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SOIL RECONNAISSANCE OF THE PANAMA CANAL ZONE AND CONTIGUOUS TERRITORY

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CONTENTS

AREA SURVEYED

The Panama Canal Zone comprises a strip of country 10 miles wide and approximately 45 miles long, lengthwise through the center of which the Panama Canal has been cut. The canal, about 50 miles long from deep water to deep water, crosses the Isthmus of Panama in a southeasterly direction from the Caribbean Sea on the Atlantic side to the Gulf of Panama on the Pacific side. The original area of the zone was about 441.5 square miles, but since the acquisition of the territory by the United States Government a small area northeast of the city of Panama has been excluded and several additions have been made in accordance with the provisions of the Hay-Varilla treaty.[2] This reconnaissance area includes 855 square miles.

The latitude and longitude of the Atlantic end of the canal are 9° 23′ N. by 79° 56′ W., and of the Pacific end, 8° 54′ N. by 79° 32′ W. The Atlantic terminal of the canal is 1,974 nautical miles from New York, 1,399 from New Orleans, and 1,065 from Key West. The

[1] This survey was made by Hugh H. Bennett, of the Bureau of Soils, while working with John C. Tredwell and C. Reed Hill, representatives of the U. S. Department of Commerce on rubber investigations, during the latter part of 1923 and the early part of 1924.

[2] Panama Canal. acquisition of land in canal zone and panama. P. 2. 1922. (Mimeographed.)

Pacific terminal is 2,913 nautical miles from Los Angeles, 3,245 from San Francisco, and 2,616 from Valparaiso, Chile.

Transportation is provided in the Canal Zone by the Panama Canal and the Panama Railroad. A good, hard-surfaced highway has been built from Panama to Gamboa and another from Colon to Gatun. A fairly good highway extends from Empire southwest to La Chorrera and thence to Puerto de La Chorrera on the Gulf of Panama; and a road from Panama to Chepo is used for automobile travel during the dry season. Trails, passable for foot and horse travel only, extend in many directions through the Canal Zone and contiguous territory. Some of these trails are so muddy during the wet seasons that they can be traveled only on foot.

Schools and churches are located in towns and villages within the Canal Zone and also beyond its limits. Healthful living conditions in the towns are generally assured by efficient sanitary measures. No mosquitoes were seen in Ancon, Balboa, or the city of Panama during the survey period. Disease-carrying mosquitoes, ticks, and other insects abound, however, in districts not protected by sanitary measures.

CLIMATE

The climate of the Canal Zone and contiguous territory is humid-tropical, with a rainy season of eight months duration (May to December, inclusive) and a markedly dry season of about four months (January to April, inclusive). March and April are the driest and October and November the wettest months. The rainfall is heaviest on the Atlantic side of the area. The dry season there is characterized by more frequent showers than on the Pacific side, and the soil usually retains an ample supply of moisture for the maintenance of green foliage in the virgin forests. On the Pacific side of the zone most of the upland soils dry and crack in the dry season, the native grasses wither in most places, and a large proportion of the forest trees shed their leaves. Some of the deeper soils, however, conserve enough moisture to maintain a luxuriant growth of vegetation, manifested in continued greenness of the forests throughout the dry season; other soils, such as the shallow limestone clay and savanna clay, become exceedingly dry, vegetable growth is checked, and the forests assume a desertlike aspect by the middle of February. At the close of one of the longest rainless periods ever experienced in this area the deeper and more friable red clay was still moist at the surface in virgin forests and at a depth of 1 or 2 inches below the surface in cleared areas. At the same time there were very few other upland areas on the Pacific side in which the surface soil was not dry to a depth varying from 4 to 6 inches and comparatively dry to a depth varying from 8 to 12 inches, depending on the character of the soil. Vegetation on the alluvial soils is practically always green.

On the Atlantic side of the zone most forested areas remain green throughout the dry season, even on the shallower uplands.

The vegetation of second-growth forest (restrojo) appears to suffer from drought even more than that of the virgin forest. Second-growth vegetation on the Atlantic side of the area shows the effects of the dry season much more than the virgin forest, but not to so great a degree as the corresponding growth on the Pacific side.

The dry season (verano) (*9*)[3] is the winter season in the sense that it is the time of the year that plants shed their leaves. On the other hand, it is summer time in that it is the flowering and fruiting season for the majority of the plants indigenous to this region. Many plants of the Canal Zone and contiguous territory put forth blossoms and develop their fruit after their leaves have fallen. In the year of this survey the dry season began a month earlier than usual, and by the last of March the brown fleecy fibers of silk cotton (kapok) were floating through the air from the bursting pods of many of the ceibas.

After the first month of dry weather, much of the grass and bush growth in the southern part of the Canal Zone, except that in the stream bottoms and on the deep, friable clay soils, becomes so dry that fires are of frequent occurrence. These are most common in the restrojo and grasslands.

The dry season is the season of strong winds. During this period, trade winds blow from the north and northeast 90 per cent of the time and have an average velocity of 15 miles an hour. Other dry-season winds, locally called "northers," frequently disturb the waters on the Atlantic coast and occasionally wreck small boats. They average 30 miles an hour and have attained a maximum velocity of 59 miles. During the rainy season, winds blow from the south and southeast, particularly on the Atlantic side of the zone.

The rainy season is winter (invierno) in Central America. Short dry seasons, coming at regular intervals within the limits of the long rainy season, are referred to as little summer (veranillo) and locally as San Juan summer. In some parts of Latin America veranillo de San Martine refers to what is known in the United States as Indian summer. Undoubtedly the same term is used for the little-summer season, as explained above, by some of the inhabitants of the more humid-tropical regions.

Table 1 shows the monthly rainfall during 1922 for a number of stations in the Pacific-island, Pacific, central, and Atlantic sections of the isthmus. At many of the stations the rainfall for that year was below normal. However, the records convey a general idea of the character and distribution of rainfall in this region.[4]

TABLE 1.—*Monthly rainfall, 1922, from Pacific side to Atlantic side of the Canal Zone*

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pacific-island section:	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Taboga	1.24	0.47	0.03	0.17	4.54	9.72	1.72	6.77	10.77	8.18	9.38	3.83
Pacific section:												
Balboa	2.49	1.64	1.19	.14	8.58	7.65	6.47	1.29	7.87	9.45	8.22	5.61
Balboa Heights	1.73	2.03	1.02	.16	9.88	7.92	5.08	1.46	8.18	9.03	8.44	3.82
Miraflores	2.00	.62	1.71	.51	12.00	8.27	8.67	3.41	7.15	14.76	14.11	9.15
Pedro Miguel	2.67	.51	3.44	1.19	13.16	10.32	7.09	7.60	5.64	9.64	14.61	8.06
Central section:												
Culebra	4.59	1.46	.35	.33	9.14	9.06	7.16	6.00	6.15	10.49	14.91	6.45
Empire	3.58	.89	.26	.00	10.99	8.70	6.53	4.90	6.28	11.55	11.33	4.31
Gamboa	8.11	1.42	.09	.24	15.04	9.09	6.12	7.20	8.74	11.82	6.58	6.65
Juan Mina	4.69	.65	.96	.05	9.42	13.63	6.46	9.20	8.78	15.79	12.00	6.35

[3] Reference is made by italic numbers in parentheses to literature cited, p. 45.

[4] Panama Canal, Department of Operation and Maintenance, Records of the Office of the Chief Hydrographer. [Unpublished data.]

TABLE 1.—*Monthly rainfall, 1922*—Continued

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Central section—Contd.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Alhajuela	3.95	0.16	0.00	0.17	12.52	13.85	7.59	9.92	8.31	16.74	11.15	4.38
Trinidad	4.81	.94	.07	1.64	15.71	8.00	3.62	13.29	10.37	16.01	16.79	11.04
Monte Lirio	6.69	1.35	.21	1.41	12.29	9.98	5.66	6.95	13.78	16.57	10.80	5.74
Atlantic section:												
Gatun	9.48	1.29	1.13	2.35	12.71	12.54	5.26	7.24	11.98	17.81	17.50	8.04
Brazos Brook	10.31	1.28	.70	1.98	7.62	7.86	5.46	6.29	12.50	9.71	15.44	4.99
Colon	6.85	.71	.92	2.11	8.88	8.30	4.40	14.53	12.73	13.87	15.63	7.20
Porto Bello	11.26	3.36	3.23	4.13	25.48	10.84	11.53	13.25	22.94	14.44	22.50	13.45
Bocas del Toro	24.25	14.91	8.04	13.98	7.93	12.57	24.29	9.14	5.37	8.46	9.57	18.01

The average rainfall for the Pacific-island, Pacific, Central, and Atlantic sections is given in Table 2, together with the number of years of record, number of rainy days, and period maximum of rainfall:

TABLE 2.—*Average annual precipitation in the four sections of the Canal Zone, number of rainy days in 1922, and maximum precipitation during 10 minutes, 1 hour, and 24 hours*

Station	Average annual rainfall	Years of record	Rainy days, 1922	Maximum precipitation in 10 minutes	Maximum precipitation in 1 hour	Maximum precipitation in 24 hours
Pacific-island section:	*Inches*	*Number*	*Number*	*Inches*	*Inches*	*Inches*
Taboga	52.29	8	102			5.90
Pacific section:						
Balboa	67.67	24	181	1.68	5.86	7.57
Balboa Heights	68.96	25	168	1.20	3.98	7.23
Miraflores	78.83	14	169	.97	4.09	4.75
Pedro Miguel	79.63	15	198	1.10	3.46	5.45
Central section:						
Culebra	86.50	32	210	1.05	3.69	5.55
Empire	80.30	18	215	1.10	4.19	6.15
Gamboa	90.56	40	227	1.17	3.32	6.56
Juan Mina	93.50	12				4.10
Alhajuela	99.96	23	228	1.20	4.19	8.19
Trinidad	103.34	15		.96	3.20	6.00
Monte Lirio	117.03	15	232			7.60
Atlantic section:						
Gatun	119.27	18	258	1.16	4.72	10.48
Brazos Brook	126.47	16	232			8.96
Colon	127.25	52	238	1.20	4.90	8.53
Porto Bello	159.76	11	314	2.56	4.53	10.86
Bocas del Toro	115.82	14	249			7.88

It will be seen from these records that there is a gradual increase in precipitation through the Canal Zone from the Pacific to the Atlantic side. This increase in rainfall is accompanied by a corresponding increase in the number of rainy days.

Table 3 gives the mean, maximum, and minimum temperatures; greatest daily range in temperature; mean relative humidity; total evaporation; and percentage of sunshiny days at Balboa Heights and at Colon:

Table 3.—*Climatic data for Balboa Heights on the Pacific side and for Colon on the Atlantic side of the Canal Zone*

	Balboa Heights	Colon
Mean temperature, ° F	80.2	80.1
Absolute maximum temperature, ° F	[1] 97	[3] 93
Absolute minimum temperature, ° F	[2] 63	[4] 66
Greatest daily range in temperature, ° F	27	20
Mean relative humidity, per cent	83	83.7
Total evaporation, inches	53.7	52.8
Percentage of sunshiny days	48	54

[1] Apr. 7, 1912. [2] Jan. 27, 1910. [3] Apr. 12, 1920. [4] Dec. 3, 1909.

Table 4 indicates far more equable temperatures in the Canal Zone than in the United States.

Table 4.—*Comparative temperatures, relative humidities, and mean annual rainfalls at various points in the United States and in the Canal Zone*

Station	Mean July temperature	Record temperatures		Mean annual relative humidity	Mean annual rainfall
		Highest	Lowest		
	° F.	*° F.*	*° F.*	*Per cent*	*Inches*
Mobile, Ala	81.4	102	−1	74	62.04
Denver, Colo	72.2	105	−29	52	14.02
Washington, D. C	76.8	106	−15	72	43.50
Key West, Fla	83.5	100	41	77	38.66
Chicago, Ill	73.9	103	−23	74	33.28
New York, N. Y	73.8	102	−13	71	44.63
New Orleans, La	82.4	102	7	78	57.42
St. Louis, Mo	78.7	107	−22	70	37.20
Oklahoma City, Okla	80.6	108	−17	70	31.70
Charleston, S. C	81.4	104	7	78	52.07
Galveston, Tex	83.4	99	8	77	47.06
Colon, Republic of Panama	80.0	93	66	84	127.25
Balboa Heights, Canal Zone	80.0	97	63	83	68.96

SURFACE FEATURES

The main axial range of the Isthmus of Panama runs northeast and southwest across the Canal Zone, the crest lying several miles south of the geographical axis of the Isthmus and within 10 miles of the coast at Panama. It is crossed by the canal at Culebra. The slope to the Pacific is comparatively steep. On the Atlantic side the slope is comparatively steep to an extremely hilly lowland belt formerly drained by Chagres River east of the canal and by a number of small tributaries of Chagres River west of the canal. These are now flooded throughout most of their extent by the waters of Gatun Lake. The following description of the southern part of the Canal Zone, including the longitudinal interior lowland just referred to and the axial range south of it, shows some of its characteristics in detail:

It would be difficult to imagine a region more hilly than the southern portion of the Canal Zone. The entire country is so broken by one hill after another that well-defined, continuous ridges are almost entirely lacking. There are, however, roughly developed drainage divides which, viewed in places from the main valley slope, sometimes appear as unbroken ridges flanked by rounded lateral hills, as is well illustrated in the valley to the west of Empire. But closer view of these divides reveals a most uneven surface configuration. The valleys between the numerous hills here are extremely variable in depth, so that there are many minor high valleys lying above the deeper major stream depressions through the divide regions. This entire southern region is ramified by an intricate drainage system which favors the rapid run-off of rain water. Along their lower courses, where the fall is less, the streams are usually bordered with narrow fringes of flat bottom land. Many of the smaller tributaries descending rapidly to the larger streams are merely wet-weather drainage ways of short length and without alluvial bottoms.

North of this hilly interior lowland which seems to occupy the geographical axis of the Isthmus from the Canal Zone eastward and southward many miles, is another ill-defined mountain ridge which lies between the interior axial lowland and the Caribbean coast of the Canal Zone. It does not extend across the canal, however, or if so is represented only by a series of low hills lying along both sides of Chagres River northwest of Gatun Dam. This ridge culminates a short distance east and southeast of Colon in the Sierra Santa Rita.

The savannas [5] include the smoothest upland areas. Those extending from the vicinity of Panama to Chepo and those occurring in the La Chorrera section are characteristically gently undulating or gently rolling, with prevailingly long, gentle slopes, broken here and there by rough gullied lands. The stream bottoms are fairly broad in the savanna districts. Savanna land is amply level for easy cultivation, but unfortunately most of the soil of the larger areas examined (the red savanna soil about la Chorrera and east of Panama) is unfavorable for growing anything except grass.

Although the Canal Zone has the lowest elevation on the Isthmus of Panama, it is one of the most hilly parts of Central America. (Pl. 1, A.) With the exception of the low swamps around Colon and between Pedro Miguel and the Pacific Ocean and the narrow strips along many of the stream bottoms, there is no flat land in the Canal Zone. Hills are numerous and range in height from less than 50 feet above sea level near Gatun and Colon to 700 feet in the southern part of the Canal Zone. The highest elevation, 1,223 feet above sea level, is reached on the hill known as Cerro de Galera (fig. 1), near the boundary southwest from Balboa. Other hilltop elevations range from about 500 feet to more than 1,000 feet above sea level.

The highest elevations, as a rule, are back from the canal, near and along the boundaries of the Republic of Panama. The lower elevations occur north of Gatun, on the east side of the canal.

Some of the slopes are too steep for easy cultivation, and, if cleared and plowed, would wash severely, unless terraced, or would develop gullies similar to those in the pastures near Darien, where the land has never been plowed. The deep-red clay, the prevailing soil of the Canal Zone, shows remarkable resistance to erosion. Few gullies, even in the initial stage, are seen on these soils along old trails or even in cleared pasture land. Areas most favorable for cultivation are along the streams and on the less rolling country adjacent to them, especially along the lower courses of Rio Cocoli and Rio Puente.

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[5] Savanna, in this region, refers to grass-covered areas where the soils are principally residual. In United States savanna is sometimes used in referring to the sparsely timbered areas of the low coastal-plain region, mainly in the Carolinas, where the soils have been developed from sedimentary material.

The lower hills have comparatively gentle slopes and are fairly well suited to agriculture. An extensive area on the Empire-La Chorrera road, beginning near the Canal Zone boundary and extending southwest almost to Caimite River and to the vicinity of Arraiján, is comparatively smooth, the difference between minimum and maximum elevations being less than that characterizing the average hill land of the region. The soil here is deeper and therefore better than that of the higher hill country.

