VOLCANIC DEPRESSIONS
IN THE CHUKA-AREA, KENYA

their origin and agricultural potential.

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SUMMARY.

Within the framework of the Training Project in Pedology of the Agricultural University of Wageningen, the Netherlands, a research has been made on volcanic depressions in the Chuka area, Kenya, from the middle of January 1986 to the middle of April 1986.
The specific objectives of this study have been to locate the present volcanic depressions, to find out something about their origin, to define the soil-types appearing in them, to find out which improvements can be carried out in the present used farming systems, and which crops can be introduced in the depressions.

In this area there are about 140 most elliptical shaped volcanic depressions in consolidated lahars, all of them with a certain direction, corresponding with the direction of the lahar-flows. About their origin there are four theories:

- During the deposition of the lahar the large amount of water drains out of the mudflow to the surface, concentrates, and forms little lakes. After consolidation of the lahar and the disappearance of the water, depressions stay behind.
- Due to local differences in texture and watercontent, some parts with a finer texture and a higher watercontent sink to a lower level during the consolidation.
- During the deposition of the lahar, a crust is formed due to evaporation of the water in the upper layers, and subsidence occurs because the lower parts are still flowing.
- During the deposition of the lahar large parts of ice (pieces of glaciers) were present within or upon it. The melting of the ice caused subsidence.

Soils on the bottoms of the depressions are Vertisols, Gleysols and gleyic and ferric Acrisols. To the upper-slopes there is a general soil-sequence, ending in chromic, humic or dystric Acrisols or in humic or dystric Nitosols.

When the growing seasons, normally starting at the beginning of the rainy seasons, are adjusted and start at the beginning of the dry seasons, because of the ponding-problem in the rainy seasons, some crops with short growing periods such as sorghum, sweet potato, cocoyam and tannia have good possibilities to give good yields. When ridges are introduced, crops like tomato, cabbage and green gram may do well. When a drainage-system is introduced, the ponding-problem is solved, and several crops like sugarcane, also have good possiblities. The present functions cattle-dip and waterhole will disappear then.

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Chapter 1. INTRODUCTION.

1.1. Background.

Within the framework of the Chuka Project, the third phase of the Training Project in Pedology (T.P.I.P.) in Kenya, researches are made into the subject of volcanic depressions. All the activities of the T.P.I.P. are carried out in close consultation with her kenyan counterpart, the Kenya Soil Survey (K.S.S.), part of the National Agricultural Laboratories in Nairobi.
The objectives of the Chuka Project are:

a) to produce a reconnaissance soil map of scale 1:100.000 of the map sheets of Chuka and that of Ishiara, both scale 1:50.000, of the Survey of Kenya, together with a detailed report and a landevaluation to assess the suitability of a number of landuses, and

b) to train post-graduate students in soil science, agronomy, vegetation and agricultural economics of the Agricultural University of Wageningen (A.U.W.), the Netherlands. The training consists of graduate-students work as well as research work for MSc-thesis.

The funds for the Chuka Project are provided by the Agricultural University of Wageningen and are estimated on a project length of 14 months. The selection of the two map sheets was spelled out in full cooperation with the K.S.S.
The funds for the travel to Kenya are provided by Bureau Buitenland of the State University of Utrecht, the Netherlands, after approval of Stichting Werkgroep Studiereizen Ontwikkelingslanden (W.S.O.), The Hague, the Netherlands.

1.2 Objectives of the study.

In general the underlying study deals with the second project objective. It also deals with the first project objective, but in a different way. The study is a detailed survey of a phenomenon that is too small to pay much attention to, within the context of the reconnaissance soil map, but is too interesting and too important for the local population to let go.
More specified objectives of this study are:

a) Location of the present volcanic depressions in the research area with the help of aerial photographs.

b) Find out something about their origin. Check if there is a pattern in their position or if there is a correlation with other geological phenomena.

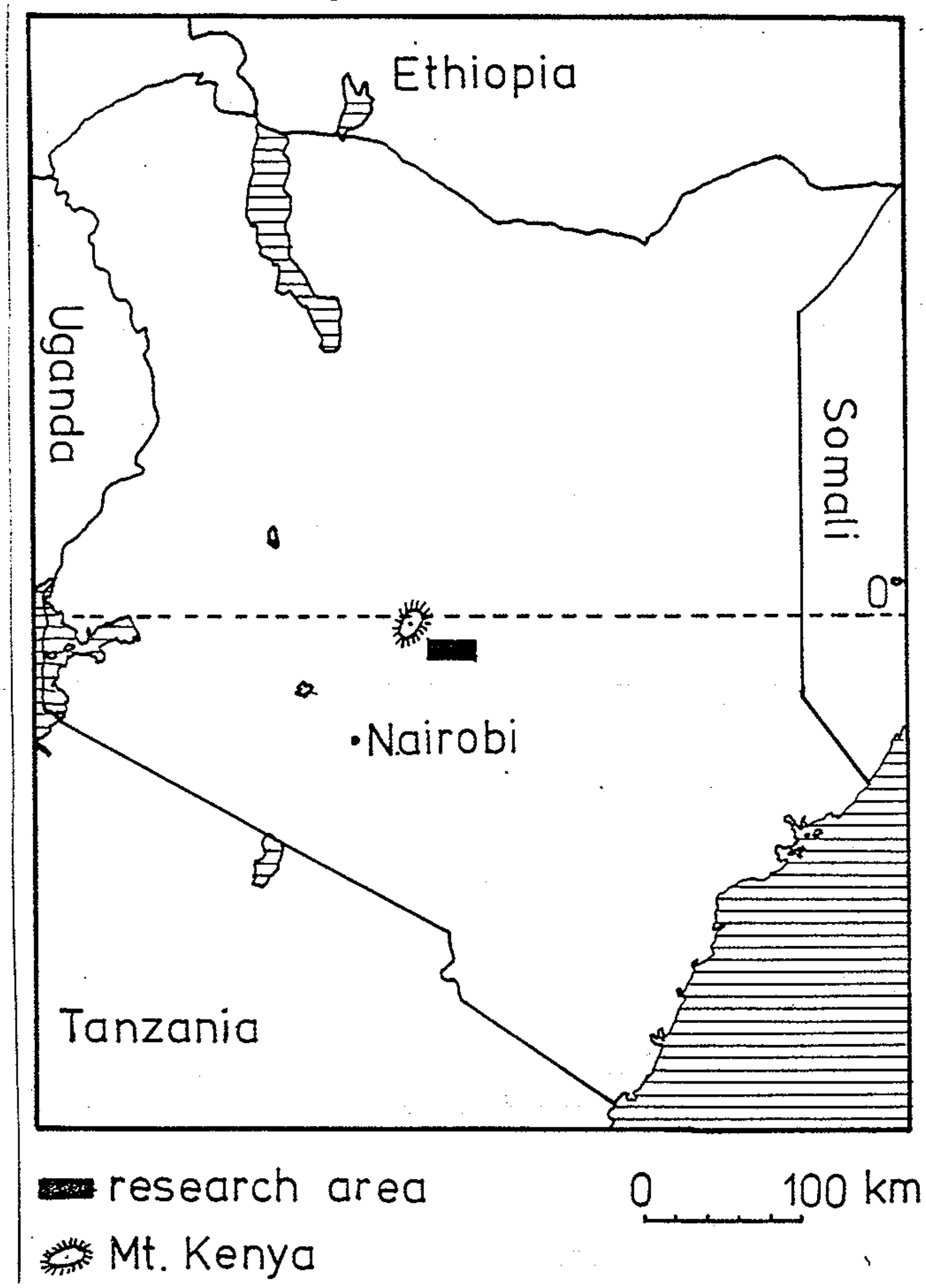
c) Define the soil types appearing in the volcanic depressions.

d) Find out in cooperation with agronomy students which improvements can be carried out in the present used farming systems, and which crops can be introduced in the depressions.

1.3. Location of the research area.

For the location of the research area see Figure 1.
The area is located 160 km north-east of Nairobi, on the east-slopes of Mount Kenya, and consists of parts of Embu district, Meru district and Kitui district.
The area has been chosen because of the many agricultural developments going on there. Besides, the big ecological variation influenced the choice of the research area.

Figure 1 **The location of the research area.**
(after: Atlas of Kenya)



Chapter 2. WORKING METHOD.

2.1. Aerial photo-interpretation.

Aerial photographs of the Chuka and Ishiara map sheet have been studied, as far as they concerned the area influenced by volcanic activity: areas now covered by lahars and lavaflows. A first draft map of the volcanic depressions was made with this information. The map has been used in the field to locate the volcanic depressions.

2.2. Development of theories.

After studying the available literature and after paying some visits to volcanic depressions in the research area, several theories were developed. All of those have been considered to be the possible origin of the volcanic depressions. These theories have been worked out, and after that, arguments had to be sought, to reject or accept the theories.

2.3. Field methods.

These arguments had to be sought in the field, where also the different soil types had to be defined.
Most of the arguments have come from the longitudinal and cross sections made in several volcanic depressions, and from measurements of certain directions in the volcanic depressions.
Augerings in the soil have been done down to 520 cm, in order to reach the lahar, the hard rock lying beneath the soil. Everywhere, the upper 150 cm of the soil has had special attention and has been sampled according to the standard FAO methods (FAO, 1977), Guidelines for soil profile description).
Soil colours have been described by the Munsell scheme (OYAMA & TAKEHARA, 1967). Soil classification has been done according to the FAO method (FAO-UNESCO, 1974) with adjustments according to the Kenyan concept (SIDERIUS & VAN DER POUW, 1980). A number of profile pits and one large profile trench have been dug in order to get some additional information.
Profile pits dug and sampled by other soil science students have provided usefull chemical data.
Some soil samples have been taken for measuring the soil reaction (pH) and the electric conductivity.
Most types of the volcanic depressions have been visited and in all of them the relationship between physiographical position and soil type, the soil sequence, has been defined, together with the present land use. Detailed soil maps have been made of two volcanic depressions.
In almost every volcanic depression a small interview with a local farmer has been done. Questions have been asked about the waterheight in the depressions during the rainy seasons, and about farming in the volcanic depressions, or why they were not farming in the depression.

2.4. Office work: land-evaluation and report writing.

Using the field data, chemical data, optained from the Kenya Soil Survey, literature and interim reports from related studies within the framework of the Chuka project, a land-evaluation has been carried out for several crops having possibilities in the volcanic depressions, according to the FAO methods (FAO, 1983). Finally, maps and figures have been drawn and this report has been written.

Chapter 3. GEOLOGY AND GEOMORPHOLOGY.

3.1. Geology of the research area.

Figure 2 shows the geological map of Central Kenya.

