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ALUMINOUS LATERITIC SOIL OF THE REPUBLIC OF HAITI, W. I.

BY

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ABSTRACT

Aluminous lateritic soil containing as much as 50 percent of alumina (Al_2O_3) is found in several places in the Republic of Haiti. The largest deposits are on the Rochelois Plateau southwest of Miragoâne on the Southern Peninsula. Mapping and drilling of the deposits indicate fifteen million long tons in place (dried basis). It is estimated that a minimum of 10 million long tons of this reserve is recoverable. The average chemical composition of this material is as follows: Al_2O_3, 46.8 percent; SiO_2, 3.4 percent; TiO_2, 2.8 percent; Fe_2O_3, 21.9 percent; P_2O_5, 0.6 percent; MnO_5, 0.5 percent; and loss on ignition, 24.1 percent. Other localities in which similar lateritic soil occurs are Beaumont in the Massif de la Hotte; the vicinity of Savane Zombi in the Massif de la Selle; and Savane Terre Rouge on the plateau northwest of Gonaïves. In none of these regions were large deposits found.

The lateritic soil is finely divided, reddish-brown, yellowish-brown, and buff-colored material. The principal minerals are gibbsite, boehmite, hematite, and goethite. Minor constituents are clay minerals and compounds of titanium, manganese, and phosphorus. Quartz, zircon, and magnetite are accessory minerals. The lateritic soil of Haiti is similar in composition to soil deposits in the limestone valleys of the Sierra de Bahoruco in the Dominican Republic and on the limestone uplands of Jamaica. All these deposits rest on Tertiary limestone and probably are closely related in origin.

Chemical analyses of the Eocene limestone bedrock from low-silica aluminous lateritic soil localities in Haiti and in the Dominican Republic show less than 0.1 percent of alumina. If this limestone is the immediate source of the lateritic soil, a large volume of limestone was weathered to yield the known deposits. Other sources than the Eocene limestone, however, may have been available. On the basis of the chemical composition of the soil an igneous parent material of intermediate composition is suggested as the ultimate source of the lateritic material.

INTRODUCTION

DISCOVERY OF ALUMINOUS LATERITIC SOIL

The accidental discovery in 1942 that certain lateritic soils of Jamaica (West Indies) contain up to 50 percent of alumina (Al_2O_3) and less than 1 percent of silica (SiO_2) aroused great interest because of the possibility that such material might be utilized as an ore of aluminum. The discovery was made when Sir Alfred D'Costa, concerned over the lack of fertility of the red soil on his property northeast of Claremont in St. Ann Parish, sent samples to the Hope Agricultural Laboratory in Kingston where chemical analyses were made. The soil is finely divided, red, reddish-brown, and buff-colored material that resembles ordinary red earth or clay so closely that its true composition had not been suspected. The soil is found on the "White Limestone" of upper Eocene and Oligocene age.

Once the alumina content of the red soil of Jamaica became known, the probability of similar occurrences on other islands of the West Indies was apparent. The numerous references to reddish-brown soil on limestone of Eocene and Oligocene age in the report on the reconnaissance geology of the Republic of Haiti made in 1920 and 1921 by the Geological Survey,[1] United States Department of the Interior, indicated that parts of Haiti might be favorable for prospecting. The actual occurrence in Haiti of aluminous lateritic soil similar to that of Jamaica was first demonstrated by geologists of the Reynolds Mining Corp. in July 1943.

USE OF TERM

The term "aluminous lateritic soil" is used in this report for surface material composed predominantly of the hydrous oxides of aluminum with admixed oxides of iron, titanium, and manganese. In composition the soil is similar to laterite from other parts of the world, but the term laterite is best reserved for products of lateritic weathering in place in which the volume of the residual material represents the greater part of that of the parent rock.[2] Thus the term laterite is not applicable to the surface accumulations of lateritic material on limestone in Haiti. This material might well be called ferruginous bauxite, but through usage in the industry the term bauxite has acquired a commercial significance implying an ore of aluminum. It therefore seems advisable, for the present at least, to use the term aluminous lateritic soil to describe the earthy aluminous deposits of the Caribbean region.

SCOPE AND METHODS OF INVESTIGATION

The investigation of aluminous lateritic soil in the Republic of Haiti was part of the program of cooperation with American Republics sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation, carried on under the auspices of the United States Department of State. The objectives were to estimate the reserves of potential commercial value and to study the geologic factors that control the origin and distribution of the lateritic soil. Prospecting was

[1] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti, Republic of Haiti, Department of Public Works, Port-au-Prince, 1924.

[2] Fox, C. S., Bauxite and aluminous laterite, pp. 1–11, London, Technical Press, Ltd., 1932.

expedited through preliminary work in Washington, D. C., by Mr. Wilbur S. Burbank, of theUnited States Geological Survey, who prepared a map showing the areas favorable for the occurrence of lateritic soil. Aerial reconnaissance was found to be an effective method of evaluating prospective areas.

Preliminary testing of soil and rock samples was done in the chemical laboratory at Damien, the Agricultural College near Port-au-Prince. As the exploratory work progressed, it became apparent that the best prospects were on the Rochelois Plateau southwest of Miragoâne on the Southern Peninsula. (See pl. 20.) A drilling and mapping program was set up in that region to determine the possible existence of the minimum reserve necessary to establish the potential commercial value of the deposits. Work in other parts of Haiti was restricted to exploratory trips.

Field work was started in October 1943 and completed in April 1944. Thirty-three days were spent in the Rochelois Plateau region. Laboratory studies of the samples were made at the University of Minnesota, because the facilities of the Geological Survey in Washington were already heavily loaded with war work.

A portable differential thermal-analysis unit designed by Mr. Sterling B. Hendricks, of the United States Department of Agriculture, was used in the field exploration and in the laboratory study of samples. The principle of this apparatus and the basic parts have been described by Hendricks, Goldich, and Nelson.[3] The differential thermal analyses in the field permitted quick identification of the principal minerals and a close approximation of the grade of lateritic soil.

ACKNOWLEDGMENTS

The active cooperation of the officials of the Haitian Government facilitated both field and laboratory work. Special contributions were made by Mr. Vely Thébaud, Secretary of State for Interior and Justice; Mr. Maurice D'Artigue, Secretary of State for Public Education, Agriculture, and Labor; Mr. Louis Décatrel, Director of the National Service for Agriculture and Rural Education, and Mr. Max Dennis, Director of the Haitian Bureau of Mines. Two reconnaissance flights were made with Capt. Edward Roy of the Haitian Air Force. Lt. Désiré Paris of the Detachment of Motor Tranpsort of the Garde d'Haiti arranged transportation for the party. Mr. Max Mangonès, while in the service of the Department of Public Works, gave valuable assistance. The chemical work at Damien was done by Mr. Arnauld Haspil and Mr. Georges Cadet. Mr. Edmond Polynice,

[3] Hendricks, S. B., Goldich, S. S., and Nelson, R. A., a portable differential thermal analysis unit for bauxite exploration: Econ. Geology, vol. 41, pp. 64–76, 1946.

chemist and agronomist, and Mr. Adrien Boucard, agronomist, assisted in the exploration on the Rochelois Plateau. Mr. Daniel Flambert of the Bureau of Mines accompanied the party on a number of exploratory trips.

The hospitality and helpfulness of government officials and of the inhabitants throughout the Republic are much appreciated. Many services were rendered by the Garde d'Haiti in providing horses and pack animals, in handling communications, and in many other ways. Useful information was supplied by the geologists of the Reynolds Mining Corp., who were prospecting for aluminum ore in the Republic. Officers of the United States Embassy in Port-au-Prince were helpful at all times in making necessary arrangements. Special thanks are due to Dr. George A. Thiel, Chairman of the Department of Geology, and to Dr. Frank F. Grout, Director of the Rock Analysis Laboratory of the University of Minnesota, who made arrangements allowing the Geological Survey to use the facilities of the department and the laboratory.

OCCURRENCE OF ALUMINOUS LATERITIC SOIL

The Republic of Haiti occupies approximately the western third of the island of Hispaniola, which lies between Jamaica and Puerto Rico in the West Indies (fig. 6); the eastern two-thirds constitutes the Dominican Republic. The aluminous lateritic soil deposits of Haiti are part of a larger area that occurs as a belt across Jamaica, southern Haiti, and the southwestern part of the Dominican Republic. The largest deposits in Haiti are on the Rochelois Plateau on the Southern Peninsula. (See pl. 21.) The other areas in which similar lateritic soil occurs are: (1) Beaumont, in the Massif de la Hotte; (2) the vicinity of Savane Zombi, in the Massif de la Selle; and (3) Savane Terre Rouge, on the plateau northwest of Gonaïves. (See pl. 21.) In none of these regions were large deposits found; the main part of this report, therefore, deals with the Rochelois Plateau region.

ROCHELOIS PLATEAU REGION

GENERAL FEATURES

Location, area, and accessibility.—The largest deposits of aluminous lateritic soil in Haiti are on the massive limestone of the Rochelois Plateau in the north-central part of the Southern Peninsula. (See pl. 20.) The lateritic soil region (pl. 22) is approximately 4 miles in length in an east-west direction and 2 miles in width. It lies about 6 miles in an air line southwest of Miragoâne but is at least 9 miles by trail. The trail follows a road that had been improved within recent years, but in 1943 was not passable by ordinary motor vehicle. The plateau can be reached also by trail from St.-Michel du Sud, about 7.5 miles south of Miragoâne on the highway to Aquin. The trails from Miragoâne and from St.-Michel join on the eastern edge of the plateau and from this point a trail leads to the west.

Vegetation and industry.—Most of the plateau is open, parklike grassland or savanna, but in the days of the French colony the Rochelois Plateau was an important coffee-producing area, and originally there must have been a good cover of forest. Continued depletion of the forests for firewood and charcoal has resulted in a gradual decline of the coffee industry. At present, coffee plants are cultivated only in scattered groves where trees provide adequate shade.

There are a large number of landowners and small holdings, and the pleasant landscape is broken by numerous hedges of yucca which are used as fences. In comparison with certain lowland areas of Haiti, the plateau is not heavily populated. The chief agricultural produce consists of red beans, sweetpotatoes, and yams. A variety of fruit trees are grown, and banana groves are usually planted near dwellings. Some beef cattle, goats, pigs, and chickens are raised.

Climate.—Meteorological data are not available for the Rochelois Plateau, but the altitude of the region serves to modify the tropical climate that characterizes the lowlands of Haiti. The climate is a healthful one; although the days are hot, the nights are cool, and blankets are necessary, especially during the rainy season. The mean annual temperature is probably about 21° C. (70° F.). The rainfall comes in two wet or rainy seasons and is estimated to be between 1,500 and 2,000 millimeters (60 to 80 inches) annually. The greatest part of the rain falls during September, October, and November. December, January, and February are dry months. The summer rains are chiefly in April, May, and June. July and August are hot and relatively dry.

TOPOGRAPHY

The eastern part of the Rochelois Plateau southwest of Miragoâne is marked by large sinkholes partly filled with red soil. There are no permanent surface streams; the heavy rainfall is absorbed by the soil and passes away through the subterranean drainage of the limestone. The valleys and depressions on the plateau probably were developed by solution. These valleys and their complementary limestone hills and ridges give a relief of about 1,300 feet to the plateau. The floor of the largest valley on the plateau is approximately 2,700 feet above sea level. Northwest of this valley a limestone range trending northeast rises to 3,500 feet above sea level and is the most prominent physiographic feature on the plateau. From this range the land surface slopes eastward, and the eastern part of the Rochelois Plateau lies about 2,000 feet above sea level.

The edges of the Rochelois Plateau are being dissected by streams, and on the northern scarp are the Rivière Charlier, Rivière Dupuy, and Petite Rivière de Nippes, the last-mentioned forming the western boundary of the region of particular interest in this report. On the southern slope of the plateau the streams are less well defined.

Ste.-Croix Valley.—The main valley is centrally situated and is known locally as Ste.-Croix. It is an arcuate depression convex to the north and concave to the south. Measured along an east-west line on the map (pl. 22) the Ste.-Croix Valley is 7,850 feet in length. Along a north-south line, centrally located, the valley is 3,250 feet in width. The floor of the valley, approximately 2,700 feet above sea level, is characterized by a hilly or undulating sinkhole topography. Along the southern edge of the valley the slope off the limestone is rather gentle, but along the northern edge scarplike ridges rise 100 to 200 feet above the valley floor. At the foot of the scarp along the northwestern margin of the Ste.-Croix Valley is a chain of prominent sinkholes.

Tranquille-Trahison Valley.—North of the Ste.-Croix Valley and similar to it in shape is a smaller arc-shaped valley known as Tranquille-Trahison. The well-developed southwestern limb of this second valley lies 100 to 150 feet above the level of the Ste.-Croix depression. The southeastern limb can be recognized in remnants northeast of the Ste.-Croix Valley, but this part of the plateau has been dissected by the headward-cutting branches of Rivière Charlier and Rivière Dupuy, which have cut deep valleys on the northern edge of the plateau. The Tranquille-Trahison Valley is 10,000 feet long in a northeast-southwest direction and ranges in width from 600 to 2,100 feet. At about the middle and near the constricted part of the valley is a large sinkhole. (See pl. 22.) A second sinkhole was mapped just north of the soil boundary. These and other sinkholes control the drainage of the Tranquille-Trahison Valley. The undulating surface of the valley slopes toward the northeast from an altitude of about 3,000 feet in the southwestern part of the valley to an altitude of about 2,800 feet in the northeastern end.

A range of limestone ridges and hills on the plateau along the northwestern edge of the Tranquille-Trahison Valley is the most conspicuous physiographic feature of the Rochelois Plateau. This range attains an altitude of 3,500 feet and is visible on the horizon from the eastern part of the plateau. At the northeastern end of the range and north of the main convex bulge in the Ste.-Croix Valley is a small rounded hill of limestone, approximately 2,950 feet above sea level, that marks the northern edge of the plateau. From this point Miragoâne and other coastal towns and Gonâve Island are visible.

East extension valleys.—In the eastern part of the Rochelois Plateau region are several valleys between ridges of limestone trending southward. These valleys, between 2,000 and 2,600 feet above sea level, are at a lower elevation than the main Ste.-Croix Valley and slope to the south and southeast. They have not been fully explored and are shown only in part on plate 22. The fluted and pinnacled limestone ridges that rise steeply on the northern edges of the soil areas become less pronounced to the south.

STRUCTURE

The main structural lines of Rochelois Plateau probably conform to the nearly east-west structural trend of the rocks of the Southern Peninsula of Haiti. According to Woodring[4] the Eocene limestone of the peninsula may have been folded near the end of the period or in the Oligocene, but the main deformation probably took place in late Miocene or Pliocene time. The folding was accompanied by thrusting and crumpling of the beds that produced many local structures. The bow-shaped Ste.-Croix depression and its smaller counterpart at a higher level partly represented in the Tranquille-Trahison Valley were developed in a secondary anticlinal fold plunging at a low angle to the north. Subordinate folds are suggested by the valleys and ridges to the east. This interpretation suggests that the arcuate valleys represent beds of two stratigraphic levels in the folded strata, which because of characteristics of texture or composition were slightly more soluble than the others. The local plunge of the folded strata northward controlled ground-water movements and thus influenced the development of the sinkholes in the limestone.

Lack of exposures and the fact that the traces of bedding planes in the limestone have been obliterated by solution and recrystallization make it difficult to obtain reliable structural data, and details of the structure await time for further study. The inferred relationship of topography and soil accumulation to structure is shown in the cross sections. (See pl. 22.)

