# INVESTIGATION OF THE MINERALOGY OF A TOPOSEQUENCE ON THE SLOPES OF MOUNT KENYA

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# Acknowledgements

During the mineralogical investigation of Mt. Kenya soils I learned to use many techniques common in mineralogy. During this study I recieved a lot of cooperation from the people from the Departement of Soil Science and Geology, Agricultural University Wageningen, and from the Technical and Physical Services (TFDL), Wageningen, who allowed me to make use of their sophisticated electron microscope apparatus. Therefore, this study could not have been possible without the help of the following persons :
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# 1. Introduction

## 1.1 Area of study

The present study has been carried out within the framework of the Training Project in Pedology (TPIP) in the Chuka-area, Kenya. TPIP is a training project of the Department of Soil Science and Geology of the Agricultural University of Wageningen.
The main object of the project was the production of a soil map of the Chuka-South area. This was done in close cooperation with the Kenya Soil Survey (KSS), Nairobi.
The Chuka-South area is located in the centre of the country on the eastern slopes of Mount Kenya (fig. 1.1).

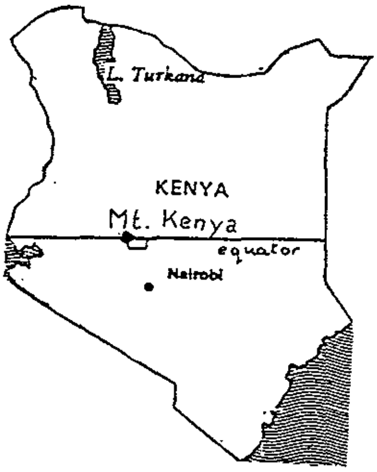

Fig. 1.1: Location of the Chuka-South area

First a semi-detailed (1:25,000) soil map was produced of a so-called sample-strip area. This is the area marked with a shading in fig. 1.2
After that the whole Chuka-South area (fig. 1.2) was surveyed on a scale of 1:100,000 (reconnaissance scale). For detailed information about these soil surveys I refer to the relevant reports (Bongers, Pulles and Legger, in press; de Meester, in press).
During the training project several studies related to the soil survey have been carried out.
The present study has concentrated on the volcanic deposits of Mt. Kenya. It concerns the weathering of the volcanic deposits on the slopes of Mt. Kenya. These consist primarily of lahars and have been deposited over the Basement System peneplain in the late-Tertiary.
The rate of weathering is predominated by the prevailing climate. The climate varies considerably from the top, at about 5100 m, to the foot, at about 1100 m. This produces a topo-sequence in which the profiles at different heights are in a different stage of weathering.

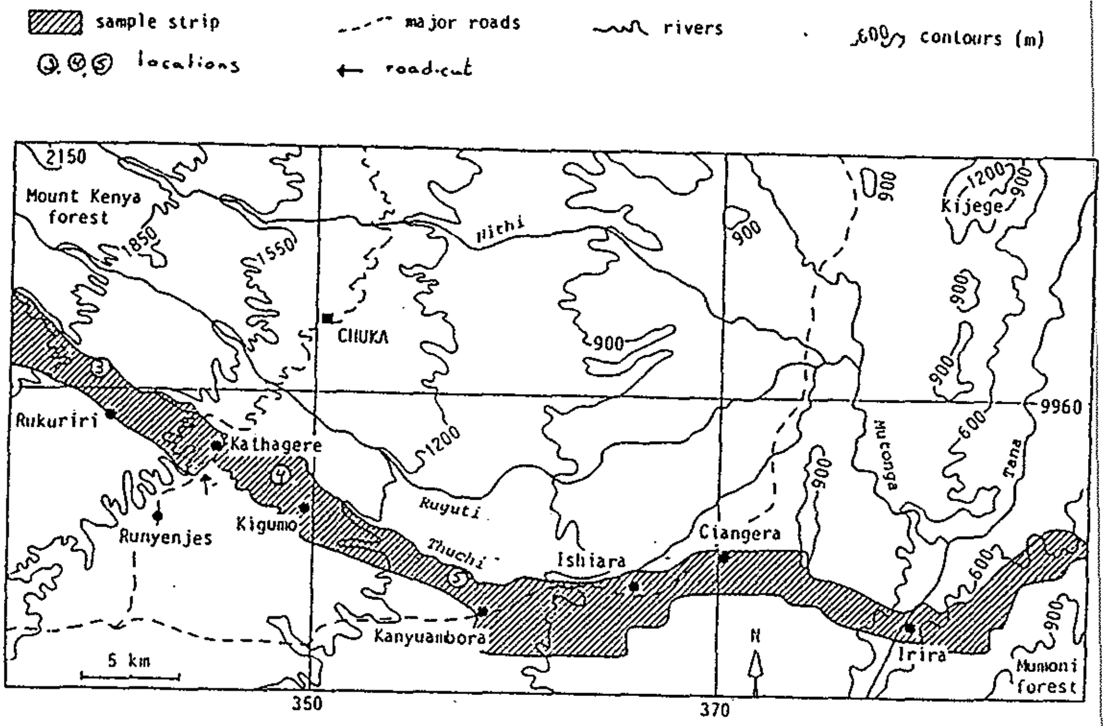

Fig. 1.2 Chuka-South area

## 1.2 Geology

The Chuka project area consists of two major geologic parts. The eastern part is located in the Basement System of the Mozambique Belt. The Basement System is an extended peneplain built up from material mainly of metamorphic origin.
The western part is located on the slopes of Mount Kenya. Mt. Kenya is a dormant volcano, which had its main eruptions in the Lower and Upper Pleistocene.
Geologic investigations of the Mt. Kenya area (Baker (1967) in Speck, 1982) have pointed out that the Mt. Kenya volcanics consist of basic and intermediate rocks (e.g. phonolites, trachytes, basalts, kenytes and syenites). Much of the mountain, however, is covered by pyroclasic rocks and volcanic ash, originating from various secondary eruptions especially on the north and north-eastern slopes.

Table 1.1: Chemical composition (%) of (a) nepheline syenite, (b) phonolite and (c) pyroclastic rock (Speck, 1982)

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | $Na_2O$ | $K_2O$ | $P_2O_5$ | L.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | 51.64 | 1.58 | 19.12 | 3.03 | 4.20 | 0.19 | 1.29 | 9.46 | 4.37 | 0.33 | |
| (b) | 52.10 | 0.30 | 22.29 | 1.37 | 4.10 | 0.23 | 1.17 | 8.60 | 4.66 | 0.46 | |
| (c) | 51.22 | 0.58 | 22.54 | 8.10 | | 0.29 | 0.28 | 5.36 | 2.70 | 0.06 | 8.45 |

In Table 1.1 the chemical composition of (a) nepheline syenite, (b) phonolite and (c) pyroclastic rock are cited from Speck (1982).
The chemical composition of the rocks is important for the weathering process. The chemical composition of these rock-types in Table 1.1 does not vary much. The structural variations of the parent material, however, are of great significance. Ash and pyroclastic rocks, for example, weather much faster than volcanic rocks (Speck, 1982).

## 1.3 Climate

The main climatic parameters that have an influence on the weathering process are the average annual rainfall and the average annual temperature. For the Chuka-South area the average annual rainfall (mm) is indicated in fig.1.3. The temperature zones of the Chuka-South area are indicated in fig. 1.4.
Table showes the temperatures associated with the temperature zones in fig. 4.

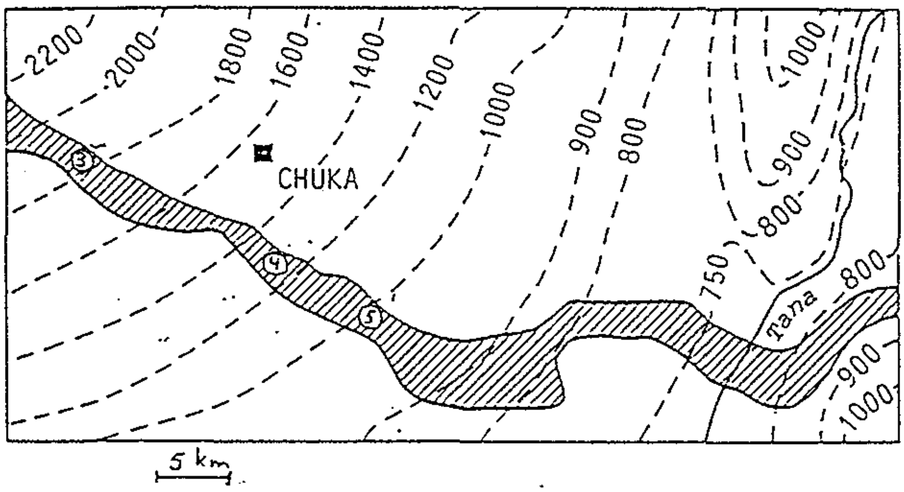

Fig. 1.3: Average annual rainfall of the Chuka-South area (mm)

