26.1	26.0	5.2	.70	.26	.42	.09
B21	15-38	28.3	10.1	31.8	27.3	5.2	.76	.33	.45	.05
B22	38-60	24.2	13.6	30.4	29.0	5.3	.89	.45	.42	.05
B23	60-62	27.2	7.2	38.0	22.7	5.1	.31	.13	.26	.09
11 A1	62-65	26.7	8.0	35.1	27.7	5.6	.52	.18	.33	.03
111 B2	65-72	25.4	3.5	39.2	27.7	5.2	.75	.09	.34	.05
111 A1	72-77	24.0	9.4	29.0	30.8	6.4	.28	.27	.17	.04
111 B21	77-83	25.8	8.1	33.7	29.5	5.4	.89	.14	.14	.03
111 B22	83-85	26.6	2.4	39.2	26.8	5.2	.40	.09	.25	.02
1V A1	85-90	23.5	10.9	28.5	33.6	6.6	.58	.36	.22	.03
1V B21	90-93	22.9	14.7	31.7	26.5	5.4	.63	.63	.20	.02
1V B22	93-102	19.5	18.6	32.5	28.9	6.2	.53	.66	.20	.02
1V B23	102-110	13.2	19.9	23.1	38.0	8.5	.70	.75	.18	.01
<u>Hilo 2:</u>										
Ap	0-16	28.8	11.7	22.3	32.0	6.4	.76	.32	.23	.12
B21	16-31	27.7	11.3	30.6	27.4	5.3	.46	.39	.32	.07
B22	31-39	23.3	15.4	27.9	30.1	6.0	.66	.71	.23	.05
11 A1	39-43	26.4	8.3	29.4	29.3	6.1	.64	.36	.24	.06
11 B21	43-46	25.4	10.9	38.2	26.2	5.5	.45	.26	.29	.06
11 B22	46-49	26.7	6.1	35.2	27.7	5.0	.35	.11	.27	.05
111 A1	49-54	26.0	8.5	34.9	28.8	5.4	.45	.18	.32	.06
111 B2	54-60	25.7	5.7	38.4	29.8	4.3	.39	.08	.14	.04
1V A1	60-65	23.8	8.9	31.6	32.9	6.3	.62	.23	.22	.04
1V B21	65-68	25.4	8.0	35.9	28.2	4.9	.30	.21	.14	.03
1V B22	68-73	25.6	4.6	28.4	28.9	5.3	.34	.13	.20	.04
1V B23	73-75	26.3	3.6	33.1	27.8	4.6	—	.07	.15	.02
V A1	75-95	15.9	22.2	26.2	33.0	6.9	—	.92	.14	.03

Table 5: (continued) Total silicate analysis of Hilo soils.

Soil and Horizon	Depth "	LOI %	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	TiO ₂ %	CaO %	K ₂ O %	MnO %	P ₂ O ₅ %
<u>Hilo 3:</u>										
Ap	0-18	28.9	9.8	26.7	29.2	6.5	—	.21	.14	.07
B21	18-22	26.7	10.8	25.4	30.0	3.9	—	.22	.17	.05
B22	22-30	24.4	11.0	33.8	27.0	5.6	—	.28	.14	.05
B23	30-40	20.0	9.2	23.3	31.8	5.7	—	.23	.14	.05
11 A1	40-61	24.2	12.8	31.2	29.9	5.4	—	.35	.13	.05
11 B21	61-64	25.2	6.1	38.7	26.6	4.6	—	.12	—	.04
11 B22	64-68	25.0	7.2	38.6	23.5	5.7	—	.12	—	.05
11 B23	68-73	26.0	4.3	28.2	35.5	5.4	—	.08	—	.04
11 B24	73-77	25.1	2.9	31.6	21.8	4.8	—	.09	—	.05
111 A1	77-84	19.1	11.4	21.2	41.1	5.9	—	.37	—	.04
111 B2	84-87	25.0	7.6	31.3	31.2	4.1	—	.06	—	.02
1V A1	87-92	23.7	10.8	32.2	32.5	5.1	—	.18	—	.03
1V B21	92-96	24.9	7.9	38.2	29.2	4.2	—	.12	—	.03
1V B21a	—	23.6	7.4	36.0	32.0	4.2	—	.04	—	.02
1V B22	96-101	19.6	11.9	31.5	36.5	5.6	—	.45	—	.03
1V B23	101-110	17.3	20.0	27.1	32.3	5.3	—	.96	—	.03
<u>Hilo 4:</u>										
Ap	0-8	29.1	10.2	29.2	28.2	5.1	4.06	.28	.20	.03
B21	8-11	23.1	10.5	30.9	25.3	5.0	1.07	.21	.20	.02
B22	11-14	22.8	10.7	27.9	26.0	4.0	.47	.15	.29	.01
11 A1	14-23	22.4	13.4	27.3	28.1	5.8	.51	.42	.23	.02
11 B21	23-27	23.1	11.3	26.3	27.4	5.2	.50	.25	.40	.03
11 B22	27-34	23.6	11.7	31.6	24.4	5.5	.55	.20	.34	.03
11 B23	34-36	22.6	9.7	33.7	25.3	5.3	.48	.08	.44	.04
111 A1	36-40	23.9	10.1	33.5	25.4	5.2	.53	.17	.35	.04
111 B21	40-50	23.1	5.6	36.6	30.4	5.7	.61	.07	.38	.02
111 B22	50-59	23.1	8.6	33.9	25.1	5.6	.14	.06	.31	.01
111 B23	59-61	23.6	6.0	37.6	28.3	5.0	.06	.14	.36	.02
1V A1	61-70	23.3	7.4	35.1	28.9	6.3	.10	.14	.46	.02
1V B21	70-72	24.5	4.2	38.6	30.0	5.1	.08	.09	.38	.01
1V B22	72-74	20.4	5.9	35.6	34.4	5.9	.06	.11	.30	.02
1V B23	74-76	22.2	6.1	29.0	30.4	6.0	.09	.15	.46	.01
V A1	76-86	19.2	14.1	28.0	31.4	6.2	.07	.38	.36	.02

horizon, or horizons, developing from the tuff.

