SOILS INFLUENCED BY PYROCLASTICS

In the Nguu Volcano Area (Wilaya ya Machakos, Kenya)

by

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This Thesis is dedicated to my brother

Mwangi Nguya,

Who used to be my greatest inspiration.

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

Signed ____________________

W.N. Wamicha

This thesis has been submitted for examination with my approval as the University supervisor

Signed ____________________

Dr. V.P. D'Costa

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LIST OF ABBREVIATIONS

1. ORGANISATIONS

FAO - Food and Agricultural Organisation (of the United Nations)

INQUA - International Union for Quarternary Research

KSS - Kenya Soil Survey

NAL - National Agricultural Laboratories

UNESCO - United Nations Educational Scientific and Cultural Organisation

USDA - United States Department of Agriculture

2. WEIGHTS

g - gramm

3. DISTANCES

mm - millimetre

cm - centimetre

km - kilometre

4. AREA

Ha - Hectare

km^2 - kilometre squared

5. VOLUME

cm^3 - cubic centimetre

6. RATIOS

g/cm^3 - gramm per cubic centimetre

me/100g - milliequivalents per 100 gramms

% - percentage

7. pH

pH - Negative log base 10 of hydrogen ion concentration

pH-H_2O, 1:2½ - pH at soil to water volume ratio of 1 to 2½

pH-KCl, 1:2 - pH at soil to potassium chloride volume ratio of 1 to 2

8. EXCHANGEABLE CATIONS

CEC - Cation exchange capacity

Exch (Ca) - Exchangeable (calcium)

9. SOIL COLOUR NOTATION

The colour may be given at dry or moist state of soil as follows:

10YR 3/2 - Very dark greyish brown

10YR - Colour hue which is 10 yellow-red

3 - Colour value

2 - Colour chroma

10. NUMBERING OF PROFILE PITS

The soil profile pits are numbered from 174/1-170 - 174/1-185 in the Kenya Soil Survey (KSS) Data Storage as shown on Tables 2 to 6. In this text, they have been numbered from 1-13 (Tables 2 to 6).

11. CITING OF REFERENCES (PUBLICATIONS)

loc.cit. - Publication was cited elsewhere

Longwell, et.al. - Longwell and others.

12. SOIL HORIZON DESIGNATION SUFFIXES

As per FAO (1977) guidelines

b - Buried or bisequal soil horizon

k - Accumulation of calcium carbonate

t - Illuvial accumulation of clay

u - Unspecified

ABSTRACT

A reconnaissance soil survey was carried out of sample strip about 2km wide and running 14km west from the Nguu Volcano. The main objectives of the study were to find out the effect of the Nguu pyroclastics on the soils and to classify the soils.

The thickness of the pyroclastic surface soils and their dominant particle sizes decrease away from the Nguu Volcano (source of the pyroclastics). On the volcano, there are bombs and blocks (>2.00mm diameter) which constitute a coarse particle zone. Here the entire soil profiles are developed from the pyroclastics per se. Between 2-10km west of the Nguu Volcano, is a sand (2.0-0.2mm) sized particle zone where the thickness of surface soils decreases gradually westwards from 65cm to 46cm. In this sand zone the soil profiles show surface soils, with additions of the Nguu pyroclastics and the paleosols being developed from the gneisses or basanites. West of the sand zone is a silt one (<0.2mm) which extends from 10km to the end of the project area (14km). In the silt zone, the depth of surface soils increases from 46cm to 60cm corresponding to rising altitude and overlie the basanite paleosols.

Using the FAO-UNESCO 'Legend' eight soil classification units were established which are found on four physiographic forms. On the Nguu Hill are found the

Vitric Andosols unit (Tv-6D/H/V), and Ochric Andosols (To-5C/U/V). These Andosols are characterised by textural breaks which mark the different layers of volcanic pyroclastics from which the soils were developed. Further, the soils are dark coloured (dark brown) reflecting the dark vitreous pyroclastic parent materials. They also contain the pyroclastic index minerals (volcanic glass, olivine, augite and allophane) which shows that they are developed on the pyroclastics *per se*. Compared with other soils in the area, the Andosols (Tv- and To-) have abundant reserve of plant nutrients as reflected by; weatherable minerals (>20%), total bases (13-46 me/100g soil) and CEC (20-45 me/100g soil). But their agricultural use would be hindered by the steep slopes, stony-bouldery surface and pockets of very shallow soils.

From the foot of the Nguu Hill to the end of the project area are the Orthic Ferralsols with units (Fo-3BC/U/U) on uplands and (Fo-5A/P/B) on plains. These Ferralsols are characterised by a layer of surface soils having additions of fine (<2.0mm) pyroclastics overlying the gneissic paleosols (Fo-3BC) and basanitic paleosols (Fo-5A). The boundary between the surface soils and paleosols is marked by 'textural breaks' as indicated by; the sandy loam to sandy clay loam textures of the surface soils and clay loams of the paleosols. The distinction is also shown by darker (dark brown) surface soils compared with the respective paleosols that are strong brown. Further, the surface soils of Ferralsols (Fo-3BC and Fo-5A) contain volcanic glass, olivine, augite and allophane - the index minerals of pyroclastics. On the other hand, the paleosols of unit (Fo-3BC) have muscovite, microcline and hornblende minerals indicative of the metamorphic gneisses. But, the paleosols of (Fo-5A) contain augite and olivine which are constituent minerals of pyroclastics as well as basanites. However, unlike the pyroclastic surface soils the basanite paleosols of unit (Fo-5A) lack volcanic glass or allophane (index minerals of the pyroclastics). The nutrient reserve in the surface soils (weatherable minerals >10%, total bases 7.0 me/100g soil and CEC 9.0 me/100g soil) is slightly higher than in the paleosols (weatherable minerals <10%, total bases 4.0 me/100g soil and CEC 7 me/100g soil). These Ferralsols which are on gentle slopes, are very deep and have surface fertility, and are therefore suitable for cultivation of adaptable crops.

A valley association of soils occurs along the intermittent Minor Valleys in the area. The Chromic Luvisols (Lc-3BC/U/F) and Orthic Luvisols (Lo-3B/U/F) are on the Valley sides while Pellic Vertisols (Vp-1AB/V/X) and Dystric Planosols (Wd-6AB/V/F) occur in the Valley bottoms. The valley sides are affected by severe soil erosion therefore conservation measures are required. The valley bottom soils (Vertisols and Planosols) are imperfectly drained and have compact B-horizons. If the valley bottoms were to be cultivated, artificial drainage and deep tillage would be necessary.

Thus the Andosols (Tv- and To-) though with high basic fertility, their cultivation would be hindered by steep slopes of the volcanic cones, coarse pyroclastics on the surface and in places by shallowness. On the other hand, the Ferralsols (Fo-3BC and Fo-5A) would be suitable for cultivation since they occur on gentle slopes, have moderate fertility in the surface soils and are very deep

CHAPTER 1: INTRODUCTION

In pedology four categories of soils have been recognized (Ruellan, 1971). In the first category are the pedoliths which are pieces of soil found in sedimentary rocks. In the second, are soils which are in balance with their environment, supposedly have developed in an environment similar to their present one. And in the third category are relict soils which have certain (sometimes all) characteristics that are the outcome of a former pedological environment, while in the fourth category, are soils buried by volcanic or sedimentary rocks. Soils buried by pyroclastic (volcanic) materials are of main interest in this study. The buried soils are paleosols while the soils influenced by the pyroclastics are surface soils. Gibbs (1971) identified two groups of paleosols, buried by volcanic rocks. In the first group are soils which predate the volcanic activity - the pre-volcanic paleosols. The second group has paleosols that are formed between different volcanic activity episodes, therefore, found sandwiched between volcanic rocks, which are the inter-volcanic paleosols.

Kenya has many volcanoes, especially those which are Tertiary to Recent in age. Pyroclastics from Vulcanian and Pelean type of volcanoes are spread and deposited over extensive areas by wind (Alvarado, 1974).

The importance of the soils influenced by such pyroclastics in the country is therefore apparent, at least when their possible extent and land use in Kenya is considered.

Pyroclastics are known to have their depths and their particle sizes decreasing with distance from the source of the pyroclastics (Pettijohn, 1975). The influence of the pyroclastics on the soils also expectedly lessens away from the volcanic source of the pyroclastics.

Gibbs (1971) observed that due to the weight of the overlying pyroclastics, diagenesis rather than pedogenesis processes take place in the paleosols (buried by the pyroclastics). Such diagenetic processes may result in the destruction or partial preservation of soil properties in the buried soils (paleosols). Paleosols have been identified with the use of soil characteristics, such as colour, texture, structure, chemical properties and mineralogy (INQUA, 1971).

Soil colour may reflect the differences in soil parent materials such as those of the surface soils and paleosols. But Gey, et al. (1971) also observed that colour differences in a soil can be caused by pedogenetic processes, for example, the different soil horizons which may be confused with surface soils and paleosols.

Soil structure may be used as a differentiating criteria, if the surface soils have structures completely different from those of the paleosols. Beukenkamp and Sevink (1971) concluded that structure in a paleosol is destroyed by compaction or cracking due to the weight of burying materials otherwise it is preserved.

Holmes (1965) found that wind deposits are usually sorted into one textural class which later dominates the surface soils developed on those deposits. Textural profiles can therefore be used to differentiate the surface soils from their respective paleosols. But with time, the paleosols and surface soils may be homogenised by pedogenetic processes (Hunt, 1972). It is also noted that Planosols (FAO-UNESCO, 1974) have epipedons of sandy textures due to a pedogenetic process but can be confused with the influence of wind deposits.

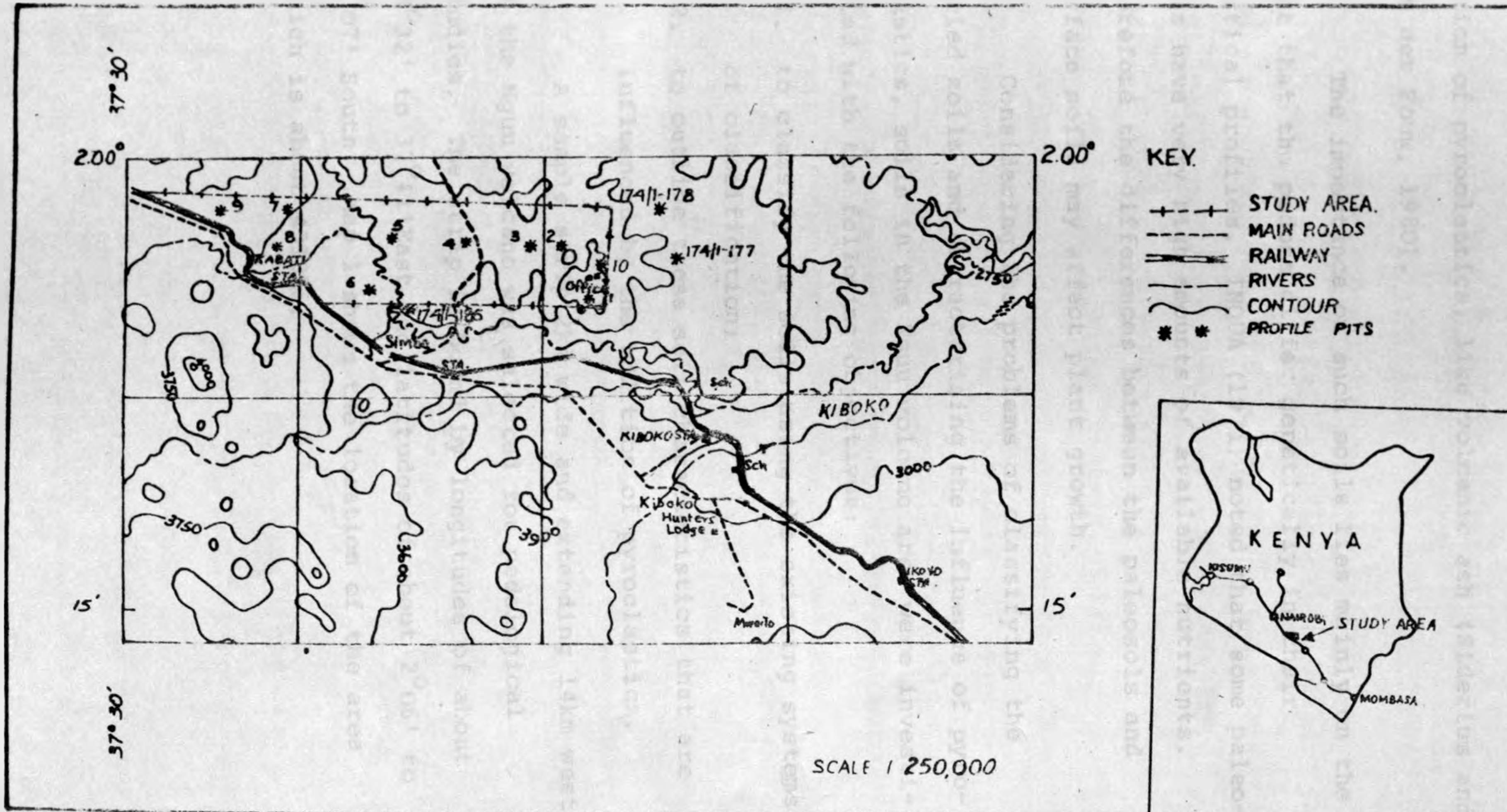
The paleosols and surface soils may differ in terms of CEC, pH and bases (Price et al., 1974). The soil characteristics are also very much affected by the movements of the soil solution, so any difference may be due to such movements but not due to the presence of paleosols.

Every rock has its characteristic or its index minerals (identified from sand sized particles using a light microscope). The rock upon which a paleosol has developed may have a mineralogical composition completely different from the covering material (pyroclastics). The surface soils can therefore be identified after having a knowledge of the mineralogy of the source (volcano) area. Even in the very old soils, some minerals are very resistant and are hardly affected by the pedogenetic processes. Index minerals have been termed as being very useful in identifying the surface soils (INQUA, 1971).

Rocks which have different mineralogical composition and therefore different in chemical makeup may weather to varying clay minerals. Since the surface soils and paleosols usually have two or more parent materials, their clay mineral assemblages can differ. But clay sized particles and clay minerals are also affected by the movements of the soil solution. Therefore, distribution of clay minerals and clay sized particles in a soil profile does not always reflect differences in the lithology.

A classification system for the soil pedons with surface soils and paleosols is not well developed. The use of the already existing systems of soil classification disregarding the vertical differentiation in the pedons has been recommended by some scholars (INQUA, 1971). Others have modified the existing systems of classification by adding prefixes. For example, prefix "cumuloandic" for the pedons that have thickened surface soils caused by a repetitive accumu-

MAP I. LOCATION OF THE STUDY AREA



lation of pyroclastics, like volcanic ash (Siderius and van der Pouw, 1980).

The importance of such soils lies mainly on the fact that the pedons differ genetically in their vertical profiles. INQUA (1971) noted that some paleosols have very high amounts of available nutrients. Therefore the differences between the paleosols and surface soils may affect plant growth.

Considering the problems of classifying the buried soils and characterising the influence of pyroclastics, soils in the Nguu volcano area were investigated with the following objectives:

1. to classify the soils using the existing systems of classification;
2. to outline those soil characteristics that are influenced by the addition of pyroclastics.

A sample strip 2km wide and extending 14km west of the Nguu volcano was selected for pedological studies. The strip is bound by longitudes of about $37^{o}32'$ to $37^{o}41'$East and latitudes of about $2^{o}06'$ to $2^{o}07'$ South. Map 1 shows the location of the area which is about 4313ha.

CHAPTER 2: REVIEW OF LITERATURE

2.1.1 Sorting of pyroclastics into particle sizes

The term pyroclastic is applied to rocks produced by explosive aerial ejection of material from a volcanic vent (Hatch et al., 1975). Longwell et al. (1969) and Alvarado (1974) stated that the volcanoes which eject pyroclastics are of the Vulcanian or Pelean type. Vents, craters, volcanic cones and geothermal activity are the features found in areas which have had volcanic activity.

The pyroclastic materials are transported by the volcanic explosive and the aerodynamic (wind) forces in the air and each pyroclastic particle settles gravitationally, when the two forces can no longer move it. The coarse particles (>4mm), being the heaviest, settle and accumulate around the vent to form volcanic cones (Saggerson, 1963; Holmes, 1965; and Longwell et al., 1969). The cones are normally 'cinder-shaped' but due to wind action they may be 'dune-shaped' (Holmes, 1965).

Next to be deposited are sand (0.4-0.15mm) particles which are intermediate to the coarse and fine particles. The aerodynamic force transports sand particles with a series of elastic bounces called saltation, for short distances (Veenebos, 1967 and Longwell et al., 1969). Whites (1973) observed that the sand stops moving when aerodynamically stable objects use a lot of wind energy. Such stable objects include even grass tufts (Holmes, 1965).

Longwell et al. (1969) observed that very fine sand, silt and clay (particles <0.15mm) are transported by wind in suspension. The suspension load is transported the farthest and according to Pettijohn (1975) they may cover an area of up to $10.4 \times 10^3 km^2$. And usually the clay particles stay in suspension for a longer time and over longer distances (Veenebos, 1967 and Mohr et al., 1972). High topographic features are some of the features where the suspension load is deposited (Hunt, 1972). Holmes (1965) observed that rain water can cause the fine particles to aggregate therefore settle gravitationally.

2.1.2 Classification of pyroclastic materials

Hatch et al. (1965) stated that pyroclastic materials had not been studied extensively due to the following two reasons. First, the rocks are partly igneous and partly sedimentary therefore tend to be left out by scholars of the two disciplines. Secondly, they are likely to decompose very quickly, therefore the optical characteristics and crystal shapes which enable minerals to be identified are often missing. The classification of pyroclastic rocks given by Hatch et al. (1975) and Pettijohn (1975) is referred to in this review.

Pyroclastic rocks are classified according to their lithology, grain size and mineralogy. Using the lithology, there are lithic, vitric and crystal pyroclastics. The grain size classification is somehow related to soil texture and there are block, lapilli and volcanic ash grain sizes. Blocks which are the largest fragments (>32mm diameter) consolidate into volcanic breccias. Lapilli grains are 4-32mm and form lapilli tuff after diagenesis. The volcanic ash grains which consolidate to tuff are less than 4mm.

Mineralogical classification of pyroclastics is similar to that of other igneous rocks. Table 20 shows minerals characteristic of basalt (basic igneous rock) and granite (acid igneous rock). The pyroclastics in the study area have a basic composition (Saggerson, 1963).

2.2 Surface soils and paleosols with pyroclastic influence

Wind deposits (like the pyroclastics) tend to be sorted into grain sizes, therefore, pyroclastic surface soils may then have their texture dominated by one textural class, especially when relatively young. Pettijohn (1975) stated that pyroclastic particles diminish in grain sizes away from the source of volcanic eruptions. In this case, pyroclastics compare with other wind deposits like sand dunes and loess. Some coastal and desert areas have sandy surface soils due to the former sand dunes (Holmes, 1965 and Sombroek, 1980). Loess surface soils tend to decrease in thickness away from the source and are dominated by the silt fraction (Holmes, 1965; Ruhe et al., 1971; Hunt, 1972 and Ruhe et al., 1974).

Hunt (1972) concluded that soil development can obliterate the textural dominance especially when the silt and sand fractions weather to clay sized particles. The surface soils may also be mixed with the paleosols by the soil organisms (Ruellan, 1971 and Buol et al., 1973). In soil profiles where the mixing has not occurred, textural profiles have been used to differentiate the surface soils from paleosols. Such profiles were used mainly for loessial surface soils where silt was found to be a better index of paleosols than clay, since clay is affected by movements during pedogenesis (Price et al., 1974; Ruhe et al., 1974 and Foss et al., 1978).

The surface soils and paleosols may have different colours due to the differences in parent materials especially because pyroclastics are usually dark coloured (INQUA, 1971; Gibbs, 1971 and; Bleeker and Parfit, 1973). Colour changes are also known to occur in paleosols after burial. In a paleosol there is general browning due to decomposition of organic matter (Gerasimov , 1971). Further, Gibbs (1971) noted a distinct increase in soil colour value from 2/ or 3/ to 6/ or 7/ on the Munsell scale. Colour of the paleosols may also change due to illuviation of organic matter and other colloids from the surface soils (Beukenkamp and Sevink, 1971); Polach and Costin, 1971; Scharpensel, 1971 and Gey et al., 1971).

INQUA (1971) observed that structure is a relatively stable pedological property and can be preserved after burial. But, various processes that occur during and after burial may alter the soil structure. For example, the weight of overlying materials may increase the soil density and cause the loss of structure (Gibbs, 1971). Also, Beukenkamp and Sevink (1971) noted that hot volcanic rocks may cause the baking and cracking of the paleosols resulting in the change of structure.