Most of the streams are bordered by narrow strips of alluvial soil which, as a rule, are not continuous but occur in patches on both sides, the broader bottom lands occurring in the bends of the streams. Few of the strips of bottom land exceed one-eighth mile in width, and most of them vary in width from about 100 to 400 feet. Exceptionally broad stretches of alluvial lands lie along Chagres and

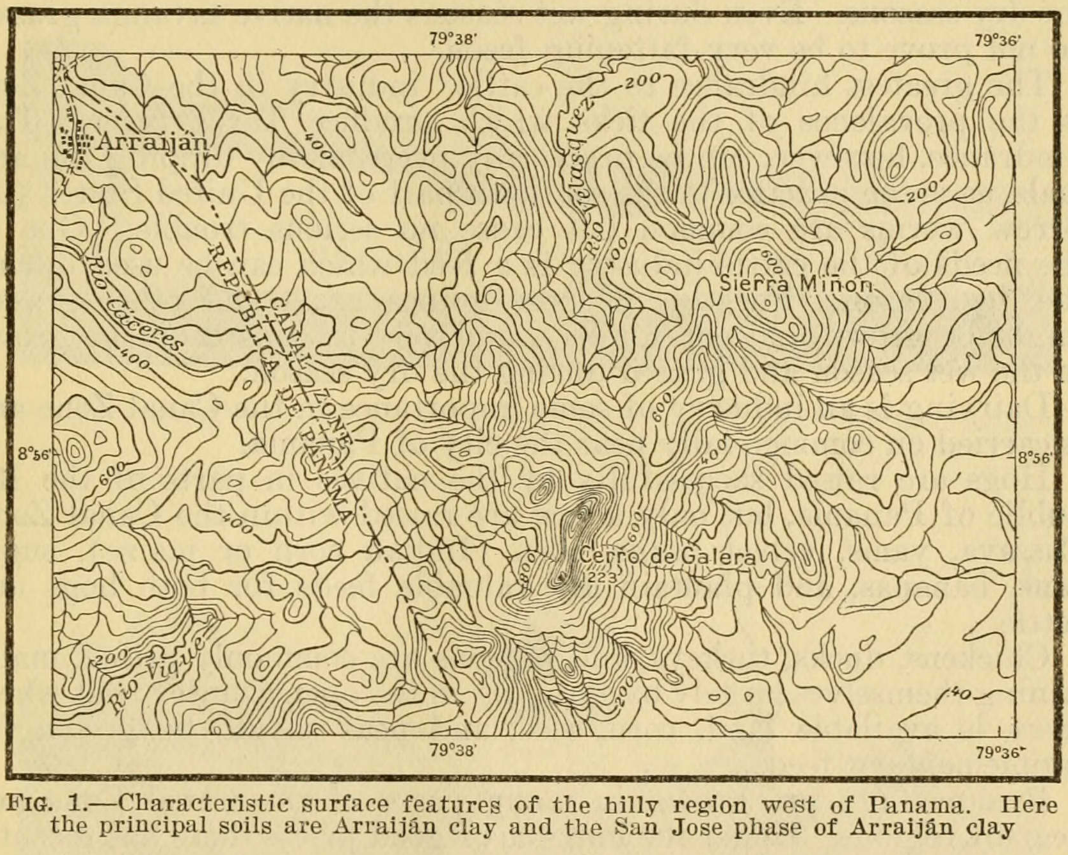


FIG. 1.—Characteristic surface features of the hilly region west of Panama. Here the principal soils are Arraiján clay and the San Jose phase of Arraiján clay

Pequeni Rivers. In places, gently sloping lands adjacent to the bottom lands along the streams have deep soils.

Many ravines (quebradas) carry water following heavy rains only, and some of the hill streams practically cease flowing toward the end of the dry season. Most of the streams, especially the smaller ones, are actively cutting their channels deeper. Some of the larger ones, however, have practically reached base level.

AGRICULTURE [6]

No full discussion of agriculture and its possibilities in the Canal Zone will be undertaken in this report, but references to some of

[6] The data in this report relating to crops and farm methods are based on (1) The agricultural possibilities of the Canal Zone; (2) the work of the plant-introduction garden of the Panama Canal; (3) the supply department of the Panama Canal; and (4) the experiences of farmers and personal observations.

the outstanding features will be made. The principal farm industries of the Canal Zone and contiguous territory at the present time consist of growing bananas and raising livestock.

Some years ago a large area in the Canal Zone was cleared and set to guinea grass (*Panicum maximum*) (pl. 1, B.), which was used for fattening cattle for the Panama Canal Commission. At one time 15,000 head of cattle were maintained on these pastures. Napier grass is also a promising grass for the clay uplands, and Rhodes grass has grown well at the plant-introduction garden. Bermuda grass and some of the native species of Paspalum thrive and remain fairly green during the dry season. Elephant grass has done well in other places and is highly valued as feed for livestock. Pastures of guinea grass or Para grass will support about one animal to the hectare (2.47 acres). New savannas will afford about the same amount of pasturage during the rainy seasons but very little during the dry seasons. Even during wet seasons the native savanna grasses do not prove to be very fattening feeds.

The greatest hindrance to the cattle[7] industry in the Canal Zone is the prevalence of the ticks which produce Texas fever. This hindrance, however, can be practically overcome by dipping the animals, as is the practice in the southern part of the United States (*6*). Screw worms are common but cause no serious trouble. One of the needs of the cattle industry is a feed which can be used during the dry season. For this purpose guinea grass and other grasses might be grown and cut for hay, and velvet beans could be grown in the wet season and grazed during the dry season.

Dairying is an industry of some importance in the Canal Zone and is carried on commercially near the city of Panama.

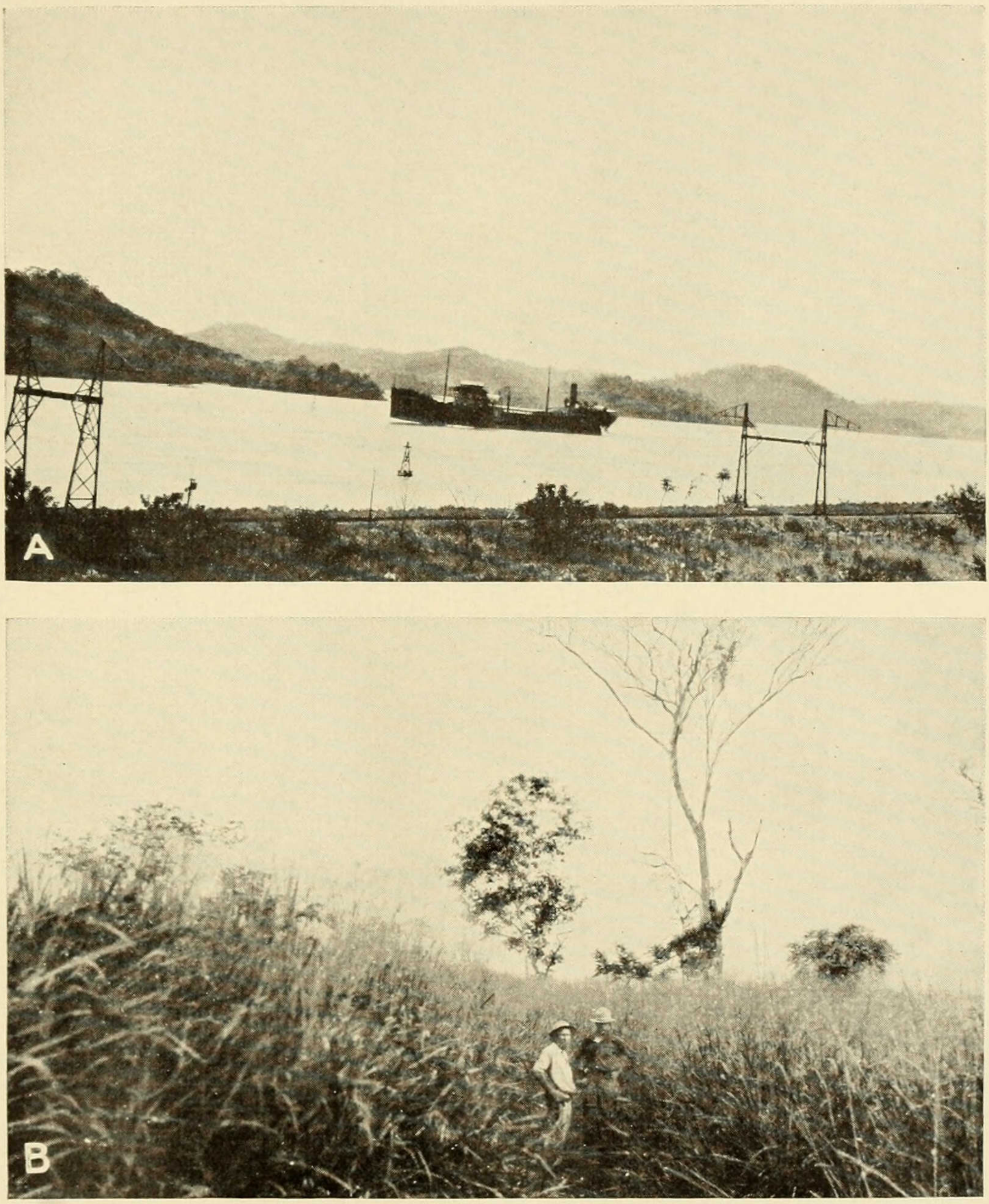
Hogs are raised successfully by the natives in parts of the Republic of Panama, but only a few are raised within the Canal Zone. Cassava, yams, velvet beans, corn (Indian corn or maize), sugar cane, bananas, and plantain are valuable feeds for both hogs and cattle.

Chickens, ducks, turkeys, and pigeons are commonly raised, maintaining themselves largely by foraging in the open country; but where there is available land, corn, rice, and peas should be grown for supplementary feed.

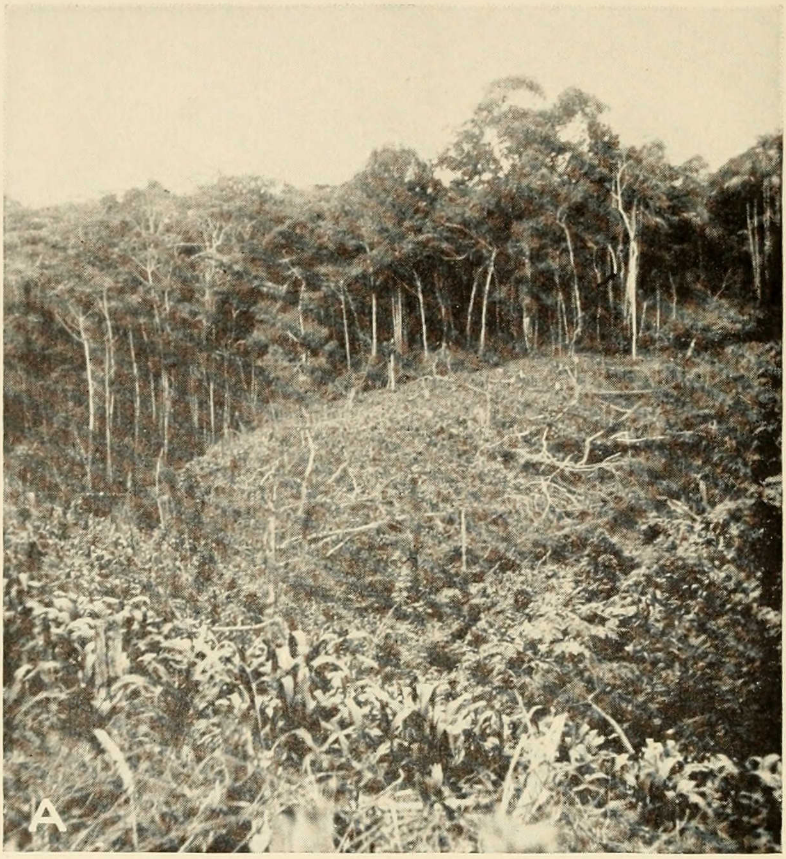
Bananas (*1*) are grown in many parts of the Canal Zone and near-by regions. Under the impetus of good prices there has recently been a very considerable increase in banana production both within the Canal Zone and in the Republic of Panama. This fruit gives best results on the deeper soils of the Atlantic side of the zone, where the moisture is sufficient to carry the crop through the dry season. In the southern part of the zone the fruit suffers severely through the drying out of the soil. The plants seldom die, but many of the leaves turn yellow and parch, and the plants cease to grow and produce little fruit, except on the more moist, deeper soil.

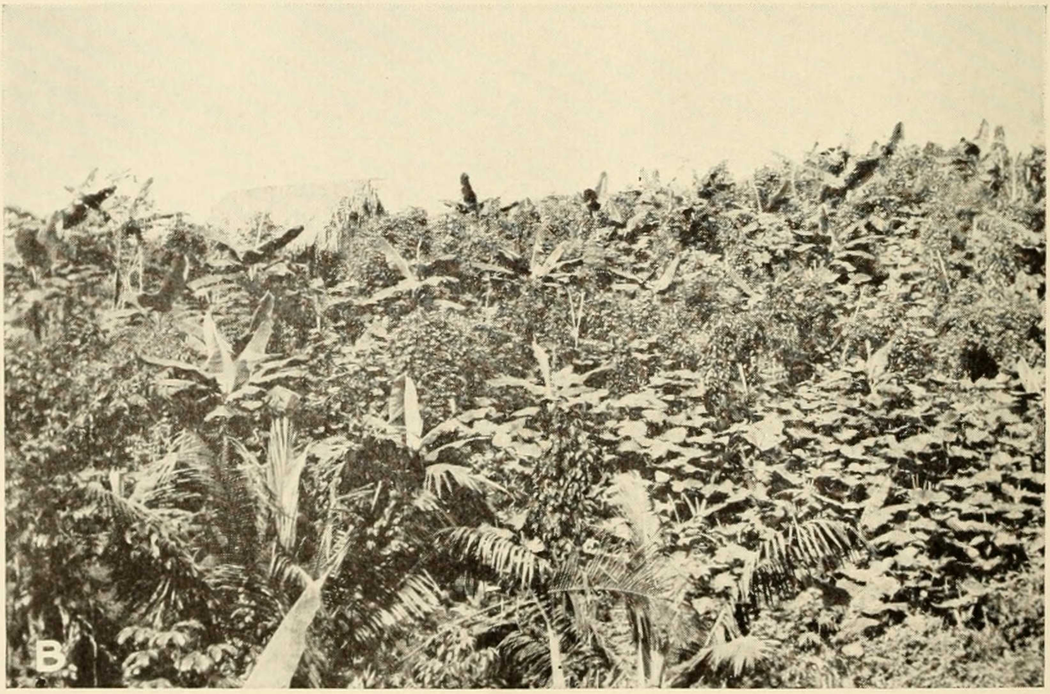
Selection of the proper soil is necessary for the successful growing of bananas. Best results are obtained on well-drained alluvial soils

[7] Beef cattle of the Canal Zone consist largely of Herefords crossed with native stock and the half and three-quarter grades again crossed with a grade Brahman, the purpose being to develop a type of desirable size and also immune from Texas fever. For dairy cattle, Holsteins have been introduced and crossed with native Colombian cows which are nearly immune to Texas fever and are good milk producers.



A.—Hills bordering an arm of Gatun Lake along Panama Canal
B.—Planted guinea grass on red clay (Gatun clay) near Cuipo





A.—Small clearing of a native (milpa) farmer
B.—Mixed plantings made by a milpa farmer

or on friable, deep, red clay upland soils, such as Frijoles clay and Gatun clay. Bananas do not thrive on soils with plastic, impervious clay subsoils, especially if the soils are wet and soggy. Wherever mottled bluish, rust-brown, and yellow stiff clay or hardpan layers are present within 2 or 3 feet of the surface, the plants do not, as a rule, produce good marketable fruit, and failures are common. Some conspicuous failures were observed on the west side of Chagres River above Gamboa in the Canal Zone. In selecting land for planting bananas, it has been the practice to examine the surface soil only. In the growing of bananas and most other crops, subsoil conditions are of as much or even more importance than conditions of the surface soil.

The Panama disease, produced by a Fusarium fungus, is so prevalent in this region that all banana growers expect their plantings to be attacked sooner or later but hope to obtain from three to five crops, or even more, before the plants are ruined. In some cases, bananas planted on neutral and slightly alkaline soils have been more resistant to this disease than those planted on acid soils. However, badly diseased plants on neutral and alkaline soils were seen in the Talamanca Valley of Costa Rica, and on the other hand some excellent fruit has been produced on acid soils.

Market gardening is carried on in small plots, chiefly by Chinese and negro farmers. The products are either sold in the local markets or are peddled from house to house. Small-sized tomatoes, a loose-leaf variety of lettuce, okra, small onions, cucumbers, sweet potatoes, peppers, cowpeas, chayotes (*10*), and a variety of tropical vegetables are grown in these little gardens. During the dry months, the gardens are either irrigated or watered by hand. Some vegetables which do not do well during the wet season produce fairly well in the dry season. Tomatoes, cabbage, carrots, and certain other vegetables are sometimes injured during periods of rainy weather. The dasheen (*20*) (tanier) flourishes, and the tropical yam is easily and widely grown.

Corn and rice are the most important subsistence crops grown by the natives. These are grown in patches on both upland and bottom-land soils, better yields being obtained on the latter. Some actual clearing of the land is done where rice is to be sown, but corn is planted by putting the seed into the ground with a sharpened stick, then chopping down the bushes and trees. Usually no cultivation is given corn or other crops by native farmers. The only farm implements are the machete, used in felling trees and slashing weeds, and a sharpened stick used to make a hole in the ground for planting seeds. In many places yams, sugar cane, cassava, papayas, chayotes, taniers or taros, and other crops are grown indiscriminately, jumbled together on the same small plot of ground.

Plots of ground near the houses of some of the natives are farmed for six or seven years, but as a rule fresh land is sought after two or three crops have been grown, the old land being considered undesirable for use. This is known as the milpa system of farming (*5*). (Pl. 2).

As the native farmer does not plow or otherwise cultivate the ground before planting a crop, very little erosion occurs during the brief period of its use. Although grass and weed invasion is undoubtedly one cause for a change of ground for planting, it has been noticed that the native farmer sometimes changes ground even where the grass growth has not become troublesome. As the yields decrease, probably on account of constant cropping without cultivation, fertilization, or rotation, new ground is sought. Second-growth vegetation is cleared and recleared repeatedly, and the land is successively cropped, indicating that the soil itself has not become exhausted but that aeration and oxidation through proper cultivation are necessary to maintain it in a productive condition. The growing of legumes, particularly velvet beans, jack beans or sword beans, and probably crotalaria, would aid in lengthening the period of soil productivity. However, as the native farmer has, in most cases, plenty of available land for his few wants, he is not easily induced to change his farming methods. He seems content to dwell in his palm-thatched shack made of poles, and to live in his primitive way.

Most of the common tropical fruits may be grown in this locality. Mangoes, avocados, plantains, papayas, oranges, pineapples, limes, breadfruit, coconuts, sapotes, Annonas, star apples, and other fruits are successfully grown; and litchis, mangosteens, and others are being tried experimentally. Some very sweet, juicy, thin-skinned oranges were growing on a strip of well-drained alluvial soil at Juan Mina, on Chagres River. The less common tropical fruits that thrive in the Canal Zone are the guava, Surinam cherry, soursop, granadilla, and tamarind. Almonds are grown principally as ornamental trees. A great variety of native fruits and vegetables are seen in the native beach markets to which boats from up and down the coast come, loaded with these products.