Table 1.2: Mean annual temperature zones (°C)

| zone | mean annual temperature | mean max. temperature | mean min. temperature |
|---|---|---|---|
| V | 16-18 | 22-24 | 10-12 |
| IV | 18-20 | 24-26 | 12-14 |
| III | 20-22 | 26-28 | 14-16 |
| II | 22-24 | 28-30 | 16-18 |
| I | 24-30 | 30-36 | 18-24 |

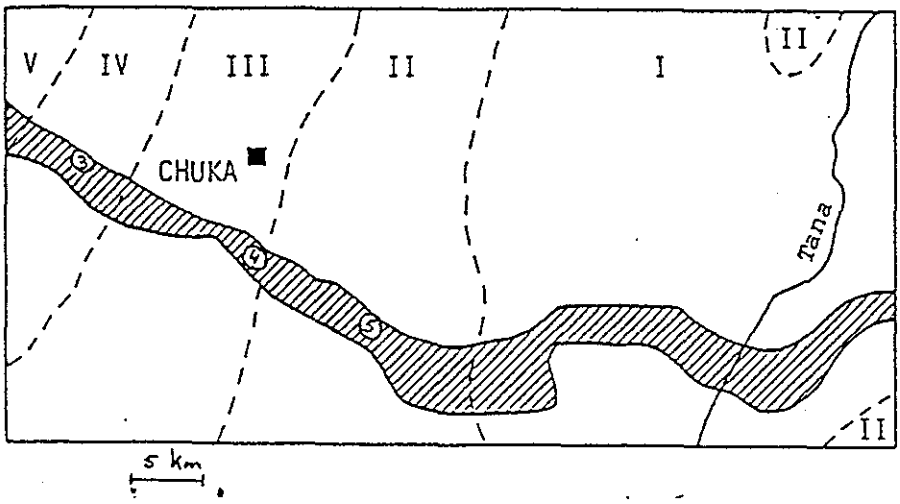

Fig. 1.4: Temperature zones in the Chuka-South area

## 1.4 Selection of the profiles

Between the altitudes of 3000 m and 1000 m five locations were selected, which link on to other research sites as closely as possible. The lowest three locations are indicated in fig. 1.2. The upper two are outside the Chuka project-area, further west.
The profile descriptions of the selected profiles are presented in Appendix I.
As indicated in paragraph 1.1, we are dealing with a weathering sequence. The upper profile (no. 1) shows very little soil formation and has been classified as an Andosol. In profile 2 soil formation is slightly more expressed but still in its initial stage. This one has been classified as a Cambisol. Profile 1 and 2 are found under the protective vegetation cover of bamboo forest and rainforest, respectively.
Location 3 (profiles 6, 7 and 9) is located on the transition from the rainforest to the cultivated area. In order to make comparison possible both a profile in the rainforest (no. 9) and a profile cultivated with tea for about 25-40 years (no. 6) have been sampled. At the same time samples were taken from a profile in the valley bottom (no. 7). At this location soils have been classified as Nitosols and Acrisols (Acrisol when insufficiently deep to be classified as a Nitosol).
Although the soils at location 4 (profiles 3 and 5) have also been classified as Nitosols and Acrisols, they dry out more often and more deeply than those at location 3. The predominant crop here is coffee.
Descending even further to location 5 (profiles 4 and 8) one comes into the region of the Acrisols (chromic to plinthic), where apart from crops like cotton and tobacco much land is kept fallow.

For more detailed information about the soils I refer to the soil survey report (Bongers, Pulles and Legger, in press).

The terrain on the footslopes of Mt. Kenya is covered with a pattern of parallel ridges and valleys. Therefore, the samples, if possible, were taken from both a profile on the crest of the ridge and a profile in the valleybottom at each location. At the fixed depths of 0-20 cm, 50-70 cm and 130-150 cm mixed samples were taken. All samples were air-dried and stored for laboratory-analysis.
Two rock samples were taken too. In this area it is difficult to find good rock samples, because the solid rock is at a depth of several metres. The rocks one can find in the bed of the gullies and streams are mostly phonolites. The rock samples were taken from a road-cut at a depth of about 4-5 m from the surface. This road-cut is located near Kathagere (fig. 1.2).

## 2 Methods of analysis

### 2.1 Introduction

The main object of this investigation is to study the weathering process in relation with the various climate regimes at different altitudes on the slopes of this volcano. Therefore, the mineralogical composition of soil samples taken at different locations is studied. It is assumed that the mineralogical and, to a certain extend, the chemical composition of the parent material was similar at the onset of the weathering process. This assumption, however open to criticism, allows for a model encompassing the analytical data. Such a model may indicate differences and similarities elucidating relations between climatic zone and weathering progress.
In order to arrive at the necessary analytical data, the clay fraction was separated from the samples and studied with X-ray diffraction analysis. The sand fraction has been studied with optical methods.
As these two methods leave a number of questions unanswered, the individual clay minerals were morphologically and chemically studied with electron microscopy using a STEM/EDAX system allowing for a qualitative chemical analysis of each clay mineral too. For the determination of the total chemical composition of the clay-fraction and the bulk of the samples X-ray fluorescence was used. These chemical analysis can be transformed into a mineral composition provided the Gibbs free-energy of the minerals most likely occurring in the parent rocks and in the weathering residues is known. Comparing these mineral assemblages with the analytical studies of the mineral composition may indicate trends of the weathering process and the possible control of altitude.

### 2.2 X-ray diffraction

Every crystalline mineral is a regular repetition of specific unit cells. The d-spacing between the layers of unit cells can be determined by X-ray diffraction.
The unknown minerals are hit by a monochromatic X-ray beam ($K_{\alpha\,Cu}$; $\lambda_{\alpha}$ = 1.542 A). Most of the X-ray beam will go through unhindered, but part will be diffracted. Part of these diffraction rays will be extinguished again. A diffraction beam can only exist when the diffraction rays of the individual atoms in the cristal lattice are in phase and thus reinforce one another.
This is formulated in Bragg's law:

$$2d \sin \theta = n \lambda$$

in which d is the distance between the layers of unit cells, $\theta$ is the angle of diffraction, $\lambda$ is the wavelength of the incident beam and n is a integer. So in order to get a diffraction beam the distance travelled by the diffracted waves of every layer of unit cells need to be some full time the wavelength of the incident radiation (Dent Glasser, 1977). The diffraction beam can be measured directly by some counter or can be measured by the blackening of a photographic film. The direct approach has been used with the identification of the clay minerals, the second approach has been used with Guinier camera for the identification of some heavy minerals.

Pre-treatment:
* oxidation of the organic matter with hydrogen peroxide
* dispersion with Na-pyroposphate
* adjusting the pH to about 7 with Na-hydroxide
* siphoning the clay fraction at a calculated time period after stirring
* sedimenting the clay fraction on ceramic platelets for the diffractometer

Because the quality of some of the produced diffractograms was so poor we decided to improve the samples with Na-dithionite (Jackson, 1956). This was done for the clay fractions in the 50-70 cm samples of every profile. With this method both iron(coating) and allophane is removed. Thus it is no longer possible to trace the presence of allophane in this weathering sequence.

## 2.3 X-ray fluorescence

X-ray fluorescence can be used to determine the total chemical composition of a sample.
When an atom is bombarded by high-energy electrons the electron in the inner (K-) shell of the target atom will be broken loose. This electron will be replaced by an electron from an outer shell. With this transition energy will be released as X-rays. The energy transitions or the wavelength of the produced X-rays are characteristic for every element. In this way the X-ray wavelengths produced and their relative intensities can be used to determine the elements present and their relative amounts.

Pre-treatment:
* production of a dispersed clay fraction as for X-ray diffraction (2.2)
* drying by freezing
* determination of the loss on ignition
* melting at high temperature with $Li_2B_4O_7$ to form a glass disc for analysis

## 2.4 Optical microscopy

Transparent minerals can be identified with the use of the optical microscope.
In the optical microscopy the specimen or object is illuminated by a suitable light source. Two compound lenses collect and condense the light onto the object. Above the object, the objective lens forms a magnified image of the object. An eye-piece lens is positioned so that a magnified image can be viewed directly by the eye. An additional lens can be inserted between the objective and the eye-piece to change the magnification. The smallest size of an object that can just be detected is called resolution. For the naked eye the resolution is usually 0.1 - 0.2 mm. The best resolution of the optical microscope ( with the use of oil immersion fluid) is 0.2 µm. So the heighest useful magnification of the optical microscope is 1000x (Tovey and Smart, 1982)
From the magnified image of the optical microscope minerals can be distinguished on the score of some optically perceptible features like form, width, angle of extinction under cross-polarised light and colour.
This method was used for the heavy minerals in the sand fraction.