The surface soils may have clay mineralogy, pH, CEC and base saturation different from that of paleosols and such differences have been found in other types of surface soils. Price et al. (1974) also Ruhe et al. (1974) used differences of CEC, pH and bases in profiles with loess surface soils. But the characteristics (CEC, clays, pH and bases) are very much influenced by leaching in a soil. In fact, INQUA (1971) and Gibbs (1971) concluded that the four characteristics are not very useful criteria for recognising presence of paleosols.

Each rock has its characteristic minerals which have been used in the mineralogical classification of all rocks (Longwell et al., 1969 and Hatch et al., 1975; Table 20). The surface soils and paleosols, partly develop on different rocks and are likely to have such characteristic or index minerals from those rocks. Index minerals have been used more extensively by geologists while working out the sources of sedimentary rocks or their provenance (Pettijohn, 1975). Augite and olivine (Siderius and Wamicha, 1978 and 1979 also Siderius, 1979) have been used as index minerals of volcanic ash (pyroclastics) influence in soils otherwise developed on metamorphic rocks. The index minerals have been termed as a very useful tool for studying paleosols (INQUA, loc.cit.).

INQUA (loc.cit.) also recommended the use of buried diagnostic horizons for example accumulations of clay and carbonates. Such diagnostic horizons were defined by FAO-UNESCO (1974) and USDA (1975). Horizon designations have been prefixed or suffixed to reflect the buried paleosols. Roman numerical prefixes have been used for example IIB, and IIC (USDA, 1960 and 1975). In New Zealand, prefix 'u' is used for horizons buried by loess or pyroclastics (Gibbs, 1971). The FAO-UNESCO (1977) guidelines gave suffix 'b' to bisequal or buried horizons.

The depth at which a soil can be said to be buried has been difficult to define. Ruellan (1971) recognised two groups of buried soils, first those buried beneath the present zone of direct biological activity as the 'true' paleosols. In the second group are paleosols which are under direct action of pedogenesis and in such profiles the depth of surface soils is hard to ascertain. FAO-UNESCO (1974) considered the paleosols as those buried by 50cm or more of new material. Since the depth of wind deposits diminishes away from the point of origin (Gibbs, 1971; Ruhe et al., 1971 and Wielemaker, 1979), the depth of pyroclastic materials is then expected to decrease away from a volcano.

2.3.1 Pyroclastic materials and soil development

A soil can be dated in two ways, that is by getting the absolute geological age and the relative age. The age of the surface upon which a soil has developed is usually taken as the absolute age of that soil (Wielemaker and Dijk, 1981). The relative age of a soil is a measure of the extent to which a pedon has developed (van Wambeke, 1962). Wielemaker, (1979) concluded that soils that have had additions of volcanic ash (pyroclastics) usually have uniform relative age regardless of the age of underlying geology (rocks and surface).

Weatherable reserve has been used during soil classification. One criteria for defining the oxic B-horizon is that, it should not have more than traces of primary aluminosilicates such as feldspars, micas and ferromagnesian minerals (FAO-UNESCO, 1974 and USDA, 1975). Also the two systems of soil classification in defining the cambic B-horizon gave the amount of weatherable minerals other than muscovite as >3% or more than 6% muscovite. The more weatherable minerals a soil has, the younger it is relatively. The contribution of pyroclastic materials to the weatherable mineral reserve is of importance in this study. Table 18 shows the stability or weatherability of various minerals under different environments (Brewer, 1964; Longwell et al., 1969 and Pettijohn, 1975).

By using the definitions given by FAO-UNESCO (1974) and USDA (1975), the weatherable reserve of a soil can also be indicated by the CEC. The cambic B-horizon has CEC (by NH_4OAc, pH 7.0) of more than 16 me/100g clay. Whereas the oxic B-horizon retains 10 me or less of ammonium ions per 100g clay from unbuffered $N.NH_4Cl$ solution or has less than 10 me of bases extractable with $N.NH_4OAc$ plus Al extractable with N.KCl per 100g clay. A cambic horizon is characteristic of young soils whereas the oxic horizon is of old soils relatively. Therefore low CEC may indicate relatively old soils or soils with low weatherable reserve.

2.3.2 Genesis of the allophanes

According to FAO-UNESCO (1974) Andosols, which are soils developed on pyroclastic materials, have an exchange complex dominated by amorphous clay minerals (Allophanes), therefore, allophane can be used as an index mineral of soils that have been influenced by pyroclastic materials. Fieldes (1966) defined allophanes as lacking the specific properties conferred upon chemical substances by regular arrangement of atoms within their molecules or structures. Fieldes (1966) and Gieseking (1975) outlined the conditions under which allophanes form in soils as mentioned below

Volcanic glasses and feldspars from pyroclastic materials have predominantly random structures and hydrous aluminosilicates formed from such minerals, during weathering, are likely to have random atomic arrangement. Sericitisation or the process of mica formation does not occur in feldspars that have a random structure during weathering, instead allophanes may form. Minerals are also reduced into a state of disorder by grinding or any other mechanical treatment. Such a treatment occurs when the minerals are transported (by wind, water and glaciers) or due to frost action. After the grinding, the resulting material upon hydration and removal of bases corresponds by definition to allophanes.

Synthesis of allophanes can also occur during the early weathering stages of basic (basalt) and ultrabasic rocks. Silica tetrahedra released from the 'basic' minerals lack orderly arrangement and pass into solution. Such basic minerals include the olivines, pyroxenes (augite), amphiboles (hornblende) for example. The bases released from the minerals have the effect of raising the pH, causing silicon and aluminium to dissolve from the nearby minerals. Subsequently when the bases are leached and CO_2 gains access the pH is lowered making it possible for allophanes to precipitate.

2.4 Studies conducted in the area

2.4.1 Geology of the study area

The geological survey of the area was carried out by Saggerson (1963). Rocks of the area belong to the geological eras of Archean and Cenozoic; the Archean rocks being metamorphosed equivalents of sedimentary rocks, while those of Cenozoic are volcanics. From a geologic map of Kenya, the area is seen to be on the fringes of a zone with Tertiary volcanics along the Great Rift Valley (Morgan, 1969 and Survey of Kenya, 1970).

The metamorphic rocks are of the Kasigau series, with Semi-calcareous and Middle semi-pelitic Groups being represented in the area (Saggerson, 1962 and 1963). The semi-calcareous group has the following rocks; hornblende-biotite gneisses, calc-silicate granulites, amphibolites and augen gneisses. The semi-pelitic group includes hornblende-biotite gneisses and granitoid gneisses with graphite and sillimanite bands. The metamorphic rocks belong to the Mozambique Belt (the Basement System) which extends from Mozambique in the south to Sudan and Ethiopia in the north (Holmes, 1965 and Sanders, 1965).

In Kenya, volcanism which is related to the Rift Valley is noted to have occurred in three phases; lava flows first, followed by explosive volcanic activity and finally geothermal activity (Baker, 1958 and McCall, 1967). A similar pattern was noted in the study area where a period of volcanicity commenced during the lower Pleistocene times (Saggerson, 1963 and Searle, 1954) when an analcime basanite lava flooded the east flowing proto- Muooni River valley in the lower Pleistocene times. The basanite is mainly composed of olivine microphenocrysts in a microlitic groundmass of augite, feldspars, magnetite and analcime. Saggerson (1963) further stated that the Upper Pleistocene volcanic activity was characterised by explosions on localised vents. Analcime basanite intercalated with bedded pyroclastics were exuded first, followed by olivine basalts intercalated with volcanic ash and agglomerates. According to Searle (1954) some of the pyroclastics were deposited as far as 9 miles (14km) from each of the volcanic cones. Such pyroclastics have spread over larger areas in other parts of Kenya (Wielemaker, 1979)—(Fig. 4). Hydrothermal activity was still active, during the fieldwork, to the south of the Nguu volcano where there are hot springs. A generalised Geological Time Scale is shown on Table 21.

2.4.2 Geomorphology of the study area

The study area has polycyclic landscapes like many other parts of the African continent; such landscapes are erosional levels of different ages and different altitudes (King, 1967). Uplands on the metamorphic rocks, to the west of Nguu, are part of the sub-Miocene level (Saggerson, 1963; Saggerson and Baker, 1965; and Ojany, 1975). The sub-Miocene uplands are about 1,000-1,060 metres in altitude. Post-Miocene has been a period of upwarps related to the Rift Valley formation (Saggerson and Baker, 1965) and such upwarps have resulted in the erosion of sub-Miocene level along what are now minor valleys (Plate 10).

The early Pleistocene basanites flow resulted in the formation of a lava plain. During the volcanic explosions two topographic features were formed; uplands of basanites intercalated with volcanic ash and hills (cones) of olivine basalts intercalated with volcanic ash and agglomerates (Plate 10).

2.4.3 Soil studies

On the soil map of Kenya the soils were described as having developed on Basement complex (metamorphic rocks) and volcanic rocks (Survey of Kenya, 1970). Touber (in prep.) described the soils as being influenced by volcanic ash: further, Touber classified the soils using the FAO-UNESCO (1974) 'Legend' as Chromic Cambisols, Eutric Nitosols and Pellic or Chromic Vertisols on volcanic rocks and Ferral-Ferric and Ferral-Chromic Luvisols on the metamorphic rocks, While soils on the basanites are Ferralsols. Sombroek (1980) used mapping units similar to those of Touber (loc.cit.). Michieka and van der Pouw (1977) also described volcanic ash influenced soils in an area to the south of the study area, with a similar geological history.

2.5 Classification of the soils influenced by pyroclastics

The French System, as reviewed by INQUA (1971), has subgroups prefixed with for example rejuvenated and penevolved to reflect the presence of paleosols. The USDA (1960 and 1975) System used prefix pale to indicate old development for several Great Groups of the four Orders; Alfisols, Aridsols, Mollisols and Ultisols.

Despite recognising the buried soils, the FAO-UNESCO (1974) 'Legend' did not come out with any classification units for such pedons. During various soil surveys in Kenya the cumuloandic unit was added as a modification of the FAO-UNESCO (1974) 'Legend' (Michieka and van der Pouw, 1977; also Siderius and van der Pouw, 1980). The unit was for thickened epipedons caused by repetitive accumulation of small amounts of volcanic ash.

2.6 The soil mapping units

There are several approaches to cartographic representation of soil mapping units. The two approaches shown here are; fisrt, the FAO-UNESCO (loc. cit.). Secondly, the KSS approach as outlined by van der Pouw and Rachilo (1977), then van de Weg (1978a).

The FAO-UNESCO soil mapping unit code, shown below, denotes Soil classification, Soil texture and the Slope upon which the unit is found.

FAO-UNESCO CODE

Chromic Luvisol } Soil classification
Association number }
Medium textured soil
Lc3-2a — Level to gently undulating area (slope)

The KSS code denotes Physiography, Lithology and a selected soil characteristic as follows:

KSS CODE

Uplands
Undifferentiated volcanic rocks
UVb — Brown coloured soils

The FAO-UNESCO code has a 'soils approach', due to the fact that soil is given the first preference.

The approach is difficult to use especially when a soil surveyor is unable to classify some soils in the field. The system also gives very few textural and slope classes which are inadequate for large scale soil maps, for which it is not presently devised.

The 'physiography-lithological Kenyan approach' gives inadequate emphasis to what is being mapped - the soil. The system is readily used in the field, especially in areas where a geological map is available. Also physiography and lithology play a significant role in the soil genesis (Buol et al, 1973).

2.7 The moisture and temperature regimes

Sombroek et al (1982) gave the Agro-climatic zone of the Nguu as (V2). Where (V) indicates that the ratio of average annual rainfall to the potential annual evaporation (r/Eo%) is 25 to 40%. The (2) shows that the mean annual temperature is 22 to 24^{o}C.

Some of the major towns of Kenya in a (V2) Agro-climatic zone are Isiolo, Moyale and Naivasha. The soil moisture and temperature regimes for the three towns as worked out by van Wambeke (1982) are as follows:

Town	Soil moisture regime	Soil temperature regime
Isiolo	Ustic	Isohyperthermic
Moyale	Ustic	Isohyperthermic
Naivasha	Ustic	Isohyperthermic

Since the towns where the Agroclimatic zone is (V2) have Ustic and Isohyperthermic soil moisture and temperature regimes respectively; these regimes were assumed for the Nguu area.

CHAPTER 3: METHODS AND MATERIALS

3.1 Soil survey methods

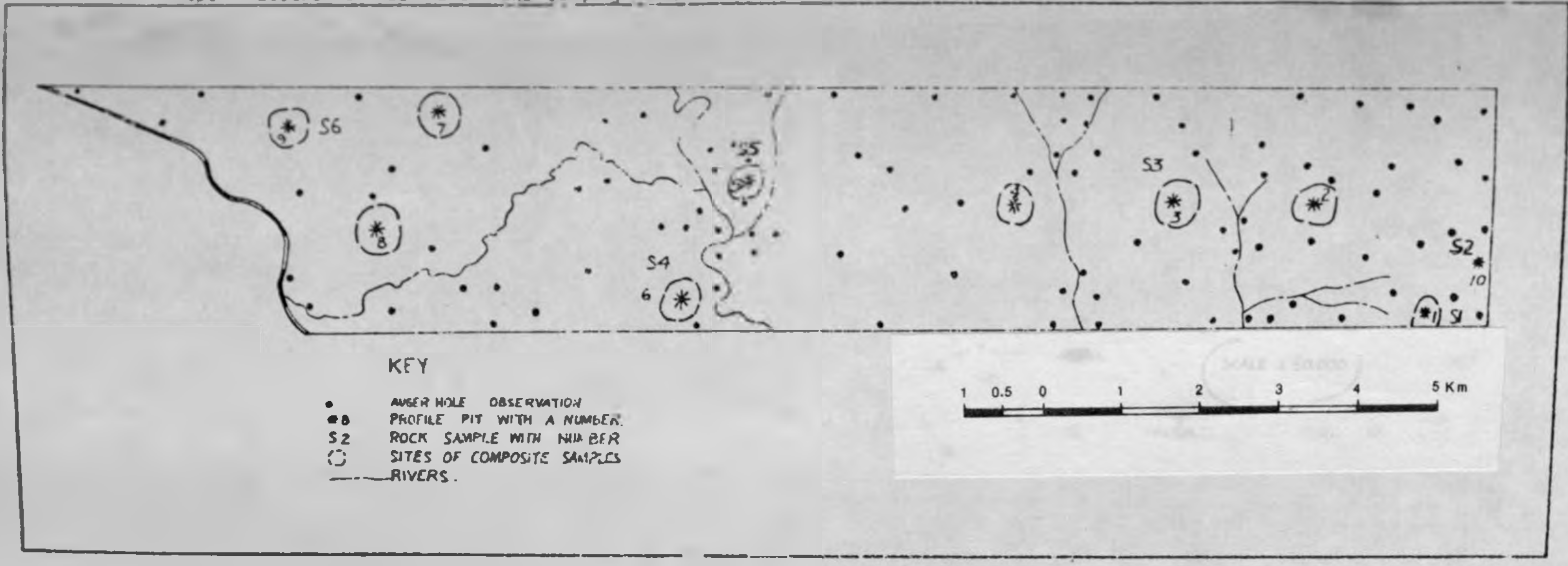
The Nguu volcanic cones have East-West orientation similar to sand dunes. So, during their formation the prevailing winds were Easterlies. The sample strip is therefore to the west of the Nguu hill, that is the leeward side.

Aerial photographs, at a scale of 1:50,000, were interpreted for soils following the physiographic method (FAO, 1967 and; Bennema and Gelens, 1969). The photos were analysed into physiographic units, each of which containing unique association of soils. The associations were further separated on the basis of phototone, texture, drainage patterns and vegetation. The soil (photo interpretation) boundaries, which resulted, were transferred onto a topographical map scale 1:50,000 drawn by the Survey of Kenya.

Initially, 100 auger hole observations were made, to a depth of 150cm or the rock, for correlating the photo boundaries with soil features (Map 2). In all 110 observations, inclusive of 10 representative profile pits, were made covering an area of about 4313ha therefore a density of one for about 40ha. The soils were described following the USDA (1962) and FAO (1977) methodology as outlined by van de Weg (1978b).

Disturbed samples were taken for every pedogenic horizon of the profiles and a composite sample to a depth of 10-30cm; all samples were for physical, chemical and mineralogical analyses. Undisturbed core samples, for bulk density analysis were obtained in some profile pits.

Map 2 Location of observation and sampling sites



The profile characteristics and analytical data were used to classify the soils at soil unit level of FAO-UNESCO (1974) 'Legend' and at subgroup level of USDA (1975) 'Taxonomy' system. The soil units found are:

Tv - Vitric Andosols	Fo - Orthic Ferralsols
To - Orthic Andosols	Vp - Pellic Vertisols
Lc - Chromic Luvisols	Wd - Dystric Planosols
Lo - Orthic Luvisols	

The units were further subdivided to show the following classes or features: textural class (top 30cm of the profiles), slope class, physiography and parent rock as shown below (Fig. 1).

Fig. 1: Example of mapping unit code

Orthic Ferralsols
Clay loam
Flat to very gently undulating area
Plain
Fo-5A/P/B —— Basic igneous rocks

Texture: Soil textural classes are shown with numerical figures. The textural classes determined according to (USDA, 1962) system were numbered as follows:

1.	Clay*	7.	Silt
2.	Silty clay	8.	Silt loam
3.	Sandy clay*	9.	Loam
4.	Silty clay loam	10.	Sandy loam
5.	Clay loam*	11.	Loamy sand
6.	Sandy clay loam*	12.	Sand

Slope classes: Capital letter(s) denoting the slope class(es) follow the textural class figure. The "KSS slope classes" (van de Weg, 1978b) were used:

Slope class symbol	Slope %	Definition
A	0-2	flat to gently undulating
B	2-5	gently undulating
C	5-8	undulating
D	8-16	rolling to hilly

Physiography: The physiographic landform (van de Weg, 1978a) is shown after a stroke. The land forms are:

H - Hills
U - Uplands
P - Plain
V - Minor valleys

Parent materials: The soil parent material is shown after another stroke (Fig. 1):

(a) Mixed parent materials;

X - mixed igneous, metamorphic or sedimentary,

---

* Classes found in the study area

(b) Volcanic (igneous) parent materials;

V - undifferentiated volcanic rocks,

B - basic (igneous) volcanic rocks (basanites),

(c) Metamorphic parent materials;

U - undifferentiated metamorphic rocks,

F - gneisses rich in ferromagnesian minerals (hornblende gneisses).

3.2 Soil analytical methods

The soils were analysed for bulk density, texture, pH, CEC, bases, organic carbon and mineralogy.

Bulk density determination: Undisturbed core samples were taken with a cylindrical metal sampler and dried to 105°C. The oven-dried mass was divided by the field volume to obtain the bulk density. The core method is as described by Blake (1965).

Mechanical analysis: Organic matter was removed from the samples, with H_2O_2 then segregation done with sodium hexametaphosphate and the sand fraction obtained by sieving with 300-mesh (USDA, 1972). Clay and silt fractions were separated with the pipette method as described by Day (1965).

pH determination: The pH was determined after preparing 1:2½ v/v of soil to water ratio and 1:2 v/v soil to KCl ratio, suspensions. The suspensions were equilibrated for 1 hour and Philips Type Pr 9403/01 pH meter used to read out the pH.

CEC and bases: The CEC was determined by the Peech (1945) Na saturation procedure as outlined by Chapman and Pratt (1961). The exchangeable bases Ca, Mg, K and Na were extracted with 1N NH_4OAc (pH 7.0) following the method described by USDA (1972). The concentrations of Ca, K and Na were measured with a Flame Photometer while Mg was determined with Atomic Absorption Spectrometer.

Organic carbon determination: The Walkley-Black (1934) procedure of acid dichromate digestion and titration with ferrous sulphate was followed.

Sand mineral analysis: The rock samples were first crushed into sand sized particles. The soil sand fraction and sand mineral slides were prepared as outlined by Hinga et al. (1980). The minerals were studied and counted, using a petrographic microscope, as outlined by Milner (1962) and Brewer (1964).

Clay mineral analysis: The removal of flocculating and cementing agents was as outlined by Kunze (1965) and USDA (1972). The sand was separated from silt by a 300-mesh sieve and silt from clay by centrifuging. K saturated and Mg saturated clay samples were prepared on glass slides and dried. Clay minerals were analysed with a Philips Type Pw 17-0 X-ray diffractometer. The diffraction patterns were interpreted using the methods of Carrol (1969) and Gieseking (1975).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Comparison of the soil mapping units

Based on their physiographic position, the soils were separated into 4 groups as follows (Plate 10):

(a) Soils of the Nguu Hill - Andosols (Tv-6D/H/V) and To-5C/U/V),

(b) Soils of the Uplands and Plains - Ferralsols (Fo-3BC/U/U and Fo-5A/P/B),

(c) Soils of the Valley Sides - Luvisols (Lc-6BC/U/F and Lo-3B/U/F),

(d) Soils of the Valley Bottoms - Vertisols (Vp-1AB/V/F) and Planosols (Wd-6AB/V/F).