Immediately above the lithic contact of the Hilo soils the last few ash horizonz have increased silica : alumina ratios. This is due to lack of vertical drainage caused by the gray clay from the weathered lithic contact and the horizontal drainage that it promotes. This soil zone would naturally be the last to be depleted of silica as the silica from the upper horizons and from the higher elevations move through the soil in the drainage water.

This enrichment of silica in the drainage water has been studied previously (Kunishi, 1956). While upstream areas near Pepeekeo and Hakalau had SiO_2 contents of 5.4 and 14.4 ppm respectively, downstream areas of the same streams had SiO_2 contents of 12.4 and 17.8 ppm respectively.

No significant differences exist in the average total silica content of the eight profiles studied, but there is a difference in the mean alumina contents. The Akaka soils contain a mean alumina content of 27 % and the Hilo soils contain 30.5 % Al_2O_3 . These figures, representing approximately 100 inches of development, would indicate a higher grade of bauxite than previously considered.

Total iron oxide contents of the soils vary from 20 to 40 %. No apparent patterns exist for the variations in total iron content.

The same is true for titanium. With contents ranging from 4 to 8 %, the average falls near 5.5 % TiO_2 .

Manganese ranges between .10 % MnO and .80 % MnO with no apparent patterns showing up in its occurrence.

Total calcium and total phosphorus are both very low when compared to other soils of Hawaii. Levels of CaO are uniformly below 1 % and levels of P_2O_5 are less than 1000 ppm.

The total P_2O_5 is correlated with the organic matter and total nitrogen both at correlation values of $r = .5$. The correlation of total P_2O_5 with the carbon : nitrogen ratio is also highly significant.

Extractable Iron Oxides :

Extractable iron oxides are shown in tables 2 and 3 for the eight soils. There is no significant differences between the mean extractable iron contents of the Hilo or Akaka soils, with averages for both between 28 and 30 % Fe_2O_3 .

When correlated with various other soil characters, a negative highly significant correlation was found between extractable iron oxide and total phosphorus, $n = -.304$ and a negative significant correlation was found between extractable iron oxide and C/N ratio, $n = -.253$.

No other correlations of significance were found.

If extractable iron oxide is subtracted from the total iron oxide, the "fixed" iron oxide content is found. This "fixed" iron oxide may represent the magnetic iron oxide minerals in the soil. These minerals have been shown to contain a 2 : 1 : 1 ratio of $\text{FeO} : \text{Fe}_2\text{O}_3 : \text{TiO}_2$ (Matsusuka, 1965).

On the average 80 - 85 % of the total iron oxide is extractable.

This compares with soil developed from andesite rock with 35 to 39 % extractable iron oxide from New Zealand that had 95 % of its total iron content extractable (Claridge, 1962).

It is also believed that hydrated iron oxides may have cation exchange capacities ranging from 10 to 20 mil equivalents per 100 grams (MacKenzie, 1952).

Extractable Cations, Extractable Phosphorus, Base Saturation and CEC:

The result of cation extraction with normal, neutral ammonium acetate, extractable phosphate, % base saturation and CEC for the Akaka, site 2 and Hilo, site 1 are shown in table 6. Cation exchange capacity for the remaining soils is given in tables 2 and 3.

Exchangeable calcium, magnesium and potassium are all uniformly very low. Extractable phosphorus as P_2O_5 is extremely low, with the Akaka soil containing double the extractable phosphorus of the Hilo

Table 6: Extractable Cations, Extractable P_2O_5 , Base Saturation, and Cation Exchange Capacity of Akaka and Hilo Soils.

Soil and Horizon	me/100 grams				ppm	me/100 grams	
	Ca	Mg	K	Na	P_2O_5	B/S %	CEC
<u>Akaka 2:</u>							
A1	.24	1.16	.22	.58	2.5	2.3	91.4
B21	.17	.18	.78	.39	1.6	2.2	68.0
B22	.13	.16	.04	.18	3.2	.8	67.6
B23	.20	.16	.02	.99	2.5	1.5	88.4
B24	.14	.13	.02	.50	3.0	1.1	73.2
11 A1	.17	.19	.03	.78	3.5	2.2	53.8
11 B2	.18	.19	.02	.36	1.9	1.1	65.5
111 A1	.29	.47	.03	1.42	3.0	2.7	81.7
111 B21	.18	.13	.02	.40	2.3	2.6	28.0
111 B22	.16	.13	.03	.23	1.8	.8	68.1
1V A1	.22	.19	.03	1.99	2.6	7.8	31.3
1V B21	.18	.24	.03	.26	3.3	2.1	33.8
1V B22	.13	.10	.02	.46	1.7	2.5	26.6
V A1	.15	.08	.03	.16	3.6	1.2	35.4
<u>Hilo 1:</u>							
Ap	.87	.23	.09	.19	1.3	3.2	42.8
B21	.36	.17	.05	.73	1.9	2.9	44.8
B22	.34	.11	.04	.40	1.3	2.3	37.9
B23	.20	.05	.02	.19	1.0	1.0	47.5
11 A1	.14	.05	.02	.21	1.3	.7	58.0
11 B2	.26	.26	.01	.90	1.3	6.2	23.0
111 A1	.24	.19	.02	1.27	1.3	3.5	49.2
111 B21	.47	.04	.01	.26	1.7	1.9	40.2
111 B22	.30	.32	.02	1.25	1.2	11.3	16.8
1V A1	.56	.40	.05	2.54	1.7	8.5	41.6
1V B21	.22	.13	.04	.65	1.4	3.4	31.0
1V B22	.34	.25	.06	.31	1.3	4.3	22.1
1V B23	.31	.08	.05	.22	1.0	4.0	16.6

soil.

An interesting pattern occurs with the extractable sodium. Those horizons with higher exchangeable sodium are either the gibbsite horizons or horizons immediately below the gibbsite horizons. This would support the concept that sodium and potassium (in this case only sodium) in the weathering solution would assist in silica removal (Keller, 1965 and Ruxton, 1968) and the promotion of accumulations of hydrated oxides of aluminum.

