AMANI MEMOIRS

# A PROVISIONAL SOIL MAP OF EAST AFRICA

## (KENYA, UGANDA, TANGANYIKA, AND ZANZIBAR) WITH EXPLANATORY MEMOIR

*by*

G. MILNE
East African Agricultural Research Station, Amani

in collaboration with

V. A. BECKLEY and G. H. GETHIN JONES, Department of Agriculture, Nairobi; W. S. MARTIN and G. GRIFFITH, Department of Agriculture, Kampala; and L. W. RAYMOND, Department of Agriculture, Zanzibar.

Price 5/- post free.

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# A PROVISIONAL SOIL MAP OF EAST AFRICA

## Part I

## GENERAL DESCRIPTION

### 1. AIMS, ORIGIN, AND AUTHORSHIP OF THE MAP.

In the research programme drawn up by the Director of the East African Agricultural Research Station, Amani, when work was begun there after its reconstruction in 1927–28, the following item appeared, amongst others relating to soils (1)* :—

"*Surveys.*

1. The study of the basic types of East African soils, their characteristics, formation, distribution, and variation in relation to climatic and other influences. This work to be contributory to and correlated with the projected African soil survey."

The map and short descriptive memoir now published are intended as a summary of progress in the investigations thus planned, in the fields of "soil systematics," or classification by morphology, and "soil geography," or the distribution of soil types in relation to the natural features of the country.

Eastern equatorial Africa is still in many respects new ground for the scientific geographer, and a regard for its soils, except locally for immediate agricultural purposes, is one of the newer aspects of its exploration. It may, therefore, be thought premature to attempt to put forth for a part of it what many "older" regions of the world still lack, namely, a soil classification and a soil map. The question may reasonably be asked, are these not at present likely to be affairs of hypothesis rather than of verified observation, and in that degree to be misleading, at least to readers more interested in the *conclusions* than in the *processes* of soil investigation ?

Let it be acknowledged that of the soils of large parts of these four dependencies we can only say "We know almost nothing" ; for much of the remainder, "The general soil distributions are such and such, we do not know detail" ; and for pieces of country here and there, "We can plot the soil types to a first approximation as regards their position and extent, and something is known of their morphology and properties." If, then, a map is to be drafted as a report on the present state of soil knowledge, and it is not to mislead the reader, it is in some such terms as these that it should be made to speak. It should not only express what are thought to be the facts of soil distribution in each district, but also give warning of the amount of evidence, greater or less, that has been found for the opinion offered, and whether the statement is to be understood as true in particular or only as a guiding generalisation. Such a map, by its nature provisional and destined to be superseded as soon as the facts are better known, will in the meantime make generally available the body of information gathered to date, and also do service as an invitation and signpost to further enquiry.

Policy in this matter was settled, in favour of making the attempt at producing a map on the lines indicated, at a conference of the soil chemists working in the four northern British-administered dependencies in East Africa (Kenya, Uganda, Tanganyika, and Zanzibar) which was held at Amani in May, 1932, under the chairmanship of Mr. W. Nowell. At that meeting (2) it was decided to work towards the production of a generalised map on a scale of one in two million. A provisional scheme of soil classification was drawn up, and certain principles of construction of the map were agreed upon, which may be summarised as "inductive." That is to

* See the numbered list of references at the end of Part II.

say, the only admissible basis for mapping a district was to be some direct record of the properties of its soils, and where such evidence could not be brought forward we were not to have recourse to the method of plotting *theoretical* distributions of soil types from unsupported data on climate, geology, and the like presumed factors in soil formation. It would of course be necessary to generalise locally, in constructing a two-dimensional diagram from observations made originally at scattered single points or along the routes of journeys. The risks involved in this local generalisation would in any case be considerable in most of our area, and we were not to incur the greater risks of carrying over local correlations into unknown country, where unsuspected new factors might enter. It was realised that on these terms disconcertingly large parts of the map would have to be left blank for some time to come.

Progress in the collection of the necessary data was to be reported at a second meeting after two or three years, when the provisional classification would come under review, draft maps of the several dependencies would be considered, and arrangements made for their co-ordination and publication as one map.

This second conference was held at Zanzibar, by invitation of the Government of that Protectorate, in August, 1934, again under Mr. Nowell's chairmanship. The outcome of the decisions taken there (recorded in the published report of the conference) (3) is the present map and memoir. Responsibility for the authorship of these is shared as follows. In each of the four political divisions of the region the compilation of its own section of the map in first draft was undertaken locally: for Kenya, by V. A. Beckley and G. H. Gethin Jones at the laboratories of the Department of Agriculture at Kabete, Nairobi; for Uganda, by W. S. Martin and G. Griffith at Kampala; for Tanganyika, by G. Milne at Amani; and for Zanzibar, by L. W. Raymond. Descriptive text was drafted sectionally in the same way. The material thus assembled was then entrusted to Milne at Amani for redrafting as a single-sheet map, and for compilation of an explanatory memoir. Not much consultation between the collaborators was possible during this editorial stage of the work, which was mostly done in England; and the final form and content of both map and memoir has been the responsibility mainly of the editing joint-author.

## 2. AREA INCLUDED, OUTLINE, AND SCALE.

The sheet-lines of the map correspond to latitudes 4°N. and 11°45′S., longitudes 29° and 41°E. A portion of north-eastern Northern Rhodesia is thus included, but as there is little information to hand up to the present for this part of the map, it has been left blank and used for the legend. Similarly the provinces of Ruanda and Urundi, formerly part of German East Africa but now governed from the Belgian Congo under mandate, fall within the sheet, but have been left blank; for although there is a considerable geographical literature upon them, a search of it has produced very little of value for classifying and plotting their soils, and these provinces lie outside our own fields of investigation. The total area of the remaining land surface is about 685,000 square miles (1,750,000 sq. km.), roughly one-sixteenth of the Continent of Africa.

The map was drawn in original to the scale of 1 in 1 million. The topographical sheets available on this scale are those compiled between 1915 and 1919 and published by the Geographical Section, General Staff, War Office, London. Eight of them, each including four degrees of latitude and six or seven of longitude, together cover the region. The black outline was traced from these, with suppression of much detail and omission of local-government boundaries and contours. Various more recent sources have been consulted for railways and a few places that have come into importance since 1919.

The islands of Zanzibar and Pemba, being of political, economic and also (as it has proved) pedological interest great in proportion to their size on the map, have been shown separately to a three times larger scale as an inset. Space has been found for this in the north-east corner, where the country, bordering on Abyssinia and Italian Somaliland, is mainly desert and has inspired no-one to describe its soils.

In printing, the scale has been reduced by half, and the map is published at 1 in 2 million, with Zanzibar and Pemba at 1 in 666,666.

The omission of contours requires a word of explanation. It has been judged inadvisable to overcrowd the map with topographical information, which would often have been difficult to see under the overlay of colour and hatching of the soils notation, and which the reader will in any case seek for himself from published orographical maps such as the "Africa, 1 in 2 million" (Geogr. Sect., Gen. Staff, Sheets KENYA COLONY and ZANZIBAR, London, 1927), on which relief is shown by contours and layer tints. Some guidance as to land forms is, however, given by showing river systems* in some detail, and by marking a few prominent high points.

In many parts of the region the plotting of soil records from our own or others' field notes has brought painful realisation of the unsatisfactory nature of the published topographical maps, both those on the million scale and the larger-scale sheets such as the 1 : 250,000 or 1 : 300,000. It is often difficult to identify a locality or a natural feature, or to trace a route, on these maps. The issue of a revised series of maps, embodying at least the results of the many district and route surveys that have been carried out by various hands since the war but never published, is becoming an urgent requirement in East Africa.

## 3. SOURCES OF INFORMATION.

In none of the four dependencies is any organised soil survey in progress.

Except in so far as District Agricultural Officers and others interested are able to assist by describing and sampling particular soil types, survey work falls to the chemical staffs to do as best they can during travelling and laboratory time devoted primarily to problems of soil management and manuring. Information of the kind that results from detached pedological investigation is small in amount in relation to so large an area, and the map is mainly a piecing together of "by-product" observations. Even in the few closely-settled districts, where the interest in soils has been most concentrated, both the classification applied and the boundaries drawn must be looked upon as experimental approximations. The fundamental nature of the soils and their relationships to each other and to the associated factors of topography and drainage, climate, parent rock, vegetation and human activity, and to the climates and land conformations of the recent past, are in the very earliest stages of recognition. A great part of the country is covered only by scanty field notes unsupported by samples or laboratory data, and by the generalised impressions that result from long journeys by motor car.

* In this connection it should not be forgotten that many East African streams carry water during short periods only, in each rainy season. It must not be inferred from river courses shown on the map that a particular piece of country possesses surface supplies of water.

For Kenya and Uganda the map is based almost entirely on data accumulated by the agricultural chemists at Nairobi (including Mr. D. S. Gracie, now of Cairo) and Kampala. Acknowledgment is made to the publications and maps of the Uganda Geological Survey and to its Director (Mr. E. J. Wayland) and his officers for advice on parent rock questions. As has been mentioned above, the goodwill and assistance of the district agricultural staffs have been invaluable. In Kenya, the scanty information outside the highlands and more populous native districts has been supplemented a little from occasional soil notes made by early travellers of the caravan days and by later administrators.