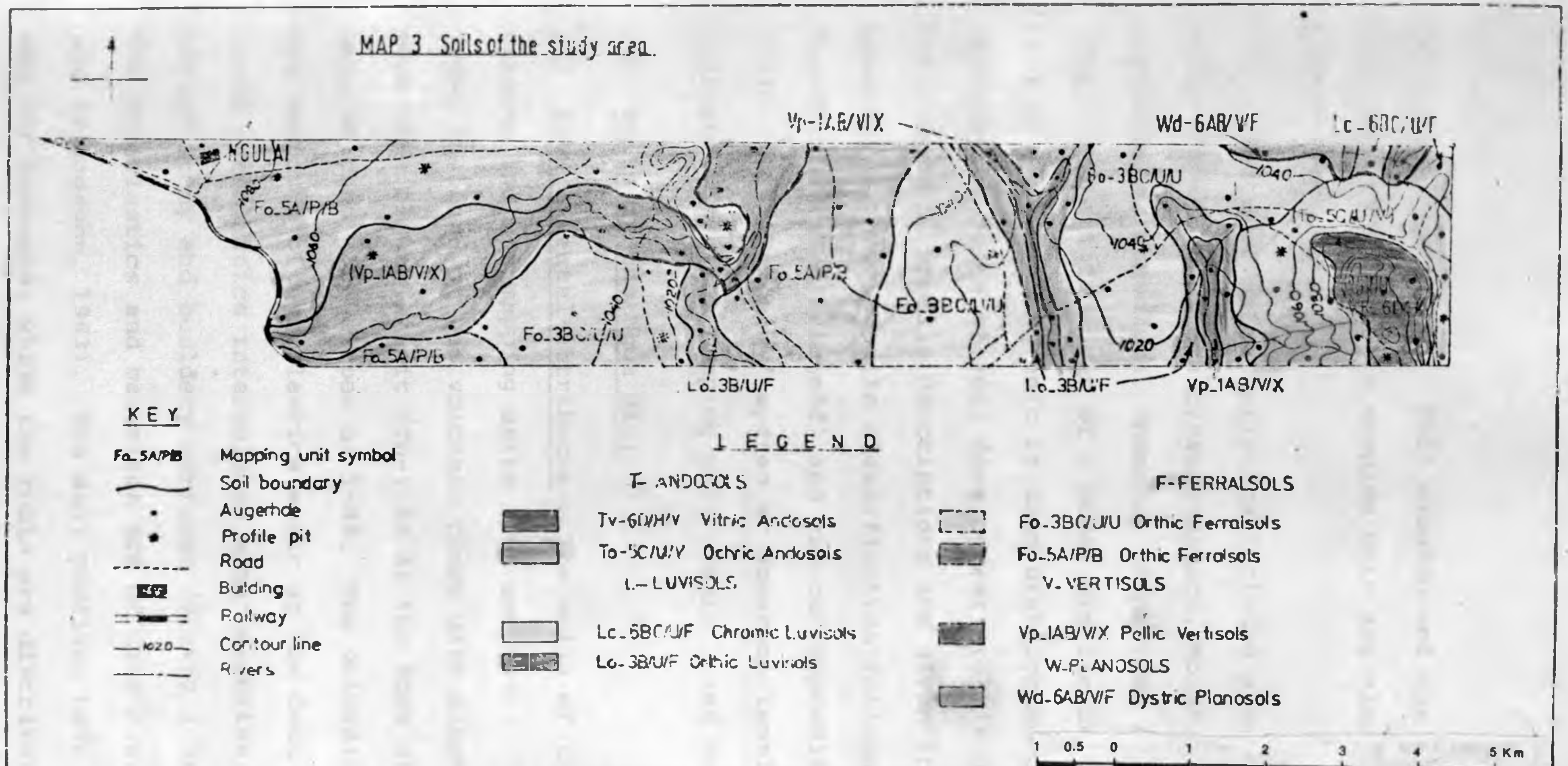
Each of these four groups has two soil mapping units (Table 1). The units within each group and between the groups can be distinguished according to their environmental attributes, their physio-chemical characteristics and consequently in their classification.

The environmental attributes included are the physiography and the slope class as shown in the mapping unit code (Fig. 1). The age of the parent rock and/or that of the surface upon which the soils are found, is (are) taken as the age of the soil (Wielemaker and Djik, 1981). Other environmental attributes include the faunal activity as demonstrated by animal channels and the floral activity shown by

Table 1: Summary of soil classification

Mapping unit	Extent (ha)	Profile pit Numbers	Soil Classification Units	
			Main units	Other units of the association
Tv-6D/H/V	37.5	1	Vitric Andosols (Lithic Vitrandepts)	Cambisols Lithosols
To-5C/U/V	415.0	2, 10	Ochric Andosols (Entic Eutrandepts)	Chromic Vertisols (Paleustollic Chromusterts)
Fo-3BC/U/U	1260.0	3, 4, 6	Orthic Ferralsols (Typic Eustrustox)	Orthic Luvisols (Oxic Paleustalfs) Xanthic Ferralsols (Typic Eustrustox)
Fo-5A/P/B	1380.0	5, 7, 9	Orthic Ferralsols (Typic Haplustox)	Orthic Luvisols (Oxic Haplustalfs)
Lc-6BC/U/F	42.5	(174/1-177) 11	Chromic Luvisols (Oxic Haplustalfs)	-
Lo-3B/U/F	345.0	(174/1-185) 12	Orthic Luvisols (Oxic Haplustalfs)	-
Vp-1AB/V/X	775.5	8	Pellic Vertisols (Entic Pellusterts)	Chromic Vertisols -
Wd-6AB/V/F	47.5	(174/1-178) 13	Dystric Planosols (Typic Albaqualfs)	-

FAO-UNESCO (1974) Soil classification units are given with corresponding USDA (1975) classification at subgroup level shown in brackets.



MAP 3 Soils of the study area.

the root distribution. Soil erosion and the present land use status of each mapping unit are also taken into account.

The soil characteristics included are: the solum depth, drainage class, texture, moist colour, consistence, structure, chemical properties and mineralogy. Salient features of a modal profile representative of each mapping unit is then highlighted and the important aspects of soil development are discussed. Detailed soil profile descriptions are given in Appendix 2. The profile classification follows the FAO-UNESCO (1974) 'Legend' and the corresponding USDA (1975) 'Soil Taxonomy' system at subgroup level is indicated for each mapping unit (Table 1 and Map 3).

(a) <u>Soils of the Nguu Hill</u>

(i) <u>Environmental attributes</u>: The soils of the Nguu volcano include mapping units (Tv- and To-). Unit (Tv-) is found on the volcanic cones with slopes of more than 8% while unit (To-) is at the foot of the Nguu volcano with slopes of 5-8%. The volcanic cones are composed of pyroclastics while at the foot are found pyroclastics intercalated with basanites; both having stony and bouldery surfaces (Plates 1 and 2). The pyroclastics and basanites are of late Pleistocene age (Saggerson, 1963). The soil profiles have worm and ant channels, while the roots are distributed in all horizons and extend for some depth into the pyroclastics but not into the basanites. Sheet, rill and gully erosion are common especially in places where there is no vegetation cover because of the nature of slopes (>5%). Cultivation, especially where mechanised, is not possible due to the high slopes and/or the bouldery-stony surface therefore, the two units are used for grazing.

(ii) Soil characteristics: Profile pit 1 is representative of unit (Tv-) while unit (To-) is represented by pits 10 (Pl.2 & App. 2) and 2 (inclusion) The solum thickness of unit (Tv-) ranges from 5-60cm and that of unit (To-) is 90-150cm. The sequence of horizons in profiles of (Tv-) is ACR but that of (To-) is ABCR. Therefore, soils of (To-) with less steep slopes (5-8%) are more developed than those of (Tv-) with slopes >8%. Due to these steep slopes, soils of the two mapping units are well to excessively drained.

The (Tv-) soils have sandy loam to sandy clay loam texture in the A-horizons while the B-horizons have sandy clay loam to loamy sand. But, (To-) soils have sandy clay to clay texture both in the A- and B-horizons. Therefore soils of (To-) which are more developed have finer textures than those of (Tv-). The two mapping units, with pyroclastics, have dark brown (10YR 3/3) colour in the A-horizons and dark greyish brown (10YR 4/2) in the AC- and B-horizons.

Plate 1

Layers of Pyroclastic Materials on Nguu Volcano

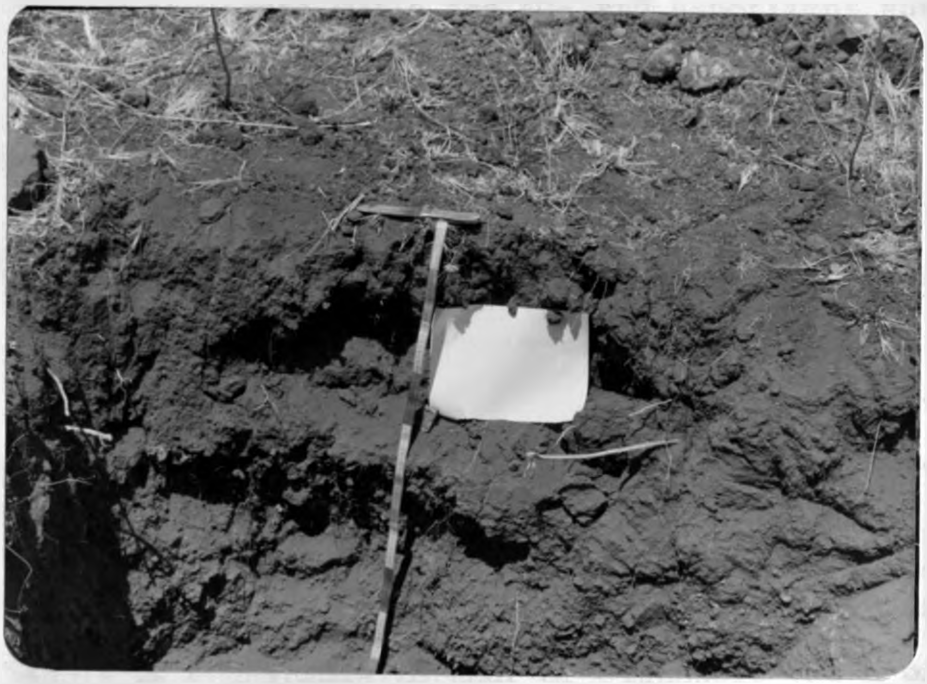
Near Profile pit number - 1

Mapping unit - Tv-6D/H/V

Soil classification - Vitric Andosols

(Note the coarse particles on the surface and in the soil profiles)

Plate 2



Profile pit number - 10

Mapping unit - To-5C/U/U

Soil classification - Ochric Andosols

(Note the coarse particles on the surface and in the soil profile)

All the soils are generally slightly sticky and slightly plastic when wet, friable when moist and hard when dry but, unit (To-) is also smeary when wet. The A-horizons show moderate crumb or moderate subangular blocky structure while the AC- and B-horizons have weak subangular structure.

The organic carbon content is 1.9% in the A-horizons of (Tv-) and 0.91 (in To-). Unit (Tv-) has clays dominated by allophanes which form resistant organo-allophane complexes therefore has more carbon (Gieseking, 1975). Infact, it was more difficult to digest soils of unit (Tv-) with H_2O_2 due to these complexes. Andosols have pH of 6.5-7.0.

The Andosols have CEC of 15-45 me/100g soil which is comparable to that of Planosols (Wd-) of 13-25 me/100g soil (Tables 2 and 6). Further, the Andosols (Tv- and To-) have more CEC than the Ferralsols (Fo-3BC and Fo-5A) and the Luvisols (Lc- and Lo-) both with a CEC of less than 13 me/100g soil. But lower than for the Vertisols (Vp-) which have CEC of about 50 me/100g soil. Total bases in the Andosols are 13-46 me/100g soil which are more than for all the other groups of soils (Tables 2-6). The Andosols with high CEC and bases are, therefore, not heavily leached.

The sand fraction of the Andosols contains highly weatherable minerals, for example, volcanic glass 4-20%, olivine 5-15% and augite 10-15% (Table 12).

Table 2: Analytical data of the soils of the Nguu Volcano - Andosols

Mapping unit	Tv-6D/II/V				
Profile pit number	1(174/1-172)		2(174/1-171)		
Horizon designation	A	CB	A	Bu_1	Bu_2
Horizon depth(cm)	0-10	10-39	0-20	20-83	83-120
Gravel %	20	25			
Sand %	44	47	8	7	6
Silt %	23	33	15	14	20
Clay %	33	20	77	79	74
Textural class	CL	SCL	C	C	C
pH-H_2O (1:2½ v/v)	6.5	6.8	6.8	6.6	6.9
pH-KCl (1:2 v/v)	5.9	6.1	5.6	5.8	5.9
CEC pH 7.0 (me/100g) soil	43.2	49.7	34.2	30.3	31.0
Exch. Ca " "	17.9	22.0	17.4	17.1	12.2
" Mg " "	18.4	24.6	14.72	12.12	17.62
" K " "	0.4	0.2	0.46	0.50	0.56
" Na " "	0.2	0.1	0.15	0.40	0.60
Total bases	36.9	46.9	32.73	30.12	30.98
Base saturation %	85.41	94.37	95.70	99.40	99.93
C %	1.93	0.64	1.13	0.64	0.63
Bulk density (g/cm^3)	0.81	0.80	1.05	1.20	1.01

To-5C/U/V				
10(174/1-170)				
A	AB	B	BC_1	BC_2
0-12	12-31	31-41	41-86	86-106
8	8	10	18	25
32	24	24	20	40
24	28	26	28	18
44	48	50	52	42
C	C	C	C	C
6.5	6.8	6.6	6.9	7.1
5.4	5.7	5.8	6.2	6.3
21.2	19.8	20.3	25.4	17.3
6.7	6.9	6.5	7.0	6.5
8.2	6.3	6.1	6.9	8.1
2.0	1.2	0.4	0.1	0.2
0.1	0.1	0.2	0.1	0.15
17.0	14.5	13.2	14.1	14.95
80.19	73.23	65.02	55.51	66.41
1.18	1.55	1.21	1.1	0.9
0.81	0.80	0.83	0.82	0.82

Allophane is the dominant clay mineral but unit (To-) has montmorillonite and illite also.

(iii) Soil development and classification: The high amounts of CEC, total bases, weatherable minerals and allophanes indicate that the Andosols are relatively young (van Wambeke, 1962; FAO-UNESCO, 1974 and USDA, 1975). Infact they have cambic B-horizons because the weatherable minerals are more than 20% and the CEC greater than 16 me/100g soil.

The soils which are dominated by pyroclastic parent materials and allophanes also have low bulk density (<0.83 g/cm^3) and are classified as Andosols. Since the epipedon is less than 18cm thick they lack mollic- or umbric A-horizons. The consistence of unit (Tv-) is not smeary and the texture is coarser than silt loam with abundance of vitreous materials, therefore, the soils are Vitric Andosols. While unit (To-) has some vitreous materials but smeary consistence which group the soils as Ochric Andosols (Table 1 and Map 3).

Thus, the classified soil units are Vitric Andosols (Tv-) according to FAO-UNESCO (1974) or Lithic Vitrandepts according to USDA (1975), with localised pockets of Cambisols and very shallow Lithosols (Table 1). Those of mapping unit (To-) are Ochric Andosols (FAO-UNESCO, loc.cit.) or Entic

Eutrandepts (USDA, loc.cit.) with pockets of Chromic Vertisols. These units concur with the study of Touber (in prep.), in the same area, except that in the project area there was no evidence of Eutric Nitosols.

(b) Soils of the Uplands and Plains

(i) Environmental attributes: Soil mapping unit (Fo-3BC) is found on Uplands with slopes of 0-6% and unit (Fo-5A) is on Plains with slopes of 0-2%. The topography and slopes are as a result of the geological history of the two areas. The first soil mapping unit is developed from Archean metamorphic gneisses which form part of the sub-Miocene surface (Saggerson, 1963 and; Saggerson and Baker, 1965). But, the second unit overlies lower Pleistocene basanite lavas which formed a plain (Saggerson, 1963). The soils have many biopores and termite mounds about a metre high and 30 metres apart. The roots are distributed in all soil horizons and through cracks in the rocks (Plate 9). Cleared parts of (Fo-3BC) are affected by rill and gully erosion unlike unit (Fo-5A) which is almost flat (Plate 10). These units are mainly utilized for livestock grazing but charcoal burning is also practised in unit (Fo-3BC) which has a bushland (Plate 10).

(ii) Soil characteristics: Profile pits 3, 4 and 6

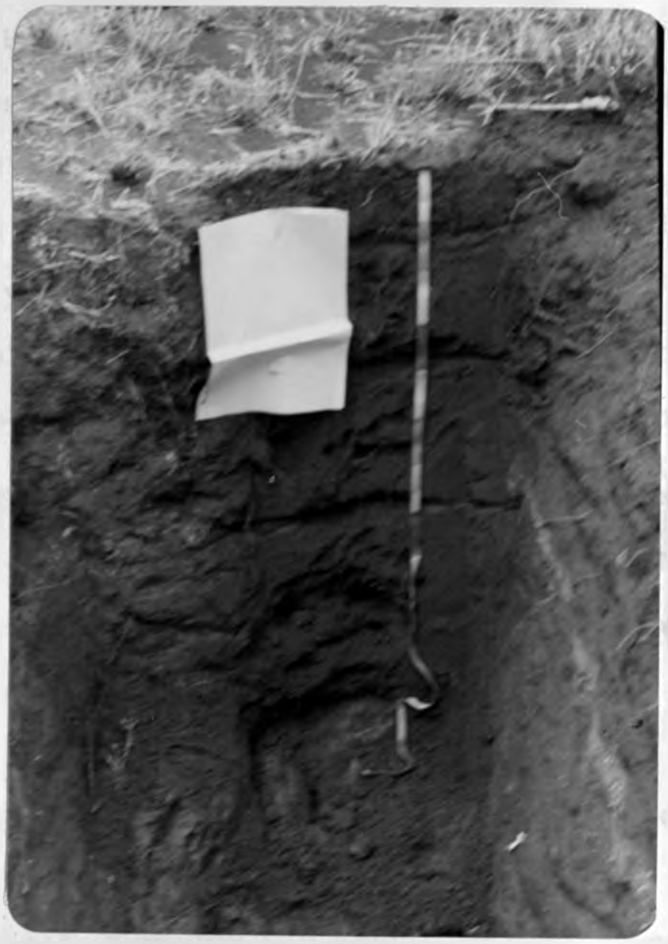
Plate 3

Profile pit number - 4

Mapping unit - Fo-3BC/U/U

Soil classification - Orthic Ferralsol

Plate 4



Profile pit number - 7

Mapping unit - Fo-5A/P/B

Soil classification - Orthic Ferralsol

(Photo taken when wet)

are representative of unit (Fo-3BC) and pits 5, 7 and 9 unit (Fo-5A) also (Pl. 3 & 4 and App. 2). The solum thickness of the two units averages 80-120cm with the profiles having ABCR sequence of horizons. Such a sequence of horizons indicates that the soil profiles are fully developed. All the soil profiles are generally well drained except some low-lying pockets of unit (Fo-5A), which are flat and flood seasonally.

There are no marked variations of texture, colour, consistence and structure between the two mapping units. The upland soils (Fo-3BC) have sandy clay to clay texture both in the A-horizons (topsoil) and the B-horizons (subsoil). Soils of the plains have clay loam texture in the A-horizons and clay loam to clay in the B-horizons. The A- and B -horizons of unit (Fo-3BC) are coloured dark brown (7.5YR 4/2) and the Bb-horizons strong brown (7.5YR 5/6). Unit (Fo-5A) has reddish brown (5YR 4/4) A- and B - horizons, while the Bb-horizons are dark brown (7.5YR 4/2). So, there is a difference of colour between the surface soils (A- and B -horizons), which have additions of pyroclastics, and the paleosolic subsoils (Bb-horizons). Soils of the two units are generally slightly sticky and slightly plastic when wet, friable when moist and slightly hard when dry. The A-, B - and Bb-horizons have weak subangular blocky structure.

