THE PROPERTIES AND GENESIS OF FOUR SOILS

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By

Adul Chotimon

Thesis Committee:

Haruyoshi Ikawa, Chairman
Wade W. McCall
Goro Uehara

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Soil Science.

THESIS COMMITTEE

Haruyoshi Ikawa
Chairman

Wade W. McCall

Goro Uehara

ACKNOWLEDGMENTS

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INTRODUCTION

The change in the properties of soils is influenced by the soil forming factors, climate, vegetation, topography, parent material, and time (Jenny, 1941).

The dominating influence of climate in Hawaii has been shown for soils derived from andesite ash (Loganathan, 1967) and basaltic ash (Hassan, 1969), and from weathered andesitic and basaltic rocks (Kimura and Swindale, 1967).

Soil formation in other areas of the world on very old land-scapes and highly weathered parent materials has been reported by many investigators (for example, Alexander and Cady, 1962; Ollier, 1959; and Stephen, 1952). These studies showed that although the influence of climate was dominant, the effect of parent material on soil formation was equally important.

The general objectives of this study are:

1. To study the effect of climate on soil formation in highly weathered parent material in Hawaii.

2. To study the chemical, physical, and mineralogical properties of four soils and to classify these soils according to the U. S. Comprehensive Soil Classification System.

REVIEW OF LITERATURE

Climate, which includes precipitation, evaporation, and temperature, greatly affect the formation of soil. These major climatic factors, including seasonal variation, therefore, should be considered in the study of soil formation. For example, Prescott (1949) has used a climatic index based on rainfall, evaporation, and drainage to determine the geographical boundaries of Australian soils. The Thornthwaite water balance, another form of climatic index, was used by Arkley (1967) to show the existence of relationships between some great soil groups of the Western United States and climate.

In many tropical and subtropical areas of the world, rainfall or precipitation and temperature is considered to be the major climatic factor controlling soil formation. Jessup (1961) attributed the formation and erosion of once deep lateritic soil on very old and arid landscape of Southeast Australia to alternate wet and dry periods during the Tertiary-Quaternary. In the Natal Midlands, Africa, Macvicar (1965) showed the effect of climatic differences, rainfall and temperature, on the properties of five soil sequences which were of different parent materials. Within a sequence of B horizons of a given parent material, he found, in general, that the cation exchange capacity and total extractable bases decreased as rainfall increased. Montmorillonite or illite was present in the

region of lower rainfall, whereas kaolinite and gibbsite were identified in the region of higher rainfall. A stronger structure was also observed in the soils of lower rainfall. In each sequence, a higher temperature was associated with the lower rainfall. Although dealing primarily with climatic factor, Macvicar also recognized the importance of the other soil forming factors.

In Hawaii, the effect of climate on soil formation has been extensively studied. Ayres (1943), working with volcanic ash soils, and Kanehiro and Chang (1956), working with volcanic ash as well as other soils, established that cation exchange capacity and base saturation decreased as rainfall increased. Swindale and Sherman (1964) also observed that base saturation of volcanic ash soils generally decreased as rainfall increased. Dean (1937) found that the carbon and nitrogen contents increased as rainfall increased. In a study of a sequence of andesitic volcanic ash soils, Loganathan (1967) obtained results similar to those reported by these previous investigators. In a sequence of basaltic volcanic ash soils, Hassan (1969) similarly reported that cation exchange capacity, base saturation, and pH decreased as rainfall increased, while organic carbon, total nitrogen, including the C/N ratio, and free iron oxide increased as rainfall increased.

In a sequence of soils which included the Oxisols at lower rainfall and the Ultisols at higher rainfall, G. Uehara (personal

communication), Swindale and Uehara (1966), and Juang and Uehara (1968) observed that the structure and horizon differentiation became more pronounced and the amounts of quartz and mica increased in the surface horizons as rainfall increased. Kaolin clay also generally decreased while iron oxide and gibbsite increased.

The influence of parent material on soil formation may be readily observed in certain cases and less obviously in others. The properties of highly weathered Oxisols of Hawaii and Thailand are very similar, with kaolin and gibbsite as the dominant materials (Yaibuathes, 1969). However, the Oxisols of Hawaii are derived from parent material of basic igneous rock and do not contain certain primary quartz. The Oxisols from Thailand, on the other hand, are derived from parent material of acid igneous rock and contain much primary quartz. When certain Oxisols of Hawaii derived from basaltic parent material are compared with those derived from andesitic parent material, it is difficult to determine the original parent rock because these soils show a high degree of pedogenic convergence. Even in this less obvious case, the zirconium and nickel contents of the strongly weathered soils can be analyzed and a discriminant function be used to differentiate the parent rocks (Kimura and Swindale, 1967).

MATERIALS AND METHODS

Materials

Location of Samples

Four soil profiles collected by the Soil Conservation Service, USDA, on the island of Kauai were used in this investigation. The names of the soil series, the locations, and some of the genetic factors are listed in Table 1. The approximate locations of the samples are also shown in Fig. 1.

The Makaweli soil occurs in an area of the Koloa volcanic series. According to Stearns (1966), this volcanic series erupted during Pleistocene time and is composed primarily of olivine basalt, picrite basalt, and feldspathoid-containing basalt. The other three soils have developed from rocks of the Waimea volcanic series which extruded during the Tertiary period. These rocks are composed primarily of basalt and olivine basalt. By radiogenic measurements, the Koloa lavas are estimated to be 1.42 million years old, while the lavas of the particular Waimea volcanic series, the Napali formation, are believed to be 4.5 to 5.7 million years old.

Description of Soil Profiles

Descriptions of the soil profiles provided by the Soil Conservation Service, USDA, are included in this section. The Makaweli and Niu soils are classified as Oxisols, while the Puu
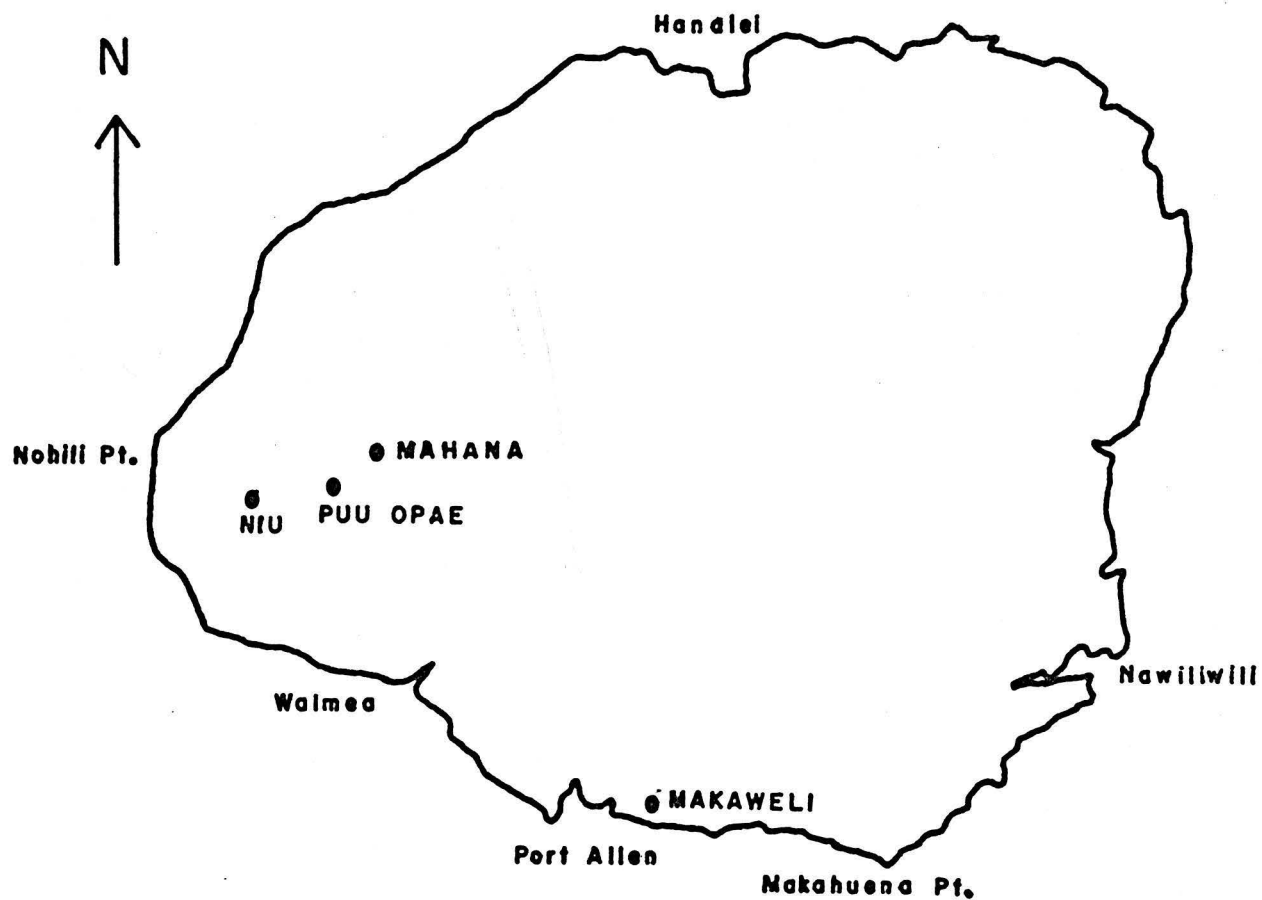
Fig. 1.   Approximate Locations of Sample Sites
on Kauai

Table 1. Names of Soil Series, Locations, and Some Genetic Factors

| | Soil Series | | | |
	Makaweli	Niu	Puu Opae	Mahana
Present SCS Classification	Tropeptic Eutrustox	Tropeptic Eutrustox	Typic Rhodustult	Oxic Dystrandept
Former Classification	Low Humic Latosol	Low Humic Latosol	Humic Ferruginous Latosol	Humic Ferruginous Latosol
Location	159°33'55"W 21°53'45"N	159°44'37.5"W 22°02'6.7"N	159°41'52"W 22°02'16.6"N	159°41'11"W 22°03'N
Rainfall (mean)	32"	27"	34"	40"
Air Temperature	74°F	71°F	70°F	67°F
Soil Temperature	74°F	71°F	69°F	66°F
Parent Material	Koloa Volcani Series	Waimea Canyon Volcanic Series	Waimea Canyon Volcanic Series	Waimea Canyon Volcanic Series
Elevation	150'	1,200'	1,950'	2,250'
Physiographic Position	Low Upland	Medial Upland	Upland	Upland
Drainage Class	Well Drained	Well Drained	Well Drained	Well Drained

Opae and the Mahana soils are classified as Ultisol and Inceptisol, respectively.

MAKAWELI SERIES

The Makaweli series is a member of a fine-silty, halloysitic, isohyperthermic family of Tropeptic Eutrustox. Typically, these soils have a dusky red A horizon and dusky red B horizon that are friable and have weak prismatic structure and friable throughout the profile.

Ap1   0-7"   Dusky red (10R 3/2) silty clay loam, dark red (10R 3/6) when dry; cloddy breaking to weak fine and medium and very fine granular structure; hard, friable, sticky, plastic; abundant very fine and fine roots; many very fine and fine pores; many very fine black concretions; moderately magnetic; numerous fragments of charcoal from burning cane; violent effervescence with hydrogen peroxide; slightly acid (pH 6.1); clear smooth boundary.

Ap2   7-12"   Dusky red (10R 3/3) silty clay loam, material of (10R 3/2) mixed by tillage, dusky red (10R 3/4) dry; weak medium and coarse subangular blocky structure; hard, friable, slightly sticky, slightly plastic; abundant roots; common very

fine and fine tubular pores; many black concretions; moderately magnetic; strong effervescence with hydrogen peroxide; slightly acid (pH 6.4); clear smooth boundary.

B21   12-25"   Dusky red (10R 3/4) silt loam, red (10R 4/6) dry; weak coarse prismatic structure; slightly hard, very friable, slightly sticky, plastic; plentiful roots; many very fine and fine medium pores; common black concretions; moderately magnetic; black manganese dioxide staining along root channels; strong effervescence with hydrogen peroxide; neutral (pH 7.0); clear smooth boundary.

B22   25-36"   Dusky red (10R 3/4) silty clay loam, dark red (10R 3/6) dry; weak coarse prismatic breaking to weak fine medium and coarse subangular blocky structure, with pockets of moderate very fine subangular blocky structure; slightly hard, friable, slightly sticky, plastic; plentiful roots; many very fine and fine and common medium pores; few black concretions; patchy glazed surfaces on peds that appear like pressure surfaces; root channels are lined with black manganese dioxide staining; moderately magnetic;

slight effervescence with hydrogen peroxide; neutral (pH 7.3); gradual wavy boundary.

B23   36-60"   Dusky red (10R 3/3) silty clay loam, dark red (10R 3/6) dry; weak medium and fine subangular blocky with pockets of moderate medium subangular blocky structure; slightly hard, friable, slightly sticky, plastic; few fine and medium roots that seem to be confined between ped faces; many very fine and fine pores; few black manganese dioxide concretions; common very fine weathered mineral particles that tend to impart a gritty feel; few glazed coatings on ped surfaces that appear to be pressure faces; several large stones in this horizon; slight effervescence with hydrogen peroxide; neutral (pH 7.1).

NIU SERIES

The Niu series is a member of a clayey, halloysitic, iso-hyperthermic family of Tropeptic Eutrustox. Typically, these soils have dark reddish brown A horizons and dark red B horizons with nearly continuous coatings on ped faces in the lower B2.

Ap 0-10" Dark reddish brown (2.5YR 3/4) silty clay loam, same color rubbed, dark reddish brown (2.5YR 3/4) dry; weak fine subangular blocky structure; hard, friable, sticky and plastic; plentiful medium, fine and very fine roots; strong to violent effervescence with hydrogen peroxide; medium acid (pH 5.9); abrupt wavy boundary.

B21 10-22" Dark red (2.5YR 3/6) silty clay loam, red (2.5YR 4/6) dry; weak prismatic structure; hard, friable, sticky and plastic; plentiful medium, fine and very fine roots; common medium, many fine, very fine and micro pores; thin patchy coatings on peds, coatings look like clay films; upper 2 inches compacted by tillage; slight to moderate effervescence with hydrogen peroxide; neutral (pH 6.8); gradual smooth boundary.

B22 22-36" Dark red (10R 3/6) light silty clay, dark red (10R 3/6) dry; weak to moderate fine and very fine subangular blocky structure; hard, friable, sticky and plastic; few medium, plentiful fine and very fine roots; few medium, common, fine, many very fine and micro pores;

nearly continuous moderately thick coatings on some peds, coatings look like clay films; compact in places; slight to moderate effervescence with hydrogen peroxide; neutral (pH 6.8); gradual smooth boundary.

B23   36-60"+   Dark red (10R 3/6) silty clay, same color rubbed, dark red (10R 3/6) dry; moderate fine and very fine subangular blocky structure; hard, friable, sticky and plastic; few medium, fine and very fine roots; few medium, common fine and very fine pores; continuous moderately thick coatings on some peds, coatings look like clay films; compact in places; no effervescence with hydrogen peroxide; neutral (pH 6.8).

PUU OPAE SERIES

The Puu Opae series is a member of a clayey, oxidic, isothermic family of Typic Rhodustult. Typically, these soils have a dark reddish brown silty clay loam A horizon and a reddish brown silty clay argillic horizon.

A11   0-7"   Dusky red (2.5YR 3/2) silty clay loam, weak red (2.5YR 4/2) dry; moderate fine and very fine subangular blocky structure; slightly hard, friable, sticky, and plastic; abundant roots;

many fine pores; strong effervescence with hydrogen peroxide; strongly acid (pH 5.3); clear smooth boundary.

A12   7-10"   Dusky red (2.5YR 3/2) loam, dark reddish brown (2.5YR 3/3) dry; weak fine subangular blocky structure; weakly coherent, very friable, slightly sticky and slightly plastic; abundant roots; many fine pores; strong effervescence with hydrogen peroxide; medium acid (pH 5.6); clear smooth boundary.

B1   10-14"   Dark reddish brown (2.5YR 3/3) light silty clay, reddish brown (2.5YR 4/3) dry; moderate fine and very fine subangular blocky structure; hard, friable, sticky and plastic; abundant roots; many fine pores; very few thin clay films on ped faces; moderate effervescence with hydrogen peroxide; strongly acid (pH 5.5); clear smooth boundary.

B21t   14-29"   Reddish brown (2.5YR 4/4) silty clay, same color dry; weak fine and very fine subangular blocky structure; hard, firm, very sticky and plastic; plentiful roots; common fine and very fine pores; thin patchy clay films on ped faces, no effervescence with hydrogen peroxide;

strongly acid (pH 5.3); gradual smooth boundary.

B22t   29-61"   Reddish brown (2.5YR 4/3) silty clay, same color dry; moderate fine and very fine angular blocky structure; hard, firm, very sticky and plastic; few roots; few fine and very fine pores; nearly continuous moderately thick clay films on ped faces; sugar-like coatings of higher chroma in pores; strongly acid (pH 5.1); gradual smooth boundary.

B23t   61"+   Dark reddish brown (2.5YR 3/4) silty clay, weak red (2.5YR 4/2) dry; strong fine and very fine angular and subangular blocky structure; hard, firm, sticky and plastic; very few roots; few fine pores; glazed appearance; continuous moderately thick clay films on ped faces; sugar-like coatings of higher chroma in pores; very strongly acid (pH 4.8).

MAHANA SERIES

The Mahana series is a member of an ashy, isothermic family of Oxic Dystrandept. Typically, these soils have dark reddish brown moderately fine textured A horizon with moderate to strong granular structure. The B horizon is dark red and has

weak coarse prismatic structure in the upper part.

A1   0-7"   Dusky red (10R 3/4) silty clay loam, dark reddish brown (2.5YR 3/4) dry; strong fine and very subangular blocky structures; very hard, friable, sticky and plastic; abundant roots; moderate effervescence with hydrogen peroxide; medium acid (pH 6.0); clear wavy boundary.

B21   7-11"   Dark red (2.5YR 3/6) silt loam, reddish brown (2.5YR 4/4) dry; weak coarse prismatic structure; slightly hard, very friable, non-sticky and nonplastic; abundant roots; many fine pores; slightly acid (pH 6.2); gradual smooth boundary.

B22   11-20" Dark red (2.5YR 3/6) silt loam, reddish brown (2.5YR 4/4) dry; weak coarse prismatic structure; soft, very friable, slightly sticky, slightly plastic, slightly smeary; abundant roots; many fine pores; medium acid (pH 6.0); gradual smooth boundary.

B23   20-35" Dark red (2.5YR 3/6) silt loam, reddish brown (2.5YR 4/4) dry; weak coarse prismatic structure; soft, very friable, slightly sticky, slightly plastic and smeary; few roots; many fine

pores; medium acid (pH 6.0); gradual smooth boundary.

IIB3   35-48"   Dark red (2.5YR 3/6) silty clay loam, reddish brown (2.5YR 5/4) dry; weak, fine and medium subangular blocky structure; slightly hard, friable, sticky, plastic and slightly smeary; few roots; many fine pores; contains hard earthy lumps; slightly acid (pH 6.2); clear smooth boundary.

IIC   48-61"+   Dark reddish brown (5YR 3/3) silty clay loam, some coatings of dark red (10R 3/8), reddish brown (2.5YR 4/4) dry; moderate, fine and medium angular and subangular blocky structure; compact in place, hard, firm, sticky, and plastic; few roots; many fine and very fine pores; continuous stress cutans, dark red (10R 3/8) coatings that look like clay films, weak patchy slickensides; medium acid (pH 6.0).

Methods

Preparation of Samples

The samples were air dried and subdivided. One sub-sample was gently crushed with a wooden roller and sieved through a 10-mesh (approximately 2-mm) screen, removing the

large roots and coarse fragments. This subsample was used to determine the particle size distribution, water retained at 15 bars, cation exchange capacity, exchangeable bases, soil pH, and total nitrogen. The other subsample was ground to pass a 100-mesh screen and was used to determine organic carbon and free iron oxide. Both of the subsamples were used to determine the mineralogical properties.

Particle Size Distribution

The particle size distribution was determined by the pipette method proposed by Kilmer and Alexander (1949) using sodium metaphosphate as the dispersing agent. This method was used to conform to the procedure described by the Soil Survey Staff (1960) so that the data obtained in this investigation can be compared with the data and criteria of the U. S. Comprehensive Soil Classification System. Future investigation on the nature of dispersion of Hawaiian and other tropical soils is necessary to measure the absolute texture.

Water Retained at 15 Bars

The moisture content retained at 15 bars was measured with the pressure membrane apparatus by following the procedure of Richards (1954).

Differential Thermal Analysis

Air dried 100-mesh sample was used for differential thermal analysis. The sample was stored for at least three days in a desiccator which was maintained at 50% relative humidity with saturated $Mg(NO_3)_2$ solution. A 0.1-g sample diluted with an equal amount of calcined Al_2O_3 was heated from room temperature to 1,000°C at a rate of approximately 10°C per minute. Calcined Al_2O_3 was used as reference standard, and nitrogen gas was flushed through the sample chamber to suppress oxidation of organic matter.

X-Ray Diffraction Analysis

For the clay minerals investigation by X-ray diffraction analysis, the 10-mesh sample was fractionated by the procedure described by Jackson (1956). Preferentially oriented slide of K-saturated clay was then examined by means of the Philips Norelco X-ray Diffractometer using Cu radiation filtered with Ni. X-ray diffraction traces were obtained after the sample was air dried at room temperature and after heating to 105°C, 350°C, and 550°C. The instrument was set to operate at 500 cps for the Makaweli clay sample and at 1,000 cps for the remaining clay samples with the goniometer scanning from 2° through 40° 2θ.

Randomly oriented powdered silt fraction was also examined by X-ray diffraction analysis. The parameters were 500 cps and

a goniometer scan from 2° through 64° θ.

Cation Exchange Capacity

Cation exchange capacity was determined by the method described by Peech et al. (1947). After allowing the 10-mesh sample to stand in ammonium acetate (pH 7.0) for 24 hours, the suspension was filtered through a Buchner funnel. The filtrate was saved for the determination of exchangeable bases. After filtration of the suspension, the excess ammonium ions were removed from the soil with a $\underline{N}$ NaCl solution. The amount of ammonium ions on the exchange sites were then determined by the Kjeldhal method.

Exchangeable Bases

The filtrate from the cation exchange capacity determination was used to measure the amount of exchangeable bases in the soil. Exchangeable Na and K were determined by means of the Beckman DU Flame Spectrophotometer while exchangeable Ca and Mg were determined by means of the Perkin-Elmer Atomic Absorption Unit, Model 303.

Soil pH

Soil acidity was determined by means of the Beckman Zeromatic II pH Meter. Soil suspensions using water (1:5 and 1:1) and $\underline{N}$ KCl solution (1:1) were used. These suspensions

were allowed to equilibrate for at least one hour with occasional stirring before being tested on the pH meter. Delta pH was also calculated by taking the difference in pH obtained in KCl (1:1) and H_2O (1:1).

Organic Matter

Organic matter was determined by the Walkley-Black (1934) method. The organic carbon in the air dried 100-mesh soil was oxidized in a potassium dichromate-sulfuric acid mixture, and the excess dichromate was back-titrated with ferrous sulfate solution. The amount of organic matter was calculated by multiplying the amount of organic carbon by a factor of 1.72.

Total Nitrogen

Total nitrogen was determined by the Kjeldahl method (AOAC, 1955). The organic carbon in the air dried 10-mesh soil was oxidized in a potassium sulfate-sulfuric acid mixture and the nitrogen in the sample was allowed to combine with the sulfate ion to form ammonium sulfate. The ammonium ion was then distilled into boric acid and the product was titrated with standard sulfuric acid using methyl red-methylene blue mixed indicator.

Free Iron Oxides

The free iron oxides were determined by the method outlined by Kilmer (1960). The method was modified (R. T. Watanabe,

personal communication) by reducing the sample size because of the high amounts of free iron oxide in Hawaiian soils. The ferric iron was reduced to ferrous ion with sodium dithionite and the amount of free iron oxides was determined volumetrically with a standard potassium dichromate solution using barium diphenylamine indicator.

RESULTS AND DISCUSSION OF RESULTS

Particle Size Distribution

The percentages of sand, silt, and clay and the textural class as determined by the pipette method are presented in Table 2. The apparent texture as determined by the feel method in the field is also included in the same table.

When the 21 horizons of the four profiles are considered collectively, 13 horizons show that the apparent texture is coarser than the texture obtained by the pipette method. These results indicate that these soils, also observed in other Hawaiian soils by other investigators, have a tendency to form stable aggregates which are reflected in the apparent texture.

On the other hand, when the four profiles are compared one against the other, a coarser texture is encountered by the pipette method in the Makaweli and Mahana soils. These results suggest the presence of stable secondary sesquioxides which may be the product of advanced stage of weathering.

When the three soils associated with the Waimea Canyon volcanic series are considered, there is a decrease in the clay content and a corresponding increase in the coarser fractions with an increase in the rainfall. These findings are not in accord with those of Loganathan (1967) and Klemmedson and Jenny (1966) who observed an increase in the clay content with an increase in

Table 2. Particle Size Distribution and Textural Class

Soil	Horizon	Sand %	Silt %	Clay %	Pipette Method	Apparent Texture
Makaweli	Ap1	26.19	48.69	25.12	loam	silty clay loam
	Ap2	30.91	50.59	18.50	silt loam	silty clay loam
	B21	6.18	83.76	10.06	silt	silt loam
	B22	29.01	28.42	42.57	clay	silty clay loam
	B23	27.80	34.03	38.17	clay loam	silty clay loam
Niu	Ap	12.15	33.24	54.61	clay	silty clay loam
	B21	1.49	16.79	81.72	clay	silty clay loam
	B22	4.07	25.42	70.51	clay	light silty clay
	B23	3.16	25.54	71.30	clay	silty clay
Puu Opae	A11	11.28	48.44	40.28	silty clay	silty clay loam
	A12	36.15	39.18	24.67	loam	loam
	B1	1.96	38.61	59.43	clay	light silty clay
	B21t	0.77	13.40	85.83	clay	silty clay
	B22t	1.36	18.21	80.43	clay	silty clay
	B23t	2.06	21.66	76.28	clay	silty clay

Table 2. Particle Size Distribution and Textural Class (Continued)

Soil	Horizon	Sand %	Silt %	Clay %	Pipette Method	Apparent Texture
Mahana	A1	10.75	46.87	42.38	silty clay	silty clay loam
	B21	53.66	34.41	11.93	sandy loam	silt loam
	B22	49.98	41.53	8.49	loam	silt loam
	B23	53.64	41.61	4.75	sandy loam	silt loam
	IIB3	26.66	38.94	34.40	clay loam	silty clay loam
	IIC	16.05	36.15	47.80	clay	silty clay loam

rainfall.

Although rainfall plays a dominant role in soil formation, parent material also show great influence. Loganathan's investigation dealt with relatively youthful andesitic volcanic ash whereas the parent material of the soils in this study is primarily highly weathered basic or ultrabasic basaltic rock. There is some suggestion in Hawaiian soils that clay content increases up to a point and then decreases with soil age. Soils formerly classified as the Low Humic Latosols probably constitutes those with maximum clay content. The origin and development of ferruginous concretions in Hawaiian latosols are discussed by Sherman and Kanehiro (1954).

Water Retained at 15 Bars

The water content retained at 15 bars is shown in Table 3. When the data are compared with those in Table 2, it is difficult to see any relationship between 15-bar water and particle size distribution including textural class. Although there is an increase in rainfall in the Niu-Puu Opae-Mahana sequence, the relationship between 15-bar water and rainfall distribution is also not clear.

However, when the data in Table 3 are examined with the soil descriptions in the Materials and Methods section, some relationship can be observed. In general, horizons which contain clay or clay-like coatings show 27 - 31% 15-bar water. The

Table 3.   Water Content Retained at 15 Bars

Soil	Horizon	15-bar Water (%)
Makaweli	Ap1	22.06
	Ap2	22.12
	B21	21.31
	B22	22.19
	B23	23.21
	Mean	22.18
Niu	Ap	24.31
	B21	27.15
	B22	26.23
	B23	27.96
	Mean	26.41
Puu Opae	A11	22.89
	A12	22.59
	B1	16.49
	B21t	30.29
	B22t	30.91
	B23t	28.10
	Mean	25.21

Table 3. Water Content Retained at 15 Bars (Continued)

Soil	Horizon	15-bar Water (%)
Mahana	A1	25.49
	B21	28.85
	B22	31.93
	B23	33.40
	IIB3	31.56
	IIC	30.18
	Mean	30.24

Mahana soil which is classified as a soil derived from volcanic ash also shows 29 - 33% 15-bar water in the subsurface horizons.

A matrix of linear correlation for 14 variables which were determined in this investigation is shown in Table 4. This table shows a highly significant negative correlation between 15-bar water and free iron oxide.

In systems such as these, it is not possible to estimate the clay content by multiplying the 15-bar water content by a factor of 2.5 as suggested by the Soil Survey Staff (1967). This weakness lies not so much in the factor as in the method of dispersion employed in the procedure for mechanical analysis. No adequate method for dispersing high iron oxide soils is presently available, and for this reason many soil properties which normally correlate with texture do not in soils such as these. The resistance to dispersion might be a useful index for predicting the behavior of these soils.

In highly weathered Oxisols, the secondary aggregates behave as true sands; that is, these aggregates do not retain as much clay aggregates. For this reason, as the free iron oxide content increases, the sand-like secondary oxide aggregate content increases and the 15-bar water content decreases.

Table 4. Matrix of Linear Correlation for 14 Variables

	pH H$_2$O	pH KCl	C	N	C/N	CEC	Ca	Mg	Na	K	BS	Free Fe	Clay	15-Bar
pH H$_2$O	1.00													
pH KCl	0.96	1.00												
C	-0.39	-0.43	1.00											
N	-0.22	-0.24	0.92	1.00										
C/N	-0.70	-0.74	0.77	0.53	1.00									
CEC	-0.40	-0.43	0.90	0.74	0.81	1.00								
Ca	0.56	0.58	-0.23	0.02	-0.62	-0.20	1.00							
Mg	0.84	0.79	-0.35	-0.16	-0.65	-0.26	0.80	1.00						
Na	0.68	0.65	-0.43	-0.37	-0.56	-0.34	0.32	0.61	1.00					
K	-0.05	-0.16	0.67	0.78	0.32	0.51	0.24	0.09	-0.12	1.00				
BS	0.87	0.87	-0.56	-0.32	-0.88	-0.56	0.83	0.89	0.61	-0.08	1.00			
Free Fe	0.51	0.52	0.34	0.46	-0.14	0.18	0.36	0.35	0.27	0.36	0.35	1.00		
Clay	-0.10	-0.06	-0.54	-0.51	-0.44	-0.47	0.44	0.15	0.09	-0.23	0.32	-0.27	1.00	
15-Bar	-0.63	-0.61	0.15	-0.13	0.54	0.41	-0.46	-0.48	-0.34	-0.25	-0.59	-0.61	0.07	1.00

d.f. = n - 2 = 19; $P_{.05}$, r = 0.433; $P_{.01}$, r = 0.549.

Differential Thermal Analysis

Figures 2, 3, 4, and 5 show kaolin to be the dominant clay mineral in the four soils. There are also indications of small amounts of hydrous oxides of aluminum (gibbsite) and/or iron, magnetite and possibly maghemite, and moderate to large amounts of organic matter in some of the horizons. These curves also show adsorbed water which is commonly associated with allophane.

Adsorbed water is characterized by an endothermic peak at approximately 125°C. Gibbsite shows an endothermic peak at 295°C (Ross and Kerr, 1931), while magnetite and possibly maghemite show an exothermic peak between 300 and 400°C (Walker, 1964). Kaolinite is characterized by an endothermic peak at 525°C (Ross and Kerr, 1931). This clay mineral also shows an exothermic peak near 1,000°C. Organic matter is commonly oxidized between 100 and 400°C and such oxidation is suppressed when nitrogen gas is passed through the sample holder of the differential thermal unit. However, even with an inert atmosphere, it has been shown that the presence of organic matter can give a broad exothermic peak at 550°C. There is a positive correlation between the size of this peak and soil organic carbon content.

Discussion on the occurrence of the minerals will be made in conjunction with the results of X-ray diffraction analysis.

MAKAWELI
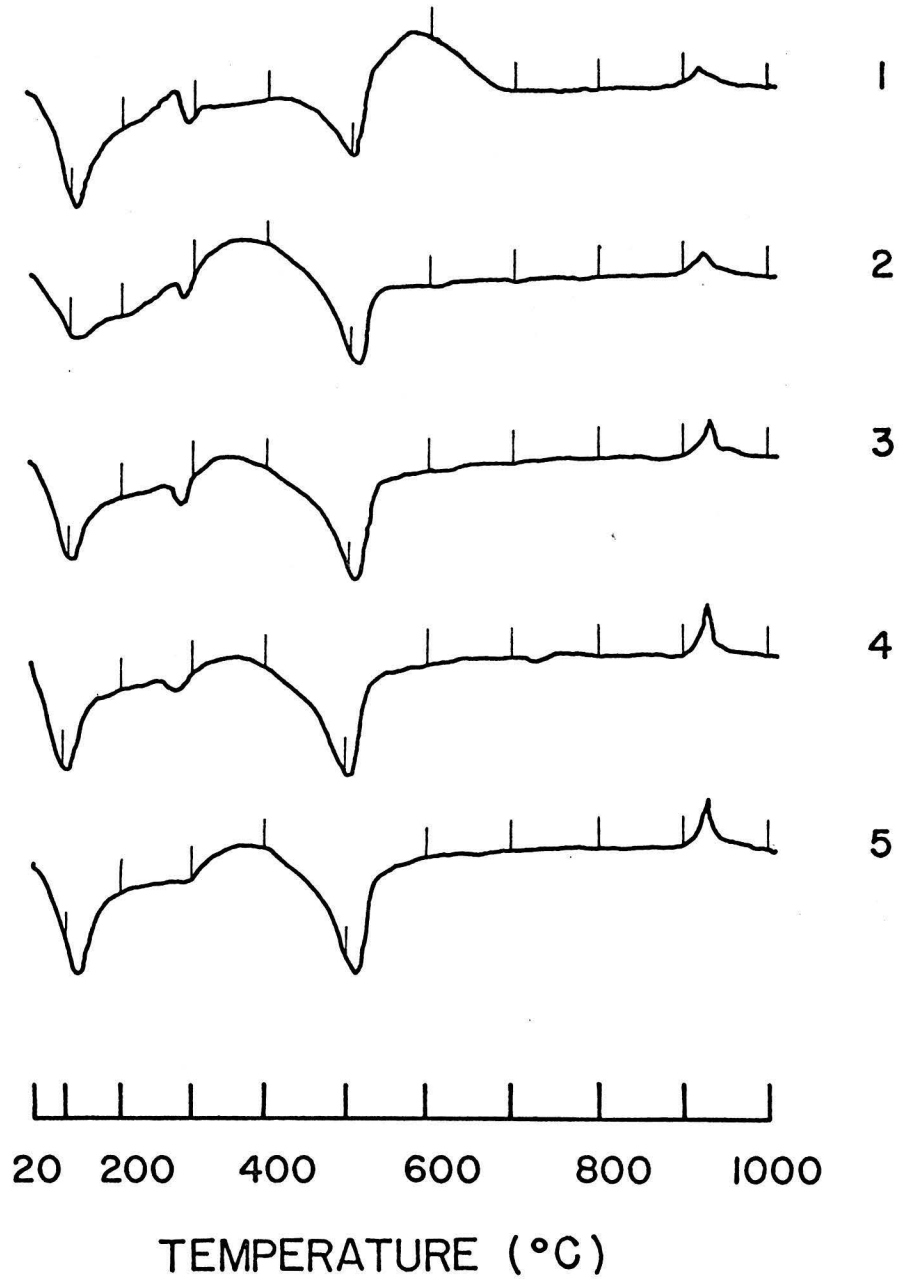
Fig. 2. Differential Thermal Curves of Makaweli Soil

NIU

TEMPERATURE (°C)

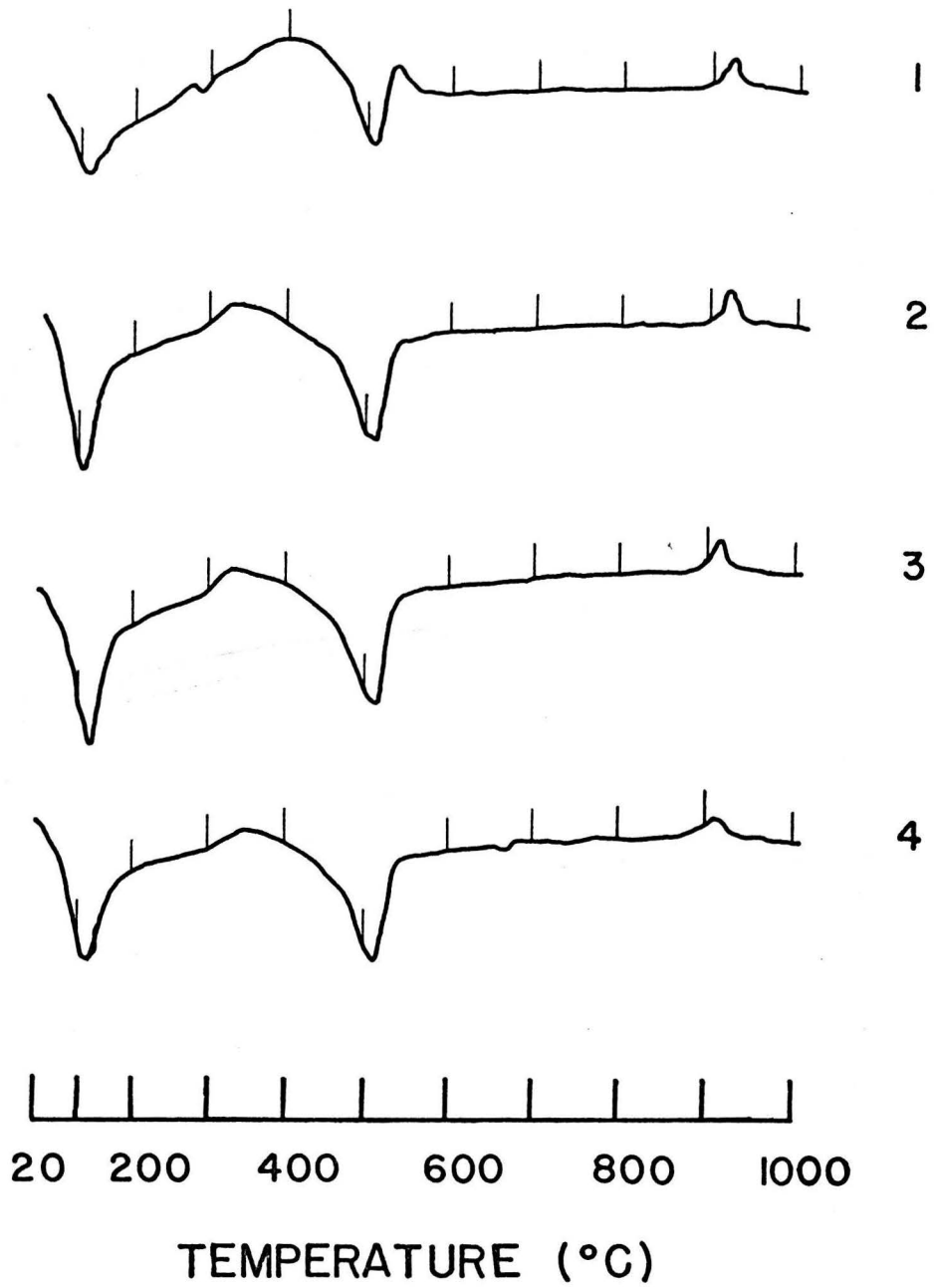Fig.3.   Differential Thermal Curves of Niu Soil

PUU OPAE

1

2

3

4

5

6

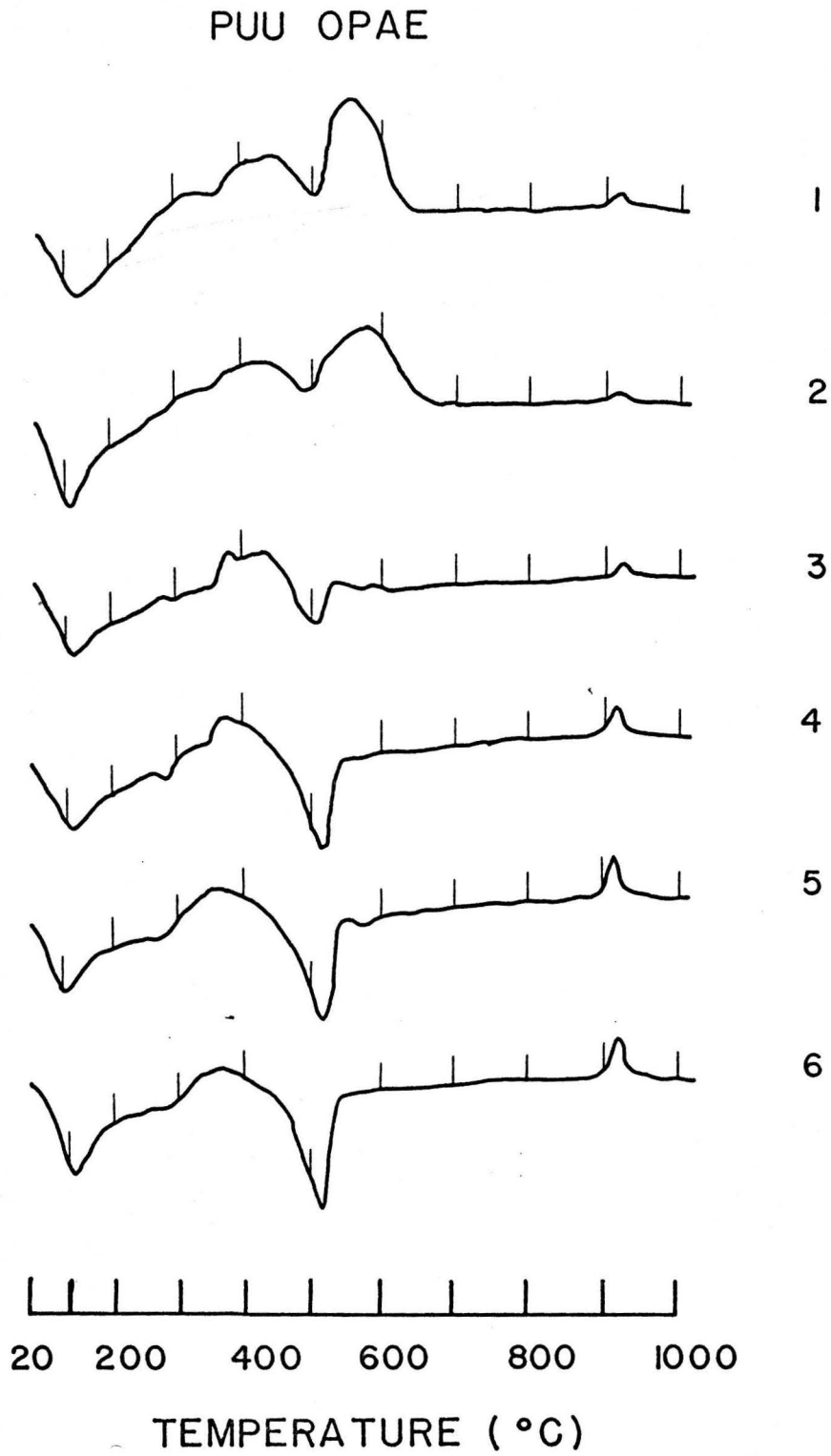20   200   400   600   800   1000

TEMPERATURE (°C)

Fig. 4.   Differential Thermal Curves of Puu Opae Soil
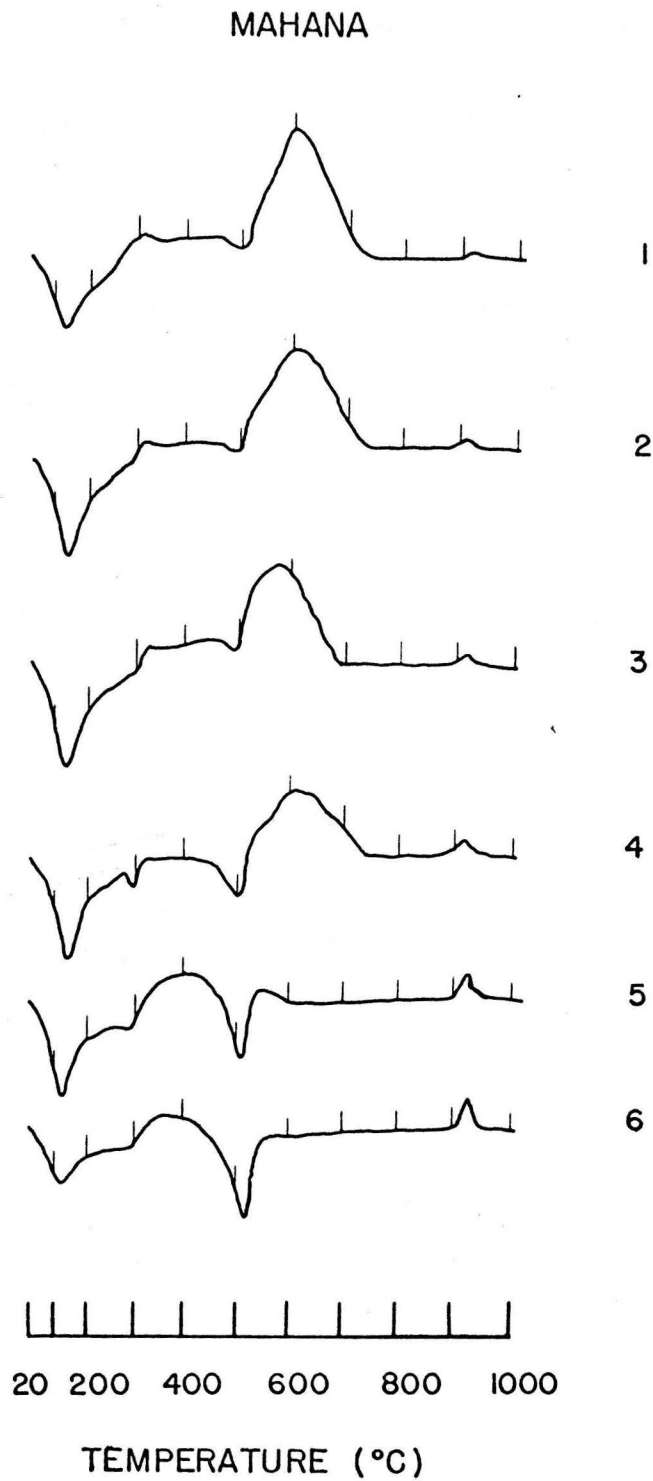
MAHANA

Fig. 5. Differential Thermal Curves of Mahana Soil

X-Ray Diffraction Analysis

Figures 6, 7, 8, and 9 show the X-ray diffraction traces of the deferrated clay fraction of the four soils. Except for organic matter, these traces also show the presence of kaolin (7.14, 3.56, and 2.38A peaks) and gibbsite (4.85A peak) which were observed in Figs. 2 - 5. The presence of magnetite and possibly maghemite (2.5A peak at 35° 2θ) is only weakly expressed in the X-ray diffraction traces of the Makaweli soil and the lower horizons of the Puu Opae and Mahana soils. This weak expression may be due to the occurrence of these iron oxides in the coarse fractions rather than in the clay fraction of the soils.

As indicated by differential thermal analysis, the X-ray diffraction analysis shows kaolin to be the dominant mineral in the clay fraction of the four soils.

X-ray diffraction analysis data of randomly oriented powdered silt fraction of the four soils are presented in Table 5. The table shows that much of the silt fraction is composed of iron-titanium oxides and quartz. No data were collected for the sand fraction.

The mineralogy of the Makaweli soil is quite different from that of the other soils. In addition to kaolin and gibbsite, large amounts of boehmite (6.10 and 3.16A peaks) are observed especially in the upper three horizons. Mica (9.9, 4.9, and
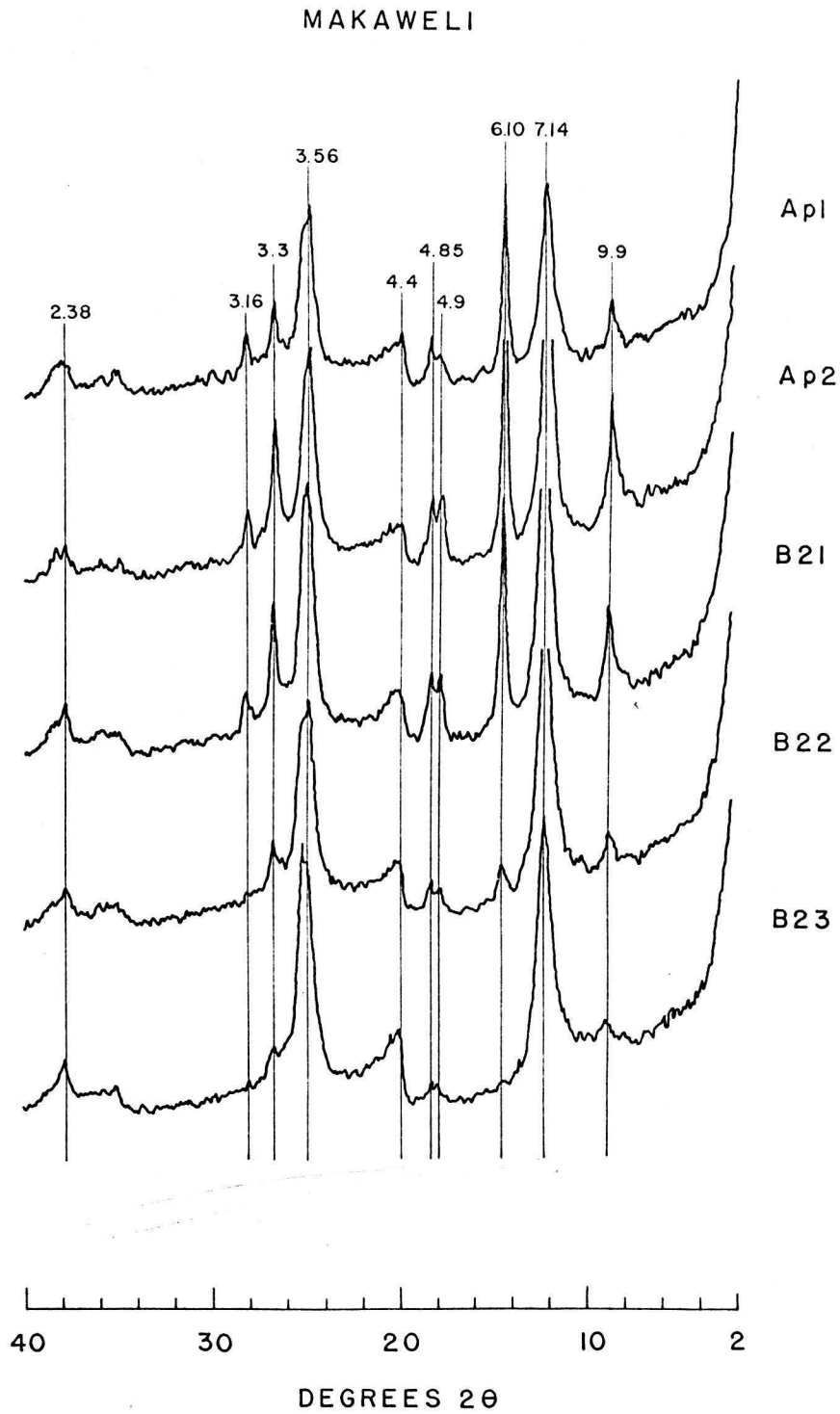
MAKAWELI

Fig. 6. X-Ray Diffraction Traces
of Clay Fraction of Makaweli Soil

NIU
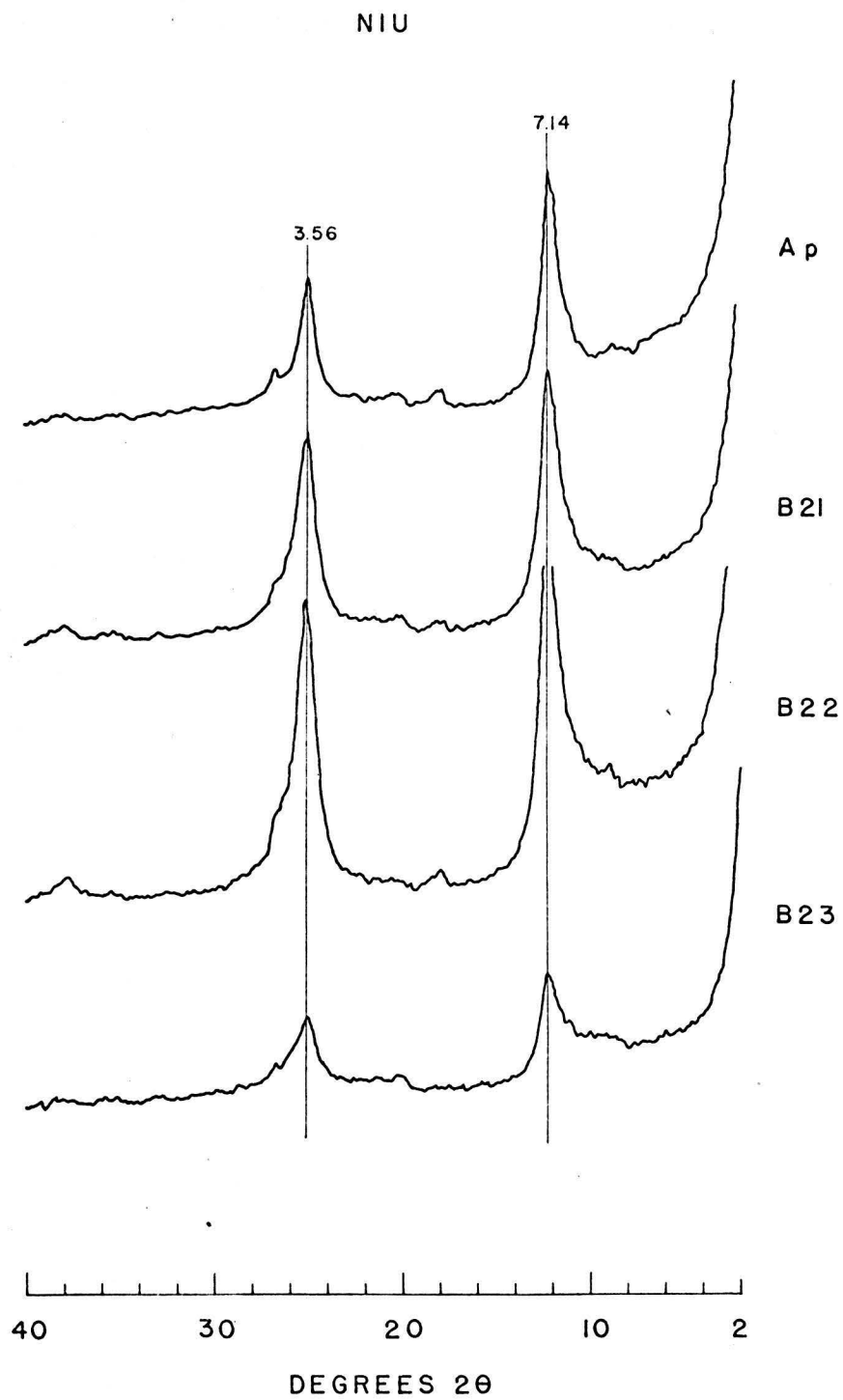
Fig. 7. X-Ray Diffraction Traces
of Clay Fraction of Niu Soil
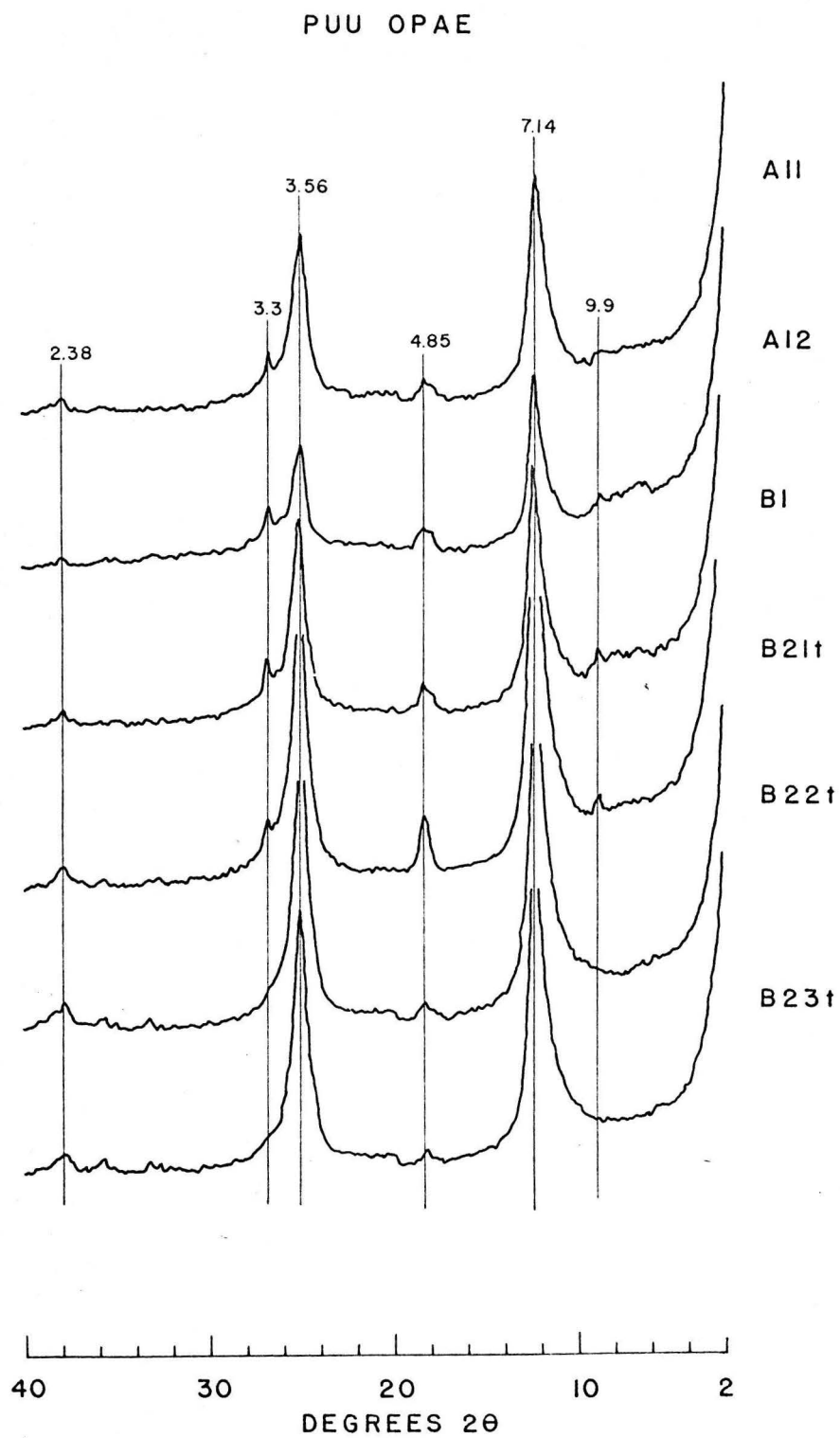
PUU OPAE

Fig. 8. X-Ray Diffraction Traces
of Clay Fraction of Puu Opae Soil
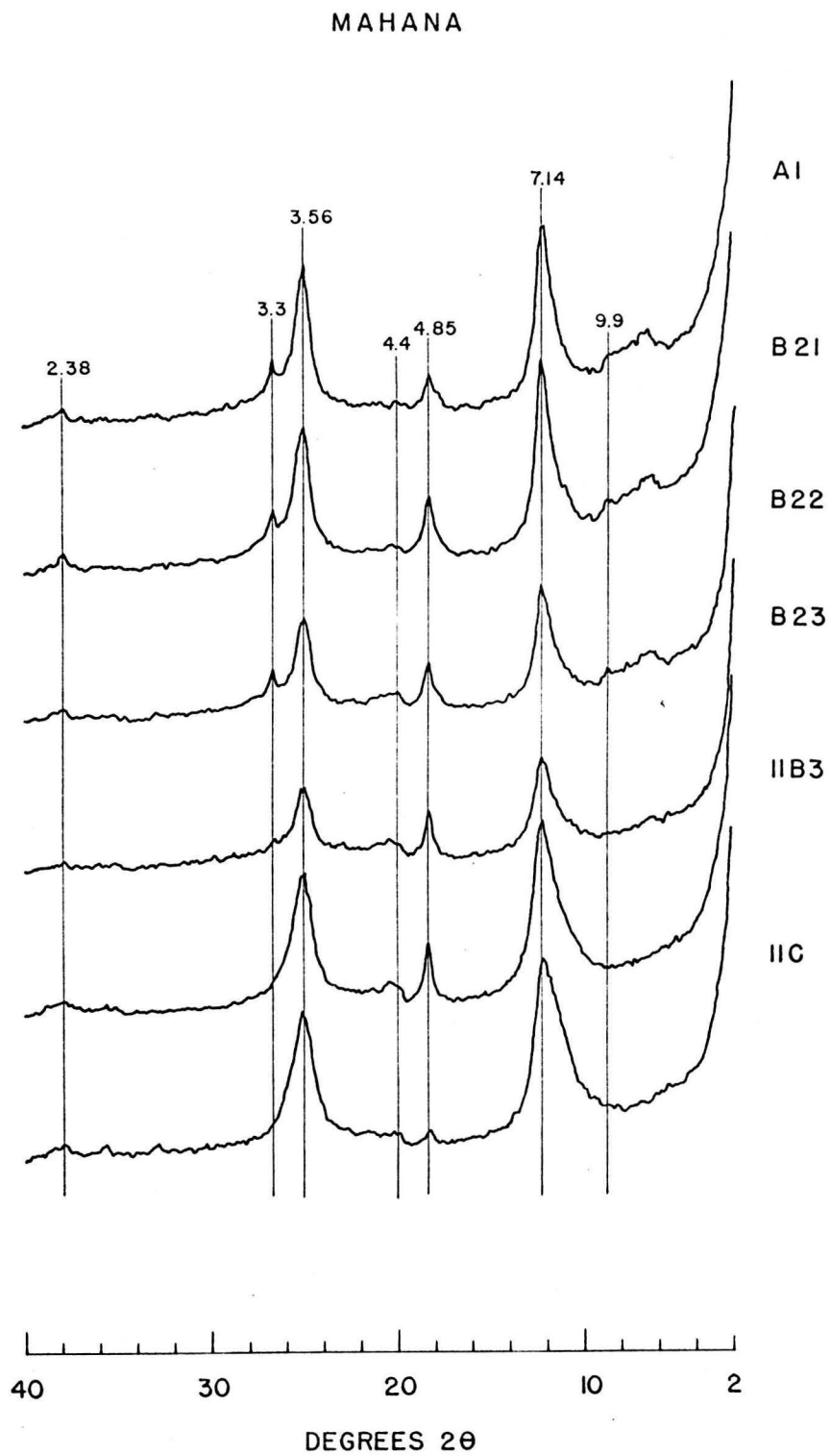
MAHANA

Fig. 9. X-Ray Diffraction Traces
of Clay Fraction of Mahana Soil

Table 5. X-Ray Diffraction Data of Silt Fraction

Horizon	Mica	Kaolin	Boehmite	Hematite	Ilmenite	Magnetite-Maghemite	Quartz
				Makaweli Soil			
Ap1	X	X	X	-	-	XX	X
Ap2	X	X	X	-	-	XX	X
B21	X	X	X	-	-	XX	X
B22	-	XX	-	-	-	XX	-
B23	-	XX	-	-	-	XXX	-
				Niu Soil			
Ap	X	X	-	XX	XX	XX	X
B21	-	-	-	XX	XX	XX	X
B22	-	-	-	X	XX	X	X
B23	-	-	-	X	XX	X	X
				Puu Opae Soil			
A11	-	-	-	X	X	XXX	XX
A12	-	-	-	X	XX	XXX	XXX
B1	-	-	-	X	XX	XXX	XXX

Table 5. X-Ray Diffraction Data of Silt Fraction (Continued)

Horizon	Mica	Kaolin	Boehmite	Hematite	Ilmenite	Magnetite-Maghemite	Quartz
				Puu Opae Soil (Continued)			
B21t	-	-	-	XX	XX	XXX	XX
B22t	-	-	-	XXX	X	XXX	X
B23t	-	-	-	XXX	X	XXX	X
				Mahana Soil			
A1	-	-	-	XX	XX	XX	XX
B21	-	-	-	X	X	XX	XX
B22	-	-	-	X	XX	XX	XX
B23	-	-	-	X	X	XX	X
IIB3	-	-	-	X	X	XXX	X
IIC	-	-	-	-	X	XXX	X

X = Very few, few
XX = Common
XXX = Abundant

3.3A peaks) and possibly quartz (3.3A peak) are also present in this soil.

The occurrence of boehmite, a monohydrate of alumina, is significant because it is rare in Hawaiian soils. Gibbsite is the common hydrous aluminum oxide end product in the highly weathered soils. Tamura and Jackson (1953) stated that gibbsite may transform not only to allophane and kaolinite or montmorillonite by resilication but also to boehmite. Sherman (1958) also pointed out that boehmite may be found in well-drained locations where bauxite occurs. Loughnan and Bayliss (1961) found boehmite in the upper horizons of three bauxite profiles developed from kaolinitic sandstone near Weipa in Queensland, Australia. Gibbsite was abundant in these deposits, and these authors believed that boehmite was developed by partial dehydroxylation of gibbsite. The climate in the Weipa area is described as hot and monsoonal "with a mean temperature of 82°F and an average rainfall of 60 inches per annum concentrated in the period from December to March".

The Makaweli soil is found in an area where the parent rock is nepheline basalt and melilite nephelite basalt. It is highly likely that weathering of these silica-deficient rocks under wet and dry climate may have contributed to the formation of boehmite. The genesis and the nature of the lateritic and laterite soils in Hawaii are presented by Sherman (1949, 1950).

Although the peaks of boehmite are strong, it is interesting to note the peaks of kaolin are equally strong. The presence of a small to moderate 020 reflection band at 4.4A indicates that the kaolin is primarily kaolinite with only small amounts of halloysite or disordered kaolin. If the Makaweli soil is a highly weathered soil, why should boehmite and kaolinite occur together? Is it possible that boehmite is the end product of the present climate and kaolinite and gibbsite the remaining end products of the past climate? Mica and quartz are present in this soil. Juang and Uehara (1968), Loganathan (1967), Gardiner (1967), and others have found increasing amounts of these minerals with increasing rainfall. Did the sample site once receive much more rainfall than today? Studies of more soils near the sample site as well as other soils classified as Makaweli soil series must be made to answer these questions.

Small amounts of gibbsite, mica, and quartz are also observed in the sequence which includes the Niu, Puu Ópae, and Mahana soils. In addition, as stated earlier, magnetite and possibly maghemite are observed in the lower horizons of the Puu Opae and Mahana soils. These iron oxide minerals, together with ilmenite and quartz constitute a major portion of the silt fraction. The occurrence of the iron oxide has been cited by Sherman and Kanehiro (1954). The large amount of quartz in the Puu Opae soil is especially interesting, and further study of

the silt and sand fractions is necessary to determine its genesis or origin.

There are even indications of layer silicate minerals of higher d-spacing as evidenced by the presence of a weak and broad peak at approximately 6° 2θ in the X-ray traces of the B1 horizon of the Puu Opae and of the upper three horizons of the Mahana soil.

The Niu soil was formerly classified as Low Humic Latosol while the Puu Opae and Mahana soils were classified as Humic Ferruginous Latosols. According to Tamura et al. (1953), the Low Humic Latosols contain dominantly kaolinite and hematite. No hematite is observed in the X-ray diffraction traces because the iron oxide was removed. The Humic Ferruginous Latosols are characterized not only by kaolin but also by free iron oxide and iron-titanium oxides. The free iron oxide is not observed in the X-ray diffraction traces of the Mahana soil because they were removed during the pretreatment of the clay fraction. The iron-titanium oxides are also virtually absent in the same traces because much of these oxides occur as concretions or nodules. These oxides, primarily titanomagnetite, have been studied by Walker (1964).

The X-ray traces of the clay fraction, therefore, show a kaolinitic end product in the Niu-Puu Opae-Mahana sequence with a slight increase in gibbsite as rainfall increased. The X-ray

data of the silt fraction show moderate to large amounts of iron-titanium oxides and quartz, especially in the Niu, Puu Opae, and Mahana soils.

Cation Exchange Capacity, Exchangeable Bases, and Base Saturation

The data relating to cation exchange capacity, exchangeable bases, and base saturation are presented in Table 6.

Except for the third horizon of the Makaweli soil, the cation exchange capacities of the Makaweli and Niu soils appear very similar. The exchange capacities of these soils are also almost similar to that of kaolin-rich soils. Some of the horizons show slightly higher than 15 meq/100 g of soil. Organic matter may account for this increase in the surface horizons, while amorphous clay colloids may account for the increase in the lowest horizon of the Niu soil (Fig. 7). The base saturation in these soils is high and ranges from 81 to 95%.

In the Puu Opae soil, a decrease in the cation exchange capacity is observed with depth in profile. Again, the higher values in the surface horizons may be due to organic matter. Clay skins observed in the lower horizons of this profile suggest the secondary accumulation of clay minerals. Such an accumulation, however, does not indicate an increase in the exchange capacity because it is dependent upon the type of clay mineral

Table 6. Cation Exchange Capacity, Exchangeable Bases,
and Base Saturation

Soil	Horizon	Exchangeable Bases					Total	BS
		CEC	Ca	Mg	Na	K	Exch.	%
			meq/100 g of soil				Bases	
Makaweli	Ap1	18.51	8.37	7.55	0.38	0.90	17.20	92.92
	Ap2	14.66	6.24	5.45	0.40	0.24	12.33	84.11
	B21	9.93	4.34	4.05	0.46	0.11	8.96	90.23
	B22	12.16	4.76	5.22	0.95	0.19	11.12	91.45
	B23	14.61	4.76	6.26	2.01	0.19	13.22	90.49
Niu	Ap	18.69	10.06	4.56	0.31	0.31	15.24	81.54
	B21	14.09	7.61	3.44	0.31	0.04	11.40	80.91
	B22	15.57	9.36	4.73	0.79	0.13	15.01	96.40
	B23	19.95	9.66	8.51	0.67	0.08	18.92	94.84
Puu Opae	A11	24.83	7.28	2.85	0.48	1.37	11.98	48.25
	A12	17.66	3.53	1.28	0.21	0.61	5.63	31.88
	B1	12.46	4.30	1.67	0.19	0.16	6.32	50.72
	B21t	14.39	5.97	2.68	0.33	0.27	9.25	64.28
	B22t	13.77	4.46	1.51	0.14	0.18	6.29	45.68
	B23t	11.53	2.32	0.76	0.32	0.16	3.56	30.88
Mahana	A1	30.25	6.65	3.71	0.16	1.18	11.70	38.68
	B21	30.00	2.07	0.86	0.12	0.40	3.45	11.50
	B22	29.69	0.08	0.15	0.09	0.28	0.60	2.02
	B23	26.09	0.03	0.06	0.08	0.20	0.37	1.42
	IIB3	20.62	0.02	0.06	0.11	0.14	0.33	1.60
	IIC	16.86	0.17	0.50	0.11	0.13	0.91	5.40

(Grim, 1953). Figure 8 shows the dominance of kaolinite. Kaolinite possesses a low cation exchange capacity. The base saturation is lower in the Puu Opae than in the Makaweli and Niu soils and ranges from 31 to 64%.

The cation exchange capacity is highest in the Mahana soil. In addition to the contribution of organic matter, the nature of volcanic ash parent material is believed to have an important role in the exchange capacity. The base saturation is very low in the Mahana soil, especially in the subsoil.

The results of this investigation show that there is no clear relationship between cation exchange capacity and rainfall. On the other hand, base saturation decreased as rainfall increased. Table 4 shows significant correlation between cation exchange capacity (CEC) and base saturation (BS), organic carbon (C), total nitrogen (N), and clay content.

Soil pH, Delta pH, and Exchangeable H^+

Soil acidity data are presented in Table 7. Except in the Makaweli soil, pH in 1:5 water suspension was slightly higher in the 1:1 water suspension. The pH in 1:1 KCl suspension was generally lower than in the 1:1 water suspension. A positive delta pH was observed only in the second and third horizons of the Niu soil. The pH (1:1 H_2O) of the Makaweli soil is the highest (mean = 6.7). When the pH (1:1 H_2O) of the other

Table 7. Soil pH, Δ pH, and Exchangeable H^+

Soil	Horizon	pH			Δ pH	Exch. H^+ meq/100 g
		1:5 H_2O	1:1 H_2O	1:1 KCl		
Makaweli	Ap1	6.6	6.5	6.1	-0.4	1.31
	Ap2	6.3	6.4	6.2	-0.2	2.33
	B21	6.6	6.9	6.5	-0.4	0.97
	B22	6.8	7.0	6.6	-0.4	1.04
	B23	6.6	6.8	6.5	-0.3	1.39
Niu	Ap	5.8	5.6	5.6	0	3.45
	B21	6.0	5.9	6.1	+0.2	2.69
	B22	6.1	6.1	6.2	+0.1	0.56
	B23	6.4	6.3	6.0	-0.3	1.03

Table 7. Soil pH, Δ pH, and Exchangeable H$^+$ (Continued)

| Soil | Horizon | pH | | | Δ pH | Exch. H$^+$ |
		1:5 H$_2$O	1:1 H$_2$O	1:1 KCl		meq/100 g
Puu Opae	A11	5.7	5.5	5.1	-0.4	12.85
	A12	5.5	5.3	5.3	0	12.03
	B1	5.7	5.6	5.5	-0.1	6.14
	B21t	5.8	5.4	5.1	-0.3	5.14
	B22t	5.4	5.1	4.6	-0.5	7.48
	B23t	4.8	4.6	4.3	-0.3	7.97
Mahana	A1	5.7	5.4	4.9	-0.5	18.55
	B21	5.6	5.3	4.8	-0.5	26.55
	B22	5.4	5.0	4.9	-0.1	29.09
	B23	5.2	4.9	4.9	0	25.72
	IIB3	4.8	4.9	4.7	-0.2	20.29
	IIC	4.8	4.7	4.4	-0.3	15.95

soils are considered, a decrease is observed going from the Niu soil (mean = 6.0) to the Puu Opae (mean = 5.2) to the Mahana soil (mean = 5.0). Therefore, there is a decrease in pH (1:1 H_2O) as rainfall increased. The acidity of the soil increases as the bases are removed by rainfall.

Table 4 shows that pH (1:1 H_2O) is significantly correlated with exchangeable bases except K, base saturation, C/N ratio, free iron oxide, and 15-bar water.

The relationship between pH and several variables are well known. For example, organic account for low pH (Helgason, 1968) and exchangeable bases, particularly Ca, is related with high pH (Kanehiro and Chang, 1956).

Organic Matter, Organic Carbon, Total Nitrogen, and C/N Ratio

The organic matter, organic carbon, total nitrogen, and the C/N ratio data are presented in Table 8.

Within each profile, the organic matter decreases with depth. Since the organic matter is calculated from the organic carbon, the latter also shows the same trend. The total nitrogen similarly decreases with depth. Although the C/N ratio is highest in the surface horizons of the Makaweli, Niu, and Puu Opae soils, no definite trend is seen. In the Mahana soil, the ratio is highest in the third horizon of the profile.

Table 8. Organic Matter, Organic Carbon, Total Nitrogen,
and Carbon-Nitrogen Ratio

Horizon	Organic Matter %	Organic Carbon %	Total Nitrogen %	C/N
		Makaweli Soil		
Ap1	4.66	2.71	0.23	11.78
Ap2	2.68	1.56	0.18	8.67
B21	0.84	0.49	0.10	4.90
B22	0.85	0.49	0.07	7.00
B23	0.86	0.50	0.07	7.14
Mean	1.98	1.15	0.13	7.90
		Niu Soil		
Ap	3.71	2.16	0.22	9.82
B21	1.15	0.67	0.09	7.44
B22	1.02	0.59	0.09	6.56
B23	0.88	0.51	0.07	7.29
Mean	1.69	0.98	0.12	7.78
		Puu Opae Soil		
A11	7.43	4.32	0.30	14.40
A12	6.04	3.51	0.31	11.32
B1	2.81	1.63	0.15	10.87
B21t	2.15	1.25	0.11	11.36
B22t	1.43	0.83	0.08	10.38
B23t	1.28	0.74	0.08	9.25
Mean	3.52	2.05	0.17	11.26

Table 8. Organic Matter, Organic Carbon, Total Nitrogen,
and Carbon-Nitrogen Ratio (Continued)

Horizon	Organic Matter %	Organic Carbon %	Total Nitrogen %	C/N
		Mahana Soil		
A1	10.95	6.37	0.36	17.69
B21	9.51	5.53	0.28	19.75
B22	9.39	5.46	0.26	21.00
B23	6.22	3.62	0.20	18.10
IIB3	3.38	1.97	0.11	17.91
IIC	1.59	0.92	0.05	18.40
Mean	6.84	3.98	0.21	18.81

Table 6 shows that organic matter including organic carbon increase as the rainfall increased. Organic carbon, furthermore, is significantly correlated with total nitrogen, C/N ratio, and cation exchange capacity (Table 4). These variables, therefore, also increase as rainfall increased. These findings are in accord with the conclusions of other investigators (for example, Dean, 1937; Loganathan, 1967; and Hassan, 1969).

Free Iron Oxide

Free iron oxide data are shown in Table 9. Although the oxide increases with depth in the Makaweli soil, no similar trends are observed in the Niu, Puu Opae, and Mahana soils. When compared with the soils investigated by Gardiner (1967) and Loganathan (1967), the soils used in this investigation contain more free iron oxide. The presence of free iron oxide is associated with highly weathered soil (Hendricks and Whittig, 1968; Ragg and Ball, 1964). Furthermore, the amount of amorphous oxides which include the free iron oxide increases as rainfall increases (Singer, 1966).

It is probably that the relationship between free iron oxide and the rainfall distribution is not apparent in this investigation because these soils represent highly weathered material. As mentioned earlier, there is a highly significant negative correlation between 15-bar water and free iron oxide (Table 4).

Table 9. Free Iron Oxide

Soil	Horizon	Free Iron Oxide %	Soil	Horizon	Free Iron Oxide %
Makaweli	Ap1	21.36	Niu	Ap	22.88
	Ap2	22.08		B21	24.80
	B21	23.60		B22	22.72
	B22	24.80		B23	18.40
	B23	24.48		Mean	22.20
	Mean	23.26			
Puu Opae	A11	21.60	Mahana	A1	29.20
	A12	24.16		B21	24.64
	B1	23.52		B22	21.76
	B21t	16.24		B23	15.92
	B22t	14.88		IIB3	15.92
	B23t	14.96		IIC	17.12
	Mean	19.23		Mean	20.76

The free iron oxide in these soils requires further study because it greatly influences soil structure (Deshpande et al., 1968) and other properties.

Classification of Soils

The chemical, physical, mineralogical, and morphological properties were used to classify the soils according to the U. S. Comprehensive Soil Classification System (Soil Survey Staff, 1960, 1967).

Makaweli--The low cation exchange capacity, the absence of primary alumino silicates, an oxic horizon with an approximate thickness of 48 inches, and a texture of sandy loam or finer in the fine earth fraction and more than 15% clay classify this soil in the order Oxisol.

A horizon below the upper 7 inches that is dry for more than 60 consecutive days, a mean annual soil temperature of 74°F (far exceeding the 59°F requirement) and a moist color value of less than 4 in the subhorizon of the epipedon make this Oxisol as Ustox.

A dark mollic epipedon and a base saturation of over 50% in the oxic horizon classify this soil as an Eutrustox.

The presence of weak prismatic and/or weak subangular blocky structures in the oxic horizon make this soil a Tropeptic Eutrustox.

A loam texture, a predominance of kaolinite, and a mean annual soil temperature of 74°F classify the Makaweli soil as a fine loamy, kaolinitic, isohyperthermic family of Tropeptic Eutrustox.

Niu--The low cation exchange capacity, the absence of primary alumino silicates, an oxic horizon with thickness of 26 inches, and a texture of sandy loam or finer in the earth fraction and more than 15% clay place this soil in the order Oxisol.

A horizon below the upper 7 inches that is dry for more than 60 consecutive days, a mean annual soil temperature of 71°F, and a moist color value of less than 4 in some parts of the epipedon place this Oxisol in the suborder Ustox.

A dark mollic epipedon and a base saturation of over 50% in the oxic horizon make this soil an Eutrustox.

The presence of weak prismatic or weak to moderate sub-angular blocky structure classify this Eutrustox as Tropeptic Eutrustox.

A textural class of clay loam, a predominance of kaolinite, and a mean annual temperature of 71°F classify the Niu soil as a clayey, kaolinitic, isothermic family of Tropeptic Eutrustox.

Puu Opae--The presence of an argillic horizon with more than 35% base saturation classify this soil in the order Alfisol.

A mean annual soil temperature of 69°F, the lack of characteristics associated with wetness, the lack of continuous dryness in the subsurface horizons between 7 and 20 inches, and the absence of a natric horizon place this Alfisol in the suborder Ustalf.

The argillic horizon with hue redder than 5YR and with moist values of less than 4, the absence of a natric horizon, a duripan, and plinthite, and the presence of other characteristics classify this soil as a Rhodustalf.

The lack of a lithic contact and a low cation exchange capacity value make this soil an Oxic Rhodustalf.

A textural class of clay, with much kaolinite, and a mean annual soil temperature of 69°F classify the Puu Opae soil as a clayey, kaolinitic, isothermic family of Oxic Rhodustalf.

Mahana--The presence of an umbric epipedon, a cambic horizon with less than 50% base saturation, and a difference of 9°F between the mean summer and mean winter soil temperature classify this soil into the order Inceptisol.

A bulk density of the fine earth fraction of less than 0.85 g/cc in the epipedon (?), the lack of water saturation at any period, and the absence of a plaggen epipedon place this soil in the suborder Andept.

An umbric epipedon, a 15-bar water retention of more than

20%, a soil temperature of more than 47°F, the lack of irreversible dehydration and the absence of gravel-size aggregates, and the absence of a duripan classify this Andept as Dystrandept.

An embric epipedon which is more than 10 inches thick, showing neither mottles nor thixotropic property within the specified horizons, the lack of lithic contact, and a cation exchange capacity of less than 30 meq/100 g of soil classify this soil as Oxic Dystrandept.

A textural class of silty clay, an abundance of kaolinite, and an annual mean soil temperature of 66°F classify the Mahana soil as an ashy, isothermic family of Oxic Dystrandept.

This investigation shows a need to modify some of the criteria which are used to classify the Oxisols. First, a reliable method of mechanical analysis must be developed especially for the highly weathered soils to ascertain the true textural class. This is necessary because the present definition (Soil Survey Staff, 1960, 1967) requires a cation exchange capacity of less than 16 meq/100 g of clay in the oxic horizon. Second, it is suspected that the highly weathered Oxisols are indeed low in clay content. If this is so, the cation exchange capacity of the oxic horizon should be based on 100 g of soil rather than 100 g of clay. Furthermore, the use of the factor 2.5 x 15-bar water content to obtain the clay content of the oxic horizon does not seem desirable.

SUMMARY AND CONCLUSION

A sequence of four soils in southwestern Kauai was investigated to observe the effect of climate on the formation of soils on highly weathered parent material. The Makaweli soil, derived from materials of the Koloa volcanic series, occurs at approximately sea level near Port Allen where the mean annual rainfall is 32 inches and the mean annual soil temperature is 74°F. The other three soils, Niu, Puu Opae, and Mahana, derived from materials of the Waimea volcanic series, occur on the southwestern slope of the Waimea Mountain, where the mean annual rainfalls are 27, 34, and 40 inches and the mean soil temperatures are 71, 69, and 66°F, respectively. The chemical, physical, and mineralogical properties were determined, and the soils were classified according to the U. S. Comprehensive Soil Classification System.

Conclusions are made based on the results of this investigation:

1. In soils developed on highly weathered basic or ultra-basic basaltic material, there is a decrease in the clay content and a corresponding increase in the coarser fractions with an increase in rainfall.

2. The water retained at 15-bars is generally high (27 – 31%) for horizons containing clay or clay-like coatings

and (29 - 33%) for subsurface horizons with a morphology which appears to be volcanic ash. There is a highly significant negative correlation between 15-bar water and free iron oxide.

3. Kaolinite constitutes the main clay mineral in the four soils. Oxides and/or hydrous oxides of aluminum and iron are also present. Significant amounts of boehmite in the Makaweli soil indicates high degree of weathering under wet and dry climate.

4. Cation exchange capacity is dominated by the type of clay mineral and the amount of organic matter. There is no clear relationship between cation exchange capacity and rainfall distribution in this sequence of soils.

5. Calcium and magnesium constitute the major exchangeable bases, and base saturation decreases as rainfall increases.

6. The pH is strongly acidic in soils of the wetter regions and medium to slightly acidic in soils of the lower rainfall. The pH is also correlated with base saturation, C/N ratio, free iron oxide, and 15-bar water.

7. The organic matter, organic carbon, and total nitrogen decrease with depth in profile. Organic carbon is highly correlated with total nitrogen and C/N ratio and they increase as rainfall increases.

8. These soils show a high free iron oxide content ranging from 15 to 29%.

9. A slight modification is suggested in the classification of the four soils. The Makaweli soil is classified as a fine loamy, kaolinitic, isohyperthermic family of Tropeptic Eutrustox; the Niu soil is classified as a clayey, kaolinitic, isothermic family of Tropeptic Eutrustox; the Puu Opae soil is classified as a clayey, kaolinitic, iso-thermic family of Oxic Rhodustalf; and the Mahana soil remains classified as an ashy, isothermic family of Oxic Dystrandept.

10. In classifying Oxisols, it is recommended that the cation exchange capacity of the oxic horizon be based on 100 g of soil rather than 100 g of clay.

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