SOIL SURVEY

(Reconnaissance)

of

ANTIGUA AND BARBUDA

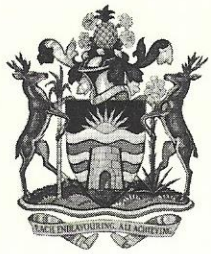
LEEWARD ISLANDS

by

CECIL F. CHARTER.

Price $3

To be obtained from the Government Printer, Antigua, W.I.



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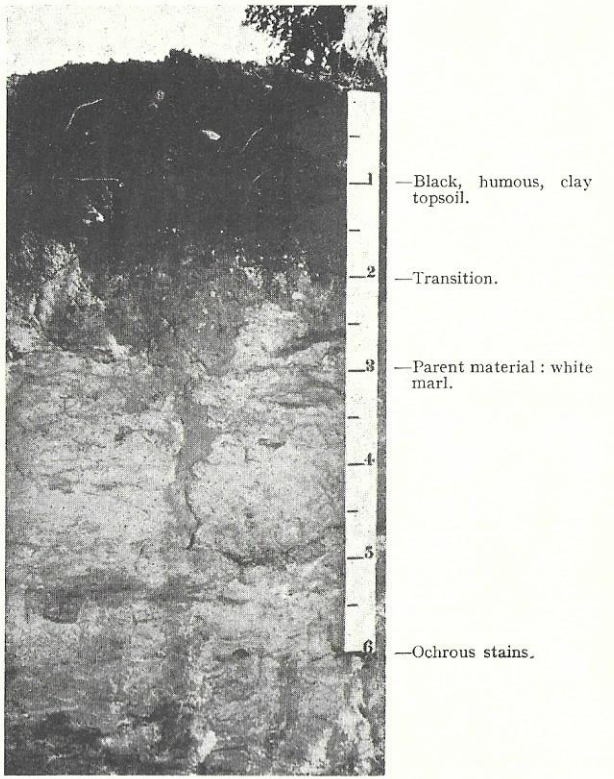
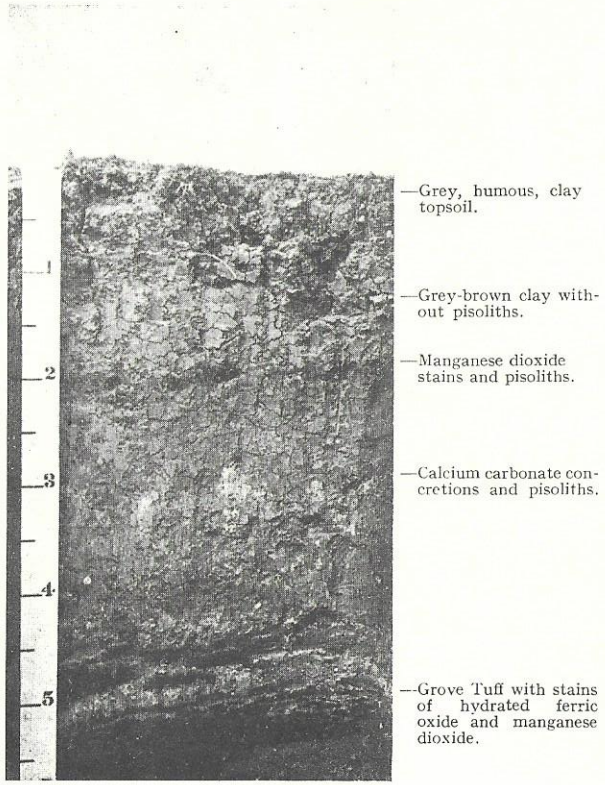
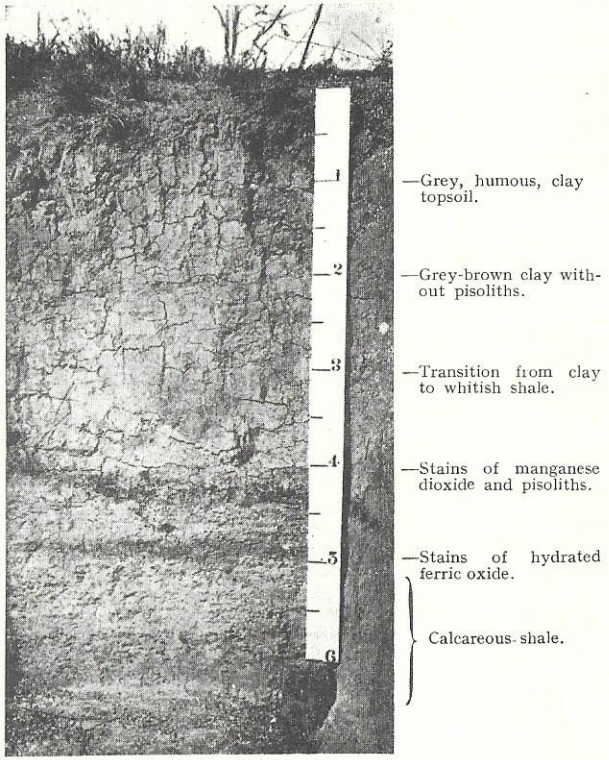


FITCHES CLAY
A typical profile at Gunthorpe's



GUNTHORPE CLAY
A somewhat shallow profile at Fitches Creek



OTTO CLAY
A characteristic profile at Bath Lodge

Divisions on the scale represent feet and half-feet.

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SOIL SURVEY (Reconnaissance) OF ANTIGUA AND BARBUDA, LEEWARD ISLANDS

AREA SURVEYED.

ANTIGUA.

Antigua, one of the islands of the Lesser Antilles, is situated between latitude 17° and 17° 10′ north, and between longtitude 61° 40′ and 61° 55′ west.

It is irregularly triangular in shape, and has an area of approximately 108 square miles.

Antigua is naturally divisible into three main physiographical regions of about equal areas : the volcanic region to the south-west, the central plain, and the limestone region to the north and east.

The volcanic region, south-west of a line joining Five Islands and Falmouth Harbours, is a rugged and mountainous district. The average altitude of the mountain summits is about 1,000 feet, Boggy Peak, the highest of these, being 1,360 feet above sea-level. This region is bounded on the south and west by a narrow coastal plain, and is intersected by a number of small alluvial valleys.

The limestone region, north-east of a line joining Wetherell Point and Willoughby Bay, consists of a number of steep hills, between 300 and 400 feet in height, separated by small valleys and gently undulating areas. It is bounded on the south by an abrupt, but discontinuous, escarpment, rising in places to over 350 feet in altitude.

The central plain, lying between the limestone region and the volcanic district, consists of gently undulating country, which occasionally rises to heights of 500 feet or more. Separating this region from the limestone district to the north is a narrow diagonal trough about a mile broad, and usually less than 50 feet above sea-level, and separating it from the volcanic district to the south-west, the flood plain of Bendal's river.

The geology of Antigua has been described by Nugent (1), Spencer (2), Purves (3), Brown (4), and Earle (5). The main geological regions coincide with the principal physiographical divisions already described. The volcanic region consists of igneous rocks such as andesites, ash-beds, and agglomerates of about eocene date. The rocks of the central plain comprise a series of water-deposited tuffs of oligocene age, and include indurated clays, soft shales, and conglomerates containing pebbles of andesite and porphyry. Interstratified with these are beds of freshwater chert, and sporadic deposits of marine chert and limestone. All these beds, like the Antigua Limestone Formation above them, have a steady dip of 12° to 20° to the north-east. The limestone region consists of oligocene deposits of hard, white, limestone and compacted marls, these beds being noted for their abundant fossil fauna, predominant amongst this being several species of *Orbitoides*. The rock formations of both the central plain and the limestone region are covered with a superficial deposit of clays and marls of about pleistocene age. The marls occurring in the limestone district were partly described by Spencer (2), but generally speaking the more recent surface deposits have been almost entirely neglected by geologists.

Some dozen small water-courses, or ghauts, have their origin in the hilly part of the central plain and in the volcanic region. Only one of these, Bendal's river, is a permanent stream ; the others, although rapid torrents during heavy downpours of rain, are for the greater

part of the year dry, or consist of a series of disconnected and stagnant pools. Natural and artificial ponds are a characteristic feature of the countryside, and according to Ferdinand Columbus the original Carib name of the island was "Jamaica," or "the land of springs and pools." Natural drainage is poor, and considerable areas of the lowlying lands are flooded or waterlogged during very wet periods.

From the records of the earliest settlers it is apparent that the whole island was originally covered with low forest or scrub, but all of this has, at one time or another, been cleared to provide land for planting sugar-cane, for pasturage, or for fuel. Small areas of second-growth scrub are now found on the limestone hills, the less fertile parts of the central plain, and on the steep slopes and in the ravines of the volcanic district. This scrub consists of low trees and dense undergrowth. *Pisonia subcordata* Sw. and *Bursera simaruba* Sarg. are the dominant trees, whilst the under-shrubs consist mainly of various Myrtaceae and Rubiaceae. Most of the trees and some of the bushes are leafless during the dry season, but others, such as the Myrtaceous shrubs, have evergreen coriaceous foliage. The scrub and low forest of the limestone region differ from that occurring on soils developed over non-calcareous materials in the smaller number of species represented, and in their poorer growth. The forest of the more protected situations in the volcanic districts shows slight, but definite, resemblances to tropical rain forest, as evidenced by the numbers of lianes, epiphytes, ferns, and forest herbs present. Much of the central plain is now covered with coarse grasses, which are annually burnt over. The greater part of the lowlying areas in the limestone region, the diagonal trough, Bendal's river valley, and the larger valleys of the volcanic district are cultivated to sugar-cane, but where land in these districts has been abandoned to pasture it is largely covered with thorny scrub consisting of various species of introduced acacias.

Of the island's 68,980 acres, some 36,000 are supposed to be cultivable, and one hundred or more years ago were under cane : to-day, however, only 15,000 acres are cultivated, and of these about 10,000 are worked by estates and the remainder by peasants. Sugar-cane is the principal crop grown, and Sea Island cotton a subsidiary crop.

BARBUDA.

Barbuda, on the same submarine bank as Antigua, is situated 25 miles due north of the latter. Its area, including the large lagoon on the west, is about 62 square miles. It is divisible into two physiographical regions: the Highlands to the east with a maximum elevation of 115 feet, and a marginal plain to the north, west, and south. The geology has been described in an unpublished report by Earle (6). The whole island consists of pleistocene limestones, the rocks of the Highlands being slightly older than those of the marginal plain. There are no surface streams in Barbuda. Drainage is rapid on the Highlands, but large areas of the marginal plain are flooded or waterlogged after heavy rain. The greater part of the island is covered with dense scrub which resembles very closely that found on the drier limestone hills of Antigua.