Table 3: Analytical data of the soils of uplands - Ferralsols

Mapping unit	Fo-3BC/U/U												
Profile pit number	3(174/1-173)					4(174/1-174)				6(174/1-176)			
Horizon designation	A	Bt_1	Bt_2	Bb_1	Bb_2	A	B	Bb_1	Bb_2	A	AB	Bb_1	Bb_2
Horizon depth(cm)	0-10	10-23	23-63	63-110	110-148	0-11	11-55	55-100	100-150	0-20	20-46	46-92	92-135
Gravel %													
Sand %	52	43	46	56	54	38	38	60	70	41	39	43	36
Silt %	20	16	14	12	13	23	32	15	11	31	37	29	24
Clay %	28	41	38	32	33	39	30	25	19	28	24	28	40
Textural class	SCL	C	SC	SCL	SCL	CL	CL	SCL	SL	CL	L	CL	CL
$pH-H_2O$ (1:2½ v/v)	7.2	6.9	6.2	6.4	6.8	6.7	6.8	6.4	6.5	6.4	6.6	5.5	5.7
pH-KCl (1:2 v/v)	5.0	5.4	5.2	5.5	5.3	5.6	5.6	5.5	5.1	5.1	5.1	4.5	4.4
CEC pH 7.0 (me/100g) soil	9.2	7.8	7.3	5.5	5.2	10.4	10.2	9.4	9.80	7.8	7.5	6.8	6.4
Exch. Ca " "	5.4	4.4	5.4	3.2	3.4	5.4	7.20	5.6	3.4	2.2	2.4	2.0	1.8
" Mg " "	2.7	2.32	2.52	2.2	1.12	2.9	1.7	1.72	2.32	0.24	0.26	0.32	0.23
" K " "	1.32	1.20	0.56	0.20	0.20	1.64	1.28	0.2	0.4	1.82	1.18	0.74	0.50
" Na " "	0.15	0.10	0.15	0.10	0.10	0.22	0.50	0.35	0.5	0.30	1.45	0.25	0.40
Total bases	9.57	8.02	8.63	5.7	4.62	10.26	10.68	7.87	6.62	4.56	5.29	3.31	2.93
Base saturation	100+	100+	100+	100+	92.69	98.65	100+	83.72	67.55	58.46	70.53	48.67	45.78
C %	1.15	0.75	0.52	0.9	0.62	0.75	0.42	1.1	0.35	0.87	0.63	1.2	0.64

Table 4: Analytical data of the soils of plains

Mapping unit			
Profile pit number	5(174/1-175)		
Horizon designation	A	Bt	Bb
Horizon depth(cm)	0-24	24-54	54-96
Gravel %			
Sand %	55	49	38
Silt %	26	21	29
Clay %	19	30	33
Textural class	SL	SCL	CL
pH-H_2O (1:2½ v/v)	6.9	6.3	6.5
pH-KCl (1:2 v/v)	5.3	5.4	5.8
CEC pH 7.0 (me/100g) soil	19.2	13.3	19.2
Exch. Ca " "	4.4	7.4	6.4
" Mg " "	5.1	5.4	5.1
" K " "	2.16	0.28	0.19
" Na " "	0.1	0.05	0.2
Total bases	11.76	13.13	11.9
Base saturation %	61.25	98.72	61.87
C %	0.59	0.8	0.62

- Ferralsols

Fo-5A/F/B							
7(174/1-180)				9(174/1-181)			
A	B	Bb_1	Bb_2	A	B	Bb	C
0-15	15-38	38-68	68-116	0-20	20-60	60-118	118-134
28	27	22	23	28	27	22	23
34	33	42	40	34	33	42	40
38	40	36	37	38	40	36	37
CL	CL	CL	CL	CL	CL	CL	CL
6.3	6.0	6.1	6.4	6.8	6.7	5.1	6.4
4.8	4.7	5.3	5.6	4.7	5.1	5.4	6.0
11.2	8.8	8.9	8.8	11.4	6.6	7.8	16.2
2.4	2.0	2.5	2.2	1.6	1.4	1.5	2.6
0.48	0.32	0.34	0.40	0.56	0.32	0.55	1.76
1.54	0.74	0.22	0.10	1.66	0.92	0.4	0.2
0.30	0.28	0.45	0.40	0.2	0.25	0.30	1.05
4.72	3.34	3.51	3.1	4.02	2.89	2.75	5.61
42.14	37.95	39.44	35.22	35.26	43.78	35.25	34.62
0.71	0.2	0.8	0.67	1.18	1.21	1.55	1.10

The organic carbon content of the A-horizons averages about 0.8% in unit (Fo-3BC) and 1.5 in (Fo-5A). Unit (Fo-3BC) is more truncated by soil erosion than (Fo-5A) - (Plates 3 and 4).

Soil reaction in these two units is moderately acid to neutral, with a pH of 5.7-6.9 (Tables 3 and 4). Furthermore, these soils have very low CEC (5-15 me/100g soil) and total bases (2-10 me/100g soil). Only the Luvisols have comparably low CEC (6-13 me) and total bases · 4-8.5 me (Tables 3, 4 and 5). Noteworthy is that the base saturation of (Fo-3BC) is more than 50% while that of (Fo-5A) is less, which is an important differentiating criterion between the two units. The very low CEC and total bases indicate that the soils are heavily leached and contain a low weatherable reserve (van Wambeke, 1962; FAO-UNESCO, loc.cit. and USDA, 1975).

The index minerals of gneisses (hornblende, sillimanite and diopside) are found mixed with those of pyroclastics (olivine and augite) in the surface soils of unit (Fo-3BC) - (Table 12). While the paleosolic subsoils of (Fo-3BC) contain index minerals of the gneisses only. The two units (Fo-3BC and Fo-5A) have volcanic glass in the A-horizons (surface soils) with additions of pyroclastics but not in the Bb-horizons (paleosols). Soils of the two units contain allophanes, kaolinite and illite in the A-and B -horizons (surface soils) but only kaolinite is found in the Bb-horizons (paleosols) mainly (Table 13). The volcanic glass and allophanes in the surface soils show that there have been additions of pyroclastic materials.

(iii) Soil development and classification: The B - horizons (upper subsoil) and Bb-horizons (paleosolic subsoil) have a combined thickness of more than 30cm (Tables 3 and 4). Although these B-horizons contain more than traces of weatherable minerals they qualify for oxic-B diagnostic horizon due to the low CEC of less than 11 me/100g soil (Tables 3, 4 and 16). Further their uniform development, despite being on rocks and geomorphic surfaces of different ages, can be attributed to the additions of pyroclastic materials in the surface soils (Wielemaker, 1979). Even if, the Luvisols (Lc- and Lo-) contain low CEC like the Ferralsols, clay illuviation is still occurring in the Luvisols as shown by the presence of the Bt-horizons (Table 5).

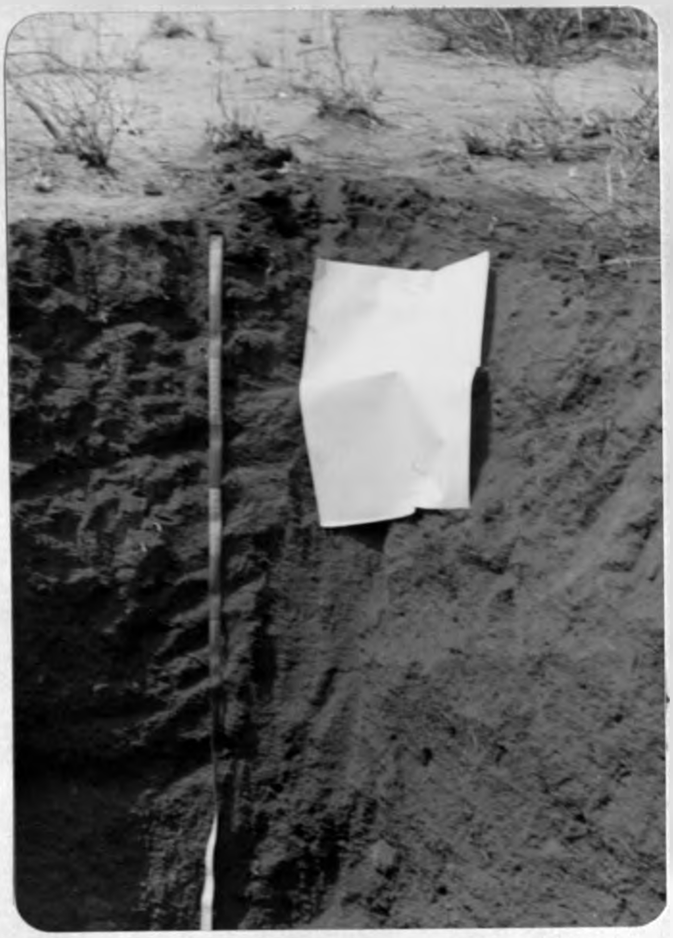
Because soil mapping units (Fo-3BC and Fo-5A) have oxic B-diagnostic horizons they are grouped as Ferralsols. They further qualify as Orthic Ferralsols according to FAO-UNESCO (loc.cit.) because they lack plinthic and humic characteristics or reddish and yellowish colours. And the corresponding USDA (loc. cit.) subgroup is Typic Eutrustox (Table 1 and Map 3).

The soil classification units of (Fo-3BC) are mainly Orthic Ferralsols with pockets of Orthic Luvisols and Xanthic Ferralsols (Table 1). While those of (Fo-5A) are Orthic Ferralsols with some areas of Orthic Luvisols. Touber's study (in prep.) shows Luvisols to be more extensive in the area of (Fo-3BC), however this was not the case in the present study.

(c) Soils of the Valley Sides

(i) Environmental attributes: Soil mapping units (Lc- and Lo-) are found on the sides of valleys with slopes of 1-6%. The soil parent materials which are gneisses rich in ferromagnesian minerals are of Archean age. The valleys have formed due to the denudation of the up-warped sub-Miocene surface (Saggerson, 1963 and; Saggerson and Baker, 1965). The area is characterised by termite mounds of about 0.5 metre high and 50 metres apart. While roots are distributed in all soil horizons and through cracks in the gneisses (Plate 9). Rill and gully erosion is common in places where slopes are more than 2% and; the Luvisols (Lc- and Lo-) are more affected by soil erosion than the Ferralsols of uplands (Fo-3BC) although the slopes (1-6%) are nearly the same (Plates 3, 5 and 6). As stated above, since the sub-Miocene epoch, accelerated erosion (denudation) has been taking place along these valleys. The units are

Plate 5



Profile pit number - 11

Mapping unit - Lc-6BC/U/F

Soil classification - Chromic Luvisols

Plate 6

Profile pit number - 12

Mapping unit - Lo-3B/U/F

Soil classification - Orthic Luvisols

grazed or cultivated in places and burning of charcoal is also practised.

(ii) Soil characteristics: Profile pits 11 and 12 are representative of mapping units (Lc-6BC) and (Lo-3B) respectively (Pl. 5 & 6 and App. 2). The solum thickness is 70-100cm and have ABCR sequence of horizons showing that the solum is well developed like that of Ferralsols (Tables 3-6). The two mapping units have well drained soils due to the nature of slopes (1-6%).

The A-horizons have sandy loam to sandy clay loam texture in unit (Lc-) therefore coarser than the sandy clay loam texture in (Lo-). The Bt-horizons have sandy clay to clay texture in both units. So, there is an increase of clay from A- to the Bt-horizons indicating clay illuviation. There is also distinct variation in colour from A- to Bt-horizons of the two units as follows. The A-horizons of (Lc-) are dark brown (10YR 4/3) while the Bt- are yellowish red (5YR 5/6). A-horizons of (Lo-) are dark greyish brown (10YR 4/2) and B-horizons are dark brown (7.5YR 4/2). Unit (Lc-) has a hue of less than 7.5YR (5YR) therefore the soils are Chromic (FAO-UNESCO, loc.cit.). Soils of the two units are sticky and plastic when wet, friable when moist and hard when dry. The structure is weak to moderate subangular blocky in the A- and Bt-horizons.

Table 5: Analytical data of the soils of valley sides - Luvisols

Mapping unit	Lc-6bC/C/F			
Profile pit number	11(174/1-177)			
Horizon designation	Ap	Bt_1	Bt_2	CB
Horizon depth (cm)	0-16	16-36	36-85	85-135
Gravel %				12
Sand %	76	59	50	64
Silt %	8	6	6	4
Clay %	16	35	44	32
Textural class	SL	SCL	SC	SCL
pH-H_2O (1:2½ v/v)	6.8	7.0	6.6	6.6
pH-KCl (1:2 v/v)	5.9	5.2	5.5	5.1
CEC pH 7.0 (me/100g) soil	8.6	13.5	13.2	11.3
Exch. Ca " "	6.0	4.5	4.6	2.6
" Mg " "	1.3	1.6	1.9	1.4
" K " "	1.0	1.2	1.3	0.5
" Na " "	0.2	0.1	0.3	0.2
Total bases	8.5	7.4	8.1	4.7
Base saturation %	98.84	54.31	61.36	41.59
C %	0.89	0.37	0.81	0.62

Lo-3P/U/F			
12(174/1-185)			
Ap	Bt_1	Bt_2	BC
0-20	20-47	47-74	74-109
			30
70	53	54	64
10	4	6	8
20	43	40	28
SL/SCL	SC	SC	SCL
6.4	6.2	6.5	6.7
4.8	4.9	5.3	5.4
8.4	10.8	7.2	6.1
2.6	3.4	3.5	2.3
1.0	1.8	2.3	2.4
0.8	1.3	0.6	0.7
Tr	0.1	Tr	Tr
4.4	6.6	6.4	5.4
52.38	61.1	88.9	88.52
0.43	0.61	0.38	0.30

The organic carbon content is 0.9% in (Lc-) and 0.45 in (Lo-). The tops of unit (Lo-) are more truncated by sheet soil erosion (Plates 5 and 6).

Soil reaction in unit (Lc-) is slightly acid to neutral (pH, 6.6-7.0) while unit (Lo-) is slightly acid (pH, 6.2-6.7). The CEC range is 8-13 me/100g soil in unit (Lc-) and 6-10 me/100g soil in (Lo-), and further, the total bases are 5.0-8.5 me (Lc-) and 4.5-6.5 me (Lo-). The higher pH, CEC and total bases in (Lc-) indicate that this unit is less leached than (Lo-). Even though, the two units have base saturation greater than 50% (Table 5).

(iii) <u>Soil development and classification</u>: In unit (Lc-) the A-horizons contain about 16% clay and the B-horizons 35% while, the A- of unit (Lo-) have 20% clay and B- have 40%. Such clay increases from A- to B- of more than 1.2%, together with evidence of clay skins in the B-horizons indicate clay illuviation or an argillic B-horizon (Bt). The soils of the Nguu volcano (Andosols) and those of uplands - plain area (Ferralsols), however, do not show a noticeable clay illuviation. Further, mapping units (Lc-) and (Lo-) are characterised by low CEC (5-12 me) comparable to those of the Ferralsols (Tables 3, 4 and 5). Finally, a base saturation greater than 50% groups units (Lc- and Lo-) with the Ferralsols (Fo-3BC) of the uplands, both groups of soil which are developed from Archean metamorphic gneisses (Saggerson, 1963).

As units (Lc-6BC and Lo-3B) have argillic B-horizons (Bt) and base saturation greater than 50%, they are classified as Luvisols. Furthermore as the soils of unit (Lc-) have colours with hues redder than 7.5YR (5YR) they are classified as Chromic Luvisols. On the other hand, the B-horizons of unit (Lo-5B) have hues yellower than 7.5YR (10YR) with chromas of 4 or less, therefore, these are classified as Orthic Luvisols. The corresponding USDA (1975) subgroup classification is Oxic Haplustalfs for the two mapping units (Table 1 and Map 3). During an earlier study of Touber (in prep.) Luvisols were identified in the project area.

(d) Soils of the Valley Bottoms

(i) Environmental attributes: Soil mapping units (Vp- and Wd-) are in the minor valleys with slopes of 0-3%. The soils have developed from depositional rock materials on the valley bottoms. This physiographic unit (valleys) formed due to the erosion of upwarped sub-Miocene surface (Saggerson and Baker, 1965). There are few worm or ant channels and the roots decrease with depth in the soils. These low faunal and flora activity in the soils may be due to the imperfect drainage. The two units have been left for grazing but, unit (Wd-) has shrubs and trees which are used for charcoal burning.

Plate 7

Profile pit number - 8

Mapping unit - Vp-1AB/V/X

Soil classification - Pellic Vertisol

Plate 8

Profile pit number - 13

Mapping unit - Wd-6AB/V/F

Soil classification - Dystric Planosol

(ii) <u>Soil characteristics</u>: The representative profiles are numbers 8 - unit (Vp-) and 13 for (Wd-) respectively (Table 6; Pl. 7 & 8 and App. 2). The solum thicknesses range from 80-115cm and horizon sequences are 1A2ACR (Vp-) and AEBCR (Wd-). Profiles of the two mapping units are imperfectly drained due to the gentle slopes (0-3%) and montmorillonitic (cracking) clays in the compact B-horizons.

Mapping unit (Vp-) has clay content of; 1A - (45%) and (>55%) in the AC-horizons, which may indicate a difference of the parent materials (between 1A- and AC-horizons). Further, unit (Vp-) is dark coloured, whereby, the A-horizons are dark greyish brown (10YR 4/2), while AC-horizons are dark grey (10YR 4/1). These soils are sticky and plastic when wet, firm when moist and very hard when dry. The A-horizons of unit (Vp-) are characterised by granular or crumb structure while the AC-horizons are blocky - (subangular or angular) or prismatic.

There are contrasts between the E- and B-horizons of unit (Wd-) as follows. The texture in the AE-horizons is sandy loam and that of the B- sandy clay. The clay content of 18% in the AE- and 40% in B- indicates a sharp textural change between the two horizons (FAO-UNESCO, loc.cit.). The bleached AE-horizons are coloured pinkish grey (7.5YR 6/2) and the

B-horizons are dark brown (7.5YR 4/2). Also, the AE-horizons are non sticky and non plastic when wet, friable when moist and hard when dry. Unlike the B-horizons that are sticky and plastic when wet, firm when moist and very hard dry. Clay eluviation from the AE horizons (Wd-) has caused the sharp differences between AE- and B-horizons but eluviation has not occurred in unit (Vp-).

The A-horizons of unit (Vp-) have organic (matter) carbon content of about 1.5% higher than that of AE-horizons of (Wd-) having 0.94%. Eluviation of organic matter from the E-horizon may have occurred together with the clay since both are colloids.

Unit (Vp-) is slightly acid to neutral (pH, 6.6-7.5) in all horizons showing limited leaching. Unit (Wd-) has slightly acid reaction (pH, 6.2-6.5) in the E- which is leached and neutral reaction in the B-horizons (pH, 6.9-7.3) where illuviation has occurred (Table 6). The CEC of 1A-horizon of unit (Vp-) is very low 11.2 me/100g soil compared with the AC-horizons where CEC is about 50 me/100g soil. Further, the total bases are 16 me/100g soil in the A1- and about 17.5 me/100g soil in the AC-horizons. But, in unit (Wd-) the CEC is 13 me/100g soil in AE- and about 20 me in the B-horizons and; total bases increase from about 10.5 me/100g soil in the AE- to about 15.2 me in B-horizons. The distribution of

Table 6: Analytical data of the soils of valley bottoms -

Mapping unit	Vp-1AB/V/X		
Profile pit number	8(174/1-182)		
Horizon designation	1A	2AC	$2CAk_1$
Horizon depth (cm)	0-11	11-31	31-84
Gravel %			
Sand %	26	26	14
Silt %	29	18	26
Clay %	45	56	60
Textural class	C	C	C
$pH-H_2O$ (1:2½ v/v)	6.6	6.8	7.5
pH-KCl (1:2 v/v)	5.6	5.7	6.9
CEC pH 7.0 (me/100g) soil	11.2	52.4	50.1
Exch. Ca " "	10.8	11.4	8.4
" Mg " "	2.8	4.32	7.52
" K " "	2.24	0.86	0.72
" Na " "	0.60	0.70	2.72
Total bases	16.44	17.27	19.36
Base saturation %	100+	32.95	38.64
C %	1.5	1.0	1.20

Vertisols and Planosols

	Wd-6AB/V/F		
	13(174/1-178)		
2CAk$_2$	AE	D	BC
84-114	0-10	10-48	48-101
13	74	53	68
14	8	7	6
73	18	40	26
C	SL	SC	SCL
7.6	6.4	7.3	6.3
7.0	5.1	5.5	5.0
50.2	13.1	24.6	16.8
9.4	8.0	8.1	10.4
4.76	1.3	1.8	3.8
0.82	1.2	1.0	0.7
3.90	0.2	0.1	0.3
18.85	10.7	11.0	15.2
37.60	81.68	44.71	90.48
0.8	0.94	0.70	0.76

organic carbon, pH and CEC in unit (Wd-) has been affected by leaching (eluviation and illuviation) comparable to the clay fraction distribution. There are no marked differences between horizons of unit (Vp-) which are barely leached.

(iii) Soil development and classification: These soils of group (d), are unlike the soils of groups (a-c) which have developed in situ (from metamorphic gneisses and volcanic rocks). Soil profiles of unit (Vp-) show little development since they have almost uniform amounts of the clay fraction (about 65%) in the AC-horizons and very high CEC (50 me/100g soil). On the other hand, there has been clay eluviation from the topsoils of unit (Wd-) leaving bleached sandy loam AE-horizons and the boundary between E- and B-horizons is marked by an abrupt textural change.