In the Canal Zone Plant Introduction Garden at Summit the introduction of new and improved varieties of fruit and the determination of the varieties of fruit, velvet beans, and other crops best suited to the soils, climate, and other conditions of the region is being actively carried on.

The velvet bean seems destined to play an important part in tropical agriculture as a soil improver and as a valuable source of livestock feed. Pigeon peas, certain varieties of cowpeas, and other legumes produce well, but the velvet bean seems very promising. The jack bean (*16*) (*Canavalia ensiformis*) has been successfully grown, and where it grows the sword bean (*C. gladiata*) no doubt will thrive.

The native farmers grow a little tobacco. The crude product, where examined, had a good flavor. Very little data regarding yields or quality of the crop, however, are available. The sandy, alluvial lands, it is believed, would produce a smoking tobacco of the Cuban cigar type, tobacco of this kind being grown on similar soils in the San Carlos River valley in northern Costa Rica.

Rubber trees are grown in many parts of the Canal Zone (*7*, *17*, *18*, *19*). Some wild Castilla trees were seen in the forest on the northwest side of Gatun Lake, near Cuipo, and nispero (balata) trees are reported as growing on the northeast side of Gatun Lake, in the vicinity of Porto Bello, along Gatuncillo and Pequeni Rivers, and elsewhere. A beautiful grove of large Castillas was seen on stony red clay soil (Arraiján clay) at Arraiján, just outside the Canal Zone. The trees are very large, tall, erect, and clean and produce latex freely. Trees of *Castilla panamensis* abound throughout the grounds of Ancon Hospital on the slope of Ancon Hill. Some of these are more than two feet in diameter and have a healthy appearance. Two *Hevea brasiliensis* trees are growing near the foot of Ancon Hill. These trees are believed to have been set out about 1907 and are now approximately 18 inches in diameter at breast height. Although the soil is well drained, it is not the most favorable soil for this tree, a fact evidenced by the growth of some of the main roots along the surface of the ground. Roots of trees seen in other places, where soil conditions are more favorable, are well below the surface of the soil. That soils suitable for the growing of rubber trees occur in the Canal Zone and contiguous territory is shown by the existence of trees of both the Castilla and Hevea species in several places. The land, however, except in some localities, is more hilly than might be desired for these trees, and many of the steeper slopes, if brought under cultivation, would require terracing to prevent erosion.

The most suitable land for Para (Hevea) rubber trees includes the smoother areas of the Frijoles and Gatun clays, which are the red clays in the northern part of the Canal Zone, and the less rugged phase of Arraiján clay, occurring in the southern part of the zone. The distribution of these soils is indicated on the accompanying reconnaissance soil map, and their characteristics are given later in this report under sections describing the different soil types. Alluvial soils having yellow, reddish, and brownish unmottled subsoils are suitable for rubber trees. Both the Hevea and Castilla species grow on such soils near Almirante, Republic of Panama.

Without irrigation or abundant watering during the dry seasons, vegetables commonly grown in the Canal Zone either cease to grow or make very slow growth, and in many places, particularly on the heavier soils on the Pacific side, completely dry up. Corn planted in the wet season usually matures by the latter part of February, sometimes earlier. Guinea grass ceases to grow during the dry season and, on the Pacific side of the zone, parches considerably. Rice ripens soon after the rains cease. Bananas wilt and stop growing, except on the deeper, more friable soils. Even cassava and yams make very little growth in March and April, and Pará grass parches except on moist lands. Certain tropical vegetables and fruits are only slightly retarded during the dry season. The mango, for instance, fruits most heavily at this time, and the chayote generally survives where the soil on which it is planted is not too shallow.

On the Atlantic side of the isthmus the more frequent showers which fall during the dry season help to maintain the moisture supply, and the foliage of forest trees is predominantly green. Some trees, such as ceibas and guayacan, shed their leaves all at once, but these trees are so scattered that their barrenness is not very noticeable in the prevailing greenness of the forest. The restrojo of the Atlantic side usually suffers somewhat on account of scant rainfall in the verano, or dry season, and vegetables are damaged in many localities. With the coming of the rainy season, the forest and pastures throughout the region turn green as if by magic, and from this time to the next dry season they flourish.

Land may be leased or bought outright from the Republic of Panama and concessions may be obtained through the proper Government officials of that country (*13*, *14*). Virgin land may be had for about $10 an acre. The annual tax rates on agricultural lands in the Republic of Panama in effect June, 1922, were as shown in Table 5.

TABLE 5.—*Annual tax rates on agricultural land in the Republic of Panama*

Kind of land	Rate per hectare (U. S. gold)	Equivalent rate per acre (U. S. gold)
Cultivated land	$0.144	$0.0583
Natural pasture	.096	.0348
Other than above	.06	.0243

Insect pests are numerous. The leaf-cutting ant (*Atta cephalotes*) often strips a fruit tree of its leaves within a day or two. These insects can be killed by pouring carbon bisulphide down each ground nest hole and closing the hole with dirt. Other remedies, such as pouring scalding water into the holes at intervals, driving in sulphur fumes with a bellows, and using sodium cyanide, calcium cyanide, and paradichlorobenzene, have been used with varying degrees of success. Termites, or wood ants, are destructive to woodwork of all kinds, except a few very hard woods. Scale insects and white flies are a menace to many kinds of trees, and coconut trees are damaged by beetles. Mosquitoes and other insects are at times a serious pest. Nematodes are in many places abundant in the soils, and tomatoes, eggplants, certain varieties of cowpeas, and some other plants are seriously affected by them. Insects and various plant diseases (*3*, *8*) are at present doing considerable damage to fruit trees, but could be controlled to some degree at least, by the use of fungicides and insecticides, especially if applied in the form of sprays.

Although the clays of the Panama Canal Zone are somewhat sticky at the surface when wet, it is claimed that they generally can be plowed soon after heavy rains without clodding or hardening. Erosion is not rapid, and plowed slopes are less susceptible to damage than are similar slopes in the United States. The nature of the clay, or of the colloids contained in the soil, undoubtedly has much to do with the unusual resistance to erosion. In some of the soils the colloids seem to exist in a flocculent condition conducive to friability and high absorptive or percolative capacity, and in other soils, the more erosive type, they seem to clog the pore space effectively. The less friable clays are more subject to erosion than those of greater permeability. Resistance to erosion may be due in some measure to the low content of sand and to the fact that these soils are never loosened by freezing and thawing.

At the plant-introduction garden at Summit a heavy yellow clay was being plowed fairly easily with a two-horse turning plow during the dry season in March, 1924. Some large clods were turned up, but after exposure to air and sun they were easily broken up by harrowing. This ease of cultivation may be due to the tendency of the plastic clay to shrink and crack.

Wherever the surface of the soil is sufficiently smooth and free of stone, plowing doubtless would be more practical than the milpa system of cropping. All furrows should be carried across the slopes at about the same level in order to minimize erosion. Level or nearly level cultivation should be practiced as much as possible, especially on the sloping areas. The use of the ridge method is sometimes advisable either for the prevention of erosion or for obtaining better drainage of the surface soil.

Chinese and other market gardeners rake, spade, or dig their plots into beds about 10 inches high and 2 or 3 feet wide across the top, with an interridge space of about 2 feet. (Pl. 3, A.) During the wet season the beds are usually made high and the tops slightly convex, whereas in the dry season they are lower and more nearly flat. The high, convex bed is very effective in providing rapid drainage in wet weather. By frequent hoeing and raking, the soil is kept well pulverized and free of weeds. Irrigation is practiced in the dry season, the plants being sprinkled two or three times a day from buckets carried either in the hand or suspended from a stick across the shoulders. Experience has shown that plants are not likely to be injured by scalding, even when sprinkled under the hot sun, except where they have suffered for a considerable time from lack of moisture or have been set out only a short time. The good results in these gardens attest the efficiency of the methods used.

Most crops would be benefited by the addition of commercial fertilizers and stable manure, as is proved by the results of the market gardeners of the Canal Zone. Legumes, particularly velvet beans, jack beans, and cowpeas, should be grown in rotation with crops such as corn, vegetables, and rice, and occasionally in fruit orchards.

The soils of this region are prevailingly neutral or alkaline, but here and there some acid land occurs. Bluefields clay usually is acid in reaction, and some of the other soils are acid in some localities. Applications of burned lime at the rate of about 1 ton to the acre, or twice this quantity in the form of ground limestone, may be made with good results on acid soils, especially in preparation for leguminous crops. The limestone soils of the Canal Zone probably would not be benefited by the addition of lime.

Although the soils in this region are not exceptionally poor in organic matter, they are sufficiently rich in clay to warrant an attempt to build up the humus supply as a means of maintaining good tilth. Not only do leaves decay at a very rapid rate in this region but within about two years following the felling of timber all the smaller trees and their branches have disappeared, leaving only the larger trunks. With the exception of certain extremely tough varieties, these also decay and crumble at a rapid rate. Ordinarily the harder trees are not cut, palms and certain hardwoods such as guayacan being left in pastures and banana clearings.

SOILS

In the Canal Zone and contiguous territory the soils are very largely of clay texture. Even the alluvial soils are mainly clays, but most of them have a higher silt content than the upland clays. Silty clay loam, clay loam, and fine sandy loam occur in patches here and there in the stream bottoms, and some strips of fine sand, the product of wave and tide action, occur in places on the Atlantic side of the zone, immediately along the beach. There are no loam soils, although some of the gravelly areas underlain by the soft rocks of the Gatun formation (*12*) approximate gravelly loam. Some strips of lower-slope land comprise exceptionally friable soils that are rich in organic matter.

The parent rocks, so far as could be determined, all contain little quartz, and on weathering the mineral components form clay which contains very little sand. There are no sandy upland soils. Ancon stony clay on Ancon Hill, being derived from rhyolite, contains a scarcely distinguishable quantity of very fine sand. The important parent rocks are of two kinds: (1) Sedimentary rocks, including limestone, claystone, sandstone (without or with only a little quartz sand), conglomerates, shales, and tuffs; and (2) igneous rocks, including basalt, andesite, granodiorite, diorite, metabreccia, and rhyolite. Some of the conglomerates, as the Bohio conglomerate, containing a very large proportion of igneous gravel, cobbles, and bowlders, give rise to an essentially igneous-rock soil.

The sedimentary rocks of the Gatun formation, which underlie much of the soil of the northern part of the Canal Zone and contiguous territory, weather into deep-red clay much like that formed from the weathering of the dark igneous rocks of the region. Arraiján clay, which is underlain by basalt, andesite, granodiorite, and a conglomerate, is composed of material originating largely from these rocks.

Frijoles clay resembles not only Gatun clay but also Arraiján clay. These three red clays comprise a group of soils which are closely related, at least in apparent physical properties, although Gatun clay has developed from materials originating directly from entirely different kinds of rocks. It is possible that the materials of the Gatun clay parent rock, the noncalcareous beds, were washed down from soils corresponding in origin to the Frijoles and Arraiján soils, deposited in water, and subsequently lifted up to form the present red clay. Such a process, it would seem, should have had some effect on the chemical composition of the soil, and it is possible that chemical analyses will reveal some differences. The separation made in the field was based on differences in the parent rock and the somewhat less friable character of Gatun clay. Arraiján clay was differentiated from Frijoles clay partly because of its greater susceptibility to desiccation, hardening, and cracking in the dry season, and on account of the lighter rainfall in the region where the former soil occurs.

The regional normal soil, derived from the three groups of rocks constituting the parent materials of Gatun, Frijoles, and Arraiján clays, consists of brick-red or deep-red clay, moderately friable when dry, and underlain at a depth varying from about 1 to 8 feet by soft, partly weathered, friable parent-rock material, red, yellow, whitish, and bluish gray in color. The depth to the underlying friable material is slight in Arraiján clay, in many places not more than 1 foot. This depth in the Frijoles soil varies from about 2 to 5 feet. In Gatun clay the depth is still greater, in many places 6 or 8 feet. The partly weathered rock underlying Frijoles clay and Arraiján clay shows less complete decay or, in other words, contains more rather hard rock fragments, and in many places large stone fragments. These occur in the subsoil and scattered over the surface on some of the higher and steeper areas. Neither hard nor semihard rock is associated with Gatun clay, but soft rock fragments occur at some depth in its mottled, partly decayed substratum material.

The limestone rocks seem to give rise to distinctly different soils. The Emperador limestone occurs in extensive areas along Chagres River and elsewhere in smaller patches. The surface soil, in areas where it has weathered deeply, consists of brown or dark-brown clay. This is underlain by a yellow, rather stiff clay subsoil. Depth to bedrock ranges from a few inches to 20 or 24 inches. Some of the very shallow soil, where erosion has about kept pace with rock decay, is somewhat granular, owing to the rock particles therein. Some areas consist of bare limestone rock without sufficient soil covering to support vegetation. The shallow limestone soils dry out quickly in the dry season, and the trees lose their foliage more completely than they do on other soils of the region. Actual desert conditions prevail on shallower areas of limestone land during the latter part of the dry season, but the duration of the rainless season is so brief that desert plants have not been able to establish themselves in successful competition with those of the humid-tropical jungle or rain-forest vegetation, which have eight or nine months, or even more, of heavy rainfall.

Catival clay is underlain by limestone of the Gatun formation. This soil is red at the surface and grades down to partly decayed bluish limestone. Whether the red clay is derived from the limestone or from calcareous beds superimposed on the limestone is not known, although the former seems the most likely origin.

The tuff beds weather to red or pale-red clay underlain by the incompletely decayed parent material of whitish, bluish, yellowish, and reddish color and of plastic consistence when wet. This variegated material, when moist, closely resembles the plastic material of the Susquehanna clay of the Atlantic and Gulf coastal plains region of the United States, but the latter is much more plastic, owing to a less flocculent state of the clay.

The clay soils of the Canal Zone, for the most part, are extremely friable in comparison with the heavy clay soils of the humid-temperate region of the United States. The unusual friability of the tropical clay soils is the result of extreme weathering in a humid-tropical climate. Long-continued leaching has taken out much of the silica and a considerable part of the bases, especially lime; but the iron and alumina have remained. Numerous analyses indicate that where a soil of nearly pure clay has a low ratio of silica to iron and alumina, it will be highly friable and porous, whereas those clays having a high ratio of silica to iron and alumina have opposite properties. This relation of chemical and physical properties of clay soils is not only of great value in connection with the classification of soils but has an important bearing on the value of clays for use as foundation material for hard-surfaced roads (*2*).

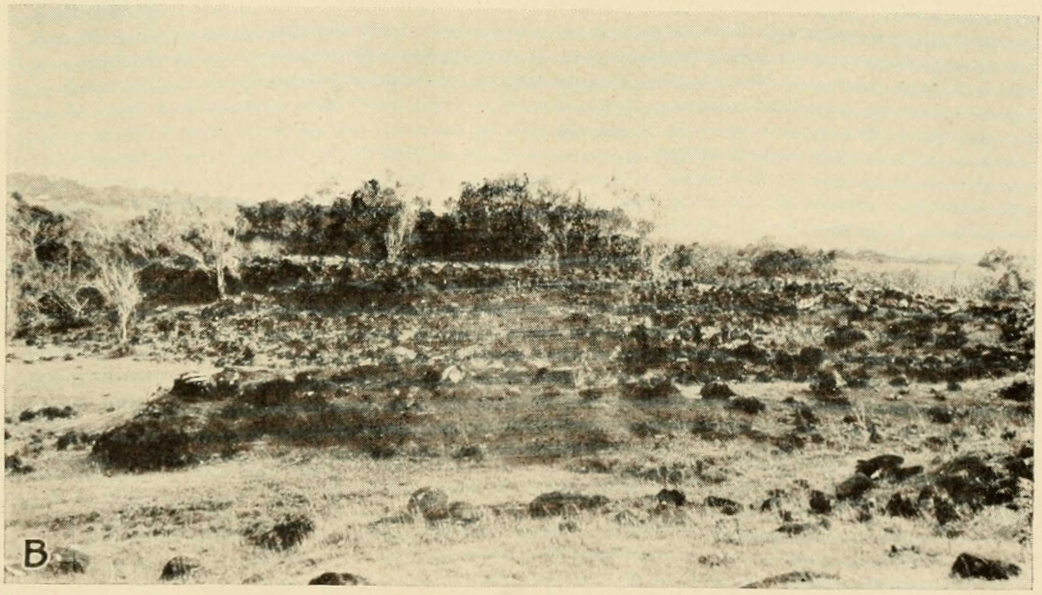
Some small areas of clay soil, such as San Pablo clay, contain a large quantity of plastic clay which holds water with such tenacity that plants have great difficulty in obtaining moisture from it. In the soil examined at the Canal Zone plant-introduction gardens at the height of the dry season, the surface 6-inch layer was thoroughly dried-out brownish clay, underlain by very sticky yellow clay. Orange trees were suffering from lack of moisture, even when the clay subsoil below a depth of 6 inches held much moisture. Clods formed by plowing crack, on drying, into small, hard pieces, indicating the plastic character of this clayey material. Nevertheless, these trees were suffering from lack of moisture, apparently because they were unable to obtain sufficient moisture from the dense subsoil to meet their needs. During the wet season this soil is very poorly drained, and the surface layer remains so saturated that the orange trees which suffered from lack of moisture in the dry season were practically drowned out during the rainy season.

The upland soils vary in reaction from faintly acid to alkaline. The poorly drained clay soils derived from tuffs and some of the imperfectly drained alluvium of flats and depressions where water stands for unusually long periods after rains are decidedly acid.

