CHARACTERISTICS OF SOME TANGANYIKA SOILS

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WITH TWO PLATES

Summary

A series of soils from two areas of Tanganyika have been studied mineralogically. They are derived in the main from amphibolite, but only a small proportion of the more resistant aluminosilicate minerals survive in the soil. The clays ($< 1{\cdot}4\mu$) of the red loams are characterized by a predominance of kaolinite, whereas the more poorly drained grey soils have a disordered kaolin. Other components of the clays are iron oxides and small amounts of illite. The pallid soils contain moderate amounts of montmorillonite in the weathering zone, some of which persists into the soil. The mbuga and black valley soils contain montmorillonite or illite, with subordinate kaolin.

APART from Milne's accounts very little has been published on the soils of East Africa, and no studies of the mineralogy of the soils appear to have been carried out. The present research was undertaken to provide some fundamental information on soils on which the (British) Overseas Food Corporation has been endeavouring to develop a system of mechanized or partly mechanized farming. Two areas in Tanganyika were involved: Kongwa in the Central Province and Nachingwea in the Southern Province (see sketch map).

Kongwa. Situation and physical features, &c.

The township of Kongwa lies at an altitude of 3,300 ft. in Lat. 6° 12′ S. Long. 36° 25′ E. The area under development is a gently undulating plain, lying between 3,200 and 4,000 ft. above sea-level, with occasional inselbergs projecting above their surroundings. The underlying rock belongs to the Lower Basement Complex. A common constituent of this complex is a biotite-gneiss, described as migmatite by Temperley (1938). This alternates with belts of quartz-granulite, plagioclase-amphibolite, and metadolerite. The rock is exposed on the inselbergs and at a few small outcrops on the lesser hills and ridges. Elsewhere it is covered by a mantle of weathered material of local origin. At the crests of the ridges the mantle or pedisediment may be only a foot or two deep, but it increases in thickness down the slope and can attain a thickness of 20 ft. at the foot.

The annual rainfall (average over 5 years and several gauges) is 19·8 in., mostly falling in January, February, and March. There is a dry season of 7 months with, normally, no rain. The maximum temperature is about 95° F. and the minimum about 50° F.

On the footslopes of the hills of the Kiboriani range to the south of Kongwa, and of some of the larger inselbergs, shifting cultivation has produced a secondary bush very similar to that at Mpwapwa described by Greenaway (1933). Elsewhere there is a continuous blanket of

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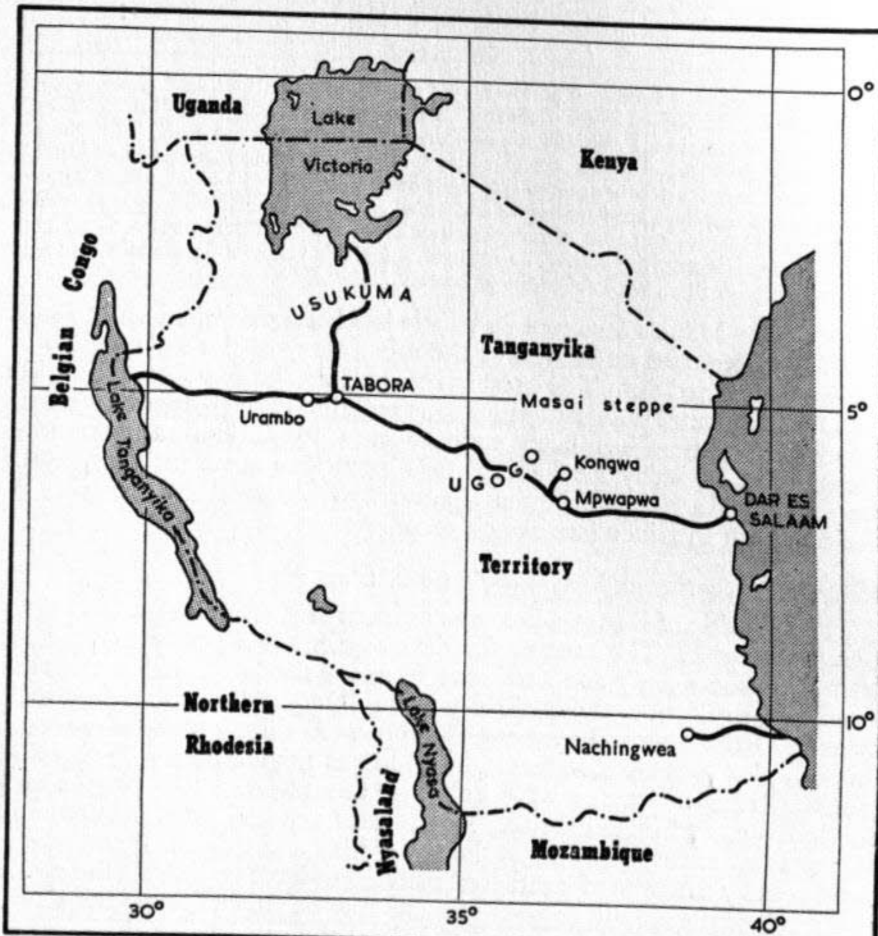
Commiphora thicket over all land except the seasonally waterlogged shallow depressions having the local name *mbugas*. The ground flora in the thicket is sparse. On the red soils baobabs are of frequent occurrence, but they are rare or absent on the pallid soils. The Commiphora thicket does not burn.



On the mbugas there is usually grassland with scattered trees and shrubs. The grasses are burnt annually by nomadic tribesmen. Locally, and probably associated with alkalinity or salinity in the soil, the grass is replaced by low shrubs such as *Croton menyhartii* Pax and *Salvadora persica* L.

The Soils. Typically the soils of the mantle are red in colour, but patches of pale grey or buff soils ('pallid soils') occur intermingled with the red. The following description is of a soil taken near the top of a slope under Commiphora thicket:

Profile 47. Chamaye (Red) sandy loam (analyses Table 1)

0–12 cm. Red-brown sandy loam (5 YR 4/6, dry). Top 5 cm. more friable than below. Merging into

12–105 cm. Red sandy clay (2·5 YR 4/8, dry). Massive; 12–35-cm. horizon harder than lower horizon. A few fragments of quartz, feldspar, and concretionary ironstone.

105–150 cm. (+) Quartz fragments and decomposing gneiss interspersed with red sandy clay (2·5 YR 4/8, dry, for the clay).