The main distinguishing criteria of unit (Vp-) are that it has vertic properties; that is cracks which are more than 2cm wide and 80cm deep, also, broken slickensides in the AC- and C-horizons. Therefore, the soils are classified as Vertisols. Furthermore, as they have chromas of less than 1.5 they fall into Pellic Vertisols soil unit (FAO-UNESCO, loc.cit.). The corresponding USDA (loc.cit.) subgroup classification is Entic Pellusterts.

The AE-horizons of unit (Wd-) are bleached with pinkish grey colour (7.5YR 6/2). The clay increase from 18% in the AE-horizons to 40% in the B-horizons is indicative of abrupt textural change (FAO-UNESCO, loc.cit.). Such an abrupt textural change is as a result of accelerated clay eluviation which is a pedological process but, it is comparable to the 'sharp textural changes' which have resulted due to the additions of pyroclastics onto the surface soils of the Ferralsols (Fo-3BC and Fo-5A), from a volcano (Fig. 4). The bleached E-horizons and abrupt textural change are diagnostic characteristics of the Planosols (FAO-UNESCO, loc.cit.). Furthermore, the B-horizons have a base saturation of less than 50% therefore the soils are classified as Dystric Planosols. The USDA (loc.cit.) subgroup classification is Typic Albaqualfs (Table 1 and Map 3).

Plate 9

A - Gneisses (Metamorphic rocks)

B - Basanites (Basic igneous rocks)

(Note the difference in the weathering pattern of the two rocks)

Plate 10

The Nguu Volcano Area

The highest point is a volcanic cone on the Nguu Hill where Vitric Andosols of unit (Tv-6D/H/V) are found. Then on the footslopes of the cone are found Ochric Andosols (To-5C/U/V). Further, the Orthic Ferralsols of mapping units (Fo-3BC/U/U) and (Fo-5A/P/B) are found in middle and foreground of the area, respectively. Unit (Fo-3BC) has a bushland while grass is found in unit (Fo-5A). The latter two units are dissected by minor valleys.

4.2* The influence of pyroclastics on the soils

The influence of the pyroclastics on the soils was investigated in two directions. First to ascertain the source of the pyroclastics and their depositional effects. Secondly, to determine the variation of the soils with their depth, which was mainly aimed at finding out the differences between the surface soils and their respective paleosols (subsoil with different parent material). The following soil characteristics or variables were considered; colour, structure, texture, mineralogy, pH, total bases and CEC.

4.2.1 Source and depositional effects of the pyroclastics

(a) The source and depositional areas

The Nguu volcano is the source of the pyroclastic material. This volcano has several volcanic cones with layered pyroclastic materials of late Pleistocene age (Plates 1 and 10). Such pyroclastics, that form cones, are indicative of explosive volcanoes which spread the materials over very large areas (Fig. 4; Holmes, 1965; Longwell et al., 1969 and Pettijohn, 1975). The pyroclastics are composed of some highly

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4.2* Parts of this section were presented as a paper during the 6th Conference on African Geology (Wamicha and D'Costa, 1982).

weatherable minerals like volcanic glass, olivine and augite (Tables 11 and 18). The dominant soils on the Nguu Hill are the 'volcanic' Andosols mapping unit (Tv-6D/H/V) on the cones having abundance of vitreous pyroclastics and; Andosols (To-5C/U/V) on the lower slopes with less vitreous materials, where the soils have a smeary consistence.

The uplands, from the foot of the Nguu volcano, are part of the area where the pyroclastics were deposited on surface soils (Map 3 and Plates 9A and 10). These uplands have Archean metamorphic gneisses with a thin overburden of the pyroclastics (Saggerson, 1963 and Touber, in prep.). Over the period of time, the gneisses that are composed of ferromagnesian minerals have weathered strongly leaving behind highly resistant minerals like quartz, orthoclase and rutile (Tables 11, 16 and 18). The soils on the uplands are Ferralsols (Fo-3BC/U/U) which are deep and highly weathered with a less weathered pyroclastic deposit on top (Fig. 4).

Moving farther westwards the topography gives rise to a plain which was formed by an early Pleistocene lava flow (Map 3 and; Plates 9b and 10). This area is also covered by a thin overburden of younger (late Pleistocene) pyroclastic materials (Saggerson, loc.cit. and Searle, 1954). The Ferralsols (Fo-5A/P/B) have developed from the highly weatherable minerals like olivine and augite which compose the basanites.

However, below the uplands and the plains are found intermittent minor valleys on Archean metamorphic gneisses rich in ferromagnesian minerals. Denudation is very active along these valleys as shown by the presence of sheet and gully soil erosion. The denudation started in the late Tertiary period after the upwarping of the sub-Miocene surface in Eastern Kenya (Saggerson and Baker, 1965). And has resulted in the removal of the early Pleistocene basanites in the valleys below the plains to expose the older Archean gneisses. Therefore the pyroclastics and the older basanites must have been eroded away together. The eroded rock materials have been deposited in the valley bottoms. Soil development on the valley sides has given rise to Luvisols units (Lc-3BC/U/F) and (Lo-3B/U/F) which are less weathered than the Ferralsols. The Vertisols (Vp-1AB/V/X) and Planosols (Wd-6AB/V/F) have developed in the valley bottoms. These Vertisols have very little soil development shown by the AC-horizon profiles but, accelerated clay illuviation has occurred in the Planosols resulting in AEBC-horizon sequence profiles.

(b) <u>Depositional particle size zones:</u>

The soils on the Nguu hill have coarse grains (>2.00mm fraction) which occur both in the soil profiles and on the surface (Plates 1 and 2). These grains have been classified by geologists as lapillis, bombs and

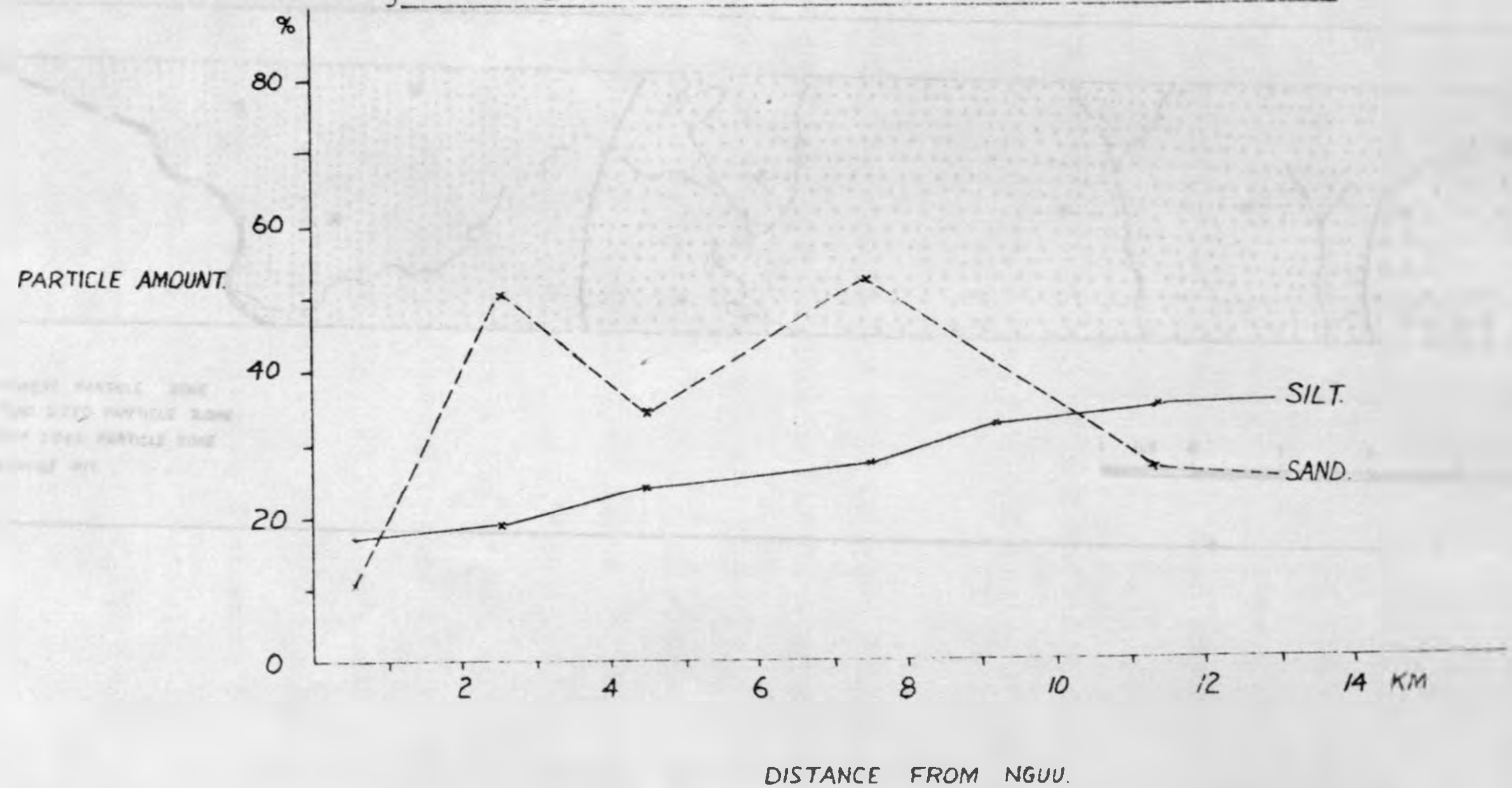
Table 7: Variation of the soils with distance from Nguu

PROFILE PIT	DISTANCE FROM NGUU (km)	DEPTH OF SURFACE SOIL (cm)*	TEXTURE							
			Composite Sample			Top Horizon Sample			Mean of two Samples	
			S	Si	C	S	Si	C	S	Si
2	0.5	On Pyroclastics	11	19	70	7	14	79	9	13
3	2.5	65	50	18	32	52	20	28	51	19
4	4.5	55	30	26	44	38	23	39	34	24
5	7.5	46	50	29	21	55	26	19	52	27
6	9.2	55	40	34	26	41	31	28	40	32
7	11.4	40	25	36	39	28	34	38	26	35
9	13.0	60	22	37	41	28	34	38	25	35

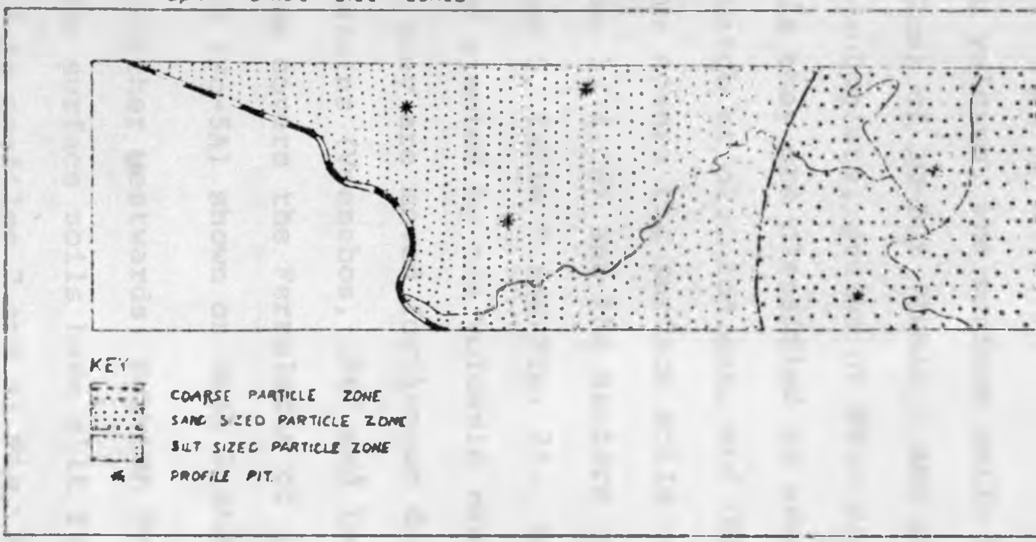
KEY

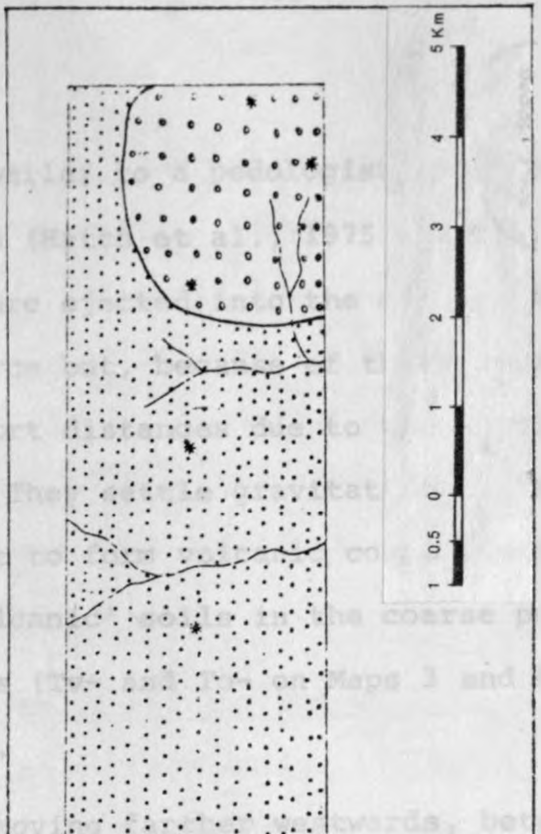
S - Sand
Si - Silt
C - Clay
* The mean depth, of surface soils, was calculated using the depth in a representative profile pit and three auger hole observations around the pit.

Fig. 2 DISTRIBUTION OF SAND AND SILT WITH DISTANCE FROM NGUU



Map 4 Particle size zones




1 0.5 0 1 2 3 4 5 Km

blocks while; to a pedologist they are stones and boulders (Hatch et al., 1975 and FAO, 1977). Such grains are ejected into the air by the volcanic explosive force but, because of their weight, they move to very short distances due to the aerodynamic (wind) force. They settle gravitationally and accumulate near the vent to form volcanic cones (Longwell et al., 1969). The 'volcanic' soils in the coarse particle zone are Andosols (Tv- and To- on Maps 3 and 4 also Plate 10 and Fig. 4).

Moving farther westwards, between 2-10km from the Nguu volcano, the surface soils have sand fraction (2.0-0.2mm) of 30-50% (Table 7 and Fig. 2). According to the geologists, grains of this size are volcanic ash while they are classified as sands by the pedologists (Hatch et al., loc.cit. and USDA, 1962). The sand zone covers the surface soils of the uplands (profiles 3, 4, 6) and the eastern part of the plains (profiles 5, Table 7 and Fig. 2). Sand sized particles are also ejected by the volcanic explosions but being lighter they are moved for longer distances than the coarse grains (Veenebos, 1967 and Longwell, 1969). The sand zone covers the Ferralsols of (Fo-3BC) and eastern parts of (Fo-5A) shown on Maps 3 and 4 (Fig. 4).

Farther westwards, between 9-13km from the Nguu Hill, the surface soils have silt fractions of 30-35% (Table 7 in profiles 7 and 9; Fig. 2). Silt sized particles are also called volcanic ash grains (Longwell et al., loc.cit.). As volcano ejects the coarse, sand and silt sized particles, the silt being the lightest is transported farthest in suspension (Veenebos loc.cit.; Longwell et al., loc.cit.; Mohr et al., 1972 and Pettijohn, 1975). Pyroclastics have been found 9 miles (14km) away from volcanoes similar to the Nguu (Searle, 1954) (Fig. 4).

(c) Depth of the surface soils:

The surface soils, influenced by the pyroclastics are about 65cm deep at the distance of 2.5km west of Nguu (in pit 3) and 40cm at 11.4km distance (pit 7). The depth of surface soils therefore decreases gradually westwards away from Nguu. This compares with the Kisii area, where the depth of surface soils decreases away from the 'Rift Valley Volcanoes' of Kenya (Wielemaker, 1979).

But, from 11.4km (pit 7) to 13km (pit 9) the depth increases from 40cm to 60cm respectively (Table 7). The increase corresponds to a rise in altitude from 1050m (pit 7) to about 1080m at pit 9 (Map 3). More silt sized particles, which make up part of the suspension load, are deposited on high topographic features (Hunt, 1972).

The buried soils in the Nguu area can be termed as 'false' paleosols (Ruhe, 1971). Since all the paleosols are under the direct and continuous influence of biological activity, as there are roots and animal channels from the surface soils to the paleosols (Appendix 2, profiles 1-9). Also, some of the surface soils are less than 50cm, especially between about 9-12km west of the Nguu volcano therefore; the respective paleosolic subsoils are not buried in the strict sense (FAO-UNESCO, 1974).

Thus the particle sizes of the pyroclastics decrease away from the Nguu volcano resulting in particle size zones. The depth of surface soils also decreases away from the volcano but fluctuates with altitude.

4.2.2 Variation in soil characteristics with soil depth

(a) Soil colour

Soils on the Nguu Hill developed from the pyroclastics are the Andosols (Tv- and To-). The Andosols (Tv-) on the volcanic cones have dark greyish brown (10YR 3/2) colour throughout the profiles (Table 8). Soils at the lower parts of Nguu Hill are Andosols (To-) which are reddish brown (5YR 4/3) throughout the profiles. Therefore both these units have homogeneous colour in any given profile.

On the uplands, from the foot of the Nguu Hill, are the Ferralsols (Fo-3BC) developed from gneisses but have additions of pyroclastics in the surface soils.

Table 8: Variation of colour with soil depth

Mapping unit	Tv-6D	To-5C	Fo-3BC	Fo-5A
Physiography	Nguu(cones) Hill	Nguu Footslopes	Uplands	Plains
Soil classification	Vitric Andosols	Ochric Andosols	Orthic Ferralsols	Orthic Ferralsols
Soil horizons	A,	A, AB, B	A, B	A, B
Soil colour	Dark greyish brown (10YR 3/2)	Reddish brown (5YR 3/2)	Dark brown (7.5YR 3/4)	Reddish brown (5YR 4/4)
Parent materials	Pyroclastics	Pyroclastics	Gneisses & Pyroclastics	Basanites & Pyroclastics
	B O U	N D	A R	Y
Soil horizons	CB	BC	Bb	Bb
Soil colour	Dark greyish brown (10YR 4/2)	Reddish brown (5YR 4/4)	Strong brown (7.5Y 5/6)	Dark brown (7.5YR 4/2)
Parent materials	Pyroclastics	Pyroclastics	Gneisses	Basanites

(Simplified from Table 15 (Appendix 1)

These Ferralsols have dark brown (7.5YR 3/4) surface soils (A- and B-horizons) and strong brown (7.5YR 5/6) paleosolic subsoil (Table 8). Farther west from the Nguu Hill, in the plains, the Ferralsols (Fo-5A) are developed from basanites and have additions of the pyroclastics. Here the surface soils, with the pyroclastics are reddish brown (5YR 4/4) while the paleosolic subsoils are dark brown (7.5YR 4/2).

Each rock has its characteristic weathering products (Table 20). Such products, for example the iron oxides cause specific colouration to the resulting soil. The surface soils of Ferralsols (having additions of pyroclastics) are coloured differently from their paleosolic subsoils (on the gneisses or basanites). But the Andosols which are on the pyroclastics per se have homogeneous colour throughout the profiles. Therefore parent rock (material) may impart a certain colour to a soil (INQUA, 1971).

(b) Soil structure

The Andosols (Tv- and To-) generally have subangular or angular blocky structure both in the A- and B-horizons (Table 9). Therefore in the Andosols, structure could not be used to differentiate the topsoils (A-horizons) from the subsoils (B-horizons). While with the Ferralsols (Fo-3BC and Fo-5A) the structure is subangular blocky both in the surface

Table 9: Variation of structure with soil depth

Mapping unit	Tv-6D	(To-5C)					Fo-3BC							(Fo-5A)					
Profile pit	1	2		10			3			4		6		5		7		9	
Soil horizons	A	A	Bu_1	A	AB	B	A	Bt_1	Bt_2	A	B	A	AB	A	B	A	B	A	B
Soil structure	sb	sb	ab	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb	sb
B O U N D A R Y																			
Soil horizons	CB	Bu_2		BC_1	BC_2		Bb_1	Bb_2		Bb_1	Bb_2	Bb_1	Bb_2	Bb		Bb_1	Bb_2	B	C
Soil structure	M	ab		sb	M		sb	sb		sb	sb	sb	sb	sb		sb	sb	Pr	M

KEY

Simplified from Table 15 (Appendix 1)

soils (A- and B-horizons) and the paleosols (Bb-horizons), except in profile pit 9. The pit 9 has sub-angular blocky structure in the surface soils (A- and B-horizons) and prismatic structure in the paleosolic subsoil (Bb-horizon on Table 9). Only in profile 9 (Fo-5A) structure was helpful to identify the presence of a paleosol. There has been contrasting views on the use of soil structure in recognising the presence of paleosols. The first view is that, the original soil structure is preserved in a paleosol after burial (INQUA, 1971). While the other view is that, the structure may be destroyed by compaction and cracking after burial of a paleosol, whereby structure cannot be useful (Beukenkamp and Sevink, 1971). In the Nguu Volcano area soil structure had a very limited use.