CLIMATE.

Meteorological data have been collected in St. John's since 1890, and monthly rainfalls from a varying number of stations throughout the island since 1874. Table I gives the more important climatic data for St. John's.

Antigua lies in the Tropical Zone, and has a mean temperature of 81·8°F. The highest temperatures are recorded in August, and the lowest in January. Temperatures as high as 93°F. and as low as 60°F. are occasionally registered.

The average annual rainfall for the whole island, based on a varying number of stations situated principally in the drier sections, is 43·62 inches for the past 63 years. The rainfall throughout the year is very unevenly distributed, roughly two-thirds of the annual precipitation falling in the second half. Frequent and prolonged droughts have rendered agricultural enterprise a hazardous undertaking. Although rain falls on approximately 240 days in the year, the greater part of the yearly total tends to fall during a few very wet periods comprising several torrential downpours. The annual precipitation also varies very much from year to year ; thus an average of 73·59 inches fell throughout the island in 1899, and only 25·51 inches in 1930. The highest rainfall occurs in the interior of the volcanic district, where it exceeds 50 inches, and the lowest in the extreme east and south-east, where it is under 35 inches. The main sugar-cane-growing regions receive a rainfall varying between 35 and 45 inches.

Antigua lies in the hurricane zone, and on occasions suffers from disastrous storms. The last event of this nature occurred in 1928 ; the average island rainfall for that year was 33·24 inches, approximately 8 inches of this fell during the two days of storm.

TABLE I.

Mean monthly, seasonal, and annual temperature and precipitation at St. John's, Antigua, for the period 1926 to 1935, inclusive. Elevation 120 feet.

Month.	Temperature, Mean.	Precipitation.		
		Mean.	Total amount for the driest year (1930).	Total amount for the wettest year (1932).
	°F.	Inches.	Inches	Inches.
December	79·8	3·80	3·73	4·83
January	79·1	2·54	3·50	4·18
February	79·4	1·50	1·30	1·56
Winter	79·4	7·84	8·53	10·57
March	80·5	2·40	0·47	1·24
April	81·6	2·43	1·97	1·42
May	82·7	3·79	1·74	4·41
Spring	81·6	8·62	4·18	7·07
June	83·3	4·58	1·63	11·65
July	83·7	4·46	2·69	5·89
August	84·0	6·13	4·18	4·97
Summer	83·7	15·17	8·50	22·51
September	83·6	5·98	2·10	8·13
October	83·1	6·05	3·05	11·07
November	81·1	6·83	6·65	6·50
Autumn	82·6	18·86	11·80	25·60
Year	81·8	50·49	33·01	65·85

SOILS.

PREVIOUS WORK.

The mechanical and partial chemical analyses of the surface foot of soil from some fifty sites, carried out by the officers of the local Agricultural Department prior to 1915, were in that year published by H. A. Tempany, who gave a general description of the seven "types" he recognized and a small soil map (7). The "types" recognized by this author were : (1) soils of the limestone district ; (2) soils of the central plain ; (3) soils intermediate between those of the central plain and of the limestone district ; (4) soils of the volcanic district ; (5) soils intermediate between those of the volcanic district and the central plain ; (6) soils of Bendal's valley ; and (7) soils of the cherty hills of the central plain. This classification is partly a physiographical one, and partly a geological one. Tempany used the term "type" with a much wider significance than is accorded that term to-day.

In 1932, F. Hardy, J. A. MacDonald, and G. Rodriguez (8), made a laboratory examination of profile samples collected from six-foot pits, the sites of which were chosen by the local Agricultural Department. On the basis of the analyses made, these authors recognized nine principal soil "types," called by them : (1) alluvium ; (2) limestone and marl : (3) siliceous limestone ; (4) gravel and chert ; (5) clay tuff ; (6) sandy tuff ; (7) tuff limestone ; (8) green tuff ; and (9) volcanic. These authors also employ the term "type" in a manner at variance with modern usage. This classification is solely a lithological one. From an agricultural point of view they divided the soils they examined into four main groups : (1) non-calcareous and non-saline ; (2) non-calcareous and saline ; (3) calcareous and non-saline ; (4) calcareous and saline. These authors, in the opinion of the present writer, have tended to over-emphasize the importance of the alkalinity and salinity of Antiguan soils.

METHODS USED IN THE PRESENT SURVEY.

The present survey differs from those previously made in the adoption of modern methods of soil classification and nomenclature, in the more precise delineations of the soil units described, in the recognition of the importance of surface, unconsolidated deposits as the parent materials of the majority of the island's soils, and in the much greater prominence given to profile characteristics. The soils described have been separated into soil series on the basis of the following characters : (1) texture, particularly of the surface horizon ; (2) colour ; (3) content of calcium carbonate and its distribution in the profile ; (4) the presence or absence of concretions and deposits containing manganese dioxide and their position in the profile ; (5) the presence or absence of an excess of soluble salts ; (6) the general structure of the visual profile ; (7) the nature of the natural and semi-natural vegetation ; (8) the position of the water table and moisture relations generally ; and (9) the character of the parent material.

The methods of classification and nomenclature of the American workers as modified by G. W. Robinson (9) have been adopted, and the soils encountered in this survey have been divided into series. By a *Soil Series* is understood a group of soils developed over the same parent material, with the same profile structure, and with the same drainage relationships, and which only differ amongst themselves in the texture of the surface horizon. The members of a soil series are known as *Soil Types ;* usually the textural variation within a series is small. No attempt has been made to differentiate or to map the textural types in this survey. A soil type is given two names—the first or series name is taken from a locality in which the series in which it is included is typically developed ; the second defines the textural class to which the soil of the

surface horizon belongs, e.g. Gunthorpe Clay, Blubber Valley Sandy-Loam, etc. Soil series that develop over the same, or lithologically similar, parent materials have been combined together in *suites*. Soil suites are named after one of the normal soil series included in the suite, or, should the normal soil not be developed, after one of its most important members.

Five suites have been recognized in the survey of the Antiguan soils, and twenty-four soil series, and in Barbuda one suite containing four Soil Series.

No reliable topographical maps of either Antigua or Barbuda exist ; the outlines of the soil series Maps included with this account have been taken from the Admiralty Charts of the two islands.

THE SOILS OF MONTERO SUITE.

The soils in this suite occur in the south-western third of the island. They are found on the mountain slopes, on the narrow coastal plain, and in the small alluvial valleys. Much of the land involved is too steep and rocky to be of much use agriculturally. Five soil series have been recognized ; two of these with very rough topography, namely Montero and Fry Series, have been mapped together as Rough Mountain Land. Doubtless, additional series could be recognized but they would be of very small extent and importance.

Montero Series.

The area covered by the Montero soils comprises the greater part of the volcanic region. Excepting for a small area of undulating land to the north of Jenning's Village, no estate cultivation is practised on these soils. The remainder of this series is found on steep hillsides ; some is cultivated by peasants, some is under pasture, and some covered with low forest or scrub.

The parent material is volcanic ash of eocene date ; it contains large numbers of andesite bombs, some of considerable size, and these weather concentrically. The ashes are roughly stratified, and form moderately hard, compact beds. They vary in colour from dull brown to a pronounced greyish-purple.

To a depth varying from four to nine inches the soils of this series consist of dark grey to grey-brown, stiff clays or clay loams with a cloddy structure, and contain stones and boulders of andesite. The surface horizon grades into a crumbly transition layer of rotten ash, which is brown, reddish-brown, or purplish in colour, and varies from a few inches to a foot or more in thickness. Below this is the parent material. Under peasant cultivation, the surface soil frequently has a brown, reddish-brown, or purplish colour ; this is due to admixture of the shallow topsoil with the underlying rotten ash, or to the loss of the former by erosion.

These soils are neutral or even slightly acid at the surface, but become alkaline at lower depths.

Typically they contain no calcium carbonate in the surface horizon, but seams of soft, pulverulent calcium carbonate may occur in the upper parts of the parent ash, although this feature is not usually developed in the very shallow soils.

Black, spherical concretions of small size containing significant amounts of manganese dioxide are scattered sparingly throughout the surface horizon, and in some localities are abundant. Stones in the transition zone and in the upper part of the parent ash are often stained black with deposits of the same material.

The soils of Montero Series receive a rainfall varying from 40 inches near the coast to nearly 60 inches in the interior. Despite the broken topography of the region in which they occur, natural drainage is not good, and there is much run-off. During periods of heavy rain these soils quickly become waterlogged, but during periods of little rain they lose their moisture rapidly, become very hard, and crack.

The natural vegetation before the settlement of the island consisted of forest and scrub ; only small areas of second-growth forest remain, and most of the series is now under bushy grassland.

Peasants grow a variety of crops on a small scale ; these include pine-apples, cassava, arrow-root, yams, eddoes, sweet potatoes, pigeon peas, bananas, plaintains, and sugar-cane. Scattered over the hillsides are frequent mango trees, limes, avocado pears, and cashews.

Associated with the soils of this series, are found a few small areas of non-calcareous, friable reddish-brown soil underlain by a bright red subsoil which, in turn, is underlain by ash, heavily seamed with calcium carbonate.

FRY SERIES.

This series resembles Montero Series very closely. It consists of a stiff, grey, cloddy clay or clay-loam topsoil overlying at a few inches depth rotten andesite, which, in turn, overlies unweathered andesite rock. A smaller area is under this series than the last.

BLUBBER VALLEY SERIES.

The soils of Blubber Valley Series are found in a number of small and narrow valleys leading from the centre of the volcanic region towards the coast. The upper parts of these valleys are often stony. The Blubber Valley Soils have a more or less level topography, and are usually under fifty feet above sea-level. Excepting for a few areas in the south, most of this series is under cultivation. In the valleys to the north-west, where access to the central plain is easy, they are under estate cane, elsewhere they are worked by peasants who grow the same varieties of crops as on the Montero soils.

The parent material consists of recent stratified sands and gravels derived from the igneous rocks of the volcanic district. It is brownish-grey or purplish-grey in colour.

The dark brown to greyish-brown surface soil is a loam or sandy-loam a foot to eighteen inches in depth, and grades almost imperceptibly into the parent material. During the dry season the surface soil frequently develops vertical cracks.