TABLE 1

Analyses of Fine-earth Fractions

Horizon (cm.)	*Fine earth as % of whole soil*	*Coarse sand* (%)	*Fine sand* (%)	*Silt* (%)	*Clay* (%)	*Moisture* (%)	*Organic carbon* (%)	pH	*Exchangeable cations (m.e./100 g.)*				
									Ca	Mg	Mn	K	X
Profile 47. Chamaye sandy loam (red loam)													
0–12	Not det.	52·0	21·7	1·9	20·4	1·5	1·44	6·50	6·8	1·8	0·03	0·8	..
12–30	96·1	43·7	18·2	2·5	32·5	1·9	0·41	5·00	2·4	1·5	0·01	0·8	..
45–55	97·2	37·1	18·2	8·0	32·3	2·6	0·34	4·95	2·4	1·9	0·01	0·8	..
75–85	96·5	38·1	21·1	8·7	26·4	2·5	0·25	4·95	2·3	2·1	0·01	0·5	..
105–115	88·6	36·3	25·4	9·5	23·7	2·8	0·25	5·40	3·2	2·6	0·01	0·7	..
140–150	50·3	61·8	26·6	5·8	2·8	2·0	0·16	6·80	3·7	2·7	0·01	0·6	..
Profile 16. Nagaga sandy loam (lower-lying grey soil)													
0–7	100·0	42·2	39·0	2·9	12·3	1·2	1·25	6·60	4·5	1·8	0·15	0·37	7·6
7–17	99·7	38·8	41·5	2·8	15·3	1·0	0·68	6·30	2·4	1·0	0·17	0·27	5·2
17–30	..	..	..	..	..	..	0·36	5·25	0·5	2·1	0·04	0·25	6·0
30–45	98·3	44·9	16·3	1·3	34·8	1·8	..	5·10	..	..	..	..	..
65–90	94·4	42·4	13·2	2·4	39·8	2·0	0·23	5·20	0·3	1·8	0·00	0·25	6·2
125–150	82·4	45·9	15·0	3·7	33·5	1·9	0·13	5·20	0·3	2·0	0·00	0·15*	5·6
190–200	75·0	44·2	15·5	3·6	34·7	1·9	0·13	5·30	..	..	..	..	..

* +0·3 m.e. Na.

There were very few fibrous roots in the profile due to the very sparse ground flora, but tree roots reached to the full depth.

Towards the bottom of the slope the soils deepen considerably but the general appearance and colour remain the same. In the case of P. 2 (Table 6, below) no rock was encountered down to 235 cm. It seems that this group of soils could be referred to Kellogg's group of red latosols.

The 'pallid soils' mentioned above appear to correspond to the light-coloured 'plateau soils' of Milne *et al.* (1936). Similar soils, also described as 'plateau soils', are mentioned by Trapnell and Clothier (1937, p. 5) and Trapnell, Martin, and Allan (1947, p. 9 of memoir) as occurring in Northern Rhodesia. Later, however, Milne (1947, pp. 230 and 247) appears to have extended the term 'plateau soil' to include red earths with a concretionary ironstone horizon. The Kongwa 'pallid soils' also appear to correspond to some soils from NW. Tanganyika which Milne (ibid., p. 196) described as 'anomalous grey soils', and which occur in association with red earths, as do the Kongwa soils.

The following is an example of a pallid soil from Commiphora thicket with occasional baobabs and sparse ground flora:

Profile 3. Mtanana sandy loam (analyses Table 2)

0–10 cm. Yellowish-brown sandy loam (7·5 YR 5/6, dry). No fibrous roots; a few small tree roots, merging into

10–50 cm. Yellowish-red sandy clay (5 YR 5/8, dry). Massive structure. A few small roots.

50–65 cm. Band of subangular quartz stones.

65–85 cm. Pale reddish-yellow sandy clay (7·5 YR 6/6, dry).

85–110 cm. (+) Decomposing gneiss (7·5 YR 6/6, with white specks).

TABLE 2

Analyses of Fine-earth Fractions

Horizon (cm.)	*Fine earth as % of whole soil*	*Coarse sand* (%)	*Fine sand* (%)	*Silt* (%)	*Clay* (%)	*Mois-ture* (%)	*Organic carbon* (%)	pH	*Exchangeable cations (m.e./100 g.)* Ca	Mg	K
Profile 48. Nachingwea loam (red loam)											
0–20	99·7	38·2	27·8	2·9	26·3	1·6	1·43	5·95	4·9	4·4	0·4
20–60	97·9	23·0	13·0	2·1	58·5	2·4	0·85	5·50	2·5	3·2	0·2
60–100	88·2	17·8	14·0	8·7	55·9	2·3	0·48	5·95	2·8	2·9	0·1
105–160	67·9	27·4	17·5	8·2	44·7	2·3	0·21	6·65	3·1	2·1	0·2
Profile 49. Namatula loamy sand (upper-lying grey soil)											
0–12	98·9	72·0	17·7	1·5	6·6	0·7	..	6·90	3·9	2·0	0·4
12–40	97·3	73·3	17·4	1·6	6·6	0·5	..	5·80	1·0	1·4	0·3
40–64	95·3	62·8	15·8	2·3	17·2	0·9	..	5·20	0·8	1·6	0·3
70–130	50·5	46·5	19·5	5·0	25·5	2·3	..	5·65	0·9	2·5	0·6
Profile 3. Mtanana series (pallid soil)											
0–5	96·7	..	..	..	..	..	0·53	5·75	1·9	1·1	0·8
5–10	95·4	62·9	20·9	1·9	12·5	0·9	0·45	4·85	2·1	0·9	0·5
15–30	90·8	58·4	20·4	2·0	17·4	1·3	..	4·55	..	..	..
30–50	84·7	56·7	16·6	1·9	23·4	1·6	0·41	4·40	2·0	0·8	0·7
66–85	73·3	52·2	15·9	3·1	25·9	2·1	0·33	4·55	1·6	2·1	0·6

The present evidence suggests that these pallid soils form on similar mantle material to the red although in the above case the gneiss was more pegmatitic in character. Their somewhat pale colour seems due mainly to removal of iron from the soil under waterlogged conditions, or by long-continued leaching. In the western part of the area, which is drained by the river Kinyasungwe, the red soils predominate and the pallid soils, where present, are usually found on the crests of the ridges. Farther east the drainage has suffered from earth movements and the former valleys have silted up to form level mbugas. Here the pallid soils predominate, occupying the crests of all ridges and often extending all the way down the slope. In these circumstances it appears that red soils are formed only where denudation is active. Where denudation is slow there is time for the iron to be removed from the profile, sometimes to be deposited as concretionary ironstone just above the underlying rock, sometimes to be removed completely in the drainage water. An underlying layer of impervious rock, by causing temporary waterlogging, may be an accessory cause in the formation of these pallid soils but does not appear to be the main one.

The mbugas, mentioned above, may be several miles across and the alluvial filling 200–300 ft. thick. The following is an example of this type of soil under natural grassland with scattered thorn trees.

Profile 5. Lubiri loam (analyses Table 3)

0–10 cm. Dark grey loam (10 YR 4/1, dry). Friable, with many fibrous grass roots. Merging into

10–62 cm. Dark greyish-brown to brown loam (10 YR 4/2 at top, 10 YR 5/3 at base, dry). Fairly hard, massive structure, with a few fibrous roots.