Pre-treatment:
* sieving off the fraction 50-425 µm
* removing of iron(coatings) with Na-dithionite
* separation between the heavy and light minerals with bromoform (specific gravity 2.89)
* preparation of slides with canada balsam

## 2.5 Tranmission electron microscopy (STEM/EDAX)

The transmission electron microscope is similar to the transmission optical microscope. In the transmission electron microscope the rays of light are replaced by beams of electrons.
The electron source is a gun consisting, usually, of a heated filament, and an anode. They also form an electrostatic condensor lens. The one or two condensor lenses condense the electrons onto the specimen. Then up to three electromagnetic magnification lenses may be used to form an image on a fluorescent screen or photographic plate. Because the electrons cannot travel through air, the whole of the microscope between the gun and the photographic plate needs to be in vacuum.
The resolution obtained with transmission electron microscopy can be 0.5 nm at 80 kV (Tovey and Smart).
TEM has been used to study the clay minerals at an enlargement of 4000x to 67000x. The use of STEM with the EDAX-analyses makes it possible to relate the chemical composition of a specific mineral to morphology.

The EDAX-analysis presents a base-line (W) for all elements. This base-line may vary a little, but is supposed to be constant. Every atom of a certain element that is present in the mineral is counted above the base-line (P). The ratio of P over W for each element, corrected for its molecular weight, gives its relative amount in the mineral composition.

Pre-treatment:
* production of a dispersed, iron-free, sample of the clay fraction (2.2)
* placing a drop of the sample onto a electron transparent support film coated with carbon, which has previously been mounted on a copper support grid, and letting the water evaporate

## 3 Results and discussion

The results will be presented in the same order as the methods in chapter 2.

### 3.1 X-ray diffraction analysis of clayfractions

In order to discriminate between clay minerals there are some determination tests as indicated in Table 3.1.

Table 3.1: Determination tests for current clay mineral

| |
|---|
| saturation with Mg |
| saturation with K and heating to 100 °C |
| glycerol treatment |
| heating to 550 °C |

The behaviour of the clay minerals towards these treatments is summarized in Table 3.2.

Table 3.2: Values of d-spacing (Å) of the basal (001) reflection of the current clay minerals after treatments

| | Mg | K | Glycerol | 550 °C |
|---|---|---|---|---|
| kaolinite | 7 | 7 | 7 | - |
| mica | 10 | 10 | 10 | 10 |
| vermiculite | 14 | 10-12 | 14 | 10 |
| smectite | 12-15 | 10-12 | 18 | 10 |
| chlorite | 14 | 14 | 14 | 14 |

(after Thorez, 1976)

Saturation with Mg is the first treatment and is considered a reference for the other treatments.
At saturation with K and a slight heating to 100 °C the hydrated cations will be replaced by dehydrated K. This causes the collapse of the structure of vermiculites and smectites to 10 Å. Chlorites are resistant to this treatment because their interlayers will keep the structure stable.
Glycerol treatment can be used to differentiate between vermiculites and smectites. Smectites will swell to about 18 Å whereas vermiculites stay stable.
At a temperature of 550 °C the structure of kaolinite will break down and the structures of vermiculite and smectite will collapse to 10 Å. Again most chlorites are resistant to this collapse because of their interlayers.

There are some specific tests to discriminate between kaolinite and halloysite, as indicated in Table 3.3.

Table 3.3: Values of d-spacing (Å) of the basal (001) reflection of kaolinite and halloysite after treatments

| | Mg | 105 °C | 400 °C | formamide |
|---|---|---|---|---|
| kaolinite | 7 | 7 | 7 | 7 |
| halloysite (hydrated) | 10 | 7 | – | 10.4 |

When the samples are first dried at about 105 °C, 7 Å minerals can be distinguised by further heating to 400 °C or by formamide treatment ( Churchman et al, 1983).
The structure of halloysite will break down below the temperature of 400 °C, whereas the structure of kaolinite will stay stable upto about 500 °C.
The formamide test will only affect the halloysite minerals. When minerals of the mica-type are present too, the height of the 10 Å peak needs to be substracted from the 10.4 Å peak after formamide treatment.

The aforementioned determination tests have been applied to the samples, with the following results (Table 3.4).

Table 3.4: Clay mineralogic composition according to X-ray diffraction analyses

| loc. | prof. | kaolinite | halloysite | vermiculite | gibbsite* |
|---|---|---|---|---|---|
| 1 | 1 | – | ++++ | +++ | +++ |
| 2 | 2 | – | +++ | ++ | +++ |
| 3 | 9 | ++ | + | ++++ | ++++ |
| | 6 | ++++ | + | + | ++ |
| | 7 | ++ | ++ | + | ++ |
| 4 | 3 | ++++ | + | – | + |
| | 5 | ++++ | + | – | – |
| 5 | 4 | ++++ | + | – | +++ |
| | 8 | ++++ | + | – | ++ |

* specific d(Å)-value for gibbsite is 4.8 Å

+, ++, +++, ++++ are indications of quantity of the mineral in the sample

The results show a decreasing tendency of halloysite and an increasing tendency of kaolinite. The halloysite, which is formed first, is later on reformed into kaolinite.
The vermiculite, which is present in the upper profiles, cannot be found in the profiles of the lower locations.
The amount of gibbsite present varies, but does not show a certain tendency.

## 3.2 Chemical analysis

### 3.2.1 Clay fractions

The composition of the topsoil (0-20 cm) is given in Table 3.5, of the subsoil (50-70 cm) in Table 3.6.

Table 3.5: Chemical composition for the major components (%) of the topsoil (0-20 cm)

| loc./ prof. | alt. (m) | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | BaO | L.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/ 2 | 2300 | 30.80 | 1.33 | 28.72 | 18.83 | 0.24 | 0.86 | 0.43 | 0.55 | 0.70 | 1.31 | 0.08 | 15.67 |
| 3/ 9 | 1800 | 32.77 | 1.12 | 33.96 | 15.50 | 0.33 | 0.18 | 0.03 | 0.31 | 0.20 | 0.35 | 0.09 | 14.89 |
| 6 | | 35.90 | 1.18 | 33.51 | 13.95 | 0.04 | 0.14 | 0.00 | 1.22 | 0.22 | 0.26 | 0.08 | 14.30 |
| 5/ 4 | 1100 | 35.84 | 1.18 | 35.08 | 11.16 | 0.18 | 0.15 | 0.03 | 0.13 | 0.22 | 0.33 | 0.12 | 15.56 |
| 8 | | 41.28 | 1.16 | 33.81 | 8.95 | 0.11 | 0.29 | 0.34 | 0.11 | 0.48 | 0.31 | 0.17 | 12.81 |

Table 3.6: Chemical composition for the major components (%) of the subsoil (50-70 cm)

| loc./ prof. | alt. (m) | $SiO_2$ | $TiO_2$ | $Al_2O3$ | $Fe_2O_3$ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | BaO | L.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/ 2 | 2300 | 28.96 | 0.56 | 34.27 | 15.09 | 0.50 | 0.21 | 0.06 | 0.82 | 0.47 | 0.58 | 0.24 | 17.96 |
| 3/ 9 | 1800 | 33.02 | 1.03 | 34.05 | 15.03 | 0.29 | 0.14 | 0.00 | 0.37 | 0.16 | 0.24 | 0.10 | 15.35 |
| 6 | | 35.65 | 1.13 | 34.41 | 13.68 | 0.04 | 0.12 | 0.00 | 0.30 | 0.17 | 0.17 | 0.08 | 14.27 |
| 5/ 4 | 1100 | 35.46 | 1.20 | 35.63 | 11.81 | 0.19 | 0.14 | 0.06 | 0.37 | 0.15 | 0.19 | 0.12 | 15.12 |
| 8 | | 40.35 | 1.15 | 33.00 | 8.86 | 0.10 | 0.29 | 0.33 | 0.11 | 0.47 | 0.30 | 0.17 | 12.95 |

The total chemical composition as such is not very illustrative for the mineralogy of the soil. From a certain dataset one can calculate the minerals that will probably be present, given their Gibbs free-energy (Brown and Skinner, 1974). In order to recalculate the chemical analysis into an equilibrium set of soil minerals, the computer programm EQUI was used (Meijer, 1980). This programm, an adapted version of the programm of Brown and Skinner (1974), manipulates the Gibbs free energy data of a large set of minerals with temperature and pressure chosen by the operator. In this case the pressure was chosen at 1 bar, the temperature at 298.15K. The calculated minerals are of course dependant on the choice of the minerals in the dataset. This means that the calculated mineral is not necessarily present in the sample. For the phyllosilicates another problem occurs. In the X-ray fluorescence analyses it is not possible to make a distinction between FeO and $Fe_2O_3$, therefore all the Fe present in the sample is listed as $Fe_2O_3$. Calculating the mineral composition of the sample, it is difficult to find a phyllosilicate with octahedral $Fe^{2+}$.