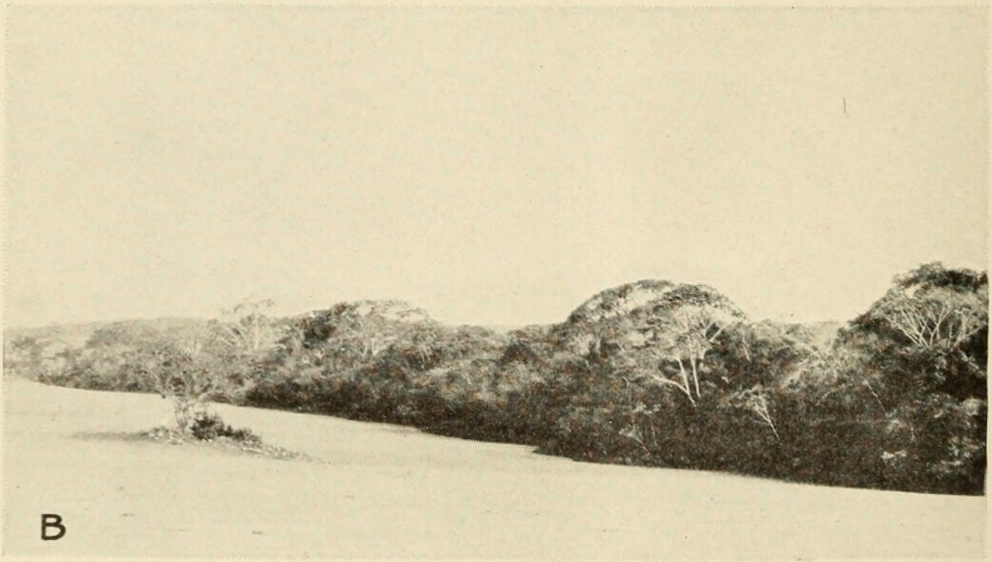
The rhyolite rock of Ancon Hill gives rise to a soil different from all other soils of the region, a cream-colored, slightly gritty clay which is underlain by either yellow or light-red friable clay containing fragments of soft, partly decomposed parent rock. This in turn overlies whitish or light-bluish soft, partly decomposed rock with reticulate fissures containing dark-brown and reddish ferruginous material. Exposures of the partly decayed rock in many places are stained dark rust brown or almost black with iron oxide. This soil is acid.

Savanna clay is distinctly different from other soils in this region. It is red, shallow clay underlain, at a depth of a few inches, by red clay containing some partly decayed parent rock, yellowish, reddish, and purplish in color. The partly decomposed rock is of a spongy or vesicular nature, and although not very hard, it is notably resistant to erosion wherever it is exposed. The parent rock is black or very dark colored igneous rock resembling basalt, which first weathers to a soft brownish-yellow material, then to a spongy material which, in exposures, is always fairly hard. (Pl. 3, B.) The red clay, the product of the weathering of the spongy material, is hard and cracked when dry and the grass growing on it dries up very soon after the rains cease.

Another kind of savanna land consists of brownish clay loam or clay, underlain at a slight depth by bluish-gray and rust-brown compact clay. This, in turn, is underlain by bluish, sticky, plastic, heavy clay, which is always moist. In the second layer a concentration of iron compounds seems to have formed a hardpan, and the sticky clay below constitutes a claypan. In such a soil, internal aeration, oxidation, and circulation of moisture are practically impossible. Only grasses and a few scattered very scrubby bushes, such as marañon, grow on this thin soil. It is too poor and changes too readily to an essentially desert condition just after the rains cease and to a supersaturated condition shortly after they begin to have any value except as pasture land.



A.—Vegetable garden in the Canal Zone, farmed by Chinese
B.—Weathered and unweathered parent-rock material beneath Savanna clay, near La Chorrera



A.—Large cuipos and other trees growing on Gatun clay
B.—Green jungle on alluvial soil

Very little fine material has been carried downward from the surface soil by percolating water, and no iron or other salts have been leached from the surface layers and precipitated in the lower layers, except in some of the savanna lands and in some of the alluvial soils. This concentration is evidenced along the banks of Chagres and Pequeni Rivers above Alhajuela. Blue and rust-brown colors appear in the subsoil in some of the flats and depressions of the stream bottoms where water stands for long periods and also here and there in similar situations of the uplands. This shows the effect of retarded aeration in the course of weathering, as opposed to oxidation. These colors in humid regions always indicate inadequate oxidation, except in a few geologic beds, and most of the soils characterized by such colors are of comparatively low productivity or are suited only to shallow-rooted plants.

Only small quantities of leaf mold have accumulated on the soils of the region, even in the densest tropical jungles. Scattered leaves are rather thick in places during the heavier defoliating period of the dry season, but when the rains come the leaves are softened, decomposed, and dissipated by the excessive moisture, molds, fungi, and the prevailingly active disintegrating and oxidizing agents. As a rule the upland consists of clay from the surface down, without any covering other than scattered leaves. Occasionally in a location which is protected from continuous sunshine by a heavy forest cover and in which an exceptionally moist condition exists by reason of seepage or other cause, a thin layer of brownish leaf mold, seldom more than one-half inch thick, occurs.

The soils contain a moderate supply of organic matter, ranging in the samples analyzed from 1.75 to 8.31 per cent. A few soils contain less than 3 per cent.

Table 6 gives the organic-matter content of some of the principal soils of the Canal Zone.

TABLE 6.—*Organic-matter content of some of the principal soils of the Canal Zone*

No.	Soil	Depth	Organic matter	No.	Soil	Depth	Organic matter
		Inches	*P. ct.*			*Inches*	*P. ct.*
22153	Beach sand	0–20	0.35	22168	Brown alluvial silty clay loam	0–36	5.00
22150	Savanna clay	0–36	1.75	22169	San Pablo clay	0–20	5.20
22148	Arraiján clay	2–36	2.26	22166	Black clay	0–8	5.70
22155	Brown alluvial silt loam	0–36	2.74	22162	Reddish-brown colluvial clay	0–8	7.95
22161	Gatun clay	0–8	3.06	22170	Black phase of San Pablo clay over limestone	0–4	8.30
22146	Ancon stony clay	0–6	3.14				
22149	Brown alluvium	0–36	3.44				
22159	Dark-brown colluvial clay	0–14	4.11				

The available mechanical analyses show the mechanical compositions listed in Table 7.

TABLE 7.—*Mechanical composition of soils of the Canal Zone and contiguous territory*

Sample	Sample No.	Depth	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
		Inches	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Arraiján clay	30514	0–3	0.3	0.3	0.6	0.3	32.0	66.5
Do	30515	3–30	.1	.1	.2	.2	17.3	82.0
Do	30516	30–40	.0	.1	.1	.3	8.5	91.0
Do	30517	40–52	.0	.1	.3	.2	13.4	86.0
Gatun clay	30530	0–1	.1	.1	.7	.8	17.9	80.4
Do	30531	1–60	.1	.1	.5	1.0	12.5	85.8
Santa Rosa clay	30522	0–6	.2	.2	.9	3.6	4.7	90.4
Do	30523	6–22	.2	.3	1.2	5.6	------	94.8
Do	30704	0–5	.4	.4	5.0	12.2	30.8	51.2
Do	30705	5–24	.1	.1	1.0	6.4	19.2	73.2
Savanna clay	31292	0–3	2.3	3.1	19.1	9.4	32.0	34.1
Do	31293	3–10	4.8	2.6	9.5	6.3	26.1	49.2
Do	31294	10–60	2.0	.9	1.7	2.2	18.7	73.1
Do	31332	0–4	.9	.4	.6	.4	27.1	70.6
Do	31333	4–11	.1	.0	.1	.1	17.4	82.2
Do	31334	11–20	.0	.1	.1	.4	15.1	84.4
Do	31335	20–40	.0	.0	.1	.3	11.2	88.3
Do	31336	40–70	.0	.0	.1	.2	10.2	89.4
Do	31337	70–100	.0	.0	.1	2.1	8.9	88.9
First product of weathering from parent rock of Savanna clay	31339	----------	.2	.1	.2	.5	55.6	43.1
Second product of weathering from parent rock of Savanna clay	31340	----------	.0	.0	.2	1.0	50.0	48.8
Bohio clay	30700	0–4	.0	.1	.1	3.8	29.9	66.1
Do	30701	4–18	.0	.0	.2	3.9	34.8	61.0
Do	30702	18–40	.0	.0	.3	3.2	33.7	62.7
Do	30703	40–60	.0	.0	.3	2.7	31.6	65.4
Alluvial bottom, southern half of Canal Zone	22157	Topsoil.	4.2	5.0	11.5	9.6	32.9	36.1
	22158	Subsoil.	1.6	1.5	4.9	10.6	35.0	46.0
Alluvial bottom, northern half of Canal Zone	22149	Topsoil.	.3	.2	3.7	18.5	30.3	47.0
Sand, back from beach	22153	---do-----	7.3	17.7	64.9	7.2	1.7	1.6
Alluvium, lower Chagres River (below Gatun Dam)	22155	---do-----	.2	.2	4.7	18.6	53.3	23.0

Table 8 shows the total content of phosphoric acid (P_2O_5), potash (K_2O), lime (CaO), and nitrogen (N) in several representative soils of the Canal Zone and near-by areas in the Republic of Panama.

TABLE 8.—*Total content of phosphoric acid, potash, lime, and nitrogen in important Canal Zone soils*

Soil	Depth	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Nitrogen (N)	Organic matter
	Ins.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Arraiján clay, one-eighth mile south of Arraiján, Republic of Panama	0–3	0.12	0.09	0.38	0.397	------
Do	3–30	.07	.14	Trace.	.093	------
Do	30–40	.02	.35	Trace.	.034	------
Do	40–50	.02	.70	Trace.	.023	------
Arraiján clay, 1½ miles north of Pedro Miguel, Canal Zone	Soil.	.12	.06	----------	.24	------
Santa Rosa clay, 1 mile east of the mouth of Rio Gatuncillo	0–6	.13	.32	1.98	.669	------
	6–22	.10	.28	1.93	.326	------
Parent rock, Santa Rosa clay, 1 mile east of Rio Gatuncillo	------	--------	--------	51.15 ($CaCO_3$=91.15)	--------	------
Gatun clay, near Gatun Dam, Canal Zone	Soil.	.35	.04	----------	.32	------
Alluvial clay, 1½ miles northwest from Empire, Canal Zone	---do--	.19	.10	----------	.38	------
Lower slope clay loam, ½ mile north of Pedro Miguel, Canal Zone	---do--	.17	.06	----------	.33	------
San Pablo clay	0–7	.08	.28	.62	--------	4.55
Do	7–48	Trace.	.32	2.41	--------	1.46

In Table 9 are shown the moisture equivalents and wilting points of several soils of the region. These values have been determined by the Briggs and Shantz method (*4*). The moisture-equivalent value gives a relative figure, under standard conditions, for the quantity of moisture held by different soils. Under these conditions a soil with a higher moisture equivalent should contain a larger quantity of available water for the plant, other conditions being similar. However, there may be moisture-interceptive layers, such as hardpan and impervious clay, or there may be an exceptional porosity, resulting in conditions that interfere with normal water movement to modify the comparison to some extent. These values, therefore, can not be taken too rigidly but must be considered in connection with the field conditions.

TABLE 9.—*Moisture equivalent and wilting points of some representative soils of the Canal Zone*

Sample No.	Type of soil	Depth	Moisture equivalent	Wilting point	Sample No.	Type of soil	Depth	Moisture equivalent	Wilting point
		Inches					*Inches*		
30514	Arraiján clay	0–3	38.0	20.3	31293	Savanna clay	3–10	30.5	16.6
30515	do	3–30	38.7	21.0	31332	do	0–4	37.4	20.3
30522	Santa Rosa clay	0–6	54.3	29.5	31333	do	4–11	39.3	21.4
30523	do	6–22	54.5	29.6	31336	do	40–70	46.0	25.0
30530	Gatun clay	0–1	48.2	26.9	31337	do	70–100	45.2	24.6
30531	do	1–60	43.5	23.6	31355	San Pablo clay	0–7	31.6	17.1
31292	Savanna clay	1–3	30.8	16.7	31356	do	7–48	35.7	19.4

Table 10 shows the moisture content of samples of soil material collected from the Pacific and Atlantic sides of the zone on February 27, 1924, and from the Pacific side on the following day.[8]

TABLE 10.—*Moisture loss from samples of soil material collected from the Atlantic and Pacific sides of the Canal Zone*

Location and soil	Character of vegetation	Depth	Character of soil material	Loss of moisture on air-drying
Atlantic side:		*Inches*		*Per ct.*
Clay, one-fourth mile south of Catival, Republic of Panama, collected Feb. 27, 1924.	Second growth (small trees and bushes).	0–2	Reddish-brown clay, moist	19.75
		2–30	Light-red, friable clay, moist	20.89
		30–50	Reddish-yellow fine sandy clay, moist.	22.79
Pacific side:				
Stony clay, from foot of Ancon Hill, Canal Zone, collected Feb. 28, 1924.	Grass and trees	0–4	Brown clay, dry and hard	6.51
		4–12	Light-red clay, moist	11.54
		12–30	Red and white plastic clay	14.32
		30–48	White, red, and yellow plastic clay.	17.86
Clay from savannas, near city of Panama, collected Feb. 27, 1924.	Dry grass	0–3	Brownish-red clay, dry, hard, and cracked.	4.43
		3–11	Red clay, hard, cloddy condition, slightly moist.	9.21
		11–30	Greenish and reddish partly decomposed parent rock material, moist.	16.39

[8] The samples were carefully sealed in glass bottles immediately upon collection and were later dried in the chemical laboratory of the board of health, Panama Canal, by exposure to air in shallow dishes protected from dust. They were weighed at intervals until reabsorption of water began with the change from the dry season to the wet season.

Although much of the rainfall runs off, considerable moisture is absorbed by the soils. Landslides occur frequently near excavations, as a result of saturated soil conditions, particularly where certain kinds of clay material or soil are underlain by soft, decomposed rock.

The more shallow and less absorptive soils in the southern half of the Canal Zone have a comparatively greater run-off than the soils in the northern half. Table 11 gives run-off data for Trinidad and Gatun Rivers, which have deep, forested clay soil prevailing in their drainage basins, and for Chagres River, which has a much larger proportion of shallow soil in the drainage basin, as well as some treeless savanna and rock-outcrop areas (*11*).

TABLE 11.—*Run-off of rainfall from the drainage basins of Trinidad, Gatun, and Chagres Rivers, 1908–1910* [1]

River	Run-off to the square mile (inches)			Total precipitation (inches)			Average percentage of rain water retained in 1908, 1909, and 1910
	1908	*1909*	*1910*	*1908*	*1909*	*1910*	*Per cent*
Trinidad	48.80	69.2	74.3	108.49	147.81	154.05	53.1
Gatun	62.05	104.8	119.9	129.72	153.39	179.73	38.0
Chagres	82.60	159.7	130.8	133.10	193.5	149.30	21.5

[1] Data supplied by the hydrographic office, Panama Canal.

In the following pages the several types of soil mapped are described in detail and their relationship to agriculture is discussed. Table 12 shows the acreage and proportionate extent of the several soils indicated on the soil map.

TABLE 12.—*Acreage and proportionate extent of the soils mapped in the Panama Canal Zone and contiguous territory*

Type of soil	Acres	Per cent	Type of soil	Acres	Per cent
Frijoles clay	37,376	13.1	Santa Rosa clay	24,192	5.1
Low and less broken areas	34,688		Low and less broken areas	3,968	
Gatun clay	62,848	20.5	Alhajuela clay	448	.1
Low and less broken areas	49,408		Savanna clay	10,240	1.9
Arraiján clay	134,080	34.3	Ancon stony clay	384	.1
San Jose phase	29,824		Catival clay	20,864	3.8
Low and less broken areas	23,232		Limestone hills	14,848	2.7
Bluefields clay	10,432	2.1	Marsh	15,168	2.8
Low and less broken areas	1,024		Alluvium	24,192	4.4
Paraiso clay	34,688	7.6	Fills and excavated areas	8,192	1.5
Low and less broken areas	7,104				
			Total	547,200	

FRIJOLES CLAY

Frijoles clay is a red clay upland soil which occurs extensively in the north-central part of the Canal Zone along the east shore of Gatun Lake and extends to the northeast and southwest beyond the boundaries of the zone. It consists of red or deep-red clay, slightly more brownish in the surface 2-inch layer of the soil than in the clay beneath. This material is friable when in a moderately moist condition. Below the thin surface layer the clay is brick red or almost blood red and in most places is not so friable. There is little or no change in the character of the clay to a depth varying from 20 to 60 inches, but below this depth soft or crumbly yellowish indurated clay occurs in many places, together with soft, bluish, partly decomposed rock, and in other places brownish or yellowish friable material is present. The latter material is locally spoken of as sand, but the grains are soft and easily crushed. The soft, partly decomposed parent-rock materials occur at a depth varying with the steepness of the slope. On a clifflike slope on the north side of Cooper Creek fragments of these materials occur on the surface and very abundantly at a slight depth. The crest of the ridge, however, is covered with deep-red clay to a considerable depth.

These rotten-rock materials contribute to the friability of the subsoil and can not be considered undesirable. It is only on the steeper slopes and in a few other localities that they are near enough to the surface to constitute a detrimental feature. Such slopes are generally too steep for profitable cultivation. The above descriptions are based on examinations made along Aojete and Cooper Creeks and in the Neuvo Limon section.

This soil has been formed through decomposition of the underlying rocks, principally of very hard nearly black and dark-green basic igneous rocks. At least part of this parent rock exists in an unaltered state, such as that outcropping along the bed of Cooper Creek above its entrance into Gatun Lake, but much of it consists of conglomerate in which dark, igneous gravel, pebbles, and bowlders predominate. MacDonald (*12*) indicates the region occupied by this soil as being underlain by the Bohio conglomerate and sandstone.

The indurated clay and sandstone associated with the parent igneous rock give rise in some places to an entirely different soil which has not been separated from Frijoles clay on the generalized soil map. Soil of this type occurs in patchy areas along the northwestern side of Aojete Bay. It consists of brown gravelly loam with a yellow, very friable distinctly granular clay or clay loam subsoil, containing an abundance of soft fragments of clay stone and the so-called sandstone but little or no quartz or other hard grains. Some soft bluish and grayish rock material and, in places, some rust-colored streaks and particles of soft whitish rock are present. This soil is very similar to the Lagarto clay loam (not mapped) of the Atlantic slope east of Cuipo on Gatun Lake.