It would also be natural for the horizon immediately below this layer to be able to retain some of the sodium on its exchange sites as the upper horizon is leached of silica.

The large variation in % base saturation is due to large variations in cation exchange capacity rather than marked differences in the actual amounts of bases retained. In any case the % base saturation is very low when determined at pH 7.

Cation exchange capacity values range from 10 to over 100 me/100 grams of soil and can be shown to be related to organic matter content, water content, total nitrogen content, total phosphorus content, carbon: nitrogen ratio, and silica : alumina ratio by simple correlation analysis.

It is obvious that the properties of cation exchange as determined by retention of potassium from normal, neutral potassium acetate is a very complex system.

The mean value of CEC from the Akaka soil, site 2, is 60 me/100 grams. For the Hilo soil, site 1, the corresponding value is 37.3 . In each case, the mean value was adjusted for the thickness of the corresponding horizons.

X-ray Diffraction and DTA :

X-ray diffraction diagrams of the Akaka, site 2, and Hilo, site 1 are presented in figures 11 and 12. They represent the organic matter

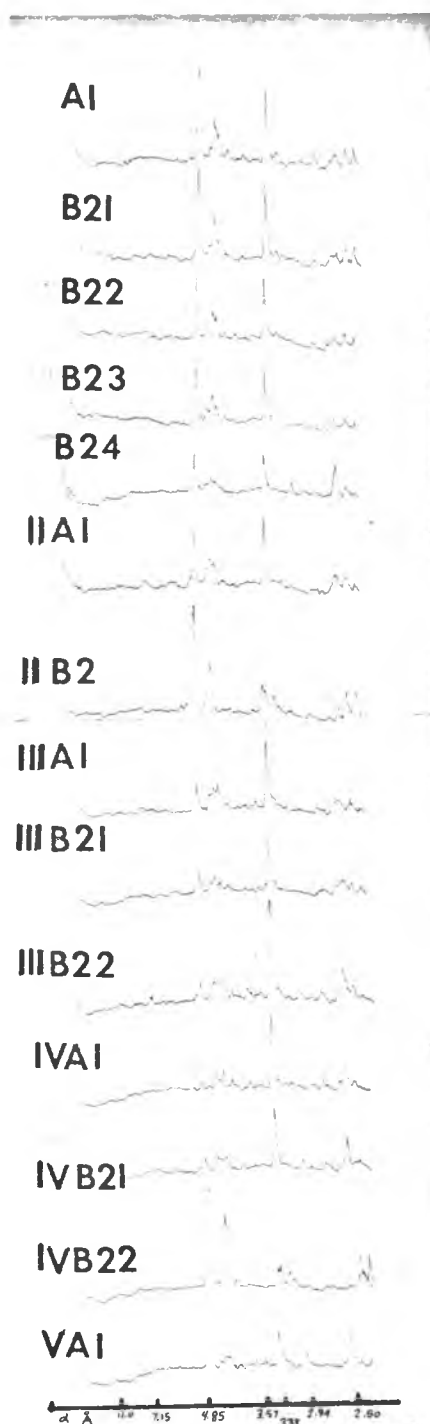


Figure 11: Power X-ray diffraction patterns of organic matter free, deferrated, oven dry, sodium saturated Akaka soil, site 2.

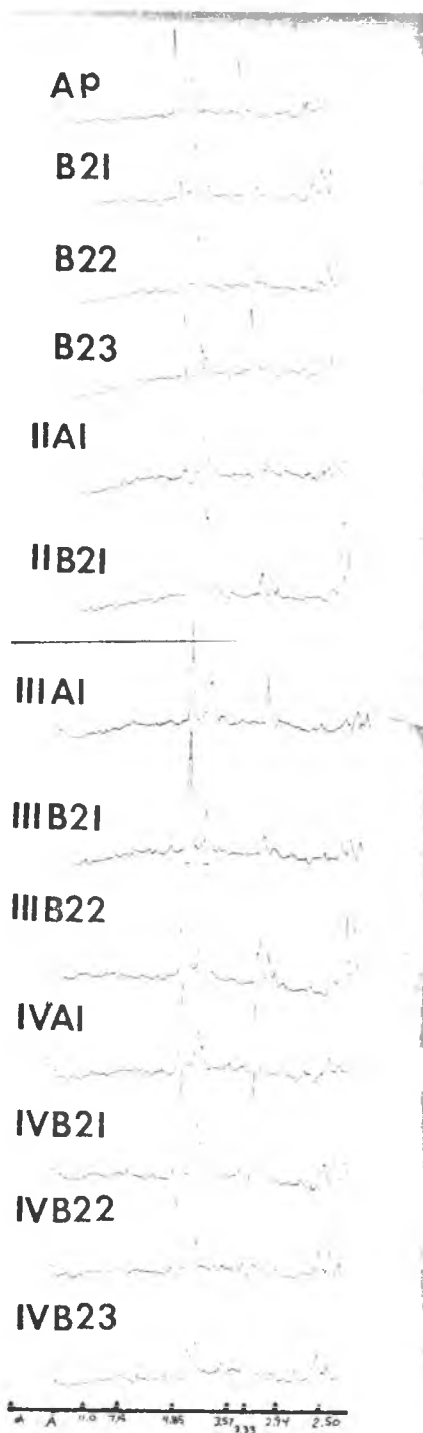


Figure 12: Power X-ray diffraction patterns of organic matter free, deferrated, oven dry, sodium saturated Hilo soil, site 1.

free, deferrated, oven-dry, sodium saturated whole soils, ground to 100 mesh.

From the Akaka soil profile it becomes apparent that the only crystalline minerals of significance are gibbsite, with X-ray diffraction maxima at 4.85 A. and quartz with a maxima at 3.34 A.

The remainder of the diffraction peaks are associated with gibbsite or quartz but are not maxima.

The first sequence of horizons, A1 to B24, shows uniform but decreasing amounts of gibbsite and quartz from the surface. At the 11 A1 horizon, the quartz and gibbsite both increase in peak size.

