R. W. Borden

SOILS OF TANGANYIKA

By B. ANDERSON
of the
RESEARCH DIVISION

MINISTRY OF AGRICULTURE
BULLETIN No. 16
1963
Price: Shs. 3/50

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GENERAL PRINCIPLES

Soil is the surface layer of the earth suitable for the growth of plants. Its origin (except in the case of peat) is the rock which constitutes the earth's crust. This may be a solid rock such as granite or an unconsolidated sediment such as a raised beach. In the conversion of rock into soil two processes can be distinguished, weathering and profile development.

(a) Weathering.

The unaltered mineral grains of which a rock is constituted will not support plant growth. Plants absorb their nutrients in solution and so cannot grow until part of the rock has been made soluble. The process of solution is called weathering and is brought about by the action of percolating water, containing oxygen, carbon dioxide and possibly other agents in solution. The more easily attacked mineral grains of the rock are decomposed and a solid rock (e.g., granite) becomes softened, allowing increased penetration of percolating water.

Most rocks contain a variety of minerals and during weathering these release into solution the elements (about ten in number) which the plant needs to obtain from the soil. The weathered rock is the "parent material" from which a soil is produced by profile development. It is useful to distinguish between this term and "parent rock". The latter is the original unweathered rock, whether massive or unconsolidated. "Parent material" is the product of the weathering processes and is the material in which development of a soil profile occurs. The process just described is known as chemical weathering and is the most important type of weathering in Tanganyika.

Where bare rock is exposed on hill-tops the alternate heating during the day and cooling at night gradually breaks up the solid rock into small fragments which fall to the foot of the rock outcrop. This is an example of physical weathering, but it is a minor factor in soil formation in this country. In some other parts of the world physical weathering is more important than chemical. In deserts we have abrasion by wind-blown sand and under freezing conditions the action of frost and moving ice-sheets slowly breaks down solid rock into small grains or a fine powder. In dry conditions or at low temperatures chemical action is very slight.

(b) Profile Development.

The top three or four feet of the weathered material are usually much changed by the action of plant roots, fungi, bacteria and the soil fauna. Dead plant material is rotted by fungi and bacteria or consumed by soil fauna (particularly termites in the tropics). In these processes much of the original plant material is converted into carbon dioxide and water but a portion is changed into the insoluble organic substances which make up the organic matter of the soil. These processes take place chiefly on the surface and in the top few inches so that most of the organic matter is found in this zone.

The weathered material is also modified by rainwater. Where the rainfall is fairly high, say over 25 inches a year, there is usually sufficient percolation to carry away the soluble products of rock weathering and plant decomposition into the rivers. As a result the soil tends to become acid. Where, however, the rainfall is low, say less than 20 inches a year, the soluble products tend to accumulate in the subsoil. In very dry climates salts may even crystallize on the surface. Under conditions of impeded drainage iron concretions may form in the subsoil.

All these changes affect chiefly the top three or four feet of the weathered material and produce a "soil profile" consisting of successive "horizons", one below the other and all roughly parallel with the land surface. The horizons are distinguished from one another by their differing contents of organic matter, differing colours, differing proportions of sand and clay, differences in acidity and by the presence or absence of concretions, salts, etc. It is by the characters of their profiles that soils are distinguished from one another.

Since profile development is restricted to the surface while weathering is not, the latter has, over much of tropical Africa, gone deeper than profile development and is currently taking place much below the depth of the "soil" (in the usual sense of the word). The depth to which weathering can penetrate depends on the resistance of the solid rock and the amount of water reaching the weathering front. Generally, in Tanganyika, this front lies at a depth of 10 to 100 feet below ground level.

As the land surface is lowered by erosion, the weathering front can penetrate to greater depths. One can imagine the weathering front advancing into the earth at a depth of 20 feet (for example) below the surface and, so long as the climate and erosion rate remain constant, the soil profile following 20 feet behind.

If erosion is slow, as in flattish country, there will be an interval of several million years between the time a given mineral grain in the rock is first reached by the weathering front and the time it is incorporated in the profile.

Most Tanganyika soils have been formed under the conditions described in the previous three paragraphs. In places, however, the land surface has, within the last few thousand years, been covered by lava flows, deposits of volcanic ash or by alluvial deposits. Once such materials have been deposited the forces both of weathering and erosion begin to act simultaneously on them. In studying such soils it is not possible to separate the two processes into weathering and profile development. For examble, clay may be forming throughout the soil profile; and phosphate will become available to plants both by decomposition of plant remains and by weathering of phosphate-containing minerals.

A similar situation, i.e., profile development occurring side by side with weathering, is found on older rock formations when the rate of erosion is particularly rapid. The land surface may be lowered so rapidly that the zone of soil formation catches up with the weathering zone. Profile development then proceeds in only partly-weathered rock.

Under a cool climate chemical weathering is much slower and the weathering front often does not get ahead of the zone of profile development; weathering and profile development then take place together.

A consequence of the separation of weathering from profile development, with weathering preceding profile development by possibly several million years, is that the climate or site drainage may change in the interval. The characters produced in a soil by the processes of profile development will have been produced in the last hundred or so years, i.e., under a climate similar if not identical with that of today. But the profile may inherit characters, e.g., iron oxide deposits, produced during weathering some millions of years ago when the climate and drainage were very different.

In the profile descriptions given in this Bulletin the units of measurement are those of the soil worker who examined the particular profile. Most workers have used the metric system. But for comparative purposes it can be assumed that 15 cm. = 6 inches.

The methods of analysis used by different laboratories have not always been stated in their reports. Most pH values are for a water suspension (commonly soil : water 1 : 2·5). "Organic matter" figures have been obtained by multiplying the organic carbon figure by 1·72. "Exchangeable" values have mostly been obtained by extraction with neutral ammonium acetate. A variety of reagents have been used to extract phosphorus so that figures obtained by different laboratories are unfortunately not comparable.

SCHEME OF CLASSIFICATION

There is not yet any general agreement about the classification of tropical soils, nor even about the naming of the more important groups. The following classification has been drawn up to include the more important Tanganyikan soils known to the writer or described in various publications and reports which he has been able to consult.

While the scheme as a whole is the reponsibility of the writer many of the groupings are those of previous workers, some in Tanganyika and others in other tropical countries. The primary division into well-drained and poorly-drained soils is adopted as being important for agricultural purposes.

Well-drained soils.

A. Non-laterised red and yellowish soils.
   (1) On metamorphic rocks and granites.
   (2) On sandy parent material.
   (3) On grits.
   (4) On volcanic ash and lava.
   (5) On calcareous material.

B. Laterised red and yellowish soils.
   (1) On metamorphic rocks and granites.
   (2) On volcanic ash and lava.

C. Brown soils of high base status.

D. Rendzinas.

E. Immature soils.

More or less badly-drained soils.

F. Tropical black earths.
   (1) Calcareous.
   (2) Non-calcareous.

G. Dark clays on calcareous sediments.

H. Leached ferruginous soils.

I. Leached sands.

J. Alluvial soils.
   (1) Young alluvial soils.
   (2) Old alluvial soils.

K. Saline and alkali soils.
   (1) Saline, non-alkaline.
   (2) Non-saline, alkaline.
   (3) Saline-alkaline.

L. Hardpan soils.

M. Peat.

Miscellaneous.

N. Palaeosols (ancient soils).

CHAPTER 2.—NON-LATERISED RED AND YELLOWISH SOILS

These are formed in well-drained situations throughout Tanganyika and on many different parent materials. They occur from sea-level up to 5,000 or 6,000 feet altitude. They can be called the zonal soil for all but the driest and the most elevated parts of Tanganyika. Their colour ranges from red through reddish-brown and orange to yellowish brown; this is the sub-soil colour, uninfluenced by organic matter.

The colours are due to iron oxides in various states of hydration. The colour develops in the weathering zone and reflects moisture conditions in that zone. It is red when this zone is subject to drying out and orange or yellowish-brown under moister conditions. Once developed in the weathering zone the colour does not seem to be much affected later by different conditions in the biological zone.

The division of the red soils into laterised and non-laterised groups follows Milne and his associates (1936) in their soil map of East Africa. The non-laterised red soils have been called Low-humic Red Earths and Low-humic Latosols by other classifiers. In the soil map in the 1956 edition of the *Tanganyika Atlas* the non-laterised red and yellowish soils are described as "Generally red soils with friable clay (Kaolinite type)".

Plate 1.—Groundnuts on a Non-laterised Red Earth at Nachingwea. Contour planting and conservation terraces are necessary on these erodible soils

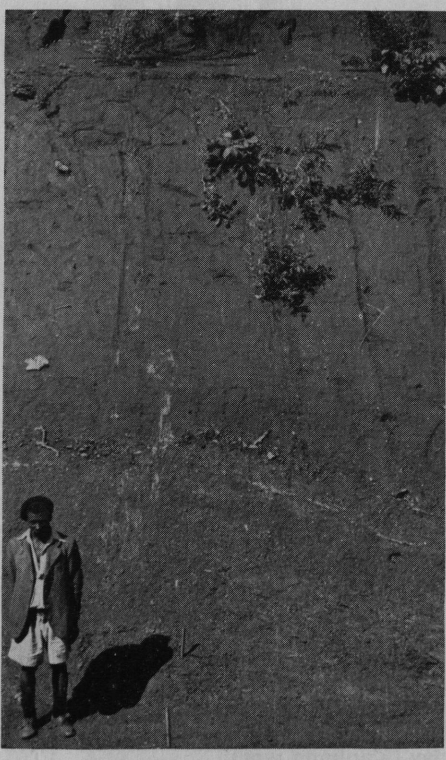

Plate 2.—A Non-laterised Red Earth. Note stone-line above weathered rock

Plate 3.—A Laterised Red Earth in the Pare Mountains

The term "non-laterised" means that the clay fraction of the soil has a ratio of silica to iron and aluminium oxides of about 2. Since the clay mineral is kaolinite, which itself has a ratio of 2, the non-laterised red soils cannot have much free iron or aluminium oxides associated with the kaolinite. Analyses show a few per cent of iron oxides and no aluminium oxides. "Laterised" soils have considerable quantities of free iron and aluminium oxides associated with the kaolinite in the clay fraction and therefore a ratio well below 2 (often below 1).

Both the laterised and non-laterised soils only form in acid material which means that the rainfall must be sufficient to give at least occasional leaching throughout the soil and the upper weathering zone. In the non-laterised soils the pH in the upper weathering zone is often about 6. The zone of biological activity, i.e., the soil proper, is often more acid, with the minimum pH (maximum acidity) at a depth of 1½ to 2 feet below the surface. This is due to a combination of the leaching effect of drainage water, carrying calcium and other bases downwards, and the withdrawal of bases by the plant roots. These factors can reduce the pH of the sub-soil to as low as 4, though about 5 is more common. The bases abstracted by the roots are returned to the surface in the leaf fall. There is therefore a higher pH in the organic matter horizon at the surface, due to the liberation of these bases when the leaves decay.

The amount of organic matter in the non-laterised soils is low, usually less than 3 per cent. The colour of this organic horizon varies from red-brown to very dark brown depending on the amount of organic matter and also on the presence or absence of carbon particles from grass fires. On sites where there is considerable sheet erosion, e.g. the pediments of rocky hills, organic material is washed away before much of it can be incorporated into the soil. The top-soil at such sites is often a bright red and strongly acid.

Deep soils, where the top of the weathering zone is 6 feet or more below the ground surface, tend to be more acid than shallow soils. This is probably because the reserve of nutrients in the deep soils is beyond the root range of most of the natural vegetation; in the shallow soils the roots can tap the reserves in the partly weathered rock and by doing so bring further calcium, potassium, etc., into the nutrient cycle in the upper soil horizons. This tapping of the weathering rock is probably one of the reasons for the improving effects of bush fallows.

The characteristics just described are those of all non-laterised red (and yellowish) soils. Other characteristics depend on the nature of the parent rock. Five important variants due to differences in the parent rock are described below. No doubt other variants exist but they are not believed to be common.

(1) On Metamorphic Rocks and Granites.

This is probably the commonest non-laterised red soil in Tanganyika.

Description.

Even within this group there can be considerable differences in soil profile, due chiefly to the varying ways in which different metamorphic rocks and granites have weathered.

Rocks rich in weatherable minerals are the hornblende gneisses and the amphibolites. These tend to weather deeply, giving bright red soils. Owing to the deep weathering they are usually strongly acid in the subsoil, as explained earlier. A soil developed on hornblende gneiss is illustrated in Plate 2.

The topsoil is usually a loam or sandy loam with 15 to 25 per cent of clay and about 2 per cent of organic matter. There is usually a weak crumb structure which is easily destroyed by raindrop impact if the soil is cultivated. On subsequent drying a crust tends to form. Preservation of the structure of soils under cultivation is helped by not ploughing in weeds and stubble any earlier than is necessary for the preparation for the following crop, so that the soil surface is to some extent protected during the first rains.

The humic horizon does not usually extend much below 6 inches depth and below this the soil is red, with a cloddy or massive structure. Cracks forming on drying are narrow and relatively far apart; this is a result of the low shrinkage of kaolinitic clay on drying.

The clay content increases with depth and may reach 40 or 50 per cent at a depth of a foot or so. In some soils there is a horizon of maximum compaction at a depth of about a foot. Evidence suggests that this is associated with the movement of clay particles under the influence of percolating water and the formation of clay films when the soil dries. This compacted horizon has been noted at Kongwa and Nachingwea and probably occurs elsewhere. It is sometimes thought to be a plough pan and it may perhaps be aggravated by the passage of implements, but it can be found in soils which have never been mechanically cultivated.

Below 18 inches the soil often becomes more friable. The proportion of clay particles does not decrease but the particles seem to form stable aggregates and to resist compaction.

At a depth of 6 feet or so the weathering rock is reached. This is usually completely weathered rock in the upper part and allows free entry of rain-water. There is therefore rarely any waterlogging in the subsoil and accordingly little or no mottling and little formation of ironstone concretions.

If the parent rock contains quartz veins these break up when the rock is weathered and the fragments collect just above the weathering zone as a *stone-line*. Mineral particles above the stone-line have been moved about by soil fauna, by the swelling and contraction of the soil on wetting and drying and by soil creep on slopes. Particles below the stone-line may be chemically changed from their original state in the rock but have not been moved appreciably.

The deep soils on easily weathered rocks, which have just been described, are contrasted with the shallower reddish soils which develop on acid gneisses.

Acid gneisses contain a high proportion of minerals resistant to weathering, particularly quartz. A weathered acid gneiss is usually less pervious to water than the more basic gneisses when weathered. Percolating water can pass into the weathered acid gneiss less rapidly than it can drain through the overlying soil. Consequently perched water tables are liable to form at the top of the weathering zone during wet weather.