62 cm. (+) Concretionary limestone.

TABLE 3

Analyses of Fine-earth Fractions

Horizon (cm.)	Fine earth as % of whole soil	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Moisture (%)	$CaCO_3$	Organic carbon (%)	pH	Exchangeable cations (m.e./100 g.)					Base exch. capacity (m.e./100 g.)
										Ca	Mg	Na	K	Mn	
Profile 5. Lubiri loam (dark grey mbuga soil)															
0–10	99·8	41·8	14·7	5·3	32·1	5·1	..	1·04	6·85	14·1	3·4	0·3	2·1	0·07	..
15–25	99·7	38·1	14·1	3·9	37·8	6·4	0·02	0·74	7·40	14·9	4·3	0·3	2·0	0·03	..
45–55	99·7	36·9	14·3	3·8	38·4	6·7	0·18	0·59	7·85	16·3	4·3	0·2	1·7	0·01	..
65–75	59·5	25·9	12·0	1·5	41·9	6·7	13·25	0·44	8·30	18·7	5·3	n.d.	1·6	n.d.	..
Profile 137. Naunga clay															
0–15	100·0	39·7	19·8	3·1	29·2	6·2	..	2·31	6·67	18·3	5·0	0·3	0·3	..	27·4
15–30	100·0	38·3	17·5	3·8	33·8	6·3	..	1·24	6·83	16·7	7·3	0·4	0·1	..	25·4
30–65	100·0	30·6	14·6	3·6	43·7	8·4	..	0·56	7·33	..	..	..	..	..	..
65–100	99·9	30·8	13·6	4·3	44·7	8·7	0·05	0·54	8·12	20·0	11·4	1·5	0·2	..	33·0
100–140	100·0	16·3	10·9	5·0	60·2	8·3	0·59	0·34	8·16	..	..	..	..	..	..
140–210	100·0	20·4	13·3	4·8	54·4	9·5	1·18	0·25	8·08	28·5	19·9	2·5	0·2	..	48·7

Nachingwea. Situation and physical features, &c.

Nachingwea is situated in the Southern Province (Lat. 10° 20′ S., Long. 38° 45′ E.) at a height of 1,500 ft. At Nachingwea itself, and for some miles to the west, the ground is gently undulating, with few hills. The country is considerably dissected with water-courses and there is evidence that it represents a former peneplain which has been elevated in geologically recent times, with resultant rejuvenation of the drainage. Namanga lies 4 miles to the north of Nachingwea and here, and also to the east of Nachingwea, there are several higher hills with exposed rock at their summits.

The annual rainfall is 33·7 in. (6-year average) mostly falling between mid-December and mid-April. Temperatures are a few degrees higher than at Kongwa and the humidity is also slightly higher.

The vegetation on soils with a sandy surface horizon is usually *miombo*, a deciduous woodland dominated by species of *Brachystegia* or *Pseudoberlina*. The ground flora is tall grass which is burnt annually in the dry season. Where the surface horizon is heavier there is usually a deciduous woodland of *Pterocarpus* sp. or *Ostryoderris* sp. associated with species of *Combretum* and tall grass or bamboo. This community is also swept by annual fires.

The Soils. The soils are all derived from Lower Basement Complex rocks, as at Kongwa. A dark amphibolite is a common constituent and a biotite gneiss outcrops fairly frequently. At Namanga, and in the eastern area, there are bands of quartz-granulite and of crystalline limestone. Near Nachingwea the higher ground is usually occupied by red loams or sandy loams, which have been named the Nachingwea series. (The word 'loams' is used in the sense that the feel of the soil when moist is similar to that of a loam from a temperate region. On drying, the soil becomes hard and massive. They probably can be considered as 'red latosols'.)

The soil represented by samples N. 27–29 (in Table 6) from 5 miles west of Nachingwea, is derived from amphibolite and it seems probable that this is true for the Nachingwea series generally. The following soil is another example from near Nachingwea under thin deciduous woodland with thick bamboo.

Profile 48. Nachingwea loam (analyses Table 2)

0–20 cm.	Dark brown loam (5 YR 3/3, dry). Friable, with weak crumb structure. Numerous fibrous roots (of bamboo?).
20–100 cm.	Dark red-brown sandy clay (2·5 YR 3/6, dry) with many coarse quartz grains. Hard and massive. Numerous fibrous roots throughout.
100–105 cm.	Line of subangular quartz stones (to 10 cm. diam.).
105–160 cm.	Dark red-brown sandy clay (2·5 YR 3/6, dry). Hard and massive, with much quartz gravel, ironstone, and MnO_2.
160–180 cm. (+)	Decomposing gneiss.

The level of the stone line and of the surface of the rotting rock undulates considerably.

Starting with these red soils a catenary succession of soils develops. Next down the slope is a brown or grey sandy loam with an orange subsoil (Nagaga series) which in turn passes into a grey sand with an orange subsoil (Nailala series). Both of these can probably be considered as tending towards 'yellow latosols'.

The following description is representative of the former series under well-grown miombo woodland with grass 4 to 5 ft. high.

Profile 16. Nagaga sandy loam (analyses Table 1)

0–7 cm.	Dark brown sandy loam (7·5 YR 4/2, dry) single grain structure. Many fibrous roots.
7–17 cm.	Brown sandy loam (7·5 YR 4/3, dry). Similar to above, merging into
17–30 cm.	Reddish-brown sandy clay (2·5 YR, 4/5, dry). Harder than above, becoming massive. Fewer fibrous roots.
30–90 cm.	Yellowish-red sandy clay (5 YR 5/6, dry). Massive, harder in upper layers than below perhaps because of drying out of upper layers. A few fibrous roots to 60 cm. depth.
90–150 cm.	Reddish-yellow clayey sand (5 YR 6/8, dry) with soft ferruginous concretions.
150–190 cm.	Yellow-brown clayey sand with red-brown, yellow, and white mottling. Some larger roots.
190–220 cm. (+)	Red-brown, yellow, and white mottled indurated clayey sand. Some earthy ironstone with MnO_2, rotten feldspar, and quartz gravel, i.e. decomposing gneiss.

Below these two series come sands with a clayey subsoil, i.e. with impeded drainage, and, finally, a range of grey or black loams and clays. In a few places to the west of Nachingwea, the Nachingwea red loam is replaced by shallow, sandier soils, brown or grey at the surface and with a yellowish-brown or light reddish-brown subsoil. These soils, from their frequent position on ridges and from the pattern of their occurrence—elongated strips parallel to the strike of the gneiss—appear to be associated with the outcrop of a parent rock different from that of the red soils. They are referred to in Table 6 (below) as 'upper-lying grey soils'. The biotite-gneiss often outcrops near areas of this soil. Samples N. 24–26 (reported in Table 6) from near N. 27–29, represents one of these soils derived from a pegmatite. Profile 49, Namatula series, from near profile 48, is probably another of this group, though the parent rock was not visible. This series is represented in the following description. The vegetation consists of thin miombo woodland, but trees individually are well grown. Grass 5 to 6 ft. high. Termite mounds are common.