For Tanganyika, the sources have been more various. Until late in 1933, when a Coffee Research Station was established at Moshi and its soil chemist (Mr. H. B. Stent) began work at Amani pending erection of his own laboratory, there was no Agricultural Chemist for the Territory, nor had it properly any centre for soil work, for although Amani is situated in Tanganyika, its function is a general one for all four dependencies. The Amani soil chemist had, however, instructions to devote time to reconnaissance survey work, and his travelling and collections began to provide material for the Tanganyika map, though they covered nothing like enough ground. The present attempt has been possible only through help received from many quarters, amongst which the following are particularly acknowledged: (1) The cordial support of the Director of Agriculture (Mr. Ernest Harrison) and the voluntary activities from time to time of some fifteen members of his field staff in sending notes, sketch-maps and material from their districts. (2) The daily notes and summary reports of many reconnaissance journeys made by Mr. C. Gillman, Chief Engineer, Tanganyika Railways. The soil descriptions in his notes, though based mainly on surface appearances and chance exposures, are so fully supported by his other physiographic data that they have enabled most of the ground covered by Gillman to be mapped, at any rate tentatively, in some detail. Personal acknowledgment is also made for his help and criticism in many matters of soil geography and genetics. (3) The Director of the Tanganyika Geological Survey (Dr. E. O. Teale) and his staff, besides giving geological and petrographic assistance, have frequently included soil descriptions in their publications and have plotted soil distributions in certain of their maps. (4) Dr. P. Vageler (now of Lichterfelde, Berlin), working in German East Africa before the war, published several local soil surveys whose substance has been incorporated. (5) Observations by the Land Development Survey Commission of 1928–31, by officers of the Veterinary Department on problems of pasturage and soil erosion, and by several colleagues at Amani in the course of their own field work on other subjects, have been utilised. (6) A number of private occupiers of land and plantation managers have contributed important material. (7) Finally a search has been made in the geographical literature of German East Africa, resulting in the recovery of a number of scattered soil notes, particularly along certain routes in the south of the territory where data for the map are otherwise very scanty.

The inset maps of Zanzibar and Pemba have similarly been compiled from several sources. Mr. G. M. Stockley, when preparing his geological memoir (22) on the Protectorate, entered notes on surface soils and crop distribution on a large-scale map of Zanzibar Island which he has kindly made available. A sketch map for Pemba soils was contributed by Mr. J. R. P. Soper, Agricultural Officer there. Mr. P. J. Greenway, Amani, collected soil profiles during a botanical survey in 1930. The soil classification for the islands is based on field work by L. W. Raymond, analytical work by him at Zanzibar and by W. E. Calton and G. Milne at Amani, and an unpublished "Sketch of Soil Conditions in Zanzibar and Pemba" (1933) by Milne.

References (4) to (23) in the list at the end of Part II are to some of the publications that have been used as sources. The list is not exhaustive.

## 4. CLASSIFICATION OF THE SOIL TYPES.

The provisional soil classification employed has been evolved from that drawn up at the Amani meeting of 1932 and revised at Zanzibar in 1934. It owed much, in its first outlines, to the classification developed by the late C. F. Marbut in his essay *The Soils of Africa* (27), published in 1923 along with a generalised soil map of Africa on a scale of 1 in 25 million. For details of the original and revised drafts of the scheme and discussions upon them, the two Reports already cited should be consulted (2, 3). The classification finally adopted for use on the map is given in tabular form below. It differs from that recommended at Zanzibar by the addition of a major group termed provisionally the *plateau soils*, and some additional sub-groups.

TABLE OF MAJOR SOIL GROUPS AND SUB-GROUPS.

| *Major Groups.* | *Sub-Groups.* | *Descriptive Notes.* |
|---|---|---|
| Desert soils .. | .. | Mapped only where characteristic desert morphology has been recorded. |
| Saline soils .. | Sub-groups not yet differentiated | Includes all types of "alkali" and salty soils, except tidal clays. |
| Plains soils .. | Calcareous .. ..<br>Calcareous, high level (Nanyuki) type ..<br>Non-calcareous .. .. | A complex and little-known group of light-coloured soils occupying the semi-arid plains, often in association with the next group. Under-drainage nil, storm water shed by surface run-off and the remainder evaporated. Much bare earth exposed, and surface hardened, but without cracking. Vegetation usually low tufted grasses and thorn, with succulents, except Nanyuki type which carries light *Juniperus* forest. |
| Black or grey clays | Calcareous (*a*) .. ..<br>Calcareous (*b*) .. ..<br>Non-calcareous (*a*)<br>Non-calcareous (*b*)<br>Calcareous lake-margin clay<br>Laterised swamp forest clay | Dark-coloured ill-drained soils having a siliceous clay-fraction, plastic when wet and cracking deeply when dry. Both clayey and sandy types alike possess these properties, and the group is well known to road users as "black cotton soils."<br>Sub-groups (*a*) are soils of bottom lands, sub-groups (*b*) occur in association with lime-yielding or shaley rocks.<br>For the lake-margin clay, see section on Uganda soils in Part II.<br>For the swamp-forest clay (anomalous in this group) see section on Zanzibar soils in Part II. |
| Mottled clays .. | .. | A limited group akin to the red earths but of impeded drainage, derived from clay beds, chiefly in Zanzibar and Pemba. |
| Red earths, non-laterised | On Basement Complex rocks, chiefly gneiss<br>On granites<br>On volcanic rocks and basic intrusives<br>On shales<br>On sandstones | Well drained, moderately leached soils of various colours in the range pink, red, red-brown, orange-brown, brown. Free from calcium carbonate, profile neutral or acid. Clod-structured, with heaviness proportional to clay content. Mol. ratio $SiO_2/Al_2O_3$ in clay fraction usually 2·0 or above. |

| *Major Groups.* | *Sub-Groups.* | *Descriptive Notes.* |
|---|---|---|
| | | When developed on basic rocks, the soil may contain scattered pisolitic concretions, but concretionary horizons are typically absent from the profile, only appearing where there is seasonally a high water table, when the soil approaches the *plateau soils* in character. |
| Red earths, laterised | Sub-groups by characters derived from parent rocks as above | Very freely drained, leached, acid soils of the same range of colours as in the group above. Uniform open structure and friable "light" texture independently of clay content. Mol. ratio $SiO_2/Al_2O_3$ in clay fraction usually less than 2·0; less than 1·0 in soils of advanced laterisation. Concretionary horizons are absent except in the non-typical case of a seasonally high water table. This group contains chiefly the soils of the evergreen forests and mountain grasslands. |
| Plateau soils .. | Sub-groups not yet differentiated (Mapped at present in Tanganyika only) | Light-coloured soils (grey, yellow, yellow-brown) of sluggish drainage or receiving excess subsoil water seasonally. Usually formed on locally-transported material lying at slight slope in maturely eroded topography, or where rock tables check percolation. Free from calcium carbonate, but often with concretionary ironstone ("murram") in the subsoil. The vegetation over large areas on this soil is open deciduous woodland. |
| Podsolised soils | Sub-groups not yet differentiated | Highly leached soils of cool high-altitude rain forests and grasslands. Accumulation of dark-coloured acid humus at surface, bleached horizon (often slight) below, uniform pale subsoil when freely drained; glei types have ferruginous concretionary horizon. |
| Lithological types | Volcanic soils .. .. Loose sands Pocket soils on karst limestone | Soils with characters little changed from those of their parent materials, except in respect of accessions of organic matter due to the establishment of plant life. |
| | Alluvial soils (del Villar's (24) definition) | *Tidal clays* are classified as a division of *alluvial soils*. |

The above list of main soil types, though suited to the scale of the map, can only be regarded as a first roughly approximate solution of the problem of classifying East African soils on a morphological basis. The provisional nature of the attempt appears particularly, for example, in the group of plains soils, which at present is a physiographic division rather than a morphological one. Access at leisure to the soils of this group is usually too difficult under the conditions of our travelling for us to have gathered any really representative data about the details of their profiles: we know them chiefly as distinctive factors in landscape and land utilisation.

In later publications supplementary to this memoir we are to offer some of the evidence from which the above classification has been built up. That will be the proper place to give detailed descriptions of typical soils from each group, to discuss the range of variation met with in the profile and to describe the associated circumstances of vegetation, climate, geology, relief, and agricultural uses. Here we add only a short commentary, chiefly on points in the sub-grouping and naming of the various soils. Some further discussion is also introduced *en passant* into the sections on the soils of the several dependencies, in Part II.

### Desert Soils.

Although considerable areas, particularly in the plateau and sunkland regions of Tanganyika and in the southern Rift Valley and "*nyika*" regions of Kenya, are in fact deserted by man and may be incapable of supporting human residence on account of water shortage, they carry a more or less dense vegetation of xerophytic types, have a rainfall of perhaps 20 inches (500 mm.), and are in no accepted technical sense "desert." It is not here that the *desert soils* of the map are found, but in the great regions in the north and north-east of Kenya Colony that lie between Kenya Mountain and the Abyssinian and Italian frontiers. Such scanty soil samples as have been brought in from this region show a characteristic red iron staining at the surface, and bare rock has been reported as carrying typical "desert crust" or "case-hardening."

### Saline Soils.

Practically nothing is yet known of the morphology of these, and not much of their chemistry beyond the occurrence of horizons or incrustations of salts (or more generally of soda), some of which are worked locally to provide *magadi*, a crude mineral supplement to native diet. Certain of the *volcanic soils* might be admissible, chemically, into this group, but we have preferred to describe them for the present purpose by their more obvious properties, which are those of little-changed volcanic ash. The saline mud-flats of tidal creeks and estuaries are provided for as a separate minor group with the *alluvial soils*.

### Plains Soils.

From a genetic standpoint the whole of this group doubtless falls into Marbut's great category of pedocals, but in sub-grouping we have had to recognise that over large areas, particularly in Tanganyika, the characterising horizon of calcium carbonate does not appear to be present or occurs only locally. Borrowing a genetical term, one might say that as a morphological feature it is recessive. If a parent material has undergone exhaustion of the mobile basic constituents of its original minerals during a previous cycle, or successive cycles, of weathering, it cannot now be expected to respond typically to current pedogenic processes which tend to develop a horizon of accumulation of calcium carbonate. Such, at any rate, is the tentative interpretation we put forward for these soils, and it seems to be justified by the geological history of the regions concerned. These *non-calcareous* and the more typical *calcareous* plains soils will probably be separated later as independent groups, when a better morphological basis for their description has been prepared. In the meantime they are conveniently bracketed together. The calcareous sub-group listed as *high-level* (*Nanyuki*) *type* is referred to in the section on the soils of Kenya in Part II.