With the boundary conditions of 25 °C and $H_2O$ and $CO_2$ available from the atmosphere the following mineral composition was calculated from the dataset:

| | |
|---|---|
| Kaolinite | $Al_2Si_2O_8(OH)_2$ |
| Muscovite | $Al_3Si_3O_{10}(OH)_2$ K |
| Clinochlore | $Mg_5Al_2Si_3O_{10}(OH)_8$ |
| Gibbsite | $Al(OH)_3$ |
| Rutile | $TiO_2$ |
| Hematite | $Fe_2O_3$ |
| Phosphoroxide | $P_2O_5$ |
| Whitlockite | $Ca(PO_4)_2$ |
| (Quartz) | $SiO_2$ |
| (Talc) | $Mg_3Si_4O_{10}(OH)_2$ |

Soil mineralogists may object to the inclusion of clinochlore and talc. Combinations of these, however, produce minerals similar to the smectites that may be encountered in such soils. Data for montmorillonite are still disputable and montmorillonites are not yet included in the dataset of EQUI. Secondly, the presence of $P_2O_5$ in the set is due to the fact that Al-phosphates or iron phosphates are not included either and the calcium content of the samples is to low to accomodate all the phosphorus.
With this choice of minerals the topsoil samples have the mineral composition as indicated in Table 3.7 and the subsoil as indicated in Table 3.8.

Table 3.7: Mineral composition (%) of the topsoil (0-20 cm)

| altitude (m) | 2300 | 1800 | | 1100 | |
|---|---|---|---|---|---|
| location | 2 | 3 | | 5 | |
| profile | 2 | 9 | 6 | 4 | 8 |
| kaolinite | 63.02 | 70.46 | 76.99 | 77.15 | 83.08 |
| muscovite | 6.35 | 1.74 | 1.91 | 1.92 | 4.13 |
| clinochlore | 2.54 | 0.51 | 0.45 | 0.43 | - |
| gibbsite | 4.60 | 9.77 | 4.85 | 7.42 | - |
| rutile | 1.43 | 1.15 | 1.21 | 1.22 | 1.18 |
| hematite | 20.19 | 15.97 | 14.32 | 11.50 | 9.11 |
| phosphoroxide | 1.02 | 0.33 | 0.27 | 0.31 | 0.02 |
| whitlockite | 0.85 | 0.06 | - | 0.06 | 0.64 |
| quartz | - | - | - | - | 0.87 |
| talc | - | - | - | - | 0.97 |

The trends from location 1 to 5 seem to be the same for topsoil and subsoil.

- Increasing kaolinite content
- Decreasing hematite content (could be the result of the absence of the possibility of octahedral Fe)
- Muscovite is theoretically present as a first weathering product, but seems also to be formed in later stages

- Gibbsite shows a decreasing tendency in the subsoil

* Remarkable is the relatively high content of clinochlore (Mg), phosphoroxide (P) and whitlockite (Ca) in the topsoil of profile 2

Table 3.8: Mineral composition (%) of the subsoil (50-70 cm)

| altitude (m) | 2300 | 1800 | | 1100 | |
|---|---|---|---|---|---|
| location | 2 | 3 | | 5 | |
| profile | 2 | 9 | 6 | 4 | 8 |
| kaolinite | 61.84 | 71.74 | 76.42 | 76.10 | 82.89 |
| muscovite | 4.24 | 1.40 | 1.47 | 1.29 | 4.13 |
| clinochlore | 0.62 | 0.40 | 0.34 | 0.39 | - |
| gibbsite | 15.92 | 9.60 | 6.54 | 8.70 | - |
| rutile | 0.60 | 1.07 | 1.12 | 1.22 | 1.20 |
| hematite | 16.10 | 15.55 | 13.95 | 12.04 | 9.22 |
| phosphoroxide | 0.56 | 0.25 | 0.17 | 0.14 | 0.02 |
| whitlockite | 0.12 | - | - | 0.11 | 0.63 |
| quartz | - | - | - | - | 0.92 |
| talc | - | - | - | - | 0.99 |

### 3.2.2 Bulk soil samples

In order to determine whether the clay fraction has the same composition as the bulk sample, we analysed both for profile 9. The results are given in Table 3.9.

Table 3.9 : Mineral composition (%) of the clay fraction and the bulk of the samples of profile 9

| depth | 0-20 cm | | 130-150 cm | |
|---|---|---|---|---|
| fraction | < 2 µm | bulk | < 2 µm | bulk |
| kaolinite | 70.46 | 77.24 | 71.74 | 77.14 |
| muscovite | 1.74 | 2.87 | 1.40 | 2.22 |
| clinochlore | 0.51 | 0.68 | 0.40 | 0.43 |
| gibbsite | 9.77 | 1.95 | 9.60 | 3.32 |
| rutile | 1.15 | 1.35 | 1.07 | 1.31 |
| hematite | 15.97 | 15.39 | 15.55 | 15.31 |
| phosphoroxide | 0.33 | 0.21 | 0.25 | 0.18 |
| whitlockite | 0.06 | 0.30 | - | 0.08 |

It is obvious that the clay minerals kaolinite and muscovite are not confined to the clay fraction (<2 um). This could be enhanced by the formation of pseudo-silt in these soils, when the clay particles are cemented together with iron-oxide.
The major particle-size of gibbsite, however, is the clay-size.

### 3.2.3 Rock samples

To relate the present chemical composition of the soil to the parent material two rock samples were analysed (Table 3.10). No. 1 was a dark coloured, quite hard piece of rock; no. 2 seemed to be already quite weathered. This is also expressed in the chemical composition. No. 2 has a higher content of Al and Fe than no. 1 and a low contents of most other elements.

Table 3.10: Chemical composition of the rock samples

| | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | BaO | L.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 52.61 | 0.84 | 20.86 | 7.19 | 0.26 | 1.00 | 1.79 | | 4.53 | 0.52 | 0.23 | |
| 2 | 41.97 | 0.90 | 35.48 | 8.69 | 0.11 | 0.04 | 0.06 | | 0.04 | 0.38 | 0.24 | |

The chemical composition of rock sample no. 1 looks very similar to the composition of the rock samples of Speck (1982)(Table 1.1)

In order to compare the rock samples with the soil samples the mineralogic composition of the rock samples can be expressed in soil minerals (Table 3.11).

Table 3.1 : Soil mineral composition (%) of the rock samples

| | no. 1 | no. 2 |
|---|---|---|
| kaolinite | 16.65 | 89.4 |
| muscovite | 40.95 | 0.34 |
| rutile | 0.90 | 0.90 |
| hematite | 7.69 | 8.66 |
| phosphoroxide | -1.06 | 0.33 |
| whitlockite | 3.53 | 0.11 |
| quartz | 27.83 | 0.07 |
| talc | 3.51 | 0.13 |

Comparing the soil mineral composition of the rock samples with the composition of the soil samples of profile no.9, we find that weathering is expressed in an increase in kaolinite and hematite content (Al and Fe, respectively) and a decrease in quartz (Si) and most other minerals. The same trend of weathering was found comparing the two rock samples.

### 3.3 Optical mineralogy of the heavy minerals

The results of the optical analyses are presented in Table 3.12. All samples had a very high content of opaque minerals. Some samples contained so little transparent minerals that counting the minerals was useless. The minerals counted in the samples are expressed in percentages in the table, for the other samples the minerals are just indicated with *.

The first four minerals in Table 3.12 are opaque. They could be identified with the use of the Guinier camera or through their similarity in shape with transparent minerals (ortho-pyroxene). It is possible that there are more different opaque minerals present (e.g. crystalline hematite), but those were not identified.