Profile 49. Namatula loamy sand (analyses Table 2)

0–12 cm.	Dark grey loamy sand (10 YR 3/1, dry). Fairly friable, with many fibrous roots.
12–40 cm.	Pale brown loamy sand (10 YR 6/3, dry). Moderately hard and massive, but with some fibrous roots throughout.
40–64 cm.	Light yellow-brown very sandy clay (10 YR 6/4, dry), with pea-sized ironstone concretions. Moderately hard and massive.
64–70 cm.	Line of subangular quartz stones.
70–140 cm. (+)	Massive concretionary ironstone, slag-like.

Lower down the slope these soils give rise to a catena of sands, impeded sands and clays, not very different from the lower part of the

Nachingwea catena, though the width of the sand belt tends to be increased.

Around Namanga the individual soils do not differ appreciably from those at Nachingwea, but their proportions are different. The Nagaga sandy loams and sands and the valley loams and clays are more extensively developed, while the Nailala sands are reduced to narrow strips. This may be due to differences in the parent rock, but is more likely to be an effect of the hillier topography and the longer slopes on catena development. The mantle of weathered rock also tends to be deeper here, so that none of the profile pits reached rock at 6 ft. On Namanga hill itself there are outcrops of quartz-granulite and limestone.

Associated with the Nachingwea group of soils in this area is a black clay of the Naunga series which appears to have been developed on finer material brought down a water-course. It would appear, therefore, to have come from the same parent rock as the red soils higher up the slope, but to have developed under conditions of poor internal drainage. In this it would seem to correspond to van der Merwe's (1941) 'Subtropical Black Clays' better than many of the other mbuga soils in Tanganyika. Petrographic analyses of the rocks of the adjoining slopes showed that they were typical basement complex rocks. The following description exemplifies this series. Although the ground in the neighbourhood of the profile has a slope of about 1½ per cent., the profile is situated at the intersection of two shallow drainage-lines and so will receive a considerable amount of surface flood water after heavy rains.

Profile 137. Naunga sandy clay

Under natural grass, about 3 ft. high, with scattered trees and shrubs (analyses Table 3).

0–15 cm. Black sandy clay (2/0, dry), with weak angular blocky structure. Wide cracks (up to 4 cm.) on drying. Many fibrous roots. Merging into

15–30 cm. Black clay (5 YR 2/1, dry). Similar to above but few fibrous roots. Merging into

30–65 cm. Dark grey clay (4/0, dry) with brown mottling. Weak angular blocky structure. Cracking widely on drying. A few fibrous roots. Merging into

65–140 cm. Dark grey clay (4/0, dry), hard and massive. Cracking on drying. A few roots. Occasional carbonate concretions; a little concretionary ironstone (up to 3 mm.) with MnO_2. Sharply defined, over most of profile face, by a slightly undulating layer of petrified strap-like tree roots, from

140–210 cm. Grey clay (3/0, dry), cloddy. Irregular vertical and horizontal cracks spaced at about 10-cm. intervals. A few carbonate concretions.

The petrified tree roots, mentioned above, while retaining their original shape had largely been converted into iron oxide. The reason for their concentration in one horizon is not at all clear but is perhaps due to seasonal waterlogging, the increase in sodium ions or some similar adverse condition, in the horizons below.

Analyses of the Soils

Tables 1 to 3 give analyses of the fine earth fraction (< 2 mm.) of the samples. Organic carbon was determined by the Walkley and

Black method, and calculated on the basis of an 80 per cent. recovery. pH values were obtained using a glass electrode at 1:2·5 soil/water ratio. The exchangeable cations were estimated in a neutral ammonium acetate extract. The magnesium was determined in some cases colorimetrically using Titan Yellow, a method giving only approximate results.

The trend in pH values resembles that of some red-yellow and of most grey-brown podzolic soils, with a pronounced minimum in the middle layers, which is especially evident in those profiles in which bedrock was reached, e.g. P. 47 (cf. Kellogg and Davol, 1949). Here the pH of the weathering rock material is about 7. In the grey mbuga soil (P. 5) the pH is high throughout as would be expected. The exchangeable cation values present no remarkable features apart from the relatively high values for magnesium which is probably due to the hornblendic rocks.

As shown by the mechanical analyses there is generally a tendency to clay accumulation in the middle horizon of the soils, but the apparent decrease in clay content in the lower layers is in many cases due to cementation by iron oxides. The clay content of the surface soils is in general low, and the silt content characteristically low throughout.

Mineralogy of the Parent Rocks

One of the main types of rock giving rise to the mantle of debris from which the soils are derived is a gneiss or amphibolite rich in hornblende, with quartz-feldspar segregations and pegmatites. A sample of the rock from 5 miles west of Nachingwea (N. 29) had the following modal composition:

hornblende	69·5	scapolite	9·0
diopside	7·0	rutile	} 0·5
quartz	2·5	magnetite	
andesine	11·5	apatite	

This rock appears to correspond closely with the plagioclase-amphibolite described by Temperley (1938) as occurring in the Kongwa area. In another specimen (from the base of P. 47) there was present a small amount of biotite. An examination of one of the pegmatite veins that occur locally showed that it consisted mainly of coarse-grained microcline with local concentrations of brown biotite. Quartz was present to the extent of about 5 per cent.

Pieces of the weathering biotite-gneiss from under the shallower red soils (e.g. P. 47) were still moderately fresh, although stained rusty brown. The feldspar was partly clouded; the biotite was weathering yellowish, probably to hydrobiotite, but still gave a good optical figure; the hornblende was only slightly weathered. Under the pallid soils, however, there appeared to be a marked difference in the course of weathering. Pieces of weathering rock of pegmatitic nature from the base of P. 3 had a white patina on the outside, due mainly to quartz, while the core was rusty stained with some relatively fresh hornblende and feldspar. The change is a fairly sharp one with an intermediate yellowish layer from which the ferromagnesians have nearly all disappeared. It would seem that a reduction and dissolution of iron must take place fairly rapidly, the iron migrating, partly to the valleys and partly being deposited in the concretionary horizon of the soil (see also below, p. 14).