The resultant soil is reddish-brown rather than red and because of the high quartz content of the acid gneiss is sandier in both topsoil and subsoil than a soil derived from basic gneiss. The topsoil, with about 10 per cent of clay and 1 per cent or so of organic matter has a very weak crumb structure and easily forms crusts.

These soils from the so-called "acid" rocks are often less acid in the subsoil than those from more basic rocks, probably because the upper surface of the weathering rock is within root range of many trees which can draw on the bases not yet leached from the rock. Whether annual crops are sufficiently deep rooting to continue to draw on this source is doubtful.

As already explained, the presence of rock resistant to percolation at no great depth results in temporary waterlogging of the upper weathering zone during wet weather. Under these conditions iron tends to go into solution in the waterlogged zone and is precipitated as concretionary nodules when the water later evaporates. The depth of this concretionary horizon is often about 3 feet. Since the water will have tended to move downhill before evaporating, this precipitation may not all take place at the site of solution but there is usually some precipitation of iron even in the highest positions on the slope. Under Tanganyika conditions the concretions are usually separate rounded bodies up to about half an inch in diameter. In particularly favourable sites, e.g. on lower slopes where seepage water from above tends to accumulate, massive slag-like sheets of ironstone may form in the subsoil. However in such cases the overlying soil is not usually a Red Earth.

Granites give rise to soils similar to the gneisses. At Urambo the red soils on granite are deep but have a considerable amount of concretionary ironstone. They are therefore somewhat intermediate between the red soils derived from basic gneiss and those derived from acid gneiss. Various profiles showed between 3 and 10 feet of red soil overlying a concretionary horizon usually 4 or 5 feet thick (but occasionally up to 10 feet thick). Below this was the weathering rock.

Of course, depth of weathering is dependent on the amount of water available and on the time for which the process has been continuing. In dry areas and in areas of young topography it is quite possible that even easily weatherable rocks may not be weathered deeply. Similarly under a high rainfall even the basic gneisses may suffer from seasonal waterlogging and develop concretionary horizons.

The depth of soil overlying the concretionary horizon is likewise affected by differences in climate and topography. Thus around Ukiriguru there are reddish-brown soils on the upper slopes of hills surmounted by granite tors (or kopjes). Natural erosion is fairly rapid in such situations and the soils do not have time to develop to the maturity of the Urambo soils. On these Ukiriguru hillsides the soil (known locally as "matongo") consists of quite a shallow horizon—often as little as 2 feet in thickness—of reddish-brown loamy coarse sand overlying weathering granite boulders. The boulders may perhaps be the relics of solid granite country rock which has weathered spheroidally.

South of Ukiriguru, but still in Usukuma, there are heavier red soils, with a considerable amount of concretionary ironstone. These are believed to develop from the banded ironstones of that area.

Yellowish Non-laterised Soils.

The soils so far described have had red or reddish subsoils. The red colours are those of iron oxide formed under dry conditions. The exact conditions are not known. It may be that the oxide is red if it is formed in barely moist situations or it may be that it becomes red if it dries soon after formation.

When the weathering zone is somewhat moister, but not waterlogged, a more hydrated iron oxide forms and this is brownish or yellowish in colour. Soils developing from such a material are orange or yellowish-brown in subsoil colour. The topsoil is dark brown or dark grey-brown. Like the red soils these yellowish soils may be deep or shallow and with or without prominent concretionary horizons.

At low altitudes they often occur just downslope of a Red Earth and their greater moisture is probably due to subsoil seepage of water from the red soils higher up the slops. Such soils are usually somewhat less acid than their associated red soil and, with their better moisture status, are more fertile.

Milne mentions a soil with a "drab brown" subsoil occurring in the Usambara foothills. It appeared to be associated with schistose gneiss into which water did not penetrate easily. Nearby soils on hornblende gneiss were red. At high altitudes, as a general rule, yellowish soils form in place of red soils, owing to the generally more humid conditions.

Example of a Red Non-laterised Soil.

The profile described below is typical of these non-laterised soils. It is a relatively shallow soil on acid gneiss and has a prominent concretionary horizon. The underlying rock apparently does not permit free percolation of all the water entering the soil. The sandy texture of the topsoil and the flatness of the landscape aggravate the situation by permitting maximum acceptance of all rain falling on the surface. The colour names and symbols are according to the Munsell colour system.

Situation: Nachingwea Experimental Farm (P 259). On an upper hillside in gently undulating country. Slope, 1·5 per cent at the site. Vegetation: miombo woodland; a fairly thick stand of well-grown trees.

0–20 cm. Dark reddish-brown (5 YR 3/2, moist) loamy coarse sand. Weak crumb to single-grain structure. Very porous. Stoneless.

20–115 cm. Reddish-brown (5 YR 4/4, moist) sandy clay loam. Weak sub-angular blocky to massive structure. Fairly campact. Stoneless.

115–240 cm. Red (2·5 YR 4/6, moist) sandy clay with many ironstone concretions (45 per cent of total mass) and much reddish-yellow mottling. Very firm consistence (moist). A sparse undulating line of quartz stones at 140 to 170 cm. depth. Grading into:—

204–600(+) cm. Weathering rock, mostly acid gneiss but some patches of hornblende gneiss. Upper portion reddish-brown (5 YR 4/4, moist) with reddish-yellow mottles. Below about 400 cm. becoming white except for reddish-brown staining associated with occurrences of hornblende gneiss.

The main analytical figures for this profile are given below. The acid-soluble phosphorus is that extracted by 0·3N hydrochloric acid.

Depth (cm.)		pH		Organic matter %		Exch. Ca. me/100g.		Acid-sol. P. ppm.
0– 20	...	6·1	...	1·3	...	1·9	...	0·5
20– 55	...	5·0	...	0·4	...	0·4	...	0·0
55–115	...	5·4	...	0·2	...	0·3	...	0·0
115–200	...	5·7	...	—	...	—	...	0·3

The dash (—) signifies "not determined".

Fertility of the Non-laterised Soils.

The non-laterised soils derived from granites and gneisses do not usually suffer from drainage troubles or excesses of salts or alkali but they are in general only of moderate to low fertility. The prolonged leaching which most of these soils have undergone has removed most of the plant nutrients originally present in the rock. Nevertheless just because they are not subject to flooding, salinity or alkalinity they are the most important arable soil in most parts of Tanganyika.

The greater part of the calcium, nitrogen and available phosphorus are concentrated in the organic matter horizon, i.e., in the top 4 to 6 inches of the profile. This is illustrated by some figures for a red soil from Urambo. The calcium and phosphorus figures are the amounts extracted by 0·3N hydrochloric acid.

Depth (inches)		pH		Organic matter %		Avail. Ca. me/100g.		Acid-sol. P. ppm.
0–2	...	6·7	...	1·24	...	1·9	...	1·0
2–4	...	6·3	...	—	...	1·2	...	0·6
4–6	...	5·7	...	—	...	0·7	...	0·8
6–12	...	5·3	...	—	...	0·3	...	0·3

Obviously the loss of the top-soil through careless management would render this soil practically useless.

One effect of this concentration of nutrients in the top few inches is that if the topsoil dries out in a dry spell during the rains the crop's nutrient supply is cut to a fraction of what it is during more favourable weather.

The shallower red soils on acid gneiss tend to be less acid in the subsoil and do not show the rapid fall in calcium. The distribution of phosphorus is, however, similar to that in the deeper soils. This is illustrated by a soil from Nachingwea. A pronounced concretionary horizon was reached at 65 cm. (26 inches) depth.

Depth (cm.)		pH		Organic matter %		Exch. Ca. me/100g.		Acid-sol. P. ppm.
0–15	...	6·1	...	1·36	...	2·2	...	3·0
15–30	...	6·0	...	0·71	...	2·0	...	0·4
30–45	...	6·0	...	0·57	...	1·8	...	0·2
45–65	...	6·1	...	0·57	...	3·0	...	0·2

Nitrogen is deficient in all these soils because of the low amount of organic matter. In addition, except in the drier areas (rain below 30 inches per annum), the organic matter is low in nitrogen. Frequently the C/N ratio is 15 to 20 in the topsoil. Responses to nitrogen are nearly always obtained with maize and similar non-legumes, except in the dry areas.

Responses to superphosphate are commonly, though not invariably, obtained. Responses to the less soluble forms of phosphate are usually poor.

Farmyard manure is usually the best fertilizer since its gradual decomposition gives a steady supply of nitrogen to the crop.

Magnesium and potassium are usually adequate and for most crops no deficiencies of these elements have been demonstrated. Sisal, however, is an exception and potassium deficiency has appeared occasionally in that crop on these soils.

Some of these soils are too acid for good yields of certain crops. In certain instances the poor growth is due to the toxic effects of certain metals (e.g., iron, aluminium, manganese, cobalt) which are absorbed in excess by the plants when there is little calcium. In other cases the poor growth or yield is probably due to the simple lack of calcium. It is often difficult to distinguish between the two effects but the practical cure in both cases is to increase the soil calcium. Unfortunately the results of liming experiments have been inconsistent. It is probable that the correct technique for reducing the acidity of tropical soils remains to be discovered. In one instance liming was successful in a pot scale, when the lime was thoroughly mixed with the soil, but unsuccessful when the lime was spread on the field. The analytical figures given above show that it is the subsoil, not usually the topsoil, which needs liming.

Red Soils on Colluvial Material.

The soils so far considered have developed from the weathering of gneisses and granites more or less *in situ*. Some red soils, however, have developed in colluvial or alluvial deposits derived from granite or gneiss. If these deposits merely consist of material eroded from previous red soils they will differ little in fertility from the original soil. Some deposits, however, contain unweathered minerals, produced by the grinding down of gneiss or granite rocks in stream beds, for example. These give rise to a relatively fertile soil. Analytical figures for such a soil in the Kilosa District are given by Leutenegger.

Depth (cm.)	pH	Exch. Ca. me/100g	Acid-sol. and absorbed P. ppm.
0–10	6·8	18·9	270
10–20	7·0	18·8	264
20–40	7·0	15·9	112
40–60	7·0	9·0	49

These soils are uncommon because alluvial, and to a lesser extent colluvial, deposits are usually found on low ground, where the drainage is poor and therefore a red soil does not develop.

(2) On Sandy Materials.

Non-laterised red soils are also found on sandy parent material, wherever the drainage is good. The soils are sandier than those forming on granites and gneisses and, since the sand is usually quartz, are of very low inherent fertility. (The special case of a soil formed on granitic grit is dealt with later.)

Typically these sandy red soils form on the Karroo sands of central southern Tanganyika and on the Jurassic, Cretaceous and later formations of the coastal regions. The following soil had developed on sandy Cretaceous material (probably somewhat transported) at Mahiwa (Southern Region). It was on a slope of about 3 per cent and had recently been cleared for cultivation, probably not for the first time.

0–15 cm. Dark grey-brown (10 YR 4/2, dry) loamy sand. Fairly compact but friable.

15–75 cm. Brown to yellowish-brown (10 YR 5/3 to 5/4, dry) loamy sand.

75–140 cm. Yellowish-red (5 YR 4/6, dry) slightly clayey sand. Massive and fairly compact but friable when moist.

140–220 cm. Similar, with slightly increasing clay.

The analytical figures show the small amount of organic matter and the low level of nutrients.

Depth (cm.)	pH	Organic matter %	Avail. Ca. me/100g.	Acid-sol. P. ppm.
0–15	6·0	0·69	1·1	5
18–40	5·4	0·41	0·5	3
40–75	5·0	—	0·5	3

The clay content of a nearby profile was 5 per cent in the top-soil, rising to 14 per cent at 170 cm. depth.

Leutenegger gives analytical figures for a red soil on Karroo sandstone near Tanga which are very close to those just quoted.

These sandy soils often have sufficient fertility for a year or two's cropping but after that yields fall rapidly. Traditionally they are restored by a long bush fallow which probably brings nutrients up from the deep subsoil and leaves them in the topsoil. Some of these sandy soils appear from analyses to be deficient in potassium but this needs confirming by field trial.

Sandy soils have a better rainfall acceptance (i.e., less loss by run-off) than heavier soils; also they have little clay to hold soil moisture against root suction. Their drought-withstanding properties are therefore often better than might be expected, especially if there is an increase in clay content at depth, so that drainage is not too rapid.

In country where the rock is gneiss or granite, with Red Earths such as are described in the previous section, on the ridge tops and upper slopes, there is often a belt of sand on the lower slopes. This develops as a result of natural erosion processes sorting the hill-slope soils into clay-rich and sand-rich fractions. The sand is left on the lower slope while the clay moves further into the valley. If the sand is well above the seasonal ground-water level it develops into a red soil. Some figures for such a soil at Nachingwea are given below (Profile 94).

Depth (cm)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.
0–15	6·3	1·30	3·1	13·2
15–35	6·1	0·67	1·7	3·2
35–60	5·1	0·36	—	4·0
60–90	5·3	0·34	1·6	1·6

This is a better soil than the Mahiwa sand described above even allowing for some loss of top-soil from the Mahiwa profile. One would in general expect better nutrient status in a soil on a lower slope than one high up the hillside. However, the fertility of these lower slope soils depends to a considerable extent on their clay content. In the soil just mentioned (Profile 94) the clay content was 8 per cent for the highest horizon, rising to 28 per cent for the 60–90 cm. horizon. Some of these soils are almost pure quartz sand and are of little value for anything. Also, by virtue of their position at the lower end of a slope, they receive considerable run-off from high ground. Serious erosion is liable to occur under cultivation unless adequate soil conservation measures are taken.

(3) On Grits.

In Usukuma, there are commonly granite outcrops (tors) at the summits of the hills. The aerial weathering of these rocks is partly physical and partly chemical. The product of this weathering is a gravelly apron of undecomposed and partly decomposed fragments of granite surrounding the out-cropping rock. This gritty material is very freely drained and reddish-brown in colour in the sub-soil, with a dark brown top-soil. Its depth is very variable. In pockets it may be several feet deep but there may be granite boulders reaching the surface next door to such pockets.

These soils have a good reserve of nutrients in the unweathered minerals present in the grit and, given adequate moisture, they may be very fertile. However their cultivation is liable to lead to their erosion since they are usually on steep slopes. They are better looked upon as regulators of the run-off from the bare rock outcrops and should be kept under bush.

On their lower boundary these soils graduate into weathered red soils—the "matongo" soils of Ukiriguru which have already been described.