Some hard gravel and cobbles were found in the bed and banks of Cooper Creek, but in the bed of upper Aojete Creek the gravel and cobbles were so decomposed that they could be cut easily with a knife or crushed with the fingers to the consistence of clay. Quartz and other hard particles are either absent or are exceedingly scarce.

Frijoles clay holds moisture well throughout the dry season and yet does not become saturated in the wet season, there being very little difference either in the moisture content or in the structural condition of the soil during the different seasons. When the soil was first examined (October 21, 1923) during the wetter part of the rainy season, it was very sticky at the immediate surface, but at a depth of 1 or 2 inches the consistence was moderately friable. It was examined again during the dry season (February 22, 1924), and was moist and friable at the surface in virgin timberland and equally moist and friable below a depth of 1 inch in unplowed banana clearings; the vegetation was green, with the exception of an occasional leafless flowering tree such as the guayacan (false lignum-vitae) and an occasional leafless Ceiba. The dry season had not caused any material change in the soil other than the drying out of a thin surface film in cleared places. No doubt some harmless shallow cracking takes place here and there in exposed situations during protracted dry spells. The soil is naturally well aerated, as is shown by its thoroughly oxidized condition, and tests showed it to vary in reaction from slightly acid to alkaline.

Areas of Frijoles clay vary in surface relief from undulating and gently rolling to hilly. There are gentle slopes, low, irregularly distributed, unsymmetrical hills, and winding ridges near Gatun Lake and in some of the less elevated stream valleys, as along the lower courses of Aojete and Cooper Creeks. On higher elevations the slopes are too steep for cultivation. Some of the hill land which is less than 250 feet above sea level could be used, without terracing, for tree culture.

The most important areas of Frijoles clay within the Canal Zone extend along the northeastern and southeastern sides of Gatun Lake and occupy some of the islands within the lake. This soil is very extensive south of the lake, outside the zone limits. Within the Canal Zone there are, according to reconnaissance estimates, 72,064 acres of this kind of land.

Erosion is nowhere very active. The trails show no gullying effects, and the waters of the streams are clear or only slightly milky at ordinary stages of high water and are only slightly turbid when the water is very high. Some bank erosion occurs in streams flowing through forested areas. More erosion would take place if the drainage basins were cleared and cultivated. Sheet erosion, too slow to be serious, takes place even in the jungles.

Most of this land is covered with a mixed virgin growth of trees and underbrush, the smaller trees growing on the shallow soil of steep slopes. Among the principal trees are bango, espavé, guayacan, nuna (or sand box), Santa Maria, cortezo, bastard mahogany (or caoba blanco), zapotillo (or leatherwood), guava, and many palms, such as caña verde, caña blanco, caña negro, and caña amargo. Nispero is said to be indigenous to this region, but most of it within the limits of the Canal Zone has already been cut by rubber gatherers.

Frijoles clay is one of the best upland soils of the Canal Zone and contiguous territory. It is much like Arraiján clay but does not dry out to so great an extent. It very closely resembles Gatun clay but is slightly more productive and is less susceptible to baking in the dry season. This is not only a good soil for the production of corn, yams, plantains, papayas, oranges, avocados, mangoes, velvet beans, grass, sorghum, vegetables, and other crops adapted to the climate, but it is one of the best upland soils for bananas.

This soil is deep, well drained, and friable; it retains moisture well, resists erosion, is well aerated and oxidized, and is generally not very acid. All of these conditions are favorable for both Hevea and Castilla rubber trees. The soil also resembles rather closely the Cukra clay which occurs in eastern Nicaragua where good Hevea rubber trees were seen. Frijoles clay, because of its occurrence on more hilly locations where the soils are thinner, is slightly less suited to these trees. On the soil map the low and less broken areas of this soil have been indicated by crosslines. The land suitable for growing rubber trees occurs very largely in these regions.

GATUN CLAY

Gatun clay is a red clay soil which predominates in the northwestern part of the Canal Zone, extends southward along the west side of Gatun Lake beyond the zone boundaries, and occurs on some of the islands in the lake. (Fig. 2.)

Gatun clay is a uniformly red, moderately friable clay, with about a 1-inch layer of brownish-red friable clay at the surface. Not much change takes place in the subsoil to a depth ranging from about 20

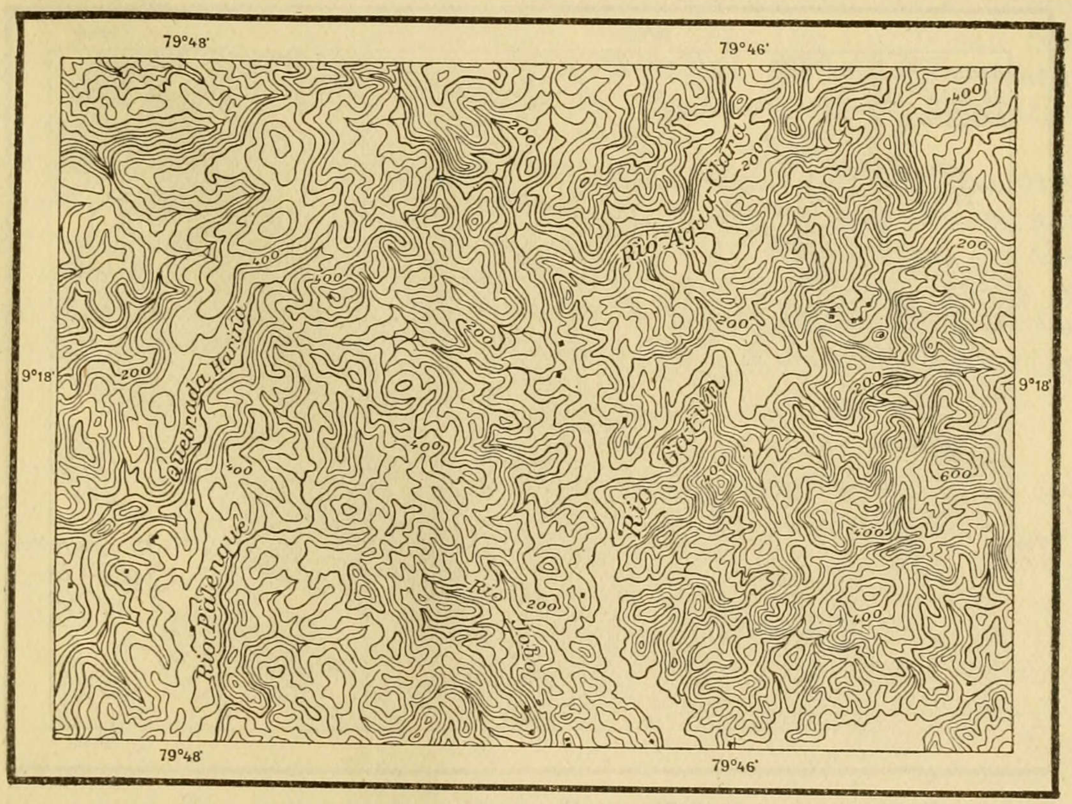


FIG. 2.—Topography of the country north of the Gatun arm of Gatun Lake. Here the principal type of soil is Gatun clay

inches to 6 feet, but beneath this depth soft, decomposed parent material consisting of rotton rock and clay occurs. Most of this material is red, whitish, and yellowish in color, and in many places it contains some very soft fragments of the partly decayed parent rock. This soil is much like Frijoles clay in color and other physical properties, but it dries out more readily.

Near Nuevo Limon the soil varies slightly, consisting of brownish-red clay underlain by red clay which is friable when moist. At a depth varying from 4 to 6 inches, this is underlain by brighter-red, moist, friable clay which grades, at a depth of 2 or 3 feet, to red, whitish, or cream-colored and yellow friable clay which prevails to a depth of more than 5 feet. The material of the mottled substratum is slightly plastic when wet but crumbles on drying. No sand grains or other hard particles are present.

Gatun clay is composed of materials weathered from the underlying sedimentary rocks which have been geologically grouped under the designation of the Gatun formation.

Gatun clay conserves moisture for continued growth of vegetation throughout the dry season. The surface cracks and bakes slightly, but there is always sufficient moisture at a slight depth. Drainage is good, and no indications of serious erosion are evident.

An exceedingly hilly area of this soil is near Gatun, but most of the hills within the limits of the Canal Zone are low. (Fig. 3.) Many of the peaks are conical, the highest, on Zorra Island, being about 320 feet above sea level. In the Sierra Santa Rita east of the northern arms of Gatun Lake, where the country is extraordinarily broken and hilly, elevations of more than 800 feet are attained within 2 miles of the lake shore. There are very few continuous parallel

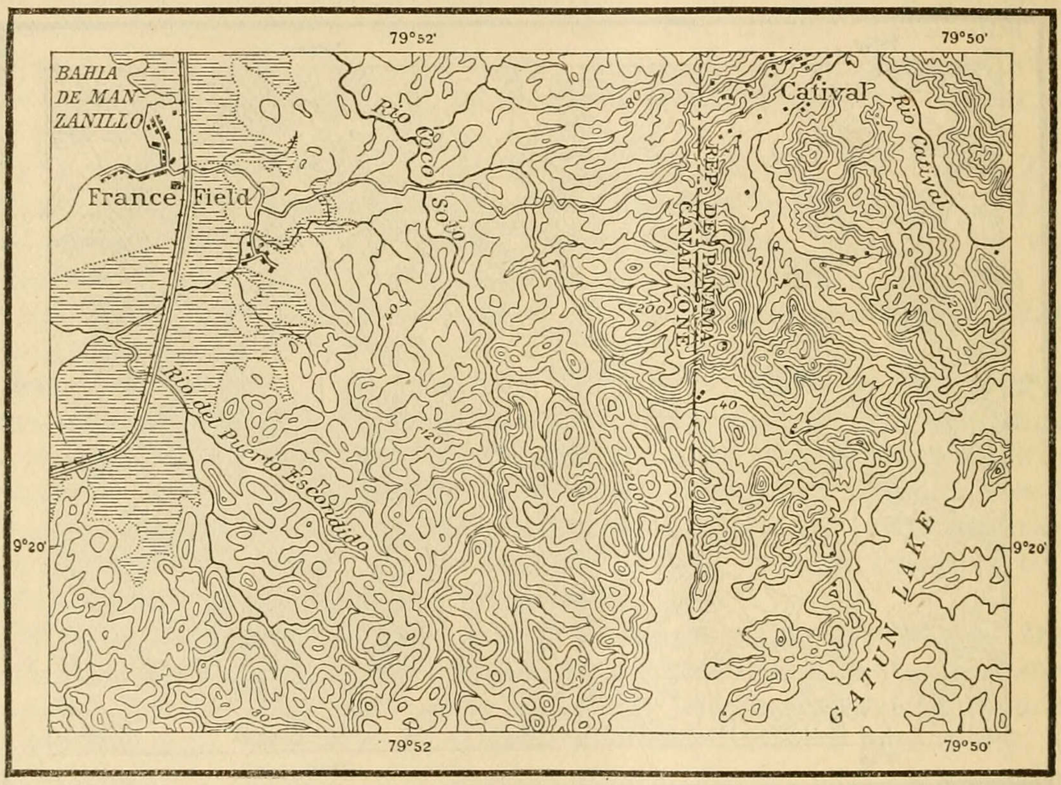


FIG. 3.—Topography east of Mount Hope. Here the principal soils are low and less broken areas of Gatun clay and areas of Catival clay

ridges in this locality. The prevailing ridges are irregular in direction and elevation, with subordinate projections. In many places the slopes are very steep. More nearly parallel ridges are west of Gatun, where elevations of 700 or more feet occur within a mile of the western end of Gatun Dam. Farther south, in the vicinity of Escobal and southwestward beyond Cuipo, a strip of comparatively low land fronts the lake. In places, it is a mile or more in width and is undulating or rolling, rather than hilly. This area and many of the low hills in the country about Gatun could be fairly easily cultivated. Some of the less favorably situated areas are suitable for tree planting.

Outside of the Canal Zone, in the hill country about 2 miles northwest of Cuipo, a clay loam soil, which on the soil map is included with Gatun clay, was found on the slopes near the headwaters of

Rio Iguana. This soil consists of brown or dark-brown friable clay loam, rich in vegetable matter to a depth of about 4 inches. The surface soil contains soft fragments of partly decomposed yellowish and slate-colored clay stone which varies in reaction from slightly acid to neutral. Below this and continuing to a depth of 8 inches is yellow, very friable gravelly clay loam material which contains angular, soft clay stone fragments. From this layer to a depth of 24 inches occurs the yellow, soft, partly decomposed parent rock.

This soil absorbs moisture readily, and because of this feature it may prove resistant to erosion when cultivated. There is a good virgin growth of trees and a light undergrowth. Espavé, caña verde, jira palm, caranao hedionda (which exudes a gray gum with an odor similar to that of balsam copaiba), bato, and many other trees are present, along with lianas, aroids, and ferns. Some forest Castilla rubber trees were seen. Both this species and Hevea probably would do well on the smoother areas near the Caribbean Sea. Apparently more higuerons and cuipos (pl. 4, A) grow on Gatun clay than on Frijoles clay, but otherwise the kind of vegetation differs very little.

Within the Canal Zone most of the virgin forest has been removed from this soil, and the land is used for pastures, banana groves, and other purposes. Some young Hevea rubber trees planted on this soil near Nuevo Limon in the fall of 1923 were growing nicely on February 22, 1924. In the smoother situations this soil would probably give about the same results with crops and trees as Frijoles clay.

ARRAIJÁN CLAY

Arraiján clay is the best upland soil in the southern part of the Canal Zone and in the region southwest of Panama outside of the zone. It consists of reddish-brown or brownish-red clay, slightly crumbly or friable when moderately moist, underlain by red clay of slightly friable or moderately stiff consistence, depending on the amount of moisture present. This continues to a depth ranging from 20 to 50 inches, where it is underlain by partly decomposed friable, yellowish, purplish, and whitish parent-rock material. The presence of this soft weathered rock material makes the subsoil more friable and more easily penetrated by the roots of trees than it otherwise would be.

Arraiján clay is a residual soil formed through weathering of underlying rocks, principally dark-colored, very tough, igneous rocks of a dioritic, andesitic, and basaltic nature. The geologists have described the basal rocks in this region as: (1) Igneous rocks, consisting of granodiorite, metabreccia, Las Cascadas agglomerate, Bas Obispo breccia, old tuffs, and small areas of other formations, and (2) basalt and andesite. It is not necessary to discuss these rocks here further than to point out that variations in them account for some of the minor soil variations existing from place to place.

A shallow phase of Arraiján clay occupies many of the steeper slopes. An examination near Las Cascadas shows the following characteristics, doubtless common to many of these shallow areas. From the surface to a depth of 2 inches is light-brown or slightly reddish brown clay which is moderately friable when moist. Below this, to a depth of about 26 inches, is light-red, moderately stiff clay containing considerable bluish, partly decomposed rock material having a pH value of 6 or 6.5. Between depths of about 26 and 40 inches a little reddish-yellow clay is mixed with this decomposed rock material, and below a depth of about 40 inches tough, igneous rock resembling diorite is present. On some of the hilltops and steeper slopes used for pasture, the soil material has been eroded to within a few inches of bedrock, leaving the remaining soil very gravelly and containing partly decomposed fragments of the parent rock.

In the low, hilly pasture section north of the Panama Railroad between Gamboa and Darien, patches of brown clay occur in association with the shallow phase of Arraiján clay, and these have been included with Arraiján clay in mapping. A sample of this soil (Gamboa clay) collected March 1, 1924, 1 mile northeast of Darien, shows the following characteristics: From the surface to a depth of 4 inches there is brown clay, finely mottled with yellowish brown, which cracks into clods of varying size when dry. This is underlain, to a depth of about 12 inches, by reddish-brown, moderately stiff clay which contains some bluish and yellowish, friable, partly disintegrated parent rock. Beneath this and continuing to a depth of about 30 inches was partly disintegrated friable or loose parent-rock material of bluish, dark-brown, and rust-brown color, containing some whitish specks. The brown material is very friable and apparently consists of iron hydrates. Similar shallow soil prevails in several other parts of the zone.

Both the brown and red soils of this locality contain soft, partly decayed rock material and in many places contain very little clay to a depth of 2 feet. The color of this material is usually yellow, creamy, or reddish brown. The red or Arraiján clay is in most places thicker than the brown soil (Gamboa clay), being 5 or more feet thick on some of the flatter areas.

The thicker soil is shown on the soil map as low and less broken areas. The shallow phases occur on the steeper slopes, sharper ridge crests, and hilltops, as well as on smooth slopes and the broader-backed ridges. The soil of the smoother areas is more valuable, as it does not erode so rapidly. That destructive washing would follow cultivation of unterraced slopes of this shallow soil is indicated by both incipient and fairly deep gullies that have already appeared in pastures near Darien, where the land has been cleared only a few years and has never been plowed. Erosion would undoubtedly be rapid and exceedingly disastrous once the gullies had cut through the stiffer surface layer into the soft material beneath.

Arraiján clay is the most extensive soil in the Canal Zone and contiguous territory. It extends from the Pacific Ocean to the headwaters of Cooper Creek, north of Frijoles, and in a southwesterly direction beyond the Canal Zone boundary to the savanna country near La Chorrera.

A large area of soil to the west and south of Arraiján is shown on the soil map as the San José phase of Arraiján clay. This soil is in most places deeper and more gently sloping than Arraiján clay. The extent of this phase of soil is roughly outlined, and areas include small patches of both the shallow phase and the typical steeply sloping land. The deeper, more gently sloping land prevails along the Empire-La Chorrera road. These smoother areas of deep soil are naturally most favorable for cultivation.

Mapped areas of Arraiján clay include patches of other soils. On the lower slopes of hills the soil in some places is deeper, more friable, has a higher content of vegetable matter, and represents accumulated material washed from adjacent slopes. This soil conserves moisture better than either the shallow or the unmodified, deep-red clay soil, but it is of such patchy and irregular occurrence that it is of little importance. In many places there is none of this deeper, better soil, even on comparatively gentle slopes. The deeper soil is very well suited to market gardening and is utilized to some extent for growing vegetables.