LIMESTONE

Description.—The limestone of the Rochelois Plateau is fine-grained, white to gray or yellowish gray. The massive, structureless character of the rock is largely the result of solution and recrystallization. Locally limestone breccia has been formed; the cementing material is calcium carbonate or red lateritic material that contrasts conspicuously with the white limestone fragments. Solution features range from large sinkholes and cavernous openings to innumerable solution pits and small cavities; pinnacles and toothlike protuberances of limestone are common. Exposed surfaces are usually pitted, honeycombed, fluted, or otherwise marked by solution. The hill slopes are generally covered

[4] Woodring, W. P., Brown, J. S., and Burbank, W. S., op. cit., pp. 331–337.

with limestone rubble ranging in size from pebbles to large boulders.

Composition.—A chemical analysis of a sample of limestone taken from a point approximately 650 feet (200 meters) southwest of the church (pl. 22) was made by Norman Davidson, of the Geological Survey. The analysis follows:

Analysis of limestone from the Rochelois Plateau

[Norman Davidson, analyst]

CaO	55.90	Al_2O_3	0.01
MgO	.05	Fe_2O_3	.08
SiO_2	.02	P_2O_5	.01

If the lime is calculated as calcium carbonate, the sample contains 99.7 percent of $CaCO_3$ The grain density of a composite of six samples of the limestone was found to be 2.706 grams per cubic centimeter. This value is slightly less than that of pure calcite crystals (2.710).

An X-ray analysis of a residue obtained by dissolving 50 grams of limestone in dilute acetic acid showed only a phosphate of the apatite group. This sample was taken from the limestone ridge just north of auger hole 22 in the northern part of the Ste.-Croix deposit. Examination of the residue with a petrographic microscope revealed no identifiable minerals other than the phosphate mineral. C. S. Ross of the Geological Survey noted a micalike flake with small 2V (optically negative). This flake contained oriented inclusions suggestive of an original mica mineral. A differential thermal analysis of the residue did not show either clay minerals or bauxite minerals. The purity of the limestone is striking, and significant in relation to probable source material of the alumina.

Stratigraphic relations.—The massive limestone of the Rochelois Plateau appears to be part of an Eocene limestone series that Woodring and Brown [5] described as the most widespread group of rocks in the Massif de la Hotte on the Southern Peninsula. This series rests unconformably on a basement of dark basaltic rocks, older limestone, and metamorphic rocks. Conglomerate beds with abundant basaltic debris, interbedded with dark shaly limestone beds, mark the base of the series. Two types of limestone were differentiated in the remaining and principal part of the series. Woodring and Brown [6] describe these types as follows:

> . . . (1) white thin-bedded limestone, generally dense but here and there open-textured and chalky, usually breaking with conchoidal fracture, most of it more or less cherty and some of it extremely so, in few places containing determinable fossils but rarely rich in orbitoid Foraminifera; (2) massive or thick-bedded white limestone, in some places crystalline, weathering gray and to pitted forms, at many places full of small undetermined Foraminifera but at a few containing

[5] Woodring, W. P., Brown, J. S., and Burbank, W. S., op. cit., p. 132.
[6] Woodring, W. P., Brown, J. S., and Burbank, W. S., op. cit., p. 134.

large Foraminifera. The second type closely resembles the massive upper Eocene limestone in the northern part of the Republic. It yields a characteristic red ocherous soil and in many places forms a solution breccia.

Woodring and Brown estimated that the Eocene limestone may be as much as 6,500 feet (2,000 meters) thick. The limestone of the Rochelois Plateau is estimated to be about 2,000 feet (610 meters) thick, but no exact measurement of the section was made. Beds younger than the Eocene limestone have not been identified on the plateau. According to Woodring and Brown,[7] nonmarine Miocene sediments occur in the Asile Valley just southwest of the plateau. The contacts of these beds with the Eocene limestone are either faulted or obscured, but the Miocene beds are said to contain debris derived from the Eocene limestone. In the northwest part of the Massif de la Hotte and southwest of Jérémie, Miocene marl occurs on the Eocene-Oligocene limestone. In the central part of the Republic a thick section of marine Oligocene and Miocene sediments overlies the Eocene.

Age.—Mrs. Esther R. Applin of the Geological Survey made a cursory examination of four samples containing foraminifera. Although the specimens are poorly preserved, they suggest a lower Eocene age. Mr. C. W. Cooke of the Geological Survey examined a collection of echinoids from the limestone ridge northwest of the Tranquille-Trahison region and identified the species as belonging to *Echinanthus* which he assigns to the Eocene. Woodring and Brown tentatively assigned the massive limestone that caps most of the upland of the Southern Peninsula west of Petie-Goâve to the upper Eocene, suggesting that some of the beds may be of Oligocene age. It is likely that further detailed studies will show a range in age for the limestone beds of the region.

LATERITIC SOIL DEPOSITS

The lateritic soil deposits in the three main valleys were explored by mapping and drilling with a hand auger in order to arrive at estimates of areas and thicknesses of the deposits for volumes and tonnages of reserves. The deposits of lateritic soil in the valleys of the Rochelois Plateau lie at successively higher elevations from east to west, and on this basis they have been divided as follows: (1) the East Extension of Ste.-Croix, or simply the East Extension deposit, which includes the valleys of the eastern part of the plateau, lying between 2,000 and 2,600 feet (610 to 790 meters) above sea level; (2) the centrally situated Ste.-Croix Valley, approximately 2,700 feet (820 meters) above sea level; and (3) the Tranquille-Trahison Valley, farther west and approximately 2,900 feet (880 meters) above sea level.

For convenience in handling samples, the deposits were further sub-

[7] Woodring, W. P., Brown, J. S., and Burbank, W. S., op. cit., pp. 228–231.

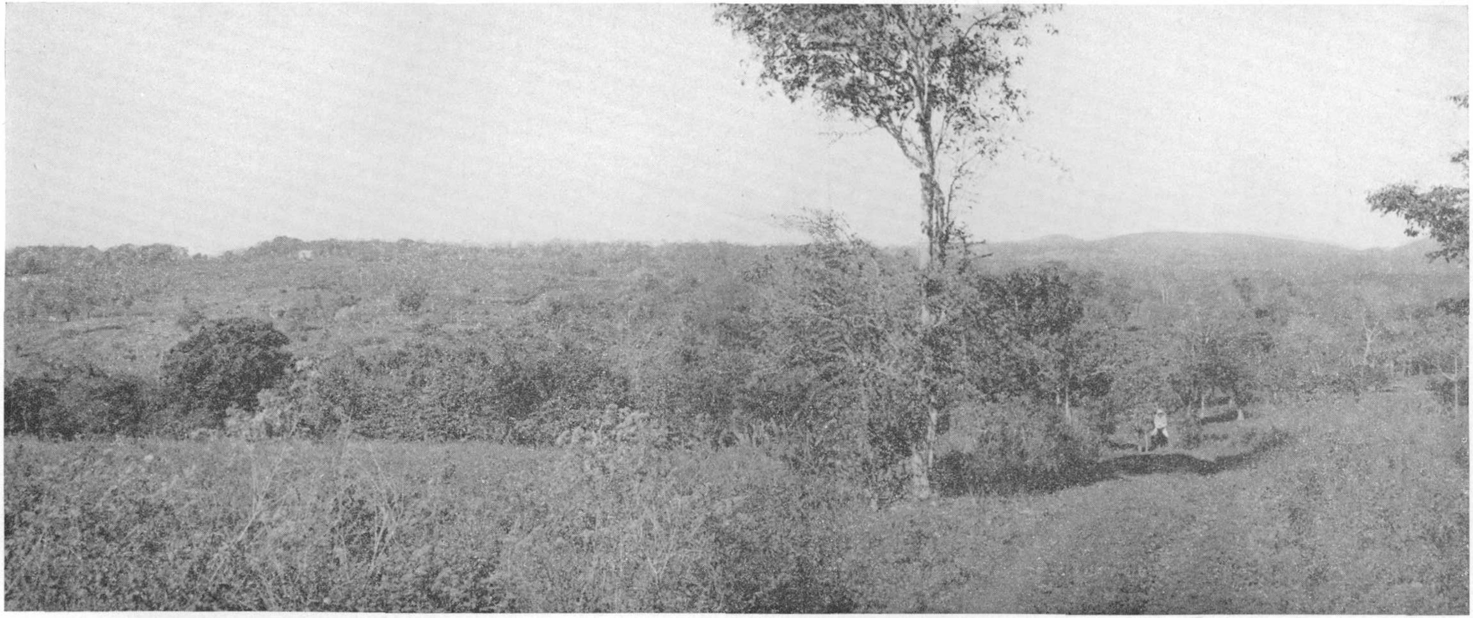
divided into 11 soil areas numbered on the map (pl. 22) from east to west. Area 4 is included in the East Extension deposit rather than in the Ste.-Croix deposit because it is the northern extension of a larger unmapped valley lying to the southeast of the Ste.-Croix Valley. The greater part of this unmapped valley is less than 2,500 feet (760 meters) above sea level or about 175 feet (50 meters) below the level of the Ste.-Croix Valley proper. The Ste.-Croix deposit is subdivided into 4 areas or quadrants in a manner to divide the number of holes and samples into nearly equal groups. The Tranquille-Trahison deposit is similarly divided into 3 areas.

EXPLORATORY DATA

A summary of the hand-auger exploration of the deposits is given in table 1. On the East Extension deposit auger-hole sites were located by Brunton compass-pace traverse and were spaced approximately 600 feet (183 meters) apart. On the main deposit in the Ste.-Croix Valley auger holes were located on a grid marked on the ground by stakes 400 feet (122 meters) apart. The locations surveyed with the plane table are indicated by an elevation figure on the map. (See pl. 22.) Other locations were made with a Brunton compass and tape. The datum for plane-table elevations is a point in the center of the road where it is joined by the path leading to the house of Henry Riquet. This point, near the center of the Ste.-Croix Valley and just south of auger hole 89, was determined by aneroid readings to be 2,650 feet (808 meters) above sea level. The Ste.-Croix deposit grid was

TABLE 1.—*Data from drilling and mapping in the Rochelois Plateau region*

Deposit	Drilling data		Soil area		Volume of soil		Average depth	
	Number of holes	Total footage	Acres	Hectares	Cubic yards (thousands)	Cubic meters (thousands)	Feet	Meters
East Extension:								
Area 1	5	37.9	57	23	434	332	4.7	1.43
Area 2	10	70.1	87	35	782	598	5.6	1.71
Area 3	9	62.9	91	37	819	350	5.6	1.71
Area 4	4	25.4	59	24	458	626	4.8	1.46
Total	28	196.3	294	119	2,493	1,906	5.3	1.61
Ste.-Croix:								
Area 5	31	230.7	137	56	1,329	1,016	6.0	1.83
Area 6	33	382.1	134	54	2,216	1,694	10.3	3.14
Area 7	30	437.6	141	57	2,843	2,174	12.5	3.81
Area 8	37	380.8	160	65	2,214	1,693	8.6	2.62
Total	131	1,431.2	572	232	8,602	6,577	9.3	2.83
Tranquille-Trahison:								
Area 9	33	230.1	177	72	1,676	1,281	5.9	1.80
Area 10	27	215.5	97	39	1,144	875	7.3	2.25
Area 11	28	213.2	103	42	1,103	844	6.6	2.01
Total	88	658.8	377	153	3,923	3,000	6.5	1.98
Grand total	247	2,286.3	1,243	504	15,018	11,483	7.5	2.29



ROCHELOIS PLATEAU, LOOKING WEST FROM THE EASTERN EDGE OF STE. CROIX VALLEY.

extended to the Tranquille-Trahison deposit where a similar procedure was used in locating auger-hole sites.

ISOPACH MAP

The distribution of the lateritic soil is shown on plate 22 by isopach lines, which connect points of equal soil thickness. The isopach interval is 5 feet, and the deeper parts of the deposits are indicated by a number of lines more or less concentrically disposed. The greatest accumulation of the soil is in the northwestern part (area 7) of the Ste.-Croix Valley where sinkholes are prominent on the northwestern edge of the valley below the limestone scarp. Two of the larger sinkholes are shown on plate 22. These sinkholes are composite sinks and have accumulations of soil as much as 30 feet (9 meters) deep, as indicated by auger holes.

PHYSICAL CHARACTER OF THE SOIL

The lateritic soil ranges in color from light yellow brown to dark chocolate brown, reddish brown or dark purplish red. The finely divided soil is remarkably permeable and soaks up the rainfall with such avidity, that within a few hours after a downpour the soil can easily be cultivated. However, the trial and spots where the soil has been packed become slick and slippery after rains. The red earth adheres tenaciously to surfaces on which it dries, and it must be scraped and brushed off or soaked in water to be removed. The surface soil is generally loose and friable; the first few feet are penetrated with ease by the soil auger, but with increasing depth the soil becomes more compact, and drilling is often slow and difficult. Auger holes stand up remarkably well; it was possible to deepen holes several weeks or months after they were first drilled.

Two trenches were dug in the Ste.-Croix deposit to study vertical sections of the soil (pl. 22). The first trench was dug 130 feet (40 meters) southwest of auger hole 6 on the western slope of a hill near the eastern edge of area 7 and approximately 1,100 feet (335 meters) north of the road. The trench was dug to a depth of 9 feet, which is probably less than half the depth of the soil at this place. A second trench was dug near auger hole 89, just north of the aneroid station. Soft, white, crumbly limestone was reached at a depth of 7.5 feet and solid limestone at 7.7 feet, the depth it was found in the auger hole. As shown by these trenches the upper 5 or 6 inches of the soil is yellowish brown changing downward to reddish brown. Irregular wavy black streaks, which are concentrations of managanese dioxide, oriented at steep angles with the surface, were observed in the walls of the first trench. In the second trench black streaks were found only near the base of the soil just above the limestone bedrock. Except for

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these streaks the soil is remarkably uniform and there are no well-defined soil horizons. Tubes and "borings" and a few roots were found through the vertical sections. Grub and worm holes were common to a depth of 2 feet; grass roots were abundant to a depth of 1 foot.

Blocks of soil removed from the trenches were somewhat friable, but with care these blocks could be shaped into bricklike forms. Exposed to the air the blocks dried to a reddish-brown, porous "brick" that possesses appreciable coherence. For laboratory study blocks of the soil were wrapped in waxed paper and placed in air-tight containers or were dipped in paraffin immediately on being removed from their original positions.

The porosity and moisture content of samples from the first trench were determined at Damien, and similar determinations on blocks from the second trench were made at the University of Minnesota. The results in table 2 show not only the high porosity of the soil, approaching 50 percent, but also its extraordinary capacity to retain water. This capacity is indicated in the degree of saturation of the available pore space, ranging from 59 to 98 percent in the samples tested, which is significant in view of the fact that the trenches were dug near the end of the dry season. The first trench was dug on February 18, 1944; the weather for the 14 days previous to that date had been clear with only a few very light showers. The second trench was dug on March 20, 1944; although the spring rains had been expected, the season was abnormally dry, and precipitation, according to the inhabitants, was much below the average. The permeable soil soaks up the heavy rainfall, allowing the excess water to pass down and away through the subterranean drainage in the limestone, but at the same time it acts as a reservoir retaining and storing an enormous amount of water.