Although these grit soils are best known from Usukuma they are found wherever granite or metamorphic rocks outcrop in hilly country and are exposed to the disintegrating effects of the sun and rain. They seem to be more extensive on granite than on gneiss. On the whole they are of little agricultural importance.

(4) On Lava and Volcanic Ash.

The first soils to be developed on fresh lavas and volcanic ash are not Red Earths and are described elsewhere. In time, however, these first-formed soils develop into Red Earths, provided the rainfall is sufficient to remove the soluble products of weathering and provided they do not suffer from poor drainage.

By the time a young soil on lava or ash has developed into a Red Earth much of its original high content of nutrients has been lost and with increasing age there is a further decline. However, Red Earths on volcanic material are normally richer than Red Earths on granites, gneisses, etc. The following figures for a soil on volcanic ash at Mbozi, in S-W. Tanganyika, should be compared with those for an immature soil on volcanic lava from near Moshi (page 14) as well as with those for a Red Earth from gneiss (page 7).

Depth (in.)		pH		Organic matter %		Exch. Ca me/100g.		Acid-sol. P. ppm.
0–10	...	5·2	...	4·3	...	3·6	...	0·4
10–24	...	5·1	...	1·9	...	2·1	...	0·0
24–40	...	5·2	...	1·0	...	1·4	...	0·0

It cannot be assumed that the Mbozi soil was ever as rich as that at Moshi. Volcanic materials are variable in composition and it is quite probable that the ash at Mbozi never had much phosphorus in it. Nevertheless the low pH value and low exchangeable calcium of the Mbozi soil indicate a long history of leaching.

The Mbozi soil described above was on the top of a ridge and was reddish-brown in colour (below the dark reddish-brown organic horizon). About a quarter of a mile away, down the slope, the soil was somewhat browner in colour and higher in pH value, organic matter, exchangeable calcium and acid-soluble phosphorus. This illustrates the lesser intensity of leaching lower down the slope.

Depth (in.)		pH		Organic matter %		Exch. Ca. me/100g.		Acid-sol. P. ppm.
0–10	...	6·3	...	5·2	...	7·0	...	2·0
10–30	...	5·6	...	2·4	...	2·8	...	0·8
30–53	...	6·1	...	0·8	...	—	...	0·3

(5) On Calcareous Materials.

The development of red soils on calcareous materials is a much-debated subject still not properly understood. It remains a fact that these soils do exist. In the coastal areas of Tanganyika there are extensive areas of red soils overlying coral or limestone. Similar red soils over limestone and over the calcareous weathering products of basic gneiss have been reported by Milne from the Morogoro District.

The following figures for a red loam over coral limestone in the Southern Region are given by Leutenegger. The underlying limestone maintains a high value of calcium throughout the profile.

Depth (cm.)		pH		Exch. Ca. me/100g.		Acid-sol. and absorbed P. ppm.
0– 20	...	6·8	...	10·2	...	6
20– 40	...	7·3	...	8·0	...	3
40– 80	...	7·6	...	6·3	...	2
80–100	...	7·6	...	5·7	...	4

This profile is particularly poor in phosphorus but Leutenegger reports that other soils were much better supplied. He also mentions that some of these soils are deficient in potassium, at any rate for the requirements of sisal. Those soils are, however, extensively planted with sisal.

Many red earths in the Central Region contain concretionary carbonate in the sub-soil, although they have developed from non-calcareous rocks like gneiss. There is little doubt that these soils were originally normal non-calcareous Red Earths and were formed under a higher rainfall than that of today. The concretionary carbonate, which is only found in soils on the lower slopes, is brought in as dissolved calcium bicarbonate in drainage water seeping down the slope from higher sites where weathering and leaching are still continuing.

CHAPTER 3.—LATERISED RED AND YELLOWISH SOILS

LATERISED RED AND YELLOWISH SOILS

In Tanganyika the Laterised Red and Yellowish Soils are found under rain forest, or where there has recently been rain forest, at fairly high altitudes. At lower altitudes they merge into the Non-laterised Red and Yellowish Soils which have already been described. In the Usambaras the boundary seems to lie at about 3,000 feet on the wetter, eastern side (rainfall about 80 inches or 2,000 mm.) and rises to about 5,000 feet on the drier, western side. These laterised soils resemble the Latosols of West Africa. The latosols can occur at quite low altitudes in West Africa, presumably because of the greater humidity of much of West Africa. It is possibly the presence of forest, rather than the direct effect of a high rainfall, which is important.

In the *Tanganyika Atlas* (3rd Edition) these laterised soils are described as "generally brownish-red rather sandy soils with a very friable clay (sesquioxidic-kaolinite type)". They are sometimes known as "Humic Red Earths".

The Laterised Red and Yellowish Soils are typically strongly acid with a well-developed humus horizon. The humus is pale in colour so that although it often forms 7 to 8 per cent of the topsoil it does not darken the colour very much. The colour of the subsoil is typically pale red, reddish-brown or yellowish-brown, in general less intense than the colour of a non-laterised red or yellowish soil.

Laterised soils have a friable and non-plastic subsoil even though there may be a high proportion of clay-sized particles. This friability is due to a considerable amount of finely-divided iron and aluminium oxides. These oxides are non-plastic themselves and maintain an open porous structure, perhaps by lightly cementing together the particles of true clay. The soils are therefore freely-drained and erode less easily than do the non-laterised red and yellowish soils. The iron and aluminium oxides give the clay fraction a low silica-sesquioxide ratio of 1·5 to 1·0 or even less. The clay associated with the oxides is kaolinitic.

Often these laterised soils are strongly leached and in such cases most of the plant nutrients are in the humus horizon. The sub-soil may have a pH down to 4 or even below 4, and will have lost the greater part of its exchangeable bases.

In Tanganyika these soils have been reported as developing on metamorphic rocks and granites and on volcanic ash and lava. They also occur on sandstone in the Bukoba area and on shales in the Kipengere area (west of Njombe) but no descriptions are available of the soils on these last two materials.

(1) On Metamorphic Rocks and Granites.

The main occurrences of laterised red and yellowish soils on metamorphic rocks and granites are in the Pare, Usambara, Nguru, Kaguru, Uluguru and Livingstone Mountains and in the Mahenge, Mufindi, Dabaga, Njombe and Ufipa Highlands.

The following description is of a profile in the South Pare Mountains. It is illustrated on Plate 3.

Situation: Mpepera. Altitude 6,000 feet. On a steep hillside, under bracken and scrub.

0– 2 ins.	Dark brown peaty layer (7·5 YR 3/2, moist). Clearly defined from:—
2–12 ins.	Brown sandy loam (7·5 YR 4/3, moist), weak subangular blocky structure. Very friable. Merging into:—
12–24 ins.	Strong brown sandy loam (7·5 YR 4/6, moist). Weak subangular blocky structure. Very friable. A few fragments of weathered rock.
24–50 ins.	Similar, becoming somewhat less friable. A few soft pisolitic concretions. Many weathered rock fragments.
50–60 ins.	Yellowish-red sandy loam (5 YR 5/6, moist). Otherwise as previous layer.
60–70 ins.(+)	Strong brown sandy loam (7·5 YR 5/8, moist). Weak granular to massive structure.

Note:—The textural descriptions refer to the feel of the soil and are not based on laboratory-determined sand, silt and clay.

Usually these soils are strongly leached. A soil at Amani (East Usambaras) had a pH of 5·25 at the surface, diminishing to 4·95 at 3 ft. depth. Nutman found that most of the feeder roots of coffee growing in this soil were in the top 12 inches of the profile. The coffee was existing mainly on nutrients liberated by the decomposing organic matter.

Under the original forest the organic matter was maintained by leaf fall but under plantation or annual crops the organic matter is progressively consumed. Clearly, continual cropping will not be possible without heavy organic mulching or the use of imported fertilizers.

Not all these soils are as leached as that quoted by Nutman. The following figures for a profile at Lushoto (presumably a laterised soil) are taken from an annual report of Lyamungu Coffee Station.

Depth (ins.)	pH	Organic matter %	Exch. Ca. me/100g.	Avail. P. ppm.
0– 6	6·8	5·1	14·9	10
6–12	6·6	2·8	11·3	20
12–18	6·5	1·4	6·5	28
18–24	6·5	1·2	6·0	22
24–36	6·3	1·0	5·5	26

A soil intermediate between the two just described is recorded in the report of the Central African Rail Link Survey. The soil was at Kalinga (Mufindi) at 6,700 feet and under a 60-inch rainfall. In the report it is described as a sandy yellowish-brown latosol. The analytical figures are given below.

Depth (ins.)	pH	Organic matter %	Exch. Ca. me/100g.	Avail. P. ppm.
0–10	5·5	6·5	3·4	3
10–14	5·5	5·0	2·2	2
14–25	5·2	1·7	1·8	2
25–39	6·2	0·9	1·6	11

In these laterised soils reddish colours prevail at lower sites with a tendency to greater yellowing with increasing altitude.

The development of these soils for agriculture requires considerable care. The fact that they support a heavy growth of forest is no proof that they can be profitably cropped. Their fertility under forest conditions is due to the continual return in the leaf-fall of nutrients removed by the roots. When the forest is cleared this cycle is broken.

The richer soils, such as the one at Lushoto described above, should be satisfactory for most crops, but, like all soils, their fertility is not inexhaustible. The poorer soils will very soon cease to produce unless their low reserves of fertility are maintained by bringing in fertility from elsewhere. Organic mulching is a possible source of such fertility but may lead to the rapid exhaustion of the soil on which the mulching material is grown. In some cases it may be possible to grow mulching material on a rich valley soil for application to nearby laterised red soils. In other cases it may be possible to use the manure of cattle grazed in such valleys. The more acid soils are suitable for tea growing.

(2) On Volcanic Ash and Lava.

Laterised soils on volcanic materials occur on Kilimanjaro and in the Mbeya area. Milne described some of these soils in the 4,000 to 5,000 feet zone of Kilimanjaro as chocolate-coloured loams. They occur under rainfalls of 35 to 80 inches a year and those analysed had from 2 to 9 per cent organic matter and 36 to 70 per cent of clay. A Laterised Red Earth on lava is illustrated on Plate 5. This example is near Tarime.

CHAPTER 4.—BROWN SOILS OF HIGH BASE STATUS: RENDZINAS: IMMATURE SOILS

BROWN SOILS OF HIGH BASE STATUS

Lying at the foot of the slope between a red soil on the higher ground and a black clay in the valley bottom there is often a brown-coloured soil of fairly heavy texture. It may be a loam or a clay loam. These brown soils have a saturated or nearly saturated cation exchange complex, the predominant ion being calcium.

These soils have escaped severe leaching by being low down in the catenary sequence. They are sufficiently above the normal levels of the water-table, in the valley bottom or mbuga flats below them, not to suffer from waterlogging. They accordingly acquire a calcium-rich base complex and develop a brown colour.

At Kongwa these soils have calcareous concretions in the subsoil. It is possible that this concretionary carbonate has developed subsequently to the formation of the brown colour. The somewhat similar case at Kongwa of red soils with calcareous concretions has already been mentioned. At Nachingwea the brown soils are non-calcareous and lie between acid reddish soils on their upper border and neutral black loams in the valley bottom. The calcareous Ibushi soils of Usukuma seem to be another example of these brown soils.

The following description and analytical data refer to a calcareous brown soil at Kongwa.

Situation.—Kongwa Experimental Farm (P.65). In a valley bottom near an incised water-course; slope about 1 per cent. Formerly under Commiphora thicket but now cultivated.

0– 12 cm.	Dark brown loam (10 YR 4/3, dry). Fairly friable.
12– 40 cm.	Similar, but harder. A few fragments of quartz and concretionary ironstone. Merging into:—
40–100 cm.	Grey brown loam (10 YR 5/2, dry). Hard. A few fragments of quartz, feldspar and concretionary ironstone. Clearly defined from:—
100 cm. (+)	Concretionary limestone; nodules about 2 cm. across.

Depth (cm.)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.
0– 12	7·5 ...	1·7 ...	11·7 ...	1·5
12– 40	6·7 ...	1·0 ...	10·7 ...	0·8
40–100	7·0 ...	0·5 ...	15·7 ...	0·4

It should be remembered that this Kongwa soil is probably more calcareous now than when it was originally formed. The non-calcareous brown soils at Nachingwea have pH values of about 6·0 to 6·5 and exchangeable calcium values of 6 to 8 me/100g.

These brown soils of high base status have a high fertility. Unfortunately, the conditions under which they form are rather critical and usually they are only found in small patches.

The weathering of lava in well-drained situations produces a fertile brown soil. These volcanic soils differ from the other brown soils just described in being transitional in nature. They are Immature Soils (*q.v.*) and under natural conditions they would, in the course of centuries, lose their calcium by leaching and become Red Earths. However there is no reason why, with good management and regular application of manures or fertilizers, these volcanic brown soils should not be kept in their present fertile state.

RENDZINAS

A rendzina is a dark grey or dark brown soil formed from soft calcareous rock. Organic matter is usually high.

Leutenegger describes rendzinas formed on marls and Jurassic limestone in the Tanga and Eastern Regions. The top-soil is dark brown with a stable crumb structure and high organic matter (about 7 per cent). Rain penetration is good, owing to the stable structure, but the high retention of moisture means that the soil cannot be worked for some time after rain.

Below the topsoil there is a brown calcareous clayey subsoil, which passes into a soft whitish marl or into limestone. The profile is calcareous throughout.

Depth (cm.)	pH	Exch. Calcium me/100g.	Acid-sol. and absorbed P. ppm.
0–10	8·0	51·8	83
10–20	8·2	43·0	64
20–30	8·3	41·5	45
30–40	8·2	35·4	13

Rendzinas are well-drained and it is this which separates them from the Dark Clays on Calcareous Sediments (described later).

IMMATURE SOILS

Immature soils form on newly-exposed parent material. This can be alluvium deposited by a river, the exposed bed of a former lake, wind-blown sand, volcanic ash and lava or marine coastal deposits. In this account, only alluvial, lake-bed and volcanic deposits will be considered. Wind-blown sand is rare in Tanganyika and the soils on recent marine deposits, e.g., mangrove swamps, have been little studied. Immature soils also arise when erosion has removed a former soil cover right down to the underlying rock; if the erosion stops an immature soil forms on the newly-exposed surface.

Soon after exposure the properties of the very young soil are mainly those of the parent material. However, weathering processes set to work and eventually convert this material into a mature soil, such as those already described in this Bulletin. This process is likely to take centuries before the soil is fully mature. In contrast to those of an immature soil, the properties of the final mature soil are usually due more to the weathering processes to which the soil has been exposed than to the composition of the parent material.