(c) Soil texture

All the representative profiles of Andosols (Tv- and To-) and Ferralsols (Fo-3BC and Fo-5A) have 'textural breaks' (Table 10). A textural break is marked by sand or silt fraction difference of 5 per cent or more between two adjacent horizons. Textural breaks usually form boundaries between different soil parent materials in a soil profile.

The Andosols (Tv-6D) on the Nguu volcanic cones are represented by profile pit 1, while on the foot-slopes, Andosols (To-5C) the representative profiles are 10 and 2 which is an inclusion (App. 2)

Table 10: Textural breaks

Mapping unit	Tv-6D	To-5C		
Profile pit	1	2	10	3
Soil horizons	A	Bu_1	A , BC_1	Bt_2
S/Si %	44/23	7/14	32/24,20/28	48/14
T E X T U R A L				
S/Si %	47/33	6/20	24/28,40/18	56/12
Soil horizons	CB	Bu_2	AB, BC_2	Bb_1

KEY

S - Sand

Si - Silt

(Simplified from Tables 2, 3 and 4)

Fo-3BC		Fo-5A		
4	6	5	7	9
B	AB	Bt	B	B
38/32	39/37	49/21	27/32	27/33
B R E A K				
60/15	43/29	38/29	22/42	22/42
Bb_1	Bb_1	Bb	Bb_1	Bb

Pit 1 has a textural break between the A- and CB-horizons marked by a silt increase of 10% from 23-33% (Table 10). In pit 2 a textural break is between Bu_1- and Bu_2- horizons where silt is 14% and 20% respectively (Table 10 and Fig. 3a). Profile pit 10 has two textural breaks; the first one between the A- and AB- horizons marked by a sand decrease from 32% to 24%. The second between the BC_1- and BC_2-horizons where sand increases by 20% to 40% (Table 10). The textural breaks in the Andosols are due to the layered pyroclastic parent materials (Plate 1). The different layers apparently have varying sizes of particles (bombs or lapilli or volcanic ash).

The Ferralsols (Fo-3BC) of the uplands are represented by profile pits 3, 4 and 6; those of the plains (Fo-5A) by pits 5, 7 and 9 (Table 10; Fig. 3b and 3c). Pit 3 has a textural break between the Bt_2- and Bb- horizons where sand increases from 48% to 56%. In pit 4, sand is 38% in the B-horizon and 60% in the Bb- horizon; while silt decreases from 35% to 15% between these two horizons. Profile 5 has a textural break between Bt- and Bb- horizons marked by; sand decrease from 49% to 38% and a silt increase from 21% to 29%. The sand is 38% in the AB- and 43% in the Bb-horizons while silt is 37% and 25% in the two horizons, respectively of pit 6. Profiles 7 and 9 have sand fraction decreasing from 27% to 22% and silt increasing by 10% from 32% to 42% in the B- and Bb- horizons, Fig 3a: VARIATION OF SAND AND SILT WITH DEPTH IN MAPPING UNIT To-5C|U|V.

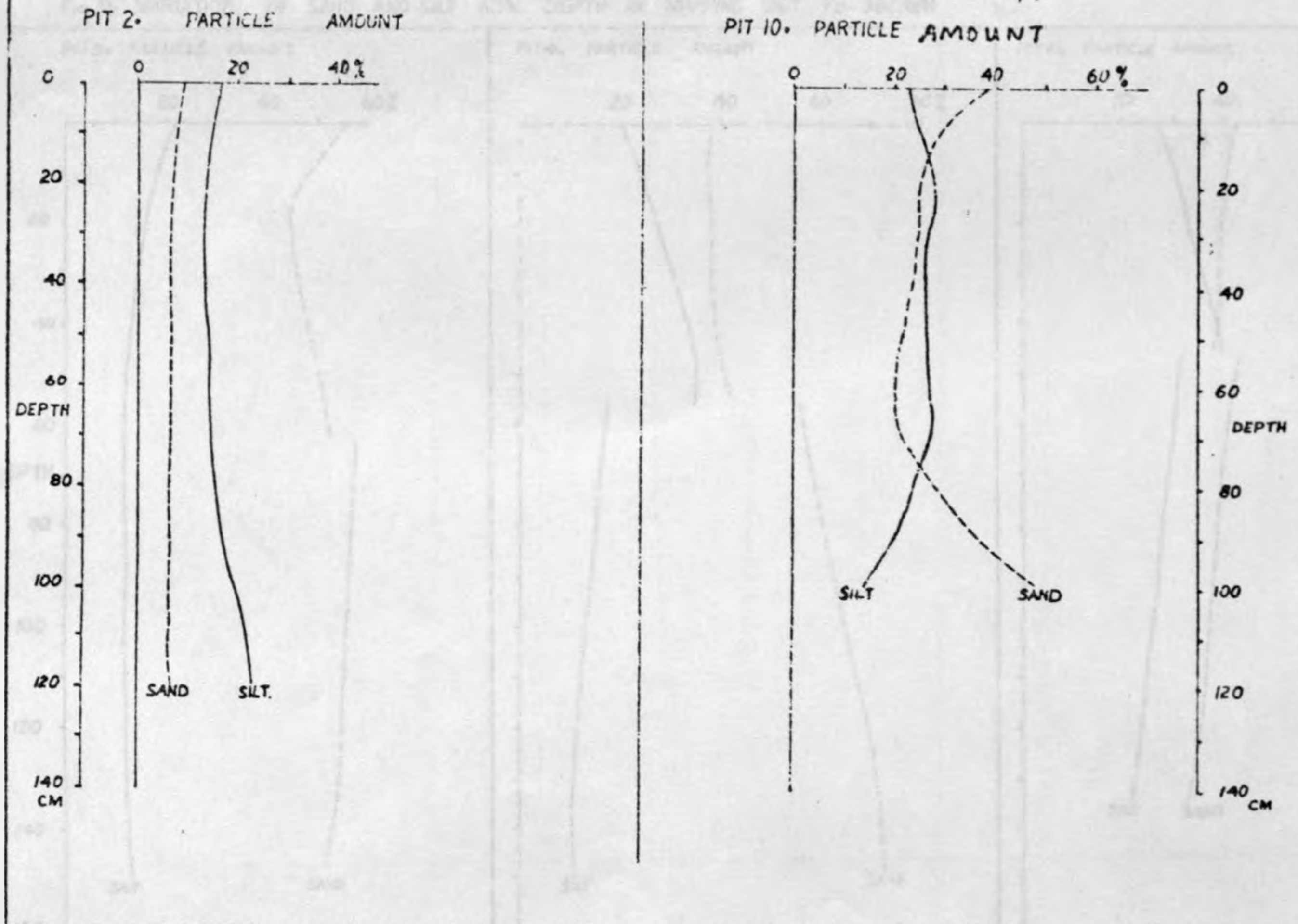


Fig 3b: VARIATION OF SAND AND SILT WITH DEPTH IN MAPPING UNIT Fo-3BC/U/U

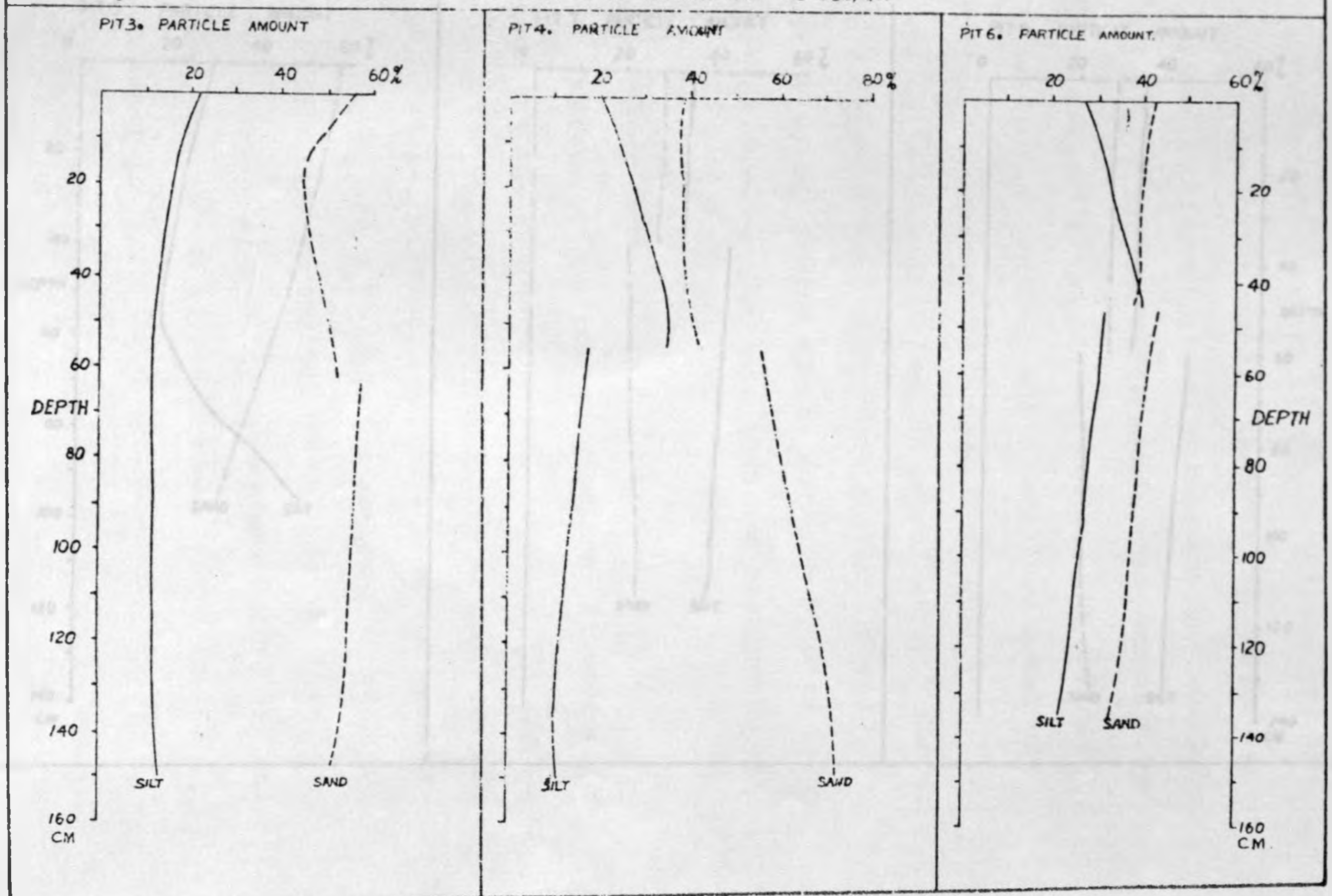
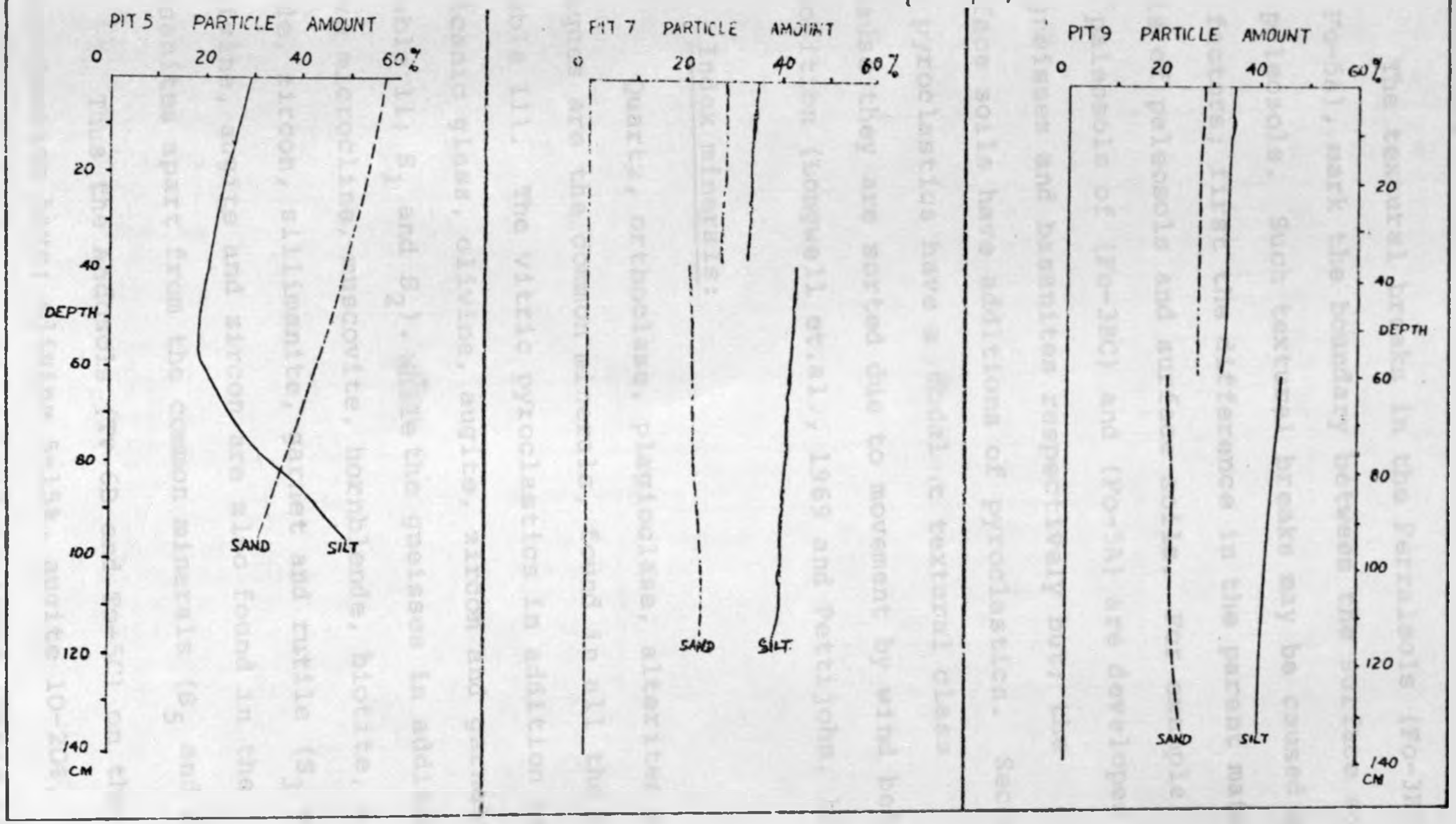


Fig 3C VARIATION OF SAND AND SILT WITH DEPTH IN MAPPING UNIT (Fo-5AP1B)



respectively.

The textural breaks in the Ferralsols (Fo-3BC and Fo-5A), mark the boundary between the surface soils and paleosols. Such textural breaks may be caused by two factors; first the difference in the parent materials of paleosols and surface soils. For example, the paleosols of (Fo-3BC) and (Fo-5A) are developed on gneisses and basanites respectively but; the surface soils have additions of pyroclastics. Secondly the pyroclastics have a modal ıt textural class because they are sorted due to movement by wind before deposition (Longwell et.al., 1969 and Pettijohn, 1975).

(d) Index minerals:

Quartz, orthoclase, plagioclase, alterites and opaques are the common minerals, found in all the rocks (Table 11). The vitric pyroclastics in addition have volcanic glass, olivine, augite, zircon and garnet (Table 11; S_1 and S_2). While the gneisses in addition have microcline, muscovite, hornblende, biotite, diopside, zircon, sillimanite, garnet and rutile (S_3 and S_4). Olivine, augite and zircon are also found in the basanites apart from the common minerals (S_5 and S_6).

Thus the Andosols (Tv-6D and To-5C) on the pyroclastics have; olivine 5-15%, augite 10-20%, garnet 5% and zircon 1%, in all horizons (Table 12 & 16). All the four minerals are characteristic minerals of the vitric pyroclastics (Table 11, S_1 and S_2), which

Table 11: Mineralogy of the rock specimens

Rock specimen No.	Rock Classification	Qu	Or	Pl	Mi	Mu	Ho	Si	Al	Op	Ga	Ru	Se	V.G	Bi	Di	Au	Ol	Zi
S1	Vitric Pyroclast	X	X	X	-	-	-	-	Tr	X	X	-	-	X	-	-	X	X	X
S2	Vitric Pyroclast	X	X	X	-	-	-	-	X	X	-	-	-	X	-	-	X	X	X
S3	Gneiss	X	X	X	X	X	X	X	X	X	-	X	-	-	X	-	-	-	-
S4	Gneiss	X	X	-	-	X	X	X	Tr	Tr	X	Tr	-	-	X	X	-	-	X
S5	Basanite (Basalt)	X	X	X	-	-	-	-	X	X	-	-	-	-	-	-	X	X	X
S6	Basanite (Basalt)	X	X	X	-	-	-	-	X	X	-	-	-	-	-	-	X	X	-

Key to the minerals

Qu-Quartz	Si-Sillimanite	V.G.-Volcanic glass
O-Orthoclase	Al-Alterite	Bi-Biotite
Pl-Plagioclase	Op-Opaque	Di-Diopside
Mi-Microcline	Ga-Garnet	Au-Augite
Mu-Muscovite	Ru-Rutile	Ol-Olivine
Ho-Hornblende	Se-Sericite	Zi-Zircon

KEY

X - Mineral present

Tr - Mineral in trace amounts

\- - Mineral not seen

Table 12: Distribution of the index minerals in the soils

Mapping unit	Tv-6D	To-5C	Fo-3BC	Fo-5A
Profile pits	1	2, 10	3, 4, 6	5, 7, 9
Soil horizons	A	A, AB, B	A, B	A, B
Index minerals	VG, Ol, Au	VG, Ol, Au	VG,Ol,Au/Mi,Mu,Ho,Si,Di	VG/Ol, Au
Parent materials	Pyroclastics	Pyroclastics	Gneisses & Pyroclastics	Basanites & Pyroclastics
B O U N D A R Y				
Soil horizons	CB	BC	Bb	Bb
Index minerals	VG, Ol, Au	VG, Ol, Au	Mi, Mu, Ho, Si, Di	Ol, Au
Parent materials	Pyroclastics	Pyroclastics	Gneisses	Basanites

Key to the index minerals

VG-Volcanic glass) -Pyrocalstics

Ol-Olivine
Au-Augite } Pyroclastics and Basanites

Mi-Microcline
Mu-Muscovite
Ho-Hornblende
Si-Sillimanite
Di-Diopside } metamorphic gneisses

(Simplified from Table 16 (Appendix 1)

leads to the conclusion that, the Andosols have developed on the pyroclastics *per se*.

The surface soils of the Ferralsols, (Fo-3BC) on the uplands have index minerals representative of the pyroclastics such as; volcanic glass 2-3%, olivine 3% and augite 2% (Table 12). These three minerals are mixed with those of the metamorphic gneisses - microcline 1-2%, muscovite 1-7%, hornblende 2-8%, diopside 5% and sillimanite 1-3% (Tables 12 and 16).

The Ferralsols (Fo-5A) of the plains contain volcanic glass of about 2% in their surface soils which is indicative of the pyroclastic influence (Table 12). Additionally, they have olivine and augite which are constituent of both the basanites and pyroclastics (Table 11 and 12). This means that the latter two minerals cannot be used as index minerals of the pyroclastics in this mapping unit.

So, the surface soils of the Ferralsols (Fo-3BC and Fo-5A) have the index minerals of the pyroclastics mixed with those of the bedrocks (the gneisses and basanites). Therefore, the surface soils have mixed parent materials while the paleosols are developed from the bedrocks. Such index minerals have been used to identify soils that are influenced by pyroclastic materials in various parts of Kenya (Siderius and Wamicha, 1978 and 1979).

