HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII

Under the joint supervision of the
UNIVERSITY OF HAWAII
AND THE
UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 66

SURVEY OF THE PHYSICAL FEATURES THAT AFFECT THE AGRICULTURE OF THE KONA DISTRICT OF HAWAII

BY

H. A. POWERS, Assistant Geologist, Hawaiian Volcano Observatory,
J. C. RIPPERTON, Chemist, Hawaii Agricultural Experiment Station
and
Y. B. GOTO, Agricultural Extension Agent, University of Hawaii

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HAWAII AGRICULTURAL EXPERIMENT STATION

HONOLULU, HAWAII

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CONTENTS

INTRODUCTION

The Kona district of Hawaii occupies a unique position in the agriculture of the Hawaiian Islands. Various physical and economic factors have prevented its agricultural development by the plantation system used in other localities. Kona has remained a district of small farms, with coffee as the chief crop. Although much has been written of popular interest regarding coffee production in Kona, very little exact information is available regarding the many factors of soil, climate, and cultural methods as they affect coffee production.

In 1929 the Kona substation, a branch of the Hawaii Agricultural Experiment Station, was established at Kainaliu to begin systematic experiments on various phases of Kona agriculture. The present investigation is intended as a general survey of the agricultural area,

[1] By permission of the Director of the United States Geological Survey.

presenting the most salient features of climate, geology, and soil formation, together with a detailed consideration of the soil types and their relation to coffee production. It is the outgrowth of a coöperative project with the Hawaiian Volcano Observatory, which mapped the geology of the district and assisted in the detailed soil survey, and the Extension Division of the University of Hawaii, which obtained the data regarding coffee culture and yields and mapped the present coffee area. Thanks are due to the many individuals, ranchers, coffee companies, and planters in Kona whose hearty coöperation has made the bulletin possible. Acknowledgment is also due to the Hawaiian Volcano Research Association, whose coöperation and financial assistance were most helpful in connection with this work.

GEOGRAPHY

The County of Hawaii is divided into six political districts. The Kona District occupies most of the western side of the island and is

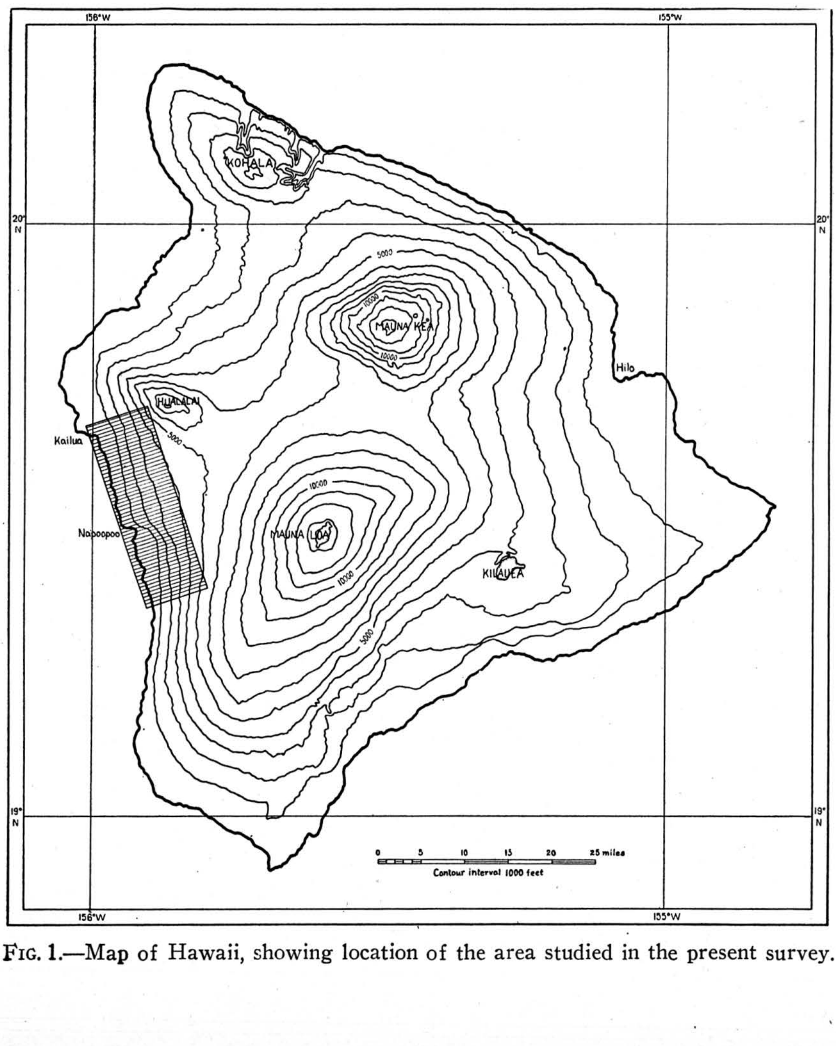


FIG. 1.—Map of Hawaii, showing location of the area studied in the present survey.

subdivided into two parts, North Kona and South Kona. The area mapped in this survey (comprising only that part of the Kona District most important in present agriculture) is a strip of land extending 22½ miles along the coast and an average of 7 miles inland, half in North Kona and half in South Kona.

The two principal seaports of the district are Kailua, in the northern part of the mapped area, and Napoopoo, in the central part. Kailua is visited twice a week and Napoopoo once a week by an interisland freight and passenger boat giving direct service to Honolulu. Two ports of lesser importance are Keauhou and Hookena. All these ports are visited once in two weeks by a smaller freight boat that makes a circuit of the islands on an indirect route from Honolulu.

A hard-surfaced belt road around the island of Hawaii traverses the length of the mapped area 3 to 5 miles inland from the coast line, and paved or graveled branch roads lead to all the seaports and to Honaunau. Kailua and Keauhou are connected by a secondary road along the shore, and a first-class graveled road joins Honaunau and Napoopoo. Daily freight and passenger service between Kona and Hilo, the principal town and seaport of the island, is provided by several motor-truck and bus lines.

A very small part of the population of the district is concentrated in the towns. Most of it (about 8,000 in 1930) is distributed evenly throughout a strip 2 or 3 miles wide along the main belt road. The majority of the inhabitants are Japanese coffee planters who lease from 5 to 10 acres of coffee land each and live on the plots which they cultivate. Most of the privately owned land in the district is held in large estates and is either leased for periods of 10 to 20 years to the coffee planters or kept in large tracts as grazing land. Most of the Government land is on the higher slopes and is leased to the local ranchers as grazing land.

The mapped area includes all the important coffee lands and soil areas crossed by the belt road. Lands to the north and south of the surveyed area are practically unaltered lava flows. The inland boundary of the area mapped was placed to include only that part of the mountain slope below the level of killing frosts.

AGRICULTURE

Kona is adapted to a remarkable variety of crops. In the past attempts have been made to establish agricultural industries based on tobacco, pineapples, sugar cane, tea, vanilla, sisal, cotton, Macadamia nuts, rubber, miscellaneous fruits and vegetables, coffee, ranching, and dairying. Of this entire list there remain ranching, cotton, Macadamia nuts, and coffee. Ranching has replaced dairying and is carried on largely in the upper areas. Cotton occupies a small and relatively constant area of about 200 acres in the low dry parts. The Macadamia nut industry occupies an area of about 200 acres and is rapidly expanding. There is one area of 150 acres of three to six year old trees. The other 50 acres is made up of numerous small groves. The coffee planters of Kona regard the Macadamia nut as a promising means of diversifying their present one-crop system and are interplanting it with coffee in several localities. Coffee is by far the most important crop, its present area being about 5,500 acres.

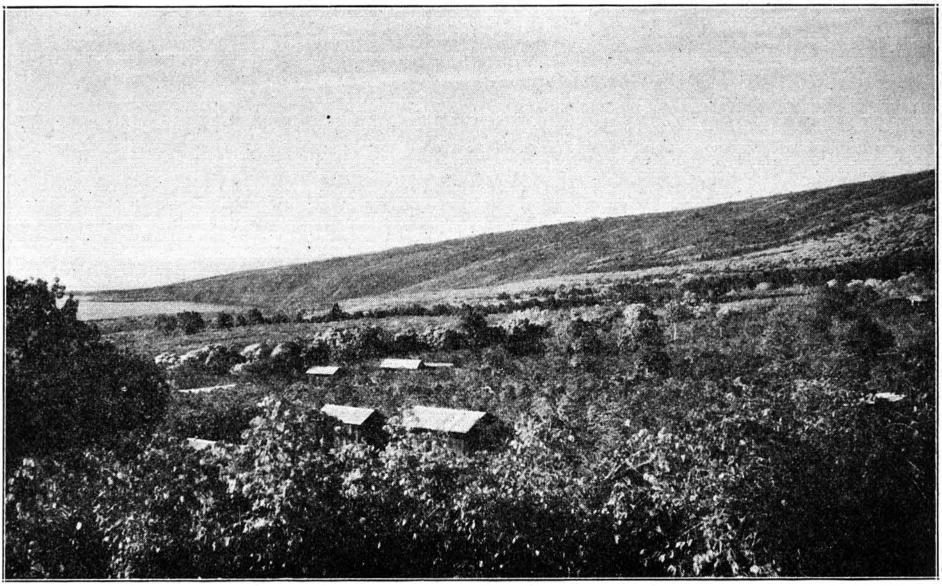
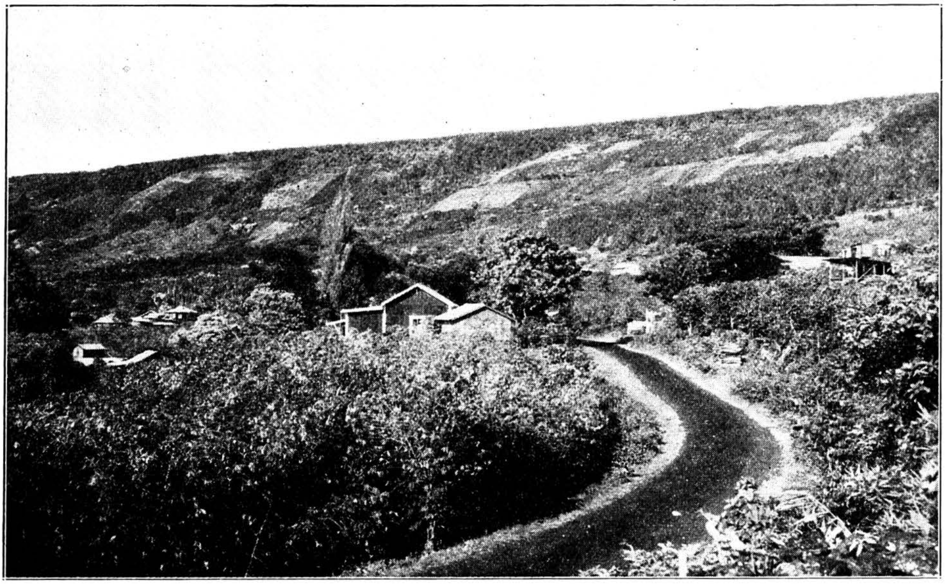


FIG. 2—Looking north at the steep slopes in Kealakekua and Keei Sections. Kealakekua below the belt road in the Honaunau Section. The light-colored vegetation in the flows of the Keei Section. In the distance are the coffee fields of the Kealakekua (on the many dwellings of the planters in the midst of the coffee.

