Studies on Mineralogy, Micromorphology and Relationships of Soils along the Sukuma Catena in Maswa District, Tanzania

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Abstract

A study was done to characterize major soils in the typical catena soils of Sukumaland.These may be ethnoclassified as Ikungu (Haplic Acrisols), Itogoro (Eutric Vertisols), Ibushi (Calcic Luvisols), Luseni (Dystric Arenosols) and Mbuga (Calcic Vertisols). Selected typical soils were described and sampled from surface and subsurface horizons for mineralogical, micromorphological and fertility studies. X-ray diffraction studies indicated that the soils have different mineral components in the surface and subsurface horizons. Quartz is the dominant mineral in topsoils of both Ibushi and Luseni soils. The subsoils in Luseni soils are dominated by quartz but also and kaolinite clay mineral. Smectite and calcite predominate in the clayey soils(Itogoro and Mbuga). Both the surface and subsurface soils of most Ibushi soils are rich in calcite clay mineral. Haematite and kaolinite are dominant in Ikungu soils. Due to presence of calcite in Mbuga, Ibushi and Itogoro soils, these soils are prone to sodicity problems. Micromorphological data show the absence of interaction between the soil matrix and the weatherable minerals which also indicate that the soils are not formed **in situ**. *However, Ikungu soils have shown all characteristics of a soil with parent material weathering* **in situ**. *The soils can be grouped into categories of agricultural importance as follows: Luseni soils are infertile with acidity problems, Ibushi, Itogoro and Mbuga soils are sodic. Ikungu soils have favourable pH and therefore relatively better for agricultural purposes at present. In view of these differences the management of the different groups soils along the Sukuma catena deserve critical attention, if better agricultural output is to be realised.*

Keywords: Sukuma catena, mineralogy, micromorphology, soil management, Tanzania

Introduction

Currently, there is paucity of information on mineralogy, micromorphology and relationships on the main soils of the Sukuma catena Documented general accounts on soils of the Sukuma land were first given by Milne (1947). Recently, information on trends on soil and land resources of the Sukuma land has been produced by Ecosystems (1982). A comprehensive account on the soils and their suitability in relation to defined land utilisation types namely extensive grazing and cropping systems has been made by Ngailo *et al.*, (1994). All major soils occurring along the Sukuma catena have been coined local names which do not reflect mode of formation but mainly management, colour and drainage (Ngailo, 1994). The worthness of the Sukuma ethnopedology for a number of more distinctive soils that occur in the local area and how to identify them in the field has recently been given by Ngailo (1998).

The understanding of soil formation processes of the Sukuma catena requires a thorough understanding of many aspects including landscape, mineralogy, macro and micro-morphological features. Sources which give details on formation and mineralogical composition of these soils are lacking. Therefore, the recognition of these soils in the area including their patterns, relationships, mode of formation and mineralogy would need a thorough research which this study is intended to do.

Much of the information due to be generated as a result of this study will not only assist in providing knowledge required by academicians and researchers but also will give proposals for proper management strategies needed by land use planners. Among the many soil studies carried out in this area, none has attempted to provide information on mineralogy, and micro-mophology to substantiate the strict catena concept which Milne (1947) had described. Without over-emphasizing, the use and management of these soils for agricultural production require a more complete understanding of such properties than now exists. Consequently, on the basis of field and laboratory observations of several of Sukuma catenas, it was hypothesized that thin sections incorporated most information about pedogenesis and relationships of soils along the catena. This hypothesis was tested by comparing variations in soil data from soil survey based on processes which take place in the soil and the relationships to parent materials.

The objectives of this study were threefold:

1. to provide general information on chemical and physical attributes of the major soils on the catena;
2. to study micro-morphological characteristics and mineralogical composition of major soils of the Sukuma catena and;
3. to relate micro-morphology and mineralogy to the development and the relationships between the soils on the landscape.

Materials and methods

The study area

Maswa District is one of the four districts in Shinyanga Region, Tanzania. The altitude range between 1200 and 1300 m. The district has a semi-arid climate. The average annual rainfall is estimated to vary from about 600 mm in the south-east to about 700 mm in the north-west, i.e in the direction of Lake Victoria. The rainfall pattern is pronounced mono-modal. Evapo-transpiration is high in longer period of the year. The mean annual air temperature is about 28^{0}C.