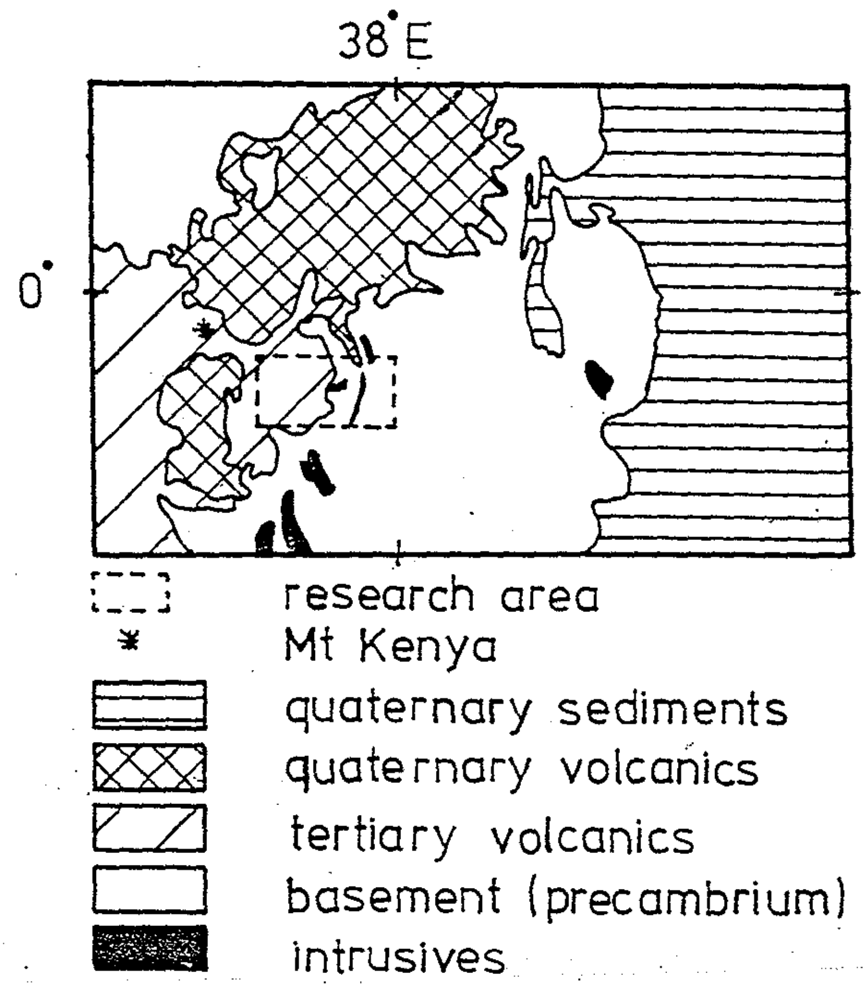


Figure 2 Geological map of central Kenya. (1:3,000,000)
(source: Survey of Kenya, 1969)

From this figure becomes clear, that in the survey area **Basement System rocks**, belonging to the Mozambique Belt, and of Precambrium age, form the floor on which all the other rocks of the area lie. These rocks are composed of heterogenous migmatic gneisses, granulites and schists of varied and complex origin.
In the Miocene (Tertiar) these Basement System rocks had formed a peneplain which became covered by volcanics from Mount Kenya from

the north-west: the **Tertiary Volcanics**. Most of these volcanics are the so called lahars. Lahars are consolidated mudflows from the slopes of the volcano and enbed all kinds of volcanic rocks, such as phonolite, in a matrix of pyroclastics.

The parts of the Basement System area which are not covered by the Tertiary volcanic rocks have undergone various erosion cycli and form the Uplands, Hills and Mountains. There are some Hill and Mountain complexes in the area, which are mostly granitoid or (ultra) mafic **Intrusives** which are more erosion resistant than their surroundings, consisting of gneisses and schists.
Some intrusions of ultra basics (hornblendites), caused by a very high grade of metamorphism in the surrounding gneisses and migmatites, resulting in zones rich in granulites.

Some Hills are built up from the same rocks as the rocks in their surroundings but form the Hills because parts of these rocks were covered by volcanic rocks which (partially) have been eroded now, but protected the underlying rocks against erosion.

In the Pleistocene there was some new volcanic activity from the Nyambeni volcanoes, especially north of the area. Some riverbeds got filled up by olivine basalts coming from the north: the **Quaternary Volcanics**. Some riverbeds fillings still exist as ridges in the area. Under these basalts the pleistocene riverbed deposits can be found. Also plateau basalts have been found.

Quaternary Sedimentary rocks only cover a small part of the area. Some remains of Quaternary terraces are found together with the recent alluvial deposits.

3.2. Lahars.

Because of the fact that the phenomenon volcanic depression in this area only appears when the parent material is lahar of the Mount Kenya Volcanic Group, the phenomenon lahar is given special attention here.
Among the strictly volcanic processes which widely distribute debris, both coarse and fine, is the volcanic mudflow, termed in Java 'lahar'.
Various agencies can cause a lahar:

- Small mudflows of a quite ordinary, i.e. non-volcanic, kind occur commonly and help to distribute and re-distribute the apron of volcanic ash. At first the volcanic ashes cool, after that the ashes become waterlogged. The ashes can become waterlogged by the **torrential rains** that accompany and follow some eruptions, and form a 'cold lahar'. In Java these are termed 'rain lahars'. Rain due to condensation of vapour of volcanic origin is not a necessary accompaniment of eruptions, but rain falling in the ordinary course of events, especially tropical rain, may be quite sufficient to cause extensive sliding and redistribution of unconsolidated ash by mudflows (COTTON, 1944). An example is the Vesuvius eruption, Italy, in 1906.

- Major lahars, on the other hand, have resulted from a mingling of 'nuees ardentes' with **river waters**, causing a 'hot lahar'. Nuees ardentes are 'glowing clouds', consisting of a mixture of extremely hot, incandescent fine ash and coarser rock fragments permeated with hot gases (THORNBURY, 1954). An example is the Merapi eruption, Java.

- Many great lahars in Java have been caused by the **rapid evacuation of crater lakes**. This type can cause 'hot lahars', resulting from uprise of cumulo-domes in the lakes or from eruptions which blow up through them, or it can cause 'cold lahars', caused by the sudden escape of crater-lake waters liberated as a result of an eruption or otherwise (COTTON, 1944). Examples are found at St.Vincent, Antilles (1902), and at the Keloet volcano, Java, (1895 and 1919).

- Other destructive mudflows have been ascribed to the **melting of snow and glacier ice** by volcanic heat (COTTON, 1944), causing a 'cold lahar'. A very disastrous example is the mudflow accompanying the eruption of the Nevado del Ruiz, Colombia (1985), in which thousands of people died.

The water mixes with the volcanic ash and forms a vast muddy stream, and this sweeps along also coarser debris, including in some cases great quantities of large boulders of lava rock. Lahars follow mainly channels already existing, filling them temporarily to the brim with rushing torrents, but mostly leaving them empty again. The whole stream travels far and may spread out and deposit its load of debris on level land at the base of the volcano. Stiff flows come to rest in thick convex tongues, but in the case of those containing much water the surface becomes finally 'that of a thin fluid' and spreads out almost horizontally (COTTON, 1944).
During the eventual settlement and draining out of lahar-transported material specific landforms arise. Very extensive fields of mounds and hummocky landscapes on the plains peripherical to the volcano are most common. Examples are the mound field of Tasikmalaja near the Galunggung volcano, Java, the mound field at Bandaisan, Japan, and the mound field in the Tongariro National Park, New Zealand. Depressions in lahars, like in the Chuka area in Kenya have so far not been reported from other areas.

3.3. Geomorphology of the research area.

The research area can be divided in two distinct geomorphological units: the volcanic deposits of Mt. Kenya in the West and the basement system terrain in the East of the area.
Mt. Kenya which is a remnant of a Tertiary volcano, has a relatively flat profile. The Western part of the area comprises the Eastern part of Mt. Kenya slopes, up to 2000 m. These slopes are classified as **mountain footridges**.
The mountain footridges are strongly dissected by perennial streams and rivers, descending from the mountain. The major streams, Nithi, Tungu and Naka river have cut gorges in the volcanics. The valleys which dissect the mountain footridges are an other geomorhological unit.

The volcanic deposits gradually become thinner towards the East. The lowest, relatively thin, flows reflect the flat sub-Miocene peneplain landscape over which they spread widely. Now these flows are strongly eroded and dissected. They form so called **uplands** as a transition from the mountain footridges to the basement system area.

In the volcanic deposits the so called **volcanic depressions** are situated which are classified as **bottomlands**. These are elliptical shaped, concave depressions which mostly have no outlet. In the rainy season water accumulates in these depressions, causing small lakes or swamps.

The basement system forms a dissected, rolling landscape, classified as **uplands**. These uplands are the remnants of the basement system rocks which have been lowered well below the level of the sub Miocene peneplain. The higher isolated parts of these uplands, with slopes of 30% or more but with a relief of less than 300 m, are called **hills**. The parts of the basement system with steep slopes and a relief of more than 300 m are classified as **mountains**.

Another landform is formed by the remnants of the river terraces which are called **alluvial plain** if they are recognizable as terraces because of their flat topography and their alluvial deposits. Most of the terrace remains are to strongly dissected to be called alluvial plain.

The village of Materi is situated on a flat area built up of basalts and bordered in the West by a small scarp, which is called a **plateau**.

The last landforms distinguished in the research area are the **footslopes**. The footslopes border some of the hills and mountains in the Eastern part of the area and are formed by colluvial materials from these mountains and hills.

3.4. Theories about the origin of volcanic depressions.

After the literature study and the study of the aerial photographs, several theories about the origin of the volcanic depressions were proposed. For each of these theories a list of characteristics of the volcanic depressions were made which should be found in or around the depressions to support or object the theory.

- **Escape of gas.**

  The hot lahars, which are the result of the mingling of nuees ardentes with riverwater, and the hot lahars formed by the uprise of a cumulo dome in a craterlake, contain a lot of gas and vapour in the matrix of mud, ashes and boulders. When the mudflow looses its speed the gas concentrates and escapes to the atmosphere when the lahar deposits.
  This proces should form circular shaped depressions spread over the area in a random way. To support this theory there also must be porous consolidated lahar because not all gas and vapour can escape immediately after deposition of the flow.

- **Faults in lahar or basement system rocks.**

  Due to tension faults in the basement system rocks and in the consolidated lahars, loose surface material disappears and depressions are formed.
  The depressions must be situated in lines with the same direction as the faults and each depression should be orientated in that direction. There must also be a lot of tension faults because there are many depressions in the research area.

- **Subsidence of lahar due to undermining I.**

  Due to subsurface erosion by groundwater caves are formed. When the consolidated lahar above a cave subsides a depression is formed.
  This means that the formation of the volcanic depressions is still going on, and that the lahar is permeable or has a lot of cracks where water can go through. To support this theory, caves must be found and seepage must occur.

- **Subsidence of lahar due to undermining II.**

  In the contact zone of the basement system rocks and the consolidated lahar subsurface erosion occurs due to a different permeability of both types of rocks. As a result of subsidence the volcanic depressions are formed.
  The volcanic depressions should be found only in areas where the lahar is thin and where the caves, formed by the subsurface erosion, can collapse.

- **A swallow hole.**

Another theory about the origin of the volcanic depressions is the disappearance of surface material by way of a hole equivalent to a swallow hole in a karst region.
Apart of a hole in the lowest point of the depressions also subsurface erosion must occur to transport the disappearing material.

- **Concentration of water on the lahar surface.**

After the lahar has been deposited and before consolidation of the lahar, the water escapes out of the matrix to the surface, because its specific gravity is lower than the specific gravity of the solid materials in the lahar. This water concentrates on the still transformable surface of the lahar and little lakes are formed. After consolidation of the lahar and disappearance of the water, depressions stay behind.

- **Differences in texture of the lahar.**

In most of the descriptions of landforms in a lahar landscape, somewhat conical mounds that have been left by coarse debris are described. These mounds, which have heights up to 15 m, are situated in a simular way as the volcanic depressions (see figure 3 and appendix 1).

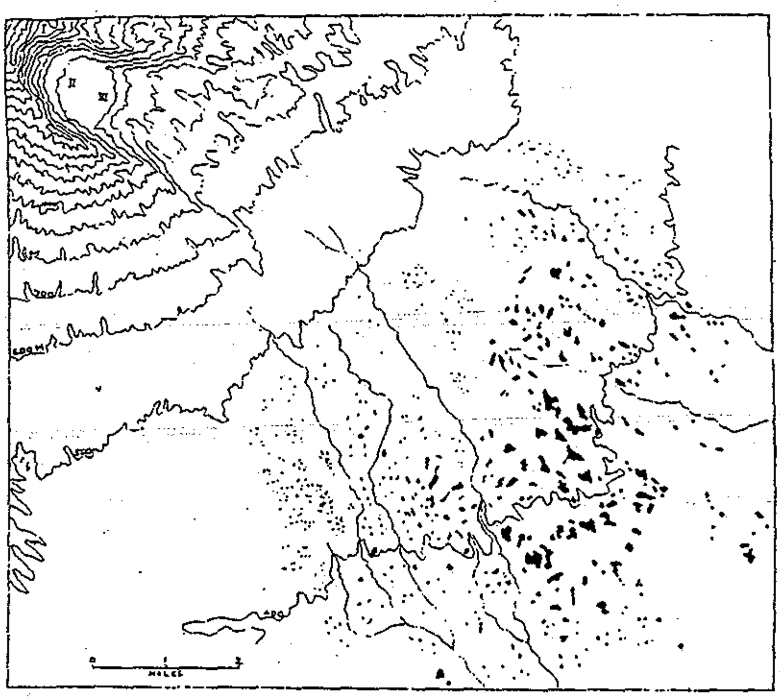


Figure 3 The summit of Galunggung volcano, Java, and the moundfield of Tasikmalaja. (After Escher, 1920)

JAGGER (1930; in COTTON, 1944), who has described the moundfield now existing where the debris of the Bandasian in Japan came to rest, finds that the material has sunk away from its highest level, which corresponded with the tops of the mounds. These mounds and the simular mounds described by BARTHUM (1926; in COTTON, 1944), and GRANGE (1931; in COTTON, 1944), all have hard bouldery cores.
The explanation for the origin of the mounds can also be used for the origin of the volcanic depressions. In contrast with the hard bouldery cores which form the mounds, a lahar could also contain parts with a finer texture and a higher watercontent. When the lahar deposits and the surface sinks to a lower level, these parts should sink to a lower level than its surroundings due to a difference in texture and watercontent.

- **Equivalent of the development of a volcanic sinkhole.**

The origin of the volcanic depressions could be the same as the development of volcanic sinkholes in lavaflows. When a lavaflow cools down a solid crust is formed and beneath this crust the lava still flows. The volcanic sinkholes are formed by subsidence after the removal of fluid lava beneath the solid crust. Also in the lahar a crust can be formed due to evaporation of the water in the upper layers of the lahar, while beneath this crust the lahar still flows. Equivalent to the formation of the sinkholes the volcanic depressions are formed by subsidence.

3.5. Volcanic depressions.

Nearly all the volcanic depressions in the Chuka area are elliptical depressions in consolidated mudflows, called lahars of the Mount Kenya Volcanic Group.
The lahars in the area are slightly porous. Remnants of **small gas bubbles** are present, but the lahars are almost impermeable. No major **cracks** in the lahar have been found.

On the Chuka mapsheet there are about **140** volcanic depressions (see appendix 1), but indications have been found that there have been many more depressions, mainly in the north-west of the mapsheet, which have been cut by a stream by backward erosion and now form a valley upper-end, not recognizable anymore as a volcanic depression. Volcanic depressions have been found which drain into a stream nearby (e.g. the volcanic depressions Karurumo-II, Kasafari-II and Kithangani-I, see appendix 2). Geologically seen it won't take much time, for these depressions to become part of a valley. So the volcanic depressions are **fossile landforms** which slowly disappear. Aerial photographs indicate many places of valley upper-ends being originally volcanic depressions. For a list of the main characteristics of the volcanic depressions, is referred to appendix 2.

The **elliptical shape** of the volcanic depressions was proven by the cross sections and longitudinal sections through the depressions done by hand augering (figure 4, 5, 6 and 7). From these sections can be

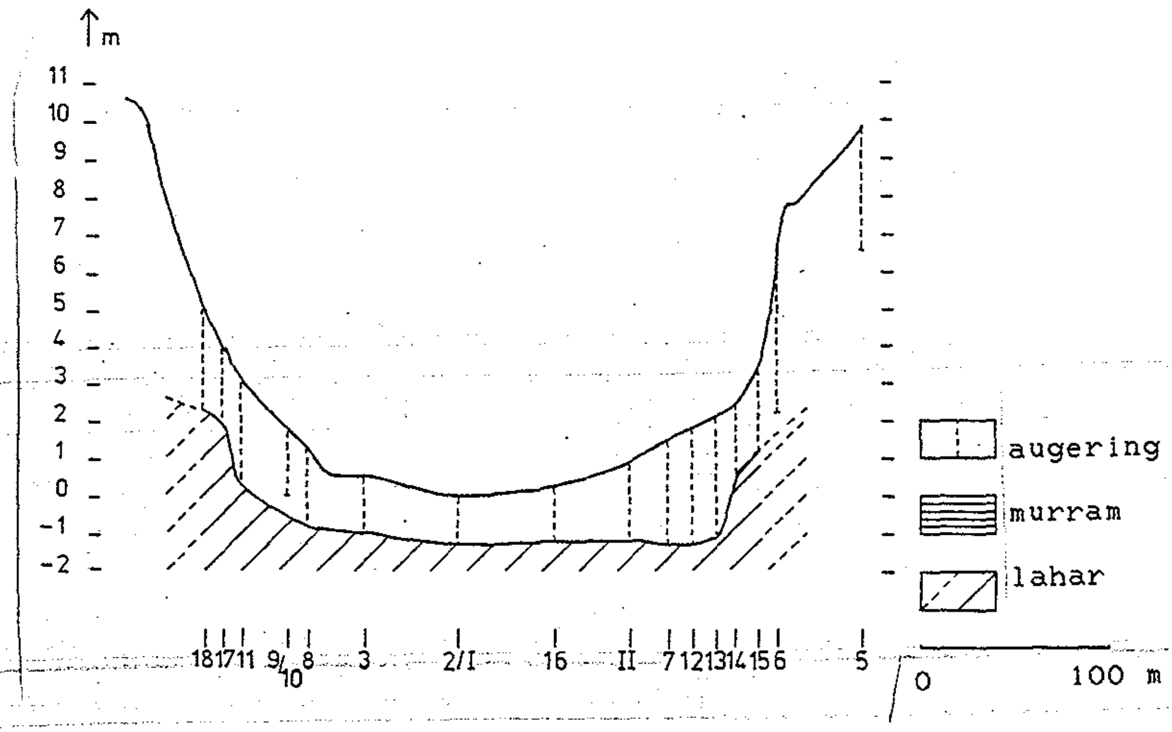


Figure 4 Cross section of the volcanic depression at Kyamboa Pri. School.

Figure 5 Longitudinal section of the volcanic depression at Kyamboa Pri. School.

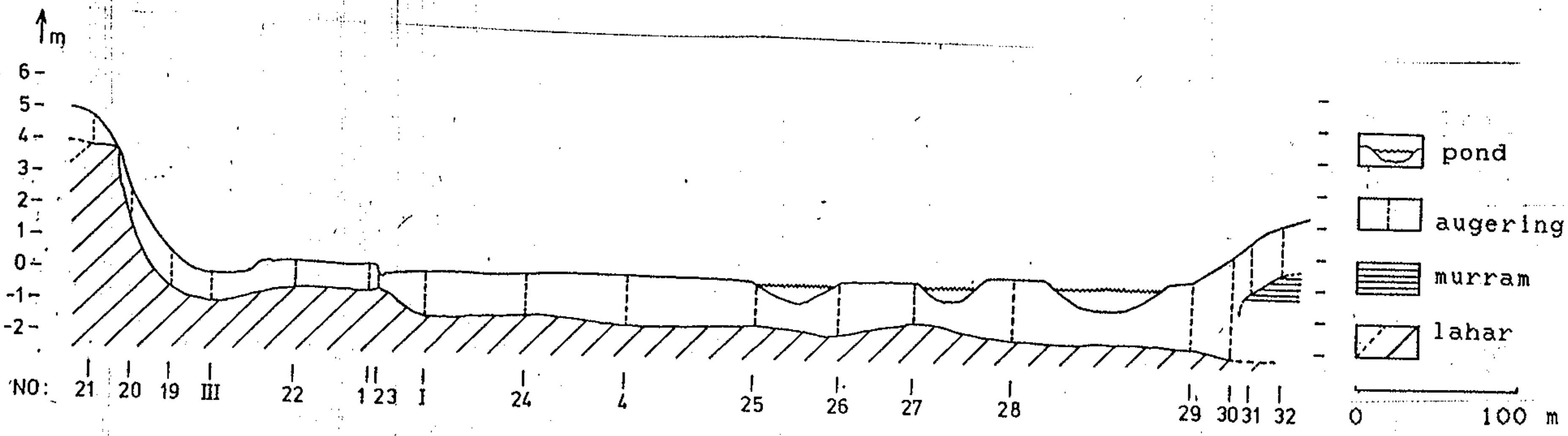
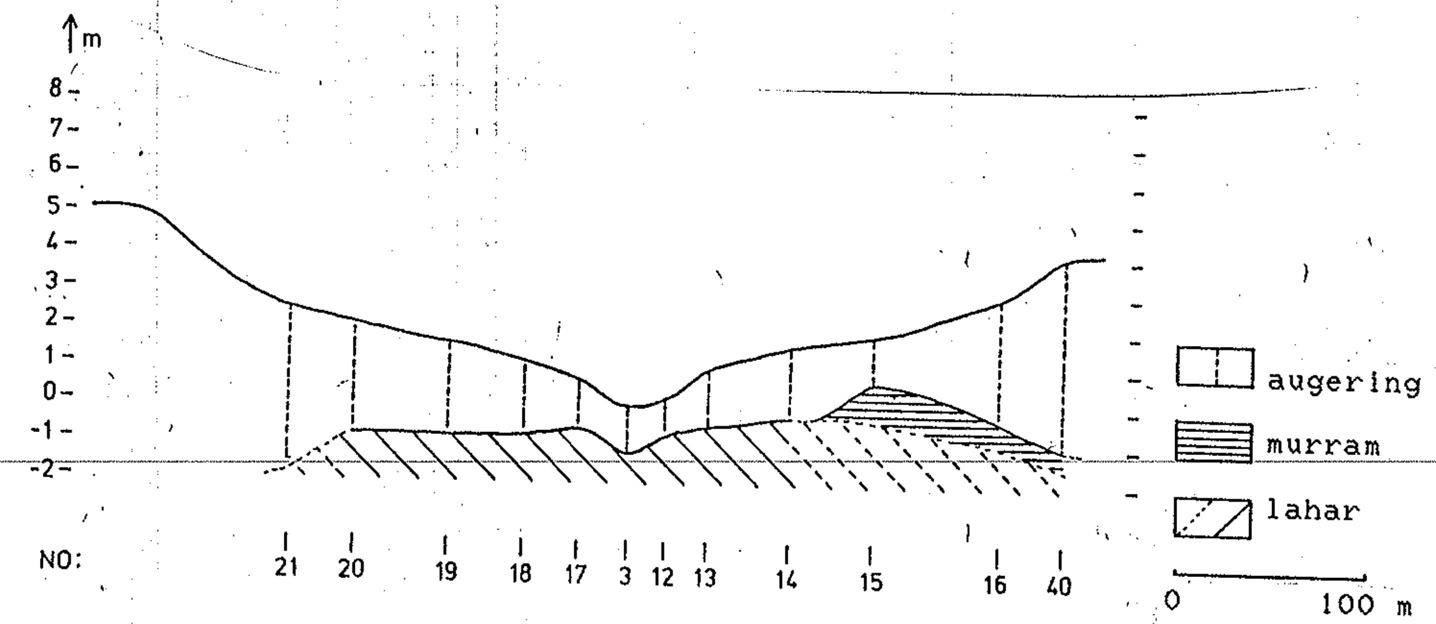


Figure 7 Longitudinal section of the volcanic depression at Kegonge Sec. School.



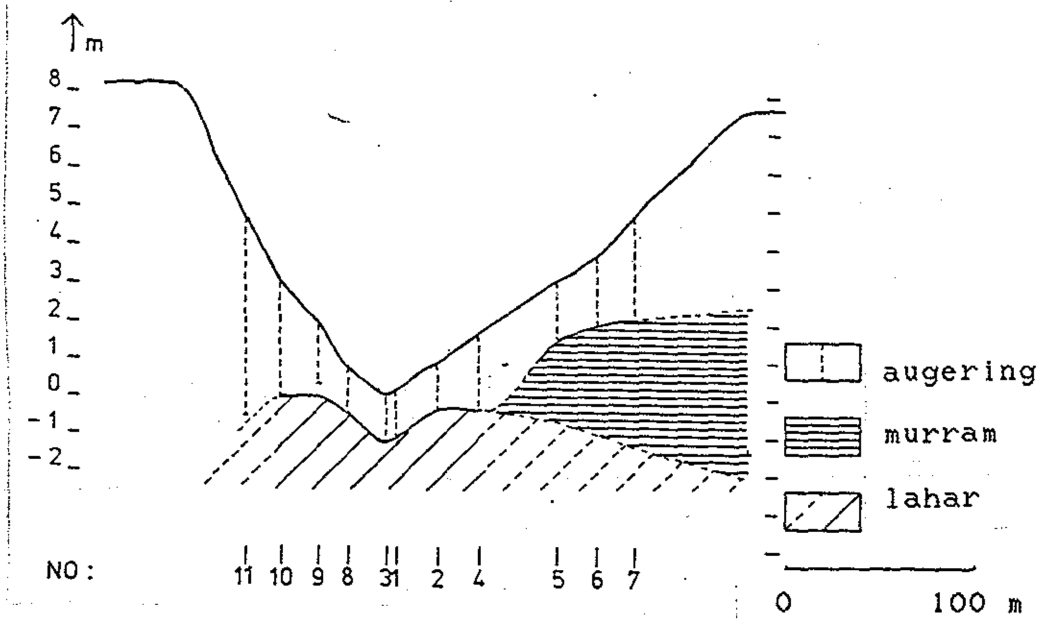


Figure 6 Cross section of the volcanic depression at Kegonge Sec. School.

seen that the slopes in the cross sections are much steeper than the slopes of the longitudinal sections. The goal of every augering has been to reach the lahar. Material has been found which is called **'rotten rock'**, weathered lahar. It consists of white pulverized material. The best places to see it are the 'murram' pit at the Embu - Ishiara road near Ugweri, and several places along the Embu - Chuka road near Kyeni.
Looking at the cross and longitudinal sections it seems that the present surface relief is bigger than the relief of the surface of the rotten rock. In the depressions the soil depth ranges from 100 cm to 150 cm, but on the mountain footridges soil depth can be several meters. Augerings have been done up to 550 cm and still no rotten rock was reached From the augerings can be concluded however, because traces of weathered lahar in the soils and boulders of resistant lahar and phonolite at the surface were found, that originally the present surface of the landscape has been the **surface of the lahar**. The weathering in the middle of the depression has not been so strong as on the edges of the depression and in the surroundings on the mountain footridges and the uplands, possibly due to the different drainage conditions and biological activity.

In the **centre of the volcanic depressions** the surface of the rotten rock is mostly almost flat, or very gently sloping (figure 4 and 5). In the centre of the volcanic depression at Kegonge Sec. School, where seems to be a hole in the middle, a detailed survey has been carried out: 22 augerings and a large profile trench (6 m * 1 m * 1.3 m) in an area of 28 m * 10 m. From the cross section and the longitudinal section (figure 8 and 9) can

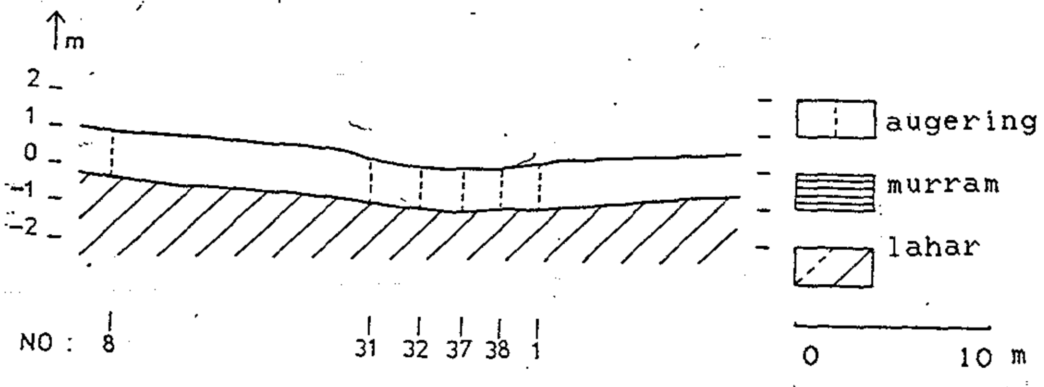


Figure 8 **Detailed cross section of the centre of the volcanic depression at Kegonge Sec. School (incl. profile trench).**

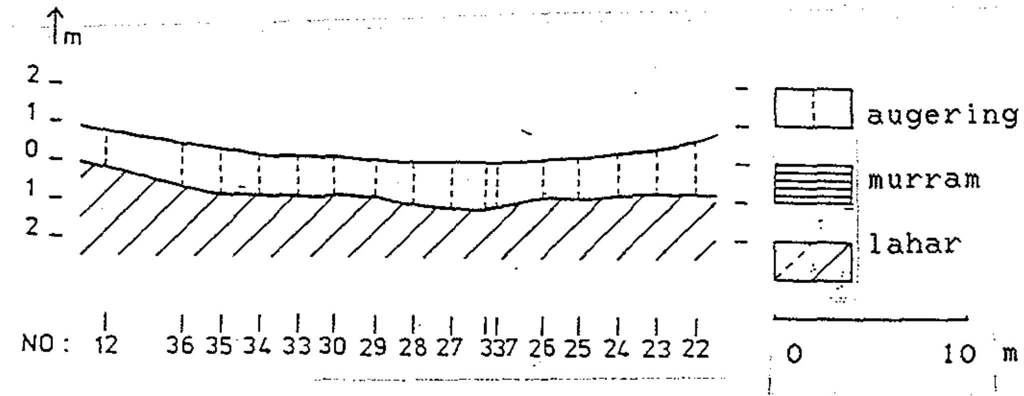


Figure 9 **Detailed longitudinal section of the centre of the volcanic depression at Kegonge Sec. School.**

be seen that the weathered lahar surface, the rotten rock, is very gently sloping towards the lowest point, at augering no. 3, but there is no such thing as **a hole** where water and/or soil material disappears into the deep.

From the sections no evidence is obtained that brings volcanic depressions in relation with **faults**. On the aerial photographs some faults have been recognized, but none of them is connected with the volcanic depressions.

In the field it has been noticed that the volcanic depressions in the Chuka area all have a certain **direction**. The largest axis of the elliptical depressions is directed in a way that seems to have something to do with the direction from where the lahar-flow has come (figure 10).

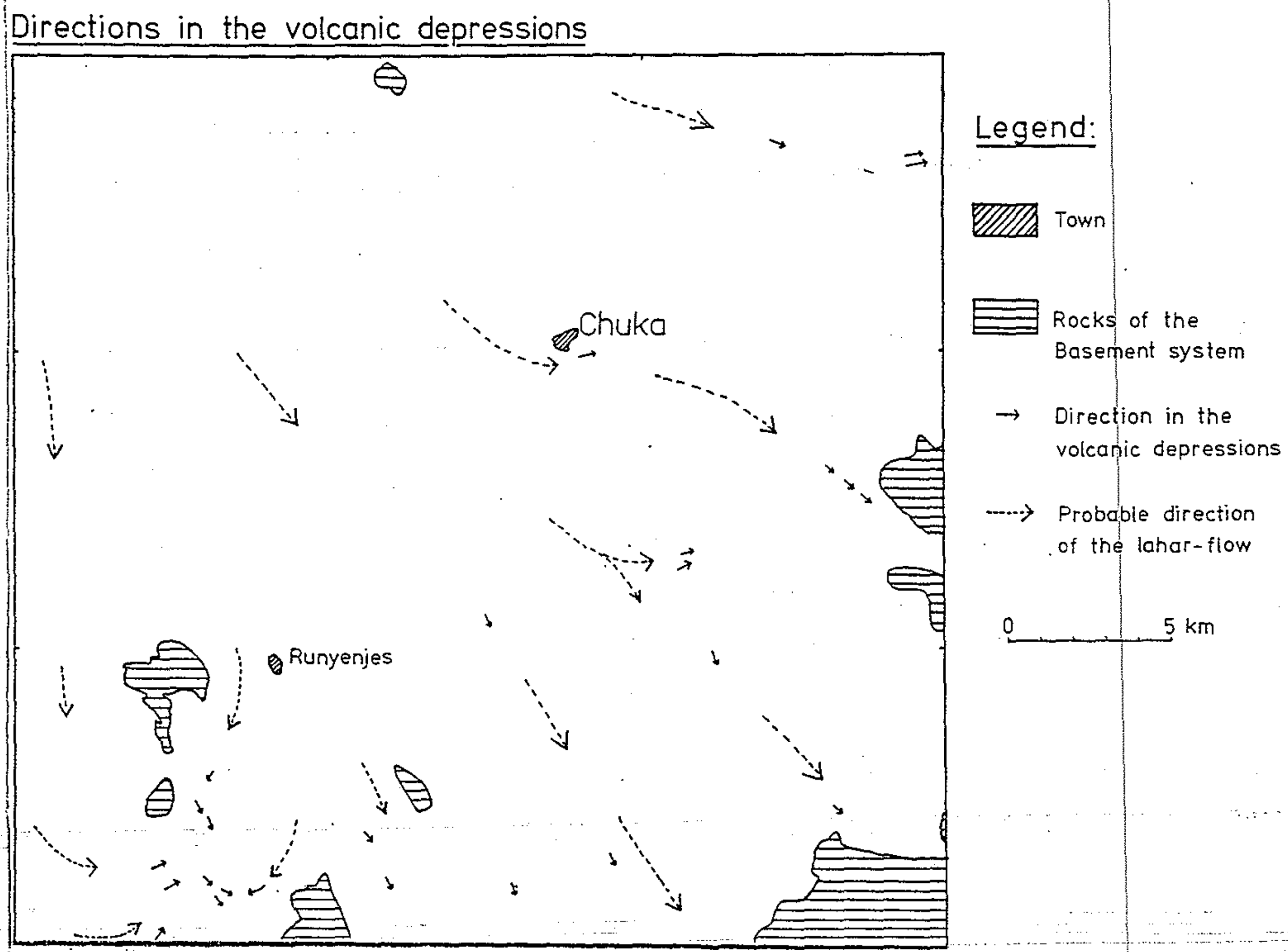


Figure 10 Directions in the volcanic depressions.

In the north of the research area, the volcanic depressions show a west-east direction, and the direction from where the lahar-flow came is the same west-east direction. In the area between Chuka and Runyenjes the depressions have a northwest-southeast direction, also corresponding with the direction from where the lahar came. The volcanic depressions in the south-western part of the research area are a special case. These depressions show various directions, corresponding with the lahars that have flown around the Basement System outcrops (like Karue hill) which are situated there. Southeast of Karue hill a valley has arised because the lahars have not filled up the area completely.

Some of the depressions are connected. For instance the depression at Weru has a subsurface drainage into the nearby depression Kithangani-II. The depression Kamarungu-I is draining its water over the surface into the depression Kamarungu-II. The depression at Kyamboa Prim. School is now a large depression, originating from two depressions, now connected. A cross section has been made that shows the narrow crossing between the two depressions (Figure 11).

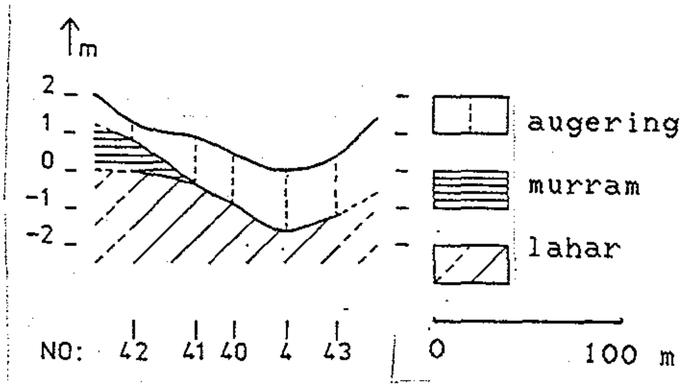


Figure 11 Cross section of the volcanic depression at Kyamboa Pri. School: crossing between the two depressions.

The depression there is only 50 m wide. In the other parts of the depression it is 160 m wide. Also the surface of the rotten rock is not flat but sloping to both sides. It is possible that in future more depressions will become connected.

In many volcanic depressions, the so called **'murram'** appears in the soil. Murram is a local name for very hard iron-manganese concretions. It appears in layers which are as hard as rock, and almost impossible to penetrate by auger (figure 5, 6 and 7). In many depressions it has been noticed that most and hardest murram appears in the north-east to south-east corners of the depressions: e.g. the depressions at Kegonge Sec. School (figure 6 and 7), Kyamboa Pri. School (figure 5), Gikuuri-II, Kanyambora, Karigiri, Karurumo-I and the murram pits at Ugweri and Kasafari (appendix 2). The precence of murram in the soil is due to certain drainage conditions. Formerly the depressions had a subsurface drainage in north-east to south-east direction. Because the present drainage-direction is mostly south-east, it is clear that drainage conditions have changed . It is possible that various overturns, part of tectonic movements in the Pleistocene, played a role. Temporary changes in drainage can have been due to some overturns. More information on the overturns can be found in the geological report of the research area by VELDKAMP & VISSER.

In most of the volcanic depressions a **pond** is formed in the rainy seasons, which varies in depth in the various depressions from 10 cm up to 300 cm. In very wet years, like 1961, the ponds can become even deeper. Shortly after the rains the water-level is dropping very quickly, because the soils at the sides are very permeable. Most of the water flows away underground, over the almost impermeable rotten rock. Most of the water is not disappearing through evaporation, because the electric conductivity, which should be high if there is much evaporation, is very low. In a few depressions there is still a pond, or ponds, in the dry seasons. This is due to almost impermeable heavy clays (mostly classified as Gleysols) which cause the water to stagnate. In the east of the research area the volcanic depressions are drier, and in some cases ponding never occurs, due to a different climate.

3.6. The origin of the volcanic depressions.

By combination of the study of the literature and of the aerial photographs with the field observations, most of the hypothesis (section 3.4.) could be rejected. All will be discussed below.

3.6.1. Rejected hypothesis.

- Escape of gas.

None of the volcanic depressions that have been examined is circular shaped. They all have elliptical forms, accept from a few with irregular shape. Besides the shape of the depressions, they are also too big to be formed by an escape of concentrated gas or vapour. A rough estimation of the volume of the big depression at Kyamboa gives a volume of 700,000 m3. For the depression at Kegonge it is estimated at 200,000 m3. This means that the lahar should have had a very high gas or vapour content. However, only a few small pores and gas bubbles have been found in the consolidated lahar.
Volcanic depressions have been found situated next to each other, which means there should have been two big gas-concentrations close to each other, which seems to be impossible. It would be logical when during the concentration of the gas one big depression is formed.

- Faults in lahar or basement system rocks.

This theory is not very likely because there are a lot of volcanic depressions in the research area . It's unlikely that they all have been formed due to faults. Both on the aerial photographs and in the field, only a few faults have been discovered and most of these are not tension faults but transcurrent faults. In the lahar no faults have been found at all.
Just a few depressions seem to be situated in a line corresponding with the direction of most of the faults (Weru and Kithangani I+II) but in fact they are situated in the direction of the laharflow (Figure 10) like the other volcanic depressions.

- Subsidence of lahar due to undermining I.

The origin of the volcanic depressions due to undermining is also not very likely. No caves or major cracks in the lahar, in which material could disappear, have been found.
Besides a small seepage horizon behind the waterfall in the Gitwa near Kathungu, no seepage was found.
Finally, according to this theory the formation of the volcanic depressions should still be going on. In reality they are disappearing by erosion.

- **Subsidence of lahar due to undermining II.**

According to this theory subsurface erosion occurs in the contact zone of the basement system rocks and the consolidated lahar due to a different permeability of both types of rocks. The erosion should be caused by the lateral movement of groundwater over the basement system rocks.
There is no evidence for the existence of caves in this contact zone. In most of the area, covered by the lahar, the lahar is to thick (up to 100 m) to collapse if there were caves in the contact zone. Only around the basement system outcrops and in the East of the area the lahar is thin enough to collapse but the volcanic depressions are not limited to this areas only. Like the previous theory, according to this theory the development of the volcanic depressions should continue while in fact they are disappearing.

- **A swallow hole.**

The detailed survey of the centre of the volcanic depression at Kegonge Sec. School (Figure 8 and 9) has proved that there is no swallow hole in the middle of the volcanic depressions.

3.6.2. Possible origins.

- **Concentration of water on the lahar surface.**

The proces of water draining out of the mudflow to the surface has been described before by MOHR & VAN BAREN, 1972. The decrease of speed, necessary for the lahar to deposit and the water to drain out, took place because the area where the volcanic depressions are situated is a former plateau. Only the elliptical form of the volcanic depressions cannot be explained well by this theory.

- **Differences in texture of the lahar.**

Everything seems in favour of this theory, but there was no possibility to examine the lahar below and besides the volcanic depressions on its texture due to lack of time and especially material (no drillings could be made in unweathered lahar). Also no useful exposure has been found to examine the possible difference in texture.
What supports the theory is the location of the volcanic depressions, which are situated in the same pattern as the mounds, described in section 3.4. (Figure 3 and appendix 1), and the elliptical shape of the depressions which resembles the conical forms of the mounds described in the literature.

- **Equivalent of the development of a volcanic sinkhole.**

The direction of the volcanic depressions, the same as the direction of the lahars, supports this theory. However, no evidence has been found about the existence of holes or tunnels in the lahar that didn't collapse. Also there is no evidence that the lahar has formed a solid crust, which is strong enough to endure for a while. It may be possible that depressions were formed because the crust was pulled down smoothly due to pressure-differences below the crust.

- **Subsidence due to the presence of ice.**

This theory is based on recent observations of volcanic eruptions. It is known that large pieces of ice (parts of glaciers) are carried along with mudstreams (KROONENBERG 1986, personal communication). Mount Kenya has at the moment a snowcover above 4900 m. and several glaciers. It is known that there has been more snow and ice on Mount Kenya, because the volume of ice is decreasing.
It is thought that during the time when the lahar was formed large parts of the glaciers broke off and were carried along with it, either upon or within the lahar. This ice melted after some time when the lahar had - completely or almost - stopped moving. This resulted in a subsidence of the lahar and depressions were formed. The elliptic shape of the depressions could have been developed because the pieces of ice had such a shape. It is likely that most pieces of ice were carried in the lahar with their longest axis in the direction of the flow.

3.7. Development of the volcanic depressions.

The weathering of the lahar in the volcanic depressions has not been homogeneous in all parts of the depressions.
The schematic development of the volcanic depressions is shown in figure 12, derived from the longitudinal and cross sections (figure 4,5,6 and 7) and augerings in the other volcanic depressions (appendix 2).

Starting point of the weathering of the volcanic depressions is shown in figure 12a. The volcanic depressions, formed by one of the previous theories (section 3.4. and 3.6.), consist only of a mixture of volcanic ash, mud and phonolite that has been consolidated to a hard rock.

Figures 12b.1 and 12b.2 are showing the next stages in the development of the volcanic depressions. The upper layers of the consolidated are weathered, in figure 12b.1 can be seen that the middle of the volcanic depressions has not been weathered as strong as the edges and the surroundings of the depressions. This is possibly due to the different drainage conditions and biological activity in the very poorly drained centres of the depressions.
Figure 12b.2 shows the weathering that occurs in some of the volcanic depressions. In this situation also in the highest edge of the depression, the left side of the figure, the weathering seems to have been less strong. In these cases very resistent rock, with a high phonolite content, can always be found on this side of the depressions.

The final stage of the development is shown in figure 12c. The surface of the rotten rock is slightly inverse to the relief, due to the difference in weathering in the still poortly drained middle of the volcanic depression. It is not very likely that this inversion of the rotten rock surface is going to increase much more, because due to the permeability of the soil the water in the middle of the volcanic depression can drain quickly over the almost impermeable rotten rock.

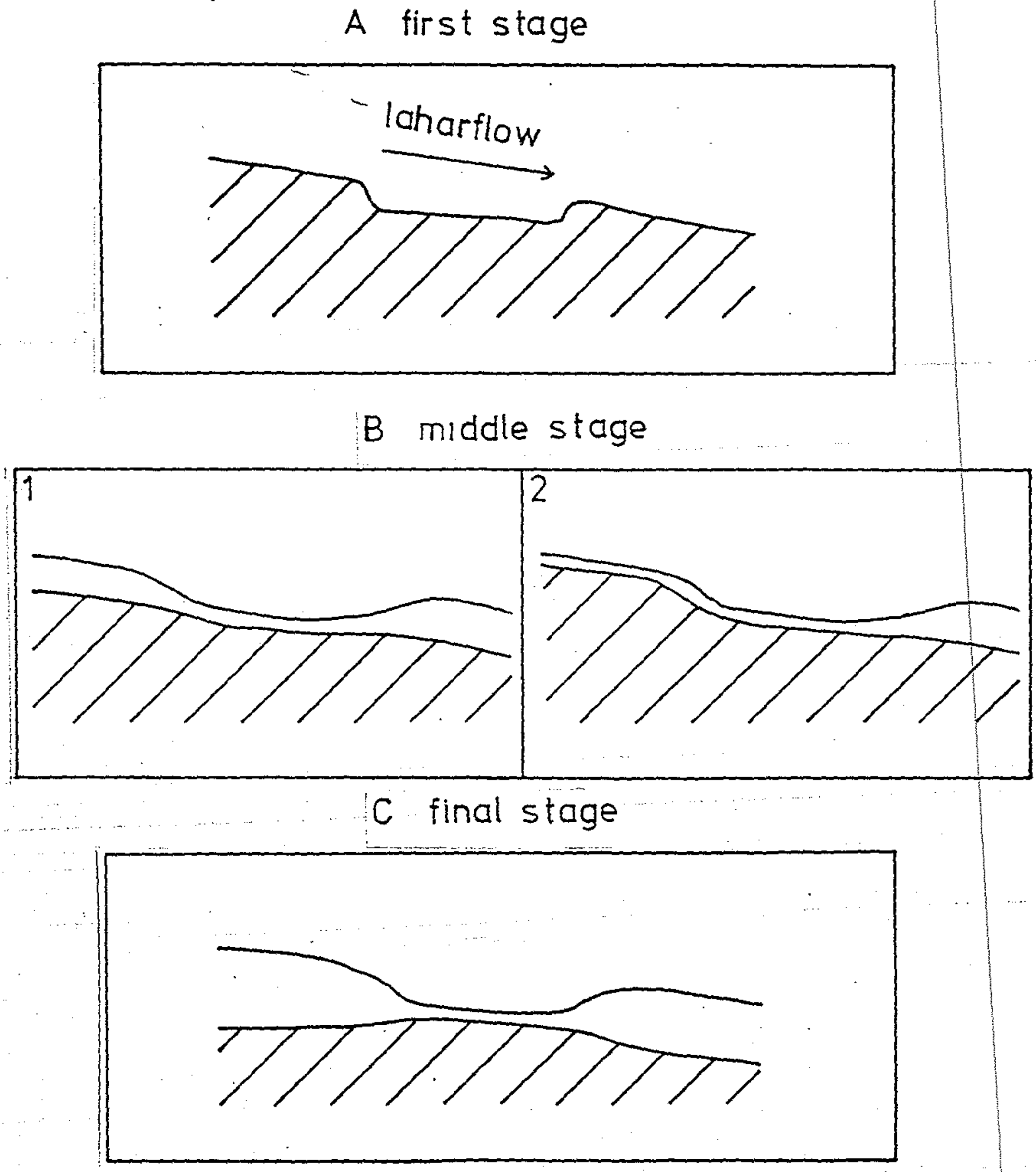


Figure 12 Schematic development of the volcanic depressions.

Chapter 4. CLIMATE.

4.1. Rainfall.

The research area is situated at the windward side of Mt. Kenya.

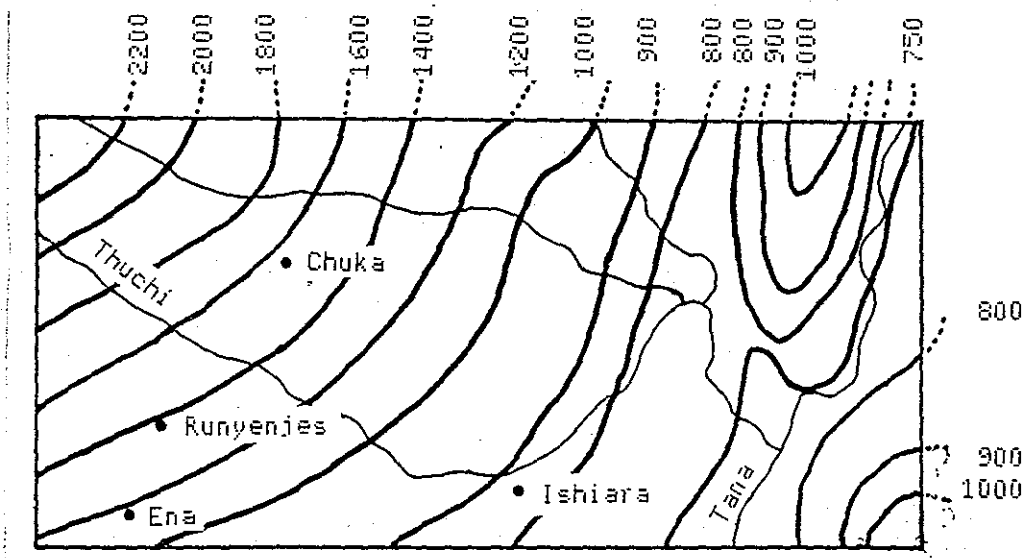


Figure 13 The average annual rainfall of the research area (in mm)
(source: Jaetzold, 1983)

The rainfall varies from an average annual rainfall of 2200 mm in the north-west, at an altitude of 2000 m, to less than 750 mm near the Tana river, at 700 m, in the eastern part of the area (see figure 13). The variation in rainfall is mainly due to the variation in altitude which, in general, increases from east to west, but also the water recycling effect of Mt. Kenya forest. The influence of the altitude on the amount of rainfall can also be seen in the eastern part of the area. The Nyamatu and Kibiro mountainous areas receive an average annual rainfall of more than 900 mm while the surrounding area receives not more than 750-800 mm of rainfall per year. In the area where the volcanic depressions are situated the annual rainfall varies from 1550 mm to 1000 mm, the stations shown at figure 14 represent the eastern and western part of this area.

Most of the rainfall is concentrated in two rainy seasons. The first rainy season is from March to May with most rain falling in April. The second rainy season lasts from October to December with most rain falling in November.
The dry seasons can be divided in a short dry season during January and February and a longer dry season lasting from June to September. During these dry seasons still some rain falls in the

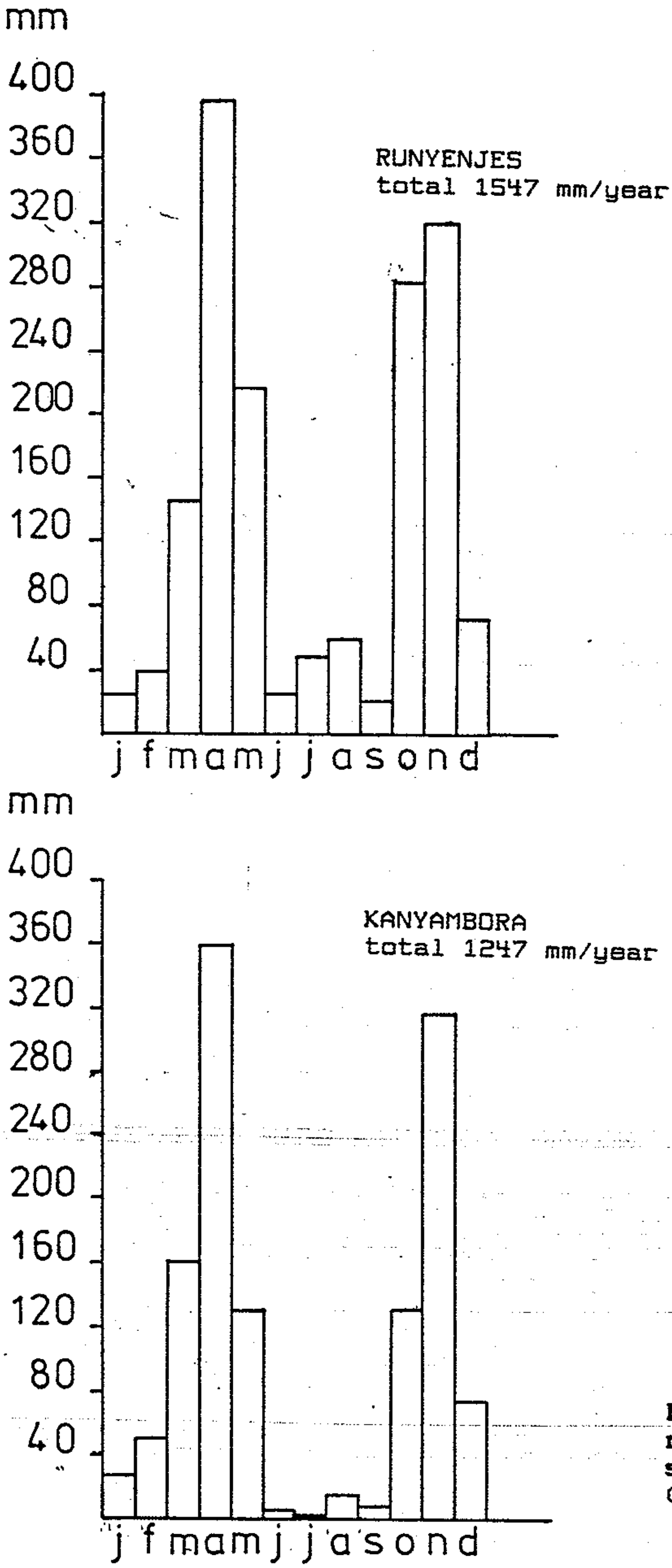


Figure 14 Average rainfall-data of two stations in the area (source: Jaetzold 1983)

western half of the area, in contrast with the eastern part of the area where during the long dry season no rain falls. This contrast even exists in the small area where the volcanic depressions are situated (figure 14).
Most of the precipitation, during all seasons, is in short showers with high intensities.

Of great importance for the agricultural production is the reliability of the rainfall. The reliability of the rainfall in the research area is shown in figure 15 and figure 16. These figures give the amount of rain in mm which is exceeded in at least 6 out of 10 years. The thick lines connect the points with the same 60% reliability of rainfall.

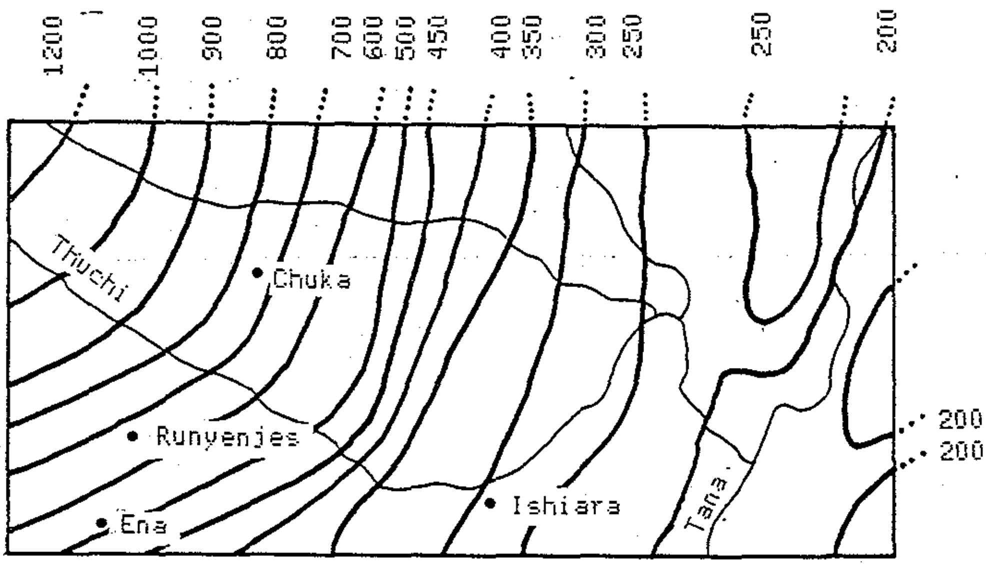


Figure 15 60% reliability of rainfall in agrohumid period of first rainy season
(source: Jaetzold, 1983)

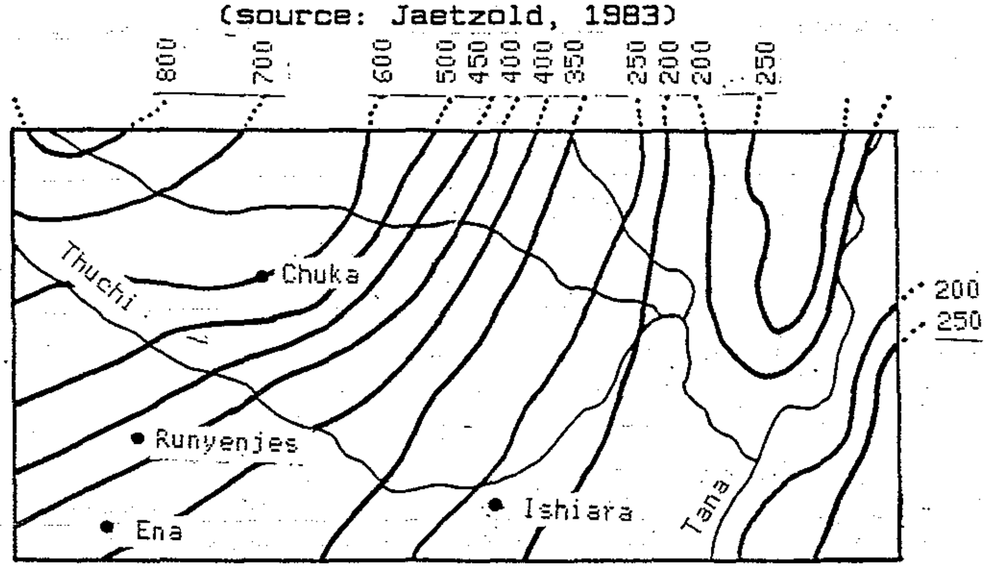
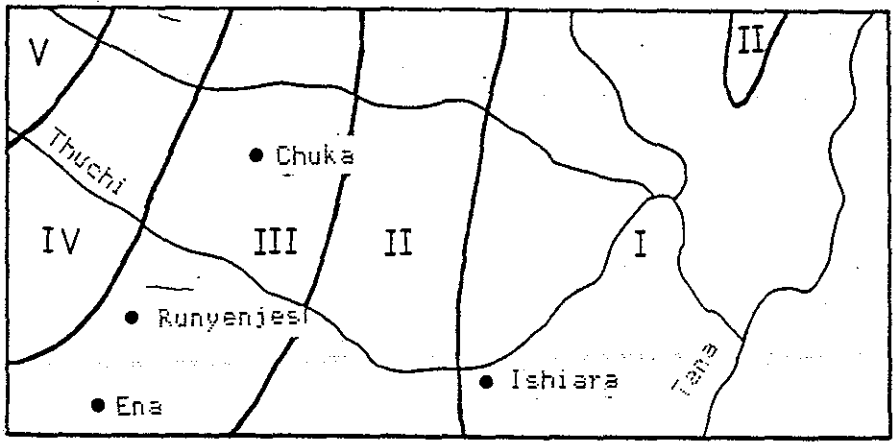


Figure 16 60% reliability of rainfall in agrohumid period of second rainy season
(source: Jaetzold, 1983)

For the area with the volcanic depressions the 60% reliability of rainfall varies from 1150 mm to 650 mm.

4.2. Temperature.

Like the annual rainfall, the mean annual temperature zones show an east-west tendency (see fig. 17), the lower east part of the area is relatively warm and the higher western part is cooler. The mean annual temperature varies from 16-18 oC in the northwest part of the area to 24-30 oC in the eastern part. The volcanic depressions are situated in the area with annual temperatures that vary from 20 to 24 oC. The mean maximum temperature in this area varies from 26 to 30 oC and the mean minimum temperature varies from 14 to 18 oC.



zone	mean annual temperature oC	mean maximum temperature oC	mean minimum temperature oC
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

Figure 17 Temperature zones (source: Braun, 1982)

4.3. Potential evapotranspiration.

According to Braun 1982, the average annual potential evapotranspiration (Eo) varies from 1200 to 2000 mm. in the north-west of the area to 1650 to 2300 mm in the east of the research area (see fig. 21).
The ratio of the average annual rainfall (r) and the average annual potential evapotranspiration varies from 80% in the north-west to 25-40% in the east of the area. Higher ratios in the east appear in the Nyambatu and Kibiro mountainous area.

Chapter 5. SOILS.

5.1. Soils in the volcanic depressions.

The soils in the volcanic depressions and on their slopes are strongly related with the physiography.
All soils are developed on consolidated lahars, which are weathered to soils with a clayey texture. On the reconnaissance soil map of the research area these soils are not specified. They are in one mapping unit: the **bottomlands**. In the semi-detailed surveys the soils have the code BV, which means soils of the bottomlands developed on consolidated lahars. The variety of soils does not appear on the map however.
Because of the concave relief of these volcanic depressions the soils are strongly influenced by the groundwater. It depends on the size of the depression, on the drainage-class and on the length of the ponding period which type of soil is developed. For a map of the soils in the volcanic depressions see figure 18. There is a general soil-sequence in the area from the bottoms of the volcanic depressions to the upper-slopes, the transition to the physiographic units mountain footridges or uplands:

Soil type	Bottom of depression	Lower to middle slope	Upper slope
- pellic Vertisols	x		
- vertic Gleysols	x		
- dystric/humic Gleysols	x		
- gleyic Acrisols	x	x	
- ferric Acrisols	x	x	
- chromic/humic/orthic Acrisols		x	x
- dystric/humic Nitosols			x

For the description of the soil units see appendix 3.

Pellic Vertisols, soils with a clayey texture, are developed in big volcanic depressions, ponded in two periods of the year. Because the groundwater disappears quickly after the rainy seasons, the soil dries out and large cracks are formed. These cracks are filled up with top-soil material or surface material. When the soil turns wet again, it expands, and the specific 'gilgai'-relief (micro-basins and knolls) is formed.
When the groundwater-level does not drop below 100-130 cm, only vertic properties can be developed, because the soil does not dry enough to form large cracks. In this case the soils are **vertic Gleysols**.
In smaller depressions, or in depressions which do not dry out, common soil-types are **dystric** or **humic Gleysols**. All these soils have a high lutum-content (about 80%) throughout the profile and have a reduced B-horizon. They have hydromorphic properties within 50 cm.
The most common soils on the bottoms of the volcanic depressions

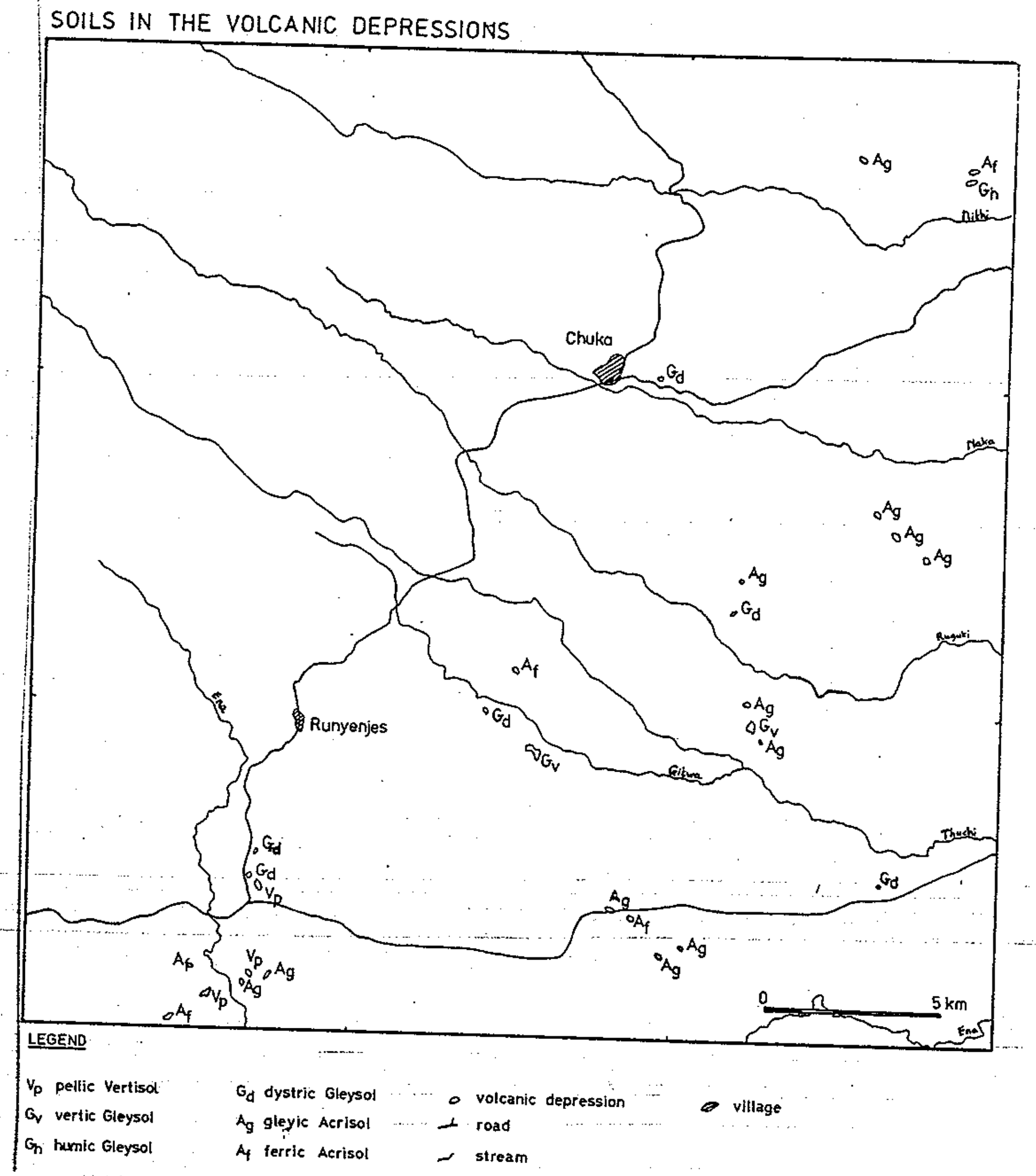


Figure 18 Soils in the volcanic depressions.

are **gleyic Acrisols**, soils with hydromorphic properties within 50 cm and an argillic B-horizon. These soils have a lighter texture than the previous soils. These soils appear on the bottoms of the volcanic depressions as well as on the lower slopes of the depressions. They are a transition to the soils on the slopes. They appear in depressions which are ponded frequently, and in depressions which are occasionally or rarely ponded. Due to their position, on the sides of the depressions, some gleyic Acrisols contain 'murram', because of the varying groundwater table.
The gleyic Acrisols change into **Ferric Acrisols**, soils with an argillic B-horizon and ferric properties: many coarse mottles and/or discrete nodules. Most murram is found in these soils, sometimes in thick layers starting within 100 cm. These soils are situated on the lower and middle slopes of the volcanic depressions. In depressions with little or no water in the rainy seasons, ferric Acrisols are found on the bottom of the depressions. In the eastern part of the Chuka map-sheet, with drier conditions, a ferric Acrisol has been found on the upper-slope of a depression (Kithangani-I). In these soils the groundwater level is mostly very deep.
On the middle and upper slopes, soils are developed which don't have hydromorphic properties or ferric properties. These are the **chromic, humic** and **orthic Acrisols**, soils mostly with a top soil of silty clay, and a sub soil of clay. Within 150 cm. the clay-content decreases. These soils can be the transition to the Nitosols, like in the western and northern part of the Chuka map-sheet, or can be the present final stage of soil-development, like in the southeastern part of the Chuka map-sheet (Kanyambora, Kamarungu-I & II). They are not ponded, and no waterlogging occurs,
In the biggest part of the Chuka map-sheet extremely deep, well drained, dark reddish brown soils are the main soils. Also on the upper-slopes of the volcanic depressions they are the main soils. They are classified as **dystric** and **humic Nitosols** (Kenyan concept: Nitisols). They have a deeply stretched clay bulge (argillic B horizon), but the increase in clay percentage is only gradual from the A to the B horizon, and there is no or only a slight decrease from the B to the C horizon. The term 'nitic' B horizon has been proposed on the basis of the available soil information mainly from Kenya (SIDERIUS & VAN DER POUW, 1980). The soils have favourable physical properties, such as a high aggregate stability.
On a few places in the south-eastern part of the Chuka map-sheet **humic** or **chromic Cambisols** are found on the upper slopes of the volcanic depressions. Thesesoils are lacking claytransport, and only have an altered B horizon (cambic B horizon), lacking properties of other diagnostic B horizons.

In the volcanic depressions at Kyamboa Prim. School and Kegonge Sec. School detailed soil maps have been made (figure 19 and 20), mainly on the basis of the augerings which have been done for the geological survey (see chapter 3). For maps of the augerings in these two depressions see appendix 4 and 5.
From figure 19 it is clear that the depression at Kyamboa

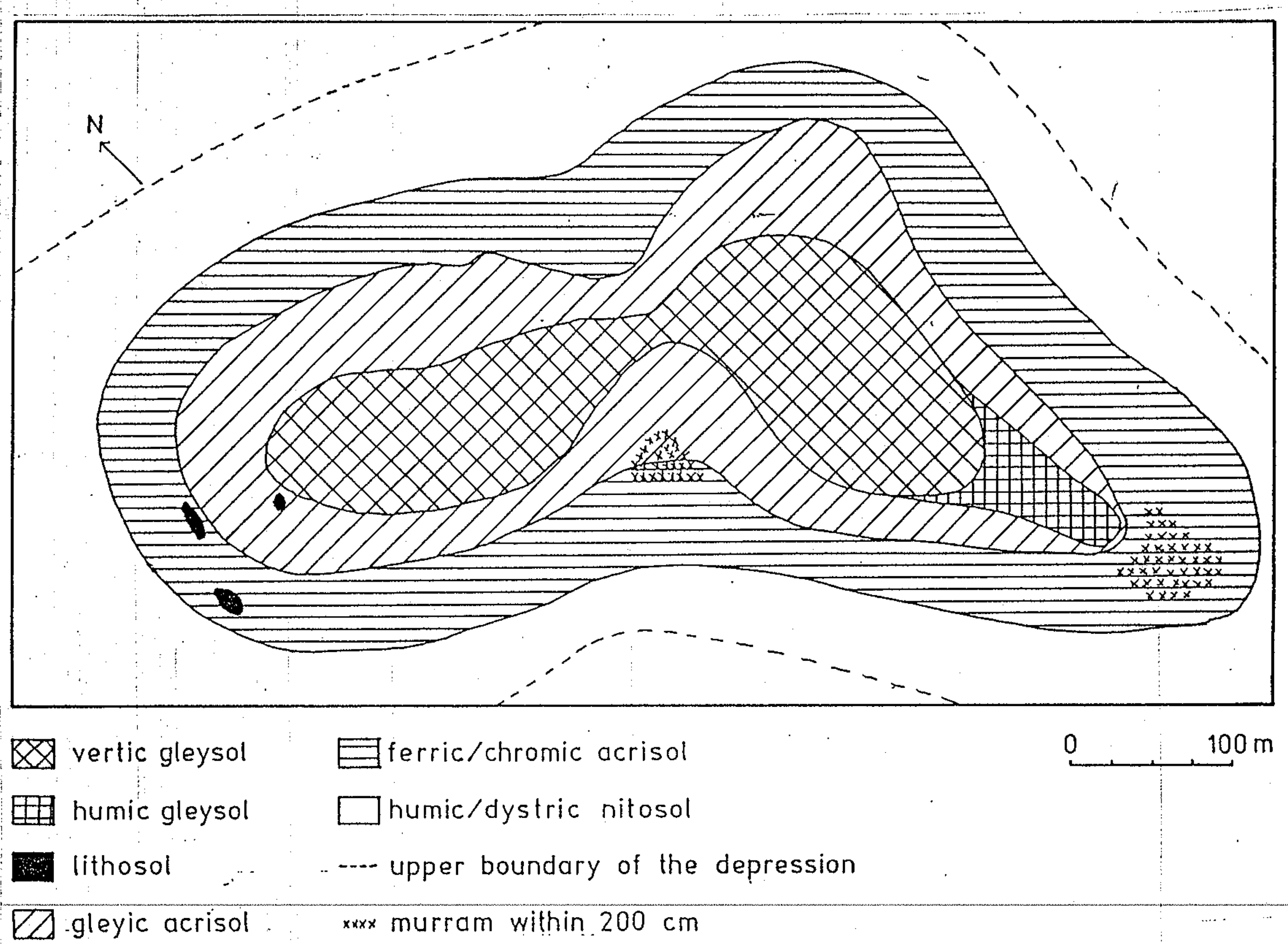


Figure 19 Detailed soil map of the volcanic depression at Kyamboa Pr1. School.