The reaction of the surface horizon varies from slightly acid to slightly alkaline, but it is alkaline, about pH 7·5, at lower depths.

Very little or no calcium carbonate occurs in the topsoil, but small patches of soft calcium carbonate may occur at depths of about four or five feet.

Manganiferous concretions are infrequent in the surface soil, but in some places the upper part of the parent material is stained black with manganese dioxide.

These soils receive a rainfall of 40 to 55 inches, and their water supply is supplemented by seepage from the surrounding hills. The water table frequently approaches to within a few feet of the surface. Natural drainage is fair in the upper parts of the valleys, but is distinctly poor in the lower parts near the coast. In a few localities the ground-water is saline.

The natural vegetation of this series has persisted to some extent in the stony, upper parts of the valleys ; it consists of a taller, more mesophytic, type of forest than is found elsewhere in the island. Mangoes grow well on these soils, many of the trees attaining a considerable size. Coconuts can also be cultivated with a certain amount of success. A few cacao trees and oil palms are found in one or two localities, the remnants of attempts to find alternative crops to sugar-cane.

York Series.

The soils in this series are grey, or grey-brown sandy-clays developed along the coast of the volcanic region over alluvial material of igneous origin. They are alkaline in reaction and frequently contain considerable quantities of calcium carbonate throughout the profile, largely due to admixture with coral sand. The water table approaches very near to the surface, and on account of their lowlying nature drainage is difficult. This is not an important soil series and very little of it is cultivated.

Bendal Series.

The soils of this series occur solely in the valley of Bendal's river. All of the land on which they are found is flat and under 50 feet above sea-level. Excepting for a few fields abandoned to pasture, all of the soils in this series are under estate or peasant cane.

The parent material consists of roughly stratified sands, clays, and gravels, derived in part from the volcanic hills to the south, and in part from the hills of stratified tuffs to the north.

The surface soil is dark grey, or purplish-grey in colour, and varies in texture from a sandy-loam to a sandy-clay ; it is cloddy in structure and cracks deeply during dry periods. At about twelve or eighteen inches it grades into the parent material that is lighter in colour.

These soils are neutral to slightly alkaline at the surface, but often very alkaline at lower depths.

Little or no calcium carbonate occurs in the surface soil, but small patches are frequently found in the parent material at depths of four or five feet.

Small, black, spherical concretions containing significant amounts of manganese dioxide are found in the surface horizon, and black stains may occur in the upper part of the parent material. Old root-channels are often filled with rusty deposits of hydrated ferric oxide, and rusty spots are encountered throughout the profile.

Some localities are slightly saline, and mace-like aggregates of gypsum crystals are scattered throughout the lower parts of the profile in such areas.

This soil series receives a rainfall of 45 to 50 inches. It is traversed by the main streams and tributaries of Bendal's river which constantly overflow during heavy rains. The water table often rises to within a few feet of the surface, and natural drainage is poor.

Hardly any of the natural vegetation has been preserved, but it seems probable that it consisted of a transition from mangrove forest to the forest and scrub characteristic of the tuff and volcanic hills. It was undoubtedly a swampy type of forest in which the principal arborescent species were *Bucida buceras* L., *Roystonea oleracea* O. F. Cook, and *Acrocomia sclerocarpa* Mart., whilst *Anona palustris* L. was one of the dominants of the shrubby undergrowth.

THE SOILS OF OTTO SUITE.

The soils of Otto Suite occur throughout the central plain, and are developed partly over thin, superficial deposits of pleistocene to recent clay, and partly over the various rock formations of the sedimentary tuffs that underlie these. The soils in this area which have developed over marls derived from the sporadic outcrops of tuff limestone are described as members of the Fitches Suite. The soils of Otto Suite occur on undulating land or gentle hill-slopes, but although the topography of the country in which they occur would appear to lend itself to satisfactory underdrainage, all of the soils in this suite, with one exception, have very poor natural drainage. Most of these soils are thin, are underlain by impervious rock, or are plentifully scattered over with large chert boulders, and, in consequence, are little utilized at the present day for estate cultivation. One hundred and fifty years ago, however, a large proportion of the soils of Otto Suite were growing sugar-cane on an estate scale. The greater proportion of their area is now covered with coarse grassland scattered over with small patches of scrub. The dominant grasses on these areas are species of *Paspalum* and *Andropogon*, and include : *P. plicatulum* Michx., *P. secans* Hitchcock and Chase, *P. notatum* Flügge, *A. glomeratus* (Walt.) B.S.P., and *A. saccharoides* Sw. Most of these species are comparatively valueless for fodder, and are annually burnt to destroy the old coarse growth. Where intensive grazing is practised, however, these grasses are suppressed in favour of species of recognized value such as *Axonopus compressus* (Sw.) Beauv. Increasing areas in this suite are now being put under peasant agriculture. Nine soil series have been recognized in this survey, but a more detailed survey would undoubtedly differentiate others owing to the very heterogeneous nature of the parent materials, but these would be of small extent and importance. The Scott, Gordon, and Tyrell Series have not been separately delineated on the Soil Map, but included with the St. Clair Series.

OTTO SERIES.

This series is encountered on gently undulating land throughout the central plain, generally at elevations below 100 feet above sea-level. Some of the better areas are under estate cane, others are worked by peasants, and others under coarse grass or bush.

The parent material consists of brown-coloured clay of pleistocene or later date, that overlies soft argillaceous shales, varying in colour from cream through ochre to rich brown. Interstratified with these shales are occasional layers of indurated clay tuff, thin seams of marl, or layers of hard limestone. The structure of the parent materials is well displayed in the cliff sections at Dry Hill and Corbison Point.

The surface horizon is a stiff, cloddy, grey, to dark grey-brown clay, varying from about six to eighteen inches in depth. This sets hard during the dry season and develops deep vertical cracks that extend into the horizon beneath. Earthworms are common in the surface soil during the wet season, and the surface of the ground under coarse grasses is frequently covered with their casts. Below the greyish, humous horizon is a layer of clay, bright brown to dull, grey-brown in colour. Frequently, when these soils are cultivated, admixture of this horizon with the topsoil gives a decidedly brown shade to the latter. This clay horizon varies in thickness, and may be almost absent, but on the average it grades into soft shale at a depth of about four and a half feet. The surface horizons of this soil series contain the remains of valves of marine molluscs of pleistocene age (*cf.* Gunthorpe Series) and frequently water-worn stones and boulders of chert which show no evidence of having been derived by weathering from the shales immediately below.

The reaction of the topsoil is neutral to slightly alkaline, becoming more alkaline at lower depths.

Excepting where these soils are adjacent to outcrops of limestone, they contain little or no calcium carbonate in the upper horizons. Patches of pulverulent calcium carbonate occur, however, in the upper parts of the underlying shales.

Black, spherical, and concentric concretions, containing large amounts of manganese dioxide, occur in the surface horizon. These are hard and attain a diameter of 1·5 cm. No concretions are encountered in the next horizon, but at a depth of about four feet, and above the calcium carbonate zone in the soft shale, a sharply-defined, dark brown to black horizon is found, approximately six inches in thickness, and containing about 1 per cent of manganese dioxide as stains in the neighbourhood of fine rootlets on the surface of the cleavage faces of the shale. Similar concretions to those that occur at the surface, but smaller in size and softer, are also found in this horizon, and are sparingly scattered throughout the clayey shale below.

This soil series receives an average rainfall of 45 to 50 inches. The underlying shales do not appear to be impervious, but nevertheless, the natural drainage of Otto Series is poor, and waterlogging occurs during the wet season, followed by intensive drying out of the humous topsoil, accompanied by much cracking, during rainless periods.

The natural vegetation consisted originally of low forest and dense scrub. At present, most uncultivated land is covered with coarse grasses.

Briggin Series.

The Briggin Series is not an important series ; it is found in lowlying areas usually adjacent to the soils of Otto or St. Clair Series. Some of the Briggin soils are under estate cane, others under coarse grasses, and others under peasant cane. In the past, however, most of this soil series must have been cultivated at one time or another on an estate scale.

The parent material consists of dull brown, very heavy clays that have been derived from the erosion of the rocks of the sedimentary tuff formations. These clays occur in depressions and lowlying areas. They frequently contain layers of weathered chert stones and boulders. The soils of this series grade imperceptibly into those of the Otto Series, from which they differ in the much greater thickness of the clay parent material.

The surface humous horizon consists of very stiff, cloddy, grey, or grey-brown clay and varies in depth from six to twelve inches; it grades imperceptibly into the dull brown clay constituting the parent material. The surface one or two feet crack very badly during prolonged dry spells. Earthworms are abundant in the humous horizon when this is moist, and their casts cover the surface of the soil when this is under grass.

The reaction of these soils varies from slightly acid to slightly alkaline at the surface, but they are quite alkaline at lower depths.

The humous topsoil contains little or no calcium carbonate, but accumulations of this substance occur at a depth of five feet or more. Sometimes these concretionary masses are abundant, and set hard when they are washed out and exposed to the air.

The surface horizon contains large numbers of hard, black, spherical concretions, containing up to 20 per cent or even more of manganese dioxide ; these vary in size from less than one millimetre to as much as three centimetres in diameter. From four to four-and-a-half feet, and above the zone of accumulated calcium carbonate, is found a sharply-defined black horizon, consisting of stains of manganese dioxide on the cleavage faces of the clay. Soft pisoliths, but generally much smaller than those occurring in the surface soil, are encountered in this layer and in

the clay below. No concretions or stains are to be found in the layer of drab clay that lies between the humous surface soil and the black horizon below four feet. Where wash-outs have occurred through erosion, the surface of the ground is covered with conspicuous numbers of these black pisoliths.

In a few lowlying areas of this series brackish or saline ground-water approaches the surface during the greater part of the year.

The soils of this series occur under a rainfall of 40 to 50 inches. Natural drainage is very poor, and during wet weather they rapidly become waterlogged. In rainless periods, however, they dry out and crack badly.

ST. CLAIR SERIES.

The soils of St. Clair Series consist of heavy grey clays developed over a relatively thin surface deposit of clay that overlies hard gritty tuff, but included in this series are a few small areas in which the surface clay overlies crumbly shale.