The 11 B2 horizon, the gibbsite or "scoria" horizon, shows a very large increase in gibbsite peak intensity, and a much smaller quartz peak.

The next sequence of horizons, 111 A1 to 111 B22 shows very little gibbsite, but higher amounts of quartz. The pattern continues through the 1V sequence of buried horizons to the 1V B22 horizon, another gibbsite accumulation.

The last horizon, V A1 shows a low gibbsite, low quartz pattern that one would have to judge was quite amorphous.

Percentages of gibbsite and quartz were estimated from the peak intensities and adjusted back to the whole sample basis for mineral allocation.

The Hilo profile does not vary so greatly as the Akaka soil from buried sequence to sequence.

The initial two horizons appear similar with less quartz in the third. The gibbsite decreases at the B23 horizon and the quartz again increases. The second sequence is a low quartz, high gibbsite sequence with the third showing much the same pattern.

The lower horizon in the third horizon of the third sequence, 111 B22, is a gibbsite horizon with low quartz.

The last sequence shows the influence of the lithic contact and shows increasing quartz with depth and decreasing gibbsite.

Just detectable in the powder diagram is the presence of clay minerals at the 10 and 7 Å spacings in the lower horizons.

Additional X-ray analysis was deemed necessary by this clay mineral detection. Figure 13 shows a representative set of treatments given to the horizons suspected of containing mica or kaolin minerals.

Kaolin minerals were detected but the levels were so low as to be deemed insignificant. In the absence of any other potassium bearing minerals, the total potassium analysis was used to determine the % mica contained in each horizon of the soils.

Differential Thermal Analysis was attempted to determine amorphous mineral content and gibbsite more quantitatively.

Figure 14 is a representative diagram of the thermal reactions found. Due to the failure of the reaction to return to the zero baseline it was virtually impossible to quantify the area under the endothermic peaks for amorphous material or gibbsite.

It is thought that this phenomenon occurs due to the gradual release of combined water in the amorphous materials and the gradual crystallization to gibbsite as the water is lost. In this case, no break is obvious in the continuum from amorphous to crystalline (Sherman, 1967) and the DTA method of analysis had very little value.

Effect of Pretreatment on CEC :

Because of the complex interrelationship of factors involved in the cation exchange capacity of the Hilo and Akaka soil, a separate experiment to determine the effect of various sample pretreatments on the CEC was conducted.

The details of the pretreatments are given under the methods section of this thesis.

Briefly, the pretreatments consisted of peroxide removal of organic matter and determination of CEC on the non-dehydrated samples,

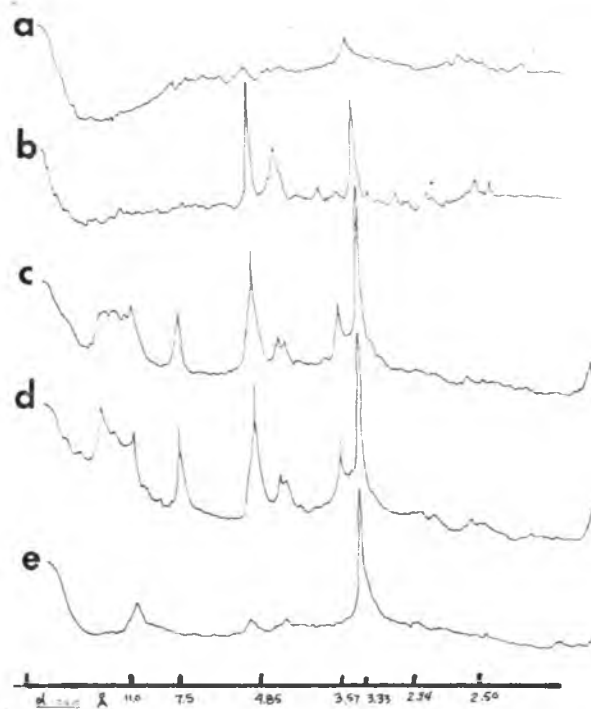


Figure 13: Effect of treatment on the X-ray diffraction pattern of Hilo soil, site 1, horizon 1V B21.

- a. wet smear.
- b. organic matter free, deferrated, sodium saturated, powder sample.
- c. oriented clay fraction from b.
- d. Mg-glycol saturated sample as c.
- e. Sample c heated to 550 C.