Kona agriculture is primarily adapted to small-farming methods. Reference to the map in the back of this bulletin shows that numerous rough, undecomposed lava flows from Hualalai and Mauna Loa divide the district into relatively small, narrow strips which are difficult to combine under large-scale agricultural operations. The soil is thin in many places and even the deeper soils are so filled with loose rock and massive outcrops as to necessitate hand labor for all field operations. The steep slope of most of the area is a further barrier to large-scale methods. The failure of most of the agricultural ventures listed above was not generally due to the poor growth of the crop but to excessive costs involved in hand labor, expensive transportation, and small land areas. The relative isolation of the district from outside markets has precluded, to a large extent, the shipping of the many perishable fruits and vegetables that grow very luxuriantly.

The resultant of these various factors has been to restrict the agriculture of Kona to small farms, and the crops to those which require a large amount of hand labor. Coffee is such a crop. With the exception of land rental and fertilizer, the entire cost of the coffee, as it is sold to the mill as "parchment" or "cherry," is represented in hand labor. The one item of harvesting the coffee cherry represents roughly one-half the selling price of the cherry coffee. Under present conditions the coffee industry is based on the small farmer who cultivates his own land, picks his own coffee, and employs very little labor outside of his own family.



Bay and the exposed cliff are on the extreme left. In the foreground are the coffee plantings
middle distance of the picture on the left is a grove of kukui trees on the bare pahoehoe
the left) and Keei Sections (on the right). Note the small size of the individual patches and

GEOLOGY

The island of Hawaii is built up entirely of volcanic material ejected from a number of vents of different geologic age. Several of the volcanoes are so young that their original makeup dominates the topography, soil conditions, drainage, and, to some extent, the vegetation of their slopes. Two of these young volcanoes are Hualalai and Mauna Loa. The Kona District includes most of the former and much of the western slope of the latter.

TOPOGRAPHY

That part of the Kona District studied in this survey includes the lower southwestern slope of Hualalai, the lower western slope of Mauna Loa, and a westward-sloping area between the two which is part of an older volcano nearly buried by the lavas of Hualalai and Mauna Loa. The mapped area is a long, rectangular strip paralleling the coast line, with its surface rising eastward from sea level to an average altitude of 4,500 feet. This general slope is made up of four unit surfaces. Three of them are the uniformly sloping surfaces of simple volcanic domes—Hualalai on the north, the older dome in the center, and Mauna Loa on the south. The fourth is a steeply sloping surface of less simple origin. It was formed by many lava cascades over a high fault cliff along the southwest edge of the old volcano. The old cliff was formed by the cracking off and subsiding of a large section of the southwestern part of the old dome. This breaking down of the outer edge of a volcanic dome by normal faulting is not uncommon. The great cliff at South

Point and the series of cliffs south of Kilauea were formed similarly by faulting and settling of the outer part of these volcanoes. Part of the cliff is still exposed as the Pali Kapu o Keoua on the north shore of Kealakekua Bay. The present steep slope indicates that the buried part of the cliff continues inland for 2½ miles, then turns to the south. Trace of it is lost in the Honaunau lands, where it either ended or has been so deeply buried by later flows that it does not affect the present slope.

Considered as a whole the steep surface of the fourth unit has an average slope of 1,500 feet to the mile. The simple slopes of the other three unit surfaces, however, average only 700 feet to the mile. In addition to the general slope, all four units show considerable variation in the details of surface. Some lava flows have a relatively smooth surface; others are extremely hummocky, with a relief of as much as 50 feet between the small depressions and irregular knolls. These original differences in the surface of the lava flows are the main factors determining the details of topography and are not entirely masked by an ash covering, even in localities where the ash is thickest. There has been almost no modification of the original lava surfaces by erosion, and very little reworking of the ash deposits by surface water. The local variations in topography, plus differences in the underlying rock, have an important effect on drainage conditions in localities with abundant rainfall.

DISTRIBUTION OF ASH AND LAVA

Although parts of three different volcanoes are included in the area of the soil survey, all three are made up of similar geologic formations of two fundamental types—ash deposits and lava flows.

The ash deposits of Kona are layers of fine particles of volcanic material which have settled from the air during a spurting eruption in which the liquid lava was blown from the throat of the volcano as from a spray gun. Lava rock is formed by the consolidation of liquid lava which welled up out of the crater and ran down the slopes as lava flows. These flows consolidate with either an aa or a pahoehoe surface depending on certain conditions existing during the cooling process.

Primary vitric ash is formed in the following manner: The magma within a volcano always contains a considerable amount of confined gases. If, for any reason, the pressure of this gas is built up sufficiently, it will cause a spurting eruption from the vent. During such an eruption the liquid magma is sprayed into the air in small drops. Contact with the air cools the magma so rapidly that the chemical compounds in the liquid do not have a chance to form crystals, but are congealed as a natural glass. Such ash eruptions are less common from basaltic volcanoes than from vents yielding andesitic or rhyolitic lavas. However, ash cones are not rare in the Hawaiian Islands. Punchbowl, Diamond Head, Koko Head, and Salt Lake Craters are well-known ash craters on Oahu. On Hawaii, Mauna Kea, Kohala, and the Pahala region of Mauna Loa are covered with a mantle of primary ash. In contrast to vitric or glassy ash is lithic ash, which is powdered old rock blown out by steam-blast eruptions. This type is usually crystalline in nature, as the particles are simply broken pieces from previously consolidated lava flows. Lithic ash is not common in Kona.

Lava flows are formed in the more common type of eruption. The magma wells up and overflows without violent explosion. Depending on many conditions, such as temperature, viscosity, stirring action from flow movement, and rapidity of gas emission, the lava cools in the flow with either a pahoehoe or an aa surface texture. Pahoehoe is formed when a skin of undercooled glass is able to form on the surface of the flow. Aa is formed when the lava is so near its crystallization point that a glassy skin can not form, but rather a rapid granulation of the exposed lava occurs, yielding a surface phase of partly crystalline scoria. The inner body of each type of flow cools slowly, owing to insulation by the surface layer, so that no differences in texture are formed within the main body of the flow. Comparatively smooth surfaces are found on both aa and pahoehoe flows which have low viscosity and so are able to spread out more evenly before consolidation. Hummocky surfaces are found on both aa and pahoehoe flows which are more viscous and so pile up irregularly during the movement of the flow.

Both types of lava flows are equally abundant and form the bulk of material in the three volcanoes of the district. Ash deposits are much less abundant than lava flows and are of different importance in the makeup of each of the three volcanoes. The lava flows of the old central slope are all buried beneath a mantle of ash from about 1 foot to 4 feet deep. This mantle is thinnest at the foot of the slope near sea level and is thickest in the belt between 2,000 and 3,000 feet above sea level. This belt also has the heaviest rainfall, and it is possible that the same conditions of air circulation which cause this local concentration of rainfall were instrumental in concentrating the heaviest falls of fine ash during explosive eruptions. One small ash crater at 5,500 feet, Puu Kikiaeae, has been found on the old slope. It and others like it which are probably buried under later lava flows must have been the source of much of this older ash deposit.

The lava flows of Hualalai are covered by varying depths of ash. The oldest flows, where they are not covered by younger flows, have an ash mantle varying in thickness from a few inches on the lower slopes to several feet on the upper slopes. The youngest flows have no ash covering, and flows of intermediate age have ash mantles of moderate thickness. All the Hualalai ash beds increase in thickness and also in coarseness of material toward the large source cones on the top of the mountain. Ash eruptions on Hualalai occurred intermittently with many lava eruptions, producing alternate layers of ash and lava in some localities. This accounts for the varying depths of ash on the different flows.

Most of the flows of the Mauna Loa slope are barren of ash, as they are younger than the main ash deposits. Some of the older flows have a pockety covering of very fine ash which probably drifted south from some of the Hualalai ash eruptions.

CHARACTERISTICS OF ASH AND LAVA

The chemical composition of the ash beds and the different lava flows may show minor variations, but these variations have no apparent connection with the differences in the soils of the district. However, the variations in texture and physical properties of these materials are of great importance in determining soil characters.

The ash beds in their original state were made up of very fine, angular fragments of natural glass rather loosely packed together. The fragments themselves were more or less perforated with bubble holes. As such deposits are extremely permeable to surface water, there was ready drainage through the ash beds. However, the open spaces between the particles were so small that water was held back sufficiently to keep the ash continually moist. Because the ash beds were made up of particles of easily decomposed material that were constantly wet, they have been completely altered to the fine-textured brownish-yellow claylike soils of the district.