### Black or Grey Clays.

Here also calcareous and non-calcareous sub-groups are distinguished, the former being pedocals, if not always very typical ones, the latter belonging rather to the category of glei soils. There is a fairly well marked climatic limit between them.

The further division shown in the list within each of these sub-groups reflects genetic differences, which can be recognised in the relationship of the soils to topography. There are two kinds of situation in which the dark-coloured clays and sandy clays of the major group may be found :

(*a*) on transported material occupying low-lying ground,

(*b*) as sedentary soils on ground which, judging from its conformation and lie, ought to be well-drained but in fact is seasonally waterlogged.

The occurrences of type (*b*) seem to be tied to a lithological factor : the parent materials on which they have been found include marly Jurassic clays, calcium-rich lavas, and shales. Where the necessary factor operates, dark-coloured plastic cracking clays, either calcareous or not according to circumstances, may be found as a continuous covering over undulating country in which it would be more usual to find red earths everywhere except in the hollows.

It is clear that while type (*a*) develops its characteristics (whatever the original nature of the material) because the site is a sump and receives excess water (carrying silica and bases in solution) from the surrounding higher ground, a quite different explanation must be sought for type (*b*). Here the waterlogging is due to the properties of the weathering clay-complex, independently of the surrounding relief. Naturally examples are found where both sets of factors have contributed, but the broad distinction between black clays that are sump soils and those that are determined by a chemical or lithological factor seems important enough to be given expression on the map where the relevant facts are known.

It should be mentioned that the dark colour of the soils of this group is only rarely attributable to a high content of organic matter or to the persistence of black primary minerals. The clay-substance itself is responsible, being blacker in the calcareous types and greyer in the acid types.

Further discussion of the group as a whole is given by the writers of the section on the soils of Kenya, q.v.

### MOTTLED CLAYS.

This group, though of minor extent on the map, illustrates well the difficulties that may arise in classifying soils developed on unconsolidated sedimentary rocks. At what depth in the profile does the soil stop and the parent material begin ?

In their uppermost horizons these soils resemble the red earths, but at a few decimetres down the character of the profile changes, and it is evident that under-drainage takes place only between the surfaces of large many-coloured clay clods. The interior of the clods is penetrated by rootlets and is in every way part of the soil however soil may be defined. Genetically, the profile is doubtless that of a red earth, immature or even skeletal, developing on a bed of clay ; but the clay bed must have functioned fully as a soil from the time when it first formed part of an exposed land surface, and still does so below a relatively shallow altered covering. The profile is in fact a document with the writing of two different epochs upon it—a palimpsest.*

It would be unsatisfactory to include these soils with the red earths without qualification, for no red earth should have signs of imperfect drainage prominent in its profile. On the other hand, they have developed too far as red earths to be accommodated in the group of lithological types. Provisionally they have been given standing as an independent group.

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* Elsewhere in referring to these soils I have used the simile of an heraldic monster, wherein the head and forequarters of one species are conjoined to the nether members of another. Such monstrosities amongst soils are probably the usual rather than the exceptional in regions of clay geology, e.g. parts of Great Britain, and add considerably to the difficulties of consistent classification.—G.M.

## Red Earths.

These have been divided into two major groups on characters of structure, field texture, degree of leaching, and clay composition. There would have been an advantage had we been able to set up *three* groups instead of two, for between the typical "non-laterised" and "laterised" soils at the extremes there are many that fall into a fairly characteristic middle group. At this stage, however, many of our records of red earths would not have been classifiable with this degree of precision, for lack of essential data. The three-group classification must wait until quantitative investigation of the critical properties has provided the necessary basis. In the meantime a considerable element of personal judgment has entered into our allocation of the red earths to one group or the other in different parts of the map, and the reader is warned that there may be inconsistencies.

The naming of these two groups is admittedly unsatisfactory. "Red earth" is, of course, a purely conventional term, as the colour range is considerable; but it perhaps succeeds in connoting the state of maximum oxidation that characterises the weathering process in these soils. We have, for the time being, continued to employ adjectivally a form of the word "laterite," because our conception of the difference between the two groups is in harmony with that of Martin (F. J.) and Doyne (25) in their definition of "lateritic soils" in West Africa, and we have been unwilling to introduce confusion unnecessarily as between East and West African usage until a better designation can be found by general agreement. We have not, however, based our distinction expressly, or even mainly, on a particular limit in the composition of the clay fraction, as did the authors named. This is partly because the analytical data at disposal are not yet numerous enough to have enabled us to cover the ground on such terms, but also because a growing body of information leads us to believe that the problems of definition amongst these soils cannot be so simply solved. Thus the well-known Kikuyu soil of Kenya is typically a laterised red earth in its morphology and field properties, but has a clay composition practically coinciding with Martin and Doyne's borderline value, viz. molecular ratio $SiO_2/Al_2O_3=2{\cdot}0$; and there are many similar cases of difficulty. It is not ultimate clay composition, so much as identity of clay minerals, that must be looked to as a criterion.

The soils "of advanced laterisation" (marked on the map by the addition of the signature Ll on the orange colour) fall unequivocally into Martin and Doyne's "lateritic" group as well by clay composition as by field properties, for they have $SiO_2/Al_2O_3$ ratios nearer 1·0 than 2·0, sometimes as low as 0·8. In such soils the figures of a clay analysis are a useful guide to the progress that has been made by "laterisation" (that is, the destructive hydrolysis of clay substance with removal of silica), currently or in time past.*

In both the red earth groups, the sub-grouping by lithology of parent rock brings to notice characteristic features that are clearly recognisable both in the field and from laboratory examination and are considered of importance enough to receive expression even on a generalised small-scale map such as this. They are, for example, of significance in land classification for economic purposes. The geological maps of the dependencies, so far as they have been completed by the Geological Survey Departments to date, have naturally been of great service in applying this lithological principle of sub-grouping, but (in accordance with our guiding rule throughout)

* It will be noted that we use the adjective "laterised" rather than "lateritic." There is perhaps a degree less of confusion attaching to the climatic weathering process *laterisation* as above defined, in the literature of geology and soils, than to the numerous end-products, some of them secondary, that have been called *laterite* at various times.

we have never used them as evidence of soil characters without support from recorded observations on the soils themselves. A geological map is in essence a *chronological* rather than a *lithological* account of the rocks of a country, and it is in the latter rôle chiefly that the soil surveyor consults it.

It has not been possible to be consistent throughout the map in separating red earths on granite from those on the acid gneisses of the African Basement Complex, though the differences are sometimes well marked. In Uganda a single notation is used provisionally for both, whereas in Tanganyika they must be distinguished if significant morphological differences are not to be concealed, e.g. as between the laterised red earths of Usambara, on gneiss, and those of the eastern rim of the Uhehe plateau, on granite.

As regards soils having limestone as parent material, the principle of classifying them on their own merits has led to a distribution of these soils between several of the groups. Red earths on sandy limestones and calcareous sandstones appear merely as "on sandstones." Marly limestones and calcareous clays provide soils usually in another group altogether, the black or grey clays. The rudimentary red earths on the karst limestone of Zanzibar are classified for convenience with the "lithological types" in the table but are given a distinctive red and yellow colouring on the map. The crystalline limestones, which occur here and there as members of the Basement Complex system, are not yet familiar enough as soil-formers to have received separate recognition. In Uluguru (Tanganyika), shallow residual soils have been observed on them in places, and have the appearance of red earths but possess a nut-structure recalling that of some English rendzinas.

### Plateau Soils.

These are discussed in their context towards the end of the section on the soils of Tanganyika, in Part II. The name is proposed, not as a definitive addition to soil nomenclature, but merely as a convenient means of referring to the group pending further study of the soils it includes.

### Podsolised Soils.

Whether or not it be true, as has been recently stated (28), that podsolisation is the fundamental soil-forming process of humid regions in the tropics as well as in the temperate zones, we have only been able to observe the signs of it in East Africa in limited areas of high ground, where temperatures are low enough to permit accumulation of acid humus and the necessary conditions of leaching are provided by an abundant rainfall. The least altitude at which profile characters that can be called podsolic have been noted is about 6,000 feet (1,800 metres) above sea level. The brief description given above in the table applies to certain examples from Tanganyika, but "glei" types occur in Kenya, and the podsolised soils cannot yet be given satisfactory definition as a group. On the map the areas where they occur are left uncoloured and marked with the signature "p." For a further reference to these soils see the section on Tanganyika, in Part II.

### Lithological Types.

In this group have been collected together a variety of soils which are in other respects difficult to classify, but possess this in common, that they have developed so little away from the original character of the parent material that they are better defined by it than by any rudimentary morphological features of their own. The sub-groups include the deep and little-changed deposits of volcanic ash, tuff or pumice found in districts of late volcanic activity, and the loose sands of the coast belt. The "alluvial soils" included in this group are to be understood in terms of a definition proposed by del Villar (24), who draws a clear distinction between the geological idea of an *alluvial formation*, on which as parent material any kind of soil may under appropriate conditions be found developing, and the pedological idea of an *alluvial soil*, in which the profile is being built up or modified by successive operations of the alluvial process. When this process ceases, or within a short time thereafter, the soil begins to evolve normally in response to the local formative influences, and in due course becomes classifiable by its acquired morphology. But so long as the development of a normal profile is held in check by recurrent accessions of material at the surface or by disturbances due to flooding, the soil belongs to a characteristic group, and it is this group that we refer to in the map under the designation "alluvial soils."

## 5. COLOURING AND NOTATION.

As far as possible the major groups of the classification are shown in different colours, and the sub-groups by applying the colour in the form of different hatchings or rulings. A general view of the soil distribution by major groups can thus be had by looking at the colours only, from a little distance, and the detail of sub-grouping appears on a closer inspection.* The use of a colour in wash instead of in rulings indicates that allocation to a sub-group has not been attempted, owing to lack of critical information or other difficulty in classification.

Broken colour, with white spaces left in bars parallel to the direction of the ruling (or vertically in the case of cross-hatching), is used wherever the available evidence on soil characters is too fragmentary to allow of more than a tentative identification of soil types.