Table 3.12: Composition of the heavy minerals (s.g. >2.89)

|  | altitude (m) | 2900 | 2300 | 1800 |  | 1500 |  | 1100 |  |
|---|---|---|---|---|---|---|---|---|---|
|  | location | 1 | 2 | 3 |  | 4 |  | 5 |  |
|  | profile | 1 | 2 | 9 | 6 | 3 | 5 | 4 | 8 |
| opaque minerals | pseudo-brookite | * | 17 | 92 | * | 99 | 44 | 91 | 83 |
|  | fayalite (ox) | * |  |  |  |  |  |  |  |
|  | augite (ox) |  |  |  | * |  |  |  |  |
|  | ortho-pyroxene (ox) |  | 68 |  |  |  |  |  |  |
| pyroxenes/ amphiboles | aegirien augiet | * | 1 | 2 | – | – | 6 | – | – |
|  | green hornblende | – | – | – | – | – | 2 | 4 | 4 |
|  | oxyhornblende | – | 14 | – | – | – | – | – | – |
|  | riebeckite | * | – | 2 | * | * | 46 | – | – |
| granate group | granate | – | – | 1 | – | * | – | – | – |
|  | melanite | – | – | – | * | – | – | – | – |
|  | biotite | – | – | – | – | * | 1 | – | 1 |
| Ti-oxides | rutile | * | – | – | – | – | – | 1 | – |
|  | zircon | – | – | – | * | * | 1 | 4 | 3 |
|  | epidote | – | – | – | – | – | 1 | – | 3 |
|  | tourmaline | * | – | – | – | – | – | – | 1 |
| $Al_2O_3$-rich silicates | sillimanite | – | – | 1 | * | – | – | – | 3 |
|  | dithene | – | – | – | – | * | – | 1 | – |
|  | andalusite | – | – | – | – | – | – | – | – |
|  | staurolite | – | – | 1 | – | – | – | – | 1 |

As was mentioned before, the volcanics of Mt.Kenya consist of intermediate and basic igneous rocks (1.2). The minerals of the group of pyroxenes/amphiboles, and olivine (fayalite) in the soil samples also indicate an intermediate to basic origin of the parent material. The last four minerals in Table 3.12 that occur in the soil samples, however, come from the group of $Al_2O_3$-rich silicates. Those minerals, together with epidote and tourmaline, are characteristic for metamorphic rocks. They appear already quite high on the slopes, which indicates that there must be a notable admixture of metamorphic rocks in the volcanics. The importance of this admixture is not reflected in the percentages, because these minerals are known to be very resistant to weathering whereas the olivines, pyroxenes and hornblendes are not.

## 3.4 Transmission electron microscopy

### 3.4.1 TEM of the clay minerals

With transmission electron microscopy single clay minerals can be made visible and as such identified on the basis of their shape and size.
Kaolinite has a platy structure, characteristic for clay minerals. It cannot be identified just visually, because e.g. vermiculite has a similar shape.
The gibbsite crystal is a elongated hexagonal one. It can be shown on a TEM-image as in fig. 3.1.

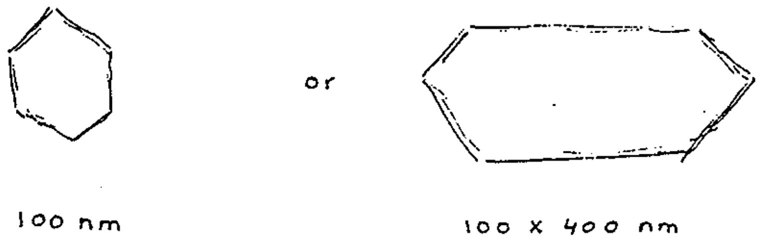

Fig. 3.1: Occurences of gibbsite (after Dixon and Weed, 1977)

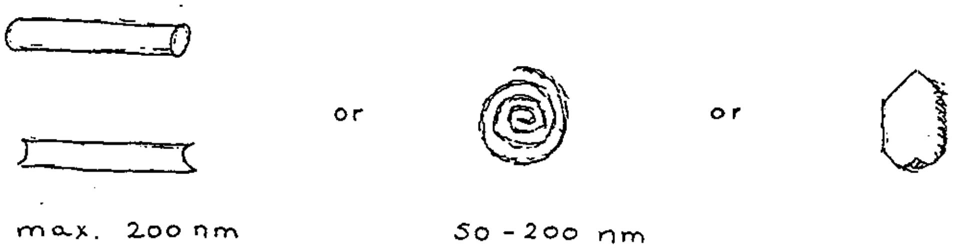

Fig. 3.2: Occurences of halloysite (after Dixon and Weed, 1977)

Halloysite can occur in various forms as indicated in fig. 3.2. Most common are the tubular and spheroidic form. These forms probably originates from the rolling of thin plates. Also hexagonal platelets with curled edges may occur.
The morphology and sizes of the minerals found in the samples are indicated in Table 3.13.

The undifferentiated form and the large size of the minerals in profile 2 could indicate that those are biotite remnants from the parent material.
The small size of the other minerals are an indication that the minerals are still quite young and have not grown to bigger particles yet.

Table 3.13: Morphology and size of the minerals

| loc/prof. | morphology | size (nm) |
|---|---|---|
| 1/1 | hexagonal | 6 * 6 |
| 1 | tubular | 5 * 30 |
| 2/2 | undifferentiated | 100-200 |
| 2 | undifferentiated | 200-500 |
| 2 | undifferentiated | 100 |
| 2 | tubular | 10 * 40 |
| 2 | spheroid | 15 |
| 3/7 | tubular | 10 * 2.5 |
| 7 | tubular | 5 * 25 |
| 7 | pseudo hexagonal | 10 * 15 |
| 7 | pseudo hexagonal | 10 * 10 |
| 7 | H-shaped | 4 * 6 |
| 4/8 | hexagonal | 6 * 10 |
| 8 | hexagonal | 15 * 15 |
| 8 | hexagonal | 5 * 8 |
| 8 | H-shaped | 3 * 10 |
| 5/3 | hexagonal | 6 * 10 |
| 3 | hexagonal | 15 * 20 |
| 3 | tubular | 6 * 30 |
| 3 | H-shaped | 3 * 10 |

### 3.4.2 STEM/EDAX-analysis of the clay fractions

For every mineral there is an ideal chemical composition. Some variations may occur due to origin or state of weathering.
The ideal chemical formula for kaolinite is $Al_4Si_4O_{10}(OH)_8$; this means Al:Si=1:1. Since the molecular weight of Al and Si is about the same, the ratio $P/W_{Al}$ over $P/W_{Si}$ of about 1 is to be expected. This ratio is supposed to be lower for halloysite.
The results of the STEM/EDAX-analysis are given in Table 3.14.
It was the first time this method was used for this kind of purpose, which presented some difficulties.
First we could only make use of a single-mineral sample of kaolinite. For halloysite (or other minerals) there were no single-mineral samples available to determine an ideal composition.
Besides, the apparatus appeared to have some problems. The base-line, which is supposed to be constant, showed peaks and dips. In the samples marked with * in Table 3.14 the base-line was steady. But still the variation between the samples was to large to draw any conclusions.

Table 3.14: STEM/EDAX-analysis (P/W-values)

| loc/ prof. | Al | Si | Al/Si | Fe | Mg | Ti | K | identification | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | morph. | chemical |
| 1/1 | 2.5 | 4.4 | 0.56 | 1.0 | - | - | - | undiff. | hall./kaol. |
| 1 | 8.6 | 15.7 | 0.56 | 16.1 | 1.2 | - | - | tubular | vermiculite |
| 1* | 22.9 | 34.2 | 0.67 | 2.4 | 1.5 | - | - | undiff. | vermiculite |
| 1 | 22.9 | 0.21 | - | 3.3 | - | - | - | acular | hall./kaol. |
| 1 | 18.8 | 1.85 | - | 0.6 | - | - | - | acular | hall./kaol. |
| 1 | 2.7 | 17.7 | 0.15 | - | 7.7 | 0.7 | - | undiff. | vermiculite |
| 1 | 9.6 | 32.9 | 0.29 | 1.9 | - | - | 0.5 | undiff. | vermiculite |
| 2/2 | 1.4 | 7.1 | 0.20 | - | - | 0.5 | - | undiff. | hall./kaol. |
| 2 | 0.8 | 5.8 | 0.15 | - | - | 0.9 | - | spheroid | hall./kaol. |
| 2 | 11.6 | 12.4 | 0.94 | - | - | 0.9 | - | undiff. | hall./kaol. |
| 2 | 3.4 | 7.9 | 0.43 | - | - | 1.1 | - | undiff. | hall./kaol. |
| 2* | - | 30.3 | - | - | 0.7 | - | 0.5 | undiff. | hall./kaol. |
| 2 | 3.6 | 10.6 | 0.34 | 18.1 | 1.0 | 1.1 | 1.3 | undiff. | hall./kaol. |
| 2 | 2.7 | 11.4 | 0.24 | - | 0.5 | - | - | undiff. | hall./kaol. |
| 3/9 | 2.6 | 7.3 | 0.36 | 13.6 | - | 8.4 | - | undiff. | hall./kaol. |
| 9* | 31.5 | 2.5 | - | - | - | - | - | ps. hexag. | gibbsite |
| 9* | 31.3 | 1.4 | - | 1.3 | - | - | - | ps. hexag. | gibbsite |
| 9* | 0.8 | 2.5 | 0.31 | 24.9 | - | 11.2 | - | undiff. | pr. min. |
| 9* | 21.8 | 8.0 | - | - | - | - | - | acular | hall./kaol. |
| 9* | 11.5 | 18.0 | 0.64 | 2.4 | - | - | 1.1 | undiff. | vermiculite |
| 9* | 11.4 | 18.2 | 0.63 | 2.5 | 0.5 | - | 1.1 | undiff. | vermiculite |
| 9* | 7.1 | 8.7 | 0.82 | 4.6 | - | - | - | undiff. | hall./kaol. |
| 3/7 | 5.1 | 19.3 | 0.26 | 1.0 | - | - | - | tubular | hall./kaol. |
| 7 | 5.0 | 17.6 | 0.28 | 1.5 | - | - | - | tubular | hall./kaol. |
| 7 | 3.5 | 15.9 | 0.22 | 2.2 | - | - | - | tubular | hall./kaol. |
| 7 | 2.6 | 9.6 | - | 0.7 | - | 0.8 | - | spheroid | hall./kaol. |
| 4/3 | 3.3 | 3.6 | 0.90 | - | - | - | - | acular | hall./kaol. |
| 3 | 7.4 | 16.3 | 0.45 | - | - | - | - | undiff. | hall./kaol. |
| 3 | 0.7 | 3.1 | 0.24 | - | - | - | - | hexagonal | hall./kaol. |
| 5/8 | - | 1.9 | - | 0.71 | - | - | - | acular | hall./kaol. |
| 8 | 0.8 | 5.4 | 0.14 | - | - | - | - | acular | hall./kaol. |
| 8* | 11.1 | 14.6 | 0.76 | - | - | - | - | acular | hall./kaol. |
| 8 | 4.2 | 25.1 | 0.17 | - | - | - | - | rectang. | hall./kaol. |
| 8 | 2.6 | 12.9 | 0.20 | - | - | - | - | hexagonal | hall./kaol. |