The soils of this series cover a very considerable part of the central plain ; they occur on the slopes of gently undulating land that attains an altitude of 500 feet and over in some localities. No estate cane is grown on this series except where the underlying tuffs are of the crumbly variety, and very little peasant agriculture is practised either. By far the greater proportion of these soils is under coarse grasses, and scattered over with small areas of scrub or low forest. Much of this series is bouldery on the surface. At one time, however, quite a large proportion of these soils were under estate cane, and the boulders of chert were collected and built into stone walls round the edges of the fields.

Occasionally the underlying tuffs are purplish in colour, but the commonest type of parent material consists of cream-coloured indurated clay tuff, with small brown inclusions. It frequently contains rotten pebbles and fragments of igneous rock as well, but chert layers do not occur, not at any rate near the surface. The bedding planes are usually several feet apart, and few joints occur.

Where these soils are more or less undisturbed, the surface horizon is dull grey-brown in colour and cloddy in structure. But where they have been partly eroded and are cultivated, their colour is largely dependent upon the nature of the underlying tuffs, thus whitish-grey and purplish-brown topsoils occur in some areas. The humous surface horizon varies in depth from a few inches to a little over a foot. Below this is a crumbly transition layer of gritty clay, a few inches to a foot in depth, containing many fragments of partly weathered tuff.

The soils of this series are neutral to slightly acid in the surface layers, and neutral to alkaline below.

Calcium carbonate is absent from the soil layers proper, but is occasionally found as soft patches in the upper parts of the underlying tuffs.

Small manganiferous pisoliths occur in the grey humous surface layer. Manganese dioxide may also be found as stains in the upper part of the indurated tuffs where partial weathering has taken place, or it may even be present as considerable-sized masses, although the latter condition is rare and the former by no means common. Frequently, the large chert boulders of the surface horizon are covered with concretionary masses of wad containing large amounts of manganese dioxide.

The soils of the St. Clair Series are found under a rainfall of 40 to 60 inches. Despite the rolling nature of the country in which they occur, drainage is poor. The surface soil quickly becomes waterlogged in wet weather, and the run-off is very considerable. During the dry season the humous surface clay becomes almost completely dried out and cracks very badly.

Tyrrel Series.

The soils of Tyrrel Series occur over limited areas from All Saints' Village south-eastwards towards the neighbourhood of Isaac Point. The rough soil map in Hardy's paper (8) greatly exaggerates their extent. These soils have little or no agricultural value.

The parent materials of this series consist of a thin surface deposit of clay overlying hard well-bedded blue-green tuff. The colour of this rock is due, according to Earle (5), to its content of a ferrous mineral resembling chlorite.

The profile characters of the Tyrrel soils resemble those of the St. Clair Series, but they have been separated from the latter on account of the different nature of the underlying tuffs.

The humous light-grey-coloured surface layer is a heavy, silty clay, cloddy in structure and varies from a few inches to over a foot in depth. It passes into a greyish-white transition zone of clay and very rotten tuff which, at a depth of eighteen to twenty inches, gives place to a layer of soft brash broken off the underlying tuffs by more or less horizontal cleavages.

The reaction of the surface layer is neutral to slightly acid, but these soils become alkaline at lower depths.

Calcium carbonate is absent from the surface, but it may be found as a powdery coating to the lower parts of the brash layer.

Small manganiferous pisoliths are common in the humous horizon, and brilliant black stains of manganese dioxide with a steel-blue sheen abundantly coat the fracture faces of the rotten upper layer of the underlying tuff.

These soils are found under a rainfall of 45 to 50 inches. Natural drainage is poor. Tyrrel soils become waterlogged in the wet season, and set hard and crack during prolonged dry periods.

The soils of this series are mostly under coarse grasses and scrub.

Scott Series.

The Scott soils are of limited extent, occurring mostly on hilly land in the western part of the central plain.

The parent material consists of a surface deposit of clay overlying well-bedded and much-jointed indurated clay tuff. These bedding planes and joints break the rock up into characteristic brick-like and diamond-shaped blocks, which break with a conchoidal fracture. At Scott's Hill, the tuffs are buff-coloured, at Gambles a dull brown, and at Golden Grove a chrome colour, whilst at Chalky Hill in the south-east they are almost white.

The surface horizon is a stiff clay, grey to dark brown in colour. This is underlain by pale brown clay that passes into a layer of rock brash which, in turn, overlies the undisintegrated tuffs.

These soils contain no calcium carbonate in the upper parts of the profile, but accumulations of pulverulent calcium carbonate may occur in the lower part of the brash layer, or coatings of calcite in the joints and fissures of the underlying tuffs.

Pisoliths have not been observed in the humous topsoils of this series, but the joints, bedding-planes, and fissures of the tuffs are abundantly coated with black stains of manganese dioxide and red-brown deposits of hydrated ferric oxide. In one profile examined, a well-defined zone of manganese dioxide accumulation, about six inches thick and forming a coating to the surfaces of the tuff fragments, occurred in the brash layer.

The soils of the Scott Series receive a rainfall of between 40 to 50 inches. As with the previous members of this suite, these soils have indifferent drainage, but rapidly lose their moisture during dry weather.

Most of the soils in this series occur under coarse grass or bush, and only a few areas are cultivated by peasants.

GORDON SERIES.

These soils are grey or greyish-brown clay-loams or clays, which are often gravelly. They are developed over indurated gritty tuff that contains large amounts of included andesite pebbles. They resemble in their profile structure the St. Clair Series, but where cultivation has resulted in the admixture of much of the coarse gritty and gravelly layer transitional to the underlying tuff with the topsoil, the latter has a more open texture, and drainage is, in consequence, freer. Soils in the Gordon Series are found in the southern part of the central plain and in the Five Islands peninsula. Some of the flatter areas have been cultivated and Sea Island cotton has done well on these when the rainfall has not been excessive. Most of the land on which these soils are found is too steep and the soils too thin to permit of their cultivation ; such areas are, at the present time, under coarse grasses and scrub.

Horizons of manganese dioxide and calcium carbonate accumulation are sometimes found in the upper parts of the rotten rock, these substances occurring as coatings round the included pebbles.

CLAREHALL SERIES.

The soils in this series are of little value agriculturally. They are developed over a surface deposit of clay that overlies the Cassada Garden Gravels at varying, but shallow, depths. They are found on the surface of small knolls that are encountered throughout the length of the diagonal trough. The Cassada Garden Gravels are the uppermost formation of the sedimentary tuffs, and consist of water-worn fragments of the underlying indurated clays, lacustrine and marine cherts, silicified wood, and igneous rocks imbedded in a reddish-brown or grey, coarse, sandy cement.

The Clarehall soils are alkaline throughout the profile. The upper parts of the gravel often contain accumulations of manganese dioxide which occur as black coatings to the included pebbles. Copious deposits of calcium carbonate occur in similar situations.

These soils are rapidly waterlogged during periods of heavy rains, but during dry spells they lose their moisture very rapidly. On this account, and due to their stony and gravelly nature, the Clarehall soils are rarely worked by estates, but peasants cultivate them, particularly in the neighbourhood of St. John's.

SHIRLEY SERIES.

The soils in this series occur in the hilly region in the south-east of the central plain, comprising Piccadilly and Shirley Heights. The surface layer is a brown to reddish-brown loam, and overlies a bright red subsoil which, in turn, overlies buff-coloured rock containing large amounts of marine chert and silicified corals. The parent material in places contains considerable

quantities of accumulated calcium carbonate. These soils are generally both stony and shallow, and although they cover quite a fair area, are little cultivated. Small areas are, however, worked by peasants who grow cane, Sea Island cotton, pine-apples, and ground provisions. At present most of this series is under coarse grasses or bush, and is utilized by peasants for grazing and for charcoal burning. The Shirley soils receive a rainfall of about 35 inches ; apparently from the prevalence of brown and red colours, these soils possess much better natural drainage than do the other members of this suite.

Falmouth Series.

The soils in this series occur between Falmouth and Piccadilly and in the neighbourhood of Bethesda Village. They are developed over colluvial and alluvial material derived from the high range of hills of gritty and gravelly tuff extending from Monk's Hill to Christian Hill. The land on which they occur is level or gently sloping. These soils vary in texture from sandy-loams to sandy-clays, and are frequently gravelly. Their colour varies from purplish-brown to grey-brown. In reaction they are slightly alkaline at the surface and more alkaline at lower depths. The surface horizon contains little or no calcium carbonate, but accumulations of this material may occur in the deeper parts of the profile. The Falmouth soils receive a rainfall of about 40 inches, and drainage is impeded during the wet season. The soils in this series are either under thorny scrub or are worked by peasants, but in the past were cultivated by sugar estates.

THE SOILS OF GUNTHORPE SUITE.

The soils in this suite are found in the diagonal trough and in the centre and east of the limestone region. The soil profile is developed wholly in a surface deposit of calcareous clays of pleistocene age that occur in depressions and lowlying areas. By far the greater proportion of these soils is under estate cultivation. Three soil series are recognized and mapped.

Gunthorpe Series.

The soils of Gunthorpe Series occur only in the diagonal trough, and extend from Dickinson Bay in the north-west to Willoughby Bay in the south-east. The greater part of this series has an elevation of under 50 feet above sea-level. These soils cover a considerable area and constitute the second most important cane-growing soil series in the island.

The parent material is a heavy, plastic, grey-buff or grey-green clay laid down under swamp or lagoon conditions in pleistocene or later times. This deposit varies from two or three feet to over twelve feet in depth. It overlies Grove Tuff (a variously coloured clay tuff containing rotten andesite pebbles), purple or grey volcanic sands, or the Cassada Garden Gravels. In some places it contains notable quantities of quartz sand, layers of fine chert gravel, or deposits of water-worn stones and boulders, some derived from the tuffs, some from the Cassada Garden Gravels, and some from the chert beds of the freshwater series. The surface of cultivated fields is scattered over with the shells and fragments of shells of recent and pleistocene marine molluscs, amongst which the following species are commonly found : *Strombus gigas* L., *Livona pica* L., *Arca chemnitzii* Phil., *Cardium muricatum* L., *Chione cancellata* L., *Codakia orbiculare* L., and *C. orbiculata* Mint. These shell beds have been described by Spencer (2) and Brown (4), but they were not associated with any particular geological deposit. In the opinion of the writer, they form part of the pleistocene lagoon-clay deposits of the diagonal trough and elsewhere. The more or less recent submergence of the part of the central plain known in this account as the diagonal trough was discussed, and its possibility not denied by Earle (5) ; and Tempany (10) sought to

account for the saline nature of some of the soils and wells of this region by the same hypothesis. Hardy (8) was unaware of the nature of the parent material of the soils of this region, and described them as developing over clay tuff. The clay tuffs are the indurated clays and shales that underlie the soils of Otto Suite. Clay tuffs do not form the parent materials of any soils occurring in the diagonal trough.