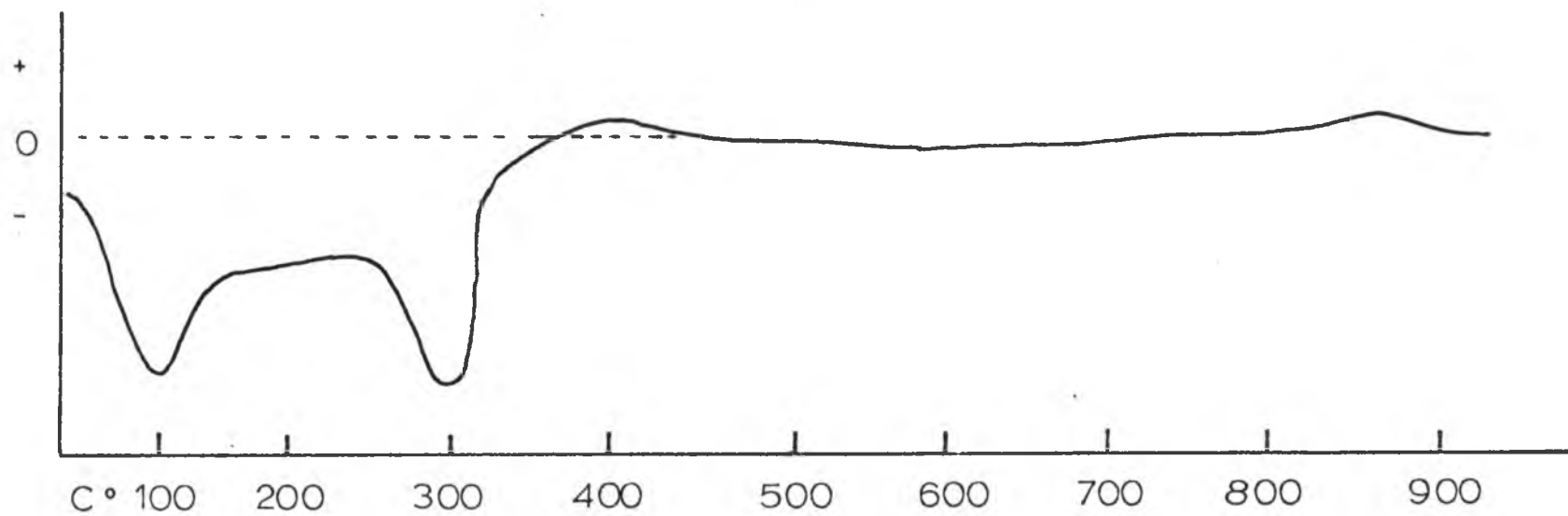


Figure 14: Differential Thermal Analysis diagram of Akaka soil, site 2, horizon B24.

organic matter removal followed by dehydration, dehydration only, organic matter removal followed by deferration and dehydration, the delta cation exchange capacity pretreatments, and the determination of the cation exchange capacity when buffered at the average pH of the soil.

The results of this experiment are presented in table 7.

Upon dehydration the soils lost approximately half of their cation exchange capacity. The exceptions to this were the surface horizons, which could be expected to have had some natural dehydration, and remarkably, the buried surface horizons of the Akaka designated A1 horizons. The largest losses upon dehydration were of the magnitude of 60 %, which is in accord with previous studies (Kanehiro, 1956).

It has been previously reported that the cation exchange capacity could be attributed to the large organic matter contents found in these soils (Tenma, 1965). Although significant correlation does exist between organic matter and CEC, organic matter removal with peroxide failed to lower the CEC to any large degree on most samples. In some horizons the removal of organic matter increased the CEC by as much as 20 to 30 %. The pH of the peroxide samples all ranged near 6. It must therefore be assumed that the removal of organic matter to levels of less than 1 % with peroxide in some way unblocks an exchange system with a higher CEC than the organic matter that was removed.

The loss of CEC due to organic matter removal on the dehydrated samples is large and corresponds to the quantity of organic matter in the original soil. But, because of the lowering of the pH with dehydration, this loss can not be used as a measure of the exchange capacity of the organic matter in the non-dehydrated samples.

In this respect, acid clays in the San Joaquin Valley of California have been found to have organic matter with pH dependent charges of the magnitude of 400 me / 100 grams of soil, while amorphous clays had pH dependent charges of only 13 to 25 me / 100 grams of soil (Pratt, 1962).

Table 7: Effect of pretreatment on CEC of Akaka and Hilo soils.

Soils and Horizon	Pretreatment									
	None	-H ₂ O	-OM	-OM -H ₂ O	pre. pH 3.5	pre. pH 8.3	Δ CEC	-OM -Fe ₂ O ₃	pH 5.6	∂ CEC (pH7- pH5.6)
<u>Akaka 2:</u>										
A1	91.4	53.6	39.5	19.6	16.6	28.1	11.5	16.4	53.2	38.2
B21	68.0	44.3	67.9	26.6	32.6	65.9	33.3	42.6	36.4	31.6
B22	67.6	45.2	92.3	26.6	37.1	84.4	47.3	55.5	21.3	46.3
B23	88.4	44.0	68.2	27.4	44.1	94.0	49.9	65.5	19.7	68.7
B24	73.2	42.3	39.0	13.6	39.6	113.2	73.6	71.3	29.2	44.0
11 A1	53.8	43.9	51.9	16.9	30.1	71.6	41.5	48.1	22.4	31.4
11 B2	65.5	33.8	38.7	7.8	29.4	58.8	29.4	53.1	13.0	52.5
111 A1	81.7	41.2	48.9	13.3	37.7	81.8	44.1	52.6	20.7	61.0
111 B21	28.0	31.3	41.6	23.5	37.1	88.2	51.1	55.4	18.1	9.9
111 B22	68.1	26.9	25.8	17.2	29.4	35.8	6.4	19.2	13.9	54.2
1V A1	31.3	31.3	42.9	27.4	33.2	86.9	53.7	62.5	22.2	9.1
1V B21	33.8	28.1	38.8	25.0	35.8	89.5	53.7	62.8	21.6	12.2
1V B22	28.6	16.6	34.0	15.6	22.4	65.2	42.8	50.8	15.3	13.3
V A1	35.4	30.1	70.2	25.0	39.0	106.1	67.1	80.7	19.9	15.5
<u>Hilo 1:</u>										
Ap	42.8	44.0	41.1	19.8	21.7	61.4	39.7	25.0	27.4	15.4
B21	44.8	35.4	43.8	18.2	5.8	46.0	40.2	28.5	22.3	22.5
B22	37.9	30.2	39.8	12.5	32.3	61.4	29.1	48.8	15.9	22.0
B23	47.5	21.1	45.5	12.5	24.3	44.2	19.9	27.4	16.2	31.3
11 A1	58.0	33.2	50.0	13.2	31.3	67.4	36.1	51.1	17.9	40.1
11 B2	23.0	14.0	29.8	4.7	10.2	19.5	9.3	13.3	5.1	17.9
111 A1	49.2	29.3	39.2	13.3	26.8	62.0	35.2	37.8	12.1	37.1
111 B21	40.2	32.8	49.2	15.3	30.0	69.7	39.7	45.8	11.7	28.5
111 B22	16.8	6.4	27.9	4.7	5.1	11.5	6.4	6.7	8.9	7.9
1V A1	41.6	17.9	39.6	11.7	21.1	52.4	31.3	36.8	17.5	24.1
1V B21	31.0	15.3	22.2	7.8	16.0	33.2	17.2	19.1	10.5	20.5
1V B22	22.1	16.6	24.7	8.6	17.9	41.6	23.7	29.5	18.2	3.9
1V B23	16.6	15.3	17.7	6.6	29.4	37.1	7.9	22.3	7.9	8.7

Peroxide treatment has also been shown to reduce the buffering capacity of the hydrol humic latosol soils in Hawaii (Matsusuka, 1950).