Mineralogy of the Sand Fractions

The fraction studied in detail was the international fine sand (0·2–0·02 mm.). The sands from the surface layers of the soils were remarkably clean and required no acid treatment. On the other hand, the sands from the basal layers, even from the mottled horizons, were heavily stained with iron oxides, and required treatment with *N*–HCl to render them clean enough for optical examination. Two fractions were separated using bromoform (s.g. 2·86), and the percentages of light and heavy minerals determined. The relative amounts of the mineral-species were determined by microscopic counts which were facilitated by the use of a mechanical stage. The distribution of minerals in the fine sands is shown in Table 4.

TABLE 4

Mineralogy of the Fine-sand Fractions

	Chamaye red loam P. 47	*Nachingwea red loam P. 48*		*Namatula grey sandy loam P. 49*	*Nachingwea red loam P. 17*		*Nagaga sandy loam P. 16*	
Soil and depth	0–12 cm.	0–20 cm.	100–160 cm.	0–12 cm.	0–10 cm.	100–150 cm.	0–10 cm.	175–220 cm.
Light minerals	96	94·8	93·4	97·2	94·6	97·4	98·7	93·4
Feldspars	20	0	9·5†	5·5	0	0	11	4·5†
Quartz	76	94·8	83·9	91·7	94·6	97·4	87·7	88·9
Heavy minerals*	4	5·2	6·6	2·8	5·4	2·6	1·3	6·6
Grains counted	368	612	536	488	532	1,003	1,037	371
Hornblende	52·4	53·1	88·0	52·5	16·0	1·1	5·3	1·5
Black Iron Ore	30·9	29·9	4·1	28·9	71·0	89·5	58·2	54·2
Kyanite	6·0	4·7	..	1·5	1·4	0·8	4·3	2·9
Almandine	1·4	2·3	8·1	0·6	1·9	0·5	..	0·4
Zircon	1·4	5·4	1·0	9·4	2·6	3·6	9·9	9·2
Rutile	1·6	1·6	..	2·0	0·4	0·9	1·2	1·8
Epidote	5·4	1·0	..	1·8	0·6	0·3	..	..
Staurolite	1·6	0·6	..	0·6	1·7	1·2	2·5	2·9
Sillimanite	..	0·5	..	2·6	4·4	2·4	18·9	26·2

* Fraction as % of fine sand; minerals as % of fraction.
† Decomposed.

In general the 'light fraction' (s.g. $< 2·86$) consisted of quartz with a varying admixture of feldspar which was sometimes partly decomposed. In the profiles from 5 miles west of Nachingwea (N. 27–29) the scapolite present in the rock had disappeared completely even from the basal soil layer.

The 'heavy fraction' (s.g. $> 2·86$) was made up principally of those minerals normally developed in metamorphic rocks of the gneissose type. The species noted include the following: amphibole, iron ores, garnet, kyanite, sillimanite, zircon, rutile, epidote, and staurolite. Small amounts of tourmaline and biotite were also present, but so sporadically that no significance could be assigned to them. Their occurrences are noted in the descriptions of the heavy mineral varieties that follow.

The *amphibole* is a dark green hornblende forming elongate 'platy' cleavage flakes with a vitreous lustre.

Iron ores. These vary from rounded to subhedral grains, often in the same separate. Indications are that most of the ore is magnetite (easily separated with a hand magnet); no leucoxene observed.

Garnet. A pink garnet varied considerably in quantity, but generally exhibited similar characteristics throughout: irregular to subrounded: even in surface layers the rounding process is incomplete. The surface of the grains is somewhat pitted and rough suggesting the beginning of weathering.

Kyanite. The quantity and quality of this mineral is a feature of the sands. It generally occurs in typical 'bladed' crystals with irregular terminations. Inclusions are uncommon.

Sillimanite. This occurs as prismatic grains, often slender, sometimes flattened, and showing some 'splitting' lengthwise. They often bear a superficial similarity to the kyanite, as they are less elongate than is usual for this mineral.

Zircon. A typical variety showing a good degree of roundness; prismatic grains are commonest, although some 'stumpy' grains are present. Inclusions are fairly common.

Rutile. Red, yellow, and amber coloured grains; some prismatic, but more commonly rounded.

Epidote. This mineral is characterized by its distinctive pleochroism from yellowish-green to colourless. Generally the grains are irregular, angular, and have a 'hackly' surface.

Staurolite. Generally occurs in poorly developed prismatic grains, brown and yellow in colour.

Tourmaline. A dark brown, very strongly pleochroic variety was noted in P. 16 and P. 17 in very minor amounts.

Biotite. In the sands of P. 16 a biotite of medium-brown colour was found in small quantity.

Although specimens of the underlying rock have been available only from one or two of the profiles, the soils from Kongwa and Nachingwea would appear to have been derived from rocks of approximately the same composition, namely the amphibolites described above. In contrast, the two soils from Namanga (P. 16 and 17), in particular the lower-lying grey soil (P. 16), appear to have been formed largely from the weathering products of a gneiss containing a fair amount of sillimanite. The ferromagnesian minerals show a low stability to weathering, and it is only in the vicinity of the weathering rock, or when the soils are shallow, that an appreciable amount of these minerals are present. Even in the basal layer of P. 48 and N. 27–28, where the samples are from near the rock, the ferromagnesians have decreased from about 70 per cent. in the rock to about 5 per cent. in the soil. The diopside in the amphibolite of a red soil profile N. 27–29 has disappeared completely in the soil and the hornblende has been reduced to 2–3 per cent. The latter, however, usually forms the main part of the 'heavy fraction' of the red soils. The iron ore is present in large amounts and may form nearly 90 per cent. of the 'heavies'. The somewhat wide variations in the hornblende and iron ore percentages do not necessarily have much significance, as the gneisses are not homogeneous even over a small area.

Composition of the Clay Fraction

The amounts of the clay fractions ($< 2\mu$ and $< 1\mu$) separated in the course of mechanical analysis (Table 5) indicate that the clay is in general below 1μ e.s.d. and this is borne out by the electron micrographs of