TABLE 2.—*Determinations of moisture, porosity, and degree of saturation of blocks of soil*

Trench No.	Depth (feet)	Weight (pounds per cubic foot)		Moisture (percent by weight)	Porosity (percent of pore space by volume)	Saturation (percent of pore-space moisture)
		Wet	Dry			
1	4 -5			23		
	5 -6	123	96	22	45	97
	6 -7	121	98	19	44	84
2	1½-2	109	92	16	48	59
	2½-3	114	92	19	48	73
	6½-7	121	92	24	48	98

CHEMICAL COMPOSITION

Because time and facilities were not available for analyzing all the samples collected, an alternative was accepted: using the samples to prepare composite samples representing deposits or portions of deposits of the soil. Analyses of 11 composite samples are given in table 3, each composite sample representing an area on plate 22. The sample numbers correspond to the areas shown in plate 22. Additional analyses are recorded in tables 6 and 7. The composite samples show the following ranges for the principal constituents:

Range of principal constituents[1] *of soil samples from Rochelois Plateau region*

SiO_2	2.4– 5.3	Fe_2O_3	20.8–23.5
TiO_2	2.3– 3.1	MnO_2	.4– .7
P_2O_5	.3– .8	Loss on ignition	20.1–25.8
Al_2O_3	42.6–49.4		

[1] Lime and magnesia are sparingly present in the soil.

TABLE 3.—*Chemical analyses of composite samples representing areas in the Rochelois Plateau deposits*

[Calculated available Al_2O_3 equals percent Al_2O_3 minus percent SiO_2 times 1.1. S. S. Goldich, analyst]

	Percent of constituents for indicated deposit and numbered sample										
	East Extension deposit				Ste.-Croix deposit				Tranquille-Trahison deposit		
	1	2	3	4	5	6	7	8	9	10	11
SiO_2	4.6	4.6	4.4	4.2	2.37	2.91	2.44	5.30	2.41	2.5	3.5
TiO_2	2.8	2.7	2.8	2.6	2.67	3.14	2.99	2.77	2.52	2.6	2.3
P_2O_5	.4	.3	.4	.6	.52	.65	.66	.62	.80	.7	.8
Al_2O_3	48.8	49.4	47.2	46.3	48.28	47.75	47.56	42.64	46.46	47.0	46.2
Fe_2O_3	22.2	22.3	21.7	21.0	21.47	21.79	22.05	23.45	21.39	21.2	20.8
MnO_2	.5	.4	.4	.4	.49	.45	.47	.62	.71	.7	.6
MgO	------	------	.1	------	.06	.04	.09	.18	.06	------	------
CaO	------	------	.0	------	tr.	tr.	.08	.04	.18	------	------
H_2O-	2.1	2.1	2.2	2.6	1.99	2.27	1.88	2.08	1.80	1.8	2.5
Loss on ignition	18.4	18.0	20.8	21.4	22.31	21.24	22.08	22.28	23.64	23.4	23.3
Total	99.8	99.8	100.0	99.1	100.16	100.24	100.30	99.98	99.97	99.9	100.0
Density	------	------	------	------	------	2.840	2.834	2.790	------	------	------
Available Al_2O_3	43.7	44.3	42.4	41.7	45.7	44.6	44.9	36.8	43.8	44.2	42.3

During the course of the field work samples were analyzed for their content of silica and total iron as Fe_2O_3, as a guide in the exploration. In this preliminary work at Damien the silica was not volatilized with hydrofluoric acid, and consequently the contaminating substances weighed with it introduced a positive error, but this error was in part compensated by loss of silica due to incomplete dehydration. The results are given in table 4. These data are sufficiently accurate to bring out significant chemical features and differences in samples. Averages for silica and total iron based on 20 of 33 holes in area 6 and on 24 of 34 holes in area 7 are comparable with results obtained for the composite samples representing these areas.

Comparison of averages based on determinations made at Damien with analyses of composite samples

Area No.	Approximate determinations (percent)		Composite samples (percent)	
	SiO_2	Fe_2O_3	SiO_2	Fe_2O_3
6	3.5	22.4	2.9	21.8
7	2.5	22.6	2.4	22.1

TABLE 4.—*Approximate determinations of SiO_2 and total iron as Fe_2O_3 on samples from the Rochelois Plateau region*

[Location of auger holes is given on plate 22. A. Haspil, analyst]

Auger hole No.	Depth in feet	Laboratory No.	SiO_2 (percent)	Total iron as Fe_2O_3 (percent)	Auger hole No.	Depth in feet	Laboratory No.	SiO_2 (percent)	Total iron as Fe_2O_3 (percent)
Surface	0- 1	7	8.0	24.7	31	1-11	156-157	3.4	22.5
Do	0- 1	16	8.1	21.6	32	1-11.9	158-159	3.8	23.0
Do	0- 1	17	7.7	21.2	33	1-18	160-163	4.3	22.0
1	1-12.9	70	3.3	21.8	35	1-11.1	165-166	3.7	21.0
2	1-13	71-73	3.4	22.2	36	1-12.7	167-169	3.2	20.8
4	1- 8	75-76	1.5	22.2	38	1-20	172-175	3.6	22.2
5	1- 5	77	2.2	23.9		20-27.5	176	2.8	22.6
	5-10	78	1.6	23.1	39	1-14.7	177-179	4.4	23.2
	10-15	79	2.4	23.5	40	1- 7.5	180	1.5	20.8
	15-18.3	80	1.4	21.2	41	1- 7.4	181	1.8	20.6
6	1-20	81-84	2.7	22.3	42	1- 9.5	182-183	2.3	22.1
	20-26	85	1.9	21.9	43	1-5	184	7.9	22.4
7	1-20.8	86-89	3.2	26.5		5-10	185	5.3	22.4
8	1-11.7	90-92	2.1	21.7		10-16	186	1.9	21.2
9	1-20	93-96	4.9	24.4	44	1- 5	193	4.9	24.0
10	1- 5	97	3.0	25.5		5-10	194	2.4	24.2
	5-10	98	1.2	20.4		10-15	195	2.6	24.5
	10-15	99	.7	21.0		15-20	196	1.7	23.5
	15-17.8	100	.8	19.2		20-26.4	197	2.1	22.2
11	1-10.3	101-102	2.9	22.6	47	1-12.7	198	4.8	21.8
12	1- 6.8	103	2.1	20.8	59	1-10	199	2.3	23.2
13	1-13	104-106	2.9	23.4	62	1- 8.5	200	3.1	23.0
14	1-21.5	107-110	3.2	22.9	63	1- 5	201	6.9	25.0
15	1- 5	111	3.1	23.3		5-10	202	6.0	24.4
	5-10	112	1.7	22.2		10-15	203	4.5	24.8
	10-14.8	113	3.7	23.4		15-20	204	4.4	24.1
17	1- 6.8	115	1.7	22.2		20-33.4	205	3.9	23.0
18	1- 7.3	116-117	2.3	22.4	66	1- 5	206	4.3	26.2
19	1- 8.5	118-119	1.5	21.4	70	1- 7.7	207	4.2	22.7
20	1- 7.9	120-121	.3	21.2	76	1- 5	208	2.3	22.2
21	1- 7.9	122	1.9	20.6		5-10	209	1.7	20.7
22	1- 5	123	4.4	21.7		10-16.5	210	1.5	20.5
	5-10	124	3.0	23.0	80	1- 7.3	211	1.7	20.8
	10-15	125	2.5	22.5	86	1- 5	212	3.8	22.1
	15-20	126	2.8	22.9	87	1- 6.5	213	1.7	20.7
	20-28.3	127	3.5	23.4	96	1- 5	215	9.0	21.4
23	1-20	128-131	3.8	22.8		5-10	216	10.3	21.1
	20-25	132	2.8	22.3		10-15	217	7.1	23.3
	25-30	191	2.9	24.2		15-20	218	4.5	23.6
	30-36.8	192	2.6	25.0		20-25	219	13.8	23.1
24	1- 5	133	2.3	22.9		25-30	220	20.4	21.3
	5- 9.2	134	1.1	20.7		30-34	221	21.8	20.9
25	1- 5	135	6.6	26.7	102	1- 7	222	1.8	22.8
	5-10	136	2.7	24.1	110	1- 9.6	223	12.6	22.9
	10-15	137	2.4	22.9	114	1- 5	224	12.2	23.6
	15-20	138	2.0	23.3		5-10	225	11.9	23.1
	20-25	139	3.1	24.0		10-15	226	11.2	24.0
	25-30	190	2.6	21.6		15-21.5	227	10.1	23.6
26	1-20	140-143	3.5	23.4	116	1- 5	228	5.7	26.5
	20-25.5	144	7.1(?)	26.5		5-10	229	5.2	26.0
27	1- 9.6	145-146	2.4	22.0		10-15	230	4.4	23.7
28	1- 7.3	147-148	4.7	22.0		15-20	231	5.4	23.0
29	1- 5	149	2.4	21.5		20-25	232	4.5	23.1
	5- 8.3	150	1.0	23.2		25-32.4	233	5.7	23.2
30	1-20	151-154	4.7	22.2	118	1- 9.5	234	2.6	23.3
	20-23	155	3.7	22.5	121	1- 5	235	3.4	21.4

TABLE 4.—*Approximate determinations of SiO_2 and total iron as Fe_2O_3 on samples from the Rochelois Plateau region*—Continued

Auger hole No.	Depth in feet	Laboratory No.	SiO_2 (percent)	Total iron as Fe_2O_3 (percent)	Auger hole No.	Depth in feet	Laboratory No.	SiO_2 (percent)	Total iron as Fe_2O_3 (percent)
123	1- 6	236	2.7	25.3	248	1- 2	262	6.3	19.7
129	1- 5	237	4.6	26.3		2- 6.7	263	.9	18.5
	5-10	238	1.5	23.4	258	1- 2	264	5.2	19.4
	10-15	239	1.3	21.8		2- 5	265	1.4	19.0
	15-20	240	7.4	23.4		5- 9	266	1.3	19.0
	20-28.5	241	13.0	19.5	302	1- 7	302	2.8	24.0
130	1- 6	242	2.1	20.4	303	1- 5.7	303	3.2	20.7
134	1- 3	243	5.5	22.8	306	1- 5.2	306	3.9	21.9
	3- 8	244	5.1	21.8	307	1-10	307	6.6	22.6
	8-12.7	245	3.2	20.7	308	1- 7.4	308	2.6	22.2
140	1- 3	246	4.6	22.6	309	1- 7.5	309	3.2	21.7
	3- 8	247	1.4	20.5	311	1- 7.5	311	3.2	21.5
	8-12.4	248	1.3	20.5	313	1- 8.2	313	2.4	21.3
155	1- 3	249	4.2	22.2	315	1- 8.6	315	4.6	22.4
	3-11.2	250	2.3	22.2	320	1-11.2	320	8.2	23.4
161	1- 3	251	6.8	22.2	322	1- 6.5	322	2.4	-------
	3- 8	252	5.6	23.2	323	1- 5	323	6.9	22.4
201	1- 3	253	7.8	22.3	324	1- 7	324	5.4	23.2
	3- 8	254	3.7	22.5	325	1- 9	325	4.5	23.4
	8-13	255	1.7	21.0	326	1- 8.2	326	2.1	22.0
212	1- 3	256	3.8	20.4	327	1-10.7	327	6.2	23.6
	3- 8.4	257	3.3	21.6					
220	1- 3	258	5.0	22.4					
	3- 8	259	3.9	22.1					
	8-14	260	4.0	21.6					
	14-20	-------	-------	-------					
	20-24	261	4.2	21.7					

REGIONAL DIFFERENCES

The differences in chemical composition indicated in the analyses of the composite samples in table 3 are small. Weighted averages for the three deposits and an average for the region have been computed and are given in table 5. These averages show a relative decrease in the content of silica and an increase in the loss on ignition in the lateritic soil deposits from east to west. The Ste.-Croix deposit averages slightly higher in titania and in total iron as Fe_2O_3. Within this deposit there is a progressive increase from east to west in total iron

TABLE 5.—*Average chemical composition of the lateritic soil deposits of the Rochelois Plateau Region*

[Calculated available alumina equals percent Al_2O_3 minus percent SiO_2 times 1.1]

	East Extension deposit	Ste.-Croix deposit	Tranquille-Trahison deposit	Average for the region
SiO_2	4.5	3.3	2.8	3.4
TiO_2	2.7	2.9	2.5	2.8
P_2O_5	.4	.6	.8	.6
Al_2O_3	47.9	46.4	46.6	46.8
Fe_2O_3	21.8	22.2	21.1	21.9
MnO_2	.4	.5	.7	.5
MgO	-------	.1	-------	-------
CaO	-------	tr.	-------	-------
H_2O	2.3	2.0	2.0	2.1
Loss on ignition	19.7	22.0	23.4	22.0
Total	99.7	100.0	99.9	100.1
Available Al_2O_3	42.9	42.8	43.5	43.1

from 21.5 percent for area 5 to 23.5 percent for area 8. The average titania content is greater in the northern areas than in the limbs of the bow-shaped valley. Area 8, farthest southwest, with a high average silica content of 5.3 percent, is exceptional in this respect.

VARIATIONS WITH DEPTH AND DIFFERENCES WITHIN AREAS

The analyses of composite samples and the computed averages tend to smooth out differences in composition of the soil that are indicated in the data for individual auger holes and for interval samples from these holes. The partial analyses of table 4 show a concentration of silica in the upper part of the soil. Two surface samples (table 6)

TABLE 6.—*Chemical analyses of surface and auger-hole samples from the Ste.-Croix deposit*

[Nos. 7 and 16, J. G. Fairchild, analyst; Nos. 201-205, 215-221, 223, S. S. Goldich, analyst]

	Percent of constituents of indicated numbered samples				
	Surface samples		Auger hole 63	Auger hole 96	Auger hole 110
	7	16	201-205	215-221	223
SiO_2	6.3	6.3	3.87	10.62	10.86
TiO_2	1.9	4.2	3.28	2.94	2.59
P_2O_5				.43	.73
Al_2O_3	[1] 45.2	[1] 38.3	48.01	38.54	41.88
Fe_2O_3	20.8	24.3	23.10	22.96	21.13
MnO_2			.21	.43	.30
MgO				.16	
CaO				.04	
H_2O-	undet.	undet.	2.48	2.32	3.52
Loss on ignition	25.8	26.9	18.76	21.01	18.44
Total	100.0	100.0	99.71	99.45	99.45

[1] By difference.

7. Surface sample (0-1 foot) near hole 76, area 5.
16. Surface sample (0-1 foot) 285 feet (87 meters) southwest of hole 9, area 7.
201-205. Composite (1-33.4 feet) from hole 63, area 6.
215-221. Composite (1-34 feet) from hole 96, area 8.
223. Composite (1-9.6 feet) from hole 110, area 8.

contain 6.3 percent of silica, or more than twice as much as is indicated in the bulk analyses for areas 5 and 6 in which they were collected. Likewise, the upper portion of the soil contains a larger relative amount of iron oxide than the lower.

Analyses of interval samples from hole 23 (table 7) show variations of the principal constituents with depth in the northern part of area 7. This hole was drilled to 36.8 feet and abandoned in soil. Total iron as Fe_2O_3 was determined in each of seven interval samples. The deviations of the interval samples from the calculated average iron content for the hole are shown in figure 4. The variations for the other constituents are also shown, the standard for comparison being the average of the analyzed intervals. This average may depart somewhat

TABLE 7.—*Chemical analyses of interval samples from auger hole 23, area 7, Ste.-Croix deposit*

[S. S. Goldich, analyst]

	Percent of constituents at indicated depth interval (in feet)							
	1-5	5-10	10-15	15-20	20-25	25-30	30-36.8	Average of analyzed intervals
SiO_2	2.58		2.46		2.47		2.36	2.5
TiO_2	3.46		3.59		2.87		2.30	3.1
P_2O_5	.72		.80		.91		.74	.8
Al_2O_3	45.08		46.28		47.81		48.91	47.0
Fe_2O_3	22.91	23.05	22.70	22.15	21.54	21.34	21.12	22.1
MnO_2	.18		.31		.49		.74	.4
H_2O-	2.10		2.06		1.91		1.75	2.0
Loss on ignition	22.57		21.48		21.90		21.86	22.0
Total	99.60		99.68		99.90		99.78	99.9

from the true average for the entire hole but probably is sufficiently accurate for the present purpose.