The humous horizon of the soils of this series is a cloddy, heavy clay, grey to almost black in colour. It varies in depth from a few inches in some infertile phases to as much as twenty-four inches in some of the cultivated soils. This horizon develops deep vertical cracks during dry periods. Immediately beneath the dark-coloured humous soil there is sometimes a pale grey zone of about a foot or more in thickness that is appreciably lighter in colour than the buff or greenish-grey clay below. The latter breaks up into irregular masses by fractures, which extend in all directions. The surface of these masses is smooth and glistening, and the deeper roots of sugar-cane and grasses pass downwards between them to depths of five or more feet.

The reaction of the surface horizon is nearly neutral in the soils farthest removed from the limestone escarpment, but increases to about pH. 8·0 as the escarpment is approached. The alkalinity also increases with depth to about pH. 8·5 or more.

The clays nearest to the limestone escarpment are calcareous throughout the profile, but farther from the escarpment the parent clay is only very slightly calcareous. The surface horizon of the soils near the limestone boundary contains as much as 25 per cent of calcium carbonate due to wash from the marl-covered hills, but as the diagonal trough is traversed in a south-westerly direction the content of calcium carbonate decreases until it is less than 0·5 per cent in the soils that abut on members of the Otto Suite. Soft concretions of calcium carbonate characteristically occur in these soils from about eighteen inches downwards. They are much more abundant than in the soils of Otto Suite. They vary in size from much less than an inch to as much as six inches in diameter. When freshly dug out they are soft, but become quite hard on exposure. Where washouts have occurred through erosion, these concretions occasionally form patches of calcareous gravel on the surface of adjacent areas. An analysis of these deposits showed them to contain about 80 per cent calcium carbonate and over 12 per cent silica.

Small hard pisoliths are commonly found in the humous horizon, and similar, but soft, concretions are scattered throughout the whole profile. There is typically no well-defined horizon of manganese accumulation at about the four-foot depth with a zone free from concretions between this and the humous layer as is characteristic of the soils of Otto Suite, although indications of this occurring are found in the only slightly calcareous soils to the south-west of the trough.

Saline areas and spots are a frequent occurrence on the soils of Gunthorpe Series. They are found in lowlying areas and depressions where the brackish ground-water approaches the surface. Such areas are characterized by the occurrence of accumulations of crystalline gypsum in either the lower parts of the profile or sometimes throughout the profile. Where such areas occur in cultivated fields they are known as "Saltpetre Patches."

The soils in the Gunthorpe Series receive an average annual rainfall of 38 to 46 inches. The diagonal trough is crossed by a number of ghauts, and these, partly because their channels are not kept clear and free from obstructions and partly because they have to cope with excessive run-off from the tuff hills to the south, frequently overflow during periods of heavy rain. The natural drainage of the Gunthorpe Soils is very poor both on this account and because of their lowlying situation and of the impervious nature of the parent clay.

From what little remains of the natural flora on the soils of the Gunthorpe Series, it is probable that these soils supported a tall swamp-forest consisting of species tolerant of calcareous and brackish soil. The dominant tree was undoubtedly *Bucida buceras* L., and this is still the commonest road- and ghaut-side tree on soils of this series, whilst prominent amongst the shrubby undergrowth was *Anona palustris* L. Where soils of this series are not under cane they are in pasture, the dominants in this community being the grass *Andropogon nodosus* (Willem.) Nash, and the ubiquitous sedge, *Abildgaardia monostachya* V. These pastures, unless given frequent attention, rapidly become covered with a dense growth of *Acacia nilotica* Delile, *A. lutea* Hitchcock, *A. farnesiana* W., and *A. tortuosa* W.

Lindsey Series.

The Lindsey Series is an important group of sugar-cane soils, but is less extensive than the Gunthorpe Series. It is found in lowlying areas in the centre of the limestone district, and an extensive area also occurs in the extreme east between Montpelier Buff and Freetown Village. Small patches of these soils a few square yards in area frequently occur amongst the adjacent soils of the Fitches Series, and the continuous areas of Lindsey Soil marked on the Soil Map are to some extent made up of such patches. Whilst considerable areas of the Lindsey Series is still under estate cane cultivation, some areas have been abandoned and are under pasture. Practically none of this series is worked by peasants.

The parent material of the Lindsey soils consists of very heavy plastic clay that is significantly heavier and more plastic than the parent clay of the Gunthorpe Series. It is usually calcareous, although areas of practically non-calcareous clay occur in some localities. This clay, which varies in colour from light grey to greenish-grey, and from dull brown to rich ochre, is a surface lagoon-deposit of pleistocene age. Sometimes, as in a small area west of Parham, it contains water-worn stones and boulders of hard orbitoidal limestone and chert derived from the Antigua Limestone Formation. The surface soil contains shells of recent and pleistocene marine molluscs as was recorded for the soils of Gunthorpe Series. The depth of this deposit varies from two or three feet to over twelve feet. It is underlain by hard orbitoidal limestone, unconsolidated marls, Elliot's Sandstone, or by soft non-calcareous shales with included andesite pebbles.

The surface horizon of this series is a cloddy clay, dark grey to almost black in colour. It often has a gun-metal shade when observed in the field in bulk. The depth of the dark grey humous horizon varies, but in the better cultivated fields it is about eighteen inches. It passes into a lighter grey-coloured clay, and then into the somewhat darker coloured parent material. The surface horizon dries out badly during rainless periods and deep cracks extend into the parent clay.

In reaction these soils are alkaline throughout the profile, being about pH. 8·0 at the surface and pH. 8·5 at lower depths.

Owing to wash from the very calcareous soils of the adjacent Fitches Series, the surface layers almost invariably contain considerable amounts of calcium carbonate. Conspicuous, soft concretions of calcium carbonate typically occur in the parent clay from eighteen to twenty-four inches downwards, but are commonest in the upper parts.

Small pisoliths are frequent in the surface horizon, and, as in the Gunthorpe Series, small, soft, black concretions are scattered throughout the profile, but there is, as a rule, no distinct horizon of manganese dioxide accumulation.

In a few localities near the coast, saline spots are found where brackish ground-water approaches the surface, but such areas are not common. The profile in such situations is characterized by accumulations of gypsum in the lower horizons. Where such spots occur in cultivated fields, sugar-cane fails to grow, and they are known as "Gall Patches" and are similar to the "Saltpetre Patches" of the Gunthorpe Series.

The natural drainage of these soils is poor, and the frequent occurrence of ponds is a characteristic feature of the Lindsey Series. Most of the areas in which these soils are found are traversed by small watercourses which only contain running water after heavy rain. These receive too little attention to act as really effective drainage outlets.

The natural vegetation of the Lindsey Series undoubtedly resembled that of the Gunthorpe soils. *Bucida buceras* L. is the commonest indigenous tree at the present day, and a swamp-forest community in which this was the dominant probably covered these soils prior to their settlement and cultivation. Areas of grassland in which *Andropogon nodosus* (Willem.) Nash and *Abildgaardia monostachya* V. are the co-dominants, scattered over with *Acacia* spp. and the shrubby *Pluchea odorata* Cass. occur where cane-fields have been abandoned to pasture.

TOMLINSON SERIES.

The soils of this series are intermediate in character between those developed over the lagoon-deposited clays of the diagonal trough and elsewhere and those developed over the much shallower deposits of superficial clay covering the tuffs in the hilly and undulating areas of the central plain.

The Tomlinson Soils occupy a relatively small area extending from the east of Gunthorpe's Estate to Clarehall. The topography of the area in which they occur varies from gently undulating land at about 100 feet in altitude to level areas of 50 feet or less above sea-level. These soils are encountered on the south-western margin of the diagonal trough, and abut on the soils of Otto Suite, to which they show certain resemblances. At one time all of these soils in this series were under cultivation, but much of them has been abandoned and is now in pasture. The continuous area delineated on the Soil Map really consists of a number of discontinuous small bodies of soil which it was impossible to map separately.

The parent material is practically non-calcareous dull grey-brown clay, which varies from two to three feet to about eight feet in depth. It occasionally contains layers of water-worn pebbles and boulders of chert and andesite. It is underlain by purple volcanic sands; over very small areas these sands may actually reach the surface.

The surface horizon of this series varies from a cloddy, dark grey, or grey-brown, heavy clay to a purplish– or reddish–brown clay-loam where the underlying sands approach the surface. The humous horizon varies in depth from about six inches to a foot or more. Where the volcanic sands are situated at some depth, the topsoil grades into heavy dull-brown clay, which gradually assumes a purple tint and lighter texture, and finally gives place to purple sands.

The reaction of these soils varies from slightly alkaline at the surface to pH. 8·5 or over in the lower parts of the profile.

Calcium carbonate is present in only very small amounts in the humous horizon and the drab clay beneath. It is found abundantly, however, as seams and patches in the upper part of the volcanic sands. These deposits of calcium carbonate are siliceous, and, as in the case of the concretions in Gunthorpe clay, they are soft when first uncovered, but harden on exposure.

The humous layer contains occasional hard pisoliths. Where a considerable depth of clay intervenes between the surface horizon and the volcanic sands, a black zone of manganese dioxide stains is found between the three and four foot depths. Small, soft pisoliths are encountered in this layer and in the clay beneath, but not in the sands. Where the volcanic sands approach the surface, the zone of manganese dioxide accumulation occurs in these as a powdery layer. Manganese dioxide may also be found as a deposit on andesite and chert pebbles occurring in the parent clay.

THE SOILS OF FITCHES SUITE.

The soils of Fitches Suite, developed over lagoon-deposited marls, occur mainly in the limestone region, although outcrops of calcareous parent materials are found scattered as small areas throughout the sedimentary formations of the central plain, and there is one outcrop on the north-western edge of the volcanic district. The topography of the land on which the soils of this suite are encountered varies from hills of 400 feet in height to relatively lowlying valleys. The soils on the hills are mostly under low forest or scrub ; the lowlying areas are nearly all cultivated and under sugar-cane. None of the soils in this suite has been developed over the hard orbitoidal limestones of either the Antigua Formation or of the Tuff Series, but upon later, surface deposits derived from these. Five soil series have been recognized and mapped.

Fitches Series.