Patches of an imperfectly drained clay with a very plastic, impervious subsoil occur here and there within the areas of Arraiján clay outlined on the soil map. The soil in these patches usually consists of or is similar to the stiff Bluefields clay. A very small area on a bench about 1 mile northeast of Darien is characteristic of this soil. This is red clay with faint brownish or bluish mottles, which grades downward, at a depth of 5 or 6 inches, to very plastic clay which is intensely mottled with bluish gray, red, and yellow. Below a depth of 4 inches the material is almost permanently moist.

Some areas of Arraiján clay are rather stony, though the stones do not greatly decrease the value of the land; indeed, they rather add to its value if it is not to be cultivated, since they catch particles of soil and organic matter washed from higher areas and thus help to maintain the fertility.

The higher hills and ridge slopes can best be used for pasturing livestock and for forestry, since tillage operations are difficult and terracing is expensive and not always effective against erosion.

The surface of typical Arraiján clay is very hilly and ridgy. There is no level land and few gently sloping areas except in the southernmost region shown on the soil map. Saddles and narrow ridges having the appearance of railroad fills locally rise high above the depressions on both sides and have very steep slopes and narrow crests. Arraiján clay, including its stony phase, occurs on the highest elevations in the Canal Zone.

Arraiján clay supports a lighter cover of vegetation than the other red clay soils of the zone. The soil bakes and cracks deeper in the dry season and plants wither more completely than on other soils. Vegetation suffers more on the shallow phase of Arraiján clay than on the deeper soil. Virgin forest on the San José phase of this soil along the Empire-La Chorrera Road was conspicuously more green than is usual on this soil elsewhere. Guinea-grass pastures on Arraiján clay become severely parched in March, and most crops suffer from lack of moisture, especially on the shallower soil. The soil dries and cracks to a depth varying from 3 to 6 inches and breaks into clods. With shallow cultivation in the dry season, there probably would be better conservation of the soil moisture.

The usual virgin forest includes trees of somewhat smaller size than those which grow on either Frijoles clay or Gatun clay, and there are more ceibas and cuipos than on the more northerly red clays of the zone.

Arraiján clay is an excellent soil for the production of guinea grass. Much of this land within the zone limits has been planted to this crop and is used for pasturing the cattle of the supply department of the Panama Canal. Most of the tropical fruits of the region grow on this soil, some very successfully. Mangoes and oranges produce good crops, and bananas succeed fairly well in the rainy season on the deeper soil, especially along the lower slopes, though they suffer in the dry season. All the vegetables common to the region can be grown, but most of these have a tendency to die in the dry season, unless continuously watered (*3*).

The most promising large area of Arraiján clay suitable for growing Hevea rubber trees is that section of the San José phase which occurs around San José. Here the soil is deeper, the contour of the land is more favorable, and comparatively better moisture conditions obtain through the dry season. The typical soil would probably be equally favorable for rubber plantations where the surface features are equally favorable; but the shallower soil is less promising because of its greater tendency to wash, its prevailingly hilly and steep-sloped surfaces, and its more pronounced inclination to droughtiness.

Some of the best Castilla rubber trees seen were those on a stony area of the shallow soil at Arraiján. Here the stony red clay is underlain, at a depth varying from 12 to 18 inches, by soft, partly decayed rock material. The stones on the surface help to retain particles of soil and fragments of decaying vegetable matter washed from higher areas, and the soft decayed rock material of the subsoil is easily penetrated by roots.

BLUEFIELDS CLAY

Bluefields clay is one of the less important soils in the Canal Zone. The largest area is in the southeastern part of the zone between the city of Panama and Pedro Miguel. A smaller area is at Summit, and other small patches occur throughout the southern part of the region.

This soil lacks uniformity in texture, color, and structure. At the Canal Zone Plant-Introduction Gardens at Summit, a sample taken from a level area showed, at the surface and to a depth of about 2 inches, brown clay, moist and moderately friable and faintly mottled with dark bluish gray and rust brown. Below this, to a depth of 4 inches, was plastic clay mottled with pale yellow and yellowish brown. At the time of the survey this clay was wet and sticky and had a pH value of 5. Underlying this, to a depth of 30 or more inches, was light bluish-gray, heavy, plastic clay mottled with red and purple. This layer hindered effective underdrainage.

West of the plant-introduction gardens, at a higher level, soil more friable in the lower part of the subsoil was found. A sample of this showed a brown clay surface layer, 3 inches thick, faintly mottled with bluish and yellowish brown. It was moist, moderately friable, and had a pH value of 6.5. Some pinkish and light-colored fragments of flinty or cherty rock were scattered over the surface. Between depths of 3 and 10 inches, reddish-brown, moist, moderately friable clay, which becomes stiffer with increasing depth, occurred. Below this, to a depth of about 20 inches, mottled light-red and yellow plastic heavy clay was found. This graded downward to friable clay mottled with light red, yellow, and pale yellow, in which the friability is the result of the presence of incompletely decomposed rock material. Below a depth of 50 inches is some black, friable material, probably of concretionary origin.

In the large area of this soil in the vicinity of Corozal and Pedro Miguel there are some hills, the lower ones showing distinct stratification in the substratum of pinkish, light-red, yellowish, whitish, and mottled clayey materials, with some interbedded yellowish rock. This hilly area, particularly on some of the higher elevations, includes some red soil which resembles Paraiso clay. The lighter-colored soil which occurs in places between Summit and Panama seems to be inferior in quality to that at the plant-introduction gardens.

Some of the soil of the low, undulating, and gently rolling section about 2 miles west of Pedro Miguel on the Arraiján trail was included in mapped areas of Bluefields clay. This is brown or very dark brown clay with a yellowish or reddish plastic clay subsoil, mottled in places with bluish and pale yellow.

The lower slope of the hills on the west side of Chagres River between Gamboa and Santa Rosa is made up of dark-brown clay which clods on drying. In this area grayish-brown plastic clay occurs at a depth of 3 or 4 inches and grades, at a depth varying from 6 to 10 inches, to gray or pale-yellow, plastic clay, which shows a little red mottling. Large and small fragments of dark, tough igneous rock, consisting in part of feldspar porphyry, are abundant over the surface and in the topsoil and subsoil. This soil does not conform, either in color or origin, to the typical Bluefields clay of the Canal Zone. There is less bluish-gray and red color present, and the parent rock is igneous.[9] However, it is an equally unfavorable soil, owing to the extreme imperviousness of its subsoil.

Typical Bluefields clay is derived from rocks which have been geologically termed "Panama tuffs," with some local modification by overwash from various soils on adjacent slopes. The Panama tuffs are described as occurring extensively from Miraflores to Panama and as being well bedded, light colored, and somewhat acid in composition. Some of the hill areas of this formation are covered with very thin soil, the geologic beds showing little change from near the surface down through 30 or 40 feet of stratified material such as that seen in the railroad cut between Panama and Corozal. Erosion probably has kept close pace with rock weathering in such places.

The surface of the better, more brownish phase of this soil, such as that at the plant-introduction gardens, is usually nearly flat, with but slight undulation. The surface relief of the inferior, lighter-colored soil ranges from flat to hillocky.

The brown soil at Summit is more productive than the lighter-colored soil nearer Panama, but Bluefields clay generally is not a good agricultural soil, particularly for rubber, citrus, and other trees that have deep taproots. Seedlings and young nursery trees may obtain a favorable start in this soil. It is best suited to grass, Napier and Rhodes grasses giving very good results. At the plant-introduction gardens, orange trees have made slow and unsatis-

[9] The Bluefields clay at Bluefields, Nicaragua, is derived, to a considerable extent, from igneous rock; but it seems more like that phase of the Canal Zone soil which is underlain by sedimentary soils than this phase of the Gamboa locality, with its crystalline parent rock.

factory growth. Grasses, some varieties of velvet beans, Groit and Victor cowpeas, and the Canavala bean were apparently thriving at this station at the time soil samples were taken. The running velvet bean is considered the best soil improver; other varieties suffer during the dry season. Pigeon peas produce well, but as the bushes are too coarse to plow under, much of their humus-supplying value is lost.

Bluefields clay, according to tests at the plant-introduction gardens, can be plowed very soon after rains without exhibiting undue stickiness and without much subsequent clodding. The undisturbed soil dries out and cracks into rather hard clods by the middle of February or the first of March, and approximately 60 per cent of the forest trees on the upper hill slopes are leafless by this time. Clods turned up in plowing crack in the sun and form a fine, fragmental seed bed.

PARAISO CLAY

Paraiso clay is a reddish-brown soil, occurring in rather large areas in the central part and on the Pacific side of the Canal Zone. The surface soil, to a depth of about 10 inches, varies from brown to reddish-brown clay which contains considerable humus. Below this, to a depth of about 32 inches, there is mottled red and yellow clay which is plastic when wet and which at a greater depth is splotched with light bluish gray and with red, friable material, apparently an iron compound. This, with a slight change in the mottling, continues to a depth of 52 inches, where yellow and light bluish-gray clay containing some soft, yellow limonite concretions and friable segregated limonite, exists. The surface soil is slightly acid, and the material beneath is nearly neutral.

Paraiso clay is not uniform, varying particularly in the depth to the underlying rock. Its subsoil is not so impervious as that of Bluefields clay, and oxidation may take place more rapidly, thus developing a good red clay—the normal well-drained soil derived from igneous rocks in this region—more quickly than does the slightly oxidized Bluefields clay. The oxidation process in Paraiso clay seems to be advancing rapidly at the present time, and much deeper red soil occurs on the crests of the low ridges than is found at their bases. The parent material has been classified geologically as Caimito sandstone and tuffs.

The higher-lying, better-drained, and better-oxidized, deep-red soil is fairly good for agricultural purposes, but that having light-colored, unoxidized clay within 2 feet of the surface can not be considered as of much value for deep-rooted crops. Most of this kind of land is thought to be fairly good for farming where the slopes are not too steep. The steep areas may best be used for forestry and pasture land.

SANTA ROSA CLAY

Santa Rosa clay is extensive north of Gamboa on both sides of Chagres River as far as its confluence with Rio Pequeni and probably also above this point. A large part of the area is outside of the Canal Zone. It is interspersed somewhat on the west side by areas of red clay derived from igneous rocks and by savanna land whose soils are also derived from igneous rocks.

The surface soil is light-brown or brown clay underlain, at a depth varying from 3 to 6 inches, by yellow clay which is rather plastic when wet and hard when dry. This in turn is underlain, at a depth ranging from about 5 to 22 inches, by the parent limestone rock, a whitish, light-brownish, or yellowish limestone which, in places, contains an abundance of marine shells. Partly decayed fragments of the limestone give some friability to the yellow subsoil. Shallow soil of this kind is abundant along Chagres River near Alhajuela and consists of friable, partly decomposed, and fragmental limestone intermingled with vegetable matter and underlain, at a depth ranging from 1 to 10 inches, by the hard parent rock. On the west side of the river there is an area covering 8 or 10 acres where the limestone crops out, too little soil material being present to support vegetation other than an occasional tuft of grass or a stunted bush. In many small areas the immediate surface soil is almost black.

The limestone (Emperador limestone) occurs as cliffs with overhanging ledges more than 40 feet high in places along Chagres River above Alhajuela. Short stalactites hang from these ledges, and ferns grow in small niches and protrude from crevices moist with seepage water. In places the rock is slabby, and on the slope of Rio Azote Caballo, upstream from Alhajuela, soft, sandy, noncalcareous, weathered rock and a white rock of light weight, apparently volcanic tuff, are associated with the limestone. At the time of the survey this latter rock was being burned for lime on Gatun Arm near the headwaters of Aojete Creek.

Santa Rosa clay occurs on hilly and ridgy surfaces. In the section along Rio Gatuncillo are many steep slopes adjacent to small drainage ways, but much of the land is characterized by slopes of favorable gradient. Smaller ridges extend down and away from the major ridges, their steeper slopes facing the smaller stream between these latter ridges.

This land is less broken than most of the other important upland soils of the Canal Zone and contiguous territory, with the exception of the savanna lands. The principal drawback to agricultural use is the shallowness of the soil and its tendency to become very dry, so that plants and grasses dry up and trees lose their leaves early in the dry season. The soil is fertile and the deeper phase supports a fairly heavy growth of forest, though the trees are smaller than on Frijoles clay or Gatun clay. The restrojo is in most places rank and dense and includes much wild plantain and coarse grasses.

The shallow Santa Rosa clay is valuable only for forestry and grazing. The deeper soil produces abundantly if the crops are planted in time to complete their growth before the dry season sets in. Corn, rice, and fruits do well. The soil is too droughty for best results with bananas, although some are grown with fair success on the deeper soil. This soil can hardly be considered favorable to Hevea rubber trees, except perhaps where the limestone is at least 15 inches below the surface. The fact that only shallow-rooted trees were seen growing here is a strong indication that those of the taproot variety will not find such a shallow soil suitable or the severe drying season endurable. On a few cleared areas of the deeper soil papayas were seen growing well.

ALHAJUELA CLAY

Alhajuela clay is a limestone soil, but it is deeper and very different from Santa Rosa clay. It consists of a surface layer, 1 or 2 inches thick, of very dark brown clay, which is sticky and almost black when wet, coarsely crumbly when dry, and rich in organic matter. The dark surface soil is underlain by very dark brown clay, stiff when dry and apparently containing considerable organic matter. The dark clay continues to a depth varying from 18 to 24 inches, where it grades downward to slightly moist (in the late dry season), brown, stiff clay, which has a buff or faint-reddish cast. Dry, hard lumps of this clay disintegrate in water much more rapidly than lumps of the overlying material. The brown layer has a pH value varying from 5.5 to 6 and is very plastic and sticky when wet. Bedrock was not reached within 4 feet of the surface in places, although limestone outcrops were seen here and there over the flat surface of the land.

The soil has good underdrainage, and the large size of the forest trees, such as espavé and sand box, indicates good soil. There are also many palms, but the undergrowth is light.

This soil could probably be successfully used for growing Hevea rubber trees, bananas, corn, rice, and many other crops. The only area of Alhajuela clay mapped is about 2 miles northeast of Alhajuela on the east side of Chagres River. It occurs as a high flat, and the foliage of the heavy virgin forest growing on it was intensely green in the middle of the dry season, a condition in striking contrast to that of the adjacent leafless forests on shallow limestone land.

SAVANNA CLAY

Savanna clay occurs in a large treeless area in the vicinity of La Chorrera outside of the Canal Zone, in several areas northeast of the city of Panama, and in a small patch in the vicinity of Alhajuela.

Near La Chorrera the soil consists of brownish-red clay which cracks into small and medium-sized hard clods on drying. The clods break into small fragments of stonelike hardness. They contain pieces of yellowish, partly decomposed parent rock, larger fragments of which occur as bowlders in places on the surface. Below a depth of 4 inches is red clay, which becomes exceedingly hard and deeply cracked by the middle of the dry season. This clay continues to a depth of about 10 inches, below which dry, hard clods of red and yellowish-red clay containing a few fragments of partly decomposed parent rock occur. This layer reaches a depth of about 20 inches and is underlain by olive-colored, red, and purplish-red, slightly moist clay, cloddy in the upper part and becoming more plastic as the moisture increases with depth. Below a depth of about 40 inches is purplish-red and bluish moist clay together with friable, partly decomposed parent-rock material which is slightly plastic and sticky. At a depth of about 70 inches this grades downward to purplish-red and dove-colored moist clay, with more partly decomposed rock material intermixed. The material was examined on an eroded escarpment during the dry season.

A.—Eroded rolling Savanna near the city of Panama
B.—Protruding basic igneous parent rock on a flat area of Savanna clay, near La Chorrera

The unweathered rock which is associated with this soil is dark-colored, tough, basic igneous rock of the nature of diorite or diabase. It weathers first to soft material of limonite-yellow color, which peels off concentrically from the unweathered rock core, so that the hard original rock assumes a somewhat round form under this process of decay and exfoliation. The same kind of material, it might be observed, is formed through the decay of diorite and related rocks in the humid parts of the United States. In the sample from La Chorrera, the content of clay in this first product of weathering is approximately half that present in the resultant soil material collected at the same place and is less than that in the second product of weathering which is described below.

The second product of weathering (a material formed through the decay of the parent rock and representing an advanced stage of weathering of the soft yellow material described above) is yellow, light-grayish, and reddish-yellow material which occurs as an irregular layer over the soft yellow material that is formed as the primary product of weathering. The grayish material is somewhat harder than the yellow and reddish-yellow materials. These varicolored materials are honeycombed, and some of the cavities contain red clay which represents the product of still more advanced weathering and may be regarded as the final product. The second product of weathering is tougher than the first and is of common occurrence in eroded places. In some places it occurs at elevations above surrounding areas of clay soil and exhibits considerable resistance to erosion. The distribution of this secondary material under the red clay is not uniform. It is very abundant, however, and is referred to as hardpan. It has the appearance of material which is called laterite in some regions.

This savanna soil bakes and hardens to an extreme degree in the dry season, and the only growth on it, with the exception of a few stunted and widely scattered bushes (mostly marañon), is short grass which completely parches shortly after the rains cease. (Pl. 4, B.) On many broad areas near La Chorrera no vegetation was seen except the short grass. When the rains begin, this grass revives and in a short time furnishes fairly good pasturage. The soil is suitable only for grass, although with irrigation other crops, including rice, might be grown.

Most of the savanna land of the La Chorrera area has a uniform surface relief. It is undulating or gently rolling, with gradual slopes. (Fig. 4.) In places erosion has developed (pl. 5, A) broad shallow-gullied areas, over which fragments of the hard parent rock are scattered and in which projections of weathered and unaltered rock are abundant. (Pl. 5, B.) Here and there escarpments varying in height from 1 to 10 feet occur. Strips of rough eroded clay, scattered stones of the parent rock, and projections of the honeycombed material are along the front of these walls.