The most pronounced variations are those shown by manganese dioxide. Dark discolorations of the soil due to local concentration of manganese dioxide in wavy streaks were noted in the trenches and in the auger samples. The observations of concentration of manganese dioxide in the soil just above the limestone bedrock were so numerous that there is no doubt of the downward migration of manganese in the soil.

Total iron, silica, and titania are above the average in the upper part of the hole and alumina is below the average. Because the principal hydrous minerals are gibbsite and boehmite, the variations of loss on ignition might be expected to follow those of alumina, but this is not the case. The presence of goethite and organic matter may explain the high loss on ignition shown by the upper soil sample. A high loss on ignition was reported also for surface samples 7 and 16 (table 6).

Very different from the usual concentration of silica in the surface soil is the increase in the relative amount of silica with depth shown by two of the deep auger holes in the southwestern part of the Ste.-Croix deposit, area 8. These are hole 96 on the edge of a small sinkhole near the center of the area, drilled to 34 feet before being abandoned, and hole 129 just north of the cemetery near the southwestern end of the area. Hole 129 was drilled to 28.5 feet.

High-silica contents are characteristic also of a number of holes in this area in which the vertical variations are small. These holes include hole 114, drilled to a depth of 21.5 feet, with an average silica content of about 11 percent, and hole 116, with an average silica content of 5 percent. The average content of silica in the soil of area 8 is 5.3 percent, and of alumina is 42.6 percent. To account for these aver-

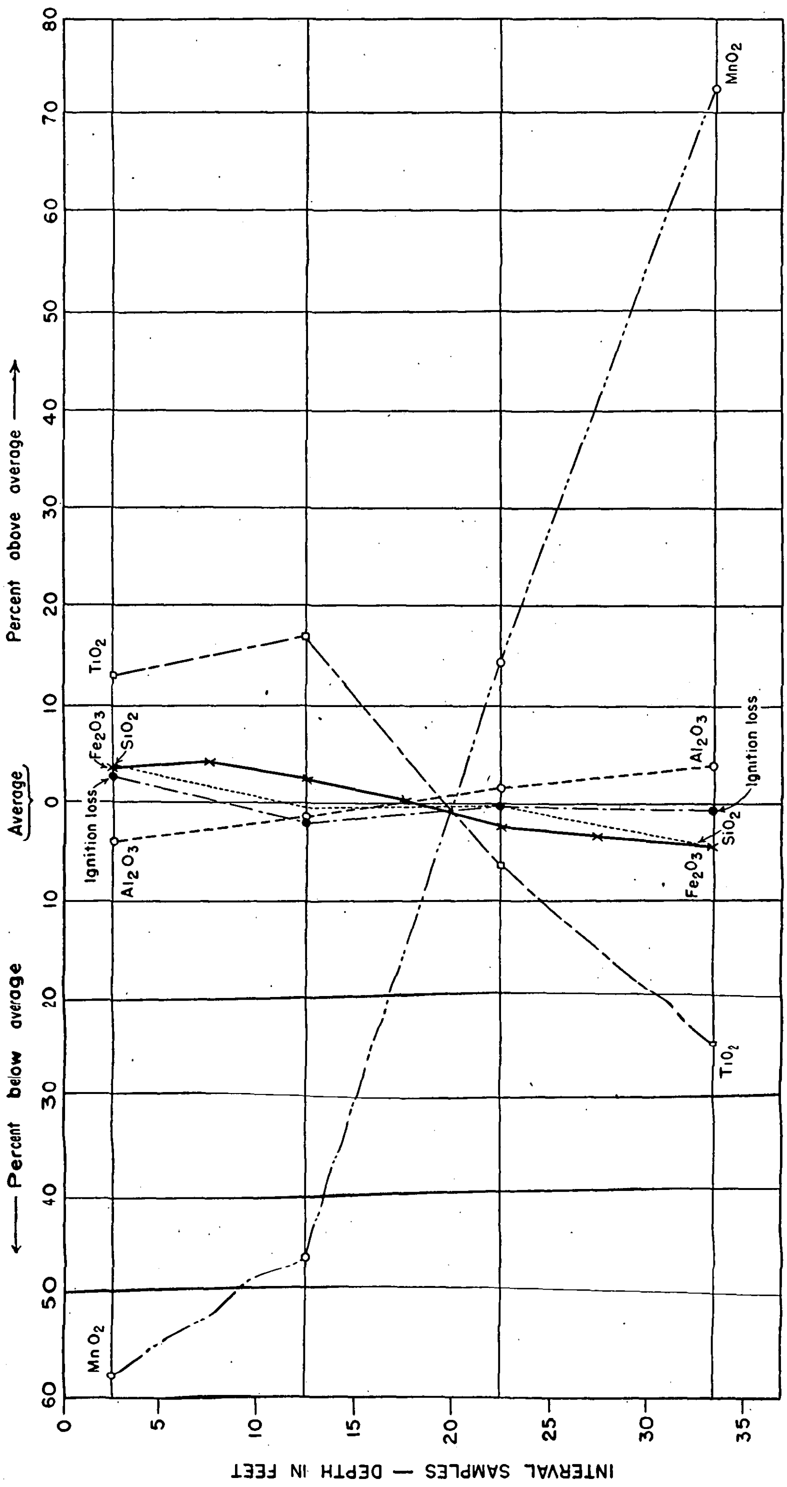

FIGURE 4.—Variations of the principal chemical constituents with depth in analyzed interval samples (table 7) of lateritic soil from auger hole 23, Ste.-Croix deposit.

ages the high silica of certain holes in the area must be offset by lower silica and higher alumina in other holes; as expected, the approximate silica determinations for holes 102, 118, 121, 123, and 130 range from 2 to 3 percent.

There are both lateral and vertical variations of the constituents in the soil, but to what extent the distribution of the principal constituents is influenced by primary differences in the source material cannot be determined because the degree of uniformity of the parent material is not known. Some of the differences noted, as in the case of manganese dioxide, appear to be the result of redistribution of the constituents by ground-water movements. Many of the features of distribution of the constituents are probably related to drainage and soil-water movements that became effective after the soil accumulated.

ORGANIC MATTER

The amount of humus or organic matter in the soil is small. Determinations on a series of samples from the trench near hole 6 are given in table 8. The relative concentration of organic matter in the upper 6 inches of the soil probably is greater than that shown for the first foot. In order to eliminate the greater part of the organic matter and litter near the surface, which would interfere in the chemical testing, the upper foot of soil was not included in the usual sampling of material from auger holes.

TABLE 8.—*Determinations of carbon and organic matter in samples from trench 1, Ste.-Croix deposit*

[A. Haspil, analyst]

Depth, in feet	Carbon (percent)	Organic matter (percent)	Depth, in feet	Carbon (percent)	Organic matter (percent)
0-1	2.53	4.3	5-6	.21	.36
1-2	1.16	2.0	6-7	.18	.31
2-3	.27	.46	7-8	.13	.23
3-4	.15	.25	8-9	.13	.23
4-5	.32	.55			

MINERALOGICAL COMPOSITION

The essential minerals of the lateritic soil of the Rochelois Plateau are gibbisite; aluminum hydroxide, $Al(OH)_3$; and boehmite, the basic oxide of aluminum, $AlO(OH)$. Other minerals that are characteristic of the soil are kaolinite, $Al_2Si_2O_5(OH)_4$, and other minerals of the kaolin group; hematite, Fe_2O_3; and goethite, $HFeO_2$. Accessory minerals include unidentified compounds of titanium, manganese, and phosphorous; quart; magnetite; and zircon. The theoretical composition in oxide form of the essential and characteristic minerals follows:

Mineral	Composition	Percent of indicated essential oxides			
		H_2O	Al_2O_3	Fe_2O_3	SiO_2
Gibbsite	$Al_2O_3{\cdot}3H_2O$	34.6	65.4		
Boehmite	$Al_2O_3{\cdot}H_2O$	15.0	85.0		
Kaolinite [1]	$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$	14.0	39.5		46.5
Goethite	$Fe_2O_3{\cdot}H_2O$	10.1		89.9	
Hematite	Fe_2O_3			100.0	

[1] This term includes possible other minerals of the kaolin group.

Gibbsite and boehmite.—Both gibbsite and boehmite were identified by X-ray and differential thermal analyses. Together they compose about 60 percent of the soil, but the proportions of the two minerals may differ considerably. The average amounts of gibbsite and boehmite in the composite samples representing areas were estimated from differential thermal analyses and the chemical analyses (table 3). About 25 percent of gibbsite and 35 percent of boehmite were found in the samples for areas 1 and 2 in the East Extension deposit. A somewhat larger amount of gibbsite and a smaller quantity of boehmite are contained in the average soil of areas 3 and 4. The soil of the Ste.-Croix deposit, on the average, contains about 45 percent of gibbsite and 15 percent of boehmite; that of the Tranquille-Trahison deposit, about 50 percent of gibbsite and 13 percent of boehmite. There is clearly an increase in gibbsite and decrease in boehmite from east to west in the soil.

Clay minerals.—Samples from auger holes in the southwestern part of the Ste.-Croix deposit (area 8) contain as much as 20 percent of silica, indicating a possible 40 percent of clay mineral. Kaolinite was identified in some of this material by differential thermal analysis. In samples from other parts of the region the amount of clay mineral is estimated to be about 10 percent; in much of the soil, about 5 percent. Data from differential thermal analyses suggest that minerals of the kaolin group less well crystallized than kaolinite may be present. Minerals such as allophane ($Al_2O_3{\cdot}nSiO_2{\cdot}nH_2O$), endellite[8] ($Al_2O_3{\cdot}2SiO_2{\cdot}4H_2O$), and halloysite ($Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$) give diffuse reflections, and patterns for small amounts of these minerals are difficult to detect in X-ray films. These minerals characteristically contain excess water held as adsorbed moisture. In the differential thermal analyses of a number of samples from the Rochelois Plateau and from other localities in Haiti, a coincidence of the presence of adsorbed water with the presence of clay mineral was noted. If the adsorbed water is held in a clay mineral, a correlation between the

[8] Alexander, L. T., Faust, G. T., Hendricks, S. B., Insley, H., and McMurdie, H. F., Relationship of the clay minerals halloysite and endellite: Am. Mineralogist, vol. 28, pp. 1–18, 1934.

amount of moisture lost at temperatures below 110° C. (H_2O-) and the silica contents of the samples can be expected. A good correlation was found in the samples.

Hematite and goethite.—Hematite and goethite make up from 20 to 30 percent of the soil. X-ray patterns of brownish-yellow soil indicate goethite, and those of red soil, hematite. The relative proportions of these minerals have not been determined.

Accessory minerals.—Accessory minerals identified in the soil include quartz, magnetite, and zircon. They usually can be found in the residue remaining after the fine material is washed out of a two- or three-gram sample. In the average soil these minerals are rare, but locally zones have been penetrated by the auger in which there is a somewhat greater concentration of the accessory minerals than usual. Possibly this local concentration is the result of a sorting action resulting from movement of the soil particles into the depressions and sinkholes.

In drill hole 13 in the south-central part of area 7, a peculiar light-yellow soil was found between 5 and 10 feet in depth. Small glistening crystals in this soil proved to be magnetite. In the washed residue quartz was abundant in grains as much as 0.5 millimeter in diameter. Most of the grains are angular or subangular, but many show crystal terminations. The extinction is sharp and uniform. These characteristics suggest that the quartz was derived from volcanic rocks rather than from deep-seated plutonic rocks. The zircon crystals are well formed and average about 0.05 millimeter in length, but crystals have been observed that are 0.1 millimeter or more in length.

The mineralogic forms of the titanium, manganese, and phosphorous have not been determined. The manganese dioxide probably is pyrolusite. Phosphorous may be present as a phosphate of aluminum or iron.

RESERVES

METHOD OF COMPUTING

By measuring the areas between isopach lines on the map with a planimeter, the surface areas underlain by various thicknesses of soil were obtained, and the volume of soil in each area was calculated. These data are given in table 1. In converting the volume figures to tonnage figures a conversion factor of 27 cubic feet of soil in place per long ton on a dried basis was used. This is a conservative factor, because the data in table 2 indicate that in the two trenches dug in the Ste.-Croix deposit a cubic foot of dry soil weighs about 92 pounds. On this basis the equivalent of 1 long ton of dry material is contained in 24 cubic feet of soil in place. Using a conversion factor of 27 cubic feet per long ton of lateritic soil, the volume figures of table 1 can be read directly as long tons.

As a check on the isopach method of estimating tonnage, the reserve of the soil in area 6 of the Ste.-Croix deposit was calculated by the average-depth-and-area method. The result of the calculation, 2,250,000 long tons, compares favorably with the estimate of 2,216,000 long tons made for this area by the isopach method. The isopach method is believed to be conservative.

RESERVES IN DRILLED AREAS

Fifteen million long tons of aluminous lateritic soil in place, calculated on a dry basis, is indicated in the drilled areas of the Rochelois Plateau region. Of this tonnage, 57 percent is in the Ste.-Croix deposit; 26 percent is in the Tranquille-Trahison deposit; and 17 percent is in the East Extension deposit. The surface areas from measurements on the map are 572 acres for the Ste.-Croix deposit, 377 acres for the Tranquille-Trahison deposit, and 294 acres for the East Extension deposit. The total soil area is about 1,243 acres. The indicated reserves in tons by areas are given in table 9. The reserves make up all the soil from the surface to the limestone bedrock.

GRADE

The different physical and chemical properties of bauxites from different parts of the world make it difficult to arrive at a satisfactory method of grading or of comparing bauxites as to quality. Experience in Bayer process plants in Arkansas has shown that, on the average, alumina is lost in the process in proportion to the silica content multipled by a factor of 1.1 On this basis the available alumina contents of the lateritic soils of Haiti have been calculated from the silica and alumina percentages for the composite samples (table 3) and for the computed average analyses (table 5). The average available alumina content of the soil for the region is about 43 percent. The

TABLE 9.—*Reserves of aluminous lateritic soil in drilled areas of the Rochelois Plateau*

[Calculated on dry basis]

	Long tons	Metric tons
East Extension deposit:		
Area 1	434,000	441,000
Area 2	782,000	795,000
Area 3	819,000	832,000
Area 4	458,000	465,000
Total	2,493,000	2,533,000
Ste.-Croix deposit:		
Area 5	1,329,000	1,350,000
Area 6	2,216,000	2,252,000
Area 7	2,843,000	2,889,000
Area 8	2,214,000	2,249,000
Total	8,602,000	8,740,000
Tranquille-Trahison deposit:		
Area 9	1,676,000	1,703,000
Area 10	1,144,000	1,162,000
Area 11	1,103,000	1,121,000
Total	3,923,000	3,986,000
Grand total	15,018,000	15,259,000

available alumina content of the composite samples ranges from 41.7 to 45.7 percent with the exception of the composite sample representing area 8, which has an available alumina content of 36.8 percent. If area 8 is not included in the calculations, the average content of silica for the Ste.-Croix deposit is 2.6 percent, and that of alumina is 47.7 percent; thus the average available alumina content for the deposit is raised from 42.8 percent to 44.8 percent.