The aa flows are made up of scoria (clinker) and solid rock in varying proportions. The most scoriaceous flows of the district, which have the most hummocky surface, probably contain as much as 40 per cent of the loose material; the least scoriaceous flows contain as little as 2 or 3 per cent. The scoria makes up the top and bottom of each flow and also is scattered through the body of the flow in pockets or lenses. It consists of an unsorted mixture of fragments ranging from fine dust particles to large fragments several feet in diameter. The bodies of more solid rock are only slightly vesicular (i.e., containing bubble holes), but are traversed by many shrinkage cracks or joints, which form during the cooling of the lava. These numerous cracks through the more solid parts and the loose texture of the scoriaceous part give the aa flows a very high permeability to surface water.

FIG. 3.—Cross sections of a pahoehoe flow made up of numerous thin flows. Note the profuse jointing, which permits the easy penetration of moisture and roots. In the rain belt these joints become filled with organic slime and bogs or "water holes" are formed in the depressions.

Pahoehoe flows are made up of many layers of separate tongues or lobes of lava, each lobe having formed as a small unit flow. These lobes vary greatly in areal dimensions and in thickness. Lobes with a thickness of a foot or two are usually highly vesicular and notably broken by many shrinkage cracks. Lobes several feet in thickness are vesicular only at the top and bottom and are broken by fewer shrinkage cracks. Pahoehoe flows are honeycombed with small cavities and tubes left when some of the inner liquid lava had drained out from the lobe after a solid crust was formed. The numerous joints and many open spaces between lobes usually give this type of flow good permeability to surface water. In localities of high rainfall, however, the depressions in a pahoehoe surface often hold small ponds or swamps, if the cracks in the flow have been filled by washed-in fine material.

The remarkable permeability of these lava flows, which make up the bulk of the volcanic piles, permits surface water to seep rapidly to great depths below the surface. This immediate removal of surface water through deep underground drainage accounts for the entire absence of permanent streams in Kona, in spite of the heavy rainfall on part of the slopes.

In contrast to the ash, the surface flows of Kona have undergone practically no chemical decomposition. Furthermore, only a small amount of mechanical breakdown has occurred on the surface of the flows. Effects of this mechanical breaking are most noticeable on pahoehoe flows, where the vesicular surface skin has broken up to fine dust which collects in pockets in the flow surface. The soil-building materials are thus the completely altered ash and the raw undecomposed lava.

FIG. 4.—Cross section of a very scoriaceous aa flow. Aa flows vary greatly in the proportion of scoria and massive rock. A flow of this type gives rise to very desirable soils, with loose texture, excellent drainage, and deep-root penetration.

The fundamental cause for the difference in the amount of chemical decomposition of the ash and lava lies in the fact that the former is an unstable glass and the latter an aggregate of crystals. The ash particles are in reality a liquid, undercooled far below the crystallization temperatures of the constituent compounds. The glass thus is in a highly unstable physical state and will rapidly break down to more stable forms under atmospheric conditions of temperature, pressure, and moisture. The first stage in this breakdown is a complete alteration of the original glass to palagonite. This is a yellow, isotropic substance which has essentially the same chemical composition as the primary basaltic glass, that is, the total composition of the basaltic magma—except that most of the iron is oxidized and water of hydration is added. Insufficient work has been done to determine the exact identity of all the secondary products resulting from the decomposition of the original glass. Much of the material large enough in particle size to be microscopically identified is definitely palagonite. On the other hand, a very considerable portion is of colloidal dimensions and highly hydrated and can not be identified by ordinary petrographic methods. It is significant, in this connection, that in the various localities where ash deposits exist in the Hawaiian Islands the decomposition products are always of the same general character as to color and physical properties. This would seem to indicate that this yellow-brown alteration product is fairly definite in composition and also rather stable in character.

The slow cooling of lava gives an opportunity for the constituents of the liquid to crystallize as minerals of fairly definite chemical composition. The bulk of the crystalline constituents consists of pyroxene, a metasilicate of calcium, iron, and magnesium; plagioclase feldspar, a polysilicate of aluminum, calcium, and sodium (and a trace of potassium); and olivine, an orthosilicate of magnesium and iron. Although much of the surface lava in Kona is older than the ash, it shows practically no decomposition. Even the very permeable scoria of an aa flow, which is largely crystalline material, yields very slowly to the alteration processes. A striking example of the differences in weathering of glassy and crystalline material under equal climatic conditions is found in the ash beds of Tantalus and Punchbowl, on Oahu. Some layers are completely altered to yellow, but other layers and pockets are black and untouched by weathering. The altered beds were made up of fine particles of basaltic glass, whereas the black unaltered material consists of coarse particles of partly crystalline basaltic rock.

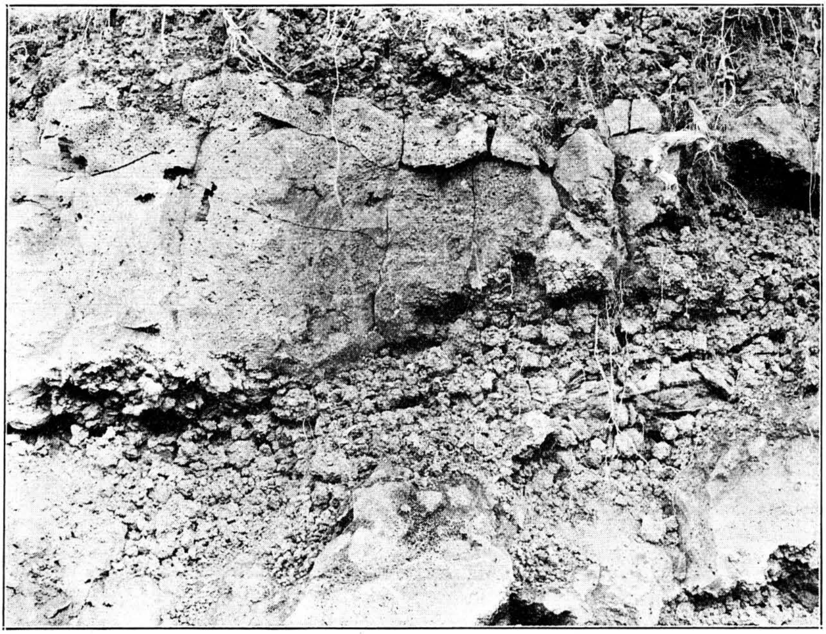


FIG. 5.—Cross section of a moderately scoriaceous aa flow, showing lenses of massive rock alternating with layers of scoria. This type produces desirable soils although here and there a massive layer, lying very close to the surface, causes a "poor growth" spot.

CLIMATE

Kona, situated on the western, leeward side of Hawaii, is completely sheltered from the northeast trade winds by the huge masses of Mauna Kea, Hualalai, and Mauna Loa. This district and the Ulapalakua district of Maui, in a similar location on the leeward slope of Haleakala, have a mild, equable climate quite different from that of the rest of the Hawaiian Islands. The outstanding feature of the Kona climate is the system of air circulation. Instead of the constant trade wind there is daily a light breeze from sea to land during a few hours in the middle of the day and a gentle breeze from land to sea during the night. Except for the few hours of light breeze, the air is exceedingly calm. This typical circulation is upset only rarely in times of so-called Kona storms, which are violent enough to approach from the southwest against the prevailing trade winds of these latitudes. These storms are characterized by high southwest winds and heavy rains of several days' duration.

Temperature records for a number of years are available from two stations on the belt road between altitudes of 1,400 and 1,500 feet. These stations show, over a 10-year period, a mean annual temperature of about 70°. The mean temperature decreases and the daily temperature range increases at greater altitudes. Frosts are very rare at altitudes below about 4,000 feet. Above 10,000 feet occasional thunder storms may produce snowfall during any season of the year.

The distribution of rainfall is also a striking feature of the climate. Rainfall at sea level averages between 20 and 30 inches a year. The precipitation increases rapidly up the mountain slope to a maximum of over 100 inches at an altitude of about 2,500 feet, then decreases rapidly to less than 30 inches a year at about 5,000 feet. This zone of maximum rainfall is continuous across the slopes. The isohyetal lines (lines of equal rainfall) divide the area into a series of rainfall belts which roughly parallel the coast line.

Rainfall records have been kept at a total of 15 places in the district, but some of the stations have only a short-time record. The following table presents all the available rainfall data.

TABLE 1

Comparison of annual rainfall data of 15 stations in the Kona district of Hawaii.

Station	Altitude (feet)	Years of record	Mean annual rainfall (inches)	Mean recalculated to period 1900-1920[2] (inches)
Ahua Umi[1]	4,960	1923-1930	23	20
Holualoa	1,450	1902-1927	65	65
Hookena	850	1927-1928	61	55
Huehue[1]	2,020	1904-1930	36	36
Kailua	950	1880-1901	55	55
Kailua	12	1929-1930	36	30
Kalahiki	750	1900-1906	49	45
Kalahiki	1,500	1904-1906	89	80
Kalahiki	1,800	1901-1903	93	85
Kanahaha[1]	4,940	1923-1930	29	25
Kealakekua (Davis)	1,580	1891-1914	67	67
Kealakekua	1,450	1901-1930	63	63
Keauhou	1,930	1929-1930	101	95
Napoopoo	16	1902-1930	35	35
Puu Lehua[1]	4,750	1923-1930	26	25

[1] Stations not within the mapped area.

[2] In order to correct for abnormalities in the data from stations having only short-time records, a correction factor has been applied, based on the records of the stations with long-time records. An example of the method of calculation is as follows: Kalahiki at 750 feet has a record from 1900 to 1906. From stations with a record of 20 years or longer, it is computed that the mean for the years 1900-1906 is 4 inches greater than the mean for the total period of record. The mean rainfall at this station is thus weighted by subtracting 4 inches. This recalculated mean is, of course, not exact, but it undoubtedly is more representative of rainfall conditions than the mean obtained from only a few years.

The average precipitation in the heavy rain belt is estimated to exceed 100 inches, but no records are available. The Hawaiian Macadamia Nut Co.'s station in Keauhou, at 1,900 feet, recorded 138 inches in a wet year, and the observer estimated the rainfall at an altitude 300 feet greater to be at least 20 per cent higher. The location of the rain belt is well marked in the field by swamps, boggy soils, and dense growth of many varieties of fern. In fact, the type and distribution of all the vegetation is largely controlled by the distribution of rainfall.