Table 13: Distribution of the clay minerals

Mapping unit	Tv-6D	To-5C	Fo-3BC	Fo-5A
Profile pits	1	2,10	3, 4, 6	5, 7, 9
Soil horizons	A	A, AB, B	A, B	A, B
Clay minerals	Allo	Allo,Ka,Illi,Mont	Allo, Ka, Illi	Allo, Ka, Illi
Parent materials	Pyroclastics	Pyroclastics	Gneisses & Pyroclastics	Basanites & Pyro-clastics
B O U N D A R Y				
Soil horizons	CB	BC	Bb	Bb
Clay minerals	Allo	Allo,Ka,Illi,Mont	Ka	Ka
Parent materials	Pyroclastics	Pyroclastics	Gneisses	Basanites

(Simplified from Table 17 (Appendix 1)

Table 14: Variation of pH, CEC and total bases with soil depth

Mapping unit	Tv-6D	To-5C	Fo-3BC	Fo-5A
Profile pits	1	2, 10	3, 4, 6	5, 7, 9
Soil horizons	A	A, AB, B	A, B	A, B
pH (H_2O)	6.5	6.5-7.0	6.6-7.0	6.0-6.8
CEC(pH 7.0)me/100g soil	43.2	20.0-34.0	7.6-10.6	8.5-11.5
Bases(pH 7.0)me/100g soil	36.9	13.0-32.5	5.0-10.5	3.0-4.5
Parent materials	Pyroclastics	Pyroclastics	Gneisses & Pyroclastics	Basanites & Pyroclastics
B O U N D A R Y				
Soil horizons	CB	BC	Bb	Bb
pH(H_2O)	6.8	7.0	5.5-7.0	5.0-6.5
CEC(pH 7.0)me/100g soil	49.7	17.0-30	5.0-9.8	7.5-9.0
Bases(pH 7.0)me/100g soil	46.9	14.0-31.0	3.0-8.0	2.5-3.5
Parent materials	Pyroclastics	Pyroclastics	Gneisses	Basanites

(Simplified from Tables 2, 3 and 4)

The volcanic glass and olivine are termed as least stable minerals while augite is a lesser stable mineral (Table 18). The pyroclastics have then contributed highly weatherable minerals to the surface soils therefore increasing the weatherable reserve in the surface soils.

(e) Clay mineralogy

The Andosols (To- and Tv-), on the Nguu volcano, contain allophanes in all pedogenetic horizons (Table 13). Profiles 2 and 10 have, in addition kaolinite, illite and montmorillonite. The Ferralsols (Fo-3BC and Fo-5A) contain allophanes, kaolinite and illite in the surface soils (A- and B-horizons) while the corresponding paleosols (Bb-horizons) have kaolinite but no allophanes (Table 13). The paleosolic subsoils of profiles 3 and 5 contain illite also.

Allophane is the clay mineral found in all the profiles of Andosols (Tv- and To-) and the surface soils of the Ferralsols (Fo-3BC and Fo-5A), associated with the distribution of pyroclastics. Clearly the lack of allophanes in the paleosolic subsoils of the Ferralsols is indicative of no pyroclastic influence. One process by which allophanes form in a soil is by weathering from pyroclastic materials (Fieldes, 1966 and Gieseking, 1975).

(f) Soil pH, total bases and CEC

Andosols (Tv- and To-) are generally slightly acid to neutral with a pH range of 6.5-7.0 (Table 14). Profile pit 1 (Tv-) has total bases of 36.0-47.0 me/100g soil. While in pits 2 and 10 (To-) the total bases are 13.0-32.5 me/100g soil. The pH in the surface soils of Ferralsols (Fo-3BC and Fo-5A) is 6.0-7.0 and that of the paleosolic subsoil 5.0-6.5 (Table 14). The total bases are 3.5-10.5 me/100g soil and 3.0-8.0 me/100g soil in the surface soil and paleosols respectively.

In profile pit 1 (Tv-) the CEC of Andosols is 40-50 me/100g soil while for the other Andosols (To-) in pits 2 and 10 CEC is 17-34 me/100g soil. The Ferralsols have CEC of 6.5-11.5 me/100g soil and 5.5-9.0 me/100g soil in the surface soils and the paleosolic subsoils respectively.

Thus the Andosols (Tv- and To-) which are developed from the Nguu pyroclastics per se contain more plant nutrient reserve (weatherable minerals, allophane, CEC and total bases) than the Ferralsols (Fo-3BC and Fo-5A). Further the surface soils (with additions of the pyroclastics) of the Ferralsols also have more nutrient reserve than their respective paleosols. These paleosols are from Archean metamorphic gneisses (Fo-3BC) and early Pleistocene basanites (Fo-5A). Therefore the Nguu pyroclastics have contributed to the nutrient reserve which is beneficial to the plants.

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 Summary

This study had two main objectives namely: first to classify the soils using the FAO-UNESCO (1974) 'Legend' and USDA (1975) 'Soil Taxonomy'. Secondly, to examine the influence of pyroclastic materials from the Nguu Volcano on the soils.

5.1.1 Soil classification

The classified soil units fit into four topographic groups which include soils on the Nguu hill, soils on the uplands and plains, soils on the valley sides and soils on the valley bottoms. Soils on the Nguu volcano are mainly the Andosols, mapping units (Tv-6D/H/V) of Vitric Andosols and (To-5C/U/V) of Ochric Andosols. The two mapping units have developed from the late Pleistocene Nguu pyroclastics and lack buried (Paleosols) horizons (map 3).

On the uplands and plains, are found the Orthic Ferralsols of units (Fo-3BC/U/U) and (Fo-5A/P/B) respectively. The uplands form part of the sub-Miocene surface on Archean metamorphic gneisses while the plains were formed by an early Pleistocene basanite lava flow. The uplands and plains have deposits of the late Pleistocene Nguu pyroclastics, therefore, the Ferralsols have buried paleosolic subsoils.

Minor valleys which dissect the uplands and plains contain the valley association of soils. There has been active denudation on the valley sides and the (denuded) materials deposited in the valley bottoms, since the late Pleistocene epoch. Soil mapping units (Lc-6BC/U/F) of Chromic Luvisols and (Lo-3B/U/F) of Orthic Luvisols occur on the valley sides developed from Archean gneisses rich in ferromagnesian minerals. The Pellic Vertisols (Vp-1AB/V/X) and Dystric Planosols (Wd-6AB/V/F) are found in the valley bottoms (Map 3).

5.1.2 Influence of the pyroclastics on soils

(a) Distribution of the pyroclastics: The Nguu pyroclastics were deposited in two main areas; first near the source (vent) where they form volcanic cones and the layered pyroclastics (in the volcanic cones) indicating explosive volcanicity. Soils developed from these pyroclastics are the Andosols (To- and Tv-). Secondly, away from the Nguu hill the pyroclastics were deposited gravitationally on rocks older than the late Pleistocene period of volcanicity. These rocks are the Archean gneisses and the early Pleistocene basanite lavas. The pyroclastics that were incorporated in the surface soils now cover the paleosols of the Ferralsols (Fo-3BC and Fo-5A). Along the minor valleys, due to denudation the late Pleistocene pyroclastics and the early Pleistocene basanites have been eroded away to expose the older Archean metamorphic gneisses on which are found the Luvisols with Vertisols and Planosols in the Valley Bottom.

The influence of the pyroclastics on the soils varies in two main directions. First, the depositional influence decreases in depth with distance from the Nguu volcano. And secondly, there are differences of soil characteristics between the surface soils and the paleosols of the Ferralsols.

(b) <u>Variation of the soils with distance from Nguu</u>: The average particle sizes of the pyroclastics decrease away from the Nguu volcano resulting in particle size zones. Therefore there is a coarse particle zone (>2.0mm fraction) on the Nguu volcano in form of cones. A sand zone from the foot of the volcano to about 10km westwards and a silt zone from 10km westwards to the end of the project area (14km).

The depth of the surface soils also decrease away from the volcano but fluctuates with altitude. The depth is 65cm at a distance of 2.5km west of Nguu, 40cm at 11.4km and 60cm at 13km. The increase in depth from 11.4km to 13km corresponds with a rise in altitude from about 1050m to about 1080m respectively.

(c) <u>Variation of soil characteristics with soil depth</u>: The Ferralsols (Fo-3BC and Fo-5A) have variation of colours from the surface soils to the paleosols. This is related to the additions of pyroclastics in the surface soils which overlie the paleosols developed from the bedrocks - the gneisses or basanites (Fig. 4). The different parent materials of surface soils and the paleosolic subsoils weather to their characteristic products (for example oxides) that impart a specific colour to the soil. But in the Andosols, where the pyroclastics *per se* are the parent materials, the soil colour is uniform from the topsoil to the subsoil of each profile.

Soil structure may be preserved after the burial of a paleosol and the preserved structure can indicate the presence of a paleosol, if different from that of the overlying surface soil. In profile pit 9, of the Ferralsols on the plains (Fo-5A), the surface soils have subangular blocky structure, while the paleosols are prismatic. Such a structural difference, between the surface soils and paleosols was not observed in any other profile pit. Therefore, structural difference was of no significance.

The Andosols (Tv- and To-) and Ferralsols (Fo-3BC and Fo-5A) have 'textural breaks' in their profiles. Textural breaks in the Andosols result from the layering of the parent (pyroclastic) materials. In the Ferralsols textural breaks mark the boundary between the surface soils and the paleosolic subsoils.

Index minerals study of the parent rocks (pyroclastics, gneisses and basanites) in the area showed that in addition to common rock forming minerals, the pyroclastics contain volcanic glass, olivine and augite; the gneisses have microcline, muscovite, hornblende, sillimanite and diopside; while the basanites have olivine and augite. Such minerals in a soil show the parent material(s) from which the soil has developed. The Andosols (Tv- and To-) contain the index minerals of pyroclastics both in their topsoils and subsoils. The Gneissic Ferralsols on the uplands (Fo-3BC) contain index minerals of pyroclastics mixed with those of the gneisses, in their surface soils but, only index minerals of the gneisses are found in the paleosols. The surface soils of the Basanitic Ferralsols (Fo-5A) on the plains contain volcanic glass and allophanes but these two minerals are lacking in the paleosols. The Andosols are therefore developed from the pyroclastics per se and the surface soils of Ferralsols have additions of the pyroclastics.

The formation of allophanes in a soil may be as a weathering product of pyroclastics. The Andosols (To- and Tv-) which developed from pyroclastics contain allophanes in all their profiles. Allophanes in the Ferralsols (Fo-3BC and Fo-5A) occur only in the surface soils where the pyroclastics were deposited. So, the distribution of allophanes in the project area is similar to that of the pyroclastics.

The weathering of rocks also releases different bases (Ca, Mg, K and Na) which affect the soil pH and

CEC. Noteworthy is the uniform distribution of the three soil characteristics in each profile of the Andosols (Tv- and To-). In the Ferralsols (Fo-3BC and Fo-5A) the pH, total bases and CEC are slightly more in the surface soils than the paleosols. This has been attributed to the additions of fine pyroclastic particles in the surface soils which have weathered to release bases. These bases in turn have affected pH and CEC, or in other words the particles have increased the plant nutrient reserve.

5.1.3 Operational 'geo-pedological' processes

Since the Archean (Precambrian) era various 'geo-pedological' processes have been operational in the project area as follows:

(a) Metamorphism of sediments, during the Archean (Precambrian) era resulted in the formation of gneisses.

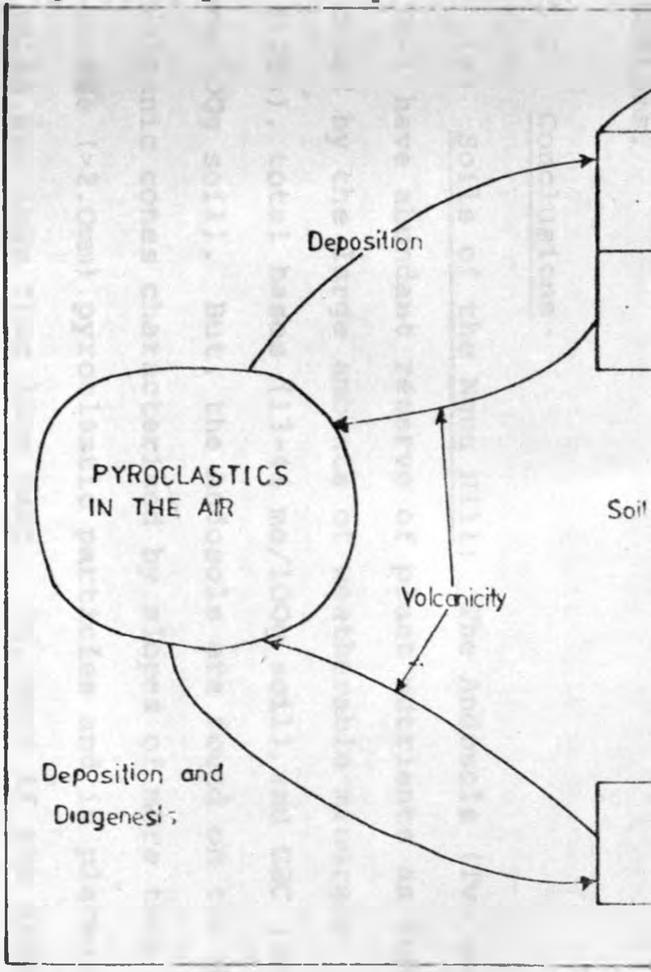
(b) Denudation (planation) of the gneisses, that culminated to the sub-Miocene surface which now forms the uplands.

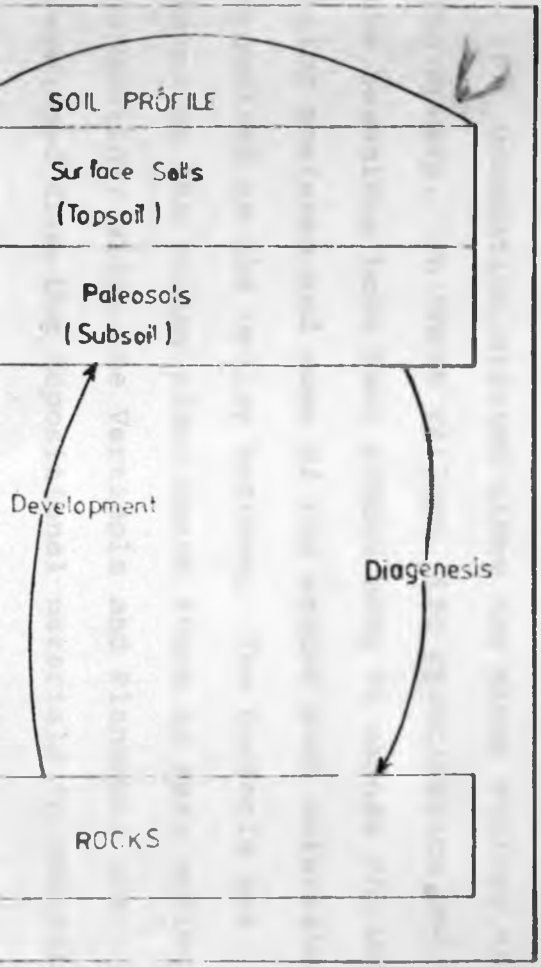
(c) During the early Pleistocene epoch there was a basanite lava flow which formed the plain.

(d) The paleosolic subsoils of the Ferralsols (have) developed on the sub-Miocene surface and the basanite lava plain (Fig. 4).

(e) During the late Pleistocene epoch there was; first eruption of the Nguu volcano which deposited pyroclastics to form the volcanic cones and in the

Fig. 4. Cycle of Pyroclastics




SOIL PROFILE
Surface Soils
(Topsoil)
Paleosols
(Subsoil)
Development
Diagenesis
ROCKS

surface soils of the Ferralsols (Fig. 4). The Andosols have developed from the pyroclastics on the volcano. Secondly, the sub-Miocene surface and the basanite lava plain were upwarped.

(f) Denudation started along the minor valleys after the upwarp. In these valleys, the pyroclastics and then the basanites have been eroded away to expose the underlying gneisses and some of the eroded rock materials deposited on the valley bottoms. The Luvisols are found on the valley sides where there is very active denudation; while the Vertisols and Planosols are developed from the depositional materials in the valley bottoms.

5.2 Conclusions

(a) Soils of the Nguu Hill: The Andosols (Tv- and To-) have abundant reserve of plant nutrients as indicated by the large amounts of weatherable minerals (>20%), total bases (13-46 me/100g soil), and CEC (20-45 me/100g soil). But, the Andosols are found on the Nguu Volcanic cones characterised by slopes of more than 6%, coarse (>2.0mm) pyroclastic particles and in places the soils are less than 10cm deep. So, even if the Andosols contain abundant reserve of plant nutrients, their agricultural use would be hindered by the steep slopes, stony-rocky surface and very shallow soil development. The coarse pyroclastics were deposited near the vents to form volcanic cones during the Nguu volcanicity period.

(b) Soils of the Uplands and Plains: The nutrient reserve (weatherable minerals >10%, total bases - about 7 me/100g soil and CEC - 9 me/100g soil) in the surface soils of the Ferralsols (Fo-3BC and Fo-5A) is slightly higher than that of the paleosols where; the weatherable minerals are <10%, total bases - (4 me/100g soil) and CEC - (7 me/100g soil). The surface fertility has been ameliorated by the deposition of fine (sand and silt sized) pyroclastic particles. Further, the Ferralsols which are generally very deep are characterised by sandy loam to sandy clay textures and are found in an area where slopes are 0-6%. Therefore, because Ferralsols are very deep, have surface fertility and fine textures, they are suitable for cultivation of adaptable crops.

(c) Soils of the Valley Sides: The Luvisols (Lc- and Lo-) have low nutrient reserve as indicated by total bases - (4.5-8.4 me/100g soil) and CEC - (6.0-13.5 me/100g soil) comparable to that of Ferralsols (Fo-3BC and Fo-5A). These Luvisols occur in an area with slopes of 1-6% and are heavily eroded in places to expose the very old metamorphic gneisses. For cultivation the area would require soil conservation measures and addition of fertilizers.

(d) Soils of the Valley Bottoms: With total bases in the range of (10.5-19.5 me/100g soil) and CEC - (13.0-52.0 me/100g soil) the Vertisols (Vp-) and Planosols (Wd-) have a nutrient reserve comparable to that of the Andosols (Tv- and To-). These soils are found in the valley bottoms with slopes of 0-3%. Their imperfect drainage and compact B-horizons are hindrance to root penetration, and so for cultivation they would require artificial drainage and deep tillage.

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APPENDIX 1: TABLES

Table 15: The soil colour and structure of the Andosols and Ferralsols

Mapping unit	Profile pit Number	Horizon Designation	Horizon Depth (cm)	Colour	Structure
Tv-6D	1	A	0-10	Very dark greyish brown	cr
		CB	10-39	Dark greyish brown	m
To-5C	2	A	0-20	Dark reddish grey	sb
		Bu_1	20-83	Dark reddish grey	pr-ab
		Bu_2	83-120	Reddish brown	ab
	10	A	0-12	Reddish brown	sb
		AB	12-31	Dark reddish brown	sb
		B	31-41	Dark reddish brown	sb
		BC	41-86	Dark reddish grey	sb
		CB	86-106	Reddish brown	m
Fo-3BC	3	A	0-10	Dark brown	sb
		Bt_1	10-23	Dark brown	sb
		Bt_2	23-63	Dark brown	sb
		Bb_1	63-110	Reddish brown	sb
		Bb_2	110-148	Reddish brown	sb
	4	A	0-11	Dark brown	sb
		B	11-53	Brown	sb
		Bb_1	53-100	Strong brown	sb
		Bb_2	100-150	Strong brown	sb
	6	A	0-20	Dark brown	sb
		AB	20-46	Dark brown	sb
		Bb_1	46-92	Strong brown	sb
		Bb_2	92-135	Strong brown	sb
Fo-5A	5	A	0-24	Dark reddish brown	sb
		Bt	24-54	Dark reddish brown	sb
		Bb	54-96	Dark brown	sb
	7	A	0-15	Reddish brown	sb
		B	15-38	Reddish brown	sb
		Bb_1	38-68	Dark brown	sb
		Bb_2	68-116	Dark brown	sb
	9	A	0-20	Dark reddish grey	sb
		B	20-60	Reddish brown	sb
		Bb	60-118	Dark brown	pr
		C	118-134	Brown	m

Key to structure

cr - crumb
ab - angular blocky
sb - subangular blocky
pr - prismatic
m - massive

Table 16: Mineralogy of the soil sand fraction

Mapping unit	Profile pit	Horizon	Depth (cm)	Qu	Cr	Fl	Mi	Mu	Ho	Si	Al	Op	Ga	Ru	Se	V.G.	Bi	Di	Au	Ol	Zi	Misc.
Tv-6D	1	A	0-10	25	20	5					Tr	Tr	3			20			10	16	1	
	2	A	0-20	32	19	2	1				7	12			5	3			13	6		
To-5C	"	Bu$_2$	83-120	30	10	3	Tr				10	3	3		8	4			14	15		
	10	A	0-12	25	20	4					11	15			6	4			8	7		
	"	CB	86-106	19	14	7					9	7			5	4			20	15		
	3	A	0-10	46	3	3	2	5	9	2	5	10		2	3	4			3	3		
	"	Bb$_1$	63-110	39	2	1	2	7	5	1	40	1		1			1					
Fo-3BC	4	A	0-11	39	4	2	Tr	4	10	2	17	10		Tr	2	3	Tr		2	3	1	
	"	Bb$_1$	55-100	38	7	1	1	1	8	3		36		3								2
	6	A	0-20	53	5			7	1	2	17	4	1		1	2	1	5			1	
	"	Bb$_1$	46-92	44	9			6	2	1	25	4		1	1		1	5			1	
	5	A	0-24	11	5	1					10	58			1	2			7	3	2	
	"	Bb	54-96	11	4	2					24	52							4	2	1	Tr
Fo-5A	7	A	0-15	10	8	4					18	40				2			9	7	2	
	"	Bb$_1$	36-68	5	15	8					15	35					1		11	10	1	
	9	A	0-20	15	11	5					25	20				1			13	10		
	"	Bb	60-118	9	20	5					20	11							20	15		

(For the key to the minerals see Table 11)

Table 17: Clay mineralogy of the Andosols and Ferralsols

Mapping unit	Profile pit Number	Horizon Designation	Horizon Depth (cm)	Clay Minerals Allo	Ka	Illi	Mont
Tv-6D	1	A	0-10	X	-	-	-
		CB	10-39	X	-	-	-
To-5C	2	A	0-20	X	-	Tr	X
		Bu_1	20-83	X	-	Tr	X
		Bu_2	83-120	X	-	Tr	X
	10	A	0-12	X	X	Tr	-
		AB	12-31	X	X	Tr	-
		B	31-41	X	X	Tr	-
		BC	41-86	X	X	Tr	-
		CB	86-106	X	X	Tr	-
Fo-3EC	3	A	0-10	X	X	Tr	-
		Bt_1	10-23	X	X	Tr	-
		Bt_2	23-63	X	X	Tr	-
		Bb_1	63-110	-	X	Tr	-
		Bb_2	110-148	-	X	Tr	-
	4	A	0-11	X	X	Tr	-
		B	11-55	X	X	Tr	-
		Bb_1	55-100	-	X	-	-
		Bb_2	100-150	-	X	-	-
	6	A	0-20	X	X	Tr	-
		AB	20-46	X	X	Tr	-
		Bb_1	46-92	-	X	-	-
		Bb_2	92-135	-	X	-	-
Fo-5A	5	A	0-24	X	X	Tr	-
		Bt	24-54	X	X	Tr	-
		Bb	54-96	-	X	Tr	-
	7	A	0-15	X	X	Tr	-
		B	15-38	X	X	Tr	-
		Bb_1	38-68	-	X	-	-
		Bb_2	68-116	-	X	-	-
	9	A	0-20	X	X	-	-
		B	20-60	X	X	-	-
		Bb	60-118	-	X	-	-
		C	118-134	-	X	-	-

KEY

X - Mineral Present

\- - Mineral not found

Tr - Mineral in trace amounts

Allo- Allophane

Ka - Kaolinite

Illi- Illite

Mont- Montmorillonite

Table 18: General stability of minerals

H E A V Y M I N E R A L S			
MOST STABLE	LESS STABLE	LESSER STABLE	LEAST STABLE
Rutile, Zircon	Garnet, Staurolite	Hornblende, Augite	Olivine
Tourmaline	Kyanite, Biotite	Sillimanite	
L I G H T M I N E R A L S			
Quartz	K-feldspar	Alkalic-plagioclase	calcic-plagioclase
	Muscovite	Alkali-calci-plagioclase	calci-alkalic plagioclase
			Volcanic glass

(The most stable mineral is the least weatherable generally).