Thus, the quantitative use of the results was impossible. But still they could be used qualitatively. It is certain that the elements detected must have been present in the minerals. From this it can be concluded that, when K was found, it must have been illite or vermiculite. Referring to X-ray diffraction it must have been vermiculite. Mg also indicates the presence of vermiculite.

Detection of just Al implies the presence of gibbsite. The minerals with a composition of only Al and Si are kaolinite and halloysite.

From the detection of Fe not much can be concluded. It is very well possible that the minerals have iron-coating or-interlayering.

From Table 3.14 it is obvious that halloysite and kaolinite are the main constituents in the lowest profiles. Especially the profiles 1 and 2 show a lot of vermiculite. This trend is similar to the trend in the X-ray diffraction analysis.

Comparing the chemistry with the morphology it can be concluded that halloysite/kaolinite has the most distinct forms (aculiar, tubular and spheroidic). Vermiculite has mostly an undifferentiated form, while gibbsite is pseudo-hexagonal.

## 4 Conclusions

Both from literature and analyses it may be concluded that the Mt. Kenya volcanics consist of intermediate to basic rocks. Presumably the parent material of the soil was built up from pyroclastic material, given the advanced stage of weathering of the soils in combination with some unaltered rocks in streambeds.
Quite remarkeable is the admixture of metamorphic rocks in the volcanics, expressed in minerals like andalusite and staurolite.
Starting from this rather basic parent material already in an early stage of weathering gibbsite and halloysite are found.
About the formation of gibbsite there is some disagreement. Some people say that gibbsite is formed as a weathering product of kaolinite, whereas others state that gibbsite can be formed directly by weathering from basic or intermediate rocks. From acidic rocks it will be formed through weathering of kaolinite (Dixon and Weed, 1977)
When weathering proceeds or when the climate becomes drier halloysite is transformed into kaolinite.
Vermiculite is also a first weathering product. Presumably the biotite, which can still be found in the lower profiles, is completely transformed into vermiculite.
The fact that no smectites are found, indicates that there must be much leaching with which the basic elements from the parent material are lost. This is also reflected in the chemical analysis.
Examining the clay fractions with the electron microscope showed the same trend visible from X-ray diffraction analysis. The small size of the minerals found indicates that the minerals are still rather young.
About the presence of allophane nothing definite can be said, since it was removed in order to study the clay minerals.
That climate is an important factor in weathering is quite well expressed in the results. Below about 1800 m the mineral composition is predominated by kaolinite and gibbsite, whereas above 1800 m much more various minerals are found. This transition in weathering seems to coincide with the transition in climate from a more moist temperate climate under rainforest to a more dry tropical climate.

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Appendix I

## PROFILE DESCRIPTION 1

Date/ season : 14/09/85, beginning of the warm season
Sheet-observation no : 121/2-1
Coordinates : 99.81.0 N, 3.28.8 E
Elevation : 2925m
Authors : Jan Kuyper
Soil mapping unit : -
Soil classification (FAO, soil taxonomy) : mollic Andosol andic Haploboroll
Geology : Mt. Kenya-series
Local petrography (Parent material) : vulcanic ashes, lapilli
Physiography : mountain
Macro-relief : rolling to hilly
Slope (length, shape and pattern) : -,convex,-
Slope gradient : -
Position on slope : -
Meso- and micro-relief : -
Vegetation/ Landuse : bamboo-Hagenia forest, forestry, game reserve
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : nil
Surface sealing/crusting/cracking : nil
Drainage class : well derained
Flooding : nil
Groundwater level (actual) : very deep
Presence of salts/ alkali : nil
Soilfauna influences : mole rat crotovinas
Expected rooting depth : 130cm

Horizons:

| | |
|---|---|
| 0 +2 - 0 cm | Black (10 YR 2/1, moist); sligthly gravelly organic matter; clear and smooth transition to: |
| Au1 0 - 14 cm | Black (10 YR 2/1, moist); moderate fine crumbs; patchy thin clay cutans; sligthly gravelly silty clay; friable when moist; non to sligthly sticky and sligthly plastic when wet; clear and smooth transition to: |
| Au2 14 - 37 cm | Black (10 YR 2/1, moist); moderate coarse angular blocky structure falling apart to crumbs; broken thin clay-humus cutans; sligthly gravelly silty clay; friable when moist, non to sligthly sticky and sligthly plastic when wet; abrupt and smooth transition to: |

| | |
|---|---|
| C 37 - 53 cm | Dark yellowish brown (10 YR 3/6, moist);weak very coarse subangular blocky structure falling apart to granules; patchy thin clay cutans; slightly gravelly sand; very friable when moist, non sticky and non plastic when wet; abrupt and smooth transition to: |
| Abu1 53 - 56 cm | Dark yellowish brown (10 YR 3/6, moist); moderate coarse to very coarse angular blocky stucture; continuous thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; abrupt and wavy transition to: |
| Abu2 56 - 62 cm | Yellowish red (5 YR 5/8, moist); moderate coarse to very coarse angular blocky structure; continuous thin clay-humus cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; abrupt and wavy transition to: |
| Abu3 62 - 66 cm | Black (7,5 YR 2/0, moist); moderate coarse to very coarse angular blocky stucture; continuous thin clay-humus cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transtion to: |
| ABb 66 - 116 cm | Dark brown (10 YR 3/3, moist); moderate coarse angular blocky stucture; abundant thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transtion to: |
| Cbu1 116 - 130 cm | Dark brown (7,5 YR 4/4, moist); common medium to coarse distinct clear dark yellowish mottles (5 YR 5/8, moist);moderate very coarse angular blocky stucture; continuous to broken thin clay cutans; silty clay; friable when moist, slightly sticky and slightly plastic when wet; clear and wavy transtion to: |
| Cbu2 130 - 150+ cm | Light olive brown (2,5 YR 5/6, moist); many coarse prominent diffuse very dark grayish brown mottles (2,5 Y 3/2, moist); weak very coarse angular blocky stucture falling apart to granules; slightly stony to stony silt; friable when moist, slightly sticky and slightly plastic when wet. |

## PROFILE DESCRIPTION 2

Date/ season : 11-2-86, long dry season
Sheet-observation no : 121/2-2
Coordinates :
Elevation : ± 2300 m.
Authors : Nicole Bongers and Jan Kuyper
Soil mapping unit : –
Soil classification (FAO, soil taxonomy) : humic Cambisol
Geology : Mt. Kenya series
Local petrography (Parent material) : vulcanic ashes, tuff
Physiography : montain
Macro-relief : rolling
Slope (length, shape and pattern) : convex, regular
Slope gradient : 0%
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : forestery
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : nil
Surface sealing/crusting/cracking : nil
Drainage class : well
Flooding : nil
Groundwater level (actual) : very deep
Presence of salts/ alkali : nil
Soilfauna influences : crotovinas, moderate activity
Expected rooting depth : > 1.20 m

### Horizons:

| | | |
|---|---|---|
| A | 0 - 8cm | Very dark gray (5 YR 3/1 moist); clay; moderate very fine granules and fine subangular blocks; loose when dry, friable when moist, slightly sticky and slightly plastic when wet; clear and smooth transition to: |
| Bu1 | 8 - 27cm | Brown to dark brown (7.5 YR 4/3 moist); clay; strong fine angular blocks; continuous thin clay cutans; friable when moist, plastic and sticky when wet; clear and smooth transition to: |
| Bu2 | 27 - 87cm | Dark brown (7.5 YR 3/2 moist); clay; strong fine angular blocks; continuous thin clay cutans; friable when moist, sticky and plastic when wet; clear and smooth transition to: |
| Bu3 | 87 -113cm | Brown to dark brown (7.5 YR 4/4 moist); clay; moderate |

| | | |
|---|---|---|
| | | fine subangular blocks; continuous thin clay cutans; friable when moist, sticky and plastic when wet; few weathered tuff gravels and stones; clear and broken transition to: |
| C | 113 -150+cm | Yellowish brown (10 YR 5/6 moist); clay; moderate fine subangular blocks; continuous thin clay cutans; friable when moist, slightly sticky and slightly plastic when wet; very frequent weathered tuff gravels and stones. |

remark: at about 75 cm a stoneline of weathered tuff appeared!