The large areas in various parts of the map where the evidence is still more fragmentary, or there is none, are left uncoloured, and such brief notes as are possible are written across the empty spaces. In such places we have little to support speculation about soil characters beyond general geographical descriptions, or the technical data of other sciences (geology, climatology, ecology). Coloured areas adjoining such empty spaces are left with an indefinite boundary.

Topographic outline and place-names are in black; soil notes, soil boundaries, and signature lettering in violet. The symbols or signatures used to give additional information are the following :—

Sk Skeletal soils : soils of shallow development whose continuity is much interrupted by outcrops or fragments of raw rock.

Tr Truncated soils. Districts where accelerated soil erosion is much in evidence are thus indicated.

Ll Soils of advanced laterisation.

p Podsolised soils.

SP Swamp peat : indicates local occurrence of true peat in upland bogs and lake margins.

(Volcanic soils):

d dust or fine ash.

B pumice.

a agglomerate or tuff.

Two features of the notation remain to be explained, viz. the vertical striping in different colours, and the discs or spots of colour. They indicate that in areas so coloured two or more soil types occur in conjunction. These notations require explanation at some length, and they are dealt with in the next section.

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* *Desert soils* and *saline soils* have had to be shown in the same colour (violet), for reasons of cost.

## 6. THE OCCURRENCE OF TWO OR MORE SOIL TYPES IN ASSOCIATION.*

Two or more soil types of different morphology and conditions of formation may sometimes be found in conjunction, their occurrences being related to factors of relief or geology which alternate and are repeated, with variations, over a considerable stretch of country.

It would, of course, be possible, given the resources of an organised survey, to map the pattern of such occurrences in detail, representing the extent and position of each soil type faithfully. Unless, however, the resulting large-scale map were the object in view, there would still remain the problem of generalising the information thus laboriously obtained for convenient and fair representation on a smaller scale. In the undeveloped countries of the tropics the method of detailed survey is rarely practicable, and one has to depend on the investigation of sample localities and the discovery of a key that will in a general way enable the soil distribution to be predicted for the rest of the area. The problem then becomes, not the detailed mapping of soil types individually, but the schematic representation of an *association* or *physiographic complex* of soils, defined in general terms in relation to a set of conditions.

The groups of a systematic classification will not serve this purpose, for by definition they are too homogeneous to accommodate complexes of soils differing from each other in the important classifying properties. To select one particular soil as the "zonal type" for the area, and (in small-scale mapping) to suppress the others as intrazonal or atypical, subtracts from our information instead of representing it, and is too arbitrary a solution except when the "atypical" soils are insignificant in relative extent. What is required is a composite summarising unit which shall denote, whether in verbal description or in maps, a specified kind of complex of differing soils.

### THE CATENA.

Soil complexes of one kind or another are a major element in the soil geography of East Africa, and for one commonly occurring type of them it has been found desirable to employ a generic term, *catena*, which can be made specific by prefixing a locality name (26).

Throughout districts characterised by an undulating or hummocky topography, or rather by a given set of physiographic conditions of which this type of relief is one, certain sequences of changing soil profiles are found repeated. An example, met with over a large part of the dissected peneplain of Uganda, is described by W. S. Martin and G. Griffith in Part II of this memoir. Here the complex consists of the sequence of soils encountered between the crest of a low hill and the floor of the adjacent swamp, the profile changing from point to point of this traverse in accordance with conditions of drainage and past history of the land surface. A somewhat similar sequence, lacking the highest-lying member of the Uganda complex, occurs regularly in the foothills of Usambara and in Uzigua, in Tanganyika. In much flatter landscape than these, but still with a repeated change of level from crest to hollow, soil complexes essentially of the same type, though with quite different member-soils, occupy large parts of the high inland plateaux and the great low-lying plains. In all these regions the distribution of soil types is a function of local differences of level and slope, which govern drainage ; and in all of them we misrepresent matters if the map is made to show but a single dominant soil.

A sequence of this kind is termed a catena, or catenary complex. The word is intended to serve as a mnemonic, the succession of different soils corresponding to the links in a hanging chain.

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* This section embodies, with some verbal changes, the text of a paper communicated by G. Milne to the Third International Congress of Soil Science, Oxford, 1935, and published in its *Transactions*, Vol. I, pp. 345–347.

The means adopted for representing catenary complexes on the map is to depict the area in question in vertical stripes, using the colours and rulings that stand for the two, three or four principal member-soils. The most freely-drained soil is that shown in the stripe at the left-hand side, and those shown next successively to the right occupy sites on successively lower ground. The approximate relative extent of the several soils of the catena is expressed qualitatively in the relative width of the respective stripes. There are, of course, always intermediate types that cannot be represented without complicating the notation unduly.

As an example, broad stripes of pink beginning on the left extreme of an area and alternating with narrower stripes of blue would indicate that throughout that area the principal soil types are a non-laterised red earth and a black or grey clay, the red earth occupying the higher-lying situations and the greater total extent of ground.

Two variants of the catena can be distinguished in the field, which deserve mention here, though they have not been given different notations on the map. In one, the topography was modelled, by denudation or other process, from a formation originally similar in lithological character at all levels at which it is exposed. Soil differences were then brought about by drainage conditions, differential transport of eroded material, and leaching, translocation and redeposition of mobile chemical constituents. Of this kind are the complexes of the plains, and the red earth–black clay catena of undulating foothill country. In the other variant, the topography was carved out of two or more superposed formations which differ lithologically, of which the uppermost now forms a capping on hilltops and ridges, while the lower ones are exposed successively down the slopes. In such circumstances we may have a soil succession catenary in form but with a geological factor added to the other conditions making for soil differences. Of this kind are some of the occurrences of the Uganda catena, where the denuded remnants of an old "plateau soil," with its resistant beds of concretionary ironstone, are found as a capping on the flat-topped hills, on whose slopes and the intervening bottom-lands the succession is continued in soils of current development on the exposed Basement Complex rocks and their erosion products. Another example awaits study in the Manyoni—Itigi district of central Tanganyika, where granite is overlaid by a thick crust ("the grey cement") belonging to a former cycle of weathering, and both crust and granite are being cut into by a present-day cycle of renewed denudation, with its concomitant development of characteristic soil profiles at each level. On a more striking vertical scale is a soil complex described by E. O. Teale (21) in the Kibondo district of western Tanganyika. Here the foundation of the country is a lava, from which, on slopes, a rich heavy chocolate-coloured red earth has been formed. The hilltop and plateau areas carry a grey stony light loam (probably best classified as a "lithological type"; yellow colouring on the map) derived from a mantle of shale and chert which once completely buried the lavas. In the bottom-lands are plateau soils with ironstone beds, and grey clays. The whole forms a catenary succession of the second kind.

## Other Complexes (Non-catenary).

Two other kinds of complex association of differing soils have had to receive recognition and diagrammatic representation on the map. In these, relief and drainage conditions are not necessarily the ruling factors determining the soil distribution. They are illustrated here briefly by one example each from Tanganyika. For both, a notation of spots or discs of colour is used.

(1) On the Ulanga plain (the flood-plain of the Kilombero River), the ruling soil type is a heavy black clay, possibly passing into soils of the "plains soils" group on slightly higher ground.

This can be represented as a catena. But there are also known to be localised occurrences of other types such as true alluvial fans still in active formation, and accumulations of loose sand. The extent and exact location of the subsidiary types are not known, but their existence cannot go unmentioned on the map, if only for the reason that the prospects of successful agricultural enterprise are probably confined to one of them (the alluvial soils). The notation used, a purely diagrammatic one, is small scattered discs of the colours for the subsidiary soils on a background of the catenary stripes of the ruling complex.

(2) A complex depending in great measure on the pattern of the geological outcrops appears to occur along the Indian Ocean Coast, extending as far inland as the limit of the sedimentary rocks. Here the position allotted to a soil in classification is strongly influenced by whether it has developed on a loose sand, a sandstone, a marly limestone, or a clay with properties already determined in a previous cycle of weathering and deposition. The association of soils is sometimes catenary, but more usually the outcrops and the soils they carry are not related in a simple manner to differences of level. For a long time to come, such a region can be described in general terms only, and cannot be shown on a soil map except diagrammatically, though the various soil types that occur are approximately known from travellers' descriptions and the investigation of sample localities. The notation used is scattered discs of the colours representing the recorded soil types, on an uncoloured background.

## 7. GENERAL CONCLUSIONS.

Some discussion of the principal features of the map for the various dependencies taken separately is given in the four sections of Part II. In this section of Part I certain conclusions from the map as a whole are given briefly. Like the map itself, they are provisional and experimental, and will doubtless be found to require amendment as the stock of ascertained fact increases.

### The Factors determining Soil Type.

No one physical factor can be said to have a directing influence on soil type over the region as a whole.

If we apply hypotheses in turn, supposing that climate, or parent material, or surface relief provides the key to soil distribution in East Africa, each may give encouraging results in some part of the map, but fails in others. In so far as we can pick out (for example) sub-regions having similar overhead climates, we find that they have similar soils only when their topography and drainage systems, their surface geology, and the past history of their land forms have a sufficient number of features in common.

When, however, we have to do with one of the major factors at an extreme of its range, we find that it tends to govern soil development, and the other factors become subordinate unless they also are at an extreme.

Thus, as regards climate, it is a fair generalisation from the map, considered alongside a rainfall map, that the wetter districts, namely those having a well distributed precipitation of 1,500 to 2,000 millimetres or more, almost always have soils falling into the group of laterised red earths, with podsolisation at the higher altitudes. These districts have rocks as various as granite and basalt, sandstone and limestone, shales, schists and gneisses, dolerite and pegmatite. Their relief varies from mountainous to undulating, though always with sufficient active dissection in progress to afford free drainage. The speed of weathering, the removal of dissolved matter from the site in the under-drainage, and the activity of plant life under these generous rainfalls, are probably such that we have here a true "climatic soil type," developing obediently in accordance with present-day overhead conditions.