The principal savanna areas of the La Chorrera section have elevations varying between 220 and 280 feet above sea level; the surrounding country has a general slope toward the east, southeast, northeast, and north. On the slopes of the mountains to the west a small area of this kind of land has an elevation of 640 feet.

As far as is known, these savanna areas have always been treeless, a condition doubtless resulting from the droughtiness of the clay soil. Even the marañon, which usually succeeds even on thin, droughty soil, is here a dwarfed shrub. Along the edges of the savanna north of La Chorrera there is some bushy growth, and the plants are larger and the trees taller in these areas of deeper soil and better moisture supply. Large trees grow on the deep, friable alluvial soil in the bottoms of streams flowing through the savannas, and in places are found at short distances up the slopes where there has been some accumulation of friable soil by wash from above. Where the typical tough clay borders the edge of the stream bottoms, the line of demarcation between treeless and forested land is very sharp.

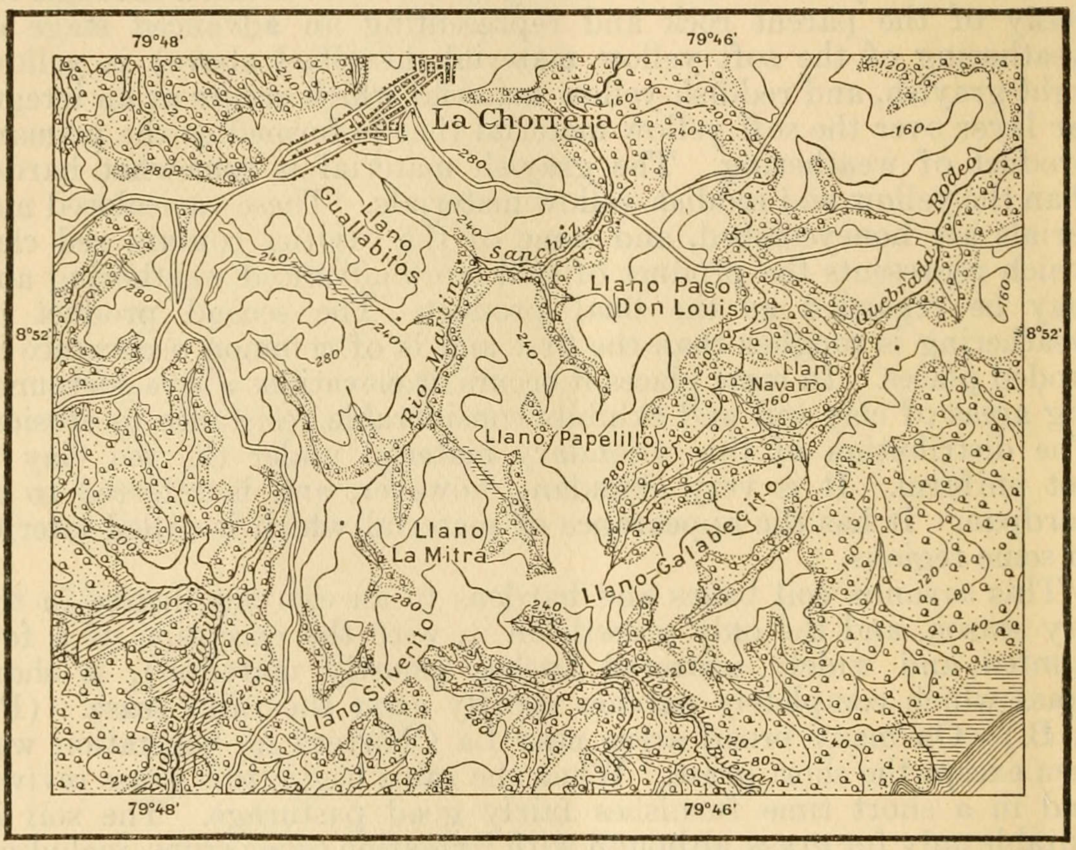


FIG. 4.—Characteristic topography of a savanna region. This shows the positions of grassland and forested areas. Here the principal soils are Savanna clay and Arraiján clay

The savannas lying northeast of the city of Panama are similar to those of the La Chorrera section in surface relief. In this location the soil has a surface layer, about 3 inches thick, composed of brownish-red, dry (during the dry season), hard, and cracked cloddy clay. Between depths of 3 and 11 inches, dry or slightly moist red clay is found. This contains considerable dark reddish-brown and black material having the appearance of iron and carrying a little yellowish, partly decomposed parent rock material in the lower part, and is essentially a hardpan layer. Below a depth of 11 inches and continuing to a depth of about 30 inches occurs greenish-yellow and reddish partly decomposed parent-rock material, containing many whitish particles. Some of the fragments are stained brown and reddish brown, apparently with iron. This layer is slightly moist and moderately hard. Below this, to a depth of about 50 inches, whitish, reddish, and black partly decomposed parent-rock material is present. The decomposition of this material is not so advanced as of that in the layer above. The parent rock is dark-colored, tough diabase of which fragments in the incipient stage of weathering have assumed a greenish cast in places. Fragments of an opallike rock and vein quartz, as well as large and small pieces of the parent rock, are scattered over the eroded areas.

Here, as in the La Chorrera section, short grass which parches completely on the baked soil in the dry season is the only vegetation other than a few scattered, stunted trees and bushes.

The soil of the savanna between Juan Mina and Alhajuela on the eastern side of Chagres River is somewhat different from that described above but is also very shallow and has a hardpan beneath. The surface soil, to a depth of about 3 inches, is brown friable clay or clay loam having a pH value of about 6. Between depths of 3 and 10 inches is light bluish-gray, compact clay which contains an abundance of rust-brown and reddish-brown material that resembles iron hydrates. This is essentially a hardpan layer and fragments of the material dry out very hard. This material forms a milky mixture when shaken in water, and it settles out with extreme slowness, indicating a high content of sticky clay. The pH value of the material constituting this layer is 4.5. Between depths of 10 and 60 inches is light bluish-gray, very sticky, plastic clay which shows a little red mottling and becomes lighter in color with increasing depth. This layer represents a very impervious claypan.

The vegetation of this soil consists of an Andropogon and other grasses, most of which grow to a height of only 6 or 8 inches. There are also a few scrubby marañon bushes.

This type of savanna soil apparently is derived from igneous rock, as is the soil of several other savannas in the same locality. On an elevated area between Rio Azote Caballo and Rio Puente, tributaries of Chagres River, fragments of dark, tough, igneous rock like that of the La Chorrera savanna are scattered over the surface, and small angular fragments of the partly decomposed rock are abundant through the reddish soil. The areas of brown savanna soil southwest of Alhajuela are surrounded by friable red Arraijan clay derived from igneous rock.

The red clay supports a heavy tropical growth. The change from grass land to forest land here is abrupt and marks the boundary between good soil and an unfavorable one, savanna clay. This savanna clay supports a growth of grass rather than of trees. Its unfavorable characteristics are a thin surface soil which dries out rapidly during the rainless season, a hardpan subsurface layer, an impervious claypan beneath the hardpan, a high content of sticky colloidal material which checks underdrainage and aeration, and its extreme hardness when dry and stickiness when wet.

The savanna soils described above differ markedly from both the black gumbo clay of the savannas west of San José, Costa Rica (the *barro de olla* land), and the black clay lowland savannas of eastern Guatemala. These black savanna soils are wet and sticky in the rainy season but dry out and crack in the dry season. They are both rated as soils of low productivity, yet they are more productive than the red savanna clay of Panama, the *barro de olla* soil being used to some extent for growing rice. Their content of organic matter is much less than that of the Panama savanna soils.

ANCON STONY CLAY

Ancon stony clay is a soil of very small extent, occurring in one principal area on Ancon Hill at the southern extremity of the Canal Zone and on a few of the small, isolated island hills in the Gulf of Panama. Nevertheless, the Ancon Hill area is important because of its location at administration headquarters of the Panama Canal, its proximity to the city of Panama, and because many employees of the canal organization and the Panama Railroad and officers and men of the Army and Navy live on the hill.

Two types of soil occur on Ancon Hill. The peak and upper slopes have a very stony soil, Ancon stony clay, whereas the lower slopes are made up in part at least of a less stony soil with a stiffer subsoil, Ancon clay, which has been included with Ancon stony clay on the map.

The more stony land consists of yellowish-brown clay containing an abundance of angular, whitish, soft, partly decomposed parent-rock fragments. It dries hard, although fragments crush readily. This layer continues to a depth of 5 inches, where it is underlain by pale-yellow, buff, or white clay, moist in the lower part and also containing an abundance of whitish, soft, partly decomposed parent rock. This is underlain, at a depth of about 24 inches, by slightly moist clay of the same color. It contains an abundance of the light-colored soft rock fragments which show a slight bluish cast on freshly fractured surfaces. The clay contains some fine grit. On old fractured surfaces is a film of rust-colored material that resembles iron compounds. This material prevails to a depth of about 60 inches and is underlain by light-red clay. The pH values vary with depth from 4.8 to 6.4. Below a depth of about 60 inches is nearly white, soft and semihard, partly decomposed parent rock which has a faint bluish cast. Faintly red and nearly white clay and decomposed rock material fill the cracks in the harder material, and the rock fragments are stained dark brown. Below a depth of 30 feet are weathered parent rhyolite and partly weathered fragments of the same rock. The parent rock is much fissured and jointed, is brittle, and crushes easily. It is feldspathic and contains some free quartz. There are accessory minerals of magnetite, ilmenite, and apatite (*12*).

The clay is rather slick when wet, but on drying it works up into a whitish or cream-colored dust in roadways. The higher stony area supports a growth of short grasses and sedges, stunted trees, and bushes of marañon, the common sumac-like bush of the drier lands, guarumos (*Cecropia sp.*), *Luehea speciosa*, corteza (*Apeiba tibourbou*), which has a fruit with burs like the chestnut, and others. Guinea grass is of low growth and parches in the dry season. This soil is too stony and steep for agricultural use, except for pasture land and trees.

Along the middle slopes the soil is deeper and a heavier forest growth, such as is seen in the woods above Ancon Hospital, prevails. Even on the deeper soil the trees are not large, though they are much larger than those on the shallower and more droughty stony land above. Very few trees are of erect growth. Many of them were leafless in the latter part of February (1924) but became green early in the spring.

Ancon clay, included in mapped areas of the stony soil, is found mainly along the lower slopes of Ancon Hill. It is a deeper soil, retains moisture better, and is much less stony. The surface bakes hard in the dry season, but moisture remains in the subsurface layer at a depth varying from 4 to 6 inches. Near the base of the hill below Ancon Hospital, the soil (during the dry season) consists of reddish-brown clay, dry, hard, and somewhat cracked, and contains some light-colored rock particles. This layer is underlain by light-red, slightly moist clay which, upon exposure to air, shrinks and cracks, forming fairly hard clods. Below a depth of about 12 inches, the clay becomes somewhat plastic. The light-colored material is rather friable and apparently represents more recently decayed rock than the red material. At a depth of about 30 inches this is underlain by light-colored, red and yellow, moist, somewhat plastic clay. The yellow material is very friable, giving this layer some friability and making it more permeable.

This soil consists, in part, of material that has washed from the slopes above. There are, in places, a few yellowish, whitish, and cream-colored small fragments of partly weathered rock through it, but not enough for classification as a gravelly or stony soil. This soil resembles Paraiso clay rather closely. In places along the lower slope of the hill is brick-red clay which grades downward, at a depth of a foot or more, to red, bluish-gray, and yellowish clay.

On this soil near Ancon Hospital two healthy specimens of Hevea rubber trees, supposed to have been planted about 1907, were seen. One of these is nearly 18 inches in diameter, and, although it is not very tall and the roots grow partly exposed near the base of the tree, it is considered a good specimen. These trees take on new leaves early in the spring prior to the beginning of the wet season, indicating that the soil here conserves moisture well.

Paspalum and Bermuda grass thrive on this soil, remaining green throughout the dry season, whereas most of the other grasses turn brown. Numerous ornamental shrubs and trees of both indigenous and introduced species have been planted on Ancon soils, and most of these seem to be thriving (*15*).

CATIVAL CLAY

Catival clay occurs in the extreme northern part of the Canal Zone on the east side of the flat marsh area skirting Limon Bay and extending eastward into the Republic of Panama. The land is extremely hilly. The soil consists of a surface layer, from 1 to 3 inches thick, of reddish-brown clay, which in the dry season is ordinarily only moderately moist and slightly hard, underlain by light-red, moderately friable, moist clay, which, below a depth varying from about 24 to 30 inches, contains some friable, yellowish material representing incompletely decayed parent rock. In some areas this soil consists of reddish-yellow, rather friable clay, underlain at a depth varying from 10 to 14 inches by red and yellow clay which contains sufficient partly decomposed parent-rock material to make it rather friable. Yellowish, granular, decayed parent limestone rock is present below a depth of about 30 or 40 inches. This grades downward to bluish-gray, moderately hard limestone beds belonging to the Gatun formation.

Some of the hills near Catival exceed 200 feet in height, but in the direction of Limon Bay lower hills are common, and some small conical hillocks rise not more than 25 feet above the intervening low, swampy, coastal-plain flats. The hills are irregular in occurrence and are largely covered with bushy restrojo. Some of this land is used for growing bananas, cassava, and other native crops. Some of the bushy growth showed a moderately desiccated effect of the dry weather when seen in late February, but this condition was not nearly so exaggerated here as in the same sort of growth during the same season in the southern part of the Canal Zone. Although much of this area could be cultivated, it would not be profitable to use it for large plantations on account of the presence of so many steep hills and the inferior quality of the soil in the interhill areas.

LIMESTONE HILLS

The uplands on the west side of Limon Bay attain elevations of more than 200 feet between the bay and Chagres River. This section is underlain by the Toro limestone, which is described (*12*) as: ". . . sandy and fragmental, being locally a coquina or shell marl . . . . In places it forms low bluffs or headlands, especially at Toro Point, west of the Gatun Dam, and at the mouth of the Chagres River."

The area is not available for general agriculture, and the very uneven surface lessens its value for farming.

MARSH

Land classified as marsh includes low swamp lands which are permanently saturated. Lying only slightly above low-tide level, these areas are repeatedly inundated by high tides. Marsh occurs most extensively around Bohia de Limon. Formerly there was a large area between Pedro Miguel and the Gulf of Panama, but most of this has been covered by dump material from the canal. The characteristic growth consists of mangrove trees and leather ferns. This land has no agricultural value, and all of it will probably be covered eventually with material which is either dumped or pumped in. If protected by dikes, and drained, the land would slowly be leached of salts and would become a good soil for rice, vegetables, and grass. Only halophytic plants survive, except on areas of more nearly fresh water along the inner margins of the marshes.

ALLUVIUM

Narrow strips of alluvium are along the courses of the larger streams of the Canal Zone. Most of the broader strips occur in the concave sides of bends. The soil material has been partly or wholly deposited by overflow water, and where the land is reasonably well drained the soil is usually rich in organic matter, is fairly friable, supports a heavy growth of virgin forest, and is very productive. Large trees grow even on the stream-bottom soils of the drainage ways ramifying the dry savanna clay lands.

The strips of alluvium have been modified in places by wash from adjacent slopes, and in other places there are some small strips of second-bottom land or stream terraces of older alluvium, deposited before the streams had cut their beds to the present level. These areas, representing remnants of former overflowed bottoms, are of very small extent.

The strips of bottom land roughly indicated on the accompanying soil map represent merely an approximation of the extent and width of alluvial land. They are exaggerated rather than underestimated in width and include some lower-slope land.

The alluvial soils in the Canal Zone are of several kinds. Owing to the small extent of the individual areas and to the small scale of the map all have been grouped under the head of alluvium. Those variations have, however, been given identifying names and their characteristics, locations, and adaptations are considered in the following paragraphs.

Bohio clay, one of the alluvial soils, occurs in association with Frijoles clay, along the streams and on low benches or second bottoms. The soil is not extensive but is locally important on account of its excellent quality. It occurs along the lower courses of Aojete and Cooper Creeks near Bohio Siding, elsewhere in association with Frijoles clay along the streams, and also along a number of the streams flowing through other red clay lands.

This soil is brownish-red friable clay, underlain at a depth of 4 or 5 inches by lighter red, moderately friable clay which, at a depth ranging from about 18 to 40 inches, assumes a purplish cast, and in places from 40 to 60 inches below the surface shows faint mottles of yellow and dark-colored granular material resembling segregated iron. In one boring yellowish and brownish colored material, resembling hydrated iron compounds, was evident at a depth of 20 inches below the red, friable, clay layer. This was taken as an indication that water stands here throughout the rainy season and for some time after. In the dry season (February 22, 1924) bananas were somewhat retarded on this patch and were not so green as on the well-drained soil, indicating the need of ditching for these wet places. In depressions of decidedly imperfect drainage, bluish clay is present in the subsoil.

Bohio clay is composed of alluvial material which has been washed chiefly from areas of Frijoles clay and related upland red clay soils and deposited by overflow water in narrow strips along the streams. Some of it now occurs on benches. The soil is subject to occasional inundation by flood water from the streams along which it occurs. The water does not remain long on the bottom lands, so that this flooding is not seriously harmful. The soil on the higher bench or terrace situations is not subject to overflow. Moisture conditions are very good, except in some swales and low flats where standing water almost permanently saturates the subsoil and retards aeration and oxidation.

Vegetation is similar to that on Frijoles clay, but the trees average somewhat larger in size and the undergrowth is denser. There are more and larger espavé trees and fewer palms, and guayacan and several other upland trees are absent. Large bamboo grows in some localities, as well as trailing or running bamboo. Wild pineapple (pita) is also locally plentiful.

Soil of this type has a wide crop adaptation. Sugar cane, corn, plantains, bananas, oranges, vegetables, and a number of other crops yield well. Some excellent oranges were seen on the strip of associated alluvial soil at Juan Mina, on Chagres River. The flat surface and friable topsoil and subsoil favor easy cultivation. This is probably the most productive soil of the region.