## PROFILE DESCRIPTION 3

| | |
|---|---|
| Date/ season | 10/5/85; rainy season |
| Sheet-observation no | 122/3-P2 |
| Coordinates | 3471 E, 99546 N |
| Elevation | 1380 m |
| Authors | Willy Simons |
| Soil mapping unit | R(P/I) |
| Soil classification (FAO, soil taxonomy) | humic NITISOL |
| Geology | Mt. Kenya series |
| Local petrography (Parent material) | pyroclastic agglomerates |
| Physiography | mountain Footridge |
| Macro-relief | undulating |
| Slope (length, shape and pattern) | 400 m, linear, single |
| Slope gradient | 3% |
| Position on slope | upper slope |
| Meso- and micro-relief | nil |
| Vegetation/ Landuse | perennial crop cultivation; coffee |
| Erosion | nil |
| Rock outcrops | nil |
| Surface stoniness | nil |
| Overwash | nil |
| Surface runoff | slow |
| Surface sealing/crusting/cracking | nil |
| Drainage class | well drained |
| Flooding | nil |
| Groundwater level (actual) | always deep, > 2m |
| Presence of salts/ alkali | nil |
| Soilfauna influences | extreme |
| Expected rooting depth | very deep |

Horizons:

| | | |
|---|---|---|
| A1 | 0-25/40 cm | Black (5YR 2.5/1) when moist; clay; moderate fine granular structure; loose when moist, sticky and non plastic when wet; many macropores; few medium and very few coarse roots; abrupt and wavy transition to: |
| AB | 25/40-60 cm | Dark reddish brown (5YR 2.5/2) when moist; slightly gravelly clay; moderate fine subangular blocky structure; common thin clayskins; friable when moist, sticky and slightly plastic when wet; few iron concretions; many macro- and biopores; few coarse roots; gradual and smooth transition to: |
| Bu1 | 60-90 cm | Dark reddish brown (5YR 3/2) when moist; slightly gravelly clay; moderate medium subangular blocky structure; continuous thin clayskins (shiny pedfaces); friable when moist, sticky and slightly |

plastic when wet; few iron concretions; many macro- and biopores: very few coarse roots; gradual transition to:

| | | |
|---|---|---|
| Bu2 | 90-150+ cm | Dark reddish brown (5YR 3/3) when moist; slightly gravelly clay; moderate coarse subangular blocky structure; continuous thin clayskins (shiny pedfaces); few iron concretions; many macro- and biopores; very few coarse roots. |

## PROFILE DESCRIPTION 4

Date/ season : 21/6/85; end rainy season
Sheet-observation no : 122/3-26
Coordinates : 3554 E, 99504 N
Elevation : 1140 m
Authors : Willy Simons
Soil mapping unit : LVr
Soil classification (FAO, soil taxonomy) : ferral-humic ACRISOL orthoxic Palehumult
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar / phonolite
Physiography : Plateaus
Macro-relief : gently undulating
Slope (length, shape and pattern) : -
Slope gradient : 0 %
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : annual crop cultivation; sweet potato
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : very slow
Surface sealing/crusting/cracking : weak sealing
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep
Presence of salts/ alkali : nil
Soilfauna influences : moderate
Expected rooting depth : very deep

Horizons:

| | | |
|---|---|---|
| Ap | 0-15 cm | Dark reddish brown (5YR 3/3) when moist; clay; moderate medium granular structure; very friable when moist, slightly sticky and slightly plastic when wet; many macropores and few biopores; common fine roots; clear and smooth transition to: |
| Ah | 15-35 cm | Dark reddish brown (2.5YR 3/4) when moist; clay; moderate medium subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; many macropores and few biopores; few fine roots; gradual and smooth transition to: |
| Bt1 | 35-85 cm | Dark red (2.5YR 3/6) when moist; clay; moderate medium subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; many macropores and few biopores; few fine roots; diffuse and smooth transition to: |
| Bt2 | 85-130+ cm | Dark red (2.5YR 3/6) when moist; clay; moderate |

coarse subangular blocky structure; friable when moist; slightly sticky and slightly plastic when wet; patchy thin clayskins; many macropores and few biopores; few fine roots.

| depth | 0-15 cm | 15-35 cm | 35-85 cm | 85-130 cm |
|---|---|---|---|---|
| sand % | 15 | 13 | 11 | 9 |
| silt % | 19 | 15 | 15 | 9 |
| clay % | 66 | 72 | 74 | 82 |
| texture class | c | c | c | c |
| pH-H2O (1:2.5) | 5.4 | 5.1 | 5.2 | 5.2 |
| pH-KCL (1:2.5) | 4.7 | 4.5 | 4.9 | 4.9 |
| EC (mS)(1:2.5) | 0.04 | 0.04 | 0.04 | 0.04 |
| % C | 1.64 | 1.22 | 0.96 | 0.50 |
| CEC (me/100g soil) | 22.5 | 19.5 | 13.9 | 10.9 |
| Ca (me/100g soil) | 5.1 | 3.8 | 2.5 | 2.1 |
| Mg (me/100g soil) | 3.40 | 2.85 | 2.50 | 1.85 |
| K (me/100g soil) | 1.57 | 0.63 | 0.13 | 0.07 |
| Na (me/100g soil) | 0.24 | 0.22 | 0.05 | 0.07 |
| Base Saturation % | 46 | 38 | 37 | 22 |

# PROFILE DESCRIPTION 5

Date/ season : 25/07/85; cold season
Sheet-observation no : 122/3-P44
Coordinates : 3468 E, 99539 N
Elevation : 1330m
Authors : Jan Kuyper
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : orthic Acrisol typic (ustic) HAPLOHUMULT
Geology : Mt. Kenya-series
Local petrography (Parent material) : alluvium/colluvium,(pyroclastic material)
Physiography : Valley
Macro-relief : undulating
Slope (length, shape and pattern) : 150m, concave, regular
Slope gradient : 2%
Position on slope : valley bottom
Meso- and micro-relief : nil
Vegetation/ Landuse : small scale groundwater-fed, bananas, sugarcane, maize, napirgrass
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : very slow
Surface sealing/crusting/cracking : nil
Drainage class : imperfectly to moderately well drained
Flooding : nil
Groundwater level (actual) : 105cm
Presence of salts/ alkali : nil
Soilfauna influences : moderate
Expected rooting depth : 105cm

Horizons:

A1 0-20 cm

Dark reddish brown (5YR 3/4 dry, 2.5 YR 3/4 moist); clay; moderate very fine medium granular-subangular blocky structure slightly sticky slightly plastic when wet; very friable when moist, soft when dry; gradual and wavy transition to:

B 20-60 cm

Dark reddish brown (5YR 3/3 dry, moist); clay; weak to moderate very fine medium, subangular blocky structure; thin patchy clay cutans; slightly hard when dry, very friable when moist, slightly sticky slightly plastic when wet; smooth and gradual transition to:

| | |
|---|---|
| Btg2 60-105 cm | Dark reddish brown (2.5 YR 3/4 moist); many fine distinct clear black mottles; very fine to medium moderate subangular blocky structure; broken thin clay cutans; silty clay; consistence: sligthly hard when dry, very friable when moist, sligthly sticky and sligthly plastic when wet; few medium manganese concretions; smooth and gradual transition to: |
| Bg3 105-140 cm | Dark brown (7.5 YR 4/4 moist); many tubular iron (rootrost) mottles (7.5 YR / ?); silty clay; moderate fine to very fine angular blocky structure; very friable when moist, sticky and plastic when wet; smooth and gradual transition to: |
| Gu1 140-160 cm | Grayish brown (10 YR 5/2 wet) |
| Gu2 160-185 cm | Gray (5 Y 5/1 wet) |
| Gu3 185-200 cm | Dark gray (10 YR 4/1 wet) |
| Gu4 200+ cm | Grayish green (5 G 5/2 wet) |