Exceptions to this dominance of a wet climate are of course provided where the factor of *relief* intervenes at an extreme. Bottom-lands that receive seepage and run-off water from surrounding slopes but cannot part with it readily under gravity have soils falling almost always into the group of black or grey clays. These may therefore be termed a "topographic soil type," amongst which climatic effects have the subordinate rôle, in conjunction with parent material, of influencing merely their classification into sub-groups. It is perhaps justifiable to regard the plateau soils, with their pale colours and their tendency to concretionary ironstone formation at a horizon of fluctuating subsoil water-table, as another mainly topographic type, though here a necessary condition (almost always fulfilled in East Africa) is an unequal seasonal incidence of rainfall.

There are frequent instances on the map where the factor of surface geology intervenes as a ruling element. A rock which is in an extreme state of mechanical sub-division from the outset of its career as a surface formation will (except under desert conditions) possess all essential attributes of a soil long before it has had time to receive an impress from climatic forces or to show the chemical weathering and horizon development characteristic of its situation. Examples of such ready-made soils, or "lithological types," are found on volcanic dust or pumice, unconsolidated sands and clays, and present-day alluvia. The sub-groups (*b*) of the black or grey clays (see tabulated classification in Section 4) are probably to be regarded as lithological types from a genetic standpoint.

In general it appears that the factor of parent material increases in importance in determining soil type as one passes from wetter to drier climates.

### The Persistence of Effects from Past Time.

A phenomenon akin to the *hysteresis* of physics, namely a lag in reaching the new equilbrium when a governing condition has been changed, is undoubtedly to be reckoned with when studying soil type in relation to general physiography. We cannot always account for soil properties by reference to present-day conditions alone. A particular factor in soil development may be operating at a changed value, or may have been eliminated altogether, but its effects are erased only slowly, or may persist indefinitely if they were of an irreversible or destructive kind.

The map shows extensive occurrences of red earths, and of other soil types having an unsaturated or even a laterised clay-substance, outside the limits of what may be regarded as the proper climatic domain of such leached soils. The régime under which they are found is semi-arid and cannot be supposed to provide nowadays the necessary leaching conditions even when allowance has been made for the ready permeability of some of the materials. We must conclude that in the fairly recent past the climate has changed in the direction of becoming drier. Since the change the soils have no doubt undergone some modification, in most cases suffering truncation of the profile by surface erosion; but in the main they survive with the impress of former conditions still upon them.

The soils found in the central plateau regions show also, as Gillman has pointed out (29), that we have to allow for changes not only of regional climate, but also of relief, drainage, elevation, and, of course, vegetation, not very distant in time or still continuing, and rapid enough to fall within the life-history of a present-day " mature " soil.

These effects persisting from the past add their complication to the pattern of the East African soil map, and still further obscure the correlations that might be looked for between soil type and the simple physiographic factors of the present, such as climate and relief. In the incomplete state of the map it is too early to say whether the "soil zone" of trans-continental extent, that striking feature of soil maps of Russia and of North America, will be discernible, in spite of these local complexities, in East Africa also.

## THE MAP IN RELATION TO LAND CLASSIFICATION.

A simple correspondence should not be looked for between the statements of a soil map such as this (even when in due course the gaps of the present version shall have been filled) and the facts or possibilities of land utilisation, settlement, and crop production.

It is true that the map is based upon properties which are of fundamental significance in soil utilisation, though they have been selected primarily as of significance in the scientific description of soil as a natural body. But in reality there are many more kinds of soil in East Africa than the dozen or so major groups, with a few subdivisions of each, which are all that can be distinguished on a diagram drawn to a scale of 1 in 2 million. There are differences between soil and soil that are of great importance in determining fertility, but which are insufficient to separate them in a broad natural classification of the kind that has been attempted here. Small-scale maps such as these are too generalised for many purposes; they answer some questions, particularly those of the geographer, but leave the agriculturist in many respects uninformed. The detailed answer he wants can only be provided by field parties equipped for systematic soil survey and backed by a proportionate laboratory service. Such work has yet to be begun in East Africa, but it is perhaps not too much to hope that it is being planned for.

It must not be overlooked also that soil classification and land classification are by no means the same problem. They are problems less and greater, and the greater requires the study of many questions in crop and animal husbandry, the technique and economics of soil amelioration, and the ways of Man, that fall outside the province of the soil surveyor as such. A comprehensive classification of land in this sense is without doubt an essential task to be undertaken for the guidance of policy in a new country, and the present map can claim no more than to be an experimental contribution towards it from the field of soil morphology.

# Part II

## THE SOILS OF THE FOUR DEPENDENCIES

In this part of the Memoir the soil geography of each of the four dependencies included in the map is described in turn, with some amplification of particular points in classification and morphology.

### 1. KENYA COLONY AND PROTECTORATE.

It has already been stated in the introductory section, and should be repeated here with particular reference to Kenya, that the soil classification and delineation of boundaries are tentative and experimental. Except for field work in connection with coffee, which is grown mainly on one soil type, there has been little close study of general soil conditions, and the major part of the effort expended has been directed to problems of economic interest in the more settled and populous areas rather than to an impartial pedological survey. In drafting the map for outlying districts, it has been necessary to employ the broken colouring indicating fragmentary information, and for much country of which still less is known only brief notes of probable soil conditions can be given, as, for example, in the Northern Frontier Province.

The parts of the Colony for which there is any substantial information are the central highlands between about 1° north and 2° south of the equator, the included portion of the floor of the Rift Valley, and the neighbourhood of the Gulf of Kavirondo on Lake Victoria.

#### The Red Earth Districts.

In the highlands the most widespread soil type is the red earths, which are for the most part classified provisionally in the " laterised " group on account of their physical properties and behaviour in tillage.

The most important sub-group is that derived from volcanic rocks, particularly the porous tuffs and underlying phonolitic lavas of the Kikuyu country. This productive region, which is high-lying land originally carrying evergreen forest, lies between Nairobi and the southern slopes of Mt. Kenya, to the east of the Rift Valley. It consists mainly of broad parallel ridges whose descending slopes are at first gentle, then increasingly abrupt, often terminating in the steep sides of gullies. Under a good rainfall (40–50 in. = 1000–1250 mm.) and with free drainage, the tuffs have weathered deeply, and there is usually over 15 feet (5 m.) of a bright red very porous and friable loam without marked horizons, though scattered iron concretions in pellet form may occur near the underlying rock. From its field texture and friability the soil must be classed as a loam, though after dispersion in the laboratory it shows a high content of particles of clay size. The top soil varies in colour from dark chocolate to dull red, depending on the preservation or depletion of the original content of organic matter. The soil reaction is variable, depending mainly on the nature of the surface cover, which influences the intensity of leaching : most commonly the acidity increases with depth, from pH = 6 to pH = 5, in the upper 2 metres. The destructive process of laterisation has not gone to an extreme in these soils, and with their highly advantageous physical properties they constitute the most generally fertile soil type in the Colony.

On the other side of the Rift Valley, on the plateau of Uasin Gishu and the slopes of Mt. Elgon, the red earths mapped as on volcanic rocks are derived from massive lavas rather than tuffs, are browner in colour, not so deep, and differ from the Kikuyu soil in other minor ways. In Uasin Gishu they occur in catenary association with non-calcareous black or grey clays, and concretionary ironstone (known locally as " murram ") is of frequent occurrence in the subsoil. It may be necessary later on, as information about them increases, to classify some of these soils in the group of plateau soils rather than, as at present, with the red earths.

Next in extent to the laterised red earths on volcanic rocks are those on gneiss and granite, formations which occur together in Ukamba and Central Kavirondo. The profile differs from that on volcanic rocks in that it is not so deep, more sandy, usually a pinkish red in colour, and less resistant to erosion. These soils usually occupy gently undulating country (in association with black or grey clays in the bottom-lands) and the lower slopes of conical hills. In the relatively wetter districts they carry a forest cover, and then resemble the corresponding soils on volcanic rocks more closely ; in drier country they carry scrub and orchard savannah.

The greater part of North Kavirondo is mapped as non-laterised red earths. The common subsoil colour is yellowish to reddish brown, with very variable top soil colours owing to local shifting of material which leads to gradual soil accumulation in some places and truncation of the profile in others. Where the soil is stationary there is more tendency to be typical of the group. The non-laterised red earths are much " heavier " than their laterised counterparts.

### The Plains Soils.

This group, in Kenya, provides a convenient means of mapping certain soils which are difficult to classify elsewhere, but it cannot be said that much is known of their morphology. Especially is this so in the "non-calcareous" sub-group, shown occupying the floor of the Rift Valley from Naivasha northwards towards Lake Baringo. Here the soils vary in colour from light grey to light brown and pinkish brown, and are very variable in depth of profile. The ground is fairly level and the parent materials are erosion-products of the rocks of the adjacent escarpments, with local additions of volcanic ash. When developed on consolidated volcanic materials, the soils are pinker in colour, and when on unconsolidated deposits, greyer or light brown.

A few exposures of a calcareous plains soil have been seen in semi-arid country in the south-eastern parts of the Colony. The soil colour is light red, and there is an almost continuous pan of lime concretions in the subsoil, often within the first 30 cms. It is possible that this soil is akin to the chestnut-brown group of South Russia or the red Karroo soils of South Africa. Observations from the Tanganyika side in the region of Taveta, south-east of Kilimanjaro, link up with these occurrences of calcareous plains soils, and it seems probable that the sub-group in question occupies in all a good deal more ground than has been shown in colour on the map, especially in the country traversed by the Uganda railway east of the 38th meridian, and as far south as the foot of the Paré—Usambara mountain chain on its north-eastern side.

A local area of calcareous plains soil occurs under semi-humid conditions in the neighbourhood of Nanyuki to the west of Mt. Kenya. The profile shows a deep friable fawn-coloured soil with columnar secondary limestone in the horizon from 30 to 100 cms. This soil has provisionally been given separate standing as a sub-group in the classification, and a distinctive hatching on the map.