Original vegetation in the area has been removed by human activities leaving behind alarming ecological conditions. Woodland and bushland species such as *Acacia*, *Combretum*, *Brachstegia*, and *Dalbergia* are among the original vegetation which can be traced in the area. The grass species are mainly composed of *Hyperrenia*, *Panicum*, *Chloris* and *Cynodon* species. These form the major part of the grazing land important for indigenous people who are mainly agro-pastoralists. There are many soil types in the district and can be identified on the basis of workability, colour;also type of crop which they can support (Ngailo, 1998). These soils are known by various names,but the major ones are locally classified as Ikungu (Haplic Acrisols), Itogoro (Eutric Gleysols, or Eutric Regosols), Ibushi (Calcic

Luvisols), Luseni (Dystric Arenosols) and Mbuga (Calcic Vertisols).

Sampling procedures

A detailed plan was followed in the collection of the samples to enable all soils to be represented properly. The soils were first studied by auger observations, then representative profiles were dug out. Soils were sampled from different horizons. Soil samples from major horizons, were air dried and fractions passing a 2-mm sieve were analysed at the Central Soil Laboratory at Mlingano for: particle size distribution by pipette method (Day, 1965), Organic carbon (O.C) by Walkley - Black method (Nelson and Sommers, 1982) and pH was measured in water and KCl; suspension using a soil/solution ratio of 1:2.5. The preceding ratio was also used for the measurement of salts likely to dissolve in soil solution by preparing a saturation extract . A saturation paste of soil and water was prepared from which the solution was extracted. The total salinity of this solution was measured by electrical conductivity (EC) (NSS, 1991). Cation exchange capacity (CEC) and exchangeable bases were determined by the neutral 1M NH_4OAc method (NSS, 1991).

Mineralogical analysis

Clay from the soil samples was separated and prepared for X-ray diffraction (XRD) analysis according to Emmerson (1971). The different minerals were identified according to Jackson (1965). From the same samples the mineral composition of sand and silt fractions were determined by optical methods. The results were cross-checked with the cation exchange capacity (CEC) data.

Micromorphological studies

Pedons for micromorphological characterisation were selected in typical soil types derived from different geological substrates. Undisturbed dry samples were used in this exercise. Thin sections were prepared using the technique described by Bullock *et. al.*, (1985). Additional micromorphological features were described employing the terminology and definitions found in Bullock *et. al.*, (1985).

Results and discussion

Physio-chemical properties

Table 1 presents some of the chemical data of the major soils. Comparing to other soils Luseni soils have low pH, low organic carbon and therefore low organic matter too. Organic carbon decreased gradually from A to C horizons in the profile. The ability of these soils to retain and supply nutrients to the crops is also low due to the low levels of cation exchange capacity. These soils are the poorest in terms of soil fertility. Generally, the cation exchange capacity of clay (CEC-clay) of soils is relatively high and exceeded the 16 cmolkg-1 clay limit of low activity clays. Both Luseni and Kikungu soils are characterised by low activity clays. Luseni soils are mostly found on the crests and upper slopes. It is assumed that these Luseni soils have been subjected to the adverse effects of leaching of exchangeable cations thereby resulting in lower pH values. Generally Luseni soils are moderately deep with a gravely layer in the deeper subsoil. A crust of iron and manganese is found within a depth of about 75 to 100 cm. but not obstructive to roots of most crops grown in the study area.