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The average precipitation in the heavy rain belt is estimated to exceed 100 inches, but no records are available. The Hawaiian Macadamia Nut Co.'s station in Keauhou, at 1,900 feet, recorded 138 inches in a wet year, and the observer estimated the rainfall at an altitude 300 feet greater to be at least 20 per cent higher. The location of the rain belt is well marked in the field by swamps, boggy soils, and dense growth of many varieties of fern. In fact, the type and distribution of all the vegetation is largely controlled by the distribution of rainfall.

Except for the rains accompanying Kona storms, the heaviest precipitation occurs during the spring, summer, and autumn. December, January, and February are usually dry. Under normal conditions most of the rain falls in the afternoon and evening, and during the rainy season it either rains or is cloudy every afternoon.

This regular distribution of rainfall is due entirely to the system of air circulation. During the morning hours the sun heats the surface of the land more rapidly than the surface of the ocean. The warmed air over the land rises, and the cooler air over the water moves inland to take its place, creating the gentle breeze that blows from sea to land during the middle of the day. As this moisture-laden air moves inland up the mountain slope it cools below its saturation point, and the excess moisture condenses to form clouds and rain. As daily conditions of temperature and pressure are fairly constant, this cloud blanket begins to form between 10 a. m. and noon at about the same altitude every day. As the clouds continue to form, they spread both inland and seaward on an almost horizontal plane. Directly under the center of the cloud formation is the zone of maximum rainfall, as the rains start here soon after the first clouds form and generally continue throughout the afternoon. Below the rain belt the rains progress down the slope as the cloud blanket extends seaward. Above the rain belt the rains progress up the slope as the clouds extend inland and envelop this area in heavy fog. Thus conditions are actually reversed above and below the rain belt.

The rains continue until the air-circulation system is reversed and the breeze blows from land to sea. This reversal is caused by the relatively more rapid cooling of the mountain slope than of the ocean surface late in the day. Consequently, the warmer air over the ocean begins to rise and the cooler air from the land moves down and out to sea. The rain clouds formed during the afternoon are blown out to sea by this breeze and so are entirely dissipated before the beginning of the next day's cycle.

SOILS

In the ordinary system of soil classification geology is of less importance than the stage of weathering. One of the present concepts in soil science is that given conditions of moisture and temperature will ultimately produce the same kind of soil regardless of the geologic origin of the parent rock. Under tropical conditions, where decomposition takes place at high temperatures and often with abundant moisture, the ultimate type of soil is the "laterite" which is characterized by a heavy texture and red color. In composition it is low in silica and high in the oxides of iron and alumina. The red soils of the lower levels of the Hawaiian Islands are approaching this general type, although they have not yet weathered sufficiently to be classed as true laterites. In Kona, the effects of weathering are largely absent, owing to the geologic youth of the country rock. In fact, with the exception of the ash, which has been largely decomposed, the soil[1] consists of fragments of the entirely undecomposed lava rock.

[1] The term "soil" as ordinarily used is restricted to the more or less completely decomposed material resulting from the weathering of rock. In texture this material is more or less loose and friable and generally fine grained, and the surface layers contain decaying organic matter and microscopic life. In the Kona district, there is found the striking anomaly of agricultural crops being grown on bare lava rock. For this reason the term "soil" in this bulletin is used to mean any surface material that supports vegetative growth.

SOIL MATERIALS

The materials from which Kona soils are derived may be grouped under three classes—ash, scoria, and flow rock.

Ash is characterized by a brownish-yellow color and a fine uniform texture. As a soil constituent, it has unique properties. On the basis of particle size, it would be classed as a heavy clay, but actually it has a very loose and open structure. It absorbs and holds moisture readily and does not puddle. Except on the upper levels in the very wet areas, it forms a permeable soil and is remarkably resistant to erosion and washing. Slopes of as much as 25 degrees have a deep ash mantle which has been very little eroded.

The Bouyoucos hydrometer method of analysis shows that a sample of ash from medium altitudes has practically 100 per cent colloids. Under conditions of continued and high moisture content, such as exist on the middle Kona slopes, it becomes highly hydrated. Some samples have been found to contain 300 per cent or more of water expressed as percentage of dry soil. Even in the present agricultural belt, 150 per cent of water is not exceptional. If a sample of this hydrated ash is dispersed in water, it forms a semigel. Upon standing, numerous fissures appear within the mass, filled with clear ubstrate. Highly hydrated ash, when air dried, is very slow to rehydrate. In the determination of colloids it is necessary to keep the sample in its original moist condition.

Scoria is the clinkerlike material which is formed on the surface of an aa flow. It shows very little decomposition and exists in the soil as hard black particles ranging from fragments several inches in diameter to a powder fine enough to pass through a 100-mesh sieve.

Flow rock consists of angular blocks that are formed by the natural cracking or jointing of the continuous part of a lava flow, particularly relatively thin pahoehoe. These angular blocks show practically no decomposition, and except for the fact that they are utilized in coffee culture, they would not be classed as soils.

CLASSIFICATION OF SOILS

The system of classification used in this survey is based primarily on two factors—the depth of the ash mantle and the type of underlying lava. Where the ash is of sufficient thickness, it is the dominant factor, and a uniform fine-textured yellow soil results. As it becomes thinner the character of the underlying lava becomes dominant, and at the opposite extreme is the very coarse rocky black soil, with little fine-textured material other than humus. Where the underlying flow is aa the relative amount of scoria which the flow carries is of obvious importance in determining the texture of the soil. The comparatively smooth surface of a pahoehoe flow has a less pronounced effect. In addition to its effect on the texture, the underlying lava is also of vital importance in determining the drainage of the soil, the topography, and the amount of root penetration possible, and without doubt it contributes in no small measure to the fertility of the soil.

In the present survey the soils are divided into six soil classes—pure ash, scoriaceous ash, pockety ash, ashy scoria, scoria, and flow rock. These six classes may be conveniently grouped according to the thickness of the ash mantle into four divisions—deep ash soils, medium ash soils, thin ash soils, and ashless soils. The ash mantle in Kona grades from a thin sprinkling to beds several feet in thickness. For the sake of classification, the following arbitrary divisions are set up: Thin ash, less than 3 inches; medium ash, 3 to 18 inches; deep ash, more than 18 inches.

Attempts were made to group and name these soil classes according to the more orthodox soil-survey methods and terminology. Division of the soils into residual and transported soils has no significance in Kona, as there has been practically no weathering and but little transportation of material. The terms clay, loam, or sand would be decidedly misleading, as none of the constituents resemble these materials as they exist in ordinary soil. The substitution of the word gravel for scoria was tried. Here again the terms are not interchangeable, for gravel represents a size group, whereas scoria represents a type of material varying in size from rock powder to large stones. In order to emphasize the predominance of geology, the geologic terminology has been retained in naming the soil classes.

Deep ash soils. In the deep ash areas there has been practically no mixing of the ash with the underlying lava. The remarkable lack of erosion and washing of the ash layer has left the mantle practically in place. Hence the soil is of the pure ash class, regardless of the lava that may underlie it. The deep ash types do not exist below altitudes of about 1,500 feet. They have relatively few outcrops, a deep root-feeding area, and excellent fertility and are among the most highly prized soils of the district.

Medium ash soils. There are two classes of medium ash soils depending on the underlying lava. If that is an aa flow, the scoria becomes intermixed with the ash. The ash is usually sufficient in amount to be the dominant factor, however, and a scoriaceous ash soil results. If the underlying flow is pahoehoe, the ash exists without appreciable admixture, and unless affected by some external factor the soil is of the pure ash type. Scoriaceous ash is an excellent soil. Overlying aa, it usually has excellent drainage and permits deep root penetration. Outcrops are more numerous than in the deep ash soils, and small areas of poor fertility result from massive rock close to the surface. The admixture of scoria to the ash gives an excellent open texture to the soil. The pure ash soil overlying pahoehoe is not generally as desirable as the scoriaceous ash. It shows scattered areas of poor growth due to insufficient drainage and to massive rock close to the surface. Both these types can vary considerably in nature and fertility, depending on variations in the surface features of the underlying lava.

Thin ash soils. In this group the ash is so thin that the underlying lava becomes the dominant factor. With an aa flow, the scoria predominates and an ashy scoria soil results. With a pahoehoe flow, the thin ash covering tends to collect in pockets, leaving a considerable part (often as much as 60 per cent) of the rock surface exposed. This is termed a pockety ash soil. These two types differ markedly in their fertility. The ashy scoria is usually very coarse and gravelly, though extremely variable. Within a few feet there may be a transition from a huge massive outcrop to an area of very coarse scoria and thence to fine scoria and ash. Although somewhat spotty, this type is regarded as an excellent soil. Pockety ash, on the other hand, is generally much inferior. Here and there deep pockets of ash support good growth, but the slight accumulation of ash is generally not sufficient to effect any appreciable change in the properties of the soil from that of the bare flow rock. Obviously, the specific nature of the pahoehoe flow underneath is the determining factor.

Ashless soils. These comprise the bare flows of the district and consist of two soil types—scoria and flow rock. Scoria soil is the clinkery surface phase of an aa flow. This type is little used for agriculture in Kona, although the profuse growth of native vegetation on it proves its inherent fertility. The obvious reason for its lack of utilization is the prohibitive physical difficulties of growing a crop on its rough, jagged surface. The flow rock soil is restricted to pahoehoe flows. These flows differ greatly as to the extent of the jointing or cracking of the rock and the brokenness of the surface. In some areas the blocks remain in place; in others they have been dislodged and lie as a mass of loose blocks. It is a remarkable sight to see a planter clearing off a field of this bare black lava and planting his coffee trees in cracks or in holes which he has blasted, and then later to note the thrifty growth of the trees. The property of these flows most difficult to understand is that of being able to supply the plant with water even during protracted dry spells. Their extreme permeability, due to profuse jointing, causes them to take in a large part of the total rain which falls. Their ability to supply moisture for plant growth is probably based on the gradual penetration of water along the fine cracks and vesicles within the rock.

A summary of soil types described above, indicating their relation to the ash depth and nature of the underlying lava, is given in the following table.