### The Black and Grey Clays.

In this large group a natural sequence can be studied in Kenya from calcareous to non-calcareous black soils and thence to grey soils, with a further stage having a pronounced humus top soil overlying a bleached lighter-textured horizon, which in turn overlies a yellowish-brown iron-mottled zone, often with concretionary soft "murram" just below the bleached material. This last variety may be a form of tropical glei-podsol. Local variations in topography may sometimes reproduce all the required soil-water conditions, and the complete range of soils may then be seen in a small area. In other circumstances large areas may be covered by one of the types, when the governing complex of factors may include parent material, climatic conditions and regional drainage.

The calcareous black clays are very extensive in the drier and flatter regions, which are subjected to an alternation of short rainy seasons and prolonged drought. The characteristic physical properties of these black clays exaggerate the effects of drought, for they swell and become nearly impervious when wet, thus increasing run-off, and their marked shrinkage on drying results in the formation of broad deep cracks which thoroughly desiccate the soil. The alternation of shrinkage and swelling, together with the falling of loose surface soil into the cracks, produces a kneading of the soil which makes for uniformity with depth. The amount of calcium carbonate contained varies greatly in amount and in its distribution in the profile. There may be a continuous zone some six inches thick, made up of nodular limestone (kunkar) of various sizes, at about the junction with the parent material, together with small pellet limestone distributed throughout the overlying black clay. The zone of accumulation may be reduced to a thin broken layer, with no dispersed calcium carbonate ; and in extreme cases the accumulation may consist of a little pellet limestone only, distributed at the base of the black clay and within the upper layers of the weathering parent material.

Large continuous areas of such soils are shown in the more level regions at about 6,000 feet (1,800 metres) throughout Laikipia and North Nyeri, extending northwards from the foothills of the Aberdare Mountains and Mount Kenya towards the Uaso Nyiro River ; and also on the Athi and Kapiti Plains to the south of Nairobi. More limited areas of slightly calcareous black soils have been developed on sedimentary deposits in the relatively warm regions lying about the Gulf of Kavirondo in West Kenya.

In Ukamba the soil types become catenary, calcareous black clays occupying the more level country, and red earths the more elevated ground, both soils being derived from gneiss.

There is no sharp division between the calcareous and non-calcareous black clays, and the latter in turn pass insensibly through the greyish-black and grey types to those that have podsolic characters. The differentiation into horizons and the acidity of the profile both increase as we pass through this range of soils, which corresponds to a similar range in soil water conditions, increased wetness making for degradation of the black clays. The dividing line in classification should perhaps have been between the *black* clays proper and the much more acid *grey* clays.

The main area mapped as non-calcareous black or grey clays is the Kinangop Plateau, which extends as a shelf for some 30 miles to the N.N.W. from just above Kijabe, on the eastern side of the Rift Valley. The soil is of impeded drainage and is very acid in reaction. Usually a greyish bleached and mottled top soil overlies a yellowish-brown compact subsoil containing iron concretions. The vegetation is usually tufted grasses, without tree growth.

In the high-rainfall elevated mountain district of Lumbwa there is an acid black soil, containing bleached stones, overlying a stiff greyish-brown clay. Further west, at lower elevations and in a zone of warmer and drier climate, there is much non-calcareous black clay formed on alluvial deposits, merging into the calcareous type in places.

### The Coast.

The coast belt has soils generally analogous to those of Zanzibar and the Indian Ocean coast of Tanganyika. Precise information on the extent and position of the various soil types is lacking, and though a good general account of conditions is available from W. W. A. Fitzgerald's detailed route-notes made during his journeys of agricultural reconnaissance on behalf of the British East Africa Company nearly 40 years ago (23), there are few more recent observations on record, and it has not been possible to map this once very productive strip of lowland except diagrammatically. The prevailing soil in the narrow coast strip proper is a loose sand, with soils of the black or grey clay group occupying low-lying flats, and sandy red earths on ridges. Inland is a strip of fertile foothill country on older sedimentary rocks, and this is succeeded quickly by a broad, inhospitable, and almost waterless low plateau, the *nyika*, whose soils appear to belong to the group of plains soils, though their colour is predominantly red.

The alluvial soils in the delta of the Tana River deserve mention. They extend to more than 30 miles from the sea. In the upper reaches there is a great depth of dark-coloured heavy soil subjected to flooding during part of the year, and ill-drained. In the lower reaches, the soils vary markedly in texture profile from place to place, but have the common property that they are very sticky and have a high salt-content, especially in the deeper subsoil. The colouring used on the map for these tidal clays combines the horizontal ruling in yellow (for alluvial soils) with that in violet (for saline soils).

On the Lake Victoria coast alluvial soils are shown at the estuaries of the rivers Sio, Nzoia, and Yala. Their profile is variable, but there is usually a good depth of greyish to light brown material with fair natural drainage, though flooded during heavy rains.

### Volcanic Soils.

Volcanic soils are shown in the Rift Valley, south of Naivasha, with a smaller area near Nakuru. They are skeletal soils overlying comparatively recent trachytes, tuffs and ash. Those on unconsolidated volcanic ash are very open in texture and contain the primary minerals almost unaltered ; locally, glistening crystals of sanidine are very prominent. Another area of volcanic soils is shown to the north-east of Mt. Kenya.

## 2. THE UGANDA PROTECTORATE.

Over the greater part of Uganda the distribution of soil types is largely a function of the topography, which is itself determined by the geological history. To understand the soils it is necessary to give a brief review of the structure of the country. The quotation that follows is from the Uganda Geological Survey's Summary of Progress, 1919–1929 (10).

> "Uganda is part of the great African peneplain, the development of which in this country, in spite of the existence of a few residual hills, had reached a very high state of perfection before elevation to form the present plateau subjected it to the gouging action of consequent streams whereby it was dissected into a number of flat-topped hills. These hills, separated by wide papyrus-choked swamps, are highly typical of the scenery of Uganda."

The country is bordered on the north-east and in the west by rift valleys. The highest general level is in the south, where the average altitude exceeds 5,000 feet (1,500 m.), and the lowest is in the north-east, where the average is not much more than 3,000 feet (900 m.). Ruwenzori, on the edge of the western rift, has the highest peak in the Protectorate (Margherita, 16,800 feet), and carries permanent snow and glaciers. In the south-west are the Mufumbiro group of volcanoes, only recently extinct, and bordering the eastern rift is an older volcano, Elgon.

The lakes of Uganda, which form one of its principal physical features, have all had an unusual history. Lake Victoria lies in a downwarp ; Lakes Albert, Edward, and George lie in the western Rift Valley ; and small lakes near the south-western volcanoes were formed by the damming of valleys by lava-flows. Lake Kioga, once a fast-flowing river rising in the east and flowing to the Congo system via the Kafu, lost this outlet by earth movements and filled up a great part of the Eastern Province before finding its way to Lake Albert and the Nile. The lake itself and the valleys of its former tributaries are now nothing more than large papyrus swamps with comparatively little open water.

Except for small areas of sandstone, the volcanic districts, and some localities in the north-east and in the western Rift Valley where there are recent sedimentary deposits, the country is underlain either by Archean rocks of the African Basement Complex (gneisses, granites, and quartzites) and newer granites, or by the ancient sedimentary rocks of the Karagwe-Ankolean system. These latter are bedded more steeply than the Basement Complex rocks, and constitute the hillier country, except of course for Ruwenzori and the volcanic mountains. It is possible in fact for one familiar with the country to tell immediately from the topography whether a particular area is underlain by Karagwe-Ankolean or by Basement Complex rocks. This has a considerable bearing on the types of soil evolved.

Passing now to the soil map, its provisional nature must be emphasized. As survey work proceeds, the larger groups and complexes will almost certainly be sub-divided. The indication of boundaries must not be taken to imply any exactness of knowledge, and it is unlikely that for many years we shall be in a position to locate precisely, for example, the boundaries of the soils fringing Lake Kioga.

It is convenient to deal first with the soils of minor extent.

Volcanic Soils, that is, soils at a very early stage of development on almost unchanged volcanic ejectamenta, occur in scattered localities in the west. A profile typical of the Toro area consists of an intensely black top soil over an ashy grey sandy subsoil. The black colour is due to a high content of organic matter in the top 45 cm., though there is also considerable magnetite among the soil minerals. The reaction is neutral or alkaline, not changing with depth. Small angular fragments of quartz are a prominent feature of the profile.

Calcareous Black Clays and Sandy Clays occupy considerable areas as bottom-land soils on the floor of the western Rift Valley adjoining Lakes Edward, George, and Albert. They have been formed from sediments of the Kaiso series, and owe their character in part to the fossiliferous nature of those sediments. They are rich in calcium and phosphate and contain calcium carbonate in their lower horizons. Their vegetation is short grass and acacia scrub, but they would appear to be potentially fertile and owe their present unproductiveness to inadequate or poorly-distributed rainfall.

A large area in the north-east, which is not yet of any agricultural importance and has not been visited by the compilers of the map, is marked as "black soils, probably calcareous." Samples of limestone have been received which were said to have been handpicked from the surface in parts of this area. Other observers describe the soil as black and very sticky during the rains, but potentially fertile, the limiting factor being rainfall.

Red Earths, not Laterised, on Volcanic Rocks are shown covering the western slopes of Elgon. A distinction between soils at different altitudes on this mountain will probably have to be made later, but for the present purpose the whole of the slopes below the Alpine zone, at least on the Uganda side, can be regarded as carrying red earths, which at the lower levels are very fertile, with high contents of calcium, potash, and phosphate. The profile shows (to qualitative tests) no acidity down to 18 feet (5½ metres). The change to laterised red earths shown on the map in passing eastwards on the slopes of Elgon across the Kenya border is based upon reported field observations from the Kenya side.

### THE MAIN SOIL TYPES.

The soils above discussed are to be regarded as separate entities determined by localised conditions, and without immediate relationship to the main soils of the country. Those now to be described bear a more direct relation to each other and to the general physiographic conditions.