## PROFILE DESCRIPTION 6

Date/ season : 14-8-85 : end of cold season
Sheet and Observation no : 122/3 - P 45
Coordinates : 3372 E 99608 S
Elevation : 1790 m
Authors : Willy Simons, Jan Kuyper, Nicole Bongers
Soil mapping unit :
Soil Classification (FAO, soil taxonomy) : humic Nitisol
Geology : Mt. Kenya series
Local petrography (Parent material) : pyroclastic agglomerates/phonolite
Physiography : mountain Footridge
Macro relief : mountainuous
Slope (length, shape & pattern) : convex, regular
Slope gradient : 2%
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : perennial crop cultivation; tea
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep
Presence of salts/ alkali : nil
Soilfauna influences : moderate
Effective rooting depth : extremely deep

Horizons:

| | | |
|---|---|---|
| Ah | 0-20/30 cm | Dark reddish brown (5YR 3/3), when moist; clay; moderate, coarse subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; continuous thin clayskins; common macro and biopores ; frequent, fine and common medium roots; clear and wavy transition to: |
| Bu1 | 20/35-120 cm | Red (2.5YR 4/6), when moist; clay; weak very coarse subangular blocky falling apart to coarse subangular blocky structure; friable when moist, slightly sticky and slightly plastic, when wet; broken, thin clayskins; many macropores, common biopores; common fine and few medium roots; clear and smooth transition to : |
| Bu2 | 120-150+ cm | Red (2,5 YR 4/6), when moist; clay; weak to moderate very coarse subangular blocky structure; |

friable when moist; slightly sticky and slightly plastic when wet; continuous clayskins, shiny pedfaces, many macropores and common biopores; common fine, few medium roots.

# PROFILE DESCRIPTION 7

Date/ season : 26/8/85; end of cold season
Sheet-observation no : 122/3-P49
Coordinates : 3373 E, 99607 N
Elevation : 1715 m
Authors : Willy Simons and Nicole Bongers
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : dystric Acrisol
Geology : Mt. Kenya series
Local petrography (Parent material) : pyroclastic agglomerates
Physiography : Valley in mountain Footridge
Macro-relief : mountainous
Slope (length, shape and pattern) : 150m, convex, regular
Slope gradient : 3%
Position on slope : valley bottom
Meso- and micro-relief : nil
Vegetation/ Landuse : ~~grassland~~ fallow
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : rapid
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always moderately deep
Presence of salts/ alkali : nil
Soilfauna influences : none to limited
Expected rooting depth : moderately deep

Horizons:

| | | |
|---|---|---|
| A | 0-15 cm | Reddish brown (5YR4/4), when moist; clay; moderate medium subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; continuous thin clayskins; few macro- and biopores; few very fine, common fine, few medium roots; gradual and smooth transition to: |
| B | 15-50 cm | Reddish brown (5YR4/4), when moist; clay; moderate coarse subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; continuous thin clayskins; few macropores, common biopores; common fine roots; abrupt and smooth transition to: |
| B+CR | 50-65+ cm | Reddish brown (5YR4/4), when moist; very gravelly clay; coarse granular structure ( size of rock |

fragments ); friable when moist, slightly sticky and slightly plastic when wet; continuous thin clayskins; common macro- and biopores; very few fine roots.

## PROFILE DESCRIPTION 8

Date/ season : 29-08-1985; dry season
Sheet-observation no : 122/3-P54
Coordinates : 3551 E, 99501 N
Elevation : 1130 m
Authors : Jan Kuyper
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : plinthic ACRISOL
Geology : Mt. Kenya series
Local petrography (Parent material) : pyroclastic material,alluvium,colluvium
Physiography : minor Valley in Plateau
Macro-relief : undulating
Slope (length, shape and pattern) : nil
Slope gradient : 1%
Position on slope : valley bottom
Meso- and micro-relief : irrigation/drainage ditches
Vegetation/ Landuse : small scale anual crop, banana, sugarcane, cassava
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : very slow
Surface sealing/crusting/cracking : slightly hard 10mm crust, cracks 4mm width 20cm apart
Drainage class : moderately well drained
Flooding : nil
Groundwater level (actual) : temporarily shallow (170cm)
Presence of salts/ alkali : nil
Soilfauna influences : limited
Expected rooting depth : very deep

Horizons:

Ap 0-25 cm

Dark brown (7.5YR 3/2 moist, 5YR 4/4 dry); weak very coarse subangular blocky structure falling apart to very fine - medium moderate granules and crumbs; patchy thin claycutans; gravelly clay; consistence: hard and weakly cemented when dry, friable when moist, slightly sticky and slightly plastic when wet; frequent to very frequent, small to medium, hard spherical iron manganese concretions; clear and wavy transition to:

| | | |
|---|---|---|
| Au1 | 25-55 cm | Dark reddish brown (5YR 2.5/2 moist, 7.5YR 3/2 dry); very dark gray (7.5YR 3/0), common distinct sharp mottles; moderate very coarse subangular blocky structure falling apart to moderate very fine to medium crumbs and granules; broken thin claycutans; gravelly clay; hard and weakly cemented when dry, very friable when moist; slightly sticky and slightly plastic when wet; frequent to very frequent, small to medium, hard spherical iron-manganese concretions; gradual and smooth transition to: |
| Bg1 | 55-90 cm | Dark reddish brown (5YR 2.5/2 moist, 5YR 3/2 wet); black (5YR2.5/1) many medium distinct sharp mottles; moderate very coarse falling apart to moderate medium subangular blocky structure; broken thin clay-manganese cutans; gravelly clay; hard and weakly cemented when dry, friable when moist, slightly sticky and slightly plastic when wet; few small to medium hard, spherical iron-manganese concretions; gradual and smooth transition to: |
| Bg2 | 90-140 cm | Dark reddish brown (5YR 2.5/2 moist); black (5YR 2.5/1) many medium distinct sharp mottles; many very coarse falling apart to medium subangular blocky structure; broken to continuous thin clay-manganese cutans; slightly gravelly clay; hard and weakly cemented when dry, friable when moist, slightly sticky and slightly plastic when wet; few small to medium hard spherical iron-manganese concretions; clear and smooth transition to: |
| Bg3 | 140-160 cm | Very dark brown (10YR 2/2 moist); black (10YR 2/1) many medium distinct sharp mottles; moderate very coarse angular blocky structure; continuous thin claycutans; slightly gravelly clay; firm and compact when moist, slightly sticky and slightly plastic when moist; few small to medium hard spherical iron-manganese concretions; clear and smooth transition to: |
| Bg4 | 160+ cm | Brown to dark brown (7.5YR 4/2 moist); black (10YR 2/1) common fine distinct sharp mottles; continuous thin claycutans; slightly gravelly; slightly sticky and slightly plastic when wet; few small to medium hard spherical manganese concretions. |

moderately thick clayskins, shiny pedfaces.

Pore-distribution:

| | | A | Bu1 | Bu2 |
|---|---|---|---|---|
| very fine | < 1mm : | many | many | many |
| fine | 1-2mm : | few | common | common |
| medium | 2-5mm : | common | few | few |
| coarse | > 5mm : | few | few | few |

Root-distribution:

| | | A | Bu1 | Bu2 |
|---|---|---|---|---|
| very fine | < 1mm : | frequent | common | very few |
| fine | 1-2mm : | frequent | few | very few |
| medium | 2-5mm : | common | common to few | very few |
| coarse | > 5mm : | few | very few | very few |

# PROFILE DESCRIPTION 9

Date/ season : 7-2-'86
Sheet-observation no : 122/3-
Coordinates :
Elevation : 1810 m
Authors : Jeanine Kools, Nicole Bongers
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : humic Nitisol
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar/phonolite
Physiography : mountain footridges
Macro-relief : mountainous
Slope (length, shape and pattern) : convex, regular
Slope gradient : 2%
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : forest
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep, >2 m
Presence of salts/ alkali : nil
Soilfauna influences : strong influence, many species
Expected rooting depth : > 1.50 m, very deep

Horizons:

A 0 - 4 cm: clay; strong very fine to fine angular blocky structure; friable when moist, slightly plastic and slightly sticky when wet; continuous moderately thick clayskins; many biological pores and infillings; abrupt and wavy transition to:

Bu1 4 - 55 cm clay; moderate fine subangular blocky structure; friable when moist, slightly plastic and slightly sticky when wet; continuous moderately thick clayskins; diffuse and smooth transition to:

Bu2 55 - 150 cm clay; weak very fine to fine subangular blocky structure; very friable when moist, slightly plastic and slightly sticky when wet; continuous