TABLE 2

Relation of soil type to depth of ash and underlying lava type.

Soil tye	Depth of Ash[1]	Underlying lava type
Pure ash	Deep Medium	Pahoehoe or aa Pahoehoe
Scoriaceous ash	do	Aa
Pockety ash	Thin	Pahoehoe
Ashy scoria	do	Aa
Scoria	None	do
Flow rock	do	Pahoehoe

[1] Deep ash, more than 18 inches; medium ash, 3 to 18 inches; thin ash, less than 3 inches.

Mechanical analysis of soil types. Insufficient work has been done thus far to provide definitions of the textural limits of each soil type. Table 3 gives the mechanical analysis of typical samples of several of the types. By mechanical analysis is meant dividing the soil into groups of different particle size.

TABLE 3

Mechanical analysis of Kona soil types.[1]

(Results expressed as percentage of dry soil)

Diameter of particles (millimeters)	Name of fraction	Pure Ash		Scoriaceous Ash	Ashy scoria		Scoria
		1	2	3	4	5	6
10.0	——	—	—	29.1	29.4	24.9	46.1
10.0-6.0	——	2.2	2.0	2.9	9.1	11.4	14.7
6.0-3.0	——	—	—	2.5	7.5	10.6	10.5
3.0-1.0	Fine gravel	—	—	2.6	4.8	14.5	12.5
0.1-0.5	Coarse sand	.1	.4	.2	1.0	2.0	6.1
0.5-0.25	Medium sand	.2	.3	1.0	2.4	3.4	1.5
0.25-0.1	Fine sand	.2	.4	1.3	1.8	2.1	2.4
0.1-0.05	Very fine sand	4.3	6.2	12.9	7.0	8.0	5.6
0.05-0.005	Silt	17.7	19.5	22.8	18.6	13.0	.4
Less than 0.005	Clay	75.3	71.2	24.7	18.8	10.1	.2

[1] 1. (lab. No. 157) From the Konawaena section (see map); altitude 1,900 feet. Deep ash overlying aa. Pasture land with a moderate slope and very little washing or mixing of materials. Subsoil sample (4 to 10 inches).

2. (lab. No. 156) From the Keauhou section; altitude 2,000 feet. Medium ash overlying pahoehoe. This is an ash "kipuka" with very little washing or mixing of materials. Subsoil sample (4 to 8 inches).

3. (lab. No. 155) From the Konawaena section; altitude 1,100 feet. Medium ash overlying aa. The fact that this area was formerly in sugar cane has resulted in considerable mixing of the ash with the underlying lava. Surface sample (0 to 6 inches).

4. (lab. No. 154) From the Kealakekua section; altitude 2,000 feet. Thin ash overlying a very scoriaceous aa flow. Planted to coffee. Surface soil (0 to 8 inches).

5. (lab. No. 153) From the Kealakekua section; altitude 1,500 feet. The same formation as sample 4, at lower altitude. Planted to coffee. Surface soil (0 to 8 inches).

6. (lab. No. 158) Undecomposed scoria taken from the interior of an aa flow in a new road cut in South Kona.

The above table shows that soils of pure ash have negligible amounts of material coarser than very fine sand, but appreciable quantities of silt. Three-fourths of the entire soil is clay. The scoria, on the other hand, has nearly one-half of its entire bulk of particles coarser than 10 millimeters (0.4 inch) and four-fifths of fine gravel size or coarser. These two chief soil-building materials are thus the opposites of one another, and the mixing of the two in different proportions is very apparent in the intermediate soils 3, 4, and 5. As neither pure ash nor scoria has appreciable quantities of coarse, medium, or fine sand, the intermediate types have low percentages of these sizes but increase in percentage in either direction toward the coarse or the finer fractions. Samples 4 and 5, ashy scoria, both taken from the same section, illustrate the variation in texture within a single section. Sample 4, being higher up the slope than 5, with a greater admixture of ash, is intermediate in composition between samples 3 and 5.

Microscopic examination of the very fine sand and silt fractions of the pure ash samples shows that they are composed of three chief types of material—black particles of magnetite which formed within the basaltic glass and remained unaltered during its decomposition; rounded yellow particles of palagonite, the decomposition product of basaltic glass; and undecomposed, angular fragments of minerals, chiefly olivine and feldspar, which were present as crystals in the magma from which the ash was formed. The absence of any undecomposed particles of glass and the lack of decomposition of the mineral fragments bear out the conclusion that the soils of Kona are in the main the result of decomposition of basaltic glass, although it is probable that in the wetter belts the very fine particles of scoria have undergone a certain amount of decomposition.

COFFEE IN THE KONA DISTRICT

Since 1829 when the first plantings of coffee were made in Kona, coffee has been the backbone of the agriculture of the region. All the conditions of soil and climate that are regarded as favorable for coffee growth are present. In other countries these conditions are described as a loose rocky soil with a good slope to insure drainage, freedom from strong winds, a moderate climate free from extremes of temperature, and the proper proportion of shade and sunlight. Each of these requirements is met to a remarkably satisfactory degree in Kona. In many coffee districts other trees must be planted with the coffee to insure sufficient shade. This shading is provided in Kona by the daily cloud blanket.

CULTURE

Coffee-growing in Kona has many unique features. Among these are the utilization of very steep slopes (some as steep as 25°) and of bare lava flows. In the best sections coffee plantings 35 to 45 years old are still among the best producers in the region. The cultural methods vary widely with the type of planter and the climatic zone or belt. In the best sections, such as Konawaena and Kealakekua, the fields are carefully pruned, heavily fertilized, and kept weed-free by hoeing or poison spray. In the poorest districts the coffee is given little fertilizer and no care except the occasional cutting out of the coarse weeds. The pruning system is largely controlled by the zone. In the dry sections at the lower altitudes the trees are allowed to grow with a minimum of pruning. The plant resembles a small tree with a permanent trunk and main branches, often attaining a height of 15 to 20 feet. Pruning consists chiefly in a judicious thinning of the smaller branches. In the middle zone the coffee tree consists of the old trunk, from 2 to 4 feet tall, bearing 4 to 6 vertical shoots. A vertical shoot of this type grows rapidly and yields heavily for a period of about three years, when it is cut off and another vertical is allowed to grow. In the upper coffee areas (above about 1,900 feet) the topping system is used. The sublateral branches are systematically thinned out several times each year, to prevent excessive shading and induce new growth. Various combinations and modifications of these systems are also used. Differences in climate produce marked differences in the time of bearing. At the lower levels heavy blooming takes place three or four times during a single season. The yield is thus seasonal, and the bulk of the crop is harvested during about three months. In the cool, moist upper areas the trees bloom and bear the year around, ripe cherries and bloom occurring on the same tree at the same time.

YIELDS AND FERTILIZER

Compared with coffee districts in other parts of the world, Kona produces remarkably heavy yields. In the Konawaena section, one of the best two in Kona, there are fields which have been producing annually 15,000 pounds of cherry coffee (equivalent to 3,000 pounds of clean coffee) per acre. A record yield of 30,000 pounds of cherry (6000 pounds of clean coffee) was obtained in one 5-acre lot at Hokukano at an altitude of 1,600 to 1,650 feet. In 1930 the average production of 4,500 acres, which represents only that part of the coffee region which is properly tended and fertilized, was 2,000 pounds of clean coffee per acre. For the entire district, the yield of the total 5,500 acres was 1,800 pounds clean coffee per acre, or 3.6 pounds per tree. Compared with these yields are those of Brazil, with 750 pounds of clean coffee per acre; Porto Rico, 500 pounds; Mexico, 500 pounds; South Africa, 250 pounds; and Java, about 400 pounds. These figures for the other countries are only approximate, and most of them represent the average for far greater areas than that of Kona.

High-grade complete fertilizer is used, of the general formula 9 per cent nitrogen, 8 per cent phosphoric acid, and 9 per cent potash. The following table compiled from fragmentary data in the several sections gives a general idea as to the average yields and the amount of fertilizer used. These figures are taken from representative but relatively small areas in each section and are to be considered only in a general way and not as actual averages of a section.

TABLE 4

Representative yields of coffee and amounts of fertilizer used in different sections of the Kona district.

SECTION	YIELD (Pounds of cherry per acre)	FERTILIZER (Pounds per acre)
Holualoa	7,000	1,200
Kahaluu	3,500	700
Keauhou	5,800	1,400
Konawaena	12,000	1,800
Kealakekua	12,200	1,500
Keei (ash area only)	8,500	1,200
Honaunau	8,500	1,200

There is little question that these heavy yields are due in considerable measure to the large applications of fertilizer. In most of the other coffee-producing countries little or no commercial fertilizer is used. What the yields in Kona would be without fertilizer is problematical. The yields in sections using no fertilizer are low, but there the cultural methods are also poor. Fragmentary data from former field experiments in Kona indicated that on the plots receiving no fertilizer the yields dropped off very rapidly, and this is borne out by general opinion among the Kona planters.

In any consideration of coffee yields in Kona, the climatic factor must be kept in mind. The absence of winds, which permits the heavy set of fruit; the daily cloud blanket, which precludes the necessity of shade trees; and the equable distribution of rainfall all play a vital part. These factors make possible the optimum utilization by the coffee tree of the fertilizer applied.

RELATION OF COFFEE TO SOIL TYPE

Many factors operate to make it difficult to establish the relation between coffee production and soil type. The division into small holdings of only a few acres each, the different systems of pruning, climatic factors, different ages of trees, seedling variation and coffee variety, and the often extreme variation within a soil type tend to obscure any relations that may exist. Moreover, the very heavy applications of fertilizer tend to mask any inherent differences in fertility.

It is an obvious fact that excellent yields of coffee can be obtained on any type of soil in the humid belt, given the proper culture and sufficient fertilizer. What are generally regarded as the best two sections in Kona—Konawaena and Kealakekua—are located mostly on deep ash areas. However, fragmentary data and general observation indicate that the strip of ashy scoria soil adjoining the rough aa flow on the north edge of the Kealakekua section is practically as good as the deep ash. The coffee in the medium ash and pockety ash soils is correspondingly poorer, but it is not safe to attribute this difference entirely to soil type, as different strains of coffee and different cultural and fertilizer treatments are also used.