The principal soil type of Uganda is a red earth, not laterised or of incipient laterisation only: the soil of the denuded-peneplain country consisting of innumerable flat-topped hills, separated by swamps. The description "red earth" applies, however, only to the soils of the hillsides. The swamp soils are, of course, entirely a different type, and there are soils in intermediate situations that are not classifiable with either. In country of this kind no map could show soil boundaries in detail, and the whole complex is best considered as a composite unit, the *catena* already referred to in Part I, consisting of a continuous range of soils found always in the same order, their characters being determined by their topographic position.

Two different catenary complexes are shown on the map in Uganda. One is on the sedimentary rocks of the Karagwe-Ankolean system, the other on the Basement Complex rocks and newer granites. This division is somewhat arbitrary, but is regarded as justified because, firstly, the Karagwe-Ankolean rocks, being bedded more steeply, give rise to a hillier landscape and the swamps are a more subordinate feature, and secondly, no profiles from the Karagwe-Ankolean areas that have so far been examined resemble anything found on the Basement Complex, except of course in the broader classifying characteristics. The red earths on the shales of the Karagwe-Ankolean system are brown in colour rather than red, have a very low lime status and high acidity, with a relatively high organic content even at some depth in the profile, and are markedly heavier than the corresponding soils on gneiss. As regards the Basement Complex areas, differences have not so far been distinguished between the soils found on the gneissose, granitic and quartzitic members of the system that can with certainty be attributed to the effects of parent rock, though there are indications that the formation of concretionary ironstone ("murram") may be such a difference. One hatching only, that used elsewhere on the map for "red earths on gneiss," has been employed, without separate reference to the soils on the newer granites.

Typical profiles of the constituent soils of the catena on the Basement Complex rocks, as examined in detail at Bukalasa, 35 miles north of Kampala, are as follows :—

A. *Hill brow series.*—A grey soil, black when wet, passing through a layer of quartz fragments to a thick bed of rotting rock. (In Kampala there is a thick stratum of "murram" before the rotten rock is reached. It is not yet clear whether this difference is due to an originally lower iron content in the parent rock at Bukalasa than at Kampala.) The thickness of soil is variable, but is never more than about 60 cm., and where erosion has occurred the layer of quartz fragments is often exposed.

B. *The red earths.*—A brown top soil (which in many areas has been lost by sheet erosion) overlies a red subsoil many metres in thickness, with little differentiation into horizons. The molecular ratio of silica to alumina in the clay fraction is just over 2·0. This is the principal soil of agricultural land in this type of country. The natural vegetation is mainly elephant-grass (*Pennisetum purpureum*).

C. *The swamp-fringe series.*—This comprises a belt of grey sandy soils with red and yellow mottling at about 120 cm. depth, which fringe the swamps. They were first recognised around the lesser swamps that separate the hills of the typical dissected-peneplain country, but similar dark coloured sandy soils (represented on the map by a blue wash colour) exist also in larger continuous belts around the bigger swamps and Lake Kioga. The typical vegetation is acacia scrub.

D. *The swamp soils.*—These consist typically of an intensely black top soil overlying a grey or bluish-grey waterlogged clay. In the upper horizons they are very acid, but though at deeper levels in the profile they may be neutral or alkaline, calcium carbonate concretions have not, as a general rule, been found; and they are represented on the map, in the diagrammatic stripes of the catenary notation, as a non-calcareous type. The molecular ratio $SiO_2/Al_2O_3$ in the clay fraction is about 2·6.

Over a large area of country which is undulating rather than hilly, the A soil of the typical catena is not present, and the B soil (the red earth) occupies both the crowns and slopes of the ridges. Such country lies at lower absolute levels, and it is possible that the blanket of soil formerly covering the old peneplain has been incompletely removed. It has not yet, however, been possible to distinguish these areas separately on the map.

The outline of Lake Kioga, and of a number of smaller sheets of open or papyrus-choked water, is marked on the map by a heavy blue line. This represents a band of black clay soil which may differ from the ordinary swamp soils of the country (of type D above) in that it has been shown to have a considerable development of calcium carbonate concretions at a depth of about 4 feet (125 cm.).

## 3. TANGANYIKA TERRITORY.

A strip of country of varying width, of low relief, but not quite flat, and of elevation not much above sea level, borders the Indian Ocean coast along its whole length from the Kenya border to the Rovuma River. Its soils can be summarised under four heads: (1) The tidal muds carrying mangrove forest or scrub, which fringe many of the inlets and river mouths, and are of considerable extent in the delta of the Rufiji. (2) The shallow and discontinuous but fairly heavy red earths found on narrow raised benches of coral limestone immediately adjoining the coast. These are genetically akin to the "karst" soils that occupy so much of the eastern and southern parts of Zanzibar Island, and are derived directly from the limestone, accumulating in solution pockets. (3) The deep sandy red earths, the favourite soil of sisal plantations, which occupy disconnected broad low ridges. (4) The most extensive and continuous type of all, a complex consisting mainly of light-coloured loose sands, passing into sandy black or grey clays wherever there is liability to water-logging. Analyses of some of these sands, in the Bagamoyo district, where the low coast strip is unusually wide and they occupy a very large area, show them to contain only 2 or 3 per cent of material other than coarse and fine quartz sand, with an extremely low content of organic matter; yet they support a considerable population under a mixed agriculture of coconuts and annual food-crops. Their fertility is probably determined by the existence of a flowing water-table not far from the surface, derived from the drainage of the low plateau, which generally forms the western limit of the coast strip.

This low plateau, much dissected and denuded, forms a second belt of varying width roughly parallel to the coast, of undulating or hilly country with a complex soil distribution. The rocks are mainly Cretaceous and Jurassic sandstones, limestones and marls, with (locally) an overlay of later fluviatile sands and gravels. The soils appear to be determined in great measure by the nature of the parent materials. Marls and soft limestones give rise to grey or dark-coloured ill-drained clays or sandy clays, sometimes calcareous throughout the profile, sometimes having a strongly developed glei horizon just above the calcareous parent material, and acid thence to the surface. This latter type is rarely culivated and occurs in characteristic landscape, a rolling savannah of grass and widely scattered broad-leaved trees, with some low acacia thorn and dwarf palm (Hyphaene sp.), and tall Borassus palms in the hollows. The harder limestones, sandstones, shales and unconsolidated sandy deposits develop into red earths of very variable depth, texture, colour and fertility, which merge sometimes into loose sands resembling those of the coast strip, and sometimes into soils classifiable in the group of plateau soils, having grey-brown, dull orange-brown and other pale colours, and gravelly ironstone horizons in the deep sub-soil. The vegetation is usually light evergreen forest on the seaward-facing slopes, which intercept rain, and bush or scrub of more xerophytic types elsewhere.

In Cretaceous country of this type west and south-west of Dar-es-Salaam, the broad hill-tops and remnant plateau surfaces are thickly mantled by red earths, which give place on the valley slopes to a variety of gravels, clayey sands, marls and clays apparently determined by the exposure of successively lower geological formations. On the map this particular succession is shown diagrammatically as a catenary complex of red earths and undifferentiated lithological types. The same catena is reported elsewhere, notably in the Lindi district and as far west and south as long. 36°, lat. 10° S., east of the Pitu River; and may be of general occurrence in the south-east of the Territory wherever Cretaceous rocks of this formation are found.

For the most part the boundaries and relative extent of the various soil types on these sedimentary rocks and in the coast strip are not known, though records from scattered localities show what are the chief soils likely to be encountered. Except for one or two localities, as in the neighbourhood of Tanga, resort must be had to diagrammatic mapping in the "disc" notation.

Further west again are mountain chains or eastward-facing escarpments of the Crystalline Complex rocks, mainly gneisses. Opposite Tanga they approach to within 40 kilometres of the coast, and their forehills abut directly on to the formations already described. Elsewhere, both to the north and south, broad peneplain regions intervene, semi-arid and for the most part inhospitable and little-inhabited. Almost nothing is yet known about the soils of these great intervening stretches of country, in which leisurely travelling is difficult; but they must fall mainly in the groups of plains soils and plateau soils, with black calcareous clays in wide shallow depressions and red earths on the foot-slopes of scattered upstanding "inselbergs." In Uzigua, where the peneplain is considerably dissected, a red earth-black clay catena predominates.

The exposed eastward—or south-eastward—facing upper slopes of these escarpments, or the mountain regions as a whole when nearer the sea (as in Usambara and Uluguru), are covered densely by heavy rain forest, or else by the secondary forest, cultivated clearings, bracken scrub and mountain grassland which have replaced it. Here, under well-distributed rainfalls of from 1500 to 2000 mm. and very free drainage, with soil temperatures not above 20° C., are found the typical red earths of advanced laterisation. The rainfall conditions on the middle slopes of Kilimanjaro are similar, and the soils there fall into the same major group, though, being derived from basic and intermediate lavas, they differ a good deal from the gneiss soils in sub-group characters. There is some evidence of an indirect kind that laterised red earths are the ruling soil type also in a district (southern Irak, to the south of Mbulu, lat. 4° S., long. 35½° E.) near the crest of the Rift Valley escarpment, where the exposure is similar to that described above, but the rainfall is insufficient at the present day to support rain forest. Possibly we have here a relict soil from a former wetter régime.

Two other districts which have a considerable extent of soils in this group owe their high rainfall to their proximity and orientation to a great lake. They are (1) the high region lying about the north end of Lake Nyasa, including the Livingstone Mountains, the lower slopes of the Rungwe volcanic highlands, and the Bundali Mountains; parent materials include gneiss, granite, shale, sandstone and lava ; and (2) a strip of country some 25 kilometres wide running along the western shore of Lake Victoria for 100 kilometres near Bukoba ; parent materials are mainly sandstone, with dolerite intrusions.