The pH in Itogoro and Mbuga soils is alkaline. In Itogoro soils the pH range

Table 1: Chemical properties in the control sections of the major soils

soil type and horizons	Sampling depth (cm)	Sand	Silt	Clay	Silt/clay ratio	pH H_2O	pH KCl	O.C %	Ec dSm^{-1}	ESP %	Na	K	Ca	Mg cmol (+) kg^{-1}	CEC	CEC-Clay %
Luseni																
Ap	0-15	90	5	5	1.0	5.9	4.9	0.5	0.02	8	0.19	0.40	1.0	0.7	2.4	8
AB	15-56	85	8	7	1.1	5.1	4.0	0.4	0.01	2	0.04	0.11	0.4	0.4	2.5	12
Bw	56-75	81	9	10	0.9	5.2	4.1	0.2	0.01	2	0.07	0.11	0.7	0.3	3.1	23
Csm	75-120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Itogoro																
Ap	0-10	63	13	24	0.54	8.4	7.4	1.0	0.14	6	10.36	0.69	45.7	1.7	24.2	84
AC	10-30	44	15	41	0.36	9.3	7.5	1.4	0.57	37	11.91	0.50	44.2	2.2	31.9	92
Cki	30-45	54	13	33	0.39	9.3	7.5	-	0.33	-	14.66	0.11	42.0	1.1	23.4	81
Ck2	45-60	43	19	38	0.59	9.4	7.5	1.3	0.61	-	10.64	0.56	42.3	2.8	31.1	91
Ck3	70-85	44	19	37	0.50	9.2	7.5	-	0.81	34	10.74	0.50	45.4	2.8	32.2	88
2Cgk	85-100	53	15	32	0.47	9.2	7.4	-	0.91	33	10.60	0.07	45.5	3.1	31.1	97
Mbuga																
Ah	0-15	43	21	36	0.58	7.8	6.1	0.9	0.11	8	2.30	0.83	19.3	2.7	28.7	70
AC	20-65	41	20	39	0.51	8.4	6.7	0.8	0.19	12	3.52	0.82	19.9	2.6	30.2	69
Ck1	70-90	37	23	40	0.57	8.7	7.0	0.7	0.24	17	4.97	1.08	18.0	2.4	28.9	65
Ck2	95-110	34	25	41	0.61	8.8	7.1	0.2	0.33	17	5.46	1.03	19.1	2.9	32.4	77
Ck3	115-140	29	25	46	0.54	9.0	7.2	0.1	0.40	20	6.20	1.09	40.7	2.7	31.1	60
Ibushi																
AC	0.5	66	16	18	1.12	7.9	7.3	1.6	0.15	1	0.39	0.52	32.1	2.3	26.8	128
ACl	5-10	68	15	17	1.13	8.3	7.4	1.3	0.10	1	0.19	0.23	22.4	2.1	21.5	108
Ck	15-25	63	24	13	0.54	8.4	7.3	1.3	0.10	1	0.22	0.17	33.0	2.2	25.4	96
Ckm	30-40	70	21	9	0.43	8.6	7.4	1.2	0.11	1	0.26	0.10	38.6	3.4	24.4	93
Ikungu																
Ap	0-8	60	13	27	0.48	6.0	4.8	1.7	0.09	4	0.48	1.19	5.8	2.9	12.8	22
BA	15-25	49	14	37	0.38	6.2	4.8	1.1	0.02	2	0.30	0.53	9.4	5.0	15.7	20
Bt1	35-55	45	10	45	0.22	5.8	4.7	1.1	0.02	0	0.40	0.49	4.3	3.7	13.2	20
Bt2	65-90	39	7	54	0.13	6.0	5.1	1.0	0.03	6	0.40	0.39	3.4	2.9	12.5	16
Bt3	100-110	36	8	56	0.12	6.5	4.3	-	0.04	0	0.30	n.d	n.d	2.0	17.9	25
Bt4	115-130	61	16	23	0.11	6.9	5.0	-	0.09	0	0.20	n.d	n.d	2.9	18.8	24

from 8.0 to 9.4 these high pH values are accompanied by high values of exchangeable sodium percentages. Electrical conductivity in all soils data has indicated that these soils are not salt affected. However, due to high levels of sodicity (>15 %ESP), Itogoro and Mbuga soils are by far liable to crop production problems due to sodicity problem. High sodicity levels are more serious and detrimental to most crops by inducing physiological drought and on the other hand causing soil structure instability in well structured soils. The cation exchange capacity is high and the presence of high levels of exchangeable calcium has contributed to the high CEC than the organic matter content as reflected by organic carbon values. Some of calcium ions are probably present in free carbonate forms as this has been observed by the saturation of the exchange complex (B.s. 100%).