The delta cation exchange capacity and the CEC of the organic matter free deferrated samples are reported without adjustment for the materials removed. These two values have a high significant correlation value with an r value of .919 . They also correlate significantly with the amorphous material content of the soils.

The cation exchange capacity determined at the average pH value for the soils is uniformly low for both the Akaka and Hilo soils. It is correlated highly with organic matter but this does not mean it is a result of the organic matter. The correlation coefficient is $r = .914$.

It is thought that organic matter has almost no permanent charge (Coleman, 1958) and at a pH 5 has a pH dependent charge of 75 me/100 grams.

If this is true, and if the pH dependency of the inorganic colloids is great, liming will increase the soils ability to retain cations in addition to the usual benefits.

Unfortunately, previous work on the effect of liming hydrol latosols was done by determining the CEC at neutral conditions both before and after liming. It was concluded from that data (Rixon and Sherman, 1961) that the liming had no effect on the cation exchange capacity of the pH dependent charge in these soils. This pH dependency can be seen in the final column of table 7.

The variability of the values is of interest, especially when one considers that the two CEC values that they were derived from are both correlated highly with organic matter, and with each other. The correlation coefficient for CEC at pH 7.0 v.s. the CEC at pH 5.6 is $r = .599$ and is highly significant.

Mineral Allocation:

Organic matter and extractable iron oxide with its associated

water are reported in table 8 . The mean values for the two profiles are 10.4 and 6.2 % organic matter in the Akaka soil and Hilo soils respectively. There is no difference in the average extractable $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$, with both soils containing a mean value of approximately 30 % . This water associated with the extracted iron oxide was calculated to facilitate allocation of minerals.

Mica allocation was on the basis of a 7.2 % K_2O content for Hawaiian secondary micas as determined by Juang (1965).

Gibbsite was estimated by peak intensity of the 4.85 Å X-ray diffraction peak.

Quartz was estimated by X-ray diffraction peak intensities.

The fixed iron oxide is the difference between total Fe_2O_3 and the extractable Fe_2O_3 , TiO_2 is reported as titania.

The non-crystalline mineral content, non-crystalline * , Table 9, was estimated by taking the remaining loss of ignition, silica and alumina after the other minerals were allotted according to their silica, alumina and loss on ignition as follows :

O.M. - - 100 % loss on ignition.

$\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ - - 25 % loss on ignition.

Mica - - 45.2 % Silica, 38.4 % Al_2O_3 and 4.5 % loss on ignition.

Gibbsite - - 65.5 % Al_2O_3 and 34.5 % loss on ignition.

Quartz - - 100 % SiO_2

The silica : alumina ratio is reported for this remainder.

As a comparison, the cation exchange capacity delta values adjusted to their original organic matter and iron oxide content are reported as non-crystalline ** . Unaccountable losses on pretreatment for the delta value were of the magnitude of only a few percent as determined by weight of sample taken and final weight of organic

Table 8: Total mineral and non-mineral content of Akaka and Hilo soils.

Soils and Horizon	O.M. %	Ext. Fe ₂ O ₃ nH ₂ O %	Mica %	Gibbsite %	Quartz %	Fixed Fe ₂ O ₃ %	TiO ₂ %	non- crystal %
<u>Akaka 2:</u>								
A1	21.5	32.8	4.2	19.0	5.4	0.5	5.4	13.4
B21	12.6	26.8	3.8	24.0	7.3	4.1	5.1	18.5
B22	12.2	29.1	9.6	16.0	7.0	3.2	5.1	22.1
B23	10.6	30.4	3.8	15.0	4.7	0.3	5.4	28.5
B24	9.0	21.7	2.9	10.0	3.5	7.9	5.2	41.3
11 A1	10.3	31.8	4.4	16.0	6.4	4.7	5.2	30.6
11 B2	7.0	30.4	1.7	25.0	2.5	2.9	4.9	24.6
111 A1	9.5	31.4	5.0	7.0	7.7	5.3	5.6	31.3
111 B21	8.7	35.9	2.8	6.0	5.0	4.5	6.0	30.7
111 B22	6.5	32.0	12.9	5.0	11.1	7.0	7.2	23.5
1V A1	10.2	36.8	4.0	1.0	6.4	5.1	6.4	31.8
1V B21	9.2	28.9	6.4	4.0	6.2	6.2	5.5	32.7
1V B22	5.3	28.3	1.1	37.0	2.0	5.0	3.8	9.7
V A1	9.1	28.4	3.1	5.0	3.1	9.8	5.7	39.0
mean *	10.4	30.6	5.1	12.5	6.0	4.7	5.6	26.9
<u>Hilo 1:</u>								
Ap	12.9	28.4	3.6	33.0	5.9	3.1	5.2	9.1
B21	7.6	28.6	4.6	35.0	7.1	4.3	5.2	10.8
B22	5.5	29.4	6.3	33.0	2.0	5.3	5.3	16.5
B23	4.8	28.5	1.8	17.0	6.7	0.0	5.1	36.8
11 A1	6.0	30.2	2.5	20.0	3.2	3.4	5.6	30.6
11 B2	2.4	30.8	1.3	50.0	2.0	2.9	5.2	6.9
111 A1	5.0	32.3	3.8	19.0	4.4	4.8	6.4	24.3
111 B21	5.4	29.3	1.9	23.0	3.3	5.9	5.4	28.5
111 B22	2.9	32.2	1.3	59.0	1.9	0.9	5.2	0.1
1V A1	5.6	32.4	5.0	22.0	6.2	7.5	6.6	17.6
1V B21	4.0	26.0	8.8	36.0	11.5	5.5	5.4	5.8
1V B22	3.6	24.2	9.2	20.0	10.8	9.4	6.2	22.4
1V B23	2.1	39.1	10.4	3.0	8.8	6.5	8.5	25.5
mean *	6.2	29.7	5.3	29.5	5.7	4.9	5.7	16.0

* Mean content adjusted for respective horizon thickness.