At altitudes above about 6,000 feet (2,700 m.) on these highlands, still under rain- or mist-forest or bracken, the laterised red earths pass into soils of pale colours (grey-brown or yellow-brown, with pink in the deep sub-soil) which have a considerable accumulation of dark-coloured acid humus in the top soil, and a slightly bleached horizon below it. The typical B horizon (humus or iron oxide accumulation and induration) of the European *podsol* has not been detected in these soils,* and their clay fraction is highly sesquioxidic throughout the profile (molecular ratio $SiO_2/Al_2O_3$ well below 2·0, sometimes below 1·0), so that they cannot properly be called " tropical podsols "; but they are for convenience described as podsolised soils and shown on the map by the symbol *p*. Mean soil temperatures here probably lie below 10° C. Some considerable areas have been observed near Mufindi (lat. 8½° S., long. 35° E.), where the present surface apparently consists of the bleached horizon of such a podsolised soil, the original humic top soil having presumably been lost by sheet erosion after the clearing of the forest.

Lying at the eastern foot of two of the escarpments above-mentioned, namely, Nguru—Kaguru—northern Usagara, and southern Usagara—Udzungwa—Ubena, and also in smaller extent at the south-eastern foot of Uluguru, there are broad plains, parts of which are inundated annually by the drainage from the mountain catchment areas above them. Heavy black clays are very extensive on these plains, but locally there are also fertile alluvial soils, shifting débris fans, loose sands, and plains soils in the higher-lying parts. These facts are expressed diagrammatically by use of both the catena and the disc notation.

It may be said that hilly districts generally, including all but the wettest or most rocky parts of the mountain regions already named, carry mainly non-laterised red earths. Where there is an important proportion of mature valley lands having bad drainage, the red earths are found in catenary association with black or grey clays. These bottom-land soils fall into the non-calcareous sub-group when there is a regular seasonal overflow of run-off water and a steady output of seepage into a river system, i.e. in the more humid districts. They are then acid in reaction, grey rather than black in the subsoil, and without calcium carbonate concretions. Under semi-arid conditions, where the soil dries out completely with extensive deep cracking during many months in the year, they are usually calcareous, and darker coloured throughout the profile.

As the red earths are essentially a product of through-leaching conditions under a climate at least semi-humid, it is doubtful if they and the *calcareous* black clays can be considered strictly contemporary when found in company. The red earths of the semi-arid districts have probably ceased to develop as such, and are relicts, no longer in equilibrium with the overhead conditions and barely protected from destructive erosion by their present exiguous cover of xerophytic vegetation. It is indeed very difficult to bring some of these dead and desiccated red earths into active agricultural use without losing them altogether.

Behind the eastward-facing ranges lie great plateaux, whose investigation from the point of view of soil reconnaissance has hardly yet been embarked upon. In the aggregate they occupy a large proportion of the total area of the country, and their representation on the soil

* Profiles with typical $B_2$ horizon of iron-oxide accumulation, under a highly organic topsoil of pH 3·2 with bleached sand grains, have now been found by J. Pitt-Schenkel in Ocotea-Podocarpus-Ficalhoa rain- or mist-forest in West Usambara, Tanganyika, lat. 4° 45′ S., at 6,750 ft. (2,070 metres) altitude, and have been examined in the Amani laboratory. The parent material is gneiss.—G.M., Nov., 1935.

map, with few facts to go upon, is necessarily very incomplete. The indications given, which are based almost entirely upon an interpretation of the by-product notes of other observers, should be accepted with caution.

Topography on these plateaux usually shows mature forms, sometimes with renewed dissection evident, and broken by occasional remnant hill ranges. Except for the hills, their surface is deeply covered by a mantle of locally-transported material which has been graded down during a long process of denudation, and which may

(*a*), in bulk, represent the end-product to date of a long course of destructive hydrolytic weathering since the original hard rock was first broken down,

(*b*), as soil, have acquired profile characters corresponding to an increasingly sluggish drainage, and

(*c*), following the elevation of the peneplains into plateaux, be undergoing a fresh adjustment to conditions of rejuvenated drainage.

The soils met with are thus not very closely related to present-day climatic conditions, nor can it safely be assumed that the rocks now exposed in the neighbouring residual hills have been the only contributors to the parent materials of these soils. In their classification there are difficulties of a kind that recalls those encountered when dealing with soils formed on unconsolidated sediments.

The observations so far recorded show that the soils of the high plateaux fall sometimes into the ill-defined group of plains soils, and that these are associated with black or grey clays in the lower lying sites. For the most part, however, the country has not yet been graded down to the level, and the ruling soil type possesses an intermittent under-drainage, with more or less development of concretionary ironstone in the subsoil. Such soils lie between the well-drained red earths on the one hand, and the "plains soils—black clays" complex on the other. To accommodate them the group of "plateau soils" has been devised, within which at present we have not attempted to distinguish sub-groups, though the need for them is already evident. Thus in the Kilimatinde–Itigi area (Central Railway, long. 35°) several observers have noted some close correlations between vegetation and soil which will probably prove to be a guide to distinctions within the group when soil investigations can be undertaken there.

The plateaux thus carry catenary complexes of the four groups *red earths*, *plateau soils*, *plain soils*, *black or grey clays*, or of three or two of them. The principal vegetation type on the plateau soils is *miombo* savannah-forest (Berlinia-Brachystegia deciduous open woodland), which occupies vast areas in the Tabora, Iringa, and Lindi provinces. In Ugogo it is replaced by more xerophytic types of dense bush, with baobabs, and here also open types of grass-and-acacia-thorn savannah are widespread, corresponding to a greater proportionate area occupied by the black or grey clays.

An interesting occurrence south of Iringa is a plateau soil having a highly laterised clay fraction, now under a climate verging on semi-arid, and doubtless owing its laterisation to a wet climate of the past.

Relatively raw soils on volcanic ash and tuff are found around Arusha, occupying all the lower slopes of Meru mountain except a sector on the wet southern side. There is also a considerable total extent of such soils locally in the volcanic area further to the west across the Rift Valley, and including the Serengeti Plain. Pumice and volcanic ash soils, sometimes covering other earlier soils of the same kind to the number of four or five, superposed, occur on the upper southern and the northern slopes of the Poroto-Rungwe highland between Lakes Nyasa and Rukwa.

Saline soils occur in some of the inland-drainage basins, as around Lakes Eyasi, Manyara, and Natron, and also locally elsewhere wherever the soluble products of primary weathering of soda-rich silicate rocks have accumulated.

The principal occurrence of alluvial soils is along the lower course of the Rufiji River.

The only records of true desert morphology in Tanganyika are from the alpine rocky zones near the summits of Kilimanjaro and Meru.

## 4. THE ZANZIBAR PROTECTORATE.

### (ZANZIBAR AND PEMBA.)

These two islands are shown as larger-scale insets to the main map. Their climate is fairly hot (mean annual temperature 27° C.), and moist, Pemba having a somewhat higher annual rainfall (Pemba 1,950 mm., Zanzibar 1,500 mm.). Both have well marked wet and dry seasons, but with some precipitation throughout the year. They differ considerably from each other in stratigraphy and conformation, Pemba being the older land mass ; and they have markedly different associations of soils.

The rocks of both islands are sedimentary, and include hard pure limestones (coral), hard sandy limestones, soft clayey limestones or marls, calcareous sandy clays, and clays and sands not calcareous. The varied properties of these materials, and the manner in which they crop out and have been denuded, have resulted in a wide range of soil types, some of which are difficult to allocate satisfactorily to the groups of the broad classification needed for the soils of the mainland.

In both islands, the soils planted for cloves are mainly sandy red earths, varying in colour from yellow-brown to deep red, not appreciably laterised though often very acid. Distributed irregularly through the red earth areas, and also producing cloves, are occurrences of the soil type we have termed *mottled clays*, whose deeper horizons consist of a tenacious many-coloured clay undergoing readjustment to conditions of leaching and oxidation. (See discussion of these soils in Part I, section 4.) Surface appearances afford little clue to the extent and position of the mottled clays, and they are represented on the map by the "disc" notation. In Pemba they are more important and extensive than in Zanzibar.

In Pemba, also, the extremely dissected topography, with its intricate system of steep-sided ridges separated by flat-bottomed swampy valleys, brings another soil group into prominence, namely, the black or grey clays. These occupy the valley floors, and in aggregate cover a considerable part of the surface of the island. They are represented on the map in catenary association with the red earth—mottled clay complex. In Zanzibar these valley clays are insignificant in extent and do not require representation on a map on the present scale. The black clay group is, however, of importance in a northern district of Zanzibar in the form of a very dark grey non-calcareous coarse-sandy clay which occupies the tops and slopes of broad ridges, and appears to be derived from a calcareous parent material.

A large part of Zanzibar and a much smaller fringe on the coast of Pemba are flat but very rocky coral limestone country or karst, on which a few continuous patches of a heavy red earth occur, but where the soil is usually a mere infilling of pockets in the limestone, and may contain up to 40 per cent of organic matter. The type has been given a distinctive colouring on the map: a combination of vertical rulings in yellow, indicating its dependence on lithology, and pink, showing the tendency towards formation of red earth. The karst country is mainly covered with bush or rough grass, but a system of shifting cultivation of annual crops is practised in the pockets of soil in the neighbourhood of villages.

In both islands there are considerable areas of very sandy land, with dark-coloured sandy clays in situations less well drained. These soils are used for coconuts and food-crops instead of cloves. Though they are classified together on the present map by the common property of extreme sandiness, which they all possess at least in their upper horizons, it is not a very satisfactory solution of the problem they present, for in fact a variety of profiles are revealed amongst them on making deep exposures, and they deserve much further study.

The low plain lying to the east of Chaani is represented as non-calcareous plains soil, though it is subject to water-logging in parts during the rains, and probably includes soils in the black or grey clay group.

A distinctive hatching has been introduced for the soil of the tropical swamp forest (oil palm and *Pandanus sp.*) at Josani in the south of Zanzibar island. It is a tenacious waterlogged grey clay, not much more than 20 cm. deep, lying on a floor of coral limestone. It has the property, anomalous in this group, of a very sesquioxidic clay fraction.

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