The soils of Fitches Series are of considerable extent, occur solely in the limestone district, and are found in small valleys and on areas of almost level topography. Most of this series is under estate sugar-cane cultivation, but a considerable area is also cultivated by peasants, especially in the extreme east, and a few small areas are under pasture. This is one of the most extensive soil series in Antigua, and the constituent soils are the most important cane-soils in the island.

The parent material consists of an unconsolidated and argillaceous marl containing various amounts of calcium carbonate up to 98 per cent. It varies in colour from almost pure white to buff. Typically it contains small water-worn fragments of hard limestone, the remains of calcite, fossil corals, and fragments of orbitoides. In some localities it is full of large stones and boulders of crystalline orbitoidal limestone and of chert. It is frequently veined with pale grey or ochre-coloured clay, and contains small brown clay concretions. The base of these marls rests upon the eroded Antigua Limestone, upon Elliot's sandstone, or upon soft pebbly shales. The depth of this deposit in the valleys has not been ascertained, but it has been explored by profile pits to a depth of ten feet without encountering any sign of the underlying formations. It is not always so thick as this, however, and at the base of hills the underlying limestone may be met at depths of five or six feet. These marls are more argillaceous near the diagonal trough, and in many places pass insensibly into the calcareous clays that form the parent material of the Gunthorpe Series. The surface soil is scattered over with large numbers of shells of the extinct *Helix formosa* and *Helicina crosbyi*, and also with the valves of recent and pleistocene marine molluscs, amongst which those of *Codakia* spp. and *Cardium muricatum* L. are particularly abundant. This formation may coincide with Spencer's Friar's Hill Marls and Gravels which he describes as occurring at the base of hills and up to altitudes of 150 feet (2). These marls are supposed by that authority to have been laid down during a complete or partial subsidence of the limestone region during pleistocene times. Tempany (10) adopted this hypothesis to account for the brackish nature of some of the shallow wells in the region in which these deposits are found.

The humous horizon of the Fitches Series varies in depth from a few inches to as much as two feet in some of the deeper cultivated soils. The colour of this horizon varies from light grey to almost black in normal soils, but in shallow or eroded soils, however, it may be whitish or buff-coloured. In a few localities jet-black surface soils are encountered, and where the parent marl contains much ochre-coloured clay the topsoils take on a brownish tint. This upper horizon sometimes has a crumbly structure, but more often it is stiff, plastic, and cloddy, cracking deeply in the dry season. The organic matter content of these soils is much higher than that of the soils developed over non-calcareous materials, and frequently exceeds 3 per cent in cultivated fields.

These soils are alkaline throughout the profile, the humous horizon having a reaction of about pH. 8·0.

The surface soils of this series are very calcareous, containing from 10 per cent to over 60 per cent of calcium carbonate. Soils containing much over 60 per cent of calcium carbonate will not support proper cane-growth : the stools are stunted and the leaves chlorotic. Areas of such soil are known as "Gall Patches." They are practically confined to the slopes of hills and the summits of small knolls where the greater part of the surface soil has been lost by erosion. Much of the calcium carbonate of the normal topsoils is made up of the shells of the living mollusc, *Bulimus guadeloupensis* Bug., and of the fragmentary remains of calcite fossil corals and orbitoides.

The surface humous horizon changes fairly abruptly into a transition zone of grey or pinkish buff argillaceous marl ; this may vary in thickness from an inch or two, where the parent marl consists almost entirely of calcium carbonate, to thirty inches where the underlying marls are very clayey. The upper part of this zone may be characterized by the possession of many dark and light worm casts. The calcium carbonate content is usually about 50 per cent, and white pulverulent calcium carbonate occurs in old root channels and as a coating around included stones.

The parent marl frequently contains roughly spherical concretions of ochre-coloured clay ; the interior of these shows black stains of manganese dioxide, and may rarely contain small pisoliths. The deeper parts of the marl are usually stained a dark ochrous colour, and where the parent marl is relatively shallow and the underlying limestone can be explored, the blocks of crystalline limestone are seen to be coated with a deposit of ferric hydroxide and occasionally stained with manganese dioxide.

Very few pronounced saline spots are found in these soils, excepting in a few localities immediately adjacent to coastal lagoons. Stony soils containing water-worn fragments of hard limestone and chert occur in the eastern part of the limestone region and on Long Island.

The soils in the Fitches Series receive on the average a lower rainfall than do the other important agricultural soils of the island. The annual precipitation varies from under 35 inches in the extreme east to a little over 45 inches in the centre of the island, whilst the northern part of the district in which these soils occur receives about 40 inches or under. These soils dry out rapidly, but their natural drainage is indifferent. The parent marl is insufficiently permeable to prevent waterlogging when heavy and prolonged downpours occur.

Hardly a vestige remains of the original vegetation of these soils. It can safely be assumed, however, that they supported a somewhat taller variation of the type of forest that clothes the hills. In the wetter places that must have abounded prior to clearing and cultivation, swamp-forest in which *Bucida buceras* L. was the dominant and characteristic tree undoubtedly occurred.

Bucida buceras is still the most frequent road- and ghaut-side tree. Shallow soils that have been abandoned to pasture and grazed by estate herds support a low growth of drought-resistant grasses, amongst which *Cynodon dactylon* (L.) Pers. is dominant. On Long Island, soils with poor drainage that have been cleared of bush are covered with *Paspalum secans*, Hitchcock and Chase ; similar soils in Barbuda also support a dense growth of this grass. The four species of *Acacia* mentioned as occurring on the soils of Gunthorpe Suite also occur on the pastures in this series, but fields abandoned to grass, if not given attention, tend to come up more readily in a thick growth of *Leucaenca glauca* Benth.

Wetherell Series.

This is a relatively extensive soil series occurring on steep hills in the limestone region at elevations up to about 460 feet. Most of this series is under low scrub or forest, but increasingly large areas are being cleared by peasants and planted to cane and cotton.

The parent material resembles that of the Fitches Series, but the marl deposit is, as a rule, much thinner, and contains far more stones and boulders. Large blocks of hard Antigua Limestone, full of weathered cavities, often outcrop on the summits of the hills.

The profile characters are very similar to those of the Fitches Series. The topsoil, however, is usually thinner, very stony, and brownish in colour. Under forest, the soil proper is covered with two or three inches of root-matted leaf-mould, and over this a layer of dried leaves, etc., these two layers being largely composed of the leaves and fruits of *Pisonia subcordata* Sw., the dominant tree. They rapidly disappear when the hillsides are cleared and cultivated, and the exposed soil takes on a grey or whitish colour. Empty shells of the gastropod, *Bululimus guadeloupensis* Bug., make up a large proportion of the calcium carbonate of the topsoil when this is undisturbed.

These soils occur under a rainfall varying from a little below 35 inches to just over 46 inches. Natural drainage varies from fair to very indifferent ; it is better, however, than in the soils of the Fitches Series.

Delap Series.

These are heavy grey clay soils overlying marls derived from eroded limestone in the central plain. With them is included a small area of soil developed over marl derived from the single outcrop of Seaforth Limestone at Seaforth on the edge of the volcanic region. The Delap soils consist of small patches usually on or at the base of small knolls ; they are found widely scattered at the following places amongst others :—Union, Otto's, Bath Lodge, Belmont, Briggin's, Herbert's, Jonas's, La Roche's, Bodkin's, Willis Freeman's, Piccadilly, Morris Looby's, Blake's, and Delap's Estates. The most extensive areas are found on the last three estates mentioned.

The parent material of these soils appears, as in the case of the marl soils of the limestone region, to be a recent surface deposit overlying the hard crystalline limestone outcrops. This deposit is a marl in all essential respects resembling that overlying the limestones of the Antigua Formation. It contains similar water-worn pebbles, clay veins, and concretions. Sometimes fragments of the indurated clays of the central plain are found in it. At Seaforth it contains remains of andesite pebbles which are derived from the crystalline limestone beneath.

The humous horizons of these soils are variously coloured from light grey to brown, or even reddish-brown. These red and brown tints are undoubtedly due to material derived from adjacent rocks ; thus a highly ferruginous outcrop of marine chert at Briggin's colours the nearby soils a pronounced reddish-brown. The depth of the surface horizon varies from about six to over

eighteen inches. It is followed by a transition zone of variable depth, which is light brown in colour, and grades into the parent marl, which is white or cream-coloured. The parent material contains clay concretions that are sometimes heavily impregnated with manganese dioxide. Pisoliths are occasionally found in the surface horizon, and fragments of silicified corals occurring in the same layer are often stained black with this material.

These soils are found under a rainfall of 40 to 50 inches. Natural drainage is poor or indifferent.

Very little remains of the natural vegetation of the Delap soils, as most of the areas in which they occur have been cleared and cultivated, and are now under either estate or peasant cane.

HODGE SERIES.

The soils of this series are grey to black clays overlying marls derived from a very calcareous sandstone. They occur over a limited area in the northern part of the limestone district from Cedar Grove Village to Byam Peninsula. They were once under cane, but are now largely abandoned to pasture. The parent material appears to consist of a pleistocene marl mixed with volcanic ash, ilmenite, etc. The soil profile resembles that of the Fitches Series, but is shallower. Hodge soils receive a rainfall of 35 to 40 inches. Under-drainage is deficient, but, nevertheless, these soils dry out rapidly during rainless periods.

HERMITAGE SERIES.

These are light grey or light greyish-brown soils developed over calcareous sands derived from the debris of corals, algae, and shells around the coast. The area they cover is very small. Where undisturbed, they support a succession of plant associations commencing with typical strand-forms such as *Spartina patens juncea* (Michx.) Hitchcock, *Ipomaea pes-capri* Sw., etc., and passing by way of thickets of *Coccoloba uvifera* Jacq. to forest typical of the interior of the island. Where these soils enclose lagoons, drainage is often poor. Hermitage soils are of little value, but some have been planted to coconuts, although these plantations have not been developed.