The Mbuga soils have pronounced vertic properties. pH values in Mbuga soils is high and increases gradually with soil depth. The high levels of organic matter as reflected by organic carbon, seems to be greatly influenced by texture and not by organic matter as it is in other soils. Depending on land use, the rate of organic residues returned to the soil in normal farm operation is usually higher in finer textured and the rate of oxidation may be slower than in sandy soils. There is also an interaction between clay and organic materials and hence soils high in clay are able to protect nitrogen, and thence the organic matter from microbial degradation

(Jenkinson, 1988). Generally, Jenny (1980) has concluded that, assuming all other factors being equal, clay soils will contain more organic matter than sandy soils.This assumption however does not seem to always hold true in this situation because the Mbuga soils have less organic matter. The clay texture of the Mbuga soils retain most of the actions, this can clearly be observed by the increase in the level of exchangeable cations with depth. This phenomena is only observed in these soils but not in others.

Although Ibushi soils resembles most Itogoro soils in terms of chemical characteristics, e.g high CEC, CEC clay, Ca and B.S , it has organic matter values which do not decrease drastically with increase in depth. The behaviour of these soils need further research to explain such trend and its implications to use and management. Itogoro soils are also calcareous.

Second to Luseni soils the Ikungu soils have low pH, si/clay ratios, CEC, CEC-clay, Ca, and K levels. However the pH values are within range suitable for most crops without much difficulty. Clay content increase with depth clearly confirming the presence of an argillic B horizon. The low ratios of silt and clay and the relatively low CEC-clay partly explain that these soils are among the oldest in the area and have developed from comparatively older parent materials present in the study area.

Macro-morphological properties of major soils

The macro-morphological characteristics of the five soil types in the field are presented in Table 2. All profiles indicated marked differences in terms of colour, structure, consistence and texture. Most profiles are gradational, showing an increase in texture more importantly in the amount of clay with depth and also in a distinct change in textural class. Soils which change from finer to coarser textures have not been indicated with exception of those which are gravely in the subsoils e.g Itogoro, Ibushi and Luseni soils. Luseni soils have a weak, medium or fine granular structure in the surface horizons. In moist conditions most soils are friable particularly in deeper horizons. The structure develops to moderate, course and medium aggregates which are sub-angular blocky. The abrupt boundaries which have frequently been observed are indicated by a distinct change of colour and texture. Luseni soils are characteristically underlain by a continuous layer of iron and manganese concretions.

Itogoro soils are uniformly coloured throughout the profile. Structure is composed of moderately developed medium size aggregates with sub-angular blocky shape. The surface soils are friable in moist condition. Besides having sodicity problems, deeper in the profile the structure is relatively stronger with coarse and medium size aggregates having sub-angular blocky shapes as in the surface horizons. Full profile description indicates the presence of weathered round quartz and hard irregular calcium carbonate ($CaCO_3$) concretions and some chelonia shells at a depth of 100-120 cm.

In Mbuga soils, surface horizons bear resemblance in characteristics to those of the Itogoro soils. However, they have a strong coarse and very coarse prismatic and sub-angular blocky structure and a friable moist consistence. The subsoils have predominantly gray colours with friable aggregates in moist condition. The structure is weak very coarse and massive. There are few medium and coarse weathered round quartz gravel which to a greater extent resemble those present in the Itogoro soils. Surface horizons in Ibushi (plate 1d) soils have a very dark gray colour, with a friable soil material when moist. The structure is moderately

Table 2 : Macromorphological properties of major soils in Maswa District

Horizon designation	Depth cm	Colour (moist)	Texture	Mottles	Structure
Luseni					
Ap	0-15	10YR 4/3	LS	-	w,m,gr
AB	15-56	10YR 3/4	LS	-	m,c,sbk
Bw	56-75	7.5yr 4/4	gLS	-	w,m,sbk
Csm	75-120	iron and manganese concretion	vgLS	-	cemented
	no sample				
Itogoro					
Ap	0-10	10YR 3/1	CL	-	m,m,sbk
AC	10-30	10YR 3/1	C	-	m,c,sbk
Ck1	30-45	10YR 4/1	SCL	-	m,c,med,sbk
Ck2	45-60	10YR 3/1	CL	-	m,cm,sbk
Ck3	70-85	10YR 4/1	gCL	faint	-
2Cgk	85-100	10YR 4/1	egSCL	faint	-
		iron and manganese concretions	frequent quartz		
Mbuga					
Ah	0-15	10YR 2/1	C	-	s,c,p & sbk
AC	20-65	2.5Y 2/0	C	-	"
Ck1	70-90	2.5Y 3/0	C	-	"
Ck2	95-110	2.5Y 2/0	C	-	"
Ck3	115-140				
Ibushi					
AC	0-5	10YR 3/1	gC	-	vf,cr
AC1	5-10	10YR 2/2	slg C	-	m,f,sbk
Ck	15-25	10YR 2/1	gC	-	c,m,sbk
Ckm	30-40	10YR 4/2	gC	-	s,c,sbk
		10YR 4/2	CaC03 concretions mixed with rounded quartz		
Ikungu					
Ap	0-8	7.5YR 3/2	CL	-	s,mf,sbk
BA	15-25	5YR 3/3	C	-	s,mc,sbk
Bt1	35-55	5R4/4	C	-	m,mf,sbk
Bt2	65-90	2.5YR 2.5/4	C	-	w,mc,sbk
Bt3	100-110	2.5YR 2.5/2	C	-	w,mc,sbk
Bt4	115-130	2.5YR 4/2	C	-	w,mc,sbk