Of especial interest in this regard are the coffee plantings on flow rock—that is, bare pahoehoe. Observation of the fine growth of a field of young coffee on a perfectly bare flow, devoid of all ash or humus accumulation, suggests the query whether soil (in the ordinary sense) is of any value whatever. Moreover, there are numerous older fields on these bare flows. The following facts are generally true of coffee growth on bare pahoehoe. Coffee makes excellent growth in its early stages, before the first main crop. The drain on the plant caused by heavy yielding causes more dieback than on ash soils. Although bare flows retain moisture to a remarkable degree, a dry spell at lower levels affects the trees on them more than on ash soils. An older field on bare lava has irregular growth. Where the roots of the trees have been able to permeate the lava to sufficient depth, they persist indefinitely, but plantings on spots that are little jointed die out and must be replaced at relatively frequent intervals. It is obvious that the amount of replacement required will depend on the surface features of the individual flow. As long as a heavy application of fertilizer is made, good yields are obtained, but with little or no fertilizer the yields are much less than on ash soils. The yields on a bare flow have more of a tendency to be alternately light and heavy, owing to exhaustion of the tree, than on ash soils.

ZONING

The different climatic conditions on the Kona slope at varying altitudes above sea level divide the district into a series of zones or belts. These belts may be broadly classified as the lower semiarid belt, the lower humid belt, the rain belt, the upper humid belt, and the upper semi-arid belt.

The lower semiarid belt lies between sea level and about 800 feet. It has a relatively low rainfall, from 25 to 50 inches a year, and a great deal of sunshine, the daily cloud blanket seldom shading it for more than a brief period. Seasonal change of climate has no important influence. The vegetation is made up of types that thrive under semiarid conditions. The soils are normally dry and dusty. This belt is used for dry-land grazing and for such crops as need much sunshine and little rain.

The lower humid belt includes the slope from 800 to 2,200 feet in the northern and central parts of the area, but the upper limit is a little lower in the southern part. The rainfall ranges from 50 to 100 inches, and sunshine is limited mostly to the mornings. The soils are moist all the time and often become saturated during the rainy season. The

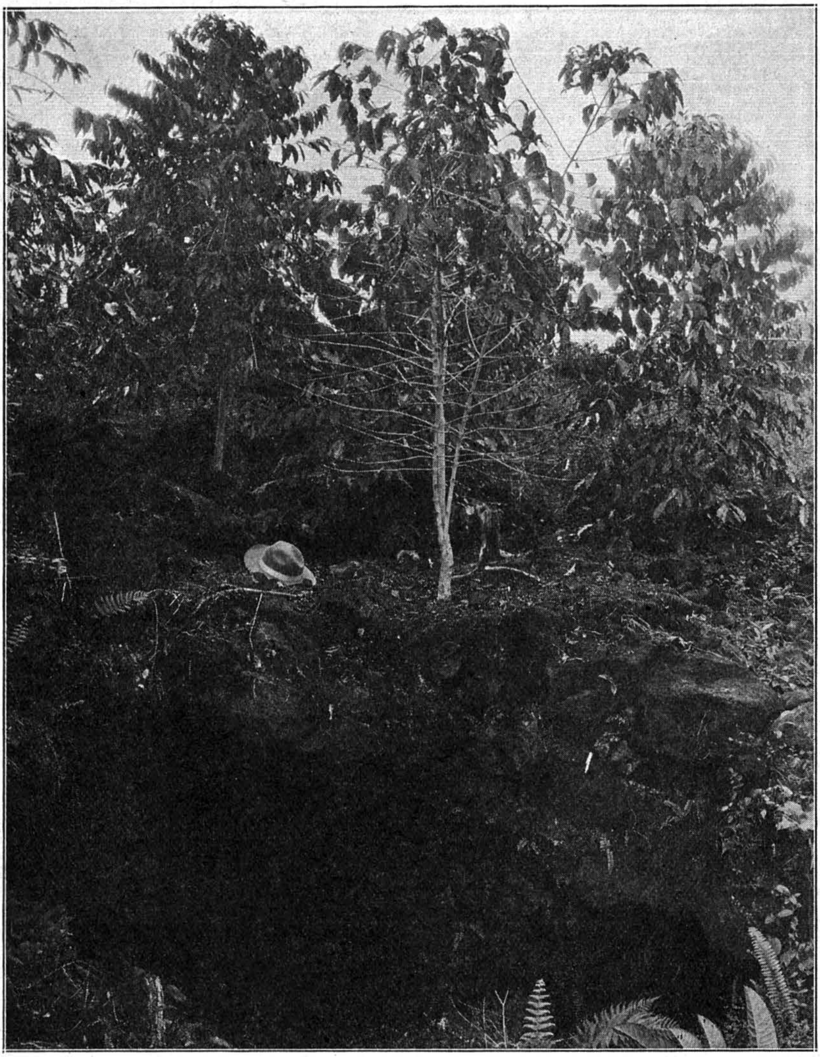


FIG. 6.—Coffee trees growing on a bare pahoehoe flow. These bare flows have a remarkable capacity of conserving moisture and supplying plant food materials. The trees in the foreground are on an old lava tunnel. All the water and plant food necessary for their growth has been supplied by the 2½-feet layer of lava rock forming the roof of the tunnel.

absence of strong winds and the natural shade of the afternoon clouds make this belt an ideal locality for coffee culture.

The rain belt lies between 2,200 and 2,800 feet. This is the zone over which the cloud blanket forms. Even during the dry months this area is cloudy nearly every afternoon. The annual rainfall exceeds 100 inches. The soils are always saturated and during the rainy season they are swampy. The natural vegetation is a dense fern jungle. Lands of this belt are used for pasture to some extent during the dry season, but they are too wet for use during the rainy months.

The upper humid belt extends above the rain belt to about 5,000 feet. The rainfall decreases rapidly from the edge of the rain belt to about 30 inches at the upper altitudes. The soils of this belt are always fairly moist but seldom swampy. During the rainy season this belt is enveloped in fog every afternoon. The upper parts are subject to moderate frosts during the dry winter months. The natural vegetation is koa and ohia forest, with a dense underbrush of small ferns and shrubs. Most of the grazing lands lie within this belt, and the underbrush has been more or less killed off in much of the pastured area.

None of the upper semiarid belt was included in this survey. It is open country, covered with shrubs and small trees, with low rainfall and subject to heavy frosts in winter.

POTENTIAL AGRICULTURAL AREA

The present cultivated area occupies a relatively small part of the lands studied in this survey. Although economic conditions have prevented the establishment of other agricultural industries and have limited coffee to its present boundaries, the obvious fact remains that there exists in Kona a very considerable area that has both soil and climate favorable to agricultural development. Two factors must be considered in any development of these unused areas in Kona—accessibility and vegetation. The lower semiarid belt is fairly accessible and would require no great expenditure to clear it of lantana, kiawe, etc. In the lower humid belt the chief difficulty to be overcome is the clearing off of the dense growth of guava and native vegetation. The cost of clearing often exceeds $50 an acre. Much of the pastured area has already been cleared. Branch roads from the main belt road would serve to reach most of the upper part.

The upper humid belt above the rain belt offers interesting possibilities for future development. The soil and rainfall are similar to those of the lower humid area. The high altitude and limited sunshine would preclude the growth of certain crops. Before this area could be utilized, adequate roads would have to be constructed.

SOIL AND GEOLOGIC MAP

Kona is conveniently divided into sections by its numerous lava flows. Each section is a relatively narrow strip, and most of them extend from sea level to the upper limit of the mapped area. Where the lava flows are comparatively recent and free from ash, the contact of two flows is very marked. With older, less rugged flows, especially those covered with an ash mantle, the contact is much less pronounced and may not be discernible except to the geologist. In the present survey the mapped area has been arbitrarily divided into eight sections. The name given to each section is that most commonly used in Kona, as a rule the name of an important land division within the section. The section boundaries adopted were based on the most obvious geologic and soil divisions and hence do not always conform to boundaries either of land grants or natural groups of coffee plantings.

At the outset attempts were made to map the variations in soil type in the different soil areas. It became evident, however, that the extreme local variations in the surface texture of the lava and in the depth of the ash mantle divided the area into units too small to be mappable. The reason for this heterogeneity is that soil-forming processes, such as weathering, transportation, and intermixing of soil ingredients, which tend to reduce these small local variations and produce larger areas similar in texture, have not yet produced an appreciable effect in this youthful region. The fact that the soil materials have remained practically in place makes it possible, by disregarding these minute variations, to map the soils on the basis of the two geologic factors—depth of ash mantle and nature of underlying lava.

A map was accordingly constructed, showing the boundaries of each different lava flow, the lava type (pahoehoe or aa), and the thickness of the ash mantle. The general soil type of any given area may be determined by noting the underlying lava type and the thickness of the ash mantle and consulting the key to the map. More detailed information as to the lava and soil type of each section is given under the sectional survey which follows.

AGRICULTURAL SURVEY OF THE KONA DISTRICT

Following is the detailed survey of the several sections beginning with the most northern section in the mapped area. For each section is given a description of its boundaries, soil features, and agriculture both past and present. Because of the uncertainty of ascribing the differences noted in coffee in the different sections to any one factor, such as soil, only general observations regarding coffee culture are given. A description of the uncultivated lands gives a general idea as to the potential agricultural possibilities of each section.

HOLUALOA SECTION

Boundaries. The Holualoa section includes all of the slope between the north edge of the mapped area and the almost bare pahoehoe flow (colored orange on map) in the southern part of the Holualoa land division. The northern boundary crosses the belt road a tenth of a mile south of Honokohau School. The southern boundary crosses about a tenth of a mile north of Holualoa School.