MINABLE TONNAGE

The mining practice and the limits of chemical tolerance set by the plant in which the aluminous lateritic soil is treated will be deciding factors in determining the minable tonnage of ore. Especially important are the limitations that might be placed on acceptable silica content.

Selective mining in area 8, where silica is above average, will permit recovery of about 1,000,000 tons of soil approaching the grade of material in other areas of the Ste.-Croix deposit. For selective mining, closer drilling is desirable to delimit the areas of higher-grade material.

The analyzed samples do not include the upper foot of soil which on the average probably contains more silica and less alumina than the underlying material. However, approximate calculations indicate that inclusion of the upper foot of soil raises the percentage of silica only a few tenths of 1 percent. Stripping the upper foot of soil would reduce the tonnage by approximately two million long tons.

A minimum estimate of recoverable lateritic soil averaging 43 percent of available alumina is 10 million long tons, on a dried basis.

RESERVES ON THE PLATEAU

There are additional reserves of aluminous lateritic soil on the Rochelois Plateau, outside of the three valley areas mapped. In the East Extension valleys the lateritic soil deposits are known to extend to the south of the mapped areas. The ground to the north and to the east has not been explored. Likewise, the continuation of the Tranquille-Trahison Valley to the northeast of the Ste.-Croix Valley has not been drilled. Northeast of the mapped Rochelois Plateau district along the trail to Miragoâne, dark-brown to reddish-brown soil was seen on the flats in the vicinity of Paillant between 1,500 and 2,000 feet above sea level. Surface samples contain appreciable quantities of gibbsite as indicated by thermal analyses, but chemical analyses have not been made.

A probable maximum tonnage of aluminous lateritic soil on the Rochelois Plateau as a whole is about of 20,000,000 to 25,000,000 long tons.

ECONOMIC CONSIDERATIONS

Whether or not the lateritic soil of Haiti can be used commercially depends on several economic considerations. The high iron content of the aluminous lateritic soil is an undesirable feature, and the fineness of material is said to cause filtration difficulties in Bayer process plants that have been utilizing Arkansas and Guiana ore. The considerable amounts of boehmite in some of the soil may present additional problems to American plants, which have been using gibbsitic bauxite, but boehmitic bauxite has been used successfully for metal manufacture in European plants. It should be noted that ferrous iron in the form of siderite, a mineral deleterious to the Bayer process, is not present in the lateritic soil of Haiti. The absence of overburden will make mining operations relatively simple, and although the fineness of grain may cause some difficulty in handling and shipping, grinding cost should be at a minimum. If plant facilities to separate the iron oxide are perfected, the aluminous lateritic soil of Haiti can be utilized for the extraction of metallic aluminum.

Although ore containing 43 percent of available alumina will not bring the price of higher-grade bauxite, this material can compete on the open market if the cost of mining and transportation is kept low enough to insure a fair margin of profit.

OTHER EXPLORATORY AREAS

Some exploratory work was done in several areas in Haiti, but such factors as the thinness of the soil, the smallness of the area, and the variability of the silica content show that those areas are not of commercial value. Brief descriptions of the areas and characteristics of their limestone and lateritic soil follow.

BEAUMONT REGION

The village of Beaumont is on the highway from Cayes to Jérémie, about 40 miles north of Cayes and about 28 miles south of Jérémie, at an altitude of approximately 2,000 feet above sea level. (See pl. 21.) A rugged topography with a relief of about 300 feet has developed on the massive limestone of the region. Large sinkholes and many minor features such as pinnacles, fluted and columnar projections, fretted and pitted surfaces, show the soluble character of the limestone.

LIMESTONE

The fresh limestone is white to grayish white or light yellowish gray; for the most part it is fine-grained and uniform in texture but has local patches of coarsely crystalline calcite. A sample collected along the highway 2.8 miles south of Beaumont was analyzed by Mr.

Davidson as given below. In composition this sample closely resembles the analyzed limestone from the Ste.-Croix region.

Analysis of limestone from highway 2.8 miles south of Beaumont

[Norman Davidson, analyst]

CaO	55.75	Al_2O_3	0.06
MgO	.27	Fe_2O_3	.02
SiO_2	.02	P_2O_5	0.01

A few specimens of the limestone from the vicinity of Beaumont were examined by Mrs. E. R. Applin who concluded that the material, on the basis of its fossil content, is probably of the same age as that from the Rochelois Plateau, which she examined and assigned to the lower Eocene.

LATERITIC SOIL

The lateritic soil is a finely divided, porous and friable, yellowish- to reddish-brown material. Gibbsite is the chief mineral. Boehmite and kaolinite, indicated on X-ray films, are subordinate. The principal iron mineral is hematite; goethite is minor. Quartz is rare. A sample of the soil from a trench 1.8 miles south of Beaumont gave 2 percent of SiO_2 and 20 percent of total iron by approximate analysis by Mr. Haspil. A more detailed analysis of the sample by Mr. Fairchild follows:

Analysis of lateritic soil from a trench 1.8 miles south of Beaumont

[J. G. Fairchild, analyst]

SiO_2	1.8	Fe_2O_3	19.3
TiO_2	2.0	Loss on ignition	27.3
Al_2O_3	46.9		

Trenches dug by the Reynolds Mining Corp. in Lachicotte Valley west of the highway and about 0.6 mile north of Beaumont were sampled, and auger holes were drilled in the bottom of three trenches that did not show limestone (fig. 5). In most of these trenches limestone was found at depths of less than 5 feet. The thinness of the soil and the variability of the silica content (table 10) indicate that the deposits are not of commercial value, and no further work has been carried on in the region.

A sample of reddish-brown soil on the Eocene limestone southeast of Corail and approximately 6 miles airline north of Beaumont gave 25 percent of silica and 15 percent of total iron by approximate analysis. Aerial reconnaissance showed no large areas of lateritic soil that would merit further exploration.

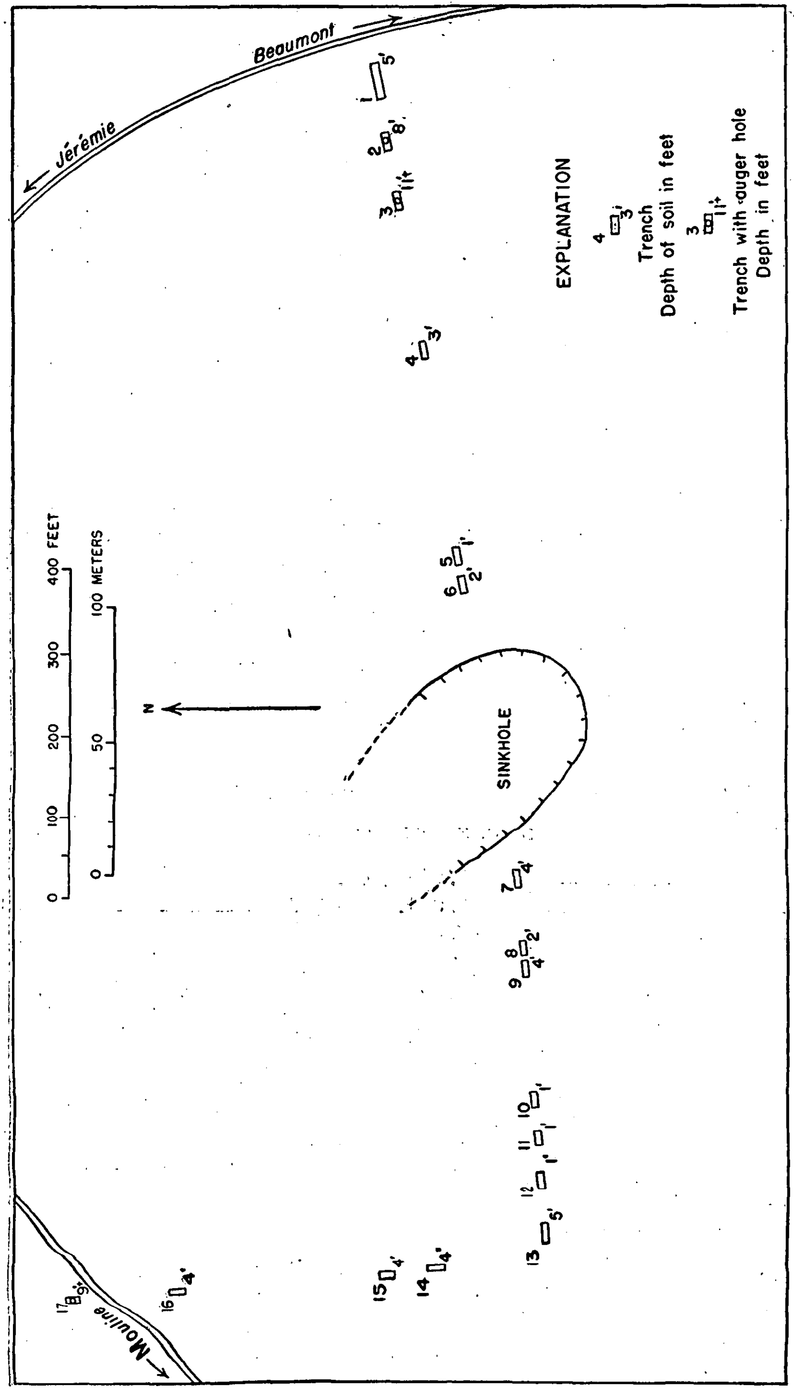

FIGURE 5.—Sketch map showing trenches of Reynolds Mining Corp. in Lachicotte Valley, Beaumont, Haiti.

TABLE 10.—*Approximate determinations of SiO_2 and total iron as Fe_2O_3 on samples from Lachicotte Valley, Beaumont*

[A. Haspil, analyst]

Trench No.	Depth (feet)	Laboratory No.	SiO_2 (percent)	Fe_2O_3 (percent)	Trench No.	Depth (feet)	Laboratory No.	SiO_2 (percent)	Fe_2O_3 (percent)
1	0-1	20	7.7	19.0	6	0-2	32	5.8	18.5
	1-3	21	8.0	19.6	7	0-4	33	1.4	18.8
	3-5	22	4.8	20.0	8	0-2	34	5.7	20.1
2	0-1	23	3.8	20.6	10	0-1	35	2.3	19.3
	1-3	24	2.3	20.8	12	0-1	36	4.5	18.7
	3-5	25	4.1	20.2	13	0-5	37	3.4	20.0
	5-7	26	5.5	21.2	14	0-4	38	3.0	19.9
	7-8	27	5.0	20.8	16	0-4	39	31.5	14.8
3	0-5	28	6.1	21.6	17	0-1	40	22.8	15.1
	5-11	29	4.1	21.0		1-5	41	48.3	12.2
4	0-3	30	16.9	16.6		5-9	42	35.1	11.3
5	0-1	31	3.7	18.1					

ANSE d'HAINAULT REGION

Four surface soil samples were collected along the road from Jérémie to Sources Chaudes in the Anse d'Hainault region (pl. 21). The parent rocks are basaltic igneous rocks and Tertiary (Miocene?) clay. The soils are siliceous. Approximate determinations of silica and total iron made by Mr. Haspil are given below.

Approximate determinations of silica and total iron

[A. Haspil, analyst]

Sample No.	Locality	Parent rock	SiO_2 (percent)	Fe_2O_3 (percent)
44	Sources Chaudes	Tertiary clay	36	21
45	do	Tertiary clay?	32	25
46	Anse d'Hainault	Basalt	32	31
47	Moron	Basalt?	37	25

MASSIF DE LA SELLE REGION

Exploratory work in the Massif de la Selle (Departement de l'Ouest) region was limited to sampling along the Saltrou highway in the vicinities of the Pine Forest lumber establishment and Savane Zombi and along the trail from Kenscoff to Furcy south of Port-au-Prince. (See pl. 21.) The Massif de la Selle is an anticlinal range of limestone with a northwest-southeast strike. To the southeast it is continued as the Sierra de Bahoruco of the Dominican Republic. Mont La Selle, with an altitude of 8,793 feet, is the summit of the range and the highest point in Haiti.

Pine Forest area.—Reddish-brown soils were sampled at a number of places in the vicinity of the Pine Forest lumbering and milling establishment (pl. 21). This area is approximately 5,200 feet above sea level. Waxy red soil is exposed to a depth of about 4 feet in a drainage pit beside the road at a point 1.5 miles southeast of the office. In addition to grains of quartz and a few crystals of zircon, the residue obtained by washing the soil contained foraminifera and small rodlike fragments. These fragments have an index of refraction below 1.475 and probably are chalcedonic silica. Although the foraminifers are poorly preserved, Mrs. Applin found a relatively large fauna indicating a Paleocene Midway age.

A sample taken near the bottom of a drainage pit 2 miles east of the office contained 31 percent of SiO_2 and 18 percent of Fe_2O_3 and yielded a residue of quartz grains on washing.

In Savane Jean Luis about 0.5 mile northwest of the first locality an auger hole struck limestone at a depth of 4.3 feet. The upper 3 feet of the soil contained considerable quartz, and the approximate analysis gave 44 percent of SiO_2 and 15 percent of Fe_2O_3. A smaller amount of quartz is present in the soil from the lower portion of the hole; this soil analyzed 34 percent SiO_2 and 16 percent Fe_2O_3.

The soil in the Pine Forest area is siliceous and comparatively thin, and the places sampled hold little promise of commercial deposits.

Savane Zombi area.—Savane Zombi is a small area about 9 miles south of the Pine Forest area on the road to Saltrou. (See pl. 21.) The savanna, about 0.6 mile in greatest dimension, is cultivated by an agricultural colony established by the Government. The yellow-brown soil is finely divided and friable. A surface sample taken near the center of the area contained about 14 percent of SiO_2 and 22 percent of Fe_2O_3. A soil sample collected in a small clearing 1.2 miles south of the Garde d'Haiti station resembles the lateritic soil of the Southern Peninsula. This soil area, however, is small. Mr. Haspil obtained approximate values of 7.4 percent for silica and 25.6 percent for total iron for this sample. An analysis is given below.

Analysis of soil sample from Savane Zombi area

[S. S. Goldich, analyst]

SiO_2	7.31	MgO	.08
TiO_2	2.80	CaO	.06
P_2O_5	.89	H_2O-	2.72
Al_2O_3	44.40	Loss on ignition	16.72
Fe_2O_3	24.68		
MnO_2	.07		99.73

Boehmite is the most abundant mineral in this sample. The approximate composition, indicated by differential thermal analysis and chemical analysis, is boehmite, 40 percent; gibbsite, 8 percent; clay mineral, 15 percent; iron oxides and others, 37 percent.

Kenscoff area.—Kenscoff village is 16 miles southeast of Port-au-Prince at an altitude of about 4,750 feet above sea level. (See pl.

21.) A sample (No. 8) of dark reddish-brown soil was collected just north of the village on the trail to Furcy at an altitude of 5,400 feet. A road-cut exposes the soil and the underlying, massive, grayish-white limestone. An approximate analysis by Mr. Haspil gave SiO_2, 20.0 percent, and Fe_2O_3, 22.3 percent. A more detailed analysis by Mr. Fairchild follows:

Analysis of soil sample from the Kenscoff area

[J. G. Fairchild, analyst]

SiO_2	19.9	Fe_2O_3	23.8
TiO_2	4.0	Loss on ignition	22.3
Al_2O_3	[1] 30.0		

[1] By difference.