Texture: LS=loamy sand, gLS=gravely loamy sand, CL=clay loam, C=clay, SC=sandy clay, gCL=gravelly clay loam, slgC= slightly gravely clay, egSCL= extremely gravely sand clay loam. **Structure**: w=weak, mod=moderate, s=strong; f=fine, med=medium, c=coarse; gr=granular, sbk=subangular blocky,p=prismatic; f=fine, vf=very fine cr=crumb. Consistence:vf=very firm, fr=friable, vfr=very friable,h=hard.
Boundary:a=abrupt g=gradual c=clear, w=wavy

strong, with medium and fine sub-angular blocky units. Strongly weathered round quartz gravel are common in the first 20 cm. The deeper subsoils have calcium carbonate concretions with quartz grains imbeded within. Masses of $CaCO_3$ are predominant below 50 cm in most Ibushi soil profiles.

In Kikungu soils the surface horizons are friable when moist. However, the colour is dark brown increasingly becoming redder with depth. Moderate, medium fine granular structure is characteristic for the topsoils in most of the described Kikungu profiles.

Subsurface soils tend to be friable when moist as in the surface horizons. The structure is moderate with medium sub-angular blocky shapes. Irregular shaped small quartz gravels are observed in subsoils. Also, irregular iron and manganese concretions are found scattered but not as a continuous layer as found is in Luseni soils.

Micro-morphology of the soils.

Figure 1 presents the thin sections (plates 1a-1e) for the different soil types. Micro-pedological features from thin sections correspond with the macro-morphological characteristics. Surface horizons varied in micropedal structure types from weak granular to strongly developed peds (Table 2). Field observations showed no clay skins and micro-morphological study has shown no oriented clays. The lack of argillic horizon in semi-arid climates similar to that in the study area, has however been attributed to the disruption of the ped surfaces during shrinking and swelling cycles (Nettleton, *et. al.*, 1975) extensive desilication (Buol, 1965); or mixing with soil fauna (Hugie and Passey, 1963). The identification of argillic and cambic diagnostic horizons is fundamental to soil classification and to the interpretation of the dominant soil forming processes. Of vital importance to the identification of argillic B horizon (Soil Survey Staff, 1990) are the:-

(a) evidence of illuviation either as films on ped surfaces or as oriented clays in thin sections;

(b) clay content of the argillic horizons should exceed that of the overlying horizon by the specified amounts, depending on the clay content of the upper layer.

In this study with exception of Ikungu (Plate 1e) soils, soil profiles from all other soil types do not show the characteristics specified above. In Luseni soils (Plate 1a) due to position on the landscape appears to have formed in situ. It thus lacks the argillic B horizon due to the effect of desilication and probably leaching. However, the data in Table 1 indicates an increase in clay content in Itogoro (Plate 1b) soil which is significant enough to be assigned an argillic B horizon. Landscape and micro-morphological studies indicate that, Itogoro and Mbuga soils (Plates1b and Plate 1c) repectively are formed in the depositional materials of an old lake basin. Due to their high clay content they have undergone swelling and shrinking cycles resulting in disruption of ped surfaces. The presence of calcium carbonate in these soils is another reason which has probably restricted the formation of argillic B horizon. Like Itogoro and Mbuga soils, Ibushi soils (plate 1d) also showed no evidence of argillic horizons. Field observations did not however indicate the presence of