TABLE 5

Composition of Clay Fraction as percentage of Ignited Clay

	Profile 3. Pallid soil			*Profile 47. Red loam*				*Profile 5. Lubiri loam*	
Method of dispersion	*International*			*Puri*				*International*	
Horizon	*0–10 cm.*†		*30–50 cm.**	*0–10 cm.*†		*45–55 cm.*†		*0–10 cm.**	*45–55 cm.**
Particle size	$< 1\mu$	$1–2\mu$	$< 1\mu$	$< 1\mu$	$1–2\mu$	$< 1\mu$	$1–2\mu$	$< 1\mu$	$< 1\mu$
% of total clay ($< 2\mu$)	95·5	4·5	98·4	81·7	18·3	91·2	8·8	95·5	96·6
SiO_2	50·2	59·3	51·7	46·7	47·3	47·9	47·9	58·2	57·7
Al_2O_3	34·6	20·4	39·3	35·6	34·4	36·4	34·8	26·8	28·1
Fe_2O_3	9·9	10·6	7·9	12·8	13·5	11·6	12·3	7·3	7·3
TiO_2	1·5	2·1	1·17	1·4	1·6	1·1	1·4	1·15	1·22
P_2O_5	0·4	0·3	n.d.	0·3	0·3	0·2	0·2	not determined	
CaO	0·02	trace	0·01	0·02	0·01	nil	nil	0·50	0·59
MgO	0·68	0·33	0·49	0·58	0·63	0·50	0·7	1·93	1·96
Mn_2O_3	0·03	0·03	0·02	trace	trace	trace	trace	0·051	0·065
K_2O	not determined		1·14		not determined			3·0	3·0
Na_2O	”	”	$< 0·3$		”	”		$< 0·3$	$< 0·3$
Molecular ratios									
SiO_2/Al_2O_3	2·47	4·96	2·24	2·28	2·35	2·24	2·34	3·68	3·52
SiO_2/R_2O_3	2·09	3·72	1·98	1·81	1·87	1·86	1·91	3·14	2·99
Al_2O_3/Fe_2O_3	5·49	3·01	7·81	4·36	3·99	4·93	4·45	5·77	6·03

* Analysis by C. L. Bascomb and H. H. Le Riche. † Analysis by B. Anderson.

Plate I. From these pictures it is evident that the majority of the platy crystallites are about 0·1 μ in diameter. The chemical composition of selected clay samples is given in Table 5.

There is little change in the composition of the clay fraction within each profile, although some differences will be noted, and it appears that each of the main soil groups described above can be characterized by the clay minerals present. This is shown in Table 6 which is based on X-ray analysis.

TABLE 6

Composition of Soil Clays

	Kaolinite	*Fire-clay mineral (Disordered Kaolin)*	*Illite*	*Montmorillonite*	*(Hydrous) iron oxides*
1. Red Loams:					
P. 2	+	..	[+]	..	+
P. 47	+	..	(+)	..	+
P. 17	+	..	[+]	..	+
P. 48	+	..	(+)	..	+
N. 27–29	+	..	(+)	..	+
2. Pallid Soil:					
P. 3	(?)	+	+	..	(+)
3. Upper-Lying Grey Soils:					
P. 49	(+)	+	..	..	..
N. 24–25	+	(+)	+	..	..
4. Low-Lying Grey Soil:					
P. 16	..	+	..	..	..
5. Black Soils:					
P. 137	+	..	..	+	..
P. 5	(+)	..	+	..	..

\+ Dominant or in moderate amount.
[+] Probably present.
(+) Present in small amount.
(?) Doubtfully present.

The red loams have a fine-grained kaolinite as the dominant mineral, associated with some haematite (up to 10 per cent.) and occasionally minor amounts of goethite and illite. The pallid and grey soils contain an illite, in addition to a kaolin, in moderate amounts and also a little haematite and some quartz. P. 3, an upland pallid soil, contains some halloysitic material as can be seen from the electron micrograph (Plate II A), and there is also a mineral giving a diffraction line at about 13·8 Å. The grey soils of the lower position in the catena at Nachingwea show a kaolin, a small amount of illite, and no iron oxides. The dark grey mbuga soil (P. 5) from Kongwa contained a dioctrahedral illite with a little kaolin. The black valley soil from Nachingwea (P. 137), which is essentially non-calcareous, showed a montmorillonoid with some 20–30 per cent. kaolin. The montmorillonoid belonged to the intermediate montmorillonite-beidellite group.

It has been possible to get an idea of the initial stages of weathering of the gneisses from the examination of clay separated from the pieces of weathering rock described above: one from under a red loam (near

P. 2) and the other from the base of the pallid soil (P. 3). The results are shown in Table 7.

TABLE 7

Clay Minerals from Weathering Rocks

Clay minerals	*Under red loam*	*Under pallid soil*
Montmorillonoid .	trace	+
Mica . . .	+	++
Kaolin . . .	+++	+
Goethite . .	(+)	(+)
Haematite . .	(+)	(+)
Anatase . .	trace	trace
Gibbsite . .	?	..
Quartz . . .	..	trace
Feldspar . .	..	present

In the case of the red loam it is evident that the primary rock minerals, e.g. ferromagnesians and feldspars, weather in the main straight to kaolinite, mica, and iron oxides. The evidence for gibbsite is doubtful and the amount present can only be quite small. There is no trace of boehmite. It may be that the apparent absence of basic feldspars precludes the occurrence of hydrous aluminium oxides in any quantity.

The contrast of the course of weathering under the pallid soil is quite striking, the amount of montmorillonite in this case possibly being of the order of 20–30 per cent., the mica content likewise being much higher. Milne (1947, p. 196) suggested in connexion with the 'anomalous grey soils' that 'petrographic examination may reveal a mineral composition that would direct the course of weathering towards the production of a water-retentive "fat" clay. . . .' The difference between the fresh rock materials in the present two cases is not such as to suggest that montmorillonite would form preferentially in the pallid soil and it must be assumed that the cause is the sluggish drainage as suggested earlier for the difference in morphology. This result may be compared with those obtained by Nye (1955) in his study of a Nigerian catenary sequence.

While there is no trace at all of montmorillonite even in the lowest soil layers of the red loams, a small amount probably persists in the pallid soil (P. 3), although the chemical analysis does not suggest that there can be much. Mica is, however, quite a prominent constituent even in the surface layer of this profile. This mineral is most prominent in the soil (N. 24–25) overlying the rock with most feldspar, and it is probable that the latter is the source of the illite constituents with the necessary magnesium and iron coming from the ferromagnesians present. The clay from the lowest layer of this soil, i.e. adjoining the rock, gave somewhat broader diffraction lines than the clay from the topsoil, suggesting an improvement in crystallinity in the surface layers.

Although the clays from the surface and lowest layers of the pallid soil (P. 3) also showed this difference in diffraction pattern to a slight extent, the electron micrograph (Plate II A) and the X-ray diagram show that the clay does not appear to be particularly well crystallized even in the surface layer. The shapes of the particles are rather indefinite and few hexagons are to be seen. The rather 'sooty' appearance of this clay is presumably due to carbonaceous matter since drastic treatment with boiling hydrogen peroxide cleaned it up fairly well. The majority of the red and grey soil clays gave electron micrographs like that of Plate I A, indicating, apparently, a well-crystallized mineral. In these photographs the kaolin particles appear to be co-sedimented in preparation with larger platelets (Plate I B). The degree of orientation of the small plates on the large is marked, but whether or not there is any genetic connexion between them is not known. The larger particles are assumed to be illite since they are commoner in the clays showing most of that constituent, but it has proved impossible to separate them for positive identification. They may, of course, in part represent strongly cemented aggregates or intergrowths of the smaller particles.