Table 9: Non-crystalline mineral content and bulk density of Akaka and Hilo soils.

Soils and Horizon	non- crystal * %	non- crystal ** %	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$ of *	B.D. "Apparent" (dry)	B.D. "Real" (wet)
<u>Akaka 2:</u>					
A1	13.4	5.3	.09	.27	.98
B21	18.5	20.8	.20	.19	.94
B22	22.1	27.7	.00	.19	.97
B23	28.5	29.4	.43	.18	.93
B24	41.3	51.0	.50	.24	1.01
11 A1	30.6	24.0	.20	.21	.90
11 B2	24.6	18.4	.79	.26	1.06
111 A1	31.3	26.1	.12	.18	.94
111 B21	30.7	28.3	.37	.19	.96
111 B22	23.5	3.9	.12	.22	.88
1V A1	31.8	29.0	.01	.18	.96
1V B21	32.7	33.3	.38	.21	1.00
1V B22	9.7	28.4	1.20	.33	1.09
V A1	39.0	42.0	.39	.16	.93
<u>Hilo 1:</u>					
Ap	9.1	25.8	1.70	.69	1.17
B21	10.8	25.6	.21	.32	1.03
B22	16.5	18.9	2.43	.38	1.10
B23	36.8	13.3	.00	.38	1.07
11 A1	30.6	23.0	2.89	.29	1.00
11 B2	6.9	6.2	.25	.43	.98
111 A1	24.3	22.0	.37	.35	1.06
111 B21	28.5	19.4	.37	.27	.97
111 B22	.1	4.2	.00	.39	.99
1V A1	17.6	19.4	.31	.26	1.03
1V B21	5.9	12.0	.00	.37	1.11
1V B22	22.4	17.1	.38	.40	.99
1V B23	25.5	4.6	.62	.62	1.18

* Non-crystalline as determined by difference.

** Non-crystalline as determined by delta CEC value.

- matter free, defferated sample.

When considering the completely different approaches used in determining the non-crystalline component of these soils, the similarity of results is remarkable.

The mean non-crystalline content of the Akaka soil is 26.9 % and the Hilo soil, 16.0 % .

Gibbsite content is 12.5 % for the Akaka soil and 29.5 % for the Hilo soil.

The gibbsite content has a very significant negative correlation with the non-crystalline or amorphous mineral content, $r = -.839$.

Bulk density reflects the difference in mineralogy as well. A mean bulk density of .21 is found for the Akaka and .42 for the Hilo. Both are based on the oven dry weight of soil and are therefore called "apparent" bulk density.

Bulk density based on the field moist weights of the soils have a smaller spread and are considered "real" bulk densities.

Particle density was determined on selected horizons and found to be approximately 2.70.

DISCUSSION

Interrelationships of Some Soil Properties in the Hilo and Akaka Soils:

Throughout the presentation of the results of this thesis the results of simple correlation analysis have been presented.

A complete array of correlation coefficients that were determined for 20 different properties are given in Figure 15.

The levels of significance for the correlation of 27 and 105 pairs of observations are as follows :

	n = 27	n = 105
Significant at 0.01 level	$r > .487$	$r > .254$
Significant at 0.05 level	r between 381 and .487	r between .195 and .254
Not significant	$r < .381$	$r < .195$

One of the most striking features of this correlation data is the complexity of the cation exchange capacity experiments.

Cation exchange capacity has been shown to relate to organic matter, moisture content, bulk density, total nitrogen, total phosphorus, carbon nitrogen ratio, mica content, and silica : alumina ratio.

Even when the soils are dehydrated and the organic matter is removed, the reflection of the organic matter content is obvious in the simple correlations. This would indicate common causes rather than cause and effect are at work in these thesis.

Throughout the array of correlation coefficients this common cause relates back to the high water holding capacity of these soils. When this ability is lost by dehydration the soil completely changes its nature. In every case, this change is irreversible.

Origin and Genesis :

It is quite evident that differences between the Akaka soil profiles are slight. The same is true for the Hilo soils, but large differences between the two soils exist.