Soil features. The northern part of this section is a young pahoehoe flow (colored pink) with no ash mantle. It has a moderately hummocky topography and a notably broken and blocky surface. There are three areas of aa in this section—one flow in the northern part, one flow through the center of the section, and a narrow strip of old aa exposed between them. The rest of the area is underlain by pahoehoe. With the exception of the northern part, the whole section is covered with ash of varying thickness. Both of the aa flows are of the more massive type, with a scanty layer of scoria. The ash mantle is very thin at the lower altitudes but thickens through scoriaceous ash to nearly pure ash at the highest altitudes. These flows give a relatively smooth topography. The narrow strip midway between these two areas is an old aa flow with abundant scoria which has a deep ash cover. The soil in this strip ranges from scoriaceous ash in the lower zone to pure ash in the middle and upper zones. A pahoehoe flow in the southern part of the section has pockety ash soil in the lower zones and a pure ash soil of medium depth in the upper zones. The flow itself has a moderately hummocky topography and only a medium-jointed surface. The rest of the area is medium-jointed pahoehoe with a varying mantle of ash. Soils on the lower slopes are pockety ash and pure ash ranging from medium to deep on the middle and upper slopes.

Agricultural crops. In the past large tracts of this section between altitudes of 800 and 2,200 feet were planted to sugar cane. There was also a sisal plantation in the northern part of the semiarid belt. Several patches of cotton, covering a total of 200 acres, in the semiarid belt are still under cultivation. The coffee plantings in this section cover 1,400 acres. The coffee fields are located largely between the belt road (altitude about 1,500 feet) and the 800 foot contour. Plantings have been made on all the soil types found at these altitudes. The fields on the northern bare pahoehoe flow are among the earliest in the district, but many of them are abandoned at the present time.

Uncultivated areas. Most of the semiarid belt is covered with haolekoa, cactus, kiawe, and lantana and is used for dry-land pasture. Part of the lower humid belt below the road and most of it above the road (up to 2,200 feet) is overgrown with guava thicket. This section contains the largest single area with ash soils in the lower humid belt that is not being cultivated, and by far the largest area with deep ash soil in the upper humid belt. The area above the rain belt is used for pasture but is fairly thickly covered with natural forest and fern undergrowth.

KAHALUU SECTION

Boundaries. The Kahaluu section adjoins the Holualoa section and extends south to the bare aa flow of the Keauhou lands. The northern boundary of the section crosses the belt road just north of Holualoa School, and the southern boundary crosses it 0.8 mile north of the junction of the southern road to Kailua.

Soil features. Most of this section is underlain by pahoehoe lava. An irregular strip through the center of the section, and part of the southern edge, are underlain by moderately scoriaceous aa flows. Most of the area is covered with a very thin to moderate layer of ash. The massive pahoehoe flow in the upper southern part of the section (colored pink on map) is moderately hummocky with an almost unbroken surface. The flow is barren of ash, but is covered by a thin mantle of humus. The long pahoehoe flow (colored orange) forming the northern part is slightly hummocky with a slightly broken surface. It has pockety ash soil with much exposed rock on the lower slopes. The pahoehoe under the lower central part of the section is made up of several flows with moderately hummocky, notably broken surfaces. Soils range from pockety ash on the lower slopes to pure ash of medium thickness above the road. The parts underlain with aa are moderately hummocky and have a good deal of exposed massive outcrop. They are covered with a thin ash mantle which gives rise to soils varying between ashy scoria and scoriaceous ash.

Agricultural crops. Sugar cane formerly occupied much of the area between the belt road and an altitude of 2,000 feet. An early tea plantation was located in this area. One patch of cotton at 700 feet is cultivated at present. Coffee is growing in a narrow strip on each side of the belt road across the section. The total area is not more than 250 acres and includes all soil types. All the coffee is of the old Hawaiian type, and most of the plantings look exhausted.

Uncultivated areas. Some of the semiarid belt is used for pasture, but a thick growth of lantana has almost ruined it for this purpose. Most of the lower humid area above the belt road is guava thicket which has taken the land since the sugar-cane plantings were abandoned. About half of the area above the rain belt is open pasture land, and the rest still has the natural forest and thick fern underbrush. The soil of all of this upper area is thin, but is rich in humus.

KEAUHOU SECTION

Boundaries. The Keauhou section extends from the northern edge of the Keauhou aa flow to the southern edge of the massive pahoehoe flow in Honalo (colored orange on map), in the lower zones, and to the southern edge of the Lehuula aa flow (colored red), in the upper zone. The northern boundary is 0.8 mile north of the junction of the Kailua road with the main belt road, and the southern boundary crosses the belt road half a mile north of Kainaliu.

Soil features. About half of this section is the bare aa flow known locally as the Hualalai Clinker. The rest is broken into narrow strips with very different soil conditions. The Hualalai Clinker and the small bare aa flow in the upper southern part (colored red) are extremely rugged and hummocky and have very scoriaceous lava. The two aa flows in the upper central part (colored pink) have no ash on top, but are very scoriaceous and are old enough so that considerable humus is mixed with the scoria. They are moderately hummocky. Two strips of pahoehoe (colored pink) in the lower part have no ash mantle, and their surfaces are badly broken and only slightly hummocky. The long pahoehoe flow (colored orange) in the southern part of the section is moderately hummocky and has a slightly broken surface. It has pockety ash soil which is slightly deeper at the upper elevations. The lower parts are almost bare rock. A narrow strip (colored yellow) crossing the road at the Keauhou School, just south of the Kailua road junction, has scoriaceous ash to pure ash soil on an old, moderately scoriaceous aa flow. There are some outcrops of massive rock, and the topography is hummocky. Just south of this area is a small strip of broken pahoehoe (colored orange) with pockety ash soil. A small patch of pure ash soil (colored deep yellow) just above the road in the center of the area is underlain by slightly scoriaceous aa and has very smooth topography.

Just above this deep soil is pockety ash on slightly broken pahoehoe. South of this area, between two long tongues of bare aa, is a long strip of slightly hummocky pahoehoe (colored light yellow) with pockety ash soil on the lower slope and pure ash soil of medium depth at the middle and higher levels. The upper part of this strip (between altitudes of 1,800 and 2,200 feet) is occupied by a Macadamia nut plantation. A similar strip just south of the narrow tongue of bare aa is covered with an ash mantle of medium thickness. Most of the upper part is underlain by a slightly scoriaceous aa flow and has scoriaceous ash soil. The lower part has pockety ash to pure ash soil on a fairly smooth pahoehoe flow.

Agricultural crops. Small areas on the deeper soils between 800 and 2,200 feet were formerly in sugar cane. Two large plantings of Macadamia nuts have been made in this section. In one the nut trees are interplanted among coffee, and the other is the plantation referred to above. About 550 acres have been planted in coffee in this section. The plantings are in four main patches, and all the different types of soil are used.

Uncultivated areas. The semiarid belt is practically a waste land of lantana. About one-third of the soil land in the lower humid belt, formerly in sugar cane or pasture, has been overrun by guava thicket. Much of the upper area is jagged aa lava covered with natural jungle and is worthless even as pasture. The rest of the upper humid belt is open pasture land.

KONAWAENA SECTION

Boundaries. The Konawaena section includes the slope between the Keauhou section and the bare aa flow of Kealakekua. The northern boundary crosses the belt road half a mile north of Kainaliu, and the southern boundary 0.4 mile south of the Konawaena School road.

Soil features. This section is a large area of deep soil with a young pahoehoe flow through the center. This flow has no ash mantle and has a rather broken surface. In the highest part of the section is a medium scoriaceous aa flow (colored light yellow on map) with scoriaceous ash soil and moderately hummocky topography. A small strip of hummocky, scoriaceous aa (colored pink) in the lower, southern part has scoria soil with a moderate admixture of humus. The rest of the area has deep pure ash soil varying to scoriaceous ash over aa flows on the lowest slopes. The deep ash soil is underlain by both aa and pahoehoe flows, but the areas of each could not be delimited in more than a general way, as the flow boundaries are obscured by the deep ash. The topography ranges from smooth to hummocky, depending on the nature of the lava surface under the ash.

Agricultural crops. Some of the best fields of sugar cane were in this section between altitudes of 1,000 and 2,200 feet. Tobacco has also been grown at the lower altitudes. Macadamia nuts are flourishing in several scattered plots. Coffee plantings cover a total of 750 acres in this section. Most of the fields are on the deep ash soils, but a considerable strip of the bare pahoehoe near the road has recently been planted to coffee. The field holding the record of the district for one year's crop is on the pure ash soil at about 1,600 feet.

Uncultivated areas. Most of the semiarid belt is pastured or is in lantana. About one-fourth of the lower humid belt is in coffee, one-third is in pasture, and the rest is guava thicket. The upper humid belt lands are almost all open pasture.

KEALAKEKUA SECTION

Boundaries. The Kealakekua section is bounded by the northern edge of the bare aa flow of Kealakekua and the southern edge of the aa flow in Keei. The northern boundary crosses the belt road 0.4 mile south of the Konawaena School road. The southern boundary crosses the lower belt road at the Napoopoo junction and the upper belt road 0.3 mile north of the junction with the secondary road into the upper Keei lands.

Soil features. This section is bounded by two rather extensive rugged aa flows with no ash cover. Between these flows are two strips of aa covered with light ash (colored orange on map) and two strips of deep ash. The two aa strips are similar in characteristics below 3,000 feet. As the aa surface is only moderately scoriaceous, massive outcrops are rather numerous. The variable distribution of the scoria and the relative thinness of the ash mantle give spotty soils of ashy scoria, scoriaceous ash, and pockety ash types. The southern strip of aa changes to pahoehoe as the slope lessens above 3,000 feet, with pockety ash soil on a relatively unbroken rock surface. A small patch of aa (colored light yellow) in the highest part of the section has a hummocky surface and scoriaceous ash soil. There is also a short narrow strip of pahoehoe with a pockety ash mantle (colored orange) in the lower northern part of the section. The rest of the area has medium to deep ash over both aa and pahoehoe lava. The soil is mostly of the pure ash type, but on the lower slopes this changes to scoriaceous ash on the aa surfaces. In this area is the steep slope of the lava cascade over the old cliff, but very little erosion of the ash mantle has taken place in spite of the steepness of the slope.