In spite of the general similarity of all the kaolins under the electron microscope the X-ray diffraction diagrams show that they can be differentiated into kaolinite and the disordered kaolin (Pugu D) of Robertson, Brindley, and Mackenzie (1954) by the band at 4·47 tailing off to higher angles (Plate II B). The well-drained soils (e.g. N. 27, &c.) appear to consist largely of kaolinite, whereas those with evidence of poor drainage (e.g. P. 16, &c.) contain predominantly a disordered kaolin. The white mottles in the lower layers of P. 16 give an apparently very pure specimen of this variety. It is evident that although such a difference may be reflected in the electron micrographs as shown by Robertson *et al.*, this need not be the case. The fact that in the present instance the grey lower-lying soils (P. 16) seem generally to contain the disordered kaolin may have a bearing on the origin of the Pugu D material which is described by these workers as a marine deposit. It is likely that in normal erosion the lower position soils would contribute a considerable proportion of the clay carried by streams to the sea on account of the more frequent flooding that they experience and thus contribute to the accumulation of a disordered kaolin deposit.

Differential thermal analysis of a selection of the clays gave curves corresponding to the minerals identified by X-rays, except for the illite in the pallid soil, P. 3, which did not register on the thermal diagram, presumably due to its lower sensitivity. The red and pallid soils give a thermogram approximating to that of a kaolin, with a slight skewness on the 600° peak possibly due to the small particle size. A broad exothermic peak about 400° seems due to sesquioxides and organic matter for it disappears after hydrosulphite treatment of the clay. In none of the thermal analyses made was any sign of gibbsite or boehmite noted, nor did these show up on the X-ray diagrams. The illite of the grey calcareous mbuga soil (P. 5) gives a fairly characteristic thermogram with a high moisture peak.

For an examination of the chemical composition of the clay two fractions, viz. $1-2\,\mu$ and $< 1\,\mu$ e.s.d. were separated in some cases by repeated decantation after pretreatment by the International method for mechanical analysis and the Puri carbonate method (Puri, 1935); the latter did not appear to give complete dispersion.

The analyses given in Table 5 show that the coarser clay fraction ($1-2\,\mu$) contains more silica than the fine clay. This is almost certainly due to admixture of quartz, for this forms the main constituent of most of the silts and extends down into the coarser clay. The X-ray results described above, which were obtained on clay that would be less than $1{\cdot}4\,\mu$ e.s.d., show very little quartz. In general the molecular ratios for the red clays agree with the mineralogical results, i.e. the silica-alumina ratios are in general close to 2. The clays are thus essentially kaolins, with more or less illite and iron oxides, but with no suggestion of any appreciable amount of free alumina. Even in the case of P. 17 (0–10 cm.), the clay of which has a silica/alumina ratio of 1·59, no evidence for crystalline hydrous aluminium oxides was obtained.

Discussion

The profiles described above are typical of large areas of soils over basement-complex rocks in Tanganyika and probably elsewhere in Africa. The examples examined form catenary sequences from the shallow red loams and pallid soils on the upper slopes and ridges, through the deeper red loams of the middle slopes to the grey soils of the lower slopes and the dark grey clays of the mbugas. The parent rock, while in general an amphibolite, varies sufficiently locally to be reflected in the appearance of some of the shallower soils. In the main, however, since the soils are formed on a mantle, or pedisediment, there has been much mixing of the weathered products and it is only by an examination of the resistant heavy minerals that an indication of the probable source rocks is obtained.

The sand mineralogy shows that in the main the soils have reached a late stage in the weathering cycle in that only minor amounts of the more complex silicates occur, in particular the feldspars, except where they are shallow (e.g. P. 47). In two cases the feldspar, although present in moderate amount, was highly decomposed. Of the heavy minerals hornblende, as might be expected, is the dominant silicate although other more resistant minerals may sometimes be abundant, e.g. sillimanite.

From the rock specimens examined the rate of decomposition of the primary minerals is evidently fairly rapid; at short distances from the rock the more readily decomposable substances, e.g. scapolite, have completely disappeared, and even hornblende is reduced to quite small amounts. This is particularly marked in the case of the pallid soil P. 3 (above, p. 3). The advance of the 'weathering front', i.e. the zone of penetration of water and air into the rock, appears, however, to be very slow.

It has not been possible to follow in detail the alteration of the various weathering minerals, although biotite apparently goes through a hydrobiotite stage in breaking down. The other minerals presumably provide the illite and the dominant kaolins, together with the iron oxides. Illite appears to persist in variable, but generally small amounts into the surface soils even in the deeper mantle material. In the initial weathering of the parent rocks, even under the red loams, small amounts of a montmorillonoid are formed, but rapidly disappear. Under the pallid soil, however, a montmorillonoid is formed in moderate amounts and persists in the soil to some extent. This difference from the red soils must be ascribed to the poorer drainage in the pallid soil. Little information seems to have been published on the clay mineralogy of soils from rocks comparable with the Kongwa amphibolites. For the Piedmont region of the United States Alexander, Hendricks, and Faust (1942) have shown that somewhat more feldspathic (andesine) amphibolites than ours can give rise to kaolin and gibbsite in the Davidson soil series, the latter mineral persisting into the surface soil. The scapolite in the Kongwa rocks could, however, be considered simply as a more readily decomposable feldspar and thus expected to produce gibbsite if the other conditions were favourable, which apparently they were not. Why this is so is not at all clear. It could, of course, be that the rainfall is inadequate, following the relationship shown by Van der Merwe and Heystek (1952) for South African soils. There, apparently, little or no gibbsite occurred if the annual rainfall was less than about 30 in.

Although it has been pointed out above that the disordered kaolin is more characteristic of the poorly drained soils (excluding mbugas) and kaolinite of the well-drained red loams, it is not suggested that this is generally true, for not enough evidence is yet available.

In the case of the mbuga and black valley soils, it is evident that they are influenced to some extent by their 'parent material'. In general it seems that, if they represent the lowest point of pedisedimentation, they are probably characterized by the dominance of a montmorillonoid in the clay fraction (e.g. P. 137). If, on the other hand, as seems fairly common in parts of East Africa, they are derived from old lake sediments, they inherit the clay minerals characteristic of the sediment (e.g. P. 5, above).