GOYAVIER PLATEAU

The Goyavier Plateau (Departement de l'Artibonite), near the northwestern end of the Chaîne des Mâteux (pl. 21) and approximately 2,950 feet above sea level, is composed of a series of valleys or savannas separated by ridges and hills of limestone. The northwest-southeast trend of the valleys and ridges follows the strike of the folded limestone. The trail from St.-Marc enters one of these valleys at a place known as Lan Source, a water hole supplying the region. About 1 mile to the south at Robion a trail leads to the community of Goyavier in the adjoining valley about 0.6 mile to the east. A third valley developed at a higher level lies to the west of the Lan Source valley.

Limestone.—The massive fine-grained limestone resembles the Eocene limestone from other parts of the Republic and exhibits similar effects of solution.

Soil.—The soil is yellowish to reddish brown, usually with a distinctly reddish color and a shiny or slick appearance, characteristics that have been found to indicate a high silica content. Toothlike remnants of the limestone, protruding from the bedrock up into the soil to within a few feet of the surface, can be seen in gullies along the edges of the savannas where the soil has been dissected by the run-off from the limestone ridges.

Approximate determinations of silica and iron oxide in seven surface samples are given in table 11. A more detailed analysis is given in table 12. Both gibbsite and boehmite were revealed by X-ray films. Hematite is the abundant iron mineral. Quartz is rare. Differential thermal analysis of sample 400 indicates a mineral of the kaolin group, possibly halloysite; boehmite; and a small amount of gibbsite. All samples tested contain 20 percent or more of SiO_2. The soil is too siliceous to be considered favorable for further prospecting.

MORNE LA PIERRE REGION

General description.—Exploratory work was done in a number of savannas north of Morne la Pierre (Departement de l'Artibonite) and

TABLE 11.—*Approximate determinations of SiO_2 and total iron as Fe_2O_3 on samples from the Goyavier Plateau*

[Georges Cadet, analyst]

Sample No.	Locality	SiO_2 (percent)	Fe_2O_3 (percent)
400	Surface sample at Lan Source	25.4	19.1
401	Channel sample of soil from gully wall 6 feet high; 1,500 feet south of Lan Source	25.5	20.9
402	Surface sample at Robion	25.0	23.4
403	From gully 2,000 feet south of junction of trails at Robion	20.0	21.4
404	From valley west of Lan Source-Robion valley; approximately 2,000 feet west of cemetery at Robion	21.8	24.5
405	About 300 feet southeast of market place at Goyavier	22.5	16.1
406	About 2,000 feet southeast of market place at Goyavier	25.2	15.0

south of Darane on the Morne la Pierre limestone plateau about 9 miles northwest of Gonaïves. (See pl. 21.) The savannas can be reached by the main trail from Gonaïves to Terre Neuve. A secondary trail, which joins this trail near Morne Soleil at an altitude of about 1,000 feet, leads to the west and southwest onto the plateau at an altitude of about 2,000 feet. Samples were collected south of Darane, in the vicinity of Gambie, and in Savane Terre Rouge south of Gambie and north of Morne la Pierre. Savane Terre Rouge is a basin or large sinkhole about 7,000 feet in length in an east-west direction and 2,000 feet in width. The depression is bounded by limestone ridges and hills except on the western and southwestern sides. The trail crossing the savanna in an east-west direction continues to the west and in descending from the plateau circles to the south and southeast rejoining the main Gonaïves-Terre Neuve trail on the flat below. South of Savane Terre Rouge a number of terraces were noted along the trail, but these flat areas are too small, and the soil cover is too thin to be of possible commercial interest.

The Morne la Pierre Plateau is rugged and difficult to traverse except along the few trails. It is a comparatively dry region, sparsely settled, and largely overgrown with brush.

Limestone.—The massive limestone capping the plateau is of Eocene age. It is fine-grained, commonly vuggy, more rarely brecciated, and

TABLE 12.—*Chemical analyses of lateritic soil from the Goyavier Plateau*

[S. S. Goldich, analyst]

	Laboratory No. 400 (percent)	Laboratory No. 405 (percent)
SiO_2	22.73	20.75
TiO_2	1.67	
Al_2O_3	34.57	
Fe_2O_3	17.49	14.78
MnO_2	.06	
MgO	1.04	
CaO	.82	
H_2O-	5.50	3.80
Loss on ignition	15.72	24.04
Total	99.60	

white to light yellowish gray on freshly broken surfaces. The limestone is honeycombed and pitted. Pinnacles and toothlike remnants protrude up through the thin soil from bedrock below. The following chemical analysis by Mr. Davidson of a specimen of limestone from Savane Terre Rouge is similar to analyses of limestone from the Rochelois Plateau and from the Beaumont region.

Analysis of limestone sample from Savane Terre Rouge

[Norman Davidson, analyst]

CaO	55.60	Al_2O_3	0.07
MgO	.36	Fe_2O_3	.07
SiO_2	.01	P_2O_5	.01

Soil.—The soil is reddish brown and generally loose and friable. Locally it is baked to hard barren surfaces and is concretionary. Small ovoid soil pellets 1 to 2 millimeters in length are abundant in the loose material. Four samples of the soil were taken from Savane Terre Rouge. Sample 60 was collected from a pit in the northeastern part of the basin and represents soil to a depth of 2 feet. Sample 61 was taken from the bottom of this pit. Both samples contained about 18 percent silica. (See table 13. Sample 63 was collected from a depth of 2 feet

TABLE 13.—*Approximate determinations of SiO_2 and Fe_2O_3 on samples from the Morne la Pierre region*

[A. Haspil, analyst]

Locality	Altitude		Laboratory No.	SiO_2 (percent)	Fe_2O_3 (percent)
	Feet	Meters			
South of Darane	2,300	700	10	20.0	----------
			11	18.6	18.2
Savane Gambie	2,050	620	57	21.0	18.0
			58	12.0	21.5
Savane Terre Rouge	1,800	550	60	18.6	18.9
			61	18.2	20.8
			63	22.2	17.4
			64	3.0	22.0
			65	8.7	20.9
South of Savane Terre Rouge	1,500	460	68	12.2	20.3

at a point 500 feet south of samples 60 and 61. Sample 64, taken at a point about 600 feet west of sample 63, is a low-silica lateritic soil with 3.0 percent SiO_2 and 22.0 percent Fe_2O_3. A detailed analysis of this sample is given in table 14. Sample 65 was collected 1,000 feet west of sample 64.

A small pocket of low-silica soil is indicated in the central part of Savane Terre Rouge. Additional auger holes should be drilled to determine the thickness and to delimit the area of low-silica soil. However, the tonnage probably is small, and unless exploration of the region is expanded to include more savannas, it is doubtful that the Morne la Pierre region will be of commercial interest.

TABLE 14.—*Analyses of soil from Morne la Pierre region*

[Sample 10, J. G. Fairchild, analyst, sample 64, S. S. Goldich, analyst]

Component	Laboratory No. and locality		Component	Laboratory No. and locality	
	10 South of Darane	64 Savane Terre Rouge		10 South of Darane	64 Savane Terre Rouge
SiO_2	17.0	2.23	MnO_2		0.18
TiO_2	2.3	3.07	H_2O-	undet.	1.34
P_2O_5		.41	Loss on ignition	23.1	20.74
Al_2O_3	39.8	50.16			
Fe_2O_3	16.5	21.67	Total	98.7	99.80
Density					2.882

MONT PUILBOREAU REGION

Four samples collected along the highway from Mont Puilboreau to Marmelade in the Mont Puilboreau region (Departement du Nord) (pl. 21), were found to be siliceous. Sample 12 is a light yellowish-brown soil taken at a point 3 miles from Marmelade on the road to Mont Puilboreau. Sample 13 is light reddish-brown, sticky, clayey soil collected 7 miles from Marmelade and about 2 miles east of the Monastery near the road fork on Mont Puilboreau. Sample 14 was collected about 2,000 feet west of sample 14. At this point the road circles a large sinkhole where bright-red soil rests on light-yellow to buff-colored limestone. Sample 15 was taken along the highway just south of the road fork on Mont Puilboreau. The first two samples represent soil formed, or at least in part derived, from the Cretaceous limestone. The other two samples are of soil developed on limestone of Eocene age. Determinations of silica and total iron by Mr. Haspil are given below. All the samples have too high a silica content for commercial prospects.

Determinations of silica and total iron

[A. Haspil, analyst]

Sample No.	Altitude		SiO_2 (percent)	Fe_2O_3 (percent)	Sample No.	Altitude		SiO_2 (percent)	Fe_2O_3 (percent)
	Feet	Meters				Feet	Meters		
12	2,295	700	68	6	14	2,960	902	40	18
13	2,985	910	52	13	15	2,940	892	25	18

BOMBARDOPOLIS PLATEAU

Reddish-brown soil occurs on Miocene limestone in the vicinity of Bombardopolis (Departement du Nord-Ouest) on the plateau south of Môle St.-Nicolas. (See pl. 21.) Two samples were collected and both proved to be siliceous. Sample 407 was collected from a roadcut at the first intersection or fork in the trail about 0.6 mile north of Bombardopolis on the main trail to Môle St.-Nicolas. Sample 408 was collected at a point about 2 miles north of Bombardopolis. Approximate determinations by Mr. Cadet gave 40 percent of SiO_2 and 15.2 percent of Fe_2O_3 for sample 407, and 35.1 percent of SiO_2 and 19.9 percent of Fe_2O_3 for sample 408. An analysis of sample 407 is given below. Differential thermal analysis of the analyzed sample showed a mineral of the kaolin group, probably halloysite. Neither gibbsite nor boehmite could be identified.

Analysis of soil sample 407 from roadcut 0.6 mile north of Bombardopolis

[S. S. Goldich, analyst]

SiO_2	36.33	MgO	.47
TiO_2	1.54	CaO	tr.
Al_2O_3	28.65	H_2O-	6.04
Fe_2O_3	14.02	Loss on ignition	12.14
MnO_2	.11		
			99.30

ILE DE LA TORTUE

Light to dark reddish-brown soils are found in the eastern half of the interior plateau of Tortue Island, Departement de Nord-Ouest (pl. 21). Sample 1 was collected at a point where the trail from Pointe des Oiseaux to Palmiste attains the crest of the plateau at about 985 feet above sea level. Schistose limestone is exposed at this place. Five samples were taken along the trail that passes through Palmiste roughly parallel to the southern escarpment of the interior plateau. The soil on this part of the island is thin. The samples represent soils developed on limestone of Oligocene or Miocene age.[9] The approximate chemical determinations given in table 15 reveal a high percentage of silica. An analysis of sample 2 is given below. This sample contains boehmite and halloysite, but the reconnaissance of the eastern part of the island showed no prospects of commercial value.

Analysis of soil sample 2 taken along trail through Palmiste, Ile de la Tortue

[J. G. Fairchild, analyst]

SiO_2	19.9	Fe_2O_3	22.8
TiO_2	2.8	Loss on ignition	15.8
Al_2O_3	[1] 38.7		

[1] By difference.

AREAS SUGGESTED FOR PROSPECTING

Additional field work and prospecting for aluminous lateritic soil in Haiti might be profitable in several areas. A few auger holes in the central part of Savane Terre Rouge on the plateau northwest of

[9] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti, p. 151, Republic of Haiti, Department of Public Work, Port-au-Prince 1924.

TABLE 15.—*Approximate locations and determinations of SiO_2 and Fe_2O_3 on samples from Tortue Island*

[A. Haspil, analyst]

Laboratory No.	Location	SiO_2 percent	Fe_2O_3 percent
1	Near crest of escarpment along trail from Pointe des Oiseaux to Palmiste	67	19
2	1 kilometer east of Palmiste along trail to the "Colonie"	26	20
3	2.5 kilometers east of Palmiste	23	8
4	1 kilometer northeast of the "Colonie"	24	20
5	4 kilometers west of Palmiste	42	26
6	9 kilometers west of Palmiste	28	13

Gonaïves where the occurrence of low-silica aluminous soil has been demonstrated would supply needed information on the depth of the soil. Soil thicknesses of 10 to 15 feet would indicate that further detailed study of the region is warranted.

Further exploration is desirable in large areas in the Massif de la Selle. These areas were not seen but deposits of aluminous lateritic soil similar in composition to that of the Rochelois Plateau are now known to occur at 4,000 to 5,000 feet above sea level in the southeastern continuation of the Massif de la Selle in the Sierra de Bahoruco of the Dominican Republic. Similar occurrences may be found in the Massif de la Selle.

Additional prospecting might be undertaken also in the Massif de la Hotte and in the mountains of the central part of Haiti where Eocene limestone occurs.

ORIGIN AND DEVELOPMENT OF ALUMINOUS LATERITIC SOIL

CONCEPTS OF LATERITIZATION

Lateritic soils are found throughout the islands of the West Indies. The Matanzas series, the most widespread group of soils in Cuba, described by Bennett and Allison[10] as the "Cuban type of lateritic material," was derived from limestone rocks. These soils are characterized by high permeability and uniformity from top to bottom and are similar in physical properties to the lateritic soil of Haiti, but chemically they are much more siliceous. The Nipe clay of Cuba derived from serpentine rock is a low-silica lateritic soil of the ferruginous type. Lateritic soils in Puerto Rico have been developed from a variety of rocks, including limestone. Bonnet[11] has described in some detail a profile of the Catalina clay, Puerto Rico, derived from

[10] Bennett, H. H., and Allison, R. V., The soils of Cuba, Tropical Plant Research Foundation, Washington, D. C., 1928.

[11] Bonnet, J. A., The nature of laterization as revealed by chemical, physical, and mineralogical studies of a lateritic soil profile from Puerto Rico: Soil Sci., vol. 48, pp. 25–40, 1939.

an andesitic tuff. Merwin and Posnjak [12] found abundant boehmite with smaller amounts of quartz, hematite, and probable kaolinite in a sample collected by T. W. Vaughan from red soil on limestone on the island of Anguilla, west of Puerto Rico (fig. 6). Hardy and Rodriques [13] described a lateritic-soil profile formed from andesite on the island of Grenada. (See fig. 6.) In the Republic of Haiti lateritic soils occur on limestone in a number of localities. There are similar soils in the Dominican Republic and in Jamaica.

Striking chemical differences in the products of weathering in tropical regions as compared to those of temperate zones have led to the recognition of two types of weathering. In temperate zones the residual products of weathering of igneous rocks are characterized by hydrated aluminum silicates, the clay minerals. This type of weathering is commonly referred to as kaolinization, although clay minerals other than kaolinite may be formed. In tropical regions a more or less complete loss of silica may result, and the products are composed of the hydrous oxides of aluminum together with the oxides and hydrous oxides of iron, titanium, and manganese. This type of weathering is called lateritization. Deposits of bauxite in regions with a present-day temperate climate, as in Arkansas, are usually interpreted to indicate a humid tropical or subtropical climate for the region at the time of the lateritization.

The occurrence of lateritic soils in the West Indies as a region probably is dependent primarily on the humid tropical climate. However, studies by Harrison [14] in British Guiana showed that both laterite and kaolin clay are formed under tropical conditions. He concluded that the only factor determining which of these products is developed is the composition of the parent rocks. Laterites are derived from basic igneous rocks; the clay from granitic rocks. A similar conclusion was reached by Mohr,[15] and this hypothesis of the weathering of calcic feldspars to gibbsite and of the alkalic feldspars to kaolin has been presented recently in considerable detail.

The close association of gibbsite and boehmite with clay minerals of the kaolin group in many bauxite deposits of the world indicates that the processes forming lateritic materials and those producing clays are not as fundamentally distinct as might be concluded from the generalization of two types of weathering. Mead [16] considered kao-

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[12] Merwin, H. E., and Posnjak, E., Clays and other minerals from the deep sea, hot springs, and weathered rocks : Amer. Jour. Sci., 5th ser., vol. 35–A, p. 184, 1938.