Table modified from Brewer (1965), Longwell et.al (1969) and Pettijohn (1975)

Table 19: Composition, specific gravity and hardness of the minerals

	Minerals	Composition
	Quartz	SiO_2
	Orthoclase	$K(AlSi_3O_8)$
	Plagioclase	$NaCa(AlSi_3O_8)$
	Microcline	$K(AlSi_3O_8)$
	Muscovite	$KAl_2(AlSi_3O_{10})(OH_2)$
	Hornblende	$Ca_2Na(Mg,Fe^{2+},Fe^{3+},Al)_5(Si_6Al_2)O_{22}(OH,F)_2$
Sand	Sillimanite	Al_2SiO_5
Fraction	Garnet (Pyrope)	$Mg_3Al_2(SiO_4)_3$
Minerals	Rutile	TiO_2
	Sericite	Fine grained muscovite
	Volcanic glass	
	Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH_2)$
	Diopside	$Ca, Mg(Si_2O_6)$
	Augite	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
	Olivine	$(Mg,Fe)_2\ SiO_4$
	Zircon	$ZrSiO_4$
	Allophane	$SiO_3\ Al_2(OH_5)$
Clay	Kaolinite	$Al_4(Si_4O_{10})(OH)_8$
Minerals	Illite	$(K\ H_2O)_2(Al,Fe,Mg)_4(Si,Al)_8\ H_2O.(OH)_4$
	Montmorillonite	$(Al,Mg)_8(Si_4O_{10})_3(OH)_{10}.12H_2O$

Information mainly derived from Hurlbut (1971) and Gieseking (1975)

Specific gravity	Hardness
2.65	7
2.57	6
2.62-2.7	6-6½
2.54-2.57	6
2.76-3.1	2-2½
3.0-3.5	5-6
3.23	6-7
2.52	6-7½
4.18-4.25	6-6½
2.75-2.8	7½-8
3.2-3.3	5-6
3.2-3.4	5-6
3.27-4.37	6½-7
4.68	7½

Table 20: Weathering of granite and basalt

Rock	Primary Constituents	Weathering Products				
	Minerals	Metallic ions	Colloids	Secondary Minerals	Primary Minerals That Persist	Ions Removed in solution
Granite	ALKALI FELDSPAR	K^+ Na^+	Silica, Alumina	Clay minerals		Na^+ K^+
	QUARTZ				Quartz	
	MICAS	K^+, Fe^{2+}, Mg^{2+}	Silica, Alumina	Clay minerals	Some mica	
	FERROMAGNESIAN MINERALS	Mg^{2+}, Fe^{2+}	Silica, Alumina	Clay minerals		
			Iron oxides	Hematite Limotite		
Basalt	PLAGIOCLASE FELDSPARS	Ca^{2+} Na^+	Silica, Alumina	Clay minerals		Na^+ Ca^{2+}
	FERROMAGNESIAN MINERALS	Mg^{2+} Fe^{2+}	Silica, Alumina			Mg^{2+}
	MAGNETITE	Fe^{2+}	Iron Oxides	Hematite Limonite		

Table derived from Longwell et.al (1969)

Table 21: Geological time scale

Subdivisions of Geologic Time			Apparent Ages
Eras	Periods	Epochs	(millions of years before the present)
	Quarternary	(Recent)	
		Pleistocene	2.5
	Tertiary	Pliocene	13
		Miocene	25
		Oligocene	36
		Eocene	58
		Paleocene	63
	Cretaceous		135
	Jurassic		180
	Triassic		230
	Permian		280
	Carboniferous		340
	Devonian		400
	Silurian		430
	Ordovician		500
	Cambrian		570

PRECAMBRIAN

ARCHEAN

Derived from Dunbar and Rogers (1957) and Longwell et.al. (1969).

APPENDIX 2: DESCRIPTION AND CLASSIFICATION OF THE REPRESENTATIVE SOIL PROFILE PITS

Profile pit 1
Mapping unit (Tv-6D/H/V)

Description

Horizon A Depth 0-10cm

Very dark greyish brown (10YR 3/2) moist and dry; gravelly sandy clay loam; moderate, medium crumb structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; 20% rock pieces as gravels; many fine and few medium roots; clear and smooth boundary to:

CB 10-39cm

Dark greyish brown (10YR 4/2) moist and dry; gravelly sandy clay loam; massive; non sticky and non plastic wet, friable to loose moist, hard dry; many macropores; 25% rock pieces as gravels; common fine roots; abrupt and wavy boundary to:

R 39-46cm+

Pyroclastic material.

Soil classification

FAO-UNESCO - Vitric Andosols
USDA - Lithic Vitrandepts

Profile pit 2.
Mapping unit (To-5C/U/V)

Description

Horizon A Depth 0-20cm

Dark reddish grey (5YR 4/2) moist and reddish brown (5YR 4/3) dry; clay; moderate, medium subangular blocky structure; sticky and plastic wet, friable moist, slightly hard dry;/ many macropores, few bio- /cracking; pores; common very fine, many fine and few medium roots; clear and smooth boundary to:

Bu_1 20-83cm

Dark reddish grey (5YR 4/2) moist and reddish brown (5YR 4/3) dry; clay; strong, very coarse prisms breaking to strong coarse angular blocky structure: sticky and plastic wet, firm moist, very hard dry; broken thick clayskins and broken thick slickensides; few macropores; many fine roots; clear and wavy boundary to:

Bu_2 83-120cm+

Reddish brown (5YR 4/3) moist and (5YR 4/4) dry; clay; moderate, fine to coarse angular blocky structure; sticky and plastic wet, firm moist, hard dry; broken, thick clayskins and broken, thin slickensides; few macropores; very few fine roots.

Soil classification

FAO-UNESCO - Chromic Vertisols
USDA - Paleustollic Chromusterts

Profile pit 3.
Mapping unit (Fo-3BC/U/U)

Description

Horizon A   Depth 0-10cm

Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry; sandy clay; moderate fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, many biopores; many fine and few medium roots; gradual and smooth boundary to:

Bt_1 10-23cm

Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry; sandy clay; moderate medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, soft dry; many macropores, few biopores; many fine roots; gradual and smooth boundary to:

Bt_2 23-63cm

Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry; sandy clay; weak, fine to medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, soft dry; many macropores, many biopores; many fine roots; clear and smooth boundary to:

Bb_1 63-110cm

Reddish brown (5YR 4/4) moist and (5YR 5/4) dry; clay; weak medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, many biopores; many fine roots; gradual and smooth boundary to:

Bb_2 110-148cm

Reddish brown (5YR 4/4) moist and (5YR 5/4) dry; gravelly clay; weak medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, soft dry; 20% quartzite gravels; few fine roots; clear and smooth boundary to:

R   148-151cm+

Rock.

Soil classification

FAO-UNESCO - Orthic Luvisols
USDA - Oxic Paleustalfs

Profile pit 4
Mapping unit (Fo-3BC/U/U)

Description

Horizon A Depth 0-11cm

Dark brown (7.5YR 4/2) moist; sandy clay loam; moderate, fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; many very fine, common fine roots; clear and smooth boundary to:

B 11-55cm

Dark brown (7.5YR 4/2) moist and brown (7.5YR 5/2) dry; clay; weak, fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, common biopores; many very fine and few coarse roots; clear and smooth boundary to:

Bb_1 55-100cm

Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry; clay; weak fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, common biopores; common very fine and fine roots; gradual and smooth boundary to:

Bb_2 100-150cm+

Dark brown (7.5YR 4/4) moist and strong brown (7.5YR 5/6) dry; gravelly clay loam, weak fine to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; few macropores; common fine roots.

Soil classification

FAO-UNESCO - Orthic Ferralsols
USDA - Typic Eutrustox

Profile pit 5.
Mapping unit (Fo-5A/P/B)

Description

Horizon A Depth 0-24cm

Dark reddish brown (5YR 3/3) moist; sandy clay loam; moderate, medium to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores, few biopores; few medium and few coarse roots:

B 24-54cm

Dark reddish brown (5YR 3/4) moist and reddish brown (5YR 4/4) dry; sandy clay loam; weak fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; many very fine and few fine roots; abrupt and wavy boundary to:

Bb 54-96cm

Dark brown (10YR 4/2) moist and brown (7.5YR 5/4) dry; clay loam; very weak, medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; many very fine and fine roots; abrupt and broken boundary to:

R 96-100cm+

Basanite.

Soil classification

FAO-UNESCO - Orthic Luvisols
USDA - Oxic Haplustalfs

Profile pit 6
Mapping unit (Fo-3BC/U/U)

Description

Horizon A Depth 0-20cm

Dark brown (7.5YR 3/2) moist; sandy clay; moderate, fine to coarse, subangular blocky structure; sticky and plastic wet, friable moist, hard dry; many macropores, few biopores; many fine and few medium roots; clear and smooth boundary to:

AB 20-46cm

Dark brown (7.5YR 4/2) moist; clay; weak, fine to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, common biopores; many fine and few medium roots; clear and smooth boundary to:

Bb_1 46-92cm

Strong brown (7.5YR 4/6) moist; clay; weak, fine to medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores, common biopores; common very fine and fine roots; gradual and smooth boundary to:

Bb_2 92-135cm+

Strong brown (7.5YR 4/6) moist; gravelly clay; weak, medium to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; common very fine and fine roots.

Soil classification

FAO-UNESCO - Xanthic Ferralsols
USDA - Typic Eutrustox

Profile pit 7
Mapping unit (Fo-5A/P/B)

Description

Horizon A   Depth 0-15cm

Reddish brown (5YR 4/3) moist; clay loam to clay; moderate, fine to coarse subangular blocky structure; sticky and plastic wet, friable moist; common macropores, few biopores; many very fine, few fine and few medium roots; gradual and smooth boundary to:

B   15-38cm

Reddish brown (5YR 4/4) moist; clay; moderate, coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores, few biopores; common fine, few medium, few coarse and few very coarse roots; clear and smooth boundary to:

Bb_1 38-68cm

Dark brown (7.5YR 3/2) moist; clay; moderate, fine to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores, few biopores; common very fine to fine roots; gradual and smooth boundary to:

Bb_2 68-116cm

Dark brown (7.5YR 4/2) moist; clay loam; weak, fine to medium, subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; few biopores; few very fine roots; abrupt and wavy boundary to:

R   116-120cm+

Rock.

Soil classification

FAO-UNESCO - Orthic Ferralsols
USDA - Typic Haplustox

Profile pit 8
Mapping unit (Vp-1AB/V/X)

Description

Horizon A   Depth 0-11cm

Dark greyish brown (10YR 4/2) moist; clay; moderate, fine to medium granular structure; sticky and plastic wet, friable moist; common macropores, few biopores; cracking calcareous; many fine and medium roots; clear and smooth boundary to:

AC   11-31cm

Dark grey (10YR 4/1) moist; clay; weak medium prisms breaking to weak fine to medium subangular blocky structure; sticky and plastic wet, firm moist, hard dry; patchy, moderately thick slickensides; few macropores, few biopores; calcareous; few fine and medium roots; clear and wavy boundary to:

CA_{k1} 31-84cm

Dark grey (10YR 4/1) moist; clay; strong very coarse prisms breaking to strong coarse angular blocky structure; sticky and plastic wet, firm moist, very hard dry; broken, thick slickensides; few macropores; few biopores; calcareous; 10%, 3-6mm calcium carbonate concretions; few very fine and fine roots; clear and wavy boundary to:

CA_{k2} 84-114cm

Grey (10YR 5/1) moist; clay; weak, fine to medium angular blocky structure; sticky and plastic wet, firm moist, hard dry; broken, moderately thick slickensides; few macropores, few biopores; calcareous; very few fine roots; abrupt and broken boundary to:

R   114-116cm+

Rock.

Soil classification

FAO-UNESCO - Pellic Vertisols
USDA   - Entic Pellusterts

Profile pit 9
Mapping unit (Fo-5A/P/B)

Description

Horizon A Depth 0-20cm

Dark reddish grey (5YR 4/2) moist; sandy clay loam; moderate, fine to medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores, few biopores; many fine and few medium roots; clear and smooth boundary to:

B 20-60cm

Reddish brown (5YR 4/4) moist; clay loam; moderate, medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; many macropores; few fine and medium roots; clear and smooth boundary to:

Bb 60-118cm

Dark brown (10YR 3/3) moist; clay loam; weak, coarse prismatic structure breaking to weak subangular blocky structure; slightly sticky and slightly plastic wet, friable moist; common very fine and fine roots; clear and wavy boundary to:

C 118-134cm

Brown (7.5YR 5/2) moist; gravelly clay loam; massive; non sticky and non plastic wet, friable to loose moist; few macropores; few biopores; few very fine and fine roots; abrupt and wavy boundary to:

R 134-136cm+

Basanite.

Soil classification

FAO-UNESCO - Orthic Ferralsols
USDA - Tropeptic Haplustox

Profile pit 10
Mapping unit (To-5C/U/V)

Description

Horizon A Depth 0-12cm

Dark reddish brown (5YR 3/2) moist and reddish brown (5YR 4/3) dry; sandy clay; moderate, fine to medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; common macropores, few biopores; many fine and medium roots; gradual and smooth boundary to:

AB 12-31cm

Dark reddish brown (5YR 3/2) moist and dark reddish grey (5YR 4/2) dry; sandy clay; moderate, medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; many fine and common medium roots; gradual and smooth boundary to:

B 31-41cm

Dark reddish brown (5YR 3/4) and reddish brown (5YR 4/4) dry; sandy clay; weak medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, few biopores; few fine and few medium roots; clear and wavy boundary to:

BC_1 41-86cm

Dark reddish grey (5YR 4/2) moist and reddish brown (5YR 4/3) dry; gravelly loam; weak medium subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, very few biopores; 20% rock pieces as gravels; few fine roots; gradual and smooth boundary to:

BC_2 86-106cm

Reddish brown (5YR 4/4) moist; gravelly loam; massive; non sticky and non plastic wet, friable to loose moist, hard dry; very few biopores; 30% rock pieces as gravels; few fine roots; abrupt and broken boundary to:

R 106-109cm

Pyroclastic material.

Soil classification

FAO-UNESCO - Ochric Andosols
USDA - Entic Eutrandepts

Profile pit (174/1-177)11
Mapping unit (Lc-6BC/U/F)

Description

Horizon Ap Depth 0-16cm

Very dark greyish brown (10YR 3/2) moist and dark brown (10YR 4/3) dry; sandy loam; weak, medium to coarse subangular blocky structure; non sticky and non plastic wet, friable moist, hard dry; common macropores, few biopores; few very fine, few fine, few medium and few coarse roots; clear and smooth boundary to:

Bt_1 16-36cm

Reddish brown (5YR 4/3) moist and yellowish red (5YR 5/6) dry; sandy clay loam; weak, medium to coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, few biopores; few fine and few coarse roots; gradual and smooth boundary to:

Bt_2 36-85cm

Reddish brown (5YR 4/4) moist and yellowish red (5YR 5/6) dry; sandy clay; weak, coarse subangular blocky structure; slightly sticky and slightly plastic wet, friable moist, hard dry; many macropores, many biopores; few very fine and few fine roots; clear and wavy boundary to:

CB 85-135cm

Dark brown (10YR 4/3) moist; gravelly sandy clay loam; massive; slightly sticky and slightly plastic wet, friable moist, slightly hard dry; many macropores, few biopores; 15% quartz crystal gravels; few fine roots; abrupt and wavy boundary to:

R 135-140cm

Gneiss.

Soil classification

FAO-UNESCO - Chromic Luvisols
USDA - Oxic Haplustalfs
"ferralitic"-USDA -

Profile pit (174/1-185)12
Mapping unit (Lo-3B/U/F)

Description

Horizon Ap Depth 0-20cm

Dark brown (7.5YR 4/4) moist; sandy loam; moderate, medium subangular blocky structure; sticky and plastic wet, friable moist; many macropores, few biopores; many fineand few medium roots; gradual and smooth boundary to:

Bt_1 20-47cm

Dark brown (7.5YR 4/4) moist; sandy clay; moderate, medium subangular blocky structure; sticky and plastic wet, friable moist, patchy, thin clay skins; many macropores, few biopores; common fine and few medium roots; gradual and smooth boundary to:

Bt_2 47-74cm

Strong brown (7.5YR 5/6) moist; sandy clay; moderate, medium to coarse subangular blocky structure; sticky and plastic wet, friable moist, slightly hard dry; patchy, thin clay skins; few macropores, few biopores; common fine, few medium and few coarse roots; abrupt and wavy boundary to:

BC 74-109cm

Dark brown (7.5YR 3/2) moist; gravelly sandy clay loam; massive; non sticky and non plastic wet, friable to loose moist, slightly hard dry; few macropores; few biopores; 30% quartz gravels; few fine roots; abrupt and wavy boundary to:

R 109-114cm

Rock - gneiss.

Soil classification

FAO-UNESCO - Orthic Luvisols
USDA - Oxic Haplustalfs

Profile pit (174/1-178)13
Mapping unit (Wd-6AB/V/F)

Description

Horizon AE Depth 0-10cm

Brown (7.5YR 5/2) moist and pinkish grey (7.5YR 6/2) dry; sandy loam; weak, fine subangular blocky structure; non sticky and non plastic wet, friable moist, soft dry; few macropores, few biopores; calcareous; few fine roots; abrupt and smooth boundary to:

B 10-48cm

Dark brown (7.5YR 3/2) moist and (7.5YR 4/2) dry; sandy clay; weak medium to coarse subangular blocky structure; sticky and plastic wet, firm moist, very hard dry; very few macropores; few medium roots; clear and smooth boundary to:

BC 48-101cm

Dark brown (7.5YR 3/2) moist and dry; mottled; sandy clay loam; massive; sticky and plastic wet, firm moist, hard dry; few macropores; very few fine roots; abrupt and wavy boundary to:

R 101-102cm+

Rock gneiss.

Soil classification

FAO-UNESCO - Dystric Planosols
USDA - Typic Albaqunlts