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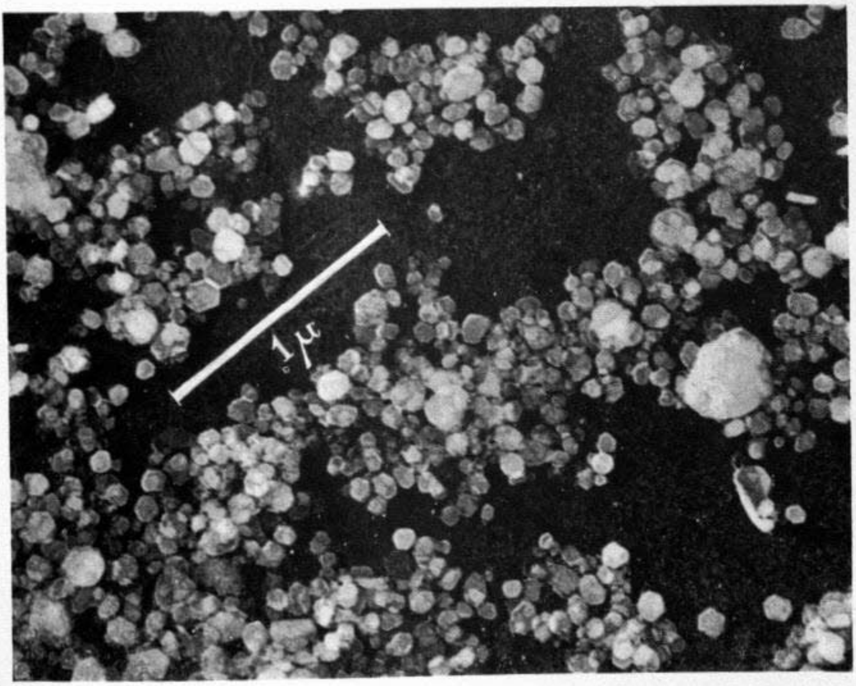
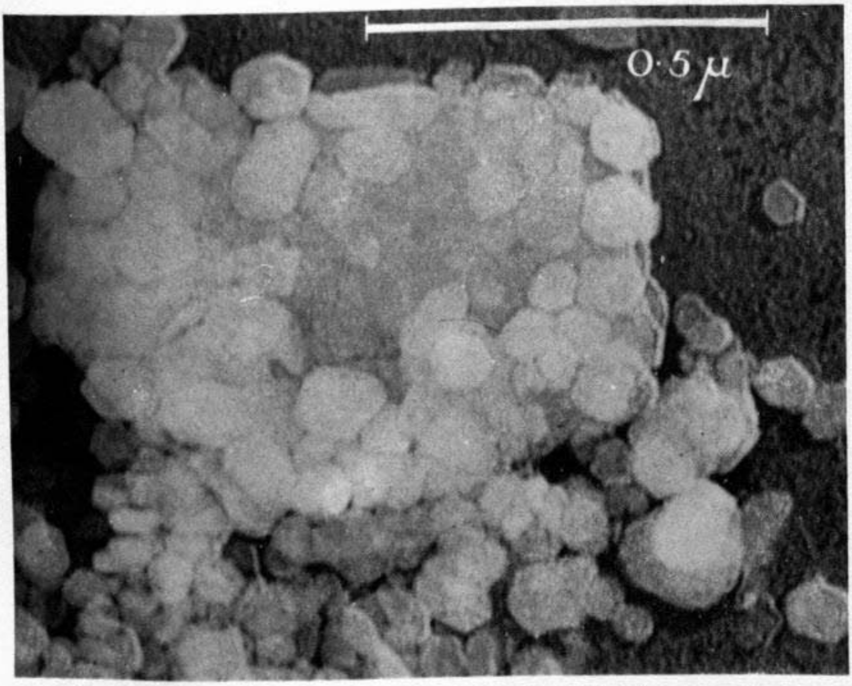
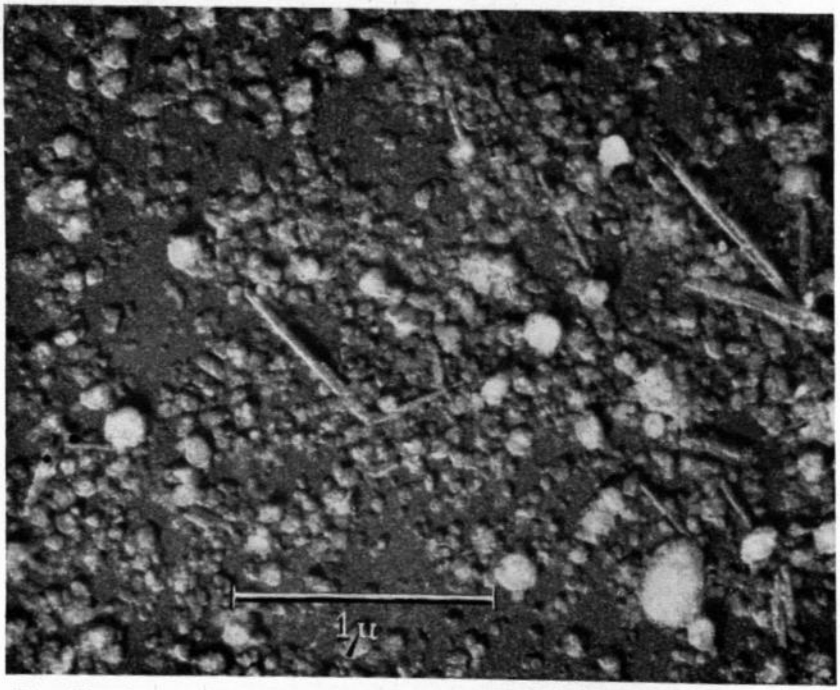


I A. Kaolinite from red loam soil (P. 48)

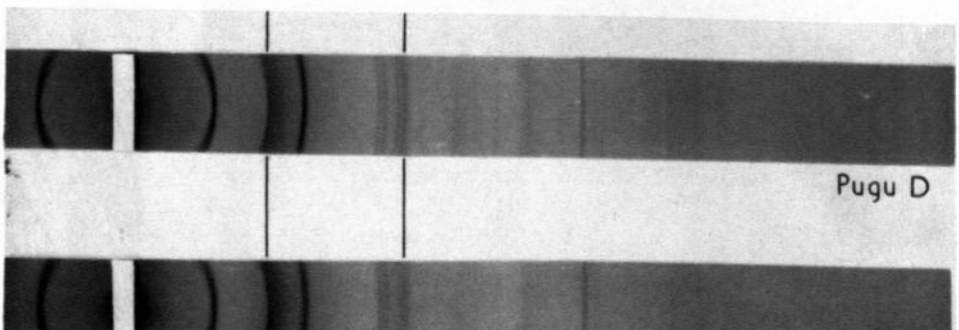


I B. Enlargement of aggregate of mica (?) and kaolinite (P. 48)

A. MUIR, B. ANDERSON, AND I. STEPHEN—PLATE I



II A. Clay from pallid soil (P. 3) showing halloysite rods with illite and kaolin



II B. X-ray photographs of soil clays showing mainly disordered kaolin (P. 16) and kaolinite (N. 27), with specimen of Pugu D for comparison. Particle size in P. 16 and N. 27 *ca.* 0·1–0·2 μ, in Pugu D, $< 2\,\mu$

A. MUIR, B. ANDERSON, AND I. STEPHEN—PLATE II