Agricultural crops. Pineapples and cotton were formerly raised on the lower slopes in the southern part of the section. Several plantings of Macadamia nuts have been made among the coffee trees. This section has the largest area of coffee (2,000 acres) in the Kona region and also shows the greatest average coffee production.

Uncultivated areas. The entire area of the two rugged aa flows is not utilized for any purpose. The semiarid belt is largely used for pasture. Most of the lower humid belt has been planted to coffee. The area above the rain belt is all open pasture.

KEEI SECTION

Boundaries. The Keei section extends from the south edge of the Keei aa flow to the south edge of the bare pahoehoe flow bordering Honaunau. The northern boundary crosses the upper belt road 0.3 mile north of the junction of the road into the upper Keei coffee lands and crosses the lower belt road at the Napoopoo road junction. The southern boundary crosses the upper belt road 0.4 mile north of Honaunau post office and the lower road the same distance north of the junction of the road from Honaunau village.

Soil features. Most of the section is pahoehoe lava with no ash mantle. The topography is generally slightly hummocky, and most of the flows have a broken, blocky surface. A notable amount of humus and rock dust gives a slight pockety covering to the bare rock. There are four strips of deep ash which have not been buried by the pahoehoe. These lie on the steepest slopes of the lava cascade over the old cliff. It is remarkable that the ash mantle maintains a fairly constant depth over the exposed area, in spite of the steep slope and the abundant rainfall. The soil type is pure ash, though both aa and pahoehoe lava underlie the ash.

Agricultural crops. Coffee is planted on pure ash and the bare pahoehoe, both on the steep and gentle slopes, though the total area in coffee is only about 150 acres. Much of the lower planting on the bare flow has been more or less abandoned.

Uncultivated areas. The semiarid lands are used for pasture to a minor extent. Much of the deep soil areas and a small percentage of the pahoehoe flows of the lower humid belt are utilized for coffee. The rain belt and the upper humid belt lands are all in the Honaunau Forest Reserve.

HONAUNAU SECTION

Boundaries. The Honaunau section is a small, elliptical area inclosed by the bare pahoehoe flow of northern Honaunau and the bare aa flow of southern Honaunau. The northern boundary crosses the upper belt road 0.4 mile north of Honaunau post office and the lower road the same distance north of the junction of the road from Honaunau village. The southern boundary crosses the upper belt road half a mile south of Honaunau post office and the lower road 0.4 mile south of the road junction to Honaunau village.

Soil features. All of the Honaunau strip is mantled with ash. The main area is a moderately hummocky aa flow with a medium amount of scoria. The soils are ashy scoria to scoriaceous ash. The northern part of the area is underlain by relatively smooth pahoehoe with medium to deep pure ash soil. The upper part (colored light yellow on map) is pockety ash soil on a hummocky pahoehoe flow with a moderately broken surface.

Agricultural crops. Tobacco has been grown at several different times in the lower part of this section. The rest of the area to an altitude of 2,000 feet has been planted entirely to coffee. The fields above the 1,750-foot contour have been generally abandoned. Active coffee fields cover about 350 acres.

Uncultivated areas. The semiarid belt lands are now used somewhat for pasture, but are mostly overrun with lantana. The land above 2,000 feet is in the forest reserve.

HOOKENA SECTION

Boundaries. The Hookena section includes all of the slope from the northern edge of the bare aa flow in Honaunau to the southern edge of the area mapped. The northern boundary crosses the belt road half a mile south of Honaunau post office, and the southern boundary about 2 miles south of the junction with the secondary road to Hookena.

Soil features. Most of this section is bare lava of both aa and pahoehoe types. A number of strips covered with light to moderate ash are exposed between tongues of the late flows. In general, the upper parts of these ash-covered strips are underlain by highly scoriaceous aa flows with a hummocky topography, and the soils are of ashy scoria and scoriaceous ash type. The lower parts of the strips are underlain by smooth to slightly hummocky pahoehoe flows with moderately broken surface, and the soils range from pockety ash at the low elevations to medium depth pure ash along the belt road.

Agricultural crops. Large plantings of tobacco were made as high as 1,700 feet, but these have been abandoned. A considerable acreage of upland taro is being cultivated in the ash soils by Hawaiian planters. Only a narrow strip along the belt road is in coffee, about 50 acres all told. Some coffee plantings above the road in Kalahiki have been abandoned. This section is but little utilized at present.

Uncultivated areas. The semiarid belt is almost all lantana thicket. The greater part of the lower humid belt is either in guava or in native vegetation. The rain belt and the upper humid belt are used somewhat for pasture, but are largely native jungle and very swampy.

SUMMARY

Kona lies on the western slopes of two young volcanoes—Hualalai and Mauna Loa. The topography of the region is almost entirely determined by the original constructional slopes of the volcanoes. The country rock is erupted material of basaltic composition, either lava flows or fine-grained, unconsolidated ash. The flows are of two main types, aa and pahoehoe, showing respectively a rugged, clinkery surface and a smooth, relatively continuous surface. The lavas and ash beds are so permeable that surface water disappears immediately by underground drainage and forms no permanent surface streams. Consequently, there has been very little removal and practically no mixing and redeposition of the surface materials. Chemical weathering has completely altered the ash, but has had little or no effect on the lavas.

Geologic factors rather than weathering are thus the determining influences in soil formation in Kona, and because of this fact the ordinary scheme of soil classification is not applicable. The classification system adopted is based on the controlling geologic factors, namely, the depth of ash mantle and the surface texture and type of the underlying lava.

Kona has a very mild, equable climate, owing to the deflection of the trade winds and the existence of land and sea breezes. These give rise to a daily cloud blanket which forms at the 2,500-foot level and spreads both up the mountain slope and out toward the sea. The result is a

series of narrow belts, each with its characteristic climate and agriculture. The belt of maximum rainfall is at 2,500 feet. Above and below this are the humid belts, best adapted to agriculture. Still higher up the mountain slope and lower down approaching sea level are the semiarid belts. Practically all of the agriculture of the district is in the lower humid belt. Large areas of potential agricultural land exist in both the lower and the upper humid belt.

Exceptionally heavy yields of coffee are produced in Kona, the average of 1,800 pounds per acre of clean coffee being two to five times as great as that of other coffee-producing countries. This is partly due to liberal use of commercial fertilizer and partly to the climate. Data on yields are too fragmentary to permit any definite correlation between yield and soil type.

For the purpose of the soil survery, the district was divided into eight sections. A detailed account of the soil types and agriculture of each section is given.

The accompanying map shows the essential features of geology and soil, together with rainfall lines and section boundaries.

KEY TO MAP

Control, culture, and topography (500-foot contour interval) taken from United States Geological Survey topographic maps of Hawaii, Kailua Quadrangle, edition of 1924, and Honaunau Quadrangle, edition of 1928.

Lava types + + + + + —Aa type

o o o o o —Pahoehoe type

Present coffee area—/ /

Isohyetal lines (lines of equal rainfall) ▬▬▬▬

Section boundaries—◆ ◆ ◆

Soil types—Red color—Ashless flows with no agricultural value.

Pink color—Ashless flows of limited agricultural value.

Soil type—**flow rock.**

Orange color—Thin ash mantle (less than 3 inches).

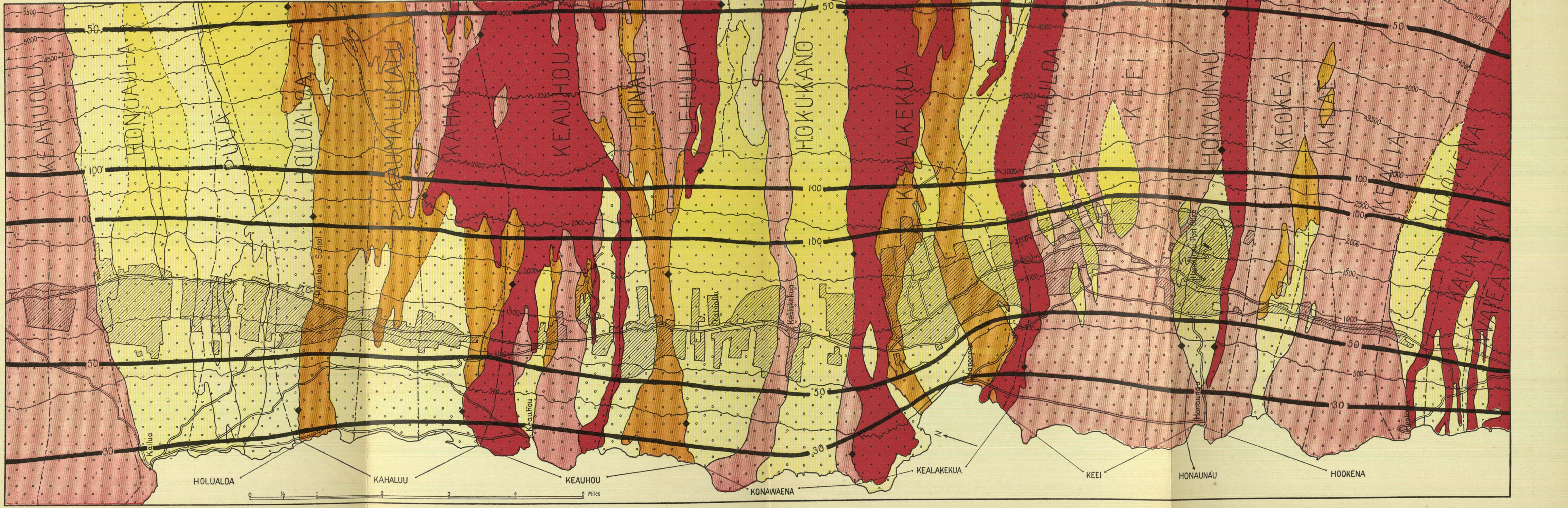
Soil types— { Over aa—**ashy scoria**; " pahoehoe—**pockety ash** }

Light yellow color—Medium ash mantle (3 to 18 inches).

Soil types— { Over aa—**scoriaceous ash**; " pahoehoe—**pure ash** }

Deep yellow color—Deep ash mantle (more than 18 inches).

Soil types— { Over aa; " pahoehoe } **pure ash.**



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