It follows, from what has been said in the last paragraph, that there will be as many kinds of immature soils as there are kinds of alluvium, lake-bed deposits, volcanic lavas and ashes and rocks exposed by erosion. Furthermore, the properties of each will be changing as the soil gradually becomes mature. Immature soils are therefore very variable in properties but it is possible to group them according to their parent material. Examples will be given of the more important ones but it should be remembered that the examples by no means cover the range which may be encountered.

Three groups will be discussed:—

(i) Alluvial soils (including old lake-bed soils).

(ii) Soils formed on volcanic ash and lava.

(iii) Soils formed on rock exposed by erosion.

Each of them could be divided into a well-drained sub-group and a poorly-drained sub-group. Alluvial soils tend to be poorly-drained and are therefore dealt with later, in the section "More or less badly-drained soils". The second and third groups of immature soils are usually well-drained and so are described in this present section.

SOILS FORMED ON VOLCANIC ASH AND LAVA

(1) Deep, well-drained Soils.

The soil first formed on volcanic material is usually grey or black in colour and sandy in texture. Leutenegger gives an analysis of a greyish-brown loam formed from lava in the Moshi area (soil A below). This is very fertile and rich in calcium, phosphorus and potassium (but rather low in nitrogen).

From the same area, and also from lava, another soil (soil B) has also been analysed by Leutenegger. Though still fairly rich in nutrients this soil is much further weathered than soil A. It was red in colour and had probably passed out of the Immature Soil class and become a Non-laterized Red Soil, such as has been described earlier (page 10).

Soil	Depth cm.	pH	Exch. Ca. me/100g.	Acid-sol. and absorbed P. ppm.
A (young)...	0–20	6·6	18·2	223
B (older) ...	0–20	6·0	6·0	80

The difference between these two sets of figures illustrates the leaching of nutrients which takes place during weathering. The development of the red colour is due to the decomposition of black iron-containing minerals in the lava into red iron oxide.

A further soil from near Moshi, again described by Leutenegger, was a grey loam formed from volcanic ash.

Depth (cm.)	pH	Exch. Ca. me/100g.	Acid-sol. and absorbed P. ppm.
0–20	7·0 ...	14·8 ...	580

This soil, also, was rather deficient in nitrogen, but was well-supplied with other plant nutrients. Its grey colour suggests that it is very young. Older soils on ash are brown or red, like those on lava.

The Rail Link Survey Team described two brown soils on volcanic ash and pumice in the Mbeya area. One was situated at a height of 7,000 feet in the Poroto Mountains. It contained 14 per cent of organic matter and was rich also in calcium and potassium. Figures for nitrogen were not given; phosphorus was rather low. The high organic matter is probably due to the cool and humid climate (50 to 60 inches of rain per annum).

The other soil was from a lower altitude (4,800 feet) and a drier climate (35 to 40 inches of rain). This is described below.

Profile 108.—11½ miles west of Mbeya. Slope 1 to 1½ per cent. Vegetation: Acacia and Combretum with Hyparrhenia grass.

0–10 ins. Greyish-brown light sandy loam (10 YR 5/2). Crumb structure.

10–33 ins. Brown sandy loam (10 YR 5/3). Weak nut structure.

33–50 (+) ins. Pale brown to brown pumicey sandy loam (10 YR 6/3 to 5/3). Many pumice fragments 1/16 to ⅜ inch in diameter.

Depth (ins.)	pH	Organic matter %	Exch. Ca. me/100g.	Avail. P. ppm.
0–10	6·2 ...	4·1 ...	5·7 ...	10
10–33	6·0 ...	1·2 ...	2·8 ...	2
33–50	6·4 ...	0·5 ...	1·9 ...	3

The lower phosphorus of these Mbeya soils, compared with those from Moshi described earlier, is probably mainly due to the ash and pumice of the Rungwe (Mbeya) eruptions having a lower phosphate content than those from Kilimanjaro (Moshi) but the methods of analysis are not strictly comparable.

The volcanic soils are some of the most fertile soils in Tanganyika and are the foundation of the coffee industries of Kilimanjaro and Tukuyu. It is, of course, the combination of a good rainfall with a fertile soil which makes these areas so productive. Areas with a good rainfall but with mature soils, e.g., the Usambaras, are less productive because these older soils have lost much of their plant nutrients during many thousands of years of leaching.

With volcanic soils there are sometimes excesses of elements harmful to plant growth or else deficiencies of essential elements. These seem to be rare in Tanganyika but wattle in the Njombe area, on the edge of the Rungwe volcanic zone, has been found to suffer from boron deficiency (Report of the Government Chemist, 1957).

(2) Other Volcanic Soils.

Volcanic soils are deep near the point of the eruption but on the fringes of the volcanic zone there are often mature non-volcanic soils which have received a light coating of volcanic ash. Where this coating was originally a foot or two thick the ash may still be recognizable in a soil section as a distinct layer overlying the original soil, thus forming a composite profile. But where the coating was originally only an inch or two in depth this will by now have become incorporated in the underlying soils and there is no visual evidence of the ash though the soil has nevertheless been enriched. Both these kinds of mixed soil have been found on the edges of the Rungwe volcanic zone, at Njombe in the east and at Mbozi in the west.

Other volcanic soils are found in areas of poor drainage. They may arise where lava has flowed out over a level plain or where volcanic ash has fallen on a flat or depressed area. With the rapid weathering of the lava or ash there is often an accumulation in the soil of the soluble products of that weathering. This has happened in places in the plains to the south and south-east of Kilimanjaro. Such soils often have too much salt in them for all but a few salt-tolerant shrubs and grasses. They cannot be cropped until the salt has been leached out of them. These saline soils are dealt with in a separate section (page 25).

SOILS FORMED ON ROCK EXPOSED BY EROSION

In cases of severe erosion the original soil cover may be removed right down to the weathered rock. This, being firmer than the soil, usually resists further erosion. If the forces of erosion are now diminished, for example by the cessation of cultivation where unwise clearing was the cause of the erosion, the weathering of the exposed rock continues while the weathered material is not removed as fast as it is formed. A shallow, immature soil then forms on the weathering rock.

A somewhat similar situation obtains on steep escarpments where natural erosion is so rapid that a deep, mature soil never gets a chance to form. Soil is washed off the top of the profile as fast as it is formed at the bottom of the profile from the weathering rock. The result is a shallow immature soil maintained by a somewhat precarious equilibrium between the forces of soil destruction and soil formation.

These shallow, immature soils are not suitable for cultivation and should be kept under a cover of vegetation to prevent further erosion.

The total area of these soils is small and they are of little agricultural importance. One such soil near Nachingwea, in a narrow valley cutting into higher ground, showed a high available phosphate (100 ppm. against 6 ppm. for the mature soil on the nearby higher ground). It appeared that both soils had formed from the same rock and that the loss of available phosphate from the mature soil was partly due to removal by leaching but mainly due to the phosphate being converted into unavailable forms. This high availability of phosphate in immature soil perhaps explains the liking shown by some cultivators for clearing and planting steep escarpment slopes, though it does not justify the practice.

The immature soils just described are those formed from freshly exposed weathering rock. All soils forming on eroded ground do not come within this category. Often the erosion merely removes the topsoil from a deep and mature soil profile. If erosion is stopped the new soil which then forms develops on the former subsoil, which has usually been denuded of plant nutrients. This new soil is exceedingly infertile and is not immature in the true sense of the word.

CHAPTER 5. TROPICAL BLACK EARTHS: DARK CLAYS ON CALCAREOUS SEDIMENTS

TROPICAL BLACK EARTHS

These are soils in which calcium accumulates in the profile. This calcium may originate in the underlying parent rock and accumulate because the rainfall is low or the soil impervious so that the calcium liberated by the decomposition of the rock is not leached away. More often the soils are low-lying and the calcium is brought in dissolved in water draining from the higher ground. Calcium is precipitated in the soil when the water evaporates.

The soils may be divided into a calcareous group in which the calcium has accumulated beyond the exchange capacity of the soil and has precipitated out as calcium carbonate; and, secondly, into a non-calcareous group in which the exchange complex is saturated with calcium but there is no excess in the form of carbonate. Considerable quantities of magnesium are usually associated with the calcium, both in the exchange complex and in the concretionary carbonate.

In a calcium-saturated soil the organic matter is intensely black and colours the whole soil although it may only constitute 3 or 4 per cent of the whole. Under such conditions iron is not mobile so that mottling or iron concretions are not found, even though there may be frequent waterlogging.

Typically these black soils are clays because sandy material usually permits some water movement and therefore some leaching. But under suitable conditions soils with only 25 to 30 per cent of clay can develop into a black, or at any rate a very dark grey, earth.

These black earths are known variously as Tropical Black Earths, Regur Soils and Grumusols. In East Africa they are popularly known as Black Cotton Soils, an unfortunate name since they are not necessarily suitable for cotton. In the soil map of the *Tanganyika Atlas* (3rd Edition) they are included in the "Illuvial group, type 9".

These are typically the soils of the extensive mbugas of the Central, Lake and Northern Regions of Tanganyika. All mbugas do not, however, contain Black Earths; the narrow mbugas of miombo country often contain Leached Ferruginous Soils.

Many Black Earths in low-lying sites accumulate sodium as well as calcium and magnesium and so become alkaline. According to American practice, when the sodium constitutes more than 15 per cent of the total exchangeable cations (bases) the soil is classed as an alkali soil. Sulphates or chlorides may also accumulate, giving a saline soil. Both these conditions are dealt with later in this Bulletin.

At the moist end of the range of true Black Earths there may be sufficient leaching to give a slightly unsaturated exchange complex (i.e., slight acidity) and rusty mottles may be found in the profile. With increasing unsaturation the Black Earths grade into the Leached Ferruginous Soils.

Some of these Black Earths crack widely on drying, others much less. To a large extent this is an effect of the proportions of clay and sand in the soil; the more the clay, the wider the cracks. There may, however, be an influence of the particular clay mineral present. This can be either montmorillonite or illite.

CALCAREOUS TROPICAL BLACK EARTHS

The calcareous Black Earths are probably commoner than the non-calcareous Black Earths. The following profile is an example of this sub-division (see also Plate 6).

Situation.—Ukiriguru, in a level mbuga under grass with scattered thorn trees.

0– 6 ins. Black clay (10 YR 2/1, moist). Strong coarse crumb structure in top ½ inch, angular blocky below. Cracks 5 cm. wide. Numerous carbonate concretions. Merging into:—

6–12 ins. Black clay (10 YR 2/1, moist). Slight yellowish-brown iron-staining along roots. Coarse subangular blocky structure. Numerous carbonate concretions. Merging into:—

12–52 ins. (+) Black clay (N 2/0, moist) becoming very dark grey at 52 inches. Coarse angular blocky structure. Few or no carbonate concretions.

The concentration of the carbonate concretions in the top foot is somewhat unusual. No analytical data are available for the above profile but some figures are given in the Central Africa Rail Link Survey Report for a calcareous, very dark grey clay on the Usangu Plain. In this profile there were calcareous concretions throughout; the clay content was 88 per cent at the surface, rising to 94 per cent below 30 inches.

Depth (ins.)	pH	Organic matter %	Exch. Ca. me/100g.	Exch. Na. me/100g.	Avail. P. ppm.
0–15	7·3	1·4	26·1	4·7	3
15–30	7·4	1·4	22·0	4·5	3
30–41	7·1	1·5	22·8	5·2	6

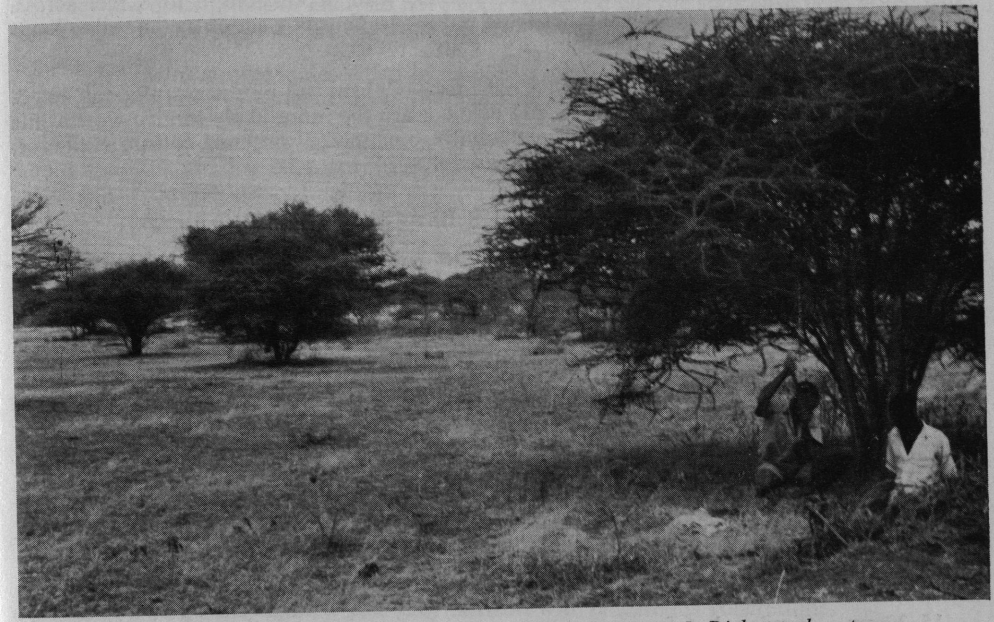

Plate 4.—An "Mbuga" near Kongwa with *Acacia* and *Dichrostachys* trees

Plate 5.—A Laterised Red Earth on volcanic lava at Tarime

Plate 6.—A Tropical Black Earth on the site shown in Plate 4. (Ruler is 18 inches long)

This soil had a hummocky surface micro-relief, with depressions 6 to 8 feet across. This is known technically as "gilgai relief" and is due to a churning action as the soil expands and contracts on successive wetting and drying.

These Black Earths are usually grazed but many of them can be successfully cultivated. Those not normally flooded and with a pH below 8 are the more likely to give worthwhile yields. Crops which will withstand some alkalinity, e.g., maize, sorghum, cotton, sunflower, are more likely to succeed than crops which will not.

NON-CALCAREOUS BLACK EARTHS

Sometimes the Non-calcareous Black Earths are found in low-lying sites, when incoming and outgoing calcium just balance. More often they occur on gentle slopes on a calcium-rich parent material when a heavy texture of the soil prevents any appreciable leaching.