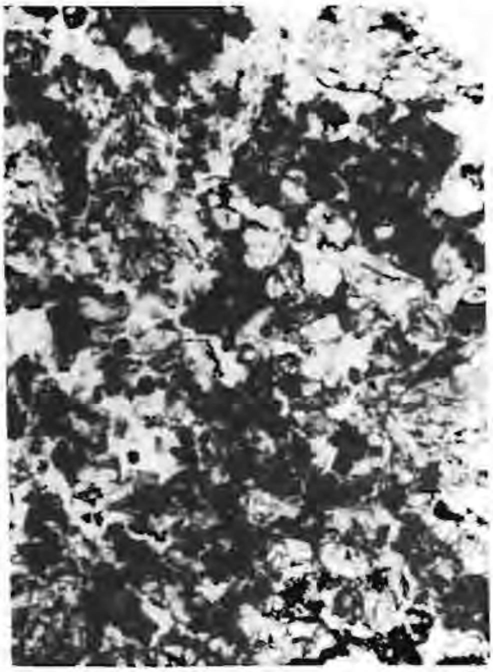

Plate 1a: Thin section of Luseni soil

Plate 1 b:Thin section of Itogoro soils

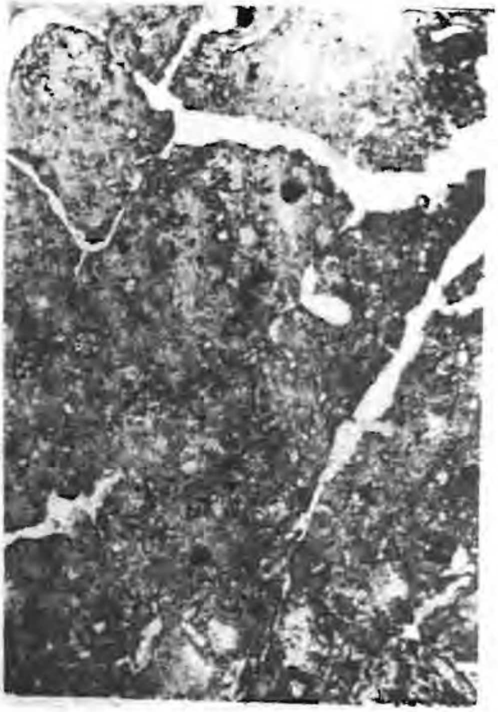

Plate 1c: Thin section of Mbuga soils

cutans, similarly thin sections have not indicated presence of oriented clays linings in pores and bridging the sand grains. This soil is dominated by calcite and has significant amounts of shrinking and swelling clays which might have disrupted argillation processes.

The only soil in the study area that has indicated the presence of argillic B horizon is Ikungu soil. Field observations showed clay cutans around ped surfaces and thin sections have confirmed the presence of oriented clays along voids (Plate 1e). Also the data on particle size distribution show very significant increase in clay content down the profile (Table 1); thus able to meet the criteria specified by Soil Survey Staff (1990) for an argillic B horizon.