[13] Hardy, F., and Rodriques, G., Soil genesis from andesite in Grenada, British West Indies : Soil Sci., vol. 48, pp. 361–384, 1939.

[14] Harrison, J. B., The residual earths of British Guiana commonly termed 'laterite' : Geol. Mag., vol. 7, dec. 5, p. 560, 1910.

[15] Mohr, E. C. J., The soils of equatorial regions with special reference to the Netherlands East Indies, Ann Arbor, Mich., J. W. Edwards Co., 1944.

[16] Mead, W. J., Occurrence and origin of the bauxite deposits of Arkansas : Econ. Geology, vol. 10, pp. 28–54, 1915.

linization to be an intermedite stage in the formation of aluminous laterite from nepheline synite in Arkansas. This interpretation implies that lateritization is a more complete type of alteration in tropical regions that carries the weathering beyond the kaolinization stage at which weathering processes in temperate regions apparently cease. Harrison's[17] conclusions from studies of gibbsite-kaolinite associations in British Guiana are diametrically opposed to those of Mead. He regards gibbsite as a product formed directly by weathering of basic igneous rocks, and kaolinite as formed by a process of resilication of aluminum hydroxide. According to Harrison, granitic rocks weather directly to kaolin, but his descriptions indicate that in some places gibbsite also is formed.

The weathering of the igneous rocks of Haiti has been discussed by Burbank.[18] Probably the deepest weathering is that of quartz diorite on Morne Madeleine in the vicinity of Vallière in the northeastern part of Haiti. This is an upland area about 2,000 feet above sea level. Remnants of flat surfaces may represent an older Tertiary surface which had been partly peneplaned. The soil, composed of kaolin and residual quartz, is as much as 15 feet thick.

Burbank estimated the mineralogical composition of the fresh quartz diorite to be quartz, 28 percent; andesine, 43 percent; hornblende, 24 percent; and magnetite and other minerals, 5 percent. The andesine (An_{40}) is calcic, but the conditions, nevertheless, were unfavorable for laterization and a residual clay was developed. The present rainfall in the vicinity of Vallière is about 2,000 millimeters (about 80 inches) annually, and the mean annual temperature is about 22° C. (72° F.). Under these climatic conditions the residual quartzose clay derived from the quartz diorite appears to be stable. A number of samples of the clay collected from the region by Burbank were tested by differential thermal analysis, and in none was gibbsite detected.

Recent soil studies show that gibbsite can form directly by weathering of igneous rock minerals. The investigations of Hardy and Rodriques[19] and of Alexander, Hendricks, and Faust[20] show that in soils gibbsite can be silicated to form kaolin minerals. In certain soils gibbsite may be a transitory or evanescent mineralogic phase characteristic of early stages of weathering, completely disappearing in later stages.

The processes of rock weathering and probably also those of soil formation are controlled fundamentally by the existing physical and

[17] Harrison, J. B., The katamorphism of igneous rocks under humid tropical conditions. Imp. Bur. Soil Sci., pp. 1–79, Harpenden, England, 1943.

[18] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti, Republic of Haiti, pp. 260–330, Department of Public Works, Port-au-Prince, 1924.

[19] Hardy, F., and Rodriques, G., The genesis of Davidson clay loam: Soil Sci., vol. 48, pp. 483–495, 1939.

[20] Alexander, L. T., Hendricks, S. B., and Faust, G. T., Occurrence of gibbsite in some soil-forming materials: Soils Sci. America, vol. 6, pp. 52–57, 1941.

chemical environment. Thus factors such as soil drainage, vegetation, time, and others, in addition to climate and rock composition, probably control the processes and determine the products. It should be emphasized that all the factors are so closely related that it is difficult to evaluate their separate influence or relative importance. In the discussion that follows brief consideration is given to some of the factors that may have influenced the origin and development of the lateritic soils of Haiti.

ALUMINOUS LATERITIC SOIL OF HAITI

The lateritic soils on the Tertiary limestone of Haiti are not residual deposits in the sense of primary laterite developed in place from igneous rock. Certain fundamental differences should be noted. The soil is an accumulation in which movement of the soil particles was involved. Some sorting may have taken place during the movement of the soil, but the fine size of the particles suggests their rapid formation from an easily weathered and probably finely divided parent material. The chemical alteration producing the lateritic constituents probably was accomplished for the most part before the material came to rest in the present sites. For this reason distinct horizons, such as characterize the soil profiles on andesitic tuff in Puerto Rico and on porphyritic augite andesite in Grenada, are not developed.

During and following the accumulation of the soil, movements of ground water caused a redistribution of the lateritic constituents. Manganese moved downward and is concentrated in the soil above the limestone. Silica, iron oxide, and titania appear to be concentrated in the upper part of the soil. Regional variations of boehmite and gibbsite in the soil of the Rochelois Plateau may be features related to drainage and soil-water movements that became effective after the soil accumulated. Similar changes, effected largely after the soil accumulation, may account for the distribution of clay mineral and for hematite-goethite relationships.

BOEHMITE-GIBBSITE RELATIONSHIPS

The regional variations with an increase in the relative amount of gibbsite and a corresponding decrease in the content of boehmite from east to west in the lateritic soil of the Rochelois Plateau region may represent an aging phenomenon, with the transformation of boehmite to gibbsite influenced by the chemical environment and drainage, although specific details of the controlling factors cannot be stated on the basis of present observations. Boehmite is the principal mineral in many of the bauxite deposits in limestone and dolomite formations of the Mediterranean region.[21] Certain of these deposits contain both

[21] Fox, C. S., Bauxite and aluminous laterite, London, Technical Press, Ltd., 1932.

boehmite and gibbsite, and De Lapparent[22] concluded that conditions of subsidence in which the parent material was in contact with humic solutions for a long time favored the formation of boehmite. Rejuvenation or uplift of the land mass bringing the parent material above the water table resulted in the later development of gibbsite.

Experimental work[23] indicates that gibbsite is stable below 155° C. Boehmite is stable between 155° and 280° C. Weiser[24] states that the gelatinous precipitate obtained by neutralizing an aluminum salt solution with ammonia is γ-$Al_2O_3.H_2O$, boehmite. Aging of the precipitate results in growth of the crystals and also in a gradual transformation from $\gamma-Al_2O_3 \cdot H_2O$ through $\alpha-Al_2O_3 \cdot 3H_2O$, bayerite, to γ-$Al_2O_3.3H_2O$, gibbsite. The transformation from γ-$Al_2O_3.H_2O$ to γ-$Al_2O_3.3H_2O$ in the laboratory was found to be accelerated in an alkaline environment. These observations suggest that boehmite may be formed in the lateritic soil and in bauxite as a metastable phase and that it is transformed to gibbsite.

In nature the weathering of igneous rocks and beds of ash or tuff even under humid tropical conditions is a slow process. The alkaline chemical environment resulting from the hydrolysis of the silicates would favor the development of γ-$Al_2O_3.3H_2O$, gibbsite. Gibbsite then should be the normal product of lateritization of massive igneous rock. Weathering under physiographic conditions of high relief such as characterize the uplands of the Southern Peninsula of Haiti may be surmised to involve good drainage with rapid removal of bases. The soils, as a result, acquire a neutral or slightly acid chemical environment. Their acidity may be further accentuated by the development of vegetation. The transformation of γ-$Al_2O_3.H_2O$, boehmite, to γ-$Al_2O_33H_2O$, gibbsite, would be retarded by the acid chemical environment.

CLAY MINERALS

The processes of weathering that produce boehmite or gibbsite and those that yield hydrous aluminum silicates, clay minerals, probably are closely related. Slight changes in physical and chemical conditions may suffice to shift the equilibrium and change the end product. It has also been shown that gibbsite may react with silica-bearing solutions to form kaolin. The stability of kaolinite has been noted by many investigators. Harrison[25] and De Lapparent[26] concluded that

[22] De Lapparent, J., Raisons géologiques de la formation des trois hydroxides d'aluminium naturels: Cong. Internat. Mines, VII, pp. 375–379, Paris, 1936.

[23] Laubengayer, A. W., and Weisz, R. S., A hydrothermal study of equilibria in the system alumina-water: Am. Chem. Soc. Jour., vol. 65, pp. 247–250, 1943.

[24] Weiser, H. B., Inorganic colloid chemistry, vol. 2, p. 99, New York, John Wiley and Sons, 1935.

[25] Harrison, J. B., op. cit., p. 37, 1943.

[26] De Lapparent, J., Boehmite and diaspore in the bauxitic clay of Ayershire, Great Britain Geol. Survey Summary of Progress, London, p. 2, 1936.

kaolinization as an intermediate stage in the formation of bauxite is improbable. This does not mean that desilication of clay minerals cannot take place but rather that the adequacy of such a process to form large deposits of bauxite from kaolin remains to be demonstrated. The behavior of clay minerals of the montmorillonite group under conditions of lateritic weathering needs further study.

Analyses of surface samples and of interval samples from auger holes in the Rochelois Plateau region show a concentration of silica in the upper soil. Possibly this surface enrichment in silica may be caused by development of kaolin similar to the resilication of gibbsite in upper zones in lateritic soil profiles and in deposits of bauxite. Also, there are regional variations of silica and of clay mineral in the lateritic soil on the Rochelois Plateau. The boehmite-rich soil of the East Extension deposit contains more clay mineral than the soil to the west with the exception of the southwestern end of the Ste.-Croix deposit. Original differences may influence the distribution of clay mineral in the soil. It is also possible that in certain stages of the soil development the clay mineral particles may be peptized and removed in colloidal solution.

HEMATITE-GOETHITE RELATIONSHIPS

The distribution of iron oxide in samples from the Rochelois Plateau deposit suggests that, relative to alumina, iron oxide is concentrated in the upper part of the soil together with titania and silica. However, the main concentration of iron oxide occurs not in the surface soil but several feet below. The upper 6 inches of the soil in which organic matter is concentrated generally is brown in color. This appears to be a zone in which hematite, because of the reducing power of the organic matter, may be taken in solution to be reprecipitated as goethite. During this process some downward movement of the iron apparently takes place. It is noteworthy that there is a slight but perceptible color change in the composite samples representing the 11 drilled areas of the Rochelois region. The boehmitic soil of the eastern part of the region is typically reddish brown. As the gibbsite content of the soil increases, the color becomes more distinctly brown. This suggests that a gradual transformation from hematite to goethite similar to the suggested transformation of boehmite to gibbsite may be taking place in the soil.

GENESIS OF THE LATERITIC SOIL

CLIMATIC INFLUENCE

Haiti, situated between latitudes 18° and 20° north, has a tropical climate modified by its insular position and mountainous topography. Because the lateritic soil may have been developed in Pliocene or

Pleistocene time, it is not certain that the present climatic conditions held when the soil was formed; nevertheless, certain characteristics of the present climate may be pertinent to the problem of origin and development of the lateritic soil. Unfortunately, the meteorological stations are in cities on the lowlands, where the greater part of the population lives, and data for the plateau and mountainous regions are few. A summary of weather observations up to 1916 is given in the Geology of the Republic of Haiti,[27] and additional data have been published by the Department of Public Works of the Republic of Haiti.[28] The available rainfall data have been summarized by Alpert [29] who prepared a map showing the areal distribution of mean annual rainfall over the island of Hispaniola.

The mountains of Haiti modify the high temperatures that characterize the lowlands. The average mean annual temperature for Port-au-Prince, at sea level, is 27° C. (80.6° F.) ; whereas at Kenscoff at an altitude of about 4,750 feet the mean annual temperature is 16.4° C. (61.5° F.) The mountains cause local precipitation, so there is an irregular distribution of rainfall. Two well-defined wet or rainy seasons characterize the precipitation: the spring rains come in April, May, and June; the fall rains start in August and last through November. December and January are the driest months of the year. Although specific data for precipitation are lacking, the uplands usually receive more rainfall than the lowlands. The rainfall for the Rochelois Plateau is estimated to be between 1,500 and 2,000 millimeters (60 to 80 inches) and probably is more nearly 2,000 millimeters. The precipitation in the Beaumont region is as great or possibly greater. The Massif de la Selle at high altitudes probably has an annual rainfall of 2,000 millimeters (80 inches) or more.

The heavy rainfall of the upland regions of the Southern Peninsula has produced notable effects of solution and undoubtedly favored the development of the lateritic soil. In contrast, the Northwest Peninsula receives less rainfall. The plateau region of Morne la Pierre probably receives 500 to 1,000 millimeters (20 to 40 inches) of rainfall annually. The soil mantle in this region is thin, and the indurated concretionary lateritic soil probably is the result of the baking of the soil during the dry season. The thin soil cover of the plateau in the vicinity of Bombardopolis, likewise, can be correlated with the relative dryness of that region. The annual precipitation is about 500 millimeters (20 inches).

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[27] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti, Republic of Haiti, Department of Public Works, Port-au-Prince, 1924.

[28] Direction Generale Des Travaux Publics, Les Eaux de Surface de la Republic d'Haiti: Bull. Hydrographique No. 16, Port-au-Prince, 1940.

[29] Alpert, Leo, The areal distribution of mean annual rainfall over the island of Hispaniola: Monthly Weather Rev., vol. 69, pp. 201–204, 1941.

DISTRIBUTION OF LOW-SILICA ALUMINOUS LATERITIC SOIL

Any consideration of the genesis of the aluminous lateritic soil must recognize the widespread distribution of this material in the West Indies. In Haiti, east of the large deposits on the Rochelois Plateau, aluminous lateritic soil is found in the vicinity of Savane Zombi on the limestone of the Massif de la Selle, and still farther to the east and southeast similar lateritic soil occurs in limestone valleys of the Sierra de Bahoruco in the Dominican Republic. West of the Rochelois Plateau, lateritic soil on limestone occurs in the vicinity of Beaumont. On Navassa Island west of the Southern Peninsula concretionary reddish-brown lateritic material cements the highly brecciated and solution-marked limestone. Farther west in Jamaica are large deposits of low-silica aluminous lateritic soil. All these deposits rest on massive limestone of remarkably pure calcium carbonate composition, for the most part of Eocene age but including Oligocene and possibly Miocene strata.