The following profile occurred in alluvial material on a slight slope. This appears to be one in which calcium brought to the profile is approximately balanced by calcium removed by leaching. There is, in fact, a slight net accumulation, with a small amount of carbonate present below a depth of 65 cm. (about 2 ft.) The clay content was 30 per cent at the surface, rising to 60 per cent below 100 cm. depth.

Situation.—Nachingwea, at the junction of two drainage lines, in alluvial material derived from basic gneiss; grassland. (P. 137).

0–15 cm. Black sandy clay (N 2/0, dry). Weak angular blocky structure. Cracks up to 4 mm. wide on drying. Many fibrous roots.

15–30 cm. Similar, but fewer roots.

30–65 cm. Dark grey clay (N 4/0, dry) with brown mottles. Weak angular blocky structure.

65–140 cm. Dark grey clay (N 4/0, dry). Massive and hard. A few carbonate concretions and a little ironstone.

140–210 cm. Grey clay (N 3/0, dry). Cloddy. A few carbonate concretions.

The following analytical figures were obtained for the upper part of the profile.

Depth (cm.)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.
0– 15	6·7	4·0	18·3	6
15– 30	6·8	2·1	16·7	3
30– 65	7·3	1·0	–	2
65–100	8·1	0·9	20·0	2

Leutenegger gives figures for a black clay on volcanic ash (transported) in the Moshi District. This soil was particularly rich in exchangeable calcium (36 me/100g).

Apart from the absence of carbonate concretions the non-calcareous Black Earths do not differ much from the calcareous. Their agricultural utilization will probably be similar, with a greater probability of the non-calcareous soils being free from harmful alkalinity.

Fertility of the Black Earths.

These soils are not usually deficient in plant nutrients. Difficulties during development are more likely to arise over poor drainage, salinity and alkalinity. They are usually under natural grassland and are used for grazing.

DARK CLAYS ON CALCAREOUS SEDIMENTS

The calcareous sediments on which these soils form are only found near the coast. They are of Cretaceous, Tertiary or later age.

Very few descriptions or analyses have been published but the soils have been noted from the Tanga, Korogwe, and Ngerengere areas and in the Southern Region.

The following profile is described by Leutenegger. The soil is derived from calcareous sediments of Tertiary age and is from the Tanga area, near the coast.

The topsoil is black at the surface and has a coarse crumbly structure. Below this, at about 5 cm. depth, it is dark grey and has a cloddy structure. The subsoil is yellow, with white calcareous nodules.

Depth (cm.)	pH	Exch. Calcium me/100g.	Acid-sol. P. ppm.
0–20	7·8 ...	46 ...	32
20–40	8·0 ...	49 ...	35
40–60	8·2 ...	48 ...	27

The soil is fairly high in plant nutrients but suffers from poor drainage.

As a result of long-continued leaching, the calcium carbonate is often dissolved out of the upper part of the profile. This upper part thus becomes acid and the fertility is reduced. There is also a tendency for loss of structure in the acid horizons. Another of Leutenegger's profiles, again from the Tanga area, illustrates this development of an acid topsoil. The soil occurred on calcareous sediments of Cretaceous age.

The topsoil is dark grey with a cloddy structure. Below this is a bluish-grey horizon with mottles and below this again a pale grey horizon with calcareous concretions.

Depth (cm.)	pH	Exch. Calcium me/100g.	Acid-sol. P. ppm.
0–10	5·6 ...	12 ...	20
10–20	5·6 ...	12 ...	9
30–50	7·2 ...	14 ...	8
60–80	8·2 ...	– ...	8

In this profile the acid horizons only extend to a depth of 10 to 12 inches but elsewhere they may be 3 feet deep. They may contain iron concretions. The nutrient levels in this soil are still quite good but drainage is poor. The natural vegetation was grassland with scattered trees and palms. Water-holes occupied the occasional depressions.

CHAPTER 6.—LEACHED FERRUGINOUS SOILS: LEACHED SANDS

LEACHED FERRUGINOUS SOILS

When a soil becomes waterlogged, interchange of oxygen between the atmosphere and the lower horizons of the soil profile is hindered. Soil micro-organisms soon exhaust the oxygen already present in the soil and reducing conditions set in. Iron oxides, normally insoluble, become reduced to ferrous compounds and, if the soil reaction is acid, the iron goes into solution in the soil water. Eventually oxidizing conditions are re-established and the iron is re-precipitated as ferric oxide. Often, however, the iron has moved in the soil while in solution so that it is re-precipitated in a different place from that at which it dissolved. This movement may be vertically upwards or downwards in the profile or it may be lateral, following the flow of water down a hillside for example.

Repeated cycles of solution and precipitation may lead to the formation of concretionary accumulations of iron oxides at a certain level in a profile or at a certain position on a hillside.

These concentrations of iron oxide can take several forms, of which the following are the chief:—

(1) As mottles of reddish ferric oxide on a whitish or pale brown ground, often with slight hardening at the site of the mottles.

(2) As a horizon of separate, hard, usually rounded iron oxide concretions (pisoliths) up to about half an inch in diameter.

(3) As irregular nodules 3 or 4 inches long. These are common in low-lying level sites with a seasonal high water table.

(4) As lateritic sheets, i.e., massive continuous sheets of slag-like appearance. In Tanganyika this form is rare and the sheets are of limited extent when they do occur.

These different kinds of concretionary iron oxide are formed within the soil profile at depths varying from a few inches to a few feet. Subsequent removal of the overlying soil may leave them exposed at the surface but they never form on the surface.

The soils are acid and are grouped together as "leached ferruginous soils".

In describing these soils the term "sesquioxides" is sometimes used in place of "iron oxides". This term includes both iron and aluminium oxides. Aluminium oxide can be precipitated along with iron oxide but in Tanganyika, at any rate, aluminium normally plays a very subordinate role to the iron.

The soil above the concretionary horizon may be anything from a sand to a sandy clay but is usually a sand or sandy loam. The colour, below the dark surface horizon, ranges from reddish brown through brown and buff to yellow and grey. Typically it is rather pale, often a pale brown, a light grey or a buff colour. The soils with reddish tints are found where drainage is rather better than usual for the class and these reddish soils grade into the Non-laterised Red Earths.

The ferruginous soils commonly occur on old land surfaces and appear to be very old soils. They have a long history of leaching and are therefore usually moderately to strongly acid and are low in nutrients.

Ferruginous soils with pale subsoil colours are common on granite and gneiss parent rocks throughout Tanganyika and extend into the Rhodesias. They are often known as Plateau Soils, from their common occurrence on the Central Plateau of Tanganyika where they were first described by Milne. This term, however, was used by Milne to include some red soils on the Plateau; Pallid Soils is perhaps a better term for the pale coloured group. In America, soils in which iron oxide concretions develop at the level of a fluctuating water-table are called "Ground-water Laterites". Soils with concretions of the third and fourth type described above seem to fall into this category.

Two Ferruginous Soils, one a loamy sand and the other a sandy clay, are described below.

Sandy Ferruginous Soil.

Situation.—Ifakara, in a wide depression with a slope of about ½ per cent, on sandy sediments (P. 174). Carrying tall grass and scattered shrubs.

0–10 cm. Grey loamy sand (10 YR 5/1, dry). Slight yellowish-brown staining along roots. Weak, blocky structure.

10–20 cm. Grey loamy sand (10 YR 6/1, dry). Slight staining as above. Weak blocky to massive structure, but soft.

20–40 cm. Light grey loamy sand (10 YR 7/2, dry). Common, fine, strong brown mottles. Somewhat harder than previous horizon.

40–70 cm. Light grey clayey sand (10 YR 7/2, dry). Numerous fine yellow-brown mottles. A few iron concretions.

70–120 cm. Concretionary horizon. Irregular hard iron concretions up to 35 mm. across. In matrix of sandy clay,

120–165 cm. Light grey sandy clay (10 YR 7/2, dry). Common, fine, reddish-yellow mottles. Massive, compact and hard.

Depth (cm.)			pH		Organic matter %		Exch. Ca. me/100g.		Acid-sol. P. ppm.
0–10	...	...	5·6	...	2·0	...	2·8	...	3
10–20	...	...	5·7	...	0·7	...	1·2	...	2
20–40	...	...	5·9	...	0·4	...	0·9	...	1
40–70	...	...	5·3	...	0·3	...	1·1	...	0·2

Heavy-textured Ferruginous Soil.

Situation. Nachingwea, in a drainage line with sluggish drainage (P. 126). Under thin miombo woodland.

0– 8 cm. Very dark grey-brown loam (10 YR 3/2, dry). Rusty staining along roots. Medium crumb structure.

8– 40 cm. Yellow sandy clay (10 YR 7/6, dry). Rusty staining along roots. Weak crumb, becoming cloddy with increasing depth. A few rounded ironstone concretions, increasing with depth.

40– 75 cm. Yellow sandy clay (10 YR 7/6, dry). Common ironstone concretions, rusty mottles, becoming more numerous with increasing depth. Massive structure.

75–120 cm. Sandy clay, mottled strong brown and very pale brown. Numerous iron concretions up to 10 mm. diameter, with some MnO_2.

120–175 cm. (+) Sandy clay, coarsely mottled strong brown and white. Fewer concretions than above.

Depth (cm.)			pH		Organic matter %		Exch. Ca. me/100g.		Acid-sol. P. ppm.
0– 8	...	...	6·5	...	2·0	...	6·2	...	0·9
8–18	...	...	5·4	...	0·8	...	4·5	...	0·3
18–40	...	...	5·0	...	0·4	...	2·8	...	0·3
40–75	...	...	5·0	...	0·3	...	1·9	...	0·3

The clay content of this profile was 28 per cent at the surface, rising to 53 per cent below 40 cm.

Utilization.

The leached Ferruginous Soils are of low agricultural value. Normally they carry rather coarse grass, with or without scattered trees or shrubs. With good management, and especially if some draining is possible, better pasture grasses could be introduced. If the land can be flooded rice does quite well but they are not suitable for other annual crops.

LEACHED SANDS

In well-drained situations a sandy parent material usually develops into a red or reddish sandy soil. If, however, the site is wet, without being permanently waterlogged, a leached pale sand usually results.

One common site for these leached sands is a colluvial sandy deposit at the foot of a slope or at the head of a drainage line. During storms such a site will receive much run-off water from higher up the slope and water soaking into the sand will flow laterally through the soil and drain into the valley just below.

These soils consist largely of quartz sand. The top few inches of the profile is darkened with organic matter while below this the colour is pale brown, buff or yellow, due to the temporary waterlogging. There may be some mottling in the subsoil but often there is none.

The soil is not usually very acid but is very deficient in plant nutrients. The organic matter content is low because plant growth is poor; as well as being deficient in nutrients those soils suffer alternately from too much and too little moisture. They are of little or no agricultural value.

Other leached sands develop in sandy sediments of Karroo, Cretaceous, etc., geological age, in situations where there is little slope and drainage is poor. In these soils there is often a foot or two of coarse sand and below this an increasing amount of clay. The clay interferes with the drainage and so there is periodic waterlogging in the profile and pale subsoil colours result. The increase in clay with depth is probably due to the mechanical carrying-down of the clay particles by descending water. Although the drainage is impeded there is usually no permanent water-table; the presence of a water-table, if only seasonally, would result in the formation of iron concretions and would put the soil in the Leached Ferruginous class. Rusty mottles may, however, be present in a Leached Sand.

These sands on sedimentary formations usually have a rather steadier moisture content than the sand on colluvium described above. They therefore carry a denser natural vegetation and have more organic matter, though still only one or two per cent. The soils are not usually very acid but they have a low nutrient status. The clay in the subsoil helps to retain some moisture during dry weather. The soils are therefore of some agricultural value, though inherently of low fertility.

The following profile was from near Kilwa and had developed on marine sediments of Paleogene Age. The clay horizon below 110 cm. depth is almost certainly due to stratification of the original sediments and is not due, or only party due, to downward movement of clay particles. It was cultivated in places for annual food crops.

Situation. Kilwa, on coastal plain (P. 270). Very slightly undulating. Water stands for about a day after heavy rain. Vegetation: Cashew and mango trees, *Hyphaenae* palms.

0– 15 cm.	Very dark grey-brown coarse sand (10 YR 3/2, moist). Single grain, soft (dry).
15– 30 cm.	Dark brown coarse sand (10 YR 3/3, moist). Single grain, soft (dry).
30–110 cm.	Brown coarse sand (10 YR 5/3, moist) with common fine yellowish-brown mottles. Single grain, slightly hard (dry).
110–160 cm. (+)	Brown very sandy clay (10 YR 5/3, moist) with many red and grey fine and medium mottles. Massive and fairly compact.

Depth (cm.)	pH (water)	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.	Clay %
0– 15	6·5	0·6	1·2	13	2
15– 30	6·4	0·3	0·7	9	—
30–110	6·2	0·2	0·3	15	2
110–160	5·4	—	1·2	12	19

Similar sands, derived from Karroo sandstones, are found in the Msolwa area near Ifakara. Some of them are flooded fairly often during the rains and on these rice is grown. Those that are above flood level are not cultivated. The flooded soils were mottled throughout the profile but were without iron concretions.

It is this absence of iron concretions which distinguishes the Leached Sands from the Leached Ferruginous Soils.

CHAPTER 7.—ALLUVIAL SOILS

ALLUVIAL SOILS

Alluvium consists of material carried in suspension in river water and deposited on land adjacent to the river in time of flood. This material is usually a mixture of mineral particles ranging in size from coarse sand to fine clay. There may also be some organic matter. So long as the flood water remains within the river banks its turbulence keeps the suspended particles uniformly mixed but once the water leaves the river-bed there tends to be a sorting of the particles. The coarse sand is deposited nearest to the river, the fine sand further away and the clay furthest away of all.

If the river course is fairly stable the sand is usually deposited in raised levees along the river bank. These become the highest parts of the flood plain. On the side of the levee away from the river the land surface gradually falls away and the texture of the soil becomes heavier, passing through sandy loam to loam and finally to clay in the lowest part of the flood plain.