	O.M.	Field H ₂ O	Extract. Fe ₂ O ₃	B.D.	Total N	Total P	C/N	Mica	Quartz	Gibbsite	Amorphous	SiO ₂ /Al ₂ O ₃	C.E.C.	Base Sat.	C.E.C. -H ₂ O	C.E.C. -O.M.	C.E.C. -H ₂ O	C.E.C. -O.M.	C.E.C. -H ₂ O	C.E.C. -O.M.	C.E.C. -H ₂ O	C.E.C. -O.M.
Field H ₂ O	.392** n=105																					
Extract. Fe ₂ O ₃	-.148 n=105	.027 n=105																				
B.D.	-.362 n=27	-.913** n=27	.356 n=27																			
Total N	.952** n=105	.310** n=105	-.077 n=105	-.314 n=27																		
Total P	.509** n=105	.067 n=105	-.304** n=105	.152 n=27	.491** n=105																	
C/N	.138 n=27	.352** n=105	-.253* n=105	-.272 n=27	-.127 n=27	.327** n=105																
Mica	-.052 n=27	.188 n=105	.066 n=27	.077 n=27	.008 n=27	.031 n=105	-.112 n=105															
Quartz	.027 n=27	-.018 n=27	-.009 n=27	.056 n=27	.107 n=27	-.210 n=27	.037 n=27	.792** n=27														
Gibbsite	-.315 n=27	-.584** n=27	-.271 n=27	.428* n=27	-.221 n=27	.018 n=27	-.210 n=27	-.369 n=27	-.363 n=27													
Amorphous	.116 n=27	.582** n=27	.000 n=27	-.436** n=27	-.010 n=27	.080 n=27	.387* n=27	-.011 n=27	.017 n=27	-.839** n=27												
SiO ₂ /Al ₂ O ₃	.273** n=105	.205* n=105	.097 n=105	.126 n=27	.323** n=105	.076 n=105	-.083 n=105	.886** n=105	.677** n=27	-.611** n=27	.236 n=27											
C.E.C.	.650** n=105	.624** n=105	-.165 n=105	-.474* n=27	.671** n=105	.364** n=105	.264** n=105	.216* n=105	.047 n=27	-.303 n=27	.283 n=27	.295** n=105										
Base Sat.	-.322 n=27	-.284 n=27	.342 n=27	.247 n=27	-.245 n=27	-.323 n=27	-.303 n=27	-.140 n=27	-.084 n=27	.437* n=27	-.498** n=27	-.244 n=27	-.534** n=27									
C.E.C.-H ₂ O	.801** n=27	.503** n=27	-.127 n=27	-.385* n=27	.822** n=27	.296 n=27	.046 n=27	-.061 n=27	-.027 n=27	-.382* n=27	.334 n=27	.039 n=27	.797** n=27	-.563** n=27								
C.E.C.-O.M.	.503** n=27	.608** n=27	-.169 n=27	-.543** n=27	.453* n=27	.360 n=27	.176 n=27	-.164 n=27	-.178 n=27	-.240 n=27	.343 n=27	-.236 n=27	.489** n=27	-.398* n=27	.628** n=27							
C.E.C.-H ₂ O -O.M.	.681** n=27	.648** n=27	.018 n=27	-.550** n=27	.573** n=27	.352 n=27	.294 n=27	.027 n=27	.057 n=27	-.517** n=27	.369 n=27	.102 n=27	.364 n=27	-.351 n=27	.635** n=27	.702** n=27						
C.E.C. Δ	.140 n=27	.762** n=27	-.236 n=27	-.707** n=27	.081 n=27	.072 n=27	.395* n=27	-.229 n=27	-.249 n=27	-.492** n=27	.666** n=27	-.086 n=27	.201 n=27	-.312 n=27	.350 n=27	.533** n=27	.543** n=27					
C.E.C.-O.M. -Fe ₂ O ₃	.444 n=27	.757** n=27	-.172 n=27	-.623** n=27	.076 n=27	.143 n=27	.490** n=27	-.199 n=27	-.301 n=27	-.566** n=27	.721** n=27	.015 n=27	.251 n=27	-.424* n=27	.418* n=27	.583** n=27	.585** n=27	.917** n=27				
C.E.C. pH 5.5	.914** n=27	.304 n=27	-.203 n=27	-.271 n=27	.892** n=27	.223 n=27	.142 n=27	-.062 n=27	-.034 n=27	-.250 n=27	.106 n=27	.028 n=27	.597** n=27	-.266 n=27	.745** n=27	.337 n=27	.535** n=27	.161 n=27	.141 n=27			

Figure 15: Simple correlation coefficients of several properties of Akaka and Hilo soils.

** significant at 0.01 level
 * significant at 0.05 level

Water contents, organic matter contents, cation exchange capacities, gibbsite content, and amorphous or non-crystalline mineral content vary greatly between the Akaka and Hilo soils.

As great as these differences are, the differences within each profile are greater.

In explaining the developmental sequence of these soils it is necessary to account for this intensive weathering of the ash forming the gibbsite horizons in the oldest portion of each major ash fall.

If we accept the hypothesis that these horizons were coarse ash or lapili layers it is not hard to assume their intensive weathering under high rainfall conditions. The rapid water intake of ash formations could very quickly account for depletion of silica from the largely glassy ash. If the coarse layers were to be situated over less pervious, formerly weathered material, they may well have become aquifers for laterally moving perched water tables, thus appreciably intensifying silica removal.

In addition, the acid forming nature of the forest debris and a small but perhaps significant CO_2 contribution from the underlying organic matter decomposition may have caused dissolution and subsequent reprecipitation of aluminum and the removal of silica from these horizons.

The Classification of the Soils:

The Akaka and Hilo soils meet the criteria designated for the typic hydrandepts in the classification of the U.S.D.A. Soil Conservation Service - The Seventh Approximation.

The gibbsite horizons, although of predominantly oxide nature, do not meet the 12-inch thickness criteria to be classified as oxic horizons. Even if they did, the fact that they occur as buried horizons exempt them from affecting the classification into the inceptisol order of soils.

The thixotropic isomesic and thixotropic isohyperthermic designa-

tion are also appropriate for the Akaka and Hilo soils respectively.

In addition to the present classification it is suggested that the modifier "gibbsitic" be added to the Hilo soil to recognize the tendency towards greater crystallization.

The soils then would have the following designation:

Akaka - thixotropic isomesic typic hydrandept.

Hilo - gibbsitic thixotropic isohyperthermic typic hydrandept.

SUMMARY AND CONCLUSIONS

There is no evidence chemically or mineralogically that the ash forming the soils has had any recent contributions from Kilauea.

As a consequence, recent studies of ash deposits in Lake Waiau on the summit of Mauna Kea may hold significant answers about the ash that the Hilo and Akaka soils formed from. Radio-carbon dating has indicated an age of 4500 years for a coarse ash layer lying 1.5 meters deep, (Woodcock, 1966). This may correspond to the last major ash fall for the area.

It is also evident that the higher rainfall in the areas of the Akaka soils has promoted organic matter build up while not accelerating the weathering sequence. To the contrary, lateral water movement has been the contributing factor in the higher weathering of the Hilo soil.

Little or no allophane exists in these soils if we take the range of allophane to have a silica : alumina ratio of between 1 and 2. In many of the horizons studied, the only non-crystalline allophane-like material has been found to be amorphous hydrated aluminum. It appears to have the same characteristics as allophane though.

Hydrated oxides of iron have not gained a lot of attention, but they do occur in significant amounts in both soils. More study is needed on whether they follow the ionic, amorphous, crystalline sequence that has been proposed for aluminum.

These two items, the amorphous aluminum and the amorphous iron need considerable study. This is especially true for their cation exchange capacities. Electron microscopy coupled with heavy metal

salvation may be able to assist in determining the nature of the exchange sites and their dependency on other factors.

Finally, the Hilo and Akaka soils are situated on a weathering sequence that includes the more common allophane containing volcanic ash soils on one hand and bauxite deposits on the other. The soils are related to both, but in reality are neither.

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