Both Hevea and Castilla rubber trees should thrive on this soil in places where the depth to the compact or blue clay subsoil is not less than 5 feet and where the water table is not less than 6 feet below the surface. Danger from bank cutting would probably be slight if the rubber groves were planted on the inner bends of the streams.

Near Cooper Creek the soil is reddish-brown, very friable clay, grading at a depth of 10 inches to deep-red, very friable clay underlain at a depth of about 3 feet by yellowish-brown, reddish-yellow, and rust-brown, friable, granular material. Seepage water is present 3 feet below the surface. This soil has a high content of iron hydrates and is neutral or slightly alkaline.

Some unimportant narrow strips on the lower slopes of the hill land of this locality consist partly of accumulated material (Cooper clay, not mapped separately), which closely resembles the Bohio soil, washed down from the adjacent higher slopes. This varies in depth and contains some partly decomposed rock fragments. An area of Cooper clay was found about 3 miles east of Bohio Siding, along the high banks of Cooper Creek.

The surface soil here is 6 inches thick, consists of reddish-brown friable clay of high organic-matter content, and contains soft fragments of partly decomposed greenish rock having a pH value of about 7. Below this is brownish-red, friable clay which contains fragments or particles of partly decomposed rock. These rock fragments increase the friability of the soil. The clay prevails to a depth of about 14 inches, where it is underlain by brownish, soft rotten rock which has a greenish cast on the freshly fractured surfaces. The rotten rock continues to a depth of about 5 feet, where it is underlain by partly decomposed harder rock.

Along Chagres River there is considerable good brown and yellowish-brown silt loam and fine sandy loam having ample underdrainage, which is well suited to the production of corn, bananas, rice, vegetables, and other crops. The fine sandy loam, Gatuncillo fine sandy loam, occurring near the mouth of Gatuncillo River, consists of yellowish-brown, heavy fine sandy loam underlain at a depth varying from 10 to 14 inches by reddish-yellow, friable fine sandy clay which grades downward at a depth of about 2 feet to moderately friable, red silty clay which contains dark-brown, black, and yellowish concretions and concretionary material, apparently segregated compounds of iron. The deep substratum in places consists of gravel beds, somewhat cemented with a reddish-brown and dark-colored ferruginous material which probably has been leached from the overlying layers and precipitated in the gravelly lower stratum.

Some associated patches in this locality have light-brown or yellowish soils and soggy subsoils of mottled blue, yellow, and brown material, occurring at a depth varying from about 10 to 30 inches.

On these soils bananas have not done well, but rice flourishes and corn grows fairly well.

The brown soil with an unmottled subsoil, Gatuncillo soil, supports a heavy virgin forest growth, with large bonga, espavé, and other bottom-land trees.

These lands are subject to overflow. In October, 1923, they were deeply covered in an unusually heavy flood that came down Chagres and Gatuncillo Rivers. A large commissary building was washed away from the point of land at the confluence of these two rivers. When the projected dam is built across Chagres River above Alhajuela, much productive alluvial soil will be inundated along that river and Pequeni River. In some comparatively broad bottoms near the junction of these two large rivers good bananas have been grown. Some of the groves were practically destroyed by the flood of October, 1923. This great flood piled up enormous bars of gravel on the river bed in places; one strip about one-eighth mile long, 200 feet wide, and 5 or 6 feet high was built up by this flood alone.

Some of the bottom land is of a rather dark color, almost black, and has a yellowish-brown subsoil. Soil of this kind occurs in narrow strips along some of the streams ramifying the Santa Rosa or limestone clay land. It is very productive, giving excellent results with bananas and corn.

Rio Indios clay is an imperfectly drained alluvial soil somewhat similar to the inferior blue clay (Bitey clay) found in Estrella Valley of southeastern Costa Rica. It is inextensive within the limits of the Canal Zone and the country contiguous to it. As seen 1½ miles northeast of Las Delicias on Gatun Lake, it consists of dark-gray or slightly bluish gray silty clay faintly mottled with yellowish brown and underlain 1 or 2 inches below the surface by yellow, rather plastic clay which shows some gray mottling. Large cuipo and espavé trees are abundant, and some fairly good bananas were seen. Wild plantain makes a luxuriant growth. This soil is probably better suited to grass, rice, and corn than to other crops.

An area of this soil on the interhill flat along the stream at Catival consists of a layer of brown or mottled brown, rust-colored, and blue clay, underlain by a soggy clay subsoil mottled with blue and yellow. The land in this area is valuable only for growing grass and rice. It could be improved by deep ditching to provide better drainage and more thorough aeration.

Other soil variations occur in the bottoms, but the important types of soil are similar to those already described. Regardless of different characteristics of texture and color, alluvial soils having good underdrainage are productive and will successfully grow practically all the crops adapted to the climate. Those having poor underdrainage, that is, those which are bluish, pale yellow, and rust brown in color, have a much more restricted range of crop adaptation and are less productive. These bottom lands usually are only of local importance, rarely being extensive enough within the limits of the Canal Zone for large plantations. However, they are very valuable, particularly where they adjoin smoother uplands of better grades of land.

Broader areas and more important plantation lands may be found in the bottoms of some of the larger streams in the Republic of

Panama. However, before large agricultural undertakings are begun, these soils should be carefully examined, not only in the surface layer but in the subsoil, in order to determine the proportion and distribution of areas consisting of the inferior kinds of alluvium. It is even more important to know the character of the subsoil of tropical alluvial lands than that of the surface soil, especially where plantings of bananas, Hevea or Castilla rubber trees, sugar cane, and other crops are to be made. In many places there is good land on the natural leaves (*bancos vegas*, or high-bank areas fronting the stream) at short distances from poorly drained land. Some clumps of bamboo grow on the well-drained areas, but the tree growth is usually indiscriminately mixed.

FILLS AND EXCAVATED AREAS

The land shown on the soil map as fills and excavated areas represents chiefly material excavated from the Panama Canal and dumped elsewhere. The largest area of this material is that between Balboa and Pedro Miguel, where formerly mangrove swamp existed. Most of this land is flat and no great use has been made of it so far. There are some vegetable patches, but unless the land is irrigated the plants suffer severely from drought. Grass seems to give best results but dries out during the rainless season, and the entire area is usually burned over. The land could be used for pasturing livestock and for growing hay if the grass were cut in the dry season before fires occur. Some areas remain sufficiently damp to keep gamilote grass green well into the dry season, but guinea grass is probably the best crop. Patches of mangrove still grow on some of the lower, wetter areas. Some of the dump areas are so rocky and droughty as to be valueless for ordinary crops.

The excavated areas are of much smaller extent than the fills. There is one large area just northwest of Gold Hill along the canal, where the soil and basal rock have been removed by landslides. These areas have no agricultural value.

SAN PABLO CLAY (NOT MAPPED)

Because of its small extent, San Pablo clay is not an important soil. It occurs on the lower slope of the plant-introduction gardens, where orange trees have failed, and it consists of brown and yellowish-brown clay which contains a few small rock fragments, underlain at a depth varying from 4 to 7 inches by bright-yellow, extremely sticky clay. Some light bluish-gray mottles appear at a depth varying from 40 to 48 inches. Plowed-up clods shrink on drying, apparently because of their high content of plastic clay, and crack into small clods giving to the soil fragmental structure which varies from fine to coarse. This surface layer is underlain by yellow, plastic clay which is so impervious to water that its upper part is moist during the driest season. However, this heavy subsoil contains much very highly plastic clay and, when plowed up, dries and quickly cracks into hard, small clods and fragments.

The foliage of the orange trees, at the height of the dry season, was wilted and yellowing as a result of the drying out of the soil, even with moist clay at a depth varying from 4 to 7 inches below the surface. The roots did not seem capable of taking moisture from the tenacious clay, and some of the trees had died. In the wet season the same soil was supersaturated much of the time, and the leaves of the orange trees were of a sickly yellow color. Drainage of this soil is difficult, and land of this kind should be used only for grass whenever better soil is available for cultivated crops.

The small area of this soil on the lower slope of the hill along the railroad just north of Ancon has a brown topsoil and an extremely stiff, plastic, yellow clay subsoil which cracks or checks into irregular clods.

This type of soil was classed as San Pablo clay in the reconnaissance of the Canal Zone made in 1909 (*3*). It is of too small extent and unfavorable quality to be considered important. It occurs here and there through the southern half of the Canal Zone, in small patches only, and has been included in mapped areas of surrounding soils.

The parent rock has not been definitely identified. The area at the plant-introduction gardens is probably derived from noncalcareous clay stone or shale.

COASTAL SAND (NOT MAPPED)

A few narrow strips of loose fine sand such as those areas at Punta Toro and about the mouth of Chagres River, range in color from light to dark and skirt the Caribbean coast in the northern part of the Canal Zone. This fringe of fine sand is only a few feet above sea level. The material represents the coarser and more resistant stream sediments and the products of shore-line weathering, which have been reworked, abraded, assorted, and deposited on the beach and beyond by waves, tides, and wind. The constituents of this material represent the more resistant particles of igneous, volcanic, and sedimentary rocks. There are large quantities of magnetite (25 per cent in one sample), ilmenite, considerable augite, hornblende, and zircon, and feldspar and quartz are present in small quantities. The content of silt and clay is very low, but there is usually enough organic matter to impart a slight loaminess to the soil. The water table stands within 2 feet of the surface in much of this soil.

Areas where coastal sand is present are abundantly supplied with moisture and are favored by sea breezes. The land is well suited to growing coconuts; some excellent groves have been established and produce good fruit. On account of its limited acreage, however, this soil is not an important one in the area covered by this survey.

SUMMARY

Both the Canal Zone and the contiguous country of the Republic of Panama are characterized by a very hilly surface relief, the only flat lands being the areas of savanna land lying near the Pacific coast, both east and west of the city of Panama, beyond the zone line and the narrow stream bottoms. Generally the numerous hills are not high, but most of them are steep, so that the land physically suited to agriculture is probably not much more than 20 per cent of the total area, and not all of this represents good soil.

The best soils are the well-drained alluvial lands along the streams and the deep, red clays found chiefly in the northern half of the Canal Zone. The former are not extensive, occurring as narrow strips along the winding streams, in the proportion of 10 or 12 acres to 1 square mile of upland. Fully 10 per cent of the bottom lands along the streams represent soggy or imperfectly aerated soil, chiefly clay, having low value except for water-loving plants such as rice and Para grass.

There are a number of fairly good upland tracts of comparatively level surface, consisting of deep, friable clay soil that could be used for agricultural enterprises requiring tillage without much danger of destructive erosion. These deep, friable clays are markedly resistant to erosion, and a large proportion of them, where the slopes are not too precipitous, could be cultivated safely, particularly with some hillside terracing. With tree culture there would be even less danger of wasteful washing.

Some of the better areas of good upland soil are: (1) The comparatively low, benchlike strip along the shore of Gatun Lake, in the Escobal-Cuipo section; (2) the gentle slopes and low hills of the Frijoles-Monte Lirio locality, in the valley of Aojete Creek; and (3) the less broken belt of the deeper phase of Arraiján clay extending from the vicinity of the village of Arraiján in a southwesterly direction across the Empire-La Chorrera road.

The climate of the region is characterized by sharply defined wet and dry seasons. The latter is of somewhat longer duration on the Pacific than on the Atlantic side of the zone, covering a period of about four months. The average annual precipitation increases toward the Atlantic side from 67.67 inches at Balboa to 127.25 inches at Colon and 159.76 inches at Porto Bello. Soaking rains occur occasionally during the dry season on the Atlantic side, but on the Pacific side of the isthmus they are extremely rare.

Ordinarily the soil in the northern part of the Canal Zone holds sufficient moisture to maintain a verdant forest growth throughout the dry season. At the southern end of the zone all soils except those of the stream bottoms and the deep, friable clay uplands become dry by the middle of February and harden, crack, and lose their moisture to such a degree that most of the trees shed their leaves, and many plants, including bananas, corn, and grass, suspend their growth or dry up entirely. Here, during the dry season, fires are of common occurrence in the dry grass and bush growth of pastures, second-growth jungle, and even in virgin forests. All grass parches on the savanna clay, and nearly every tree is leafless by the middle of the dry season on the shallow limestone soil of the Chagres Valley. The deep soils with good moisture conditions, occurring near the soils on which desertlike conditions prevail in late February and March, support at this season intensely green forest vegetation.

The principal crops of the region are bananas, guinea grass for pasturage, rice, vegetables, coconuts, papayas, mangoes, and other tropical fruits. The supply department of the Panama Canal raises a large number of cattle for local beef consumption, and some for dairy products. Bananas are grown commercially along the shores of Gatun Lake, in many of the stream valleys, and on isolated hillsides through the Canal Zone, as well as in a number of localities beyond the limits of the zone. Much better results are obtained with this crop on the Atlantic side of the Isthmus of Panama. Considerable damage has been done by the Panama banana disease.

Hevea and Castilla rubber trees will grow on the better soils of the region. Wild Castilla trees of healthy appearance were seen in many places both within the Canal Zone and in the contiguous territory of Panama.

LITERATURE CITED

(1) BENNETT, H. H.
1925. AGRICULTURE IN CENTRAL AMERICA. Jour. Amer. Soc. Agron. 17: 318-326.

(2) ———
1926. SOME COMPARISONS OF THE PROPERTIES OF HUMID-TROPICAL AND HUMID-TEMPERATE AMERICAN SOILS; WITH SPECIAL REFERENCE TO INDICATED RELATIONS BETWEEN CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES. Soil Sci. 21: 349-375, illus.

(3) ——— and TAYLOR, W. A.
1912. THE AGRICULTURAL POSSIBILITIES OF THE CANAL ZONE. U. S. Dept. Agr., Off. Sec. Rpt. 95, 49 p., illus.

(4) BRIGGS, L. J., and SHANTZ, H. L.
1912. THE WILTING COEFFICIENT FOR DIFFERENT PLANTS AND ITS INDIRECT DETERMINATION. U. S. Dept. Agr., Bur. Plant Indus. Bul. 230, 83 p., illus.

(5) COOK, O. F.
1921. MILPA AGRICULTURE, A PRIMITIVE TROPICAL SYSTEM. Smithsn. Inst. Ann. Rpt. 1918/19: 307-326, illus.

(6) ELLENBERGER, W. P., and CHAPIN, R. M.
1920. CATTLE-FEVER TICKS AND METHODS OF ERADICATION. U. S. Dept. Agr. Farmers' Bul. 1057, 32 p., illus. (Revised ed.)

(7) FIGART, D. M.
1925. THE PLANTATION RUBBER INDUSTRY IN THE MIDDLE EAST. U. S. Dept. Com., Bur. Foreign and Dom. Com., Trade Prom. Ser. 2, 317 p., illus.

(8) GODFREY, G. H.
1923. ROOT-KNOT: ITS CAUSE AND CONTROL. U. S. Dept. Agr. Farmers' Bul. 1345, 27 p., illus.

(9) HARRINGTON, M. W.
1900. CENTRAL AMERICAN RAINFALL. Bul. Phil. Soc. Wash. (1895/99) 13: 1-30, illus.

(10) HOOVER, L. G.
1923. THE CHAYOTE: ITS CULTURE AND USES. U. S. Dept. Agr. Circ. 286, 11 p., illus.

(11) INTERNATIONAL ENGINEERING CONGRESS.
1916. TRANSACTIONS OF THE INTERNATIONAL ENGINEERING CONGRESS, 1915. THE PANAMA CANAL. I. GENERAL PAPERS AND CONSTRUCTION IN THREE DIVISIONS OF CANAL. [v. 1], illus. San Francisco, Calif.

(12) MACDONALD, D. F.
1915. SOME ENGINEERING PROBLEMS OF THE PANAMA CANAL IN THEIR RELATION TO GEOLOGY AND TOPOGRAPHY. U. S. Dept. Int., Bur. Mines Bul. 86, 88 p., illus.

(13) MORROW, J. J.
1917. GARDENS FOR SILVER EMPLOYEES. Panama Canal Rec. 10: 320. (Circ. 713.)

(14) ———
1921. LAND FOR AGRICULTURAL PURPOSES. Panama Canal Rec. 15: 258. (Circ. 713-1.)

(15) PANAMA CANAL.
1925. A HANDBOOK OF THE PRINCIPAL TREES AND SHRUBS OF THE ANCON AND BALBOA DISTRICTS, PANAMA CANAL ZONE, SUBDIVIDED INTO SECTIONS ACCORDING TO LOCATION OF PLANTS. 97 p., illus. [Washington, D. C.]

(16) PIPER, C. V.
1920. THE JACK BEAN. U. S. Dept. Agr. Circ. 92, 12 p., illus.

(17) SCHURZ, W. L., HARGIS, O. D., MARBUT, C. F., and MANIFOLD, C. B.
1925. RUBBER PRODUCTION IN THE AMAZON VALLEY. U. S. Dept. Com., Bur. Foreign and Dom. Com., Trade Prom. Ser. 23, 369 p., illus.

(18) TREADWELL, J. C., HILL, C. R., and BENNETT, H. H.
1926. POSSIBILITIES FOR PARA RUBBER PRODUCTION IN NORTHERN TROPICAL AMERICA. U. S. Dept. Com., Bur. Foreign and Dom. Com., Trade Prom. Ser. 40, 375 p., illus.

(19) VANCE, C. F., MUZZALL, A. H., BUSHNELL, J. P., and BALDWIN, M.
1925. POSSIBILITIES FOR PARA RUBBER PRODUCTION IN THE PHILIPPINE ISLANDS. U. S. Dept. Com., Bur. Foreign and Dom. Com., Trade Prom. Ser. 17, 101 p., illus.

(20) YOUNG, R. A.
1924. TAROS AND YAUTIAS; PROMISING NEW FOOD PLANTS FOR THE SOUTH. U. S. Dept. Agr. Bul. 1247, 24 p., illus.

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PANAMA CANAL ZONE AND CONTIGUOUS TERRITORY

Soils by Hugh H. Bennett

Base compiled from maps by Corps of Engineers, U. S. Army and by Engineers of the Panama Canal

Scale

10 Miles

10 Kilometers

Bureau of Soils 1924

4650°—29. (Follow p. 47.)