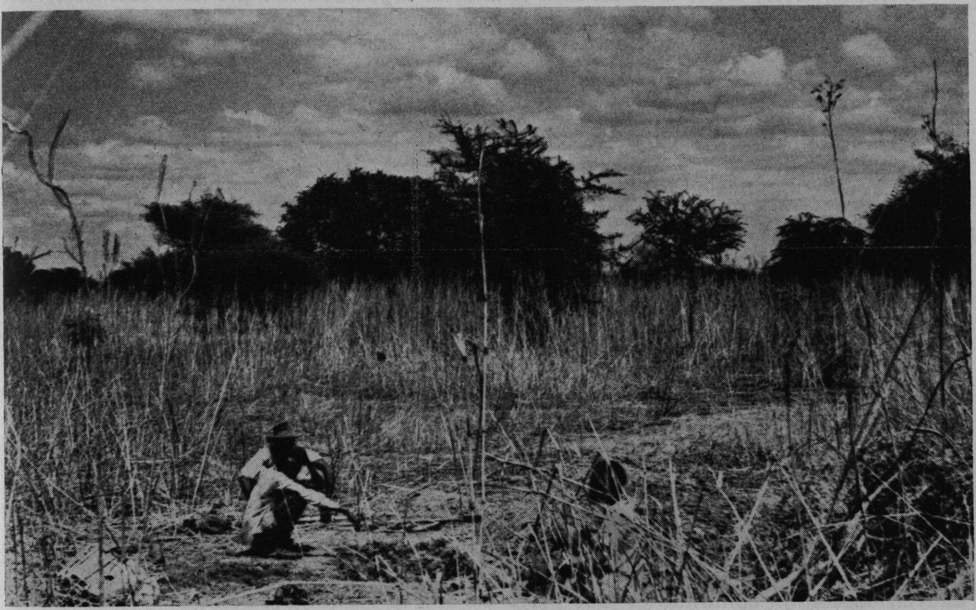

Plate 7.—Alluvial plain near the Mbarali River, Usangu; the site of the soil of Plate 8. (After dry-season fire)

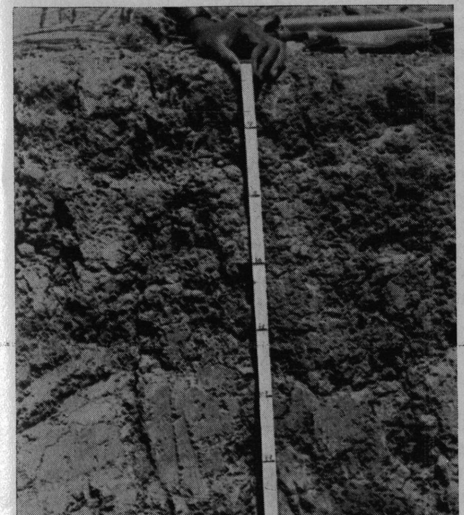

Plate 8.—Open-textured Alluvial Clay on site shown in Plate 7. The scale is marked at 10 cm. intervals

Plate 9.—Compacted Alluvial Clay in Usangu

Often, however, the river in an area of alluvial deposition changes its course every few years. In such situations stratified alluvial deposits are formed. Clay will be deposited at a particular spot for some years. The river will then move much nearer and the clay will be covered by a layer of coarse sand, to be followed perhaps by a layer of fine sand or silt.

Large rivers, like the Rufiji in its lower reaches, tend to be relatively stable and to build up considerable thicknesses of uniform alluvium, though eventually even these rivers change their courses. Frequent changes in course are characteristic of rivers forming alluvial fans at the foot of escarpments. Examples occur along the southern edge of the Usangu Plain, at the foot of the Kipengere Range.

The alluvial material carried by the river consists partly of soil washed off the catchment area of the river and partly of rock powder produced by the grinding together of rocks in the bed of the river in its steeper reaches. Normally there is a fairly high proportion of the "powder" and since this consists of rock minerals which have not been exposed to much chemical weathering such material has a high content of the mineral elements (calcium, potassium, phosphorus, etc.) required by plants. It therefore produces a fertile soil. Sometimes, however, where there has been unwise clearing of trees from a catchment area, the greater part of the alluvium may consist of eroded soil and if the soil was of low fertility, as it often is when severe erosion occurs, the alluvium deposited is also of low fertility.

Whatever the source of the alluvium, as soon as the flood waters recede the alluvial deposits become exposed to the normal weathering processes—chemical breakdown of the minerals and leaching away of the soluble products, with an accumulation of the more inert constituents. The amount of weathering which takes place in one year is small and if alluvial deposition continues to take place the soil at that site remains a "young alluvial soil", at any rate in the upper part of the profile.

If, however, deposition is much reduced or even ceases, whether due to changes in the course of the river or to a diminution in the extent of the flooding due to a lessening of the rainfall, the weathering processes gain the upper hand and eventually produce an "old alluvial soil". It is a process which probably takes centuries to produce a marked difference and there is of course no sharp distinction between a "young" and an "old" alluvial soil. It is necessary to recognize, however, that deposits which are unquestionably alluvial do not necessarily produce fertile soils.

Alluvium can also be deposited in lakes, the material being carried into the lake by rivers feeding it. Near the edge of the lake there will probably be sandy deltaic deposits not very different from river alluvium. But in the centre of the lake, if it is large enough, only the finest of clay particles will be deposited and they may be mixed with carbonates, silica or salts precipitated from the lake waters. Such deposits give rise, if the lake dries up, to calcareous, alkaline or saline soils which are often of low agricultural value.

Young Alluvial Soils.

It has already been stated that young alluvium usually contains a good reserve of mineral plant nutrients. Very sandy alluvium, although it may contain all these minerals, has often too low a water-holding capacity to be a useful agricultural soil. In the Rufiji Valley crops are sometimes planted on sandbanks in the river-bed as they emerge from the subsiding river. The water-table is always within root range and maintains a moist layer of sand above it by capillary action. Such utilization is only possible in exceptional cases.

In general the best alluvial soils are the sandy loams and the loams. They have good fertility, good permeability and are easily worked. The main trouble is the ever-present risk of floods. A method of utilization adopted by the Warufiji is to plant these soils (often with cotton) at the end of the wet season, as the flood subsides. The plant roots follow the falling water-table through the soil and a crop is produced with little or no rain. If flooding can be prevented crops can be grown on the natural rainfall but irrigation is the obvious answer in many cases.

The sandy loams are often rather too permeable for the best results under irrigation. The loams and clay loams are generally the most desirable soils for irrigated cropping, while the clays have a more limited use for crops which tolerate poor drainage conditions.

Plate 10.—Alluvial Clay at Mkula, Msolwa Valley, near Ifakara

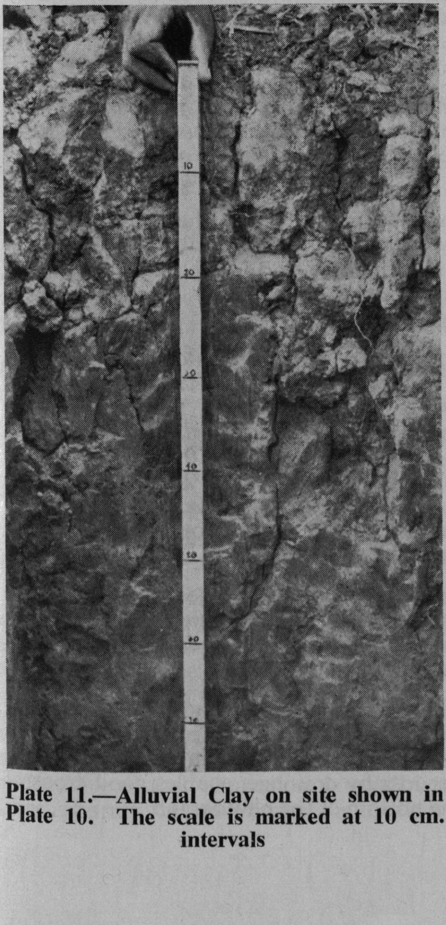

Plate 11.—Alluvial Clay on site shown in Plate 10. The scale is marked at 10 cm. intervals

Plate 12.—Sandy Alluvium at Brandt, Usangu

The following profile is an example of a young alluvial clay loam.

Situation. Ifakara, near bridge over Manjeja River (P. 170). Liable to flooding from Manjeja River. Vegetation: Tall grass (*Hyparrhenia*) and herbs.

0– 18 cm.	Very dark grey-brown clay loam (10 YR 3/2, moist). Medium subangular blocky structure; fairly porous. Fine brown mottles below 10 cm.
18– 45 cm.	Dark brown sandy loam (7·5 YR 3/2, moist). Common, reddish-brown mottles and staining along roots.
45– 90 cm.	Dark grey-brown silty clay (10 YR 4/2, moist). Coarse subangular blocky structure; fairly porous. Common, fine brown mottles.
90–180 cm.	Dark grey-brown sandy clay (10 YR 4/2, moist). Coarse subangular blocky to massive; fairly compact. Many strong brown fine mottles.
180–190 cm.	Dark grey sandy clay (10 YR 4/1, moist). Medium subangular blocky structure; very hard (dry). Some black iron concretions (3 mm. diameter). Many light yellow-brown fine mottles.

Alluvial soils are extremely variable but the dark colours, porous texture, the mottling and the considerable changes in clay content from horizon to horizon of this profile are all typical of young alluvial soils. There is no profile development; most of the differences between the successive horizons are inherited from the original alluvium.

Some analytical figures for this profile are given below.

Depth (cm.)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.	Clay %
0– 10	5·8	5·1	12·3	10	40
10– 18	5·6	4·0	8·1	6	46
18– 45	5·4	1·4	4·1	11	21
45– 90	5·3	2·5	9·1	4	51
90–180	6·2	0·3	—	2	49
180–190	7·5	—	8·3	2	41

The profile is rich in organic matter and calcium and has a fairly good phosphorus content. The rise in pH at the foot of the profile is due to a slight increase in exchangeable sodium. This sodium, together with the more compact consistency of the two lower horizons, indicate the aging of the alluvium in this part of the profile.

This Ifakara profile receives a rainfall of about 40 inches and is therefore somewhat acid and is kept free from soluble salts. In dry areas there is often saline ground water which can rapidly convert a young alluvial soil into a saline or an alkali soil. The term "young" implies lack of development since deposition and is not any measure of the number of years since that deposition.

Several Young Alluvial Soils are illustrated on Plates 7 to 12. Plates 7 and 8 show an alluvial clay which supports a good growth of grass and herbs. The roots of these maintain a porous structure in the top 1½ feet (45 cm.) of the profile. The soil shown on Plate 9 is similar to, and not far from, the first one. But, in contrast, it is heavily grazed and trampled throughout the year. In consequence the upper horizon of the soil has become compacted. The organic matter is also lower (1·7 per cent against 2·2 per cent for the first profile). Penetration of rain will be slower in the compacted profile than in the more open-textured one and the former will therefore suffer more from drought. Both these soils have about 50 per cent of clay in the surface horizon.

Plates 10, 11 and 12 show contrasts of texture in alluvial soils. The soil of Plates 10 and 11 has formed in fine-textured alluvium consisting of 34 per cent fine sand and 45 per cent silt and clay. Water penetration will be very slow and the soil is, furthermore, often flooded. The soil is used for rice-growing, for which it is well suited.

Plate 12 shows an alluvial sand consisting of 69 per cent fine sand and only 20 per cent silt and clay. The soil was used for maize-growing, under a rainfall of just over 20 inches a year. The soil was not subject to flooding and it is probably the stratum of clay at a depth of 3 feet (1 metre) which, by preventing any water loss by drainage, enables good crops of maize to be produced. This clay can be seen at the bottom of the photograph.

Old Alluvial Soils.

It is rare for alluvial deposition to continue indefinitely at any one spot. Sooner or latter the rate of deposition slows down or ceases completely. Weathering processes then gain the upper hand. The minerals in the alluvium decompose and their soluble breakdown products are leached out of the profile. With the disappearance of the micaceous minerals usually present in the fresh alluvium the soil becomes more compact, slower draining and more difficult to work. The phosphates are converted into insoluble compounds which only slowly give up their phosphorus to plants.

The following profile is not far from the Ifakara profile described above but is situated in a part of the Kilombero Valley in which there is now little alluvial deposition. Flooding still occurs, at least in some years, but the flood waters have passed across several miles of grassland and practically all suspended material has been filtered out.

Situation. Itete (P. 178). In flood plain of the Kilombero River. Vegetation: *Piliostigma-Combretum* scrub and tall grass.

0– 13 cm. Very dark grey-brown clay loam (10 YR 3/2, moist). Medium subangular blocky structure; moderately porous. Many reddish-brown fine mottles. Very hard when dry.

13– 30 cm. Very dark grey-brown silty clay (10 YR 3/2, moist). Coarse subangular blocky to massive; slightly porous. Many reddish-brown fine mottles.

30– 80 cm. Similar, but compact. Very hard when dry.

80–180 cm. Grey clay (10 YR 5/1, moist). Massive; very hard when dry. Common brown fine mottles.

The significant differences from a younger alluvial profile are the lesser porosity, the tendency to a massive structure and the somewhat paler colour (at least in the subsoil).

Fewer differences show in the analyses of the two profiles. Some analytical figures for the Itete profile are given below:—

Depth (cm.)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.	Clay %
0– 13	6·0	4·2	12·8	5	39
13– 30	6·6	2·0	10·8	1	55
30– 80	7·8	1·5	14·6	1	55
80–180	8·4	0·7	13·0	2	56

The chief points to notice are the lower phosphorus figures in the older profile and the rise in pH below 30 cm. depth which is due to accumulation of sodium. There has been little or no loss of calcium from this particular profile; its heavy texture and a seasonal high water-table have prevented any appreciable leaching. In many cases, however, weathering of alluvial profiles is accompanied by leaching of the calcium and other exchangeable bases.

CHAPTER 8.—SALINE AND ALKALINE SOILS: HARDPAN SOILS

SALINE AND ALKALI SOILS

Saline soils are those with harmful amounts of soluble salts, usually the chlorides or sulphates of calcium, magnesium or sodium. Alkali soils are soils with a high pH value due to a substantial part of the exchange complex being occupied by sodium.

The effect of salt is to increase the osmotic pressure of the soil solution so that plants cannot extract water from the soil. Plants differ in their ability to combat these conditions. Salt-tolerant ones have themselves a high enough osmotic pressure to extract water from such soils. But most useful crop plants are not salt-tolerant.

The osmotic pressure of a soil solution is laborious to measure and it is usual to determine the electrical conductivity of a soil suspension or of a water extract. The U.S. Soil Salinity Laboratory in California use the following scale for evaluating saline soils. The figure is the conductivity of the "saturation extract" which is the solution extracted from the soil at a rather arbitrary moisture content equivalent to about twice the "field capacity".

Conductivity milli-mhos/cm.	*Effect on crops*
Less than 2	Mostly negligible.
2–4	Yield of very sensitive crops restricted.
4–8	Yield of many crops restricted.
8–16	Only tolerant crops yield satisfactorily.
Over 16	Only a few very tolerant crops yield satisfactorily.

The effect of alkali, i.e., too high a level of exchangeable sodium, is to upset the nutritional balance of the plant and, in addition, to reduce permeability. Alkaline clays may be practically impermeable to water.