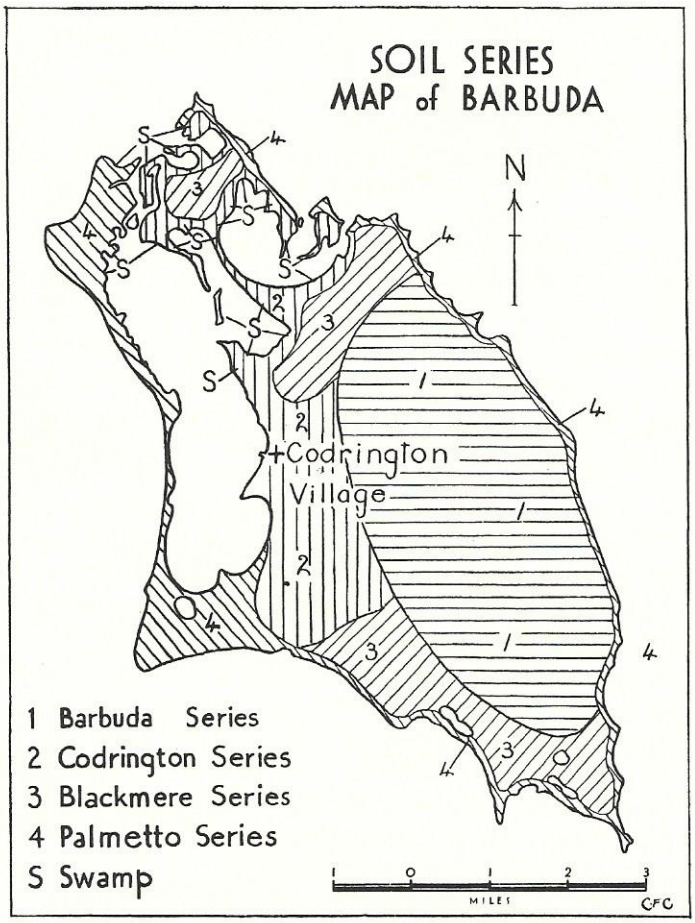
THE SOILS OF ELLIOT SUITE.

The soils of Elliot Suite occur in the central portion of the limestone region. They cover a very small area, and are developed over material derived from sandstones, and shales of igneous origin that are interstratified with the Antigua Limestone Formation. Only one soil series has been recognized in this suite.

ELLIOT SERIES.

These soils are dark grey sandy-loams or sandy-clays of very limited extent that occur over small areas of Parham Old Work and New Work, Pare's, Cotton, Betty's Hope, and Elliot's Estates. They are of little value agriculturally.

The parent material consists of sandy clay, containing blocks and fragments of Elliot's sandstone, a hard medium-textured rock that is grey in colour, well-bedded, and jointed. Elliot's sandstone is composed of grains of quartz, magnetite, and igneous ash, and is non-calcareous. It is known locally as "Firestone," and corresponds to Hardy's (8) " Siliceous Limestone " and "calcareo-siliceous sandstone," although the soils he describes as being derived from it are developed over lagoon-deposited clays, and belong to the Lindsey Series. Interbedded with the " firestone " is a soft brown shale that contains flakes of a greenish-coloured material resembling chlorite.


SOIL SERIES
MAP of BARBUDA
N
Codrington
Village
1 Barbuda Series
2 Codrington Series
3 Blackmere Series
4 Palmetto Series
S Swamp
0 1 2 3
MILES
CFC

The humous horizon of the soils of this series is dark grey in colour, but the surface often presents a whitish shade, however, due to fragments of quartz washed out of the soil. It varies in texture from a sandy-loam to a sandy-clay, and at a foot or eighteen inches grades into a very sandy or gritty clay of a buff-grey colour. This layer becomes grittier with depth, and contains fragments of rotten sandstone, and between four and five feet grades into the compact rock.

The reaction of the topsoil is alkaline, about pH. 8·0, and it becomes somewhat more alkaline at lower depths.

The surface horizon is frequently calcareous due to soil-wash from adjacent areas of the Fitches Series, but patches of soil are met with which contain only very small amounts of calcium carbonate. Accumulations of pulverulent calcium carbonate may occur at depths of about four-and-a-half to five feet.

Pisoliths have not been observed in the surface horizons of these soils, but weathered fragments of " firestone " occurring in the humous topsoil are usually stained black with a deposit of manganese dioxide. An horizon of iron and manganese deposition occurs at the base of the sandy clay layer, and the joints and bedding planes of the underlying sandstone are usually coated with a deposit of hydrated ferric oxide and frequently with manganese dioxide as well.

Most of this soil has been under estate cultivation at one time, but a great deal of it has been abandoned, as it is of very poor fertility. It occurs under a rainfall of 35 to 45 inches, and natural drainage is poor.

Swamp Soils.

These consist of recent lagoon-deposited sands and clays that occur around the coast. They are grey in colour, saline, and poorly drained. They have no agricultural value.

THE SOILS OF BARBUDA: THE BARBUDA SUITE.

One soil suite, the Barbuda Suite, has been recognized in Barbuda, and four soil series. The approximate distribution of these series has been shown on the accompanying sketch map.

The soils of the Barbuda Suite are all developed over hard or moderately hard pleistocene limestone, or upon dune sand. No argillaceous marls are found, such as occur in Antigua. All of the island has shallow soils with much bare rock exposed, soils of any depth only occurring here and there in pockets. The Barbuda soils have little or no agricultural value, both on account of their shallow stony nature and because of the low unevenly distributed rainfall that they receive. Codrington Village, the only station where records are taken, has an annual rainfall of about 36 inches, most of which falls in the second half of the year. As in the case of Antigua, the precipitation varies greatly from year to year.

Barbuda Series.

The soils of the Barbuda Series occupy about one-third of the island, and are found on the Highlands and adjacent parts of the flat marginal plain. These soils thus have an elevation varying from about 10 to 115 feet above sea-level.

The parent material consists of hard white unbedded limestone, which is non-fossiliferous, but full of fissures and underground caverns. Much of the rock is exposed, and this is pitted and cavernous.

Under scrub, the soil surface is covered with a thin layer of dried leaves, and below this lies an equally thin layer of brittle and charred leaf-fragments. The surface inch or so of soil is dark, reddish-brown crumbly clay, which grades into almost crimson-red clay, that may contain abundant small spherical concretions. At about eighteen inches the last layer passes into a light brown rubbly transitional layer of four or five inches, that overlies the parent rock. The dark red clay exhibits a rough columnar structure, and these columns are schistose. Where the surface soil is bare of vegetation it assumes a fine dusty condition and is a bright red colour.

The surface crumbly clay and the dark red clay below are both slightly calcareous.

The rainfall on these soils does not by report exceed 36 inches. Drainage is good or even excessive, and swallow holes are frequent. The natural vegetation consists of thick scrub. A little peasant agriculture is carried on on isolated patches of these soils, ground provisions and a little Sea Island cotton being grown.

CODRINGTON SERIES.

The Codrington soils occur on the marginal plain mostly to the south of the village. A considerable area of these soils has been cleared and fenced for pasture. In the early part of the century, Sea Island cotton was grown in some of these fields, but this was discontinued during the early 1920's, although recently efforts have been made to re-introduce this crop. These soils are flat and only a few feet above sea-level.

The parent material is moderately hard, pleistocene limestone a little younger than that forming the Highlands. In places it is full of fossils of marine molluscs.

The soils of this series are black, almost waxy, clays of varying depth, which crumble to a fine tilth under cultivation, and contain a high proportion of organic matter. They grade into a buff-coloured marly layer, and this into the parent rock. The whole profile is calcareous. These soils are mostly very shallow, and much bare rock is exposed. Stones in the soil profile are frequently stained with iron and manganese compounds.

Drainage is poor owing to the lowlying nature of the land, and water often stays on the surface for some time after heavy downpours, particularly in certain spots known locally as "slabs" (i.e. depressions collecting surface drainage).

The vegetation of the Codrington soils differs somewhat from that of the Barbuda Series, for besides containing most of the species met with on the latter, it contains, in addition, large numbers of *Bucida buceras* L. ; and *Wedelia carnosa* Gr., *Hymenocallis americana* Roem., and the rare pteridophyte, *Marsilea berteroi* A.Br., occur in the more badly drained areas.

BLACKMERE SERIES.

These are light, grey-brown soils overlying limestone. They occur on the marginal plain to the north and south of the soils belonging to the Codrington Series. Drainage is very poor, and water stays on the surface of the ground for days or even weeks after heavy downpours. Much of the scrub covering these soils has been cleared since settlement, and its place taken by the Coarse grasses *Paspalum secans* Hitchcock and Chase, and *Andropogon saccharoides* Sw. The soils of this series are very shallow and are not cultivated at all.

PALMETTO SERIES.

The Palmetto soils are developed over dune sands round the coast. Although quite pervious, the water-table lies near the surface, and the lowlying troughs are poorly drained. These soils are covered with maritime scrub.

SOILS AND THEIR INTERPRETATION.

Within an area as small and lowlying as Antigua, variations in climate are insufficient to account for soil differences, and the development of the various soil series described has been largely brought about by differences in the parent materials and to some extent by variations in drainage and topography.

The parent materials of Antiguan soils can be divided into three classes :—(1) shallow clays resting on impervious rocks ; (2) impervious clays occurring in depressions and lowlying areas ; and (3) impervious marls containing a high proportion of calcium carbonate. It follows from this that the under-drainage of almost all Antiguan soils is poor, and this fact accounts for the form and structure of the soil profile.

In the soils developed over non-calcareous materials the features of the profile are essentially similar in all the series described, and the profile consists of five horizons, with the following approximate dimensions and characteristics :—

0 to 12 inches : A heavy grey humous clay, containing hard spherical concretions, possessing a high content of manganese dioxide.

12 to 48 inches : A slightly heavier, dull-brown clay without concretions.

48 to 54 inches : A well-defined zone stained black with deposits of manganese dioxide, and containing soft concentric concretions of this substance.

54 to 66 inches : A zone of rotten rock or clay, containing a few soft black concretions.

66 to 78 inches : A layer containing concretions of calcium carbonate.

Below 78 inches : Non-calcareous clay or rock.

The soils with such a profile are waterlogged at some seasons and at others the two surface horizons are dried out and develop deep, vertical cracks, which greatly increase the extent of dessication.

From such analyses of the clay fractions of these soils as have been performed to date, it appears that the clays of the upper horizons have silica-sesquioxide ratios of about 3·5, and silica-alumina ratios of over 4. The intractable nature of these soils is undoubtedly due to the high clay content, which varies between 40 to 50 per cent in the humous horizon, and to the very siliceous nature of this clay, and not as suggested by Hardy (8) to the presence of considerable amounts of "sodium clay." Analyses of the exchangeable bases show calcium to be the predominant base present, and sodium to be present in insignificant proportions in typical soils.

The natural vegetation of these soils consisted of semi-deciduous scrub or low-forest, and where this has been destroyed its place has been taken largely by coarse grasses consisting of species of *Andropogon* and *Paspalum*. During the rainy season, the blue-green alga, *Nostoc commune* Vaucher, is abundant on the surface of these grasslands.