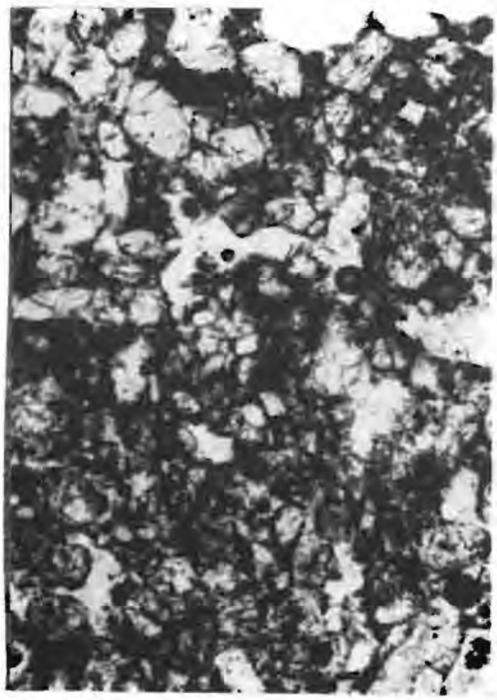

Plate 1d: Thin section of Ibushi soils

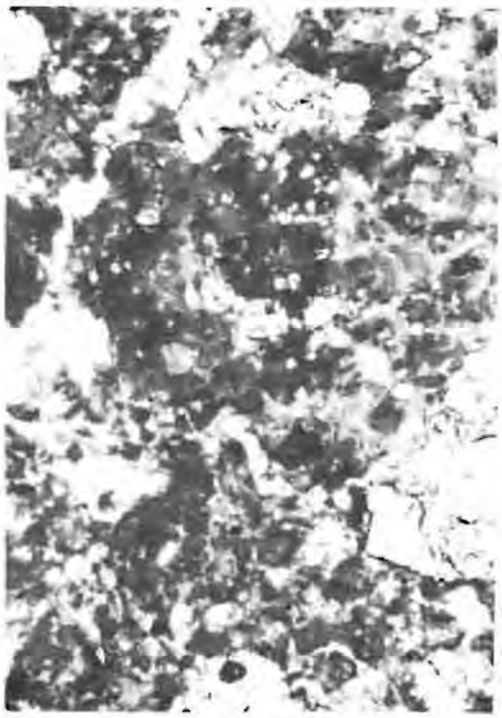

Plate 1e: Thin section of Ibushi soils

Figure 1: Thin sections of major soils

Thin section studies have shown that the quartz grains in Luseni and Ikungu soils are irregular in shape which confirm the fact that these soils have been formed in situ. The shape of quartz in Itogoro and Mbuga soils are predominantly rounded in the subsoils indicating long distance transport and deposition while in topsoils are sub-rounded. These are probably materials transported from upper slopes and have locally been deposited in the area. According to Bullock *et. al.*, 1985, the shape of quartz grains is of importance in determining the soil forming processes.

From Table 1 above based on the silt and clay fraction ratios, the age of the parent materials from which these soils ae formed can tentatively be estimated (Van Wambeke, 1962). Ratios based on individual soils are presented. They are lowest in those soils formed in depositional materials and metamorphic rocks, indicating that these are probably formed from oldest materials in the district. The si/clay ratios seem to be decreasing with depth particularly in Ikungu soils indicating that these soils are probably one of the oldest in the area.

This is assertion need to be proved further by other methods.

Clay Mineralogy

X-ray diffraction (XRD) data for dominant clay mineralogy for the major soils are presented in Table 3. The assessment has been complemented with data for CEC of the clay fraction (CEC-clay). The following are the present findings: Luseni soil has kaolinite, feldspar, quartz and haematite as the dominant mineral fractions. Kaolinite and haematite increase while the amount of quartz decrease with depth. The dominant clay minerals in Itogoro and Mbuga soils are smectite, quartz, and small amounts of feldspar and kaolinite. In Itogoro and Mbuga soils the amount of smectite and calcite also increases with depth. Haematite and kaolinite predominate in Ikungu soils.The haematite mineral is responsible for the reddish colours observed in Ikungu and to some extent in Luseni.

Relationship occurs between Luseni and Ikungu soils in the weathering patterns. Weathered minerals e.g. feldspar in Luseni soils show the interaction with the matrix (Plate 1a). Similar characteristics can be observed in Ikungu soils (Plate 1e). These characteristics are not shown in other soil types in this area. Such characteristics in Luseni and Ikungu soils show that the materials weathered in situ and were not transported. On the other hand the weatherable minerals in Itogoro, Mbuga and Ibushi soils do show a clear boundary and any compositional contrast with the matrix.

Relationship between mineralogical composition of soils, parent material and soil forming processes

There is a relationship between present mineralogical composition and the parent materials observed in the study area. The rock type which is clearly observable in the gently undulating plain is granite. The kaolinitic clay mineralogy of Luseni soils is more related to granitic parent material. In contrast, Itogoro and Mbuga soils are dominated by smectite and calcite with traces of mica which has not been altered to smectite. It clearly indicates that the origin of smectite in Itogoro and Mbuga soils is not from the granite because granite do not normally weather into smectites.