The usual measure of the soil alkalinity is the "exchangeable sodium percentage", i.e., the exchangeable sodium expressed as a percentage of the total exchangeable cations (bases). The U.S. Soil Salinity Laboratory regard soils having an exchangeable sodium percentage (ESP) of over 15 per cent as alkaline. The pH of such soils is usually more than 8·5 and may be as much as 10.

Since salinity and alkalinity can occur together there are three groups of soils to be considered:—

(1) Saline, non-alkaline.
(2) Alkaline, non-saline.
(3) Saline alkaline.

1. Saline, Non-alkaline.

These are soils in which soluble salts have accumulated. Sometimes the salt comes from sea-water as, for example, in parts of the Rufiji Delta and in mangrove swamps along the coast. More often, in Tanganyika, the salts are produced by the natural weathering of rock minerals. The amount of such salt formed in any one year at any one site is exceedingly small. In the wetter parts of the country this salt is dissolved in rain-water and washed into the rivers, and eventually into the sea. In the drier parts the salts remain where they are formed or, more often, accumulate in low-lying areas where the drainage water collects and evaporates.

Thus saline soils are a serious problem in the Pangani Valley. The head-waters of the Pangani River lie on the volcanic lavas and ashes of Kilimanjaro and Meru. These lavas and ashes weather rapidly so that the water draining from the mountain slopes has a relatively high salt content. The real trouble arises because this water, after leaving the mountain slopes, has to cross a long flattish area of low rainfall. In the wet season the Pangani River floods this flat area and the flood-water eventually evaporates, leaving its salts in the soil. Saline soils are also common in internal drainage basins such as the Rift Valley in the Northern Region and the Bahi Swamp in the Central Region.

The U.S. Soil Salinity Laboratory considers as "saline soils" those with a conductivity of the saturation extract greater than 4 milli-mhos per centimeter. Until more work has been done in East Africa it appears desirable to adopt the same standard.

In the field saline soils can often be recognized by a white efflorescence of salt showing on the sides of trenches, pits, erosion gullies, etc. In severe cases the salt may crystallize on the soil surface. Usually the natural vegetation gives a good indication of salt since salt-tolerant plants tend to become dominant on saline soils. Dames lists the following plants, amongst others, as being salt indicators in the Pangani Valley:—

Suaeda monoica, Forrsk. (Salt bush).
Triplocephalum holstii, O. Hoffm.
Volkensia prostrata.
Salvadora persica, L.
Sporobolus robustus, Kunth.

Saline soils can have a wide range of colour and texture since salting-up is usually a secondary process occurring in a previously formed soil. In so far as they usually occur in depressions their colours are usually those of poorly drained soils, greys and grey-browns.

In Tanganyika salinity usually accompanies alkalinity; saline, non-alkaline, soils appear to be fairly rare except where they are due to penetration of sea-water on the coast. The following soil from the Rufiji Delta is saline, non-alkaline, at the surface but only slightly saline in the subsoil. Good rice crops were said to be obtained nearby; some rice varieties are fairly salt tolerant and it is possible also that during the growing season the salt is partly washed down into the subsoil.

Situation.—Usimbe Island, in the Rufiji Delta (Profile R25). Level alluvium. Grassland, on edge of contract ploughing area. A few feet above sea-level.

0– 25 cm. Grey clay, with slight mottling. Many fibrous roots.

25– 85 cm. Grey clay, with slight brown mottling. Cracking on drying; fairly compact.

85–120 cm. Light grey micaceous silty clay with much orange mottling. Fairly compact; no cracking.

120–180 cm. Pale grey clayey fine sand with yellow mottles. Massive.

Depth cm.	pH	Organic matter %	Exch. Ca. me/100g.	ESP. %	Conduct. of S.E. millimhos.
0– 25	4·8	2·6	16·4	6	12
25– 85	4·7	0·9	9·6	21	1
85–120	4·3	—	—	—	—
120–180	4·4	0·3	4·4	25	4

The low values for the pH are very surprising. It seems likely that acidity has developed on the drying of the samples due to oxidative changes and that at the time of sampling the soil would have shown much less acidity.

In saline soils the clay is flocculated by the salt present so the soil usually has a good permeable structure. If subsoil drainage can be provided the salt can readily be washed out of the upper layers of the soil. Unless, however, calcium remains the predominant ion the clay will become dispersed when the salt has fallen to a low concentration. Soils with appreciable clay will then become impermeable to water. Reclamation should not be attempted without previous soil analysis and, if possible, trial leachings of small plots.

2. Non-saline, Alkaline Soils.

Following the U.S. Soil Salinity Laboratory, alkaline soils are defined as those in which over 15 per cent of the exchange complex is occupied by sodium. Such soils, if free from salt, usually have a pH value of over 8·5.

Some alkali soils have probably developed on the beds of former salt lakes and may therefore have been alkaline from the start. In other cases the soil was originally non-alkaline, i.e., with calcium dominant in the exchange complex, but has become alkaline through replacement of the calcium by sodium. This can happen if a calcium soil is exposed to drainage water with a sufficiently high sodium content. The sodium in the water gradually replaces the calcium in the soil and the displaced calcium is precipitated in the soil as carbonate or leached out as chloride or sulphate.

Like saline soils, alkaline soils are usually found at the foot of slopes and in bottomlands. They tend to develop on alluvial or colluvial material. Many of the mbugas of the dry parts of Tanganyika have an alkaline soil; some of these mbugas have been lakes in the past.

These low-lying alkaline soils are usually heavy in texture and dark grey in colour. They are sticky when wet and when dry form extremely hard clods. The clay is dispersed, with the result that permeability is low and drainage is very poor.

This poor drainage means that much of the rain is shed as run-off or is lost by evaporation. In consequence, the vegetation of alkaline soils is often typical of a lower rainfall than that actually experienced. Alkaline soils on the Usangu Plain, under a rainfall of a little over 20 inches, carry a scrub of *Commiphora* species, *Acacia kirkii*, *Acacia stuhlmannii*, etc. Adjacent more permeable soils carry *Acacia spirocarpa* woodland. The following profile is an example of the alkaline areas.

Situation. At Luhanga (near Utengule) on the Usangu Plain (P. 249). Level alluvial plain with thorn-bush; *Acacia kirkii* dominant with *A. spirocarpa*, *Commiphora* sp. and *Delonix elata*. Site flooded to about 6 inches depth for short periods in wet season.

0–15 cm. Dark grey-brown clay (10 YR 4/2, moist) with common reddish-brown mottles. Coarse subangular blocky. Extremely hard (dry).

15–40 cm. Similar; mottles fewer and yellower.

40–190 cm. (+) Brown clay (10 YR 5/3, moist). No mottles. Medium to fine subangular blocky. Hard and very compact (dry). Carbonate concretions present.

Depth (cm.)	pH	Organic Matter %	Exch. Ca. me/100g.	ESP. %	Clay %
0– 15	6·4	1·4	9·4	9	45
15– 40	7·2	0·8	—	—	—
40– 90	8·4	0·2	12·7	27	46
90–140	8·7	—	—	—	—
140–190	8·9	—	13·7	28	44

In no horizon did the conductivity of the saturation extract reach a value of 2 milli-mhos/cm.

A feature of some strongly alkaline soils is that drainage water which has passed through the soil becomes dark brown owing to the solution of part of the organic matter in the alkaline medium. Puddles of water on the surface may also be dark brown and these leave a dark crust on drying. This gave rise to the old name "black alkali" soils. "White alkali" soils were those in which white salts crystallize at the surface.

The "hardpan soils" of many parts of Tanganyika are often (but not always) alkaline These soils are often quite sandy in texture yet as little as 10 per cent of alkaline clay seems. to be sufficient to bind the angular sand-grains into a kind of "concrete", which is hard when dry and only slightly permeable to water when wet. This appears to be the explanation of the impermeability of many of the Itogoro hardpan soils of Usukuma.

Sometimes, also, soils which have formed in well-drained situations become, at a later date, converted to alkaline soils by a change in the water regime. Such soils retain their reddish or brownish colours after their development into alkaline soils.

Near Chimala, in Usangu, there are patches of brown sandy alluvial soil (20 to 30 per cent clay) in which white crystals of sodium carbonate form on the surface in the dry season. This carbonate raises the conductivity of the soil and puts it in the saline-alkaline class. The following profile, from the same area, is a milder case in which the sodium carbonate, although forming as a slight white efflorescence on the side of the profile pit below 70 cm. was insufficient in amount to raise the conductivity of the saturation extract to 4 milli-mhos. The profile was on a ridge several feet high and the soil is extremely sandy in texture so that percolating rainwater can wash down most of the sodium carbonate which may rise during dry periods to the upper part of the profile.

Situation. Brandt Mission, near Chimala (P. 243). A low ridge of sandy alluvium. Cultivated for maize.

Depth (cm.)	pH	Organic matter %	Exch. Ca. me/100g.	ESP. %	Clay %
0– 15	7·5	1·0	6·8	3	9
15– 40	7·6	0·7	5·9	17	—
40– 70	8·0	0·5	—	—	—
70–102	8·8	0·15	2·3	22	3
102–127	9·2	—	4·4	43	21

These figures illustrate the fact that the harmful effects of alkali are a combination of high pH and poor drainage. A clay soil with an ESP of 17 to 22 would have been too poorly drained to produce a good maize crop, which this very sandy soil did.

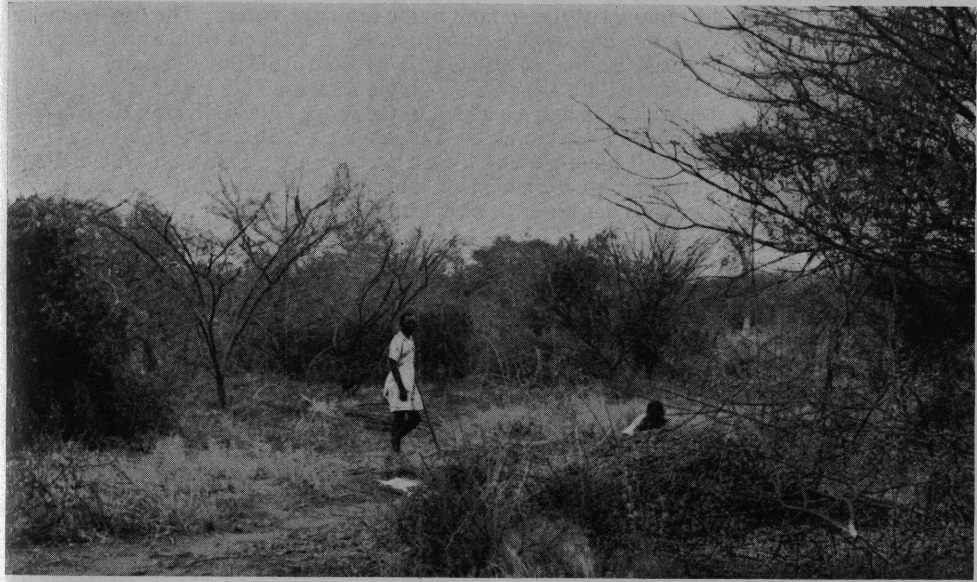

Plate 13.—Thornbush (chiefly *Acacia kirkii*) on Saline-alkaline Soil at Kimande, Pawaga

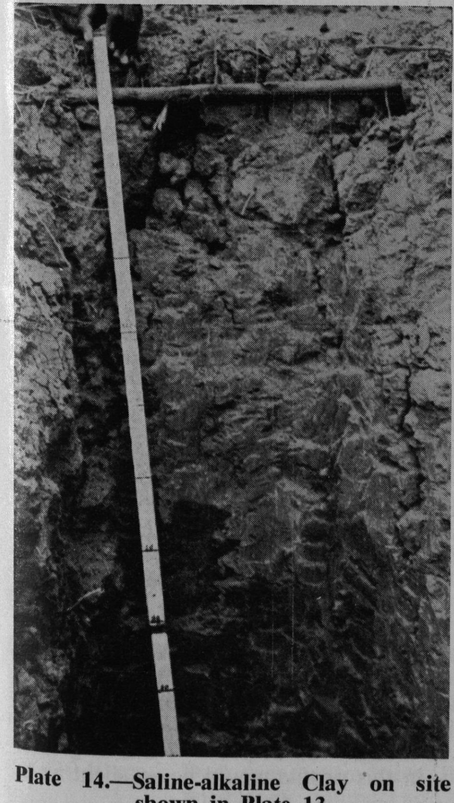

Plate 14.—Saline-alkaline Clay on site shown in Plate 13

Plate 15.—An alkaline hardpan at 20 cm. depth with a loose, sandy topsoil at Madibira, Usangu

The reclamation of alkali soils involves the replacement of at least part of the exchangeable sodium by calcium and the removal of the sodium in the drainage water. The first requisite is through drainage. When this has been secured the soil is leached with water carrying calcium in solution. The usual source of calcium is gypsum (calcium sulphate). If the soil contains calcium carbonate within the profile, simple leaching with water is sometimes sufficient. In America sulphuric acid may be added to the water to help dissolve the calcium carbonate but this is likely to be uneconomic in Tanganyika. Laboratory analysis of the soil and trial leachings of small plots should always precede any attempt at reclamation. In general, alkali soils are harder to reclaim than saline soils because they are usually so impermeable that it is difficult to get water to pass through them.

3. Saline-alkaline Soils.

The previous two sections have described soils which are saline only or alkaline only. There are also soils which are both saline and alkaline. They are found in the same sort of positions as those with only one of the characteristics; namely in low-lying sites where the drainage is poor and evaporation is high. The incoming water brings in sodium salts, the sodium replaces calcium in the clay complex, making the soil alkaline and the remainder of the sodium, often together with some calcium and magnesium, remains in the soil as salt.

The following description of a saline-alkaline profile is taken from Dames' report on the *Soils of the Pangani Valley.*

Situation. Pangani Valley. Level plain, flooded for the greater part of the year.

Vegetation: Tall grass and sedges, with the shrubs *Pluchea dioscoridis*, *Sesbania pubescens*, and the tree *Acacia xanthophloea.*

0–20 cm. Very dark grey clay (10 YR 3/1, dry). Medium blocky structure. Very many roots. No carbonate.

20–50 cm. Black clay (10 YR 2/1, dry). Coarse columnar structure. Many pale brown calcareous spots and some hard lime nodules. Fair number of roots.

50–90 cm. Very dark greyish-brown clay (10 YR 3/2, dry). Irregularly-shaped lime concretions.

90+ cm. Very dark greyish-brown fine sandy micaceous clay or clay loam (10 YR 3/2, dry). Many lime concretions. Roots present. Becomes wet at a depth of 150 cm.