This geographic belt (fig. 6) with its remarkable deposits of low-silica aluminous lateritic soil extending from the Sierra de Bahoruco in the Dominican Republic through the Southern Peninsula of Haiti and into Jamaica, is a major structural unit of the West Indies. In this zone Tertiary limestone has been folded and uplifted into an anti-

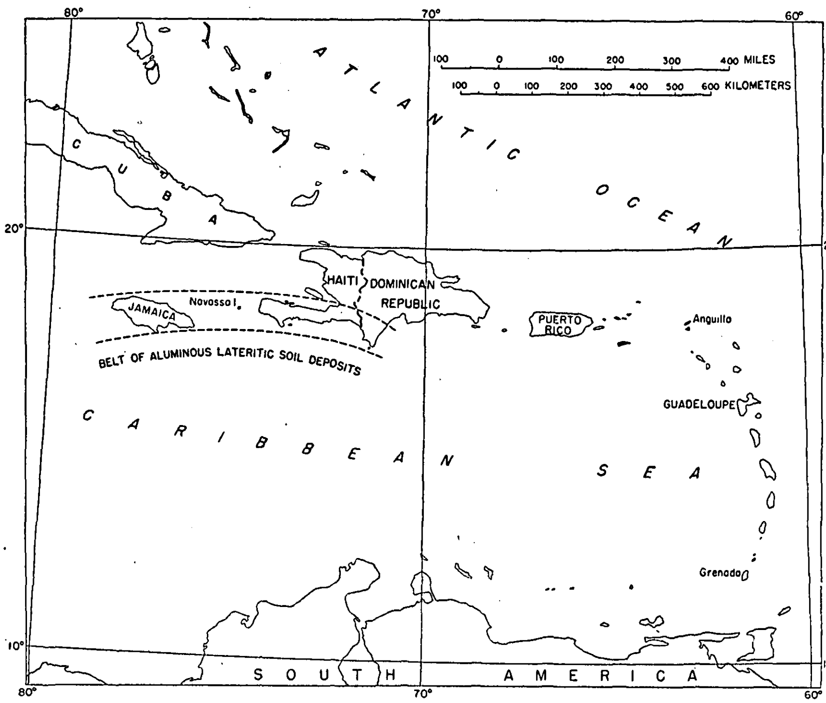

FIGURE 6.—Belt of low-silica aluminous lateritic soil deposits in the West Indies.

clinal range on which physiographic conditions were suitable for the development and preservation of the aluminous lateritic soil. Outside of this belt large deposits of low-silica aluminous soil have not been found. The soils of Cuba and of Puerto Rico, chiefly derived from Oligocene and Miocene limestones, are lateritic but not of the low-silica type. In Haiti, sandy and siliceous soil has developed on, or in part been derived from, schistose limestone probably of Paleozoic age on Tortue Island and from Cretaceous sediments in the vicinity of Mont Puilboreau. The Miocene limestone on the Bombardopolis Plateau has a thin, sandy, and ferruginous clayey soil. The soils on Oligocene and Miocene strata in a number of places are sandy and clayey, although in many boehmite and gibbsite are abundant.

The relative importance of climate and of other factors, such as rock composition and physiography in the development of the lateritic soil, cannot be stated, but the importance of the geologic factors must be emphasized. Plateau and mountainous regions underlain by limestone of early Tertiary age are the most likely regions for the occurrence of the low-silica aluminous lateritic soil. These factors should be given first consideration in prospecting.

PARENT MATERIAL

The close association of the aluminous lateritic soil with the Eocene and Oligocene limestone both in Hispaniola and in Jamaica led to the conclusion during the course of the field investigation that the limestone is the parent rock from which the soil was developed. This would mean that the source material from which the lateritic constituents were derived is contained in the limestone in the form of impurities. The uniformity and similarity in composition of the low-silica lateritic soil in deposits in Haiti, the Dominican Republic, and Jamaica suggest a widespread source of material of rather uniform composition, and the chemical nature of this source material can be appraised from a consideration of the chemical and mineralogical composition of the soil.

The ratios of $Al_2O_3 : Fe_2O_3 : TiO_2$ calculated from analyses of composite samples of soil from Haiti and from the Dominican Republic and from analyses of individual soil samples from Jamaica have been plotted in figure 7. In this diagram the ratios for these constituents in averages for igneous rock families[30] also are shown. There is a clustering of points for the soil samples in the range from average syenite to average diorite. The relative amount of titania is larger in the soil samples than in the averages for the igneous rock families, but Burbank[31] has pointed out that the igneous rocks of Haiti are above average in titania.

[30] Daly, R. A., Igneous rocks and their origin, New York, McGraw-Hill Book Co., 1914.
[31] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti, pp. 260–330, Republic of Haiti, Department of Public Works, Port-au-Prince, 1924.

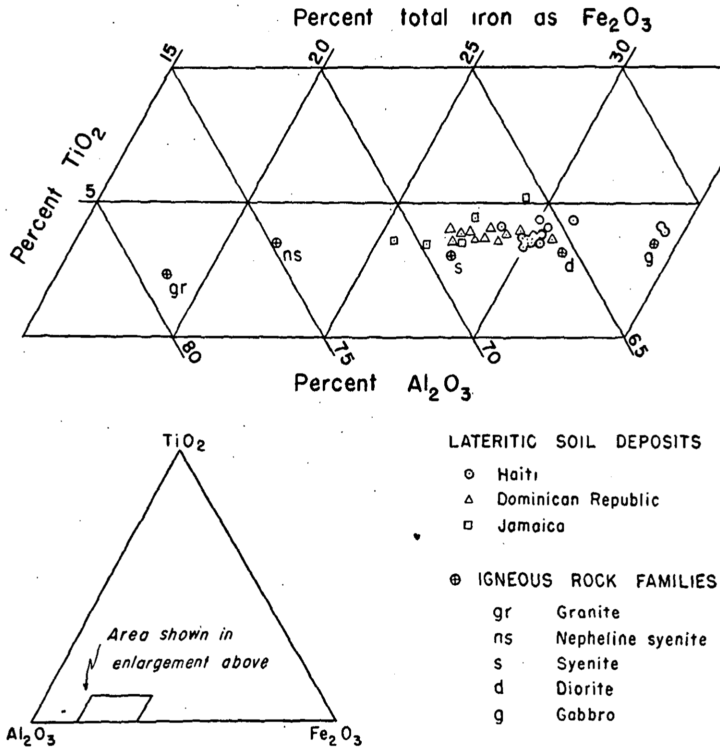

FIGURE 7.—Proportions of $Al_2O_3 : Fe_2O_3 : TiO_2$ in lateritic soils from Haiti, Dominican Republic, and Jamaica, and in igneous rock families.

There has been volcanic activity in the Caribbean region from the Cretaceous period to the present, and pyroclastic material is widespread in many of the Tertiary formations. Much of this material is of intermediate (andesitic) composition. The weathering of such material under suitable physiographic conditions would yield lateritic residues that would accumulate in the depressions and sinkholes in the limestone. Accessory minerals in the aluminous lateritic soil, such as quartz, magnetite, and zircon, are persistent minerals that have been identified in samples of the soil from Haiti, the Dominican Republic, and Jamaica. The quartz grains show sharp and uniform extinction between crossed nicols, and many have crystal terminations. These characteristics suggest volcanic rather than plutonic igneous rocks as the source material. The mineralogical and chemical characteristics of the soil suggest that the ultimate source of the lateritic constituents was volcanic ash or pyroclastic material of intermediate (andesitic) composition.

LIMESTONE AS SOURCE MATERIAL

To test the field conclusion that the immediate source of the lateritic constituents is the limestone on which the deposits rest, samples of the limestone were collected from localities of low-silica aluminous lateritic soil in Haiti and the Dominican Republic. Analyses of five samples (table 16) are strikingly similar. However, the alumina contents of these samples are so small that there is a reasonable doubt of limestone of this composition being the parent rock. If the largest value of 0.07 percent is assumed for the alumina content of the limestone, about 10 billion tons of the rock would be required to supply the alumina in the drilled deposits alone on the Rochelois Plateau. This is a concentration ratio of about 650 tons of limestone per ton of soil. If the arithmetical average of the alumina determinations (0.035 percent) is used, the concentration ratio is about 1,300 tons of limestone per ton of aluminous lateritic soil, and about 20 billion tons of limestone would be required. This is equivalent to a block of rock with the area of the Rochelois Plateau region and 1,000 feet (300 meters) in height, a height somewhat less than the present relief on the plateau.

TABLE 16.—*Chemical analyses of limestone from aluminous lateritic soil localities in Haiti and the Dominican Republic*

[Norman Davidson, analyst]

Locality	Percent of indicated constituents					
	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5
Beaumont, Haiti	55.75	0.27	0.02	0.06	0.02	0.01
Ste.-Croix, Haiti	55.90	.05	.02	.01	.08	.01
Savane Terre Rouge, Haiti	55.60	.36	.01	.07	.07	.01
Sierra de Bahoruco, Dominican Republic	55.90	.04	.05	None	.13	.01
Do	55.65	.14	.03	.03	.05	.01

The average ratio of $Al_2O_3:Fe_2O_3$ for the analyzed limestone samples is 1:2; whereas this ratio for the soil is 1:0.5. Assuming that the ratio of alumina to titania is the same in the limestone as in the lateritic soil, the average titania content of the limestone would be 0.002 percent. Titania was not found in the limestone samples by ordinary chemical methods, and for this reason composite samples were prepared for spectrographic analysis. The results in table 17 are for a composite of six limestone samples from the Rochelois Plateau region and for a composite of three samples of limestone from the Sierra de Bahoruco in the Dominican Republic. Analyses of composite samples of the aluminous lateritic soil from these localities are included in the table.

Titania was not found in the limestone composite from the Rochelois Plateau, and 0.0002 percent of TiO_2 was reported for the Dominican sample. Of the other constituents reported for the lateritic soil, only Cr_2O_3, V_2O_5, NiO, MnO and SrO are present in sufficiently large amounts in the limestone to be determined by the spectrographic method. Of these constituents strontia (SrO) is present in smaller amounts in the soil samples than in the limestone, but it is expected that

TABLE 17.—*Spectrographic analyses for minor elements in limestone and lateritic soil from Haiti and the Dominican Republic*

[Looked for but not found: W, Mo, Sn, In, Tl, Ge, Zn, Cd, Pb, As, Sb, Bi, Cu, Ag, Au, Pt, Re, Cb, Ta, ignition of lateritic soil samples before analysis would remove any As, Sb, and Tl present. Esther W. Claffy and K. J. Murata, analysts]

	1	2	3	4
	Composite of six samples of fresh limestone from Rochelois Plateau region, Haiti	Lateritic soil composite sample representing area 7, Ste.-Croix deposit	Composite of three samples of fresh limestone from Sierra de Bahoruco, Dominican Republic	Lateritic soil composite sample from deposit in Sierra de Bahoruco, Dominican Republic
TiO_2	(1)	3	0.0002	2
ZrO_2	(1)	.04	(1)	.04
Cr_2O_3	0.004	.08	.004	[2] .1
V_2O_5	.003	.05	.006	.02
NiO	(1)	.007	.0003	.009
MnO	.001	.5	.0005	.5
SrO	.006	.0005	.006	.0003
BaO	(1)	.0006	(1)	.0005
La_2O_3	(1)	.03	(1)	.01
Y_2O_3	(1)	.03	(1)	.008
Yb_2O_3	(1)	.002	(1)	.0005
BeO	(1)	.0008	(1)	.0006
Ga_2O_3	(1)	.001	(1)	.001
CoO	(1)	.005	(1)	.005

[1] Not found; the element may be present in amounts below the limit of sensitivity of the method.
[2] 0.095 percent Cr_2O_3 by chemical analysis by Norman Davidson.

this constituent would be leached out under weathering conditions. The concentration ratios of limestone required to produce the amounts of the other constituents in the lateritic soil range from 3 to 10,000 or more. It is noteworthy that all of the constituents found in the lateritic soil are present in amounts that might be expected from an igneous source material of intermediate composition.

OTHER POSSIBLE SOURCES

The few chemical analyses may be inadequate to represent fully the geologic section, the rocks of which were subjected to weathering. The lateritic soil may be a residue of beds stratigraphically younger than the limestone bedrock of the deposits. The younger beds could have been destroyed by weathering and solution except for their insoluble weathering residues, which were trapped and as a result now rest on massive Eocene limestone that has contributed little to the deposits. Thus, the lateritic material may represent an inherited rather than a derived soil. Material of a composition similar to that of certain beds assigned by Woodring and Brown [32] to the Miocene might be suitable source material. An analysis of Miocene marl from the vicinity of St.-Marc is as follows: SiO_2, 25.42 percent; Al_2O_3, 8.32 percent; Fe_2O_3, 1.93 percent; CaO, 30.33 percent; MgO, 2.27 percent; CO_2, 23.75 percent; and H_2O, 6.38 percent.[33] The description

[32] Woodring, W. P., Brown, J. S., and Burbank, W. S., Geology of the Republic of Haiti. pp. 157–196, Republic of Haiti, Department of Public Works, Port-au-Prince, 1924.
[33] Woodring, W. P., Brown, J. S., and Burbank, W. S., op. cit., p. 502.

accompanying the analysis states that this sample contains little if any free silica (sand). A petrographic examination of a fresh sample from the vicinity of St.-Marc showed volcanic glass and fragments of quartz, feldspar, and other igneous rock minerals in addition to abundant fine-grained calcite. The glass is fresh and clear, and its refractive index of 1.525 indicates a composition corresponding to intermediate igneous rock. Volcanic material of this composition without the admixture of sand and coarse detritus that characterizes much of the Oligocene and Miocene formations would be susceptible to lateritization and may be the source of the lateritic soils.

If, as the few chemical analyses suggest, the limestone bedrock is not the parent rock of the lateritic soil, it may be difficult to establish the source of the lateritic materials. Ash that fell on the Tertiary limestones, after their emergence from the sea and their exposure by erosion and solution, may have been weathered and accumulated as an inherited soil on the limestone. Detailed stratigraphic and structural studies are necessary to determine the composition of the complete geologic section that was available for weathering and for formation of the soil.

The principal role of the Eocene and related limestone strata of the belt of low-silica aluminous lateritic soil deposits may have been an indirect one. These limestone beds of remarkably pure calcium carbonate serve as an ideal physical medium for the accumulation and preservation of the lateritic material. During and subsequent to the accumulation of the soil large volumes of the limestone were removed in solution. The presence of resistant siliceous minerals, such as quartz or clay minerals in the limestone, would have been a source of contamination, and such contamination, either from the limestone bedrock or from adjacent strata subject to solution and erosion, undoubtedly explains the siliceous composition of the soil in many parts of Haiti.

SUMMARY AND CONCLUSIONS

The largest deposits of aluminous lateritic soil in Haiti are on the Rochelois Plateau on the Southern Peninsula southwest of Miragoâne. Similar aluminous lateritic soil occurs in the Beaumont region west of the Rochelois Plateau and to the east in the Massif de la Selle in the vicinity of Savane Zombi. A small deposit was found on the Eocene limestone plateau northwest of Gonaïves.

The low-silica aluminous lateritic soil of Haiti is closely related in occurrence and in origin to similar deposits in the limestone valleys of the Sierra de Bahoruco in the southwest part of the Dominican Republic and to extensive accumulations of lateritic soil on the limestone uplands of the island of Jamaica. All these deposits of similar composition rest on Tertiary limestones extending from the Sierra de

Bahoruco through the Southern Peninsula of Haiti into Jamaica. The localization of the large deposits of lateritic soil in this belt is due to a combination of geologic, physiographic, and climatic factors.

The Tertiary limestone strata have been folded and uplifted in an anticlinal range. Abundant rainfall on this limestone terrane has resulted in the development of valleys and depressions characterized by internal drainage. These valleys and depressions with numerous sinkholes afforded sites for the accumulation and preservation of the aluminous lateritic soil. Chemical analyses of the limestone from the lateritic soil localities of Haiti and of the Dominican Republic indicate a remarkably pure calcium carbonate composition with an alumina content of less than 0.1 percent. The small alumina content requires a large concentration ratio if the soils were derived from the limestone. The aluminous lateritic soil of Hispaniola may be an inherited soil derived from source material other than the limestone on which the deposits now rest. The composition of the soil suggests an igneous parent material of intermediate composition. Pyroclastic material of andesitic composition is widespread in many of the Tertiary formations of the West Indies.

The many complications of the problem of origin of the aluminous lateritic soil of the Caribbean region can hardly be minimized. Detailed studies both in the field and in the laboratory are needed. The present investigation serves to emphasize the concept that long periods of time and a combination of factors are involved in the development of lateritic materials. The problem is one that can well make use of the combined efforts of both soil workers and geologists.

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