Several theories can be related to the formation of these clay minerals in the study area. Results from Kenya on the weathering of basic igneous rocks, suggested that in early stage of weathering,

Table 3: Dominant silicate and non-silicate clay minerals identified by X-ray diffraction

Soil name	Soil horizon	Clay Minerals					
Soil type	Part of profile	q	f	k	s	h	c
Luseni	Topsoil	1	2	2	0	3	0
	Subsoil	1	2	1	0	3	0
Itogoro	Topsoil	2	2	3	1	0	1
	Subsoil	3	3	0	1	0	1
Mbuga	Topsoil	3	3	3	1	0	2
	Subsoil	3	3	3	1	0	1
Ibushi	Topsoil	1	2	2	1	0	1
	Subsoil	2	3	2	2	0	1
Ikungu	Topsoil	3	3	2	0	1	0
	Subsoil	3	3	1	0	1	0

Key: 1 = dominant, 2 = Less dominant, 3= Rare, 4 = absent

q = quartz, f = feldspar, k = kaolinite, s = smectite, h = haematite, c = calcite

smectites were produced (Kantor and Schwertman, 1974).

As weathering proceeded smectites were decomposed due to the lowering of silica and magnesium concentration in solution because of the free drainage and rapid leaching. This results into an acid soil with a clay fraction dominated by kaolinite and some gibbsite although gibbsite has not been indicated in the present study.

Drainage within the regolith is also likely to influence the weathering products. Under free drainage silica losses are unimpeded, the bases are readily leached giving rise to low pH and kaolinite as the dominant clay mineral. Under poor drainage the loss of silica is slowed down and clays are resynthesised (Nortcliff, 1988). The high quantity of smectite in some soils is somewhat due to the soils being poorly drained. Silica, aluminium and magnesium tend to remain in the profile in alkaline conditions and cause in situ formation of smectite (Buol, 1965; Milot, 1971). Al Rawi *et. al.*, (1969) and Bunnet *et. al.*, (1972) noted that smectite was dominant in alluvial soils of many districts and regions.

These above facts however, agree with the clay mineralogy of Luseni, Itogoro and Mbuga soils. Luseni soil are well drained and are dominated by kaolinite whereas Itogoro and Mbuga soils being moderately to somewhat poorly drained are dominated by smectite. The presence of calcite in Itogoro and Mbuga soils clearly differentiate Luseni soils from other soils found on the landscape.

However, based on present studies on mineralogy and partly on macro and micro-morphological studies these soils probably originate from the same parent material. The clay mineralogy of Ibushi soil is dominantly smectitic, with some quartz, feldspar and to a small extent kaolinite. The present available data shows no differences in clay mineralogy between Itogoro, Mbuga and Ibushi soils.

Kaolinite, haematite and little amount of quartz dominate in Ikungu soils. The parent materials from which these soils have developed are basic metamorphic rocks probably pyroxinite or gneisses. The most differentiating characteristics are its depth and a uniformly deep red colour which is also indicative of the extent of weathering. The red colour is due to the presence of haematite.

Conclusions

The soils in the district have developed from contrasting parent materials as evidenced from mineralogy and micro-morphology data. The following conclusions can be drawn:

1. Ibushi, Ikungu, Itogoro and Mbuga soils have not developed from granite rocks. It is only Luseni soils which are related to the granitic parent materials. Itogoro and Mbuga have probably been developed from depositional materials as indicated by both field, micromorphological and XRD data and supported by chemical data and field observations of fossils at certain depths. Ikungu soils have developed from easily weathereable parent materials.
2. With regard to soil formation the only soil whose soil forming processes are very clear is the Ikungu soils. There has been a clear genesis of argillic B-horizon which has been identified both in the field and confirmed by micro-morphological studies. On the other hand, the soil forming process in the Mbuga soils is mainly influenced by pedoturbation and soil instability.
3. The dominant soil forming process in both Luseni and Ibushi soils is not clear but based on the shape of quartz grains, it seems that Luseni soils have been formed in place, while Ibushi soils have been formed in remnants of calcareous depositional materials of an old lake.
4. A close correlation exists between the clay minerals in Luseni soils and those normally present in granite rocks with kaolinite as one of dominant derivative clay mineral. On the other hand smectite and calcite are clay minerals dominant in Itogoro, Mbuga and Ibushi soils, all these soils have very low amount of mica.
5. The XRD data has generally shown that clay mineralogy in Itogoro and Mbuga are same.
6. Managing the soils in the Usukuma catena need particular attention since these soils have developed from a series of different parent materials. Ikungu soils seem to be the oldest and therefore will need more attention to maintain its productivity different from for instance Mbuga soils since fresh materials seem to be deposited on it from time to time.

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