Depth (cm.)	pH	Conductivity of S.E. (m-mhos/cm.)	ESP.
0–20	9·0	0·6	19
20–50	9·0	10·4	57
50–90	9·0	22·9	53
90+	8·8	22·2	72

The figures quoted show that the soil is saline below 20 cm. depth and alkaline throughout.

The process of reclamation of saline-alkaline soils is similar to that of alkaline soils. Through drainage must first be obtained. Gypsum is then spread on the surface and the profile is leached with water. If the soil contains sufficient calcium sulphate or calcium carbonate the gypsum may not be necessary. The operation to cure the alkalinity will usually remove salinity at the same time.

Plates 13 and 14 show an example of an intractable saline-alkaline soil developed under a low rainfall on alluvial clay. The top foot (35 cm.) has a pH of 8·7 but is without any serious accumulation of salt. There was a sudden rise in salt content at 35 cm. giving a conductivity of the saturation extract of 7 milli-mhos/cm., increasing to 10 milli-mhos/cm. at greater depths. With this rise in salt there was a slight fall in pH to 8 but at greater depths still the pH increased again. Permeability in this profile would be so slight as to make reclamation most difficult.

HARDPAN SOILS

In the drier parts of Tanganyika there are found soils which on drying reach an almost cement-like hardness. Often there is a surface layer of loose sand overlying the hardpan but sometimes the soil is hard right to the surface. When moistened the hardpan is softened but in the more extreme examples the material is so compact that the rain only penetrates the top inch or two, and the lower layers remain dry and hard. The soils occur at the foot of slopes but usually slightly above the level of the associated valley-bottom or mbuga so that water in excess of that absorbed, runs off on to the lower ground.

The vegetation on hardpan soils is, not surprisingly, usually sparse. Commonly there are clumps of shrubs or small trees separated by wider spaces which carry a thin growth of ephemeral grasses and herbs. The grasses and herbs live on the moisture in the surface horizons of the soil. The roots of some of the shrubs and trees penetrate the hardpan, though many must rely on a wide spread of shallow roots to obtain their water.

These soils are usually alkaline, i.e., have a high percentage of exchangeable sodium on their clay particles. This sodium clay is easily dispersible. The hardpan probably forms by this dispersed clay being carried down the profile by percolating water and being deposited in the pore-spaces of the sub-soil. The original top-soil may remain as a loose sandy layer or it may be eroded away, leaving the hardpan exposed at the surface.

Hardpan soils have a fairly high content of coarse sand which provides a "framework" to be cemented by the clay. The cemented sand cannot shrink on drying because the sand grains interlock. It does not therefore produce cracks down which subsequent rain water can penetrate.

The following soil from near Mapogoro on the eastern edge of the Usangu Plain, is remarkable for the low percentage of clay which is sufficient to cement the sand.

Soil M21. Near foot of slope; almost level. Vegetation is open. *Commiphora* scrub with *Acacia senegal.*

0– 9 ins. Grey-brown slightly clayey coarse sand (10 YR 5/2, moist). Single grain structure.

9–18 ins. Grey-brown clayey coarse sand (10 YR 5/2, moist). Very hard when dry.

Depth (ins.)	pH	Organic matter %	Exch. Ca. me/100g.	Exch. Na me/100g.	Clay %
0– 9	6·0 ...	0·35 ...	0·5 ...	0·2 ...	3
9–18	5·9 ...	0·60 ...	1·0 ...	3·1 ...	12

The soil is somewhat acid in spite of a high sodium content in the lower horizon. Probably the exchange complex was saturated at some earlier stage but is now being leached. Plate 15 shows a similar soil not far from M21.

The Itogoro type of Usukuma is probably an alkaline hardpan soil. It has a higher clay content than the Usangu soil just described and is hard to the surface. In the Luseni soils (also of Usukuma) the hardpan is overlain by about a foot depth of loose grey sand. There is a significant amount of sodium in the exchange complex of the hardpan horizon.

All hardpan soils, however, do not have a high exchangeable sodium. In the following example the sodium only becomes significant at 100 cm. depth but the soil is hard right to the surface.

Situation. Brandt Mission, on southern edge of Usangu Plain (P. 246). At the foot of a gentle slope. Vegetation: Open scrub, including *Acacia spirocarpa* and *Combretum* sp. Parent material: Mainly colluvium (from granite), possibly with some admixture of alluvium.

0– 10 cm. Dark grey-brown loam (10 YR 4/2, moist) with common mottling. Weak, fine blocky; compact and hard when dry.

10– 30 cm.	Dark grey-brown coarse sandy loam, no mottling. Massive, compact and very hard (dry).
30–100 cm.	Grey-brown loam (10 YR 5/2, moist) with common mottling. Massive and very compact; very hard down to 60 cm. increasing sand and less hard below. A few iron concretions throughout and some calcareous concretions below 60 cm.
100–130 cm. (+)	Brown clayey sand (10 YR 5/3, moist), no mottling. Massive, very compact. Slightly hard (dry). Iron and carbonate concretions.

Depth (cm.)	pH	Organic matter %	Exch. Ca me/100g.	Exch. Na me/100g.	Clay %
0– 10	6·3	1·4	5·2	0·3	24
10– 30	6·9	0·5	—	—	—
30– 60	7·5	0·3	12·0	0·4	36
60–100	8·2	0·2	14·1	0·9	—
100–130	8·5	—	11·9	7·6	12

It is difficult to explain why this soil should have become so compact. The rainfall is only about 20 inches a year so that vegetation is sparse and there are few fibrous roots to maintain a good structure. Once the surface has become compacted by raindrop impact water penetration is reduced and so the herbage is still further reduced and possibly the lower horizons settle down into a compact mass. Overgrazing is common and may have started the process.

Utilization.

In their natural state the hardpan soils are of very little agricultural use but all but the very alkaline ones could probably be developed into reasonable grazing. The first step would be to stop the run-off, probably by contour ridging. The extra water held on the land will increase plant growth which will in its turn improve water penetration.

The Luseni soils of Usukuma, where there is a reasonable depth of loose sand above the hardpan, are thrown up into large ridges by the Wasukuma and used for arable cropping.

Classification.

The hardpan soils, and especially those carrying clumps of shrubs separated by almost bare ground, were described as "Plains soils" by Milne in his soil map of East Africa.

The alkaline hard pan soils are similar to *solonetz* soils of Russian workers though the domed columnar structure of eastern European and Russian *solenetzes* has not been seen in Tanganyika. The acid hardpan soils with a high exchangeable sodium appear to be "degraded alkali" or *solodised-solonetz* soils.

CHAPTER 9.—PEAT: PALAEOSOLS

PEATS

Peat is formed from the accumulation of partly decayed plant material in swamps and other wet situations. It is not common in Tanganyika, due to a scarcity of permanent swamps. The most important development of peat in Tanganyika is probably in the West Lake Region, where it occurs in some low-lying sites near Lake Victoria.

Brief descriptions of peats from this area are given in the report of the *Water Resources Survey of the Nile Basin in Tanganyika* (Sir Alexander Gibb and Partners). One soil, in the Ngono Valley, was a black clayey peat two to three feet in depth. Below the peat there was greyish-brown clay and fine sand. Another soil, near the mouth of the Kagera River, consisted of a foot of reddish-brown to black well-decomposed peat; below this there was a fibrous mass of only slightly decomposed papyrus remains.

Some of these peats, on draining, produce fertile soils. Others, for reasons at present unknown, are extremely infertile after draining.

PALAEOSOLS

Reference has already been made, in the section on General Principles, to soils surviving from some distant age when the climate or drainage conditions were different from the present-day ones. If erosion has been slight the present-day soil, i.e., its mineral constituents at least, may have survived through tens of thousands or hundreds of thousands of years. Even if the original developed profile has been eroded away, the present-day soil may have developed on material weathered in the past under different climatic conditions.

In such cases, the original soil-forming factors may have produced characteristics, such as iron concretions or mottles, which have not been erased by succeeding climatic or drainage changes. There may thus be features which would not be expected if only the present climate or drainage were considered. These anomalous soils are known as Palaeosols.

It is only in recent years that the existence of Palaeosols has been recognized but already they have been noted in many parts of the world (and especially in Australia). A few such soils certainly exist in Tanganyika and no doubt others will be discovered. Most Palaeosols exhibit features recording wetter conditions (either higher rainfall or flatter relief) in the past than now prevail. This is probably because wet conditions produce changes in the soil which are not easily obscured by subsequent drier conditions. The climate of East Africa seems to have passed through several wet and dry cycles in the last million years or so. No doubt there are present-day badly-drained soils which originally formed under better drainage conditions, only they are more difficult to recognize.

Milne considered that the pale ferruginous soils of the Itigi thicket could not have formed under present-day climatic and drainage conditions. Some of these soils have a pH of 4·5 to 5·0 at the surface diminishing to 4·0 at 12 inches depth. This suggests severe leaching in the past. The iron concretions which are found in the subsoil suggest poor drainage whereas the soils lie in what is now a very dry area. Milne's theory was that the soils formed under swampy conditions. The disappearance of the swamp may have been due to a combination of lessening rainfall and tilting of the land during faulting at the nearby Rift Escarpment.

Somewhat similar soils are found near Kongwa (Mtanana series). Here the drainage may have been improved by tributaries of the Kinyasungwe River cutting back into a former fairly level plateau area. A higher rainfall in the past is also possible.

The extensive pale-coloured soils stretching from near Iringa southwards along the Great North Road to near Iyayi also appear to be relics. It is difficult to imagine this vast elevated area having been swampy in any geologically recent period. It is, however, probable that it was forest-covered in the not very distant past. The soils have not been carefully examined, as far as the writer knows, but may possibly be old laterised Yellow Earths. The elevation is about 6,000 feet and the present-day rainfall about 35 inches. Laterised soils under forest are found at Mufindi, at the same altitude on the eastern edge of this area, where the present-day rainfall is about 70 inches a year (p. 12).

These pale Southern Highlands soils are poor in calcium and probably in most other nutrients. An example is given in the *Rail Link Survey Report* (Profile 103 from near Makumbako).

The analytical figures for this profile were:—

Depth (inches)	pH	Organic matter %	Exch. Ca. me/100g.	Acid-sol. P. ppm.
0–21 ...	6·3 ...	0·52 ...	1·8 ...	8
21–42 ...	5·2 ...	0·86 ...	1·9 ...	6
42–50 (+)...	5·8 ...	0·34 ...	1·7 ...	6

Though this is a poor soil it is not quite valueless. The Itigi and Mtanana soils have an even lower fertility. One Mtanana profile analysed contained only 0·2 me. calcium per 100g. of the top-soil and less than this in the sub-soil. This soil is of no agricultural value in its present state and it would be uneconomic to improve it.

In general, Palaeosols are likely to be of low fertility owing to the long period during which they have been exposed to the weather.

GLOSSARY

Alluvium. Rivers and moving flood-water carry solid particles in suspension. These particles are ultimately deposited either in the river-bed, on land subject to flooding or in the sea. Deposits of such material in river-beds or on land liable to flooding (but not usually deposits in the sea) are known as alluvium.

Available phosphate, potassium, etc. The available phosphate in the soil is that fraction of the total soil phosphate existing in a form which can be taken up by plant roots (and similarly for other nutrients). In actual practice, figures quoted for "available phosphate", and other nutrients, are the amounts dissolved from the soil by some chemical reagent which is supposed to have an extracting power equal to that of the plant roots.

Colluvium. Colluvium is an accumulation of rock or soil particles which have moved into their present position under the influence of gravity, often assisted by rain splash or shallow sheet flow of water. Colluvium differs from alluvium in that the particles of colluvium have been pushed or rolled along the surface and not carried any appreciable distance in suspension in water. As a result the particles of colluvium are not graded into uniform sizes of particles, as alluvium usually is.

Exchangeable bases (cations). Atoms of the basic elements (calcium, sodium, etc.) are held on clay particles and organic matter by means of electrical charges on the clay and organic matter. The total number of electrical charges is not much affected by treatments applied to the soil but the attached atoms can readily be exchanged one for another. Thus, if a soil containing calcium in most of the exchange positions is flooded with a solution of a sodium salt, e.g., sea water, many of the calcium atoms on the clay and organic matter are replaced by sodium atoms. The term "cations" is similar in meaning to "bases" but includes hydrogen. The common soil cations (with their chemical symbols) are calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and hydrogen (H).

Exchangeable sodium percentage (ESP). This is the proportion of the total number of cation exchange sites in a given weight of soil which is occupied by sodium atoms. That is:—

$$\text{ESP} = \frac{\text{Exchangeable sodium (in milliequivalents)} \times 100}{\text{Cation exchange capacity (in milliequivalents)}}$$

Ferruginous. This word means, literally, "iron-bearing". In this Bulletin the word is used for soils in which iron oxides or hydroxides have separated out in part of the soil profile as concretions.

Field capacity. If a soil is treated with an excess of water (as in a heavy rain-storm) and then receives no more water for some days, there is initially a fairly rapid flow of water downwards into the sub-soil. But after a day or two, in most soils, this flow diminishes to little or nothing. The water remaining in the soil is held in the pores of the soil and as a film on the soil particles by surface tension. The amount of water held in this manner is the "field capacity" of the soil. The term only applies to the undisturbed soil in the field (not to samples dug up and carried into the laboratory) and only to soils which are freely drained.

Lateritic. In this Bulletin the word "lateritic" is used to describe soils containing a clay fraction rich in iron or aluminium oxides, i.e., having a silica/sesquioxide ratio considerably below 2. The iron oxide colours the clay, and consequently the whole soil, red or yellow. The iron or aluminium oxide occurs in the soil either as a coating on the clay mineral particles or as separate small particles.

pH. This is a measure of acidity. A neutral soil has a pH value of 7. Values below 7 indicate an acid soil; if below 4, an extremely acid soil usually of low fertility. Values above 7 indicate an alkali soil; the effect of the alkali begins to be serious at about 8·5.

Pisolitic. This word refers to concretions of about the size of a pea, the concretions being "pisoliths". It is usually applied to iron concretions, not calcareous concretions.

Profile. If a soil is exposed by means of a vertical cut from the surface down to the parent material, the section thus exposed is the "soil profile". Normally, a soil profile can be divided into several layers, each layer differing in appearance or properties from the layer above or below it. These layers, being more or less parallel with the surface of ground, are known as horizons.

Saturation extract. If water is added to a sieved sample of soil in a basin until it just begins to flow when the basin is tipped the soil is said to be at "saturation percentage". The solution obtained from such a soil paste is the "saturation extract".

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