Profiles with the characteristics described above, but with various minor differences caused by variations in the nature of the parent materials, are found in the soils of Montero, Otto, and Elliot Suites, and in the less-calcareous soils of Gunthorpe Suite. The accumulation of calcium carbonate in the lower horizons of these soils cannot be held to place them in the Pedocal Group, since the structure and colour of the surface horizon precludes this. The calcium carbonate

accumulations in the deeper parts of the profiles of these soils would appear to be without any doubt the result of deposition by ground-water, and this would account for the lower horizon of accumulation of manganese dioxide as well. The deposition of compounds of manganese and calcium is a distinctive feature of soils with impeded drainage both in the Temperate and Tropical Zones. These soils, therefore, belong to the Intrazonal Group of soils with impeded drainage ; the term "Vlei" soils has been suggested for soils with seasonal waterlogging occurring in the tropics (9).

Soils somewhat similar to those found in Antigua have been described from Victoria County, Texas (11). They are included in the Edna and Hockley Series, and show indubitable evidence of impeded drainage. They have heavy, grey clay topsoils and tough clay sub-soils. Black concretions containing manganese dioxide occur in the lower parts of the profile and overlie accumulations of calcium carbonate or the calcareous parent materials. These soils differ from the similar Antiguan soils by being quite acid, about pH. 6·0, at the surface, but they are alkaline at lower depths where the concretions are found. The semi-natural vegetation of these Texas soils also shows decided resemblances to some of the Antiguan communities, one of the most widespread plant formations of Victoria County consisting of coarse grassland, in which species of *Andropogon* and *Paspalum* are the dominants. Other soils that display a pronounced resemblance to the Antiguan soils with impeded drainage are found in the Great Plain of China ; and have been described by Shaw (12) as Sajong Soils and by Thorpe (13) as Shashiang Soils. These are grey or grey-brown, imperfectly drained soils occurring in flat or depressed areas subjected to alternate waterlogging and intense drying-out. They are developed partly from heavy textured alluvial deposits and partly from interbedded shales and limestones underlying these. The subsoil of the Shashiang Soils is characterized by abundant irregular concretions of calcium carbonate and small black spherical concretions containing manganese dioxide. Such soils are more or less saline, and pronounced saline spots are frequent. They are sticky and intractable when wet, and become very hard and dry during droughts. Farmers consider them poor soils.

The distribution of manganese dioxide in the Antiguan soils is one of their most distinctive features, this material being accumulated in the surface humous horizon, and occurring again in the upper part of the parent material. A similar distribution has been described by W. O. Robinson for a number of American soils (14).

Soils developed over marls are grey to black in colour, and the clay fractions are undoubtedly siliceous, although to date no actual analyses are available to substantiate this. No red limestone soil or terra rossa occurs in Antigua, even on the limestone hills of 350 feet or over. They occur in Barbuda, however, at heights of 10 to 115 feet on limestones of approximately the same age as the Antiguan Marls. The absence of red soils in the limestone district of Antigua is undoubtedly due to the fact that the soils of this region are developed over marls with very poor natural drainage, and to the fact that the clay included in these marls is itself very siliceous in character. The Barbuda red soils, however, are developed over hard, fissured limestones, with good under-drainage. The black and grey-brown soils of Barbuda are developed upon limestones which, due to their low elevation, have restricted drainage and are liable to flooding, and these soils closely resemble Antiguan marl soils. The grey and black soils of the Fitches Suite show no obvious zones of accumulation of manganese dioxide, and no spherical concretions of this material occur in the surface horizons. These soils are typical rendzinas.

The calcareous soils of Gunthorpe Suite appear to be intermediate in character between the soils of Fitches Suite and the non-calcareous soils in Montero and Otto Suites. Calcareous concretions are abundant, but there are no marked zones of accumulations of manganese dioxide, manganese concretions occurring from the surface downwards.

Small areas of soil occur in the volcanic district, and a larger, but very rocky, area at Shirley Heights on the sedimentary tuffs, in which red-coloured surface soils are underlain at relatively shallow depths by marked accumulations of calcium carbonate. These are free-draining soils, developed under low rainfall and probably represent the normal soil of the region ; they are tropical pedocals related possibly to the chestnut-coloured earths of the Temperate Zone.

Since the majority of Antiguan soils consist of highly siliceous, intractable clays suffering from seasonal waterlogging, they require elaborate and expensive methods of tillage and well-organized drainage systems if they are to be worked to the best advantage. They are, therefore, little suited to small-scale peasant development.

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REFERENCES.

(1) Nugent, N., "Sketch of the Geology of the Island of Antigua" (with map), *Trans. Am. Geol. Soc.*, Vol. V, 1821.

(2) Spencer, J. W., "The Geological and Physical Development of Antigua," *Q.J.G.S.*, Vol. LVII, 1901.

(3) Purves, M. J. C., "Geological Sketch of Antigua" (with map), *Bull. Mus. Roy. Hist. Nat. Belg.*, Vol. III, 1884–5.

(4) Brown, Amos P., "Notes on the Geology of the Island of Antigua," *Proc. Acad. Nat. Sci.*, Philad., 1913.

(5) Earle, K. W., "Report on the Geology of Antigua," *Govt. Printing Office*, Antigua, 1923.

(6) Earle, K. W., "Report on Barbuda," 1921 (unpublished).

(7) Tempany, H. A., "Soils of Antigua" (with map), *West Indian Bulletin*, Vol. XV, Barbados, 1915.

(8) Hardy, F., McDonald, J. A., and Rodriguez, G., "The Sugar-Cane Soils of Antigua" (with map), Trinidad, 1933.

(9) Robinson, G. W., "Soils ; Their Origin, Constitution, and Classification," London. 2nd Edition, 1936.

(10) Tempany, H. A., "The Water-Supply of Antigua," *West Indian Bulletin*, Vol. XII. Barbados, 1912.

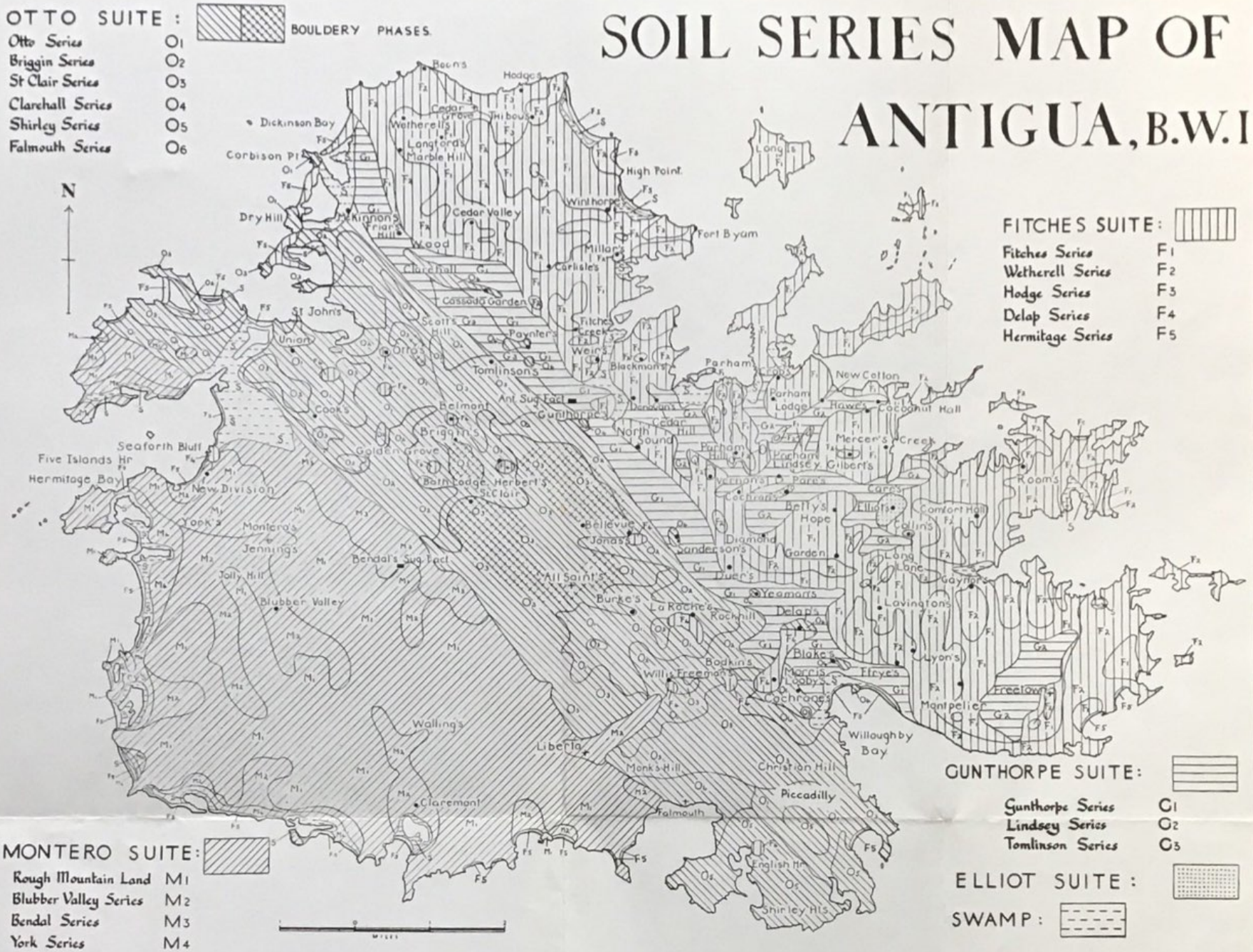
(11) Carter, W. T., and Simmons, C. S., and Hawker, H. W., and Reitch, T. C., "Soil Survey of Victoria County, Texas," *Bureau of Chemistry and Soils.* Washington, 1927.

(12) Shaw, C. F., "The Soils of China," *Geological Survey of China.* Peiping, 1931.

(13) Thorpe, J., "The Geography of the Soils of China," *Geological Survey of China.* Peiping, 1936.

(14) Robinson W. O. "Detection and Significance of Manganese Dioxide in the Soil," *Soil Science* Vol. XXVII. 1929.

SOIL SERIES MAP OF ANTIGUA, B.W.I.



RECONNAISSANCE SOIL SURVEY by C. F. Charter, 1937

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