THE PROPERTIES AND GENESIS OF SOILS DERIVED FROM PAHALA ASH IN KAU DISTRICT, HAWAII

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CHAPTER I

INTRODUCTION

Volcanic ash soils are distributed widely in the Pacific Basin. They are also common in Asia, Africa, and Europe. Therefore, it is not surprising that these soils are gradually receiving more attention.

In Hawaii, the volcanic ash soils occur under a wide range of climate which is cool, semi arid; tropical, semi arid; or tropical, perhumid (Swindale and Sherman, 1964).

Various investigators have found that climate is the dominant factor which control the formation of soil.

The sequence of soils used in this investigation occurs in Kau District on the southern slopes of Mauna Loa, Island of Hawaii. These soils are formed on volcanic ash which is called Pahala ash.

The objectives of the study are:

(1) To characterize the soils.

(2) To study the dominant influence of climate on soil formation on Pahala ash.

(3) To classify the soils according to the U. S. Comprehensive Soil Classification System.

CHAPTER II

REVIEW OF LITERATURE

DESCRIPTION OF PAHALA ASH

Pahala ash is a volcanic ash widely distributed on the Island of Hawaii. According to Frazer (1960), the Pahala ash overlies the older volcanic lava flows and underlies the younger flows of the Kilauea, Mauna Loa, and Mauna Kea volcanoes. The ash serves as a valuable horizon marker (Stearns and Macdonald, 1946), and it covers over 450 square miles. Most of it, however, is buried by later lava flow. This ash layer is named after the village of Pahala which lies at the edge of an extensive area of yellowish ash soil (Stearns and Clark, 1930). The distribution of the Pahala ash in Kau District is shown in Fig. 1.

The Pahala ash ranges from a single bed 55 feet thick in the vicinity of Pahala to several beds totaling approximately 15 feet, interstratified with overlying lavas in the Hilo District. According to Wentworth (1938), the ash shows very little cross-bedding, but usually good laminations, indicating that the deposition was only slightly affected by the wind.

The source of Pahala ash has been attributed to eruptions from Mauna Kea, Mauna Loa, Kilauea, and Kohala volcanoes during the Pleistocene Epoch by Stearns and Macdonald (1946).

Frazer (1960), on the other hand, believed that the Pahala ash was formed by phreatomagmatic explosions from cones and rift areas of the Kilauea volcanic complex. Swindale and Sherman (1964) presumed

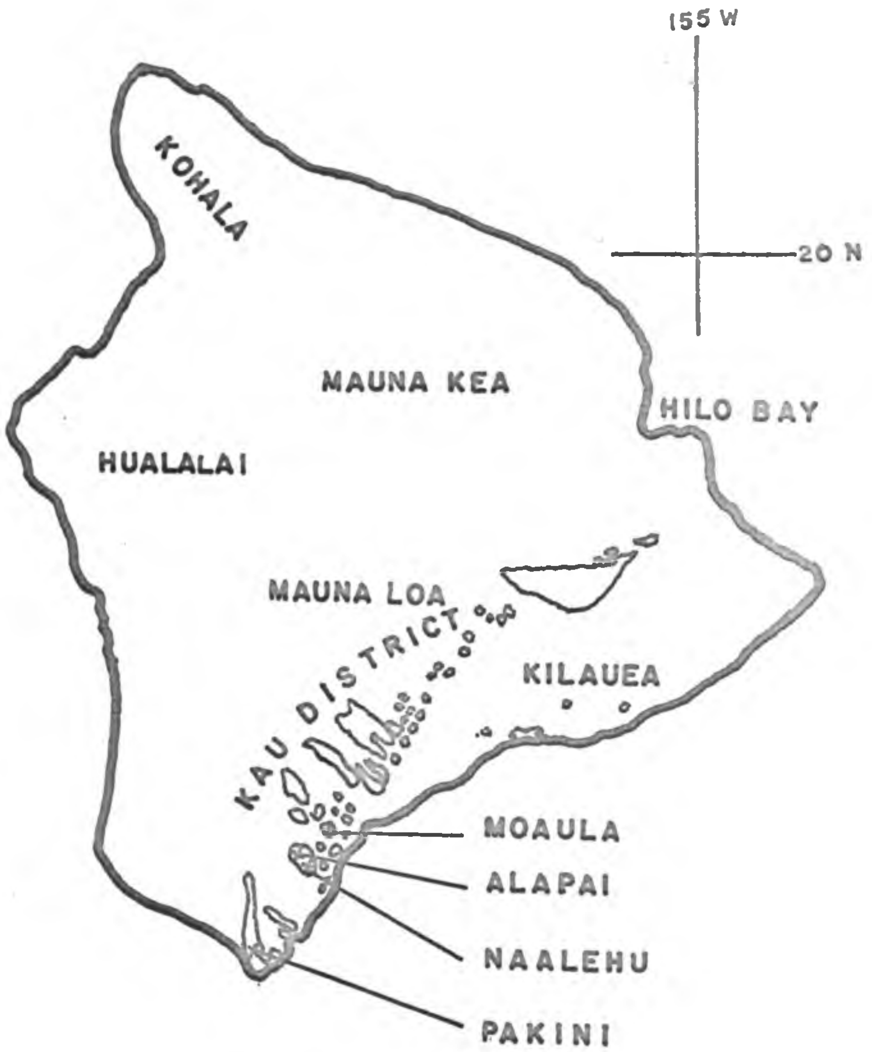

Figure 1. Map of the Island of Hawaii showing the extent of Pahala ash in Kau District and location of sample sites.

that sinking and faulting in the volcanic area caused the magma to rise and also allowed ingress of ground-water and perhaps sea-water to the magmatic chamber. The eruption then occurred with great explosive force. According to Frazer (1960), the Kilauea volcano has remained a primitive volcano extruding tholeiitic basalt, but Mauna Kea, with its many cores, has changed to a post-primitive volcano extruding primarily andesitic ash.

Swindale and Sherman (1964) classified the Pahala ash as phreatic basaltic ash. Macdonald (1946) has described this ash as consisting of pale brown or brownish-green pumiceous glass fragments. In some places, these fragments have altered to yellowish-brown or orange palagonite. The phenocrysts are olivine and plagioclase which range from sodic bytownite to medium labradorite, resembling those in the basaltic lava. The color depends upon the amount of alteration, which in turn, is largely due to the amount of vegetation and rainfall (Wentworth, 1938; and Stearns and Macdonald, 1946).

PROPERTIES OF VOLCANIC ASH SOILS

Morphological Properties

The morphological properties of volcanic ash soils depends on the intensity of weathering and the factors of soil formation. In New Zealand soils, Birrell (1964) noted that there was usually a marked difference between the surface and subsurface horizons in a profile. Morphological development in the subsurface horizon was generally restricted. Consistence of the moist soil varied from friable to firm. The surface horizon, which was as thick as one meter, was usually brown to very black, while the subsurface horizon was yellowish brown to reddish brown. In Hawaii, Cline (1955) found that most of the volcanic ash soils had dark colored surface horizon with relatively high amounts of organic matter overlying a light colored subsurface horizon.

Volcanic ash soils have either an AC or A(B)C profile (Swindale and Sherman, 1964). Flach (1964) described these soils as having a deep A horizon with moderate to strong structure and low chromas and hues. However, the A horizon was not necessarily black and the subsurface horizon was not strongly expressed. There was a possibility of a colored B (Cambic) horizon having a weak to moderate blocky structure.

Wright (1964) described that "Andosol" or "Humic Allophane" soils of South Africa were deep profiles with very dark humic surface horizon and prominant yellowish-brown subsurface horizons which were very light and porous and rather weak in structural aggregation. They were hardly sticky or plastic when moist and they possessed clay minerals which had a high iso-electric point.

Mineralogical Properties

The sand fraction of volcanic ash soils usually contains volcanic glass. In addition, there may be other rock forming minerals such as feldspars, pyroxenes, hornblende, quartz, magnetite, and little or no mica (Swindale, 1964; and Birrell, 1964). The clay fraction consists almost entirely of secondary mineral which is dominated by allophane (Kamoshita, 1958; Swindale, 1964; and Birrell, 1964). This fraction may contain other secondary minerals (Egawa, 1964; Flach, 1964; and Wright, 1964).

According to Ross and Kerr (1934), allophane and related materials were observed by Riemann in 1809 in cavities in marls. Allophane was observed in Japan by Seki (1914) and in New Zealand by Taylor (1933).

The term allophane cannot be defined precisely (Swindale, 1964). Ross and Kerr (1934) have described allophane as a clay mineral commonly associated with halloysite. It is amorphous, commonly glassy in character and variable in composition and can be distinguished neither by optical method nor by x-ray diffraction analysis. These properties of allophane have also been investigated by workers in New Zealand, Hawaii, and Japan.

Physical Properties

One of the common properties of volcanic ash soils is the very high natural moisture content throughout the profile (Kanehiro and Sherman, 1956; Birrell, 1964; and Huong, 1964). The high moisture content is associated with the very low dry bulk density value (Birrell, 1964). According to Yamanaka (1964), the specific gravity is comparatively higher in these soils than in other soils because of the high iron content. Swindale (1964) pointed out that recent studies in Hawaii showed a highly significant relationship between field moisture content and organic matter content in the Hydrol Humic Latosols.

The porosity of volcanic ash soils is also very high (Birrell, 1964; and Yamanaka, 1964). Compaction behavior may be anomalous and the pre-consolidation pressure in a standard laboratory consolidation test may exceed the existing overburden pressure. According to

Swindale (1964), Hawaiian soils with bulk density less than 0.2 g/cc are used for sugar cane production and they are required to withstand the operation of very heavy agricultural machinery. He mentioned that, in practice, the soils bear the loads well but may fail if continuous vibrating loads are applied.

Birrell (1964) stated that volcanic ash soils may present difficulty in the determination of particle size distribution due to the presence of (1) amorphous colloids which have a high iso-electric point, and (2) hydrous oxides which induce mutual co-precipitation.

Chemical Properties

The pH value of volcanic ash soils is generally above five due to high buffering capacity of allophane in the region of the iso-electric point (Swindale, 1964; and Birrell, 1964).

The cation exchange capacity is high, ranging from about 20-82 meq/100g of soil. According to Birell (1964), calculation of the cation exchange capacity of these soils by summation of exchangeable hydrogen, aluminum, and bases seems more realistic and useful than the conventional methods of leaching the soils with salt solutions. Kanehiro and Sherman (1956) found that certain Hawaiian soils having high amount of amorphous material showed lower cation exchange capacity on drying and did not regain this capacity on rewetting. They believed that this was due to crystallization of amorphous constituents on drying.

The base saturation of these soils covers a wide range. Birrell (1964) mentioned that the base saturation may be very low, even though the pH values may indicate only weak to moderate acidity. Swindale (1964) pointed out that the estimation of base saturation is unreliable because amorphous mineral colloids have pH-dependent charges and the apparent base saturation determined in laboratory at pH 7 may be much lower than the true base saturation of the soil in the field of lower pH condition.

EFFECT OF CLIMATE ON SOIL FORMATION

Climate is an important factor in soil formation. Joffe (1949) devided the soil forming factor into:

(1) Passive factors, factors representing constituents which serve as the source of the mass (mineral matter) and some environmental conditions. They are the parent material, topography, and age of the land.

(2) Active factors, factors representing agents which supply the energy that acts upon the mass and furnish reagents for the processes of soil formation. They are the elements of the biosphere, the atmosphere, and the hydrosphere.

In cases where vegetation is not significantly different in the soil sequence, the climate may act as a single dominant factor. For example, as shown by Jenny (1941, 1946):

$$S = f(Cl)_{o,r,p,t,....}$$

where S = soil property; f = symbol for "function of"; Cl = climate; o = organism; r = topography; p = parent material; t = age of soil; .... = additional unspecified factors.

In this relation of climofunction, climate (Cl) denotes a multiple soil forming factor. It may involve the moisture (rainfall) and temperature components as follows:

$$S = f(R,T)_{o,r,p,t,\ldots}$$

Where R = rainfall; T = temperature.

Since rainfall and temperature are independent of each other, this equation may be expressed as:

$$dS = \left(\frac{\partial S}{\partial R}\right)_T dR + \left(\frac{\partial S}{\partial T}\right)_R dT$$

If numerical values can be found for the unknowns in this equation, the study of soil formation can be made quantitative.

The idea of climofunction as related to soil formation is used in this investigation of a sequence of soils derived from Pahala ash.

The effect of climate on soil formation has been reported by several investigators. Ayres (1943), and Kanehiro and Chang (1956) found that cation exchange capacity and base saturation of some Hawaiian soils decreased with increasing rainfall. Swindale and Sherman (1964) pointed out that base saturation of volcanic ash soils generally decreased with increasing rainfall. Similar results were reported by Loganathan (1967).

Dean (1937) in his study of Hawaiian soils found that the carbon and nitrogen content increased with increasing rainfall. Similar results were also obtained by Loganathan (1967).

CHAPTER III

MATERIALS AND METHODS

LOCATION OF SAMPLE SITES

The sample sites are located on the southern slopes of Mauna Loa in Kau District, Island of Hawaii. The elevation ranges from 0 to 2,300 feet. The annual rainfall varies from 20 inches to 100 inches while the annual mean temperature varies from 69 to 74°F. The slope ranges from 0 to 20 percent. The natural vegetation consists of grass, scrub, and forest. Most of the soils are used for sugar cane production.

Four soil profiles were sampled. These profiles were the Pakini, Naalehu, Moaula, and Alapai soils. All of them are formed on volcanic ash which is called Pahala ash. The approximate location of these soils and the extent of the Pahala ash in this region, based on the geological map prepared by Stearns and Macdonald (1946), are shown in Fig. 1.

The Pakini soil was collected in the Ka Lae Quadrangle at 18°15'30" north latitude and 155°41'38" west longitude. The site was located about 300 yards east of a satellite tracking station at South Point, Kau. The approximate rainfall is 20 inches and mean annual temperature is 74°F. Natural vegetation is sand bur (*Cenchrus echinatus*), cocklebur (*Xanthium saccharatum*), lantana (*Lantana camara*), Bermuda grass (*Cynodon dactylon*), and pili grass (*Heteropogon contortus*). The Pakini soil is used for pasture.

The Naalehu soil was collected in the Naalehu Quadrangle at 19°4'13" north latitude and 155°35'18" west longitude. The site was located about 1.2 miles northwest of Hutchinson Sugar Company office in field 310. The approximate rainfall is 50 inches and mean annual temperature is 72°F. Natural vegetation is Christmas berry (Schinus terebinthifolius), Bermuda grass (Cynodon dactylon), guava (Psidium guajava), and kaimi clover (Desmodium canum). The Naalehu soil is used for sugar cane production and for pasture, the latter in limited amount.

The Moaula soil was collected in the Punaluu Quadrangle at 19°08'10" north latitude and 155°33'55" west longitude. This site was located about five miles north of Naalehu town in field 632 of Hutchinson Sugar Company. The approximate rainfall is 60 inches and mean annual temperature is 70°F. Natural vegetation is Christmas berry (Schinus terebinthifolius), guava (Psidium guajava), joee (Stachytarpheta cayannensis), and Kikuyugrass (Pennisetum clandestinum). The soil is used primarily for sugar cane production.

The Alapai soil was collected in the Naalehu Quadrangle at 19°05'22" north latitude and 155°36'32" west longitude. The site was located about 2.2 miles northwest of Naalehu Post Office. The approximate annual rainfall is 80 inches and mean annual temperature is 69°F. Natural vegetation is ohia (Metrosideros collina), guava (Psidium guajava), Hilo grass (Paspalum conjugatum), and California grass (Bracharia mutica). This soil is used primarily for sugar cane production.

A summary of the genetic factors of these four soils is shown in Table I.

TABLE I. SOME GENETIC FACTORS OF THE SOILS

Factors	S O I L S			
	Pakini	Naalehu	Moaula	Alapai
North Latitude	18°56'30"	19°04'13"	19°08'10"	19°05'22"
West Longitude	155°41'38"	155°35'18"	155°35'55"	155°36'32"
Elevation (ft.)	250	850	1700	2250
Annual Rainfall (# in.)	20	50	60	80
Mean Annual Temperature	74°F	72°F	70°F	69°F
Slope (%)	2 - 6	10 - 20	0 - 10	0 - 10
Drainage	well-drained	well-drained	well-drained	well-drained
Natural Vegetation	grass, scrubs	grass, scrubs, forest	grass, scrubs, forest	grass, scrubs, forest
Parent Material	volcanic ash	volcanic ash	volcanic ash	volcanic ash

DESCRIPTION OF SOIL PROFILES

The soil profiles were described by the personnel of the Soil Conservation Service, USDA.

Pakini Very Fine Sandy Loam

Horizon	Depth	Description
Ap	0 - 3"	Very dark brown (10YR 2/2) very fine sandy loam, dark grayish brown (10YR 4/2) dry; weak medium platy structure; slightly hard, very friable; many roots; common 2 to 5 mm fragments of rock; neutral (pH 7.1); clear wavy boundary. (2 to 4 inches thick)
A12	3 - 8"	Dark brown (7.5YR 3/3) very fine sandy loam, dark yellowish brown (10YR 4/4) dry; weak medium and coarse prismatic structure; slightly hard, friable; many roots along prism faces; common 2 to 5 mm fragments of rock; neutral (pH 7.1); clear wavy boundary. (4 to 5 inches thick.)
A3	8 - 16"	Dark brown (7.5YR 4/4) very fine sandy loam; yellowish brown (10YR 5/4) dry; weak coarse prismatic structure; slightly hard, friable; common roots; common 2 to 5 mm fragments of rock; neutral (pH 7.2); clear wavy boundary. (7 to 10 inches thick.)
B21	16 - 29"	Dark brown (7.5YR 4/4) loam, strong brown (7.5YR 5/6) dry; weak coarse prismatic structure;

		slightly hard, friable, slightly sticky, slightly plastic; few fine roots; common olivine sand particles; gradual wavy boundary. (10 to 18 inches thick.)
B22	29 - 45"	Brown (7.5YR 5/4) loam, yellowish brown (10YR 5/6) dry; weak coarse prismatic structure; slightly hard, friable, slightly sticky, slightly plastic; few roots; few fine fragments of rock; few streaks of calcium carbonate on vertical prism faces and in pores; mildly alkaline (pH 7.7); gradual wavy boundary. (12 to 20 inches thick.)
Cca	45 - 60"	Brown (7.5YR 5/4) very fine sandy loam, yellowish brown (10YR 5/6) dry; structureless, massive, slightly hard, friable; calcium carbonate increases as depth increases; matrix effervesces weakly with HCl, few pockets effervesce violently with HCl; mildly alkaline (pH 7.7).

Naalehu Silty Clay Loam

Horizon	Depth	Description
Ap	0 - 20"	Very dark brown (10YR 2/2) silty clay loam, dark grayish brown (10YR 4/2) dry; moderate medium and fine granular structure; hard, friable, sticky, plastic; many roots; matted at base of horizon; many fine pores; slightly acid

		(pH 6.5); abrupt smooth boundary. (16 to 24 inches thick.)
B21	20 - 31"	Dark brown (10YR 3/3) silty clay loam, dark brown (7.5YR 4/4) dry; weak coarse prismatic structure; hard, firm, sticky, plastic, weakly smeary; upper 6 inches compact; few roots mostly along old root channels; many charcoal fragments; many worm casts in old channels; neutral (pH 6.7); clear smooth boundary. (8 to 14 inches thick.)
IIB22	31 - 36"	Dark reddish brown (5YR 3/3) silt loam, dark reddish brown (5YR 3/4) dry; structureless, massive; hard, friable, slightly sticky, slightly plastic, weakly smeary; few roots; many very fine pores; tuff band nearly continuous; neutral (pH 6.7); clear wavy boundary. (5 to 9 inches thick.)
IIIB23	36 - 53"	Dark reddish brown (5YR 3/3) silt loam, dark red (2.5YR 3/6) dry; weak coarse prismatic structure; slightly hard, very friable, plastic, weakly smeary; few roots; many pores; neutral (pH 7.0); clear wavy boundary. (14 to 18 inches thick.)
IVC	53 - 65"	Dark reddish brown (5YR 3/3) silt loam, dark reddish brown (2.5YR 3/4) dry; structureless,

massive; very friable, slightly plastic, weakly smeary; few roots; many fine pores; neutral (pH 7.2).

Moaula Silty Clay Loam

Horizon	Depth	Description
Ap	0 - 9"	Very dark brown (10YR 2/2) silty clay loam, dark yellowish brown (10YR 4/6) dry; strong medium and fine subangular blocky structure; slightly hard, friable, slightly sticky, plastic; many roots, common very fine and fine roots; few firm and very firm dark red (2.5YR 3/6) 1 to 5 mm nodules of volcanic ash; very strongly acid (pH 4.9); abrupt wavy boundary. (6 to 12 inches thick.)
B21	9 - 17"	Dark reddish brown (5YR 3/4) silty clay loam; moderate medium subangular blocky structure; friable, sticky, plastic, weakly smeary; many roots; many very fine pores; patchy thin gelatin-like coatings on ped surfaces, few firm dark red (2.5YR 3/6) 7 mm nodules of volcanic ash; slightly acid (pH 6.5); clear wavy boundary. (6 to 10 inches thick.)
B22	17 - 23"	Dark reddish brown (5YR 3/3) silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic, weakly smeary; many roots; many very fine and

		fine pores; few fine pebble size dark red fragments of volcanic ash; thin gelatin-like coatings on ped faces; slightly acid (pH 6.5); abrupt wavy boundary. (4 to 8 inches thick.)
B23	23 - 31"	Dark reddish brown (5YR 3/4) silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic, weakly smeary; few roots; many very fine and fine pores; common firm and very firm dark reddish brown (2.5YR 3/4) 1/4 to 2 inches fragments of volcanic ash; slightly acid (pH 6.4); clear wavy boundary. (5 to 10 inches thick.)
B24	31 - 40"	Dark reddish brown (5YR 3/3) silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic, weakly smeary; few roots; many very fine and fine pores; few firm and very firm dark reddish brown fine pebble size fragments of volcanic ash; neutral (pH 6.6); clear wavy boundary. (7 to 11 inches thick.)
B25	40 - 48"	Dark reddish brown (5YR 3/4) silty clay loam; moderate fine and very fine subangular blocky structure; friable, sticky, plastic, weakly smeary; few roots; many very fine and fine pores; common patches of gelatin-like coatings

		on ped faces; common firm and very firm dark reddish brown fine pebble size fragments of volcanic ash; neutral (pH 6.8); abrupt wavy boundary. (5 to 10 inches thick.)
B26	48 - 54"	Dark reddish brown (5YR 3/4) silty clay loam; common fine distinct yellowish brown (10YR 5/6) mottles; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic, weakly smeary; few roots; many very fine and fine pores; common firm and very firm dark reddish brown fine pebble size fragments of volcanic ash; common patches of gelatin-like coatings on ped faces; neutral (pH 6.8); abrupt wavy boundary. (4 to 8 inches thick.)
B27	54 - 65"	Dark reddish brown (5YR 3/4) silty clay loam, few fine distinct yellowish brown (10YR 5/6) mottles; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic, moderately smeary; few roots; common patches of gelatin-like coatings on ped faces; neutral (pH 6.8); abrupt smooth boundary. (9 to 12 inches thick.)
B28	65 - 74"	Yellowish red (5YR 4/6) and dark brown (7.5YR 4/6) silty clay loam, common fine distinct dark reddish brown (2.5YR 3/3) mottles; weak fine and very fine subangular blocky

structure; friable, sticky, plastic, moderately smeary; common very fine and fine pores; few patches of gelatin-like coatings on ped faces; neutral (pH 6.7).

Alapai Silty Clay Loam

Horizon	Depth	Description
Ap1	0 - 7"	Very dark brown (10YR 2/2) silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky and slightly plastic; abundant roots; common very fine pores; few olivine crystals less than 1 mm in diameter; few volcanic ash nodules; very strongly acid (pH 4.7); abrupt wavy boundary. (5 to 9 inches thick.)
Ap2	7 - 15"	Dark reddish brown (5YR 3/3) light silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and weakly smeary; abundant roots; common very fine and fine pores; common patches of gelatin-like coatings on ped surfaces; medium acid (pH 5.9); clear wavy boundary. (6 to 11 inches thick.)
B1	15 - 27"	Dark brown (7.5YR 3/2) and dark reddish brown (5YR 3/3) silty clay loam; moderate medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable,

slightly sticky, plastic and weakly smeary; abundant roots; many very fine and fine pores; common firm to very firm volcanic ash fragments 1 to 4 mm in diameter; common patches of gelatin-like coatings on ped surfaces; neutral (pH 6.6); abrupt wavy boundary. (9 to 14 inches thick.)

B21	27 - 36"	Dark reddish brown (5YR 3/4) light silty clay loam; moderate medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and moderately smeary; few roots; many very fine and fine, common medium and few coarse pores; few volcanic ash fragments as in above horizon; smooth gelatin-like coatings on ped surfaces; slightly acid (pH 6.3); abrupt smooth boundary. (6 to 9 inches thick.)
B22	36 - 43"	Dark brown (7.5YR 3/4) and dark reddish brown (5YR 3/4) light silty clay loam; moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and moderately smeary; few roots; many very fine and fine, common medium and few coarse pores; few fine firm to very firm volcanic ash fragments; smooth gelatin-like coatings on ped surfaces; slightly acid (pH 6.5); abrupt smooth boundary. (6 to 8 inches thick.)

B23	43 - 50"	Dark reddish brown (5YR 3/4) light silty clay loam; moderate medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and moderately smeary; few roots; many very fine and fine, common medium and few coarse pores; common firm and very firm volcanic ash fragments up to 5 mm in size; common small pockets of dark brown (7.5YR 3/3) silty clay loam; smooth gelatin-like coatings on ped surfaces; neutral (pH 6.7); abrupt smooth boundary. (5 to 6 inches thick.)
B24	50 - 57"	Dark reddish brown (5YR 3/4)and dark brown 7.5YR 3/4) light silty clay loam, with common gray and black specks; moderate medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and moderately smeary; few roots; many very fine and fine, common medium and few coarse pores; common firm and very firm ash fragments up to 5 mm in diameter; smooth gelatin-like coatings on ped surfaces; neutral (pH 6.8); abrupt smooth boundary. (6 to 7 inches thick.)
B25	57 - 66"	Bands of dark brown (7.5YR 3/3), reddish brown (5YR 4/4) and dark brown (10YR 3/3) light silty

clay loam, with common fine dark reddish brown (2.5YR 3/3) mottles; moderate coarse and medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and strongly smeary; occasional roots; many very fine and fine, common medium and coarse pores; thick gelatin-like coatings on ped surfaces; neutral (pH 6.8); abrupt smooth boundary. (8 to 10 inches thick.)

B26 66 - 74" Upper 4 inches consists of very firm dark reddish brown (2.5YR 2/4) volcanic ash layer. Lower part is mottled dark reddish brown (2.5YR 3/4 and 5YR 3/4), dark brown (7.5YR 4/4), strong brown (7.5YR 4/6) and yellowish brown (10YR 5/6) light silty clay loam; moderate medium subangular blocky breaking to moderate fine and very fine subangular blocky structure; friable, slightly sticky, plastic and strongly smeary; occasional roots; many very fine and fine, common medium pores; thick gelatin-like coatings on ped surfaces; slightly acid (pH 6.3).

METHODS OF ANALYSIS

Sample Preparation

The samples were air-dried and crushed gently with a wooden roller. They were sieved through a 2-mm sieve and mixed thoroughly, and then subsampled. One subsample of each sample were ground to pass a 100-mesh sieve and stored in vials for the determination of carbon, nitrogen, extractable or free iron oxides, and for differential thermal analysis. The other subsample was used for the determination of pH, cation exchange capacity, exchangeable bases, particle size distribution, and 15-bar water.

Physical Analysis

Particle Size Distribution: Particle size distribution was determined following the procedure described by Kilmer and Alexander (1949).

15-Bar Water: The water held at 15-bar water tension was determined by using the pressure membrane apparatus. The soil samples were packed on the pressure plate in rubber rings and saturated overnight with water from the bottom. They were then subjected to a 15-bar pressure (225 pounds) and allowed to reach equilibrium. Three to four days were required for equilibrium, at which time the soils were weighed immediately and once more after oven drying.

Mineralogical Analysis

Differential Thermal Analysis (DTA): The mineralogy of the whole soil was determined by means of the Stone Automatic DTA unit. The air-drafted 100-mesh samples were equilibrated at 57 percent relative humidity in a desiccator containing saturated magnesium nitrate solution for 48 hours. One-tenth gram portion of sample was mixed with an equal amount of ignited alumina powder and then heated at the rate of $10^{o}C$ per minute from 20 to $1,000^{o}C$. Nitrogen was used to suppress the oxidation of organic matter.

X-ray Diffraction Analysis: The mineralogy of the clay fraction was determined by the procedure of Jackson (1956) with the aid of the Norelco X-ray Diffractometer. The clay samples were saturated with potassium and/or magnesium, and preferentially oriented clay slides were prepared for eventual heat treatment or ethylene glycol treatment. Since the clays tended to peel off during the preparation of the slides, one drop of 50 percent glycerine was added on the glass slide before 1 ml of approximately 1 percent clay suspension was pipetted.

Chemical Analysis

Cation Exchange Capacity: The cation exchange capacity was determined by using 1 N ammonium acetate buffered at pH 7 to saturate the soils with NH^+ ions. Ten percent NaCl solution was used to exchange the NH^+ ions adsorbed on the exchange sites. The replaced NH^+ ions were distilled with 50 percent NaOH solution and the distillate was collected in a 4 percent boric acid and titrated against standard H_2SO_4 using methyl red, methylene blue mixed indicator.

Exchangeable Bases and Base Saturation: The exchangeable bases were determined in the NH_4OAc leachate which was collected during the determination of cation exchange capacity. Exchangeable Na and K were determined by means of the Beckman DU Flame Spectrophotometer, while the exchangeable Ca and Mg were determined by means of the Perkin-Elmer, Model 303, Atomic Absorption Unit.

Base saturation was calculated by dividing the sum of the exchangeable cations by the cation exchange capacity.

Soil pH: Soil pH was measured with H_2O (1:1) and N KCl (1:1) by means of the Beckman Zeromatic pH Meter. The suspension was allowed to stand overnight with occasional shaking and the pH was determined the next morning, 40 seconds after stirring the suspension.

Organic Carbon: The organic carbon was determined by the method of Walkley and Black (1943). The readily oxidizable organic matter was treated with dichromate-sulfuric acid mixture, and the excess dichromate was back-titrated with standard $FeSO_4$ solution.

Total Nitrogen: The total nitrogen was determined by the Kjeldahl method (Jackson, 1958).

Extractable Iron Oxides: The extractable iron oxide was determined by the method of Kilmer (1960). Due to the large amount of free iron oxides in Hawaiian soils, it was necessary to modify the original procedure by reducing the weight of the sample (R. T. Watanabe, personal communication, 1968).

CHAPTER IV

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES

Particle Size Distribution

Table II shows the particle size distribution of the four soil profiles. These tables show not only the textural class as obtained by the pipette method but also the apparent texture as determined in the field.

The textures as obtained by the two methods are quite similar. This may be due to the modification made in the procedure of Kilmer and Alexander (1949). If the modification which consisted of additional breaking of the aggregates with a rubber policeman were not made, the results would certainly have been quite different from those presented in Table II, (Oshiro, personal communication, 1968). In general, it is difficult to disperse soils derived from volcanic ash (Kanno, 1964). Loganathan (1967) encountered difficulty in dispersion when he determined the particle size distribution of four Andepts from Mauna Kea, Hawaii.

The results of this investigation show that the particle size distribution in the Naalehu, Moaula, and Alapai soils is similar. The size distribution in the Pakini soil, however, is quite different by being more sandy. The low rainfall in the area of the Pakini soil may have accounted for the lack of clay sized fraction. Wentworth (1938) has also cited the possibility of wind-blown ash in the area of South Point where the Pakini soil occurs. The wind-blown material may be composed of coarser fractions.

TABLE II. PARTICLE SIZE DISTRIBUTION AND TEXTURAL CLASSES OF THE SOILS

Horizon	Sand %	Silt %	Clay %	Textural Class	Field Observation
			P A K I N I		
Ap	47.1	45.3	7.6	sandy loam	very fine sandy loam
A12	47.4	47.1	5.5	sandy loam	very fine sandy loam
A3	55.5	41.7	2.8	sandy loam	very fine sandy loam
B21	48.8	48.5	2.7	sandy loam	loam
B22	52.2	45.2	2.6	sandy loam	loam
Cca	53.3	41.8	4.9	sandy loam	very fine sandy loam
			N A A L E H U		
Ap	19.0	52.4	28.6	silty clay loam	silty clay loam
B21	19.8	52.0	28.2	silty clay loam	silty clay loam
IIB22	19.0	53.1	27.9	silty clay loam	silt loam
IIIB23	22.4	51.4	26.2	silt loam	silt loam
IVC	24.7	49.6	25.7	silt loam	silt loam
			M O A U L A		
Ap	15.5	54.8	29.7	silty clay loam	silty clay loam
B21	17.6	52.9	29.5	silty clay loam	silty clay loam
B22	18.8	50.2	31.0	silty clay loam	silty clay loam
B23	18.7	51.1	30.2	silty clay loam	silty clay loam
B24	14.2	54.8	31.0	silty clay loam	silty clay loam
B25	15.0	56.2	28.8	silty clay loam	silty clay loam
B26	19.2	51.4	29.5	silty clay loam	silty clay loam
B27	20.1	50.2	29.7	clay loam	silty clay loam
B28	22.0	48.7	29.3	clay loam	silty clay loam

TABLE II. (Continued) PARTICLE SIZE DISTRIBUTION AND TEXTURAL CLASSES OF THE SOILS

Horizon	Sand %	Silt %	Clay %	Textural Class	Field Observation
			A L A P A I		
Ap1	14.7	51.8	33.5	silty clay loam	silty clay loam
Ap2	15.3	51.0	33.7	silty clay loam	light silty clay loam
B1	16.0	49.8	34.2	silty clay loam	silty clay loam
B21	18.9	46.8	34.3	silty clay loam	light silty clay loam
B22	17.6	48.8	33.6	silty clay loam	light silty clay loam
B23	18.5	44.6	36.9	silty clay loam	light silty clay loam
B24	16.2	51.4	32.4	silty clay loam	light silty clay loam
B25	21.4	50.1	28.5	clay loam	light silty clay loam
B26	21.6	49.5	28.9	clay loam	light silty clay loam

The 15-Bar Water

The 15-bar water appears to increase with increase in rainfall when the Pakini soil and the other soils taken collectively are compared (Table III). When Tables II and III are compared, the results suggest that the 15-bar water is closely related to the amount of clay in the sample. When the profiles are compared one against another, the 15-bar water values of the Naalehu, Moaula, and Alapai soils are similar. As mentioned previously, the clay contents of these soils also appear similar.

It is interesting to note that 15-bar water content in the Pakini soil should range from 25.6 to 36.9 percent even though the clay content (Table II) ranged only from 2.6 to 7.6 percent. In general, sandy soils have less water holding capacity than clayey soils. Perhaps, the coarser fractions of this soil may contain substantial amounts of aggregates of clay minerals which have high water retention. Amorphous clay material, for example, possesses high water content.

MINERALOGICAL PROPERTIES

Differential Thermal Analysis (DTA)

Differential thermal curves of the four soils are presented in Figs. 2 through 5. These curves show the presence of a strong endothermic peak at approximately 150°C which is attributed to adsorbed water and which is characteristic of allophane (Fieldes, 1955). Most of the curves also show a small to moderate endothermic peak at approximately 500°C which is attributed to the presence of kaolin. The results show that the amount of kaolin generally increases with increase in rainfall. There is a slight decrease in the kaolin

TABLE III. 15-BAR MOISTURE VALUES OF THE SOILS

Horizon	Depth	15-Bar	Horizon	Depth	15-Bar
	PAKINI			NAALEHU	
Ap	0 - 3"	26.4	Ap	0 - 20"	28.6
A12	3 - 8"	26.9	B21	20 - 31"	41.6
A3	8 - 16"	36.9	IIB22	31 - 36"	37.7
B21	16 - 29"	36.2	IIIB23	36 - 53"	55.6
B22	29 - 45"	28.3	IVC	53 - 65"+	47.8
Cca	45 - 60"+	25.6			
	MOAULA			ALAPAI	
Ap	0 - 9"	42.5	Ap1	0 - 7"	38.1
B21	9 - 17"	54.7	Ap2	7 - 15"	55.0
B22	17 - 23"	52.6	B1	15 - 27"	46.2
B23	23 - 31"	37.6	B21	27 - 36"	41.7
B24	31 - 40"	45.2	B22	36 - 43"	44.5
B25	40 - 48"	38.7	B23	43 - 50"	41.9
B26	48 - 54"	55.9	B24	50 - 57"	44.3
B27	54 - 65"	45.5	B25	57 - 66"	50.5
B28	65 - 74"+	42.7	B26	66 - 74"+	54.7

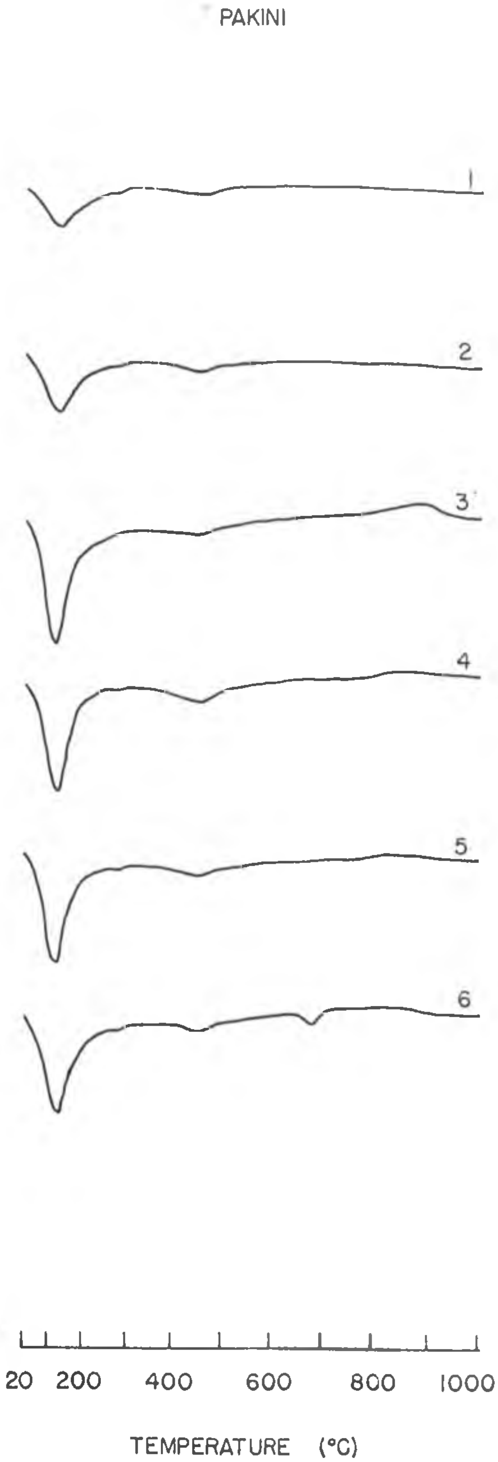

Figure 2. DTA curves of the Pakini soil.

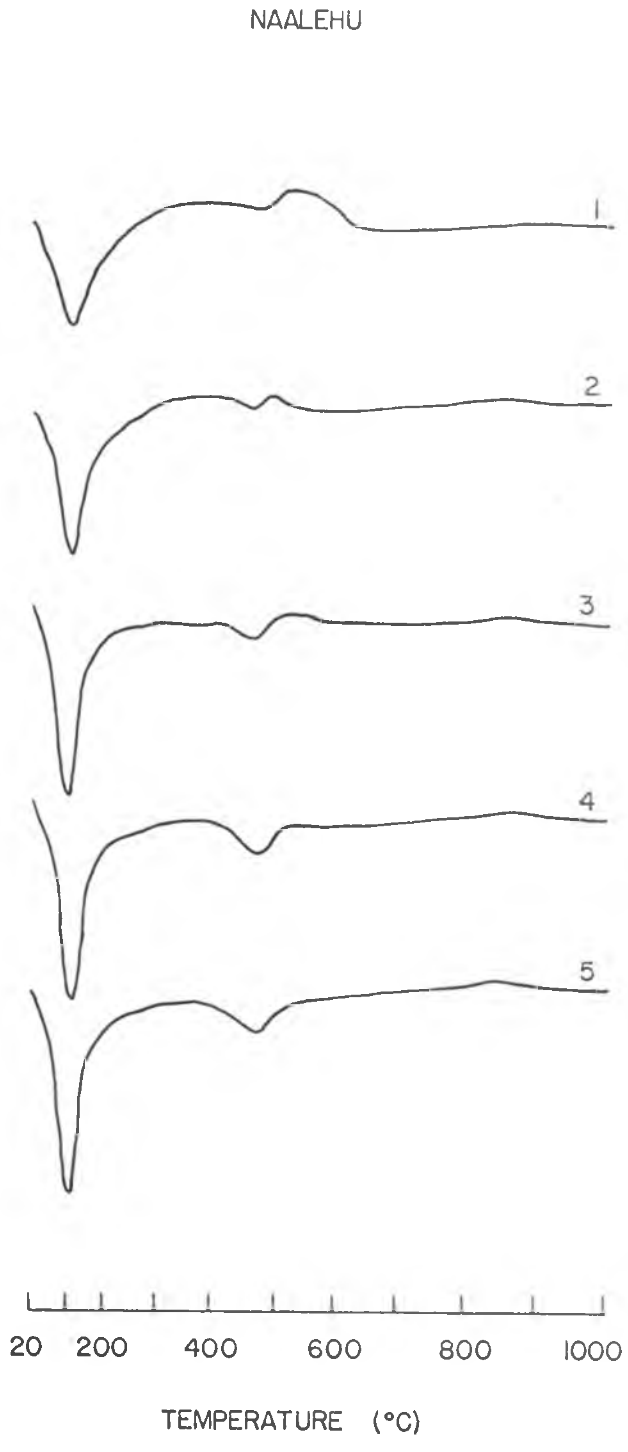

Figure 3. DTA curves of the Naalehu soil.

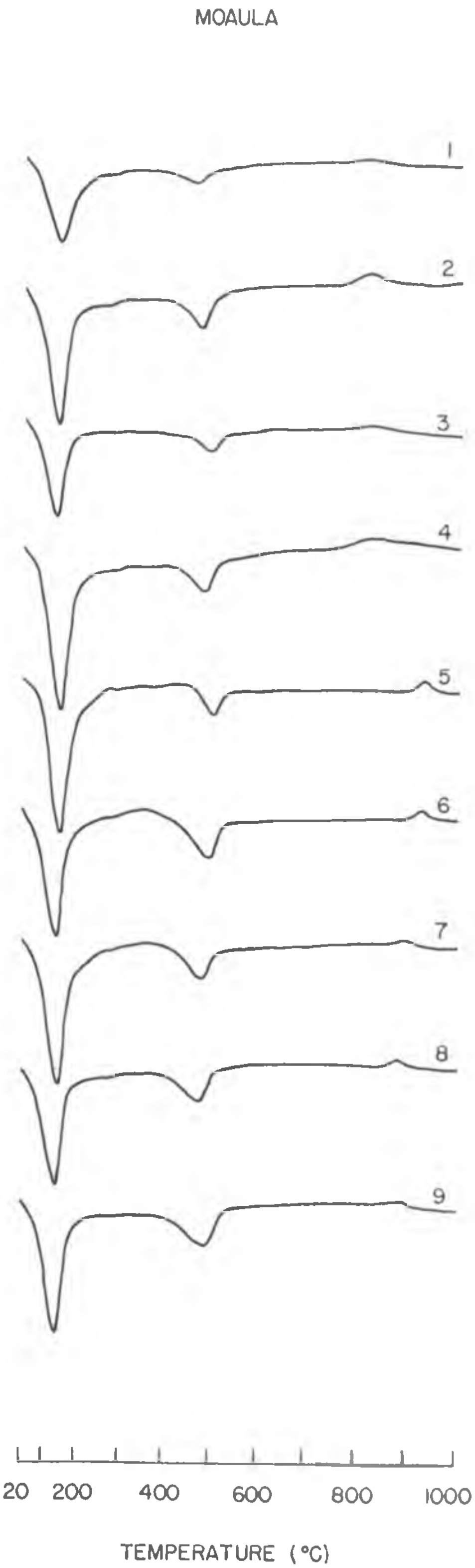

Figure 4. DTA curves of the Moaula soil.

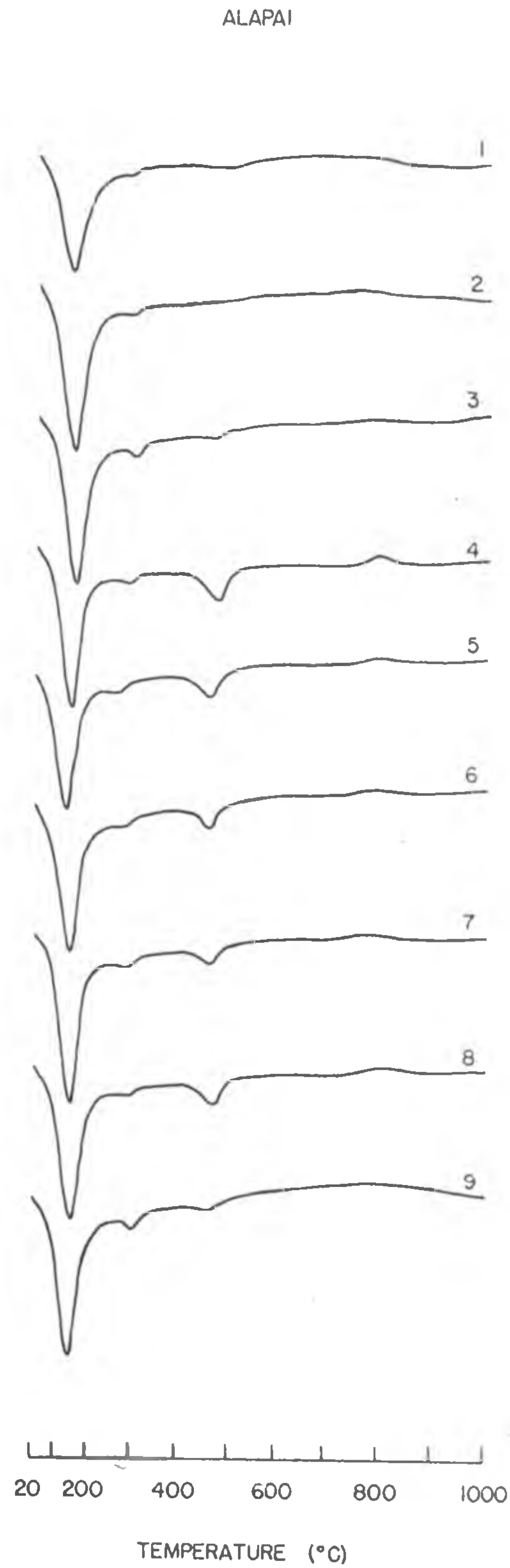

Figure 5. DTA curves of the Alapai soil.

content, however, in the Alapai soil. The upper horizons and the lowest horizons, furthermore, show very little or no kaolin. An endothermic peak at approximately 300°C indicates the presence of gibbsite.

There is a weak indication of gibbsite in the Pakini soil, none in the Naalehu and Moaula soils, and a small amount in the Alapai soils. If the very small amount of gibbsite in the Pakini soil is not considered, these results confirm the hypothesis that with increasing rainfall, allophane can transform to kaolin and the latter can eventually transform to gibbsite.

In horizon 6 of the Pakini soil (Fig. 2), a weak endothermic peak at approximately 700°C suggests the presence of montmorillonite. In the surface horizons of the Naalehu soil, an exothermic peak at approximately 550°C may be due to the presence of iron oxide or organic matter. The weak broad exothermic peak between 800 and 900°C in most of the horizons may be associated with the kaolin mineral or allophane. Fieldes (1955) has attributed the presence of these high temperature exotherms to allophane AB.

The Moaula soil also show the high temperature endothermic peak. It occurs closer to 800°C in the upper four horizons and closer to 900°C in the remaining lower horizons. Here again, this exotherm may be attributed to the presence of kaolin and/or allophane. It is common to find this high temperature exotherm occurring at slightly lower temperature in the surface horizons than in the subsurface horizons in many of the Hawaiian soils (Department of Agronomy and Soil Science Staff, personal communication, 1968).

X-ray Diffraction Analysis

The X-ray diffraction patterns (Figs. 6 through 9) of the clay fraction of the four soils indicate the dominance of X-ray amorphous material. Crystalline secondary clay minerals or oxides, however, were detected in the Moaula and Alapai soils, the wettest members of the sequence.

The X-ray patterns of the Pakini soil (Fig. 6) indicate this soil is composed primarily of X-ray amorphous material in the clay fraction throughout the profile. The presence of the 02 hk reflection (4.4A), however, suggests the presence of some disordered layer silicate mineral. Although X-ray amorphous material may be dominant, there may be the beginning of formation of halloysite. Based on heating test of the K-saturated samples, trace amount of a 10 A mineral (mica) was detected in horizon 4. This horizon may once have been a surface horizon.

In the Naalehu soil (Fig. 7), in addition to the X-ray amorphous material in the clay fraction, there were indications of kaolin mineral. A 10 A peak is observed in horizon 2, perhaps very weakly also in horizon 1. Heating the samples to 300 and 500^{o}C revealed that this 10 A peak was due to halloysite. The peak was present after heating the clay slide at 300^{o}C but was absent after heating at 500^{o}C. Jackson (1956) suggested that the 10 A peak of halloysite may be collapsed to 7 A by heating the preferentially oriented slide at 450^{o}C. The presence of the 02 hk reflection (4.4A) and the second order peak (3.6A) also confirm the presence of halloysite.

The patterns of the clay fraction of the Moaula soil (Fig. 8) show not only X-ray amorphous material but also weak 7 and 10 A peaks

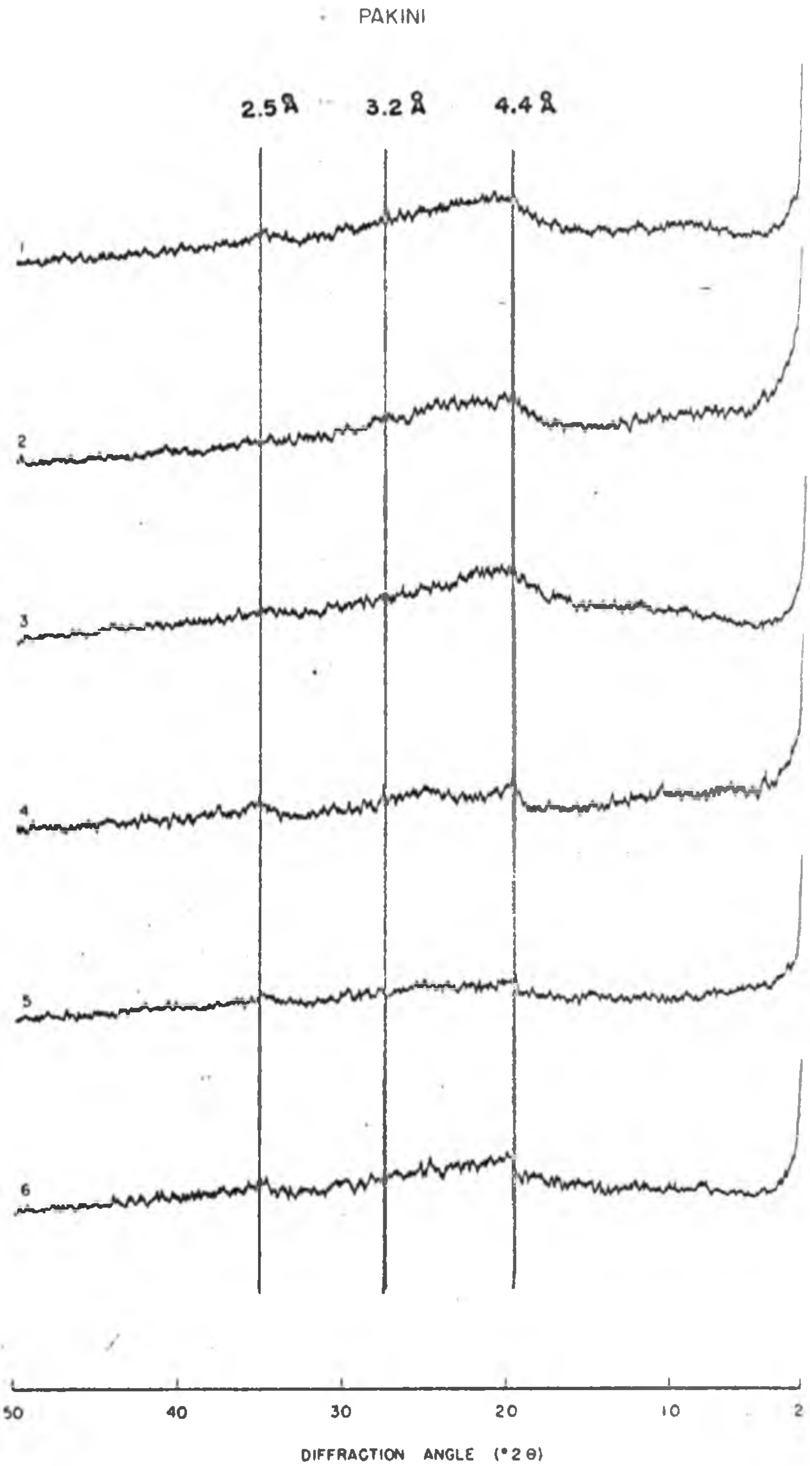

Figure 6. X-ray patterns of clay fraction of Pakini soil.

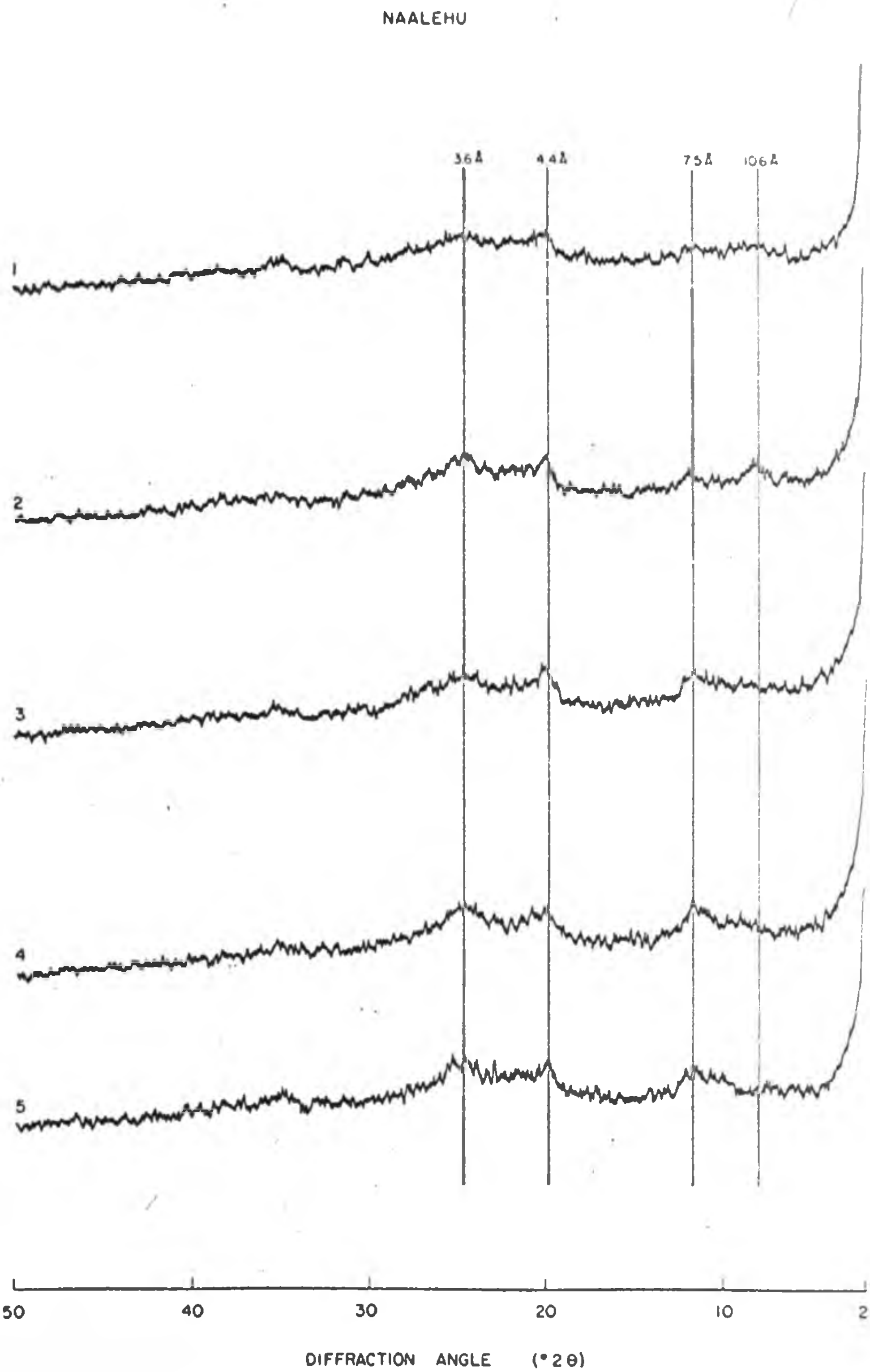

Figure 7. X-ray patterns of clay fraction of Naalehu soil.

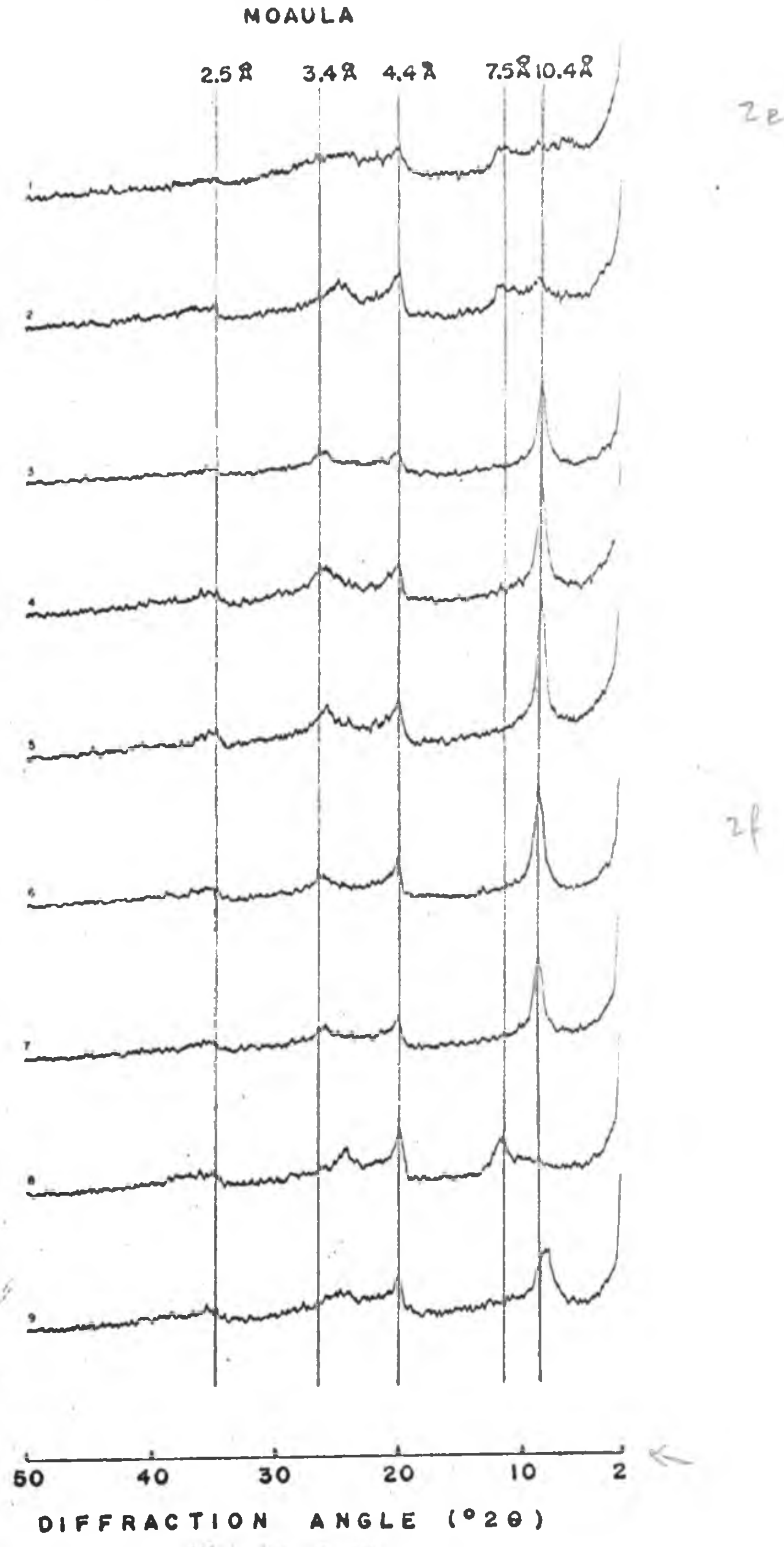

Figure 8. X-ray patterns of clay fraction of Moaula soil.

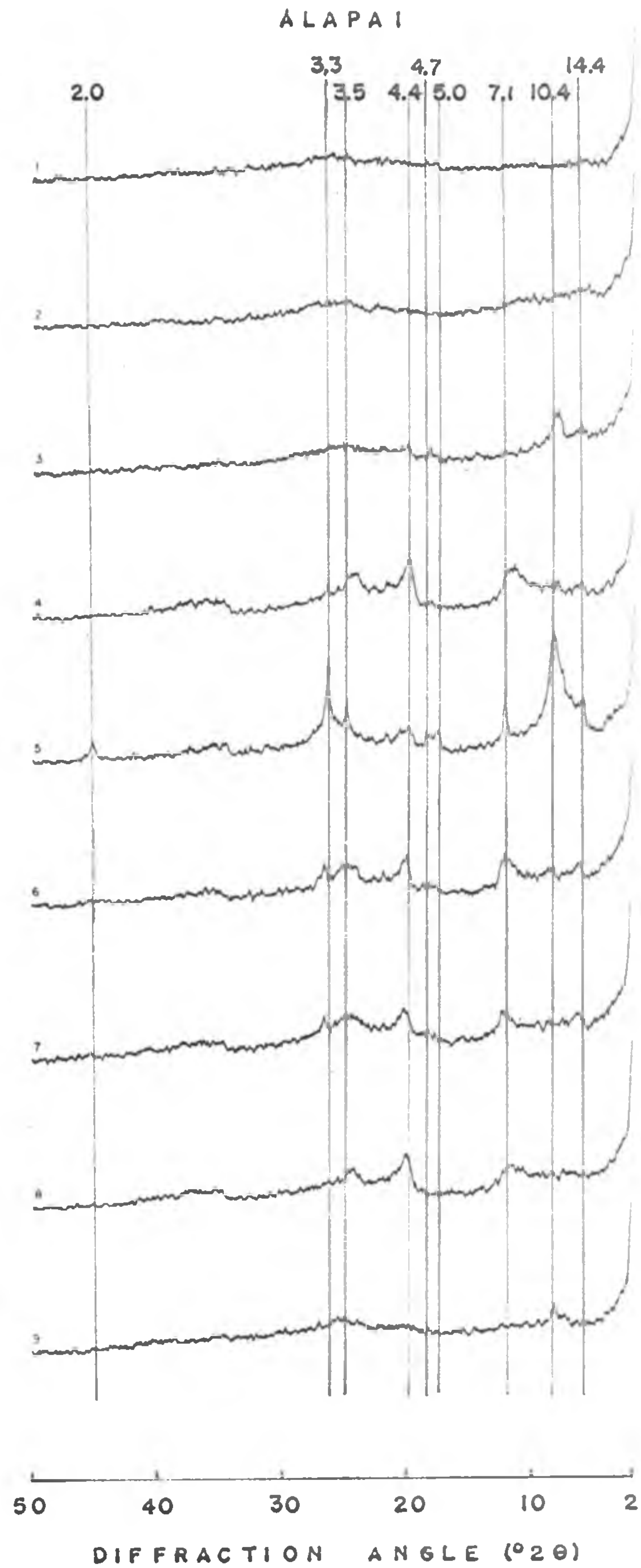

Figure 9. X-ray patterns of Clay Fraction of Alapai soil.

in horizons 1 and 2 and very strong 10 A peaks (except in horizon 8) in the rest of the subsurface horizons. At first observation, the sharp 10 A peaks suggest the presence of mica. However, the heating test of the preferentially oriented clays at 105, 300, and 500°C showed that this peak was attributable to halloysite. The 10 A peak appears strong probably because of the glycerine which was added to the suspension during the preparation of the clay slide. It was necessary to add this compound to prevent the curling and eventually peeling of the clay as the suspension dried on the glass slide. In this soil, the heating test (500°C) indicated a small amount of mica in horizons 1 and 4. It is highly probable that horizon 4 of the Moaula soil, as in the case of horizon 4 of the Alapai soil, was once a surface horizon.

The size of the 02 hk reflection (4.4A) of the Moaula soil when compared with those observed for the Pakini and Naalehu soils indicates that there is considerably more disordered mineral and/or halloysite in the former. Figure 8, furthermore, indicates that this disordered mineral and/or halloysite in the upper two horizons do not respond in a similar fashion to the addition of glycerine. There is only partial expansion of glycerine which suggests that some of the halloysite may have already transformed to kaolinite. Saing and Uehara (manuscript in preparation) have shown that halloysite is common in the subsurface horizons and that fine-sized kaolinite ($\leqslant 0.5\,\mu$) is common in the surface horizons in some oxisols derived from basaltic parent rock material. If investigation by electron microscopy confirms the presence of both halloysite and kaolinite in this soil derived from volcanic ash, it is still another contribution to the study of clay mineralogy in Hawaii. Similarity of horizon 8 to horizons 1 and 2 suggests the former may once have been surface horizon also.

The X-ray amorphous material dominates the clay fraction of the Alapai soil (Fig. 9), especially in the upper three horizons. However, heating test of the K-saturated slides and glycolation test of the Mg-saturated slides indicated the presence of halloysite and mica in horizons 4, 5, 6, and 7. In fact, Fig. 9 shows that there was considerable amount of mica (10, 3.3A) in horizon 5. The occurrence of this mica, perhaps quartz also, and the color of this horizon (Soil Descriptions) when compared with the results of the other horizons strongly suggest the presence of a buried A horizon. Trace amount of 14 A mineral (vermiculite or chlorite) was also detected in horizon 5. Finally, small amounts of halloysite and trace amount of 10 A mineral were detected in horizon 8 and 9, respectively.

CHEMICAL PROPERTIES

Cation Exchange Capacity (CEC)

All of the soils have high cation exchange capacity as shown in Table IV. These values range from 35.3 to 68.1 meq/100 g of soil. There is no trend within a profile.

The cation exchange capacity of the surface horizon of all soils was negatively correlated with the rainfall as shown in Fig. 10. Statistical analysis of the data indicates this relationship is highly significant. A lower cation exchange capacity in the surface horizon which is related to increasing rainfall may be the result of the destructive effect of rainfall upon the mineral exchange capacities of

TABLE IV. CATION EXCHANGE CAPACITY, EXCHANGEABLE BASES, AND BASE SATURATION OF THE SOILS

Horizon	Depth	CEC	Ca	Mg	Na	K	Base Sat.
			P A K I N I				
Ap	0 - 3"	51.0	22.6	14.0	1.0	7.4	88
A12	3 - 8"	45.4	17.9	12.0	1.6	4.7	80
A3	8 - 16"	60.6	31.1	18.9	2.9	4.0	94
B21	16 - 29"	68.1	37.5	23.5	2.9	4.9	100+
B22	29 - 45"	61.3	36.4	28.7	6.1	5.2	100+
Cca	45 - 60"+	57.2	30.8	28.4	12.0	6.1	100+
			N A A L E H U				
Ap	0 - 20"	45.8	17.2	9.1	0.7	0.7	60
B21	20 - 31"	50.2	22.6	11.7	1.0	0.7	72
IIB22	31 - 36"	63.1	33.7	19.2	1.8	0.5	87
IIIB23	36 - 53"	63.6	35.8	23.8	3.1	0.3	97
IVC	53 - 65"+	67.6	34.4	26.5	1.9	0.2	93

Note: Cation Exchange Capacity and Exchangeable Bases in meq/100g.

Base Saturation in percent.

TABLE IV. (Continued) CATION EXCHANGE CAPACITY, EXCHANGEABLE BASES, AND BASE SATURATION OF THE SOILS

Horizon	Depth	CEC	Ca	Mg	Na	K	Base Sat.
			MOAULA				
Ap	0 - 9"	43.8	13.8	3.7	0.9	0.7	43
B21	9 - 17"	45.4	19.2	4.2	3.2	0.1	58
B22	17 - 23"	48.8	19.0	3.1	3.6	0.2	51
B23	23 - 31"	47.0	15.8	3.9	1.9	0.1	46
B24	31 - 40"	46.2	18.6	5.5	2.3	0.1	57
B25	40 - 48"	52.0	18.2	5.3	2.6	0.1	50
B26	48 - 54"	53.2	18.1	3.7	2.5	0.1	45
B27	54 - 65"	53.9	19.3	3.5	2.9	0.1	47
B28	65 - 74"+	46.2	16.5	7.0	2.4	0.1	56
			ALAPAI				
Ap1	0 - 7"	39.3	8.8	3.3	0.5	0.5	33
Ap2	7 - 15"	42.1	6.3	0.3	0.3	0.4	17
B1	15 - 27"	40.0	5.5	0.6	0.4	0.2	17
B21	27 - 36"	51.0	10.0	0.1	1.5	0.5	24
B22	36 - 43"	39.9	9.0	0.1	1.3	0.5	27
B23	43 - 50"	35.3	6.5	0.3	1.3	0.4	24
B24	50 - 57"	41.6	7.1	0.3	1.2	0.5	22
B25	57 - 66"	46.8	7.2	0.9	1.9	0.5	22
B26	66 - 74"+	41.8	3.1	0.3	0.5	0.1	9

Note: Cation Exchange Capacity and Exchangeable Bases in meq/100g.

Base Saturation in percent.

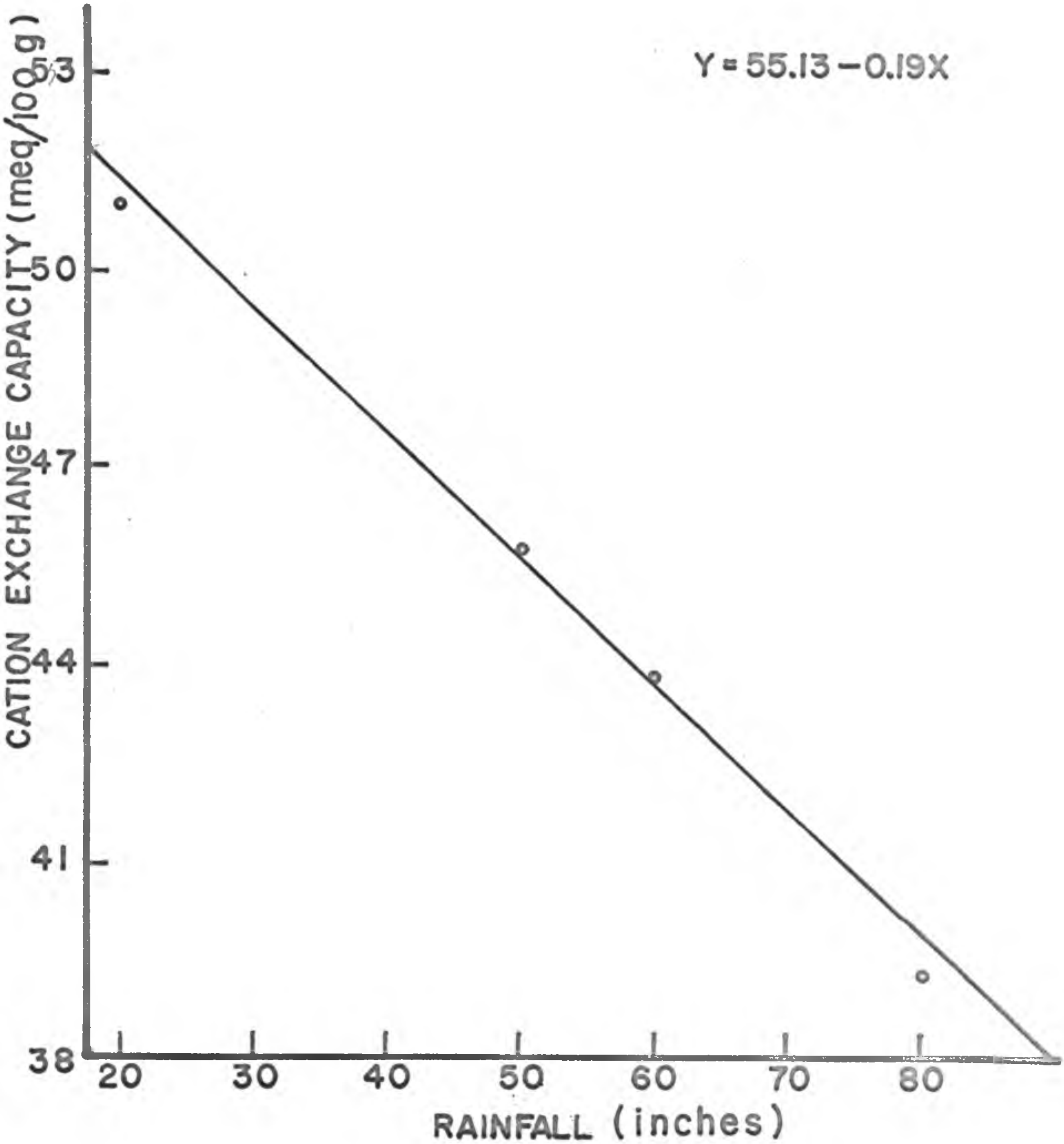

Figure 10. Relationship between Cation Exchange Capacity and Rainfall.

the soil, as the organic exchange capacities are seemingly independent of the rainfall (Ayres, 1943). In general, the cation exchange capacity of the soils decreased with increasing rainfall.

The mineralogical analysis has shown the dominance of X-ray amorphous material, in the clay fraction of these soils. Cation exchange capacity is highly correlated with amorphous material such as allophane (Fieldes, Swindale, and Richardson, 1952; and Loganathan, 1967). The values, however, may vary according to the environment (Birrell and Gradwell, 1956; Kanehiro and Sherman, 1956; and Loganathan, 1967).

Statistical analysis shows that the cation exchange capacity is highly negatively correlated with the amount of clay obtained by the pipette method ($r = -0.579^{**}$, $df = 27$). This would indicate much of the sand and/or silt fractions, especially in the Pakini soil, may be aggregates of the X-ray amorphous material or other materials which contribute to high cation exchange capacity.

Exchangeable Bases and Base Saturation

The exchangeable bases and base saturation are also presented in Table IV. Exchangeable Ca and Mg were highest in the Pakini and Naalehu soils. The amount of exchangeable Ca in the surface horizons is correlated with rainfall, and the relationship is highly significant as shown in Fig. 11. The amount in the subsurface horizons similarly decreased with increasing rainfall. These results are in accord with the observation by Ayres (1943). Similar results were reported by Loganathan (1967).

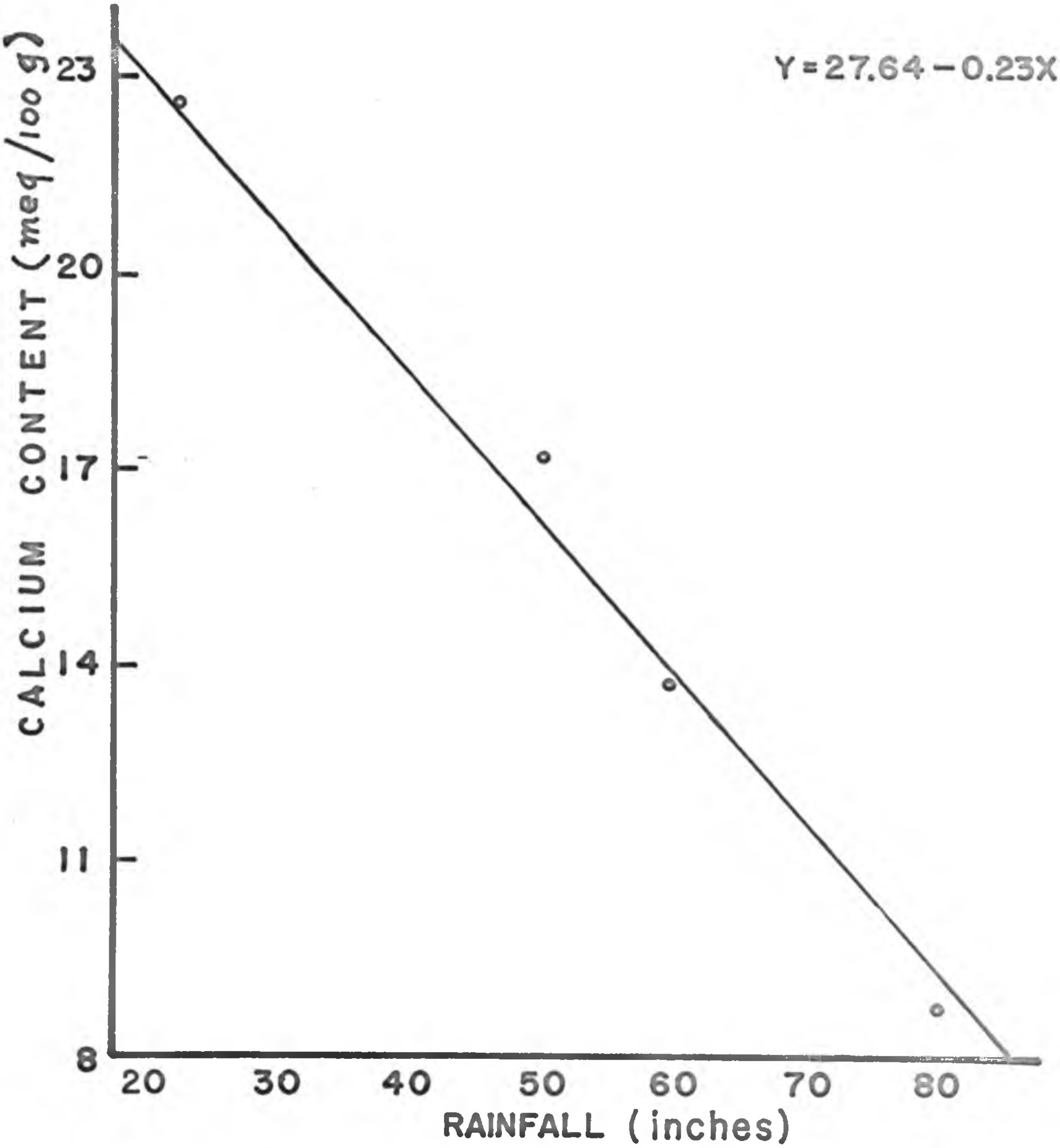

Figure 11. Relationship between Calcium Content and rainfall.

In the Alapai soil, the high amount of exchangeable Mg in the surface horizon may be due to application of potash fertilizer which usually contains Mg salts as impurities. The exchangeable Mg also decreases with increasing rainfall but this relationship is not statistically significant as in the case of the exchangeable Ca.

The soils used in this investigation show more exchangeable Na in the lower horizons than in the surface horizons. The lowest two horizons of the Pakini soil especially show very high values. The contribution of the ocean salt, in addition to incomplete leaching of salts due to low rainfall, should not be discounted.

The exchangeable K in the Pakini soil is very high when compared with the values in the other soils. As in the case of exchangeable Na, it is difficult to show the distribution trends of these bases within the profile.

Base Saturation

The base saturation ranged from 9 percent in the lowest horizon of the Alapai soil to over 100 percent in the lower horizons of the Pakini soil. There was a significant decrease in the base saturation with increasing rainfall, and this relationship is shown in Fig. 12.

Statistical analysis shows there is significant correlation between cation exchange capacity and exchangeable cations ($r = 0.922^{**}$, 0.845^{**}, 0.425^{*}, and 0.376^{*} with Ca, Mg, Na, and K, respectively). As expected, there is also a highly significant correlation between cation exchange capacity and base saturation ($r = 0.817^{**}$, df = 27).

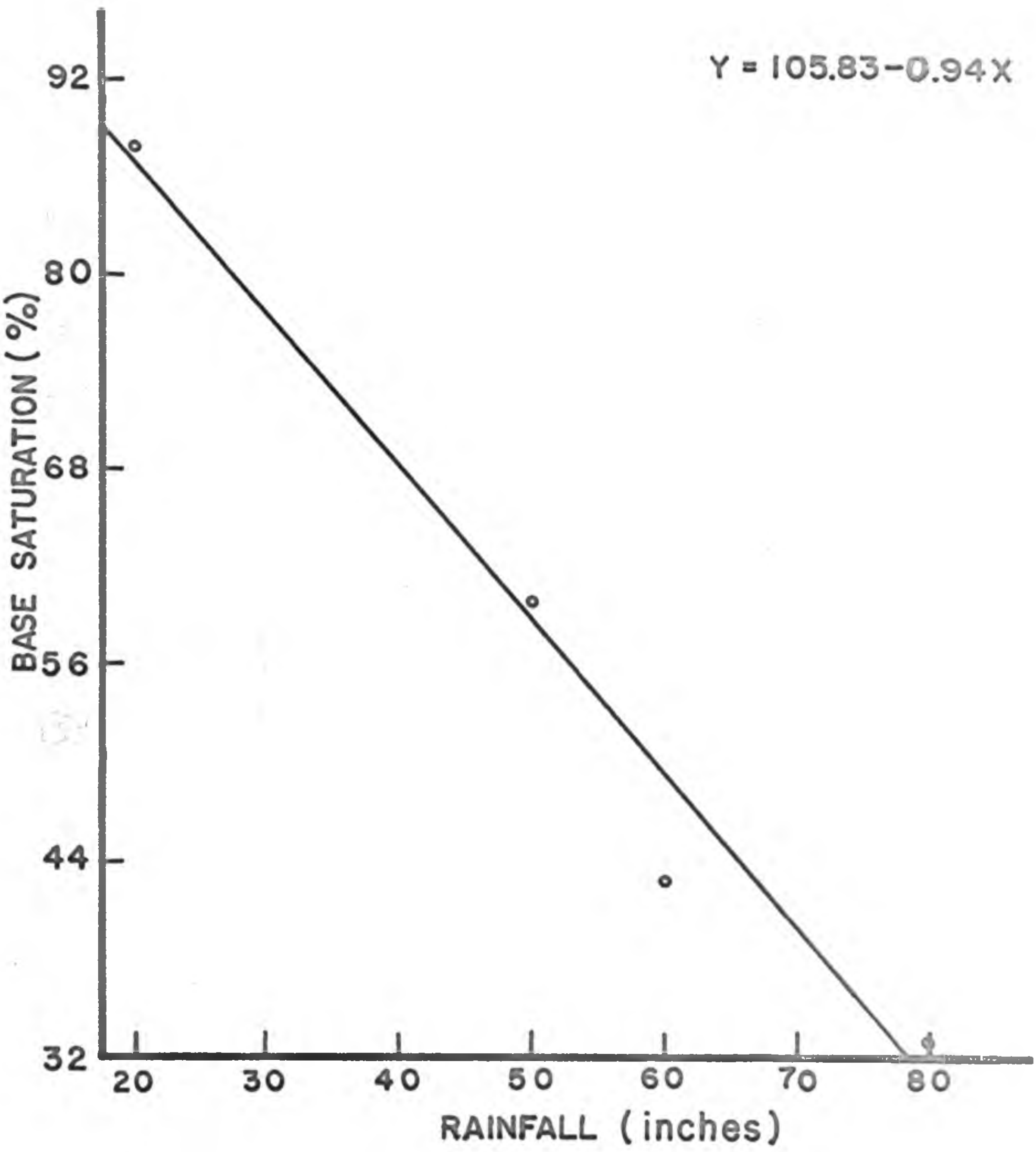

Figure 12. Relationship between Base Saturation and Rainfall.

Soil Acidity and Delta pH

Except for the surface horizons of the Moaula and Alapai soils, the pH's of these soils are above 5.0 as shown in Table V. The pH in water suspension (1:1) is generally higher than in KCl suspension (1:1). In the Moaula and Alapai soils, the pH is lower in the surface than in the subsurface horizons. This may be due to the high content of organic matter as described by Ayres (1943).

The pH value (1:1 water suspension) of the Pakini soil is higher than the others and increases with depth. The low rainfall which prevent the loss of bases and the high amounts of Ca and Mg as well as Na in the parent material may account for pH as high as 8.1 in the lowest two horizons. Although the exchangeable H^+ in the Alapai and Moaula soils and in the upper two horizons of the Naalehu soil is high ranging from 14 to 38 meq/100 g of soil, the pH value of the Naalehu, Moaula, and Alapai soils is only slightly acidic (range = 4.8 to 6.8; mean = 6.1). This may be due to the presence of X-ray amorphous material probably allophane which has a strong buffering capacity in the region of the iso-electric point (Swindale, 1964). Similar observations were made by Loganathan (1967) in his study of soils derived from andesitic volcanic ash.

The results of the delta pH indicate that the Moaula and Alapai soils have less net negative charge than the Pakini or Naalehu soils, thereby indicating that the delta pH decreases with increasing rainfall.

Organic Carbon, Total Nitrogen, and Carbon/Nitrogen Ratio

These results are also presented in Table VI. The highest

TABLE V. pH VALUES AND EXCHANGEABLE H^+ OF THE SOILS

Horizon	Depth	pH H_2O	pH KCl	Δ pH (H_2O-KCl)	Exchangeable H^+ * meq/100g
			P A K I N I		
Ap	0 - 3"	6.7	5.7	1.0	6.0
A12	3 - 8"	6.6	5.3	1.3	9.2
A3	8 - 16"	7.0	5.8	1.2	3.7
B21	16 - 29"	7.6	6.4	1.2	-0.7
B22	29 - 45"	8.1	6.9	1.2	-15.1
Cca	45 - 60"+	8.1	7.2	0.9	-20.1
			N A A L E H U		
Ap	0 - 20"	5.6	4.4	1.2	18.1
B21	20 - 31"	5.7	4.7	1.0	14.0
IIB22	31 - 36"	6.8	5.7	1.1	7.9
IIIB23	36 - 53"	6.5	5.7	0.8	1.6
IVC	53 - 65"+	6.7	5.8	0.9	4.6

*Exchangeable H^+ = CEC - Sum of Exchangeable Bases

TABLE V. (Continued) pH VALUES AND EXCHANGEABLE H^+ OF THE SOILS

Horizon	Depth	pH H_2O	pH KCl	Δ pH (H_2O-KCl)	Exchangeable H^+ * meq/100g
			MOAULA		
Ap	0 - 9"	4.9	4.5	0.4	24.7
B21	9 - 17"	6.2	5.3	0.9	18.7
B22	17 - 23"	6.2	5.4	0.8	23.9
B23	23 - 31"	6.3	5.5	0.8	25.3
B24	31 - 40"	6.2	5.4	0.8	19.7
B25	40 - 48"	6.3	5.4	0.9	26.1
B26	48 - 54"	6.4	5.5	0.9	28.8
B27	54 - 65"	6.4	5.5	0.9	28.1
B28	65 - 74"+	6.4	5.7	0.7	20.2
			ALAPAI		
Ap1	0 - 7"	4.8	4.3	0.5	26.2
Ap2	7 - 15"	5.8	5.2	0.6	34.8
B1	15 - 27"	6.4	5.4	1.0	33.3
B21	27 - 36"	6.1	5.1	1.0	38.9
B22	36 - 43"	6.2	5.4	0.8	29.0
B23	43 - 50"	6.0	5.2	0.8	26.8
B24	50 - 57"	6.0	5.1	0.9	32.5
B25	57 - 66"	6.2	5.3	0.9	36.3
B26	66 - 74"+	6.0	5.4	0.6	37.8

*Exchangeable H^+ = CEC - Sum of Exchangeable Bases

TABLE VI. ORGANIC CARBON, TOTAL NITROGEN AND C/N RATIO

Horizon	Depth	% Organic C	% Nitrogen	C/N Ratio
		P A K I N I		
Ap	0 - 3"	5.30	0.474	11
A12	3 - 8"	3.89	0.363	11
A3	8 - 16"	2.68	0.228	12
B21	16 - 29"	1.51	0.120	13
B22	29 - 45"	0.83	0.067	12
Cca	45 - 60"+	0.66	0.054	12
		N A A L E H U		
Ap	0 - 20"	3.29	0.252	13
B21	20 - 31"	1.97	0.170	12
IIB22	31 - 36"	0.90	0.080	11
IIIB23	36 - 53"	0.60	0.057	11
IVC	53 - 65"+	0.47	---	---

TABLE VI. (Continued) ORGANIC CARBON, TOTAL NITROGEN AND C/N RATIO

Horizon	Depth	% Organic C	% Nitrogen	C/N Ratio
		MOAULA		
Ap	0 - 9"	7.89	0.547	14
B21	9 - 17"	7.88	0.594	13
B22	17 - 23"	2.53	0.200	12
B23	23 - 31"	1.90	0.154	12
B24	31 - 40"	1.81	0.132	13
B25	40 - 48"	1.18	0.096	12
B26	48 - 54"	1.10	0.082	13
B27	54 - 65"	1.13	0.088	12
B28	65 - 74"+	0.65	0.047	13
		ALAPAI		
Ap1	0 - 7"	11.99	0.785	15
Ap2	7 - 15"	6.32	0.406	15
B1	15 - 27"	2.93	0.208	14
B21	27 - 36"	3.49	0.248	14
B22	36 - 43"	4.02	0.278	14
B23	43 - 50"	3.51	0.258	13
B24	50 - 57"	3.74	0.287	13
B25	57 - 66"	3.19	0.297	11
B26	66 - 74"+	1.91	0.128	14

amount of organic C occurs in the surface horizon of the Alapai soil while the lowest amount is in the C horizon of the Naalehu soil. In general, organic C is highest in the surface horizon of all soils. The organic C of the Naalehu soil is lower than that of the Pakini soil probably because of the intensive cultivation in the former.

In all soils, the organic C decreases with depth. With the exception of the Naalehu soil, for reasons already stated, the organic C also increases with increase in rainfall.

The total N is closely related with the occurrence of organic C. A test showed a highly significant correlation between these two variables ($r = 0.984^{**}$, df = 27). There were also highly significant correlations between total N and pH ($r = -0.634^{**}$) and between total N and cation exchange capacity ($r = -0.559^{**}$, df = 27). These relationships, therefore, indicate that total N also increases with increase in rainfall.

Since the organic C and total N are closely related to each other, the C/N ratio follows the same trend. The ratio is, however, slightly lower in the Pakini and Naalehu soils than in the Moaula and Alapai soils. The ratios ranged from 11 to 15 (mean = 12.7). It is interesting to note that Loganathan (1967) obtained ratios which ranged from 10 to 24 (mean = 17).

Extractable Iron Oxides

As in the case of organic C, total N, and the C/N ratio, the extractable Fe oxides were lower in the Pakini and Naalehu than in the Moaula and Alapai soils. These results, therefore, showed that the

TABLE VII. PERCENTAGE OF EXTRACTABLE IRON OF THE SOILS

Horizon	Depth	% Fe	Horizon	Depth	% Fe
	PAKINI			NAALEHU	
Ap	0 - 3"	4.4	Ap	0 - 20"	5.9
A12	3 - 8"	5.5	B21	20 - 31"	7.5
A3	8 - 16"	6.8	IIB22	31 - 36"	9.2
B21	16 - 29"	5.7	IIIB23	36 - 53"	9.7
B22	29 - 45"	5.0	IVC	53 - 65"+	7.9
Cca	45 - 60"+	5.1			
	MOAULA			ALAPAI	
Ap	0 - 9"	7.3	Ap1	0 - 7"	7.8
B21	9 - 17"	11.8	Ap2	7 - 15"	12.5
B22	17 - 23"	13.6	B1	15 - 27"	12.7
B23	23 - 31"	13.6	B21	27 - 36"	13.8
B24	31 - 40"	14.3	B22	36 - 43"	15.4
B25	40 - 48"	13.4	B23	43 - 50"	14.7
B26	48 - 54"	14.5	B24	50 - 57"	16.3
B27	54 - 65"	13.4	B25	57 - 66"	15.9
B28	65 - 74"+	12.3	B26	66 - 74"+	16.1

extractable Fe oxides increased with increase in rainfall. There was no definite distribution trend within a profile.

According to Swindale (1964), the amount of extractable Fe oxides or free Fe oxides in the soil may indicate the relative degree of weathering. This idea may not be apparent, however, in areas of very high rainfall.

In this investigation, there were significant correlations between extractable Fe oxides and amount of clay ($r = 0.740^{**}$), between extractable Fe oxides and 15-bar water ($r = 0.698^{**}$), between extractable Fe oxides and delta pH ($r = -0.418^{*}$), between extractable Fe oxides and cation exchange capacity ($r = -0.492^{**}$), and between extractable Fe oxides and base saturation ($r = -0.788^{**}$, df = 27).

CLASSIFICATION OF THE SOILS

Based on the Great Soil Group Classification System, Cline et al. (1955) classified the Pakini soil as Reddish Brown, the Naalehu soil as Reddish Prairie, and the Moaula and Alapai soils as Hydrol Humic Latosols.

In 1960, the Soil Survey Staff, USDA, introduced the Comprehensive Soil Classification System which is based on the properties of soils. This system was further modified in 1967.

The data obtained in this investigation have been used to study the effect of climate, more precisely rainfall, on this sequence of soils. This data will now be used to classify the soils by the Comprehensive Classification System.

All soils in the sequence are derived from volcanic ash or are found on young but not recent land surfaces. Based on data obtained from the field observation and laboratory analyses, the diagnostic horizons are thought to have formed rather quickly and do not represent significant illuviation or elluviation or extreme weathering. The soils are, therefore, classified into the Order Inceptisol.

The Pakini Soil

The properties of Pakini soil are summarized in Table VIII.

The surface horizon of this soil is 16 inches (40 cm) thick with dark color. The moist value and the moist chroma range from 2 to 4. The structure below this horizon is weakly platy to weakly prismatic. The organic C ranges from 2.68 to 5.30 percent and the C/N ratio is 11. Base saturation is over 50 percent and the 15-bar water retention is more than 20 percent. This soil is considered to have a mollic epipedon.

The subsurface horizons are brown, lighter in color than the surface horizon. The structure is weakly prismatic. The pH is alkaline with high amount of exchangeable Ca. Ca and Mg have accumulated to such an extent in the C horizon that it is designated a calcic horizon.

The presence of the mollic epipedon, the calcic horizon, and the high content of X-ray amorphous material place the Pakini soil in the Suborder Andept.

The mean annual soil temperature is 74°F. It has a mean 15-bar water retention value of more than 20 percent. The soil thus belongs to Great Group Eutrandept.

Because this soil is found in a dry area with approximately 20 inches of rainfall, and it has a mollic epipedon and subhorizon

TABLE VIII. SUMMARY OF THE PROPERTIES
OF PAKINI SOIL

Properties	Ap	A12	A3	B21	B22	Cca
Percent Sand	47.1	47.4	55.5	48.8	52.2	53.3
Percent Silt	45.3	47.1	41.7	48.5	45.2	41.8
Percent Clay	7.6	5.5	2.8	2.7	2.6	4.9
15-Bar Water	26.4	26.9	36.9	36.2	28.3	25.6
CEC	51.0	45.4	60.6	68.1	61.3	57.2
Ca	22.6	17.4	31.1	37.5	36.4	30.8
Mg	14.0	12.0	18.9	23.5	28.7	28.4
Na	1.0	1.6	2.9	2.9	6.1	12.0
K	7.4	4.7	4.0	4.9	5.2	6.1
B.S.	88	80	94	100+	100+	100+
pH-H_2O	6.7	6.6	7.0	7.6	8.1	8.1
pH-KCl	5.7	5.3	5.8	6.4	6.9	7.2
pH	1.0	1.3	1.2	1.2	1.2	0.9
Percent C	5.30	3.89	2.68	1.51	0.83	0.66
Percent N	0.474	0.363	0.228	0.120	0.067	0.054
C/N Ratio	11	11	12	13	12	12
Percent Fe	4.4	5.5	6.8	5.7	5.0	5.1

with soft, powdery, secondary lime, the Subgroup is Ustollic Eutrandept.

The average July temperature is 76°F (24.4°C) and the average January temperature is 72°F (22.2°C). The difference between the mean summer and winter temperature is 2.2°C. The mean annual soil temperature of this soil is 74°F, or more than 72°F (22°C). Thus, the soil temperature class is isohyperthermic.

Since the soil contains more than 60 percent sand and silt, the mineralogical class is ashy.

Based on the previous descriptions, the Pakini soil can be classified as ashy, isohyperthermic family of Ustollic Eutrandepts.

The Naalehu Soil

The properties of Naalehu soil are summarized in Table IX.

The surface horizon is 20 inches (50 cm) thick with dark color. The moist value and chroma both are 2. It has moderate granular structure. The organic C content is 3.29 percent and C/N ratio is 13. Base saturation is 60 percent (over 50 percent) and the 15-bar water retention is 28.6 percent (more than 20 percent). This soil is also considered to have a mollic epipedon.

The subsurface horizons are dark reddish brown with moist value 3 and moist chroma 2 to 3, lighter than surface horizon. The structure is weakly prismatic. The pH is neutral. The soil contains high amounts of Ca and Mg but does not have a special accumulation. This horizon is designated as cambic horizon.

The presence of a mollic epipedon, a cambic horizon, and a high content of X-ray amorphous material place the Naalehu soil in the

TABLE IX. SUMMARY OF THE PROPERTIES OF NAALEHU SOIL

Properties	Ap	B21	IIB22	IIIB23	IVC
Percent Sand	19.0	19.8	19.0	22.4	24.7
Percent Silt	52.4	52.0	53.1	51.4	49.6
Percent Clay	28.6	28.2	27.9	26.2	25.7
15-Bar Water	28.6	41.6	37.7	55.6	47.8
CEC	45.8	50.2	63.1	63.6	67.6
Ca	17.2	22.6	33.7	35.8	34.4
Mg	9.1	11.7	19.2	23.8	26.5
Na	0.7	1.0	1.8	2.1	1.9
K	0.7	0.7	0.5	0.3	0.2
B.S.	60	72	87	97	93
pH-H_2O	5.6	5.7	6.8	6.5	6.7
pH-KCl	4.4	4.7	5.7	5.7	5.8
pH	1.2	1.0	1.1	0.8	0.9
Percent C	3.29	1.97	0.90	0.60	0.47
Percent N	0.252	0.170	0.080	0.057	---
C/N Ratio	13	12	11	11	---
Percent Fe	5.9	7.5	9.2	9.7	7.9

Suborder Andept. The mean soil temperature is 72°F. It has a mean 15-bar water retention value of more than 20 percent, and the base saturation is 60 percent (over 50 percent). The soil belongs to Great Group Eutrandept.

Although this soil has a high content of Ca, it does not have a subhorizon with a soft, powdery, secondary lime with 1.5 m (60 inches) of the surface. Thus, the Subgroup is Typic Eutrandept.

The average July temperature is 75°F (23.8°C) and the average January temperature is 69°F (20.5°C). The difference between these two temperatures is 3.3°C. The mean annual soil temperature of this soil is 72°F (22°C). The temperature class is, therefore, isothermic.

Since the soil contains more than 60 percent sand and silt, the mineralogical class is ashy.

Based on the previous descriptions, the Naalehu soil is classified as ashy, isothermic family of Typic Eutrandepts.

The Moaula Soil

The properties of Moaula soil are summarized in Table X.

The surface horizon of this soil is nine inches (22.5 cm) thick with dark color. The moist value and moist chroma both are 2. It has strong subangular blocky structure. The organic C content is 7.89 percent and the C/N ratio is 14. Base saturation is 43 percent, less than 50 percent and the 15-bar water retention is very high (42.5 percent). The dominant exchangeable cation is H, 26.2 meq/100g of soil (Table V). Based on these descriptions, this soil is considered to have an umbric epipedon.

TABLE X. SUMMARY OF THE PROPERTIES OF MOAULA SOIL

Properties	Ap	B21	B22	B23	B24	B25	B26	B27	B28
Percent Sand	15.5	17.6	18.8	18.7	14.2	15.0	19.2	20.1	22.0
Percent Silt	54.8	52.9	50.2	51.1	54.8	56.2	51.4	50.2	48.7
Percent Clay	29.7	29.5	31.0	30.2	31.0	28.8	29.4	29.7	29.3
15-Bar Water	42.5	54.7	52.6	37.6	45.2	38.7	55.9	45.5	42.7
CEC	43.8	45.4	48.8	47.0	46.2	52.0	53.2	53.9	46.2
Ca	13.8	19.2	19.0	15.8	18.6	18.2	18.1	19.3	16.5
Mg	3.7	4.2	3.1	3.9	5.5	5.3	3.7	3.5	7.0
Na	0.9	3.2	2.6	1.9	2.3	2.6	2.5	2.9	2.4
K	0.7	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
B.S.	43	58	51	46	57	50	45	47	56
pH-H_2O	4.9	6.2	6.2	6.3	6.2	6.3	6.4	6.4	6.4
pH-KCl	4.5	5.3	5.4	5.5	5.4	5.4	5.5	5.5	5.7
pH	0.4	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.7
Percent C	7.89	7.88	2.53	1.90	1.81	1.18	1.10	1.13	0.65
Percent N	0.547	0.594	0.200	0.154	0.132	0.096	0.082	0.088	0.047
C/N Ratio	14	13	12	12	13	12	13	12	13
Percent Fe	7.3	11.8	13.6	13.6	14.3	13.4	14.5	13.4	12.3

The subsurface horizons are dark reddish brown with moist value 3 and moist chroma 3 or 4. Structure is moderate subangular blocky. The pH is neutral. In the lower subsurface horizons, patches of gelatin-like coatings are found on ped surfaces. This soil is thus considered to have a cambic horizon.

The presence of an umbric epipedon, a cambic horizon, and a high content of X-ray amorphous material place the Moaula soil in the Suborder Andept.

The mean annual soil temperature is 70°F. It has a mean 15-bar water retention value of more than 20 percent. It is weakly smeary throughout the horizon. Since the base saturation is approximately 50 percent it may be classified as either an Eutrandept or Dystrandept. However, the author would like to classify this soil as a Dystrandept because of its smeary consistency. This smeary consistency brings this soil into Subgroup Hydric Dystrandept.

The average July temperature is 72°F (22.2°C) and average January temperature is 67°F (19.4°C). The difference between these two temperatures is 2.8°C. The mean annual soil temperature is 70°F (21.1°C). The temperature class of this soil is thus isothermic.

Based on the previous descriptions and the smeary consistence, the Moaula soil is classified as thixotropic, isothermic family of Hydric Dystrandepts.

The Alapai Soil

The properties of Alapai soil are summarized in Table XI.

The surface horizons of this soil is 15 inches (37.5 cm) thick with dark color. The moist value is 2 or 3 and moist chroma is also

TABLE XI. SUMMARY OF THE PROPERTIES OF ALAPAI SOIL

Properties	Ap1	Ap2	B1	B21	B22	B23	B24	B25	B26
Percent Sand	14.7	15.3	16.0	18.9	17.6	18.5	16.2	21.4	21.6
Percent Silt	51.8	51.0	49.8	46.8	48.8	44.6	51.4	50.1	49.5
Percent Clay	33.5	33.7	34.2	34.3	33.6	36.9	32.4	28.5	28.9
15-Bar Water	38.1	55.0	46.2	41.7	44.5	41.9	44.3	50.5	54.7
CEC	39.3	42.1	40.0	51.0	39.9	35.3	41.6	46.8	41.8
Ca	8.8	6.3	5.5	10.0	9.0	6.5	7.1	7.2	3.1
Mg	3.3	0.3	0.6	0.1	0.1	0.3	0.3	0.9	0.3
Na	0.5	0.3	0.4	1.5	1.3	1.3	1.2	1.9	0.5
K	0.5	0.4	0.2	0.5	0.5	0.4	0.5	0.5	0.1
B.S.	33	17	17	24	27	24	22	22	9
pH-H_2O	4.8	5.8	6.4	6.1	6.2	6.0	6.0	6.2	6.0
pH-KCl	4.3	5.2	5.4	5.1	5.4	5.2	5.1	5.3	5.4
pH	0.5	0.6	1.0	1.0	0.8	0.8	0.9	0.9	0.6
Percent C	11.90	6.32	2.93	3.49	4.02	3.51	3.74	3.19	1.91
Percent N	0.785	0.406	0.208	0.248	0.278	0.258	0.287	0.297	0.128
C/N Ratio	15	15	14	14	14	13	13	11	14
Percent Fe	7.8	12.5	12.7	13.8	15.4	14.7	16.3	15.9	16.1

2 or 3. It has moderate subangular blocky structure. The organic C content ranges from 6.32 to 11.99 percent and the C/N ratio is 15. Base saturation ranges from 17 to 33 percent and the 15-bar water retention ranges from 38.1 to 55.0 percent. The dominant exchangeable cation is H, which ranges from 26.2 to 34.8 meq/100q of soil (Table V). Based on these descriptions the soil is considered to have an umbric epipedon.

The subsurface horizon is dark reddish brown to dark brown with moist value 3 and moist chroma 2 or 4. Structure is moderates sub-angular blocky. The pH is slightly acid. Gelatin-like coatings are found on ped surfaces. This soil is considered to have a cambic horizon.

The presence of an umbric epipedon, a cambic horizon, and a high content of X-ray amorphous material place the Alapai soil into the Suborder Andept.

The mean annual soil temperature of this soil is 65°F. This soil is always moist and the 15-bar water retention is very high. The average base saturation is less than 50 percent. It is moderately smeary. According to the field descriptions, this soil dehydrates irreversibly into gravel-size aggregates and lacks a lithic contact within 50 cm (20 inches) of the surface. Thus, this soil is classified in the Great Group Hydrandepts and in the Subgroup Typic Hydrandepts.

The average July temperature is 71°F (21.4°C) and the average January temperature is 65°F (18.3°C). The difference between these two temperatures is 3.1°C. The mean annual soil temperature is 65°F (18.3°C). The temperature class of the soil is thus isothermic.

Based on the previous descriptions and the smeary consistency throughout the profile, the Alapai soil is classified as thixotropic, isothermic family of Typic Hydrandepts.

CHAPTER V

SUMMARY AND CONCLUSIONS

1. Four soil samples were used to investigate the effect of climate on the genesis of soils formed from Pahala ash. The climate is expressed by variation of rainfall of different elevation.

2. The sand content decreases with increasing rainfall. The silt content seems to be constant, while the clay content increases with increasing rainfall.

3. The 15-bar water retention of all soils is generally high. The value is over 20 percent. There is indication that the 15-bar water retention increases with increasing rainfall.

4. The clay fraction of all soils is dominated by X-ray amorphous material which may be allophane. Crystalline minerals such as mica was detected in the fourth horizon of Pakini soil and in other horizons of the Moaula and Alapai soils. Kaolin and gibbsite were also detected in the four soils.

5. Cation exchange capacity of the soils is quite high and it decreases with increasing rainfall.

6. The exchangeable bases were dominated by Ca and Mg. They decrease with increasing rainfall indicating that the degree of leaching increases with increasing rainfall.

7. The pH of the soils is slightly acid to alkaline as rainfall decreases.

8. Organic C, total N and C/N ratio of the soils increase with increasing rainfall.

9. Free iron oxides also increase with increasing rainfall.

10. All soils belong to the Order Inceptisols and Suborder Andepts. The Pakini soil is classified as ashy, isohyperthermic family of Ustollic Eutrandepts; the Naalehu soil is classified as ashy, isothermic family of Typic Eutrandepts; the Moaula soil is classified as thixotropic, isothermic family of Hydric Dystrandepts; and the Alapai soil is classified as thixotropic, isothermic family of Typic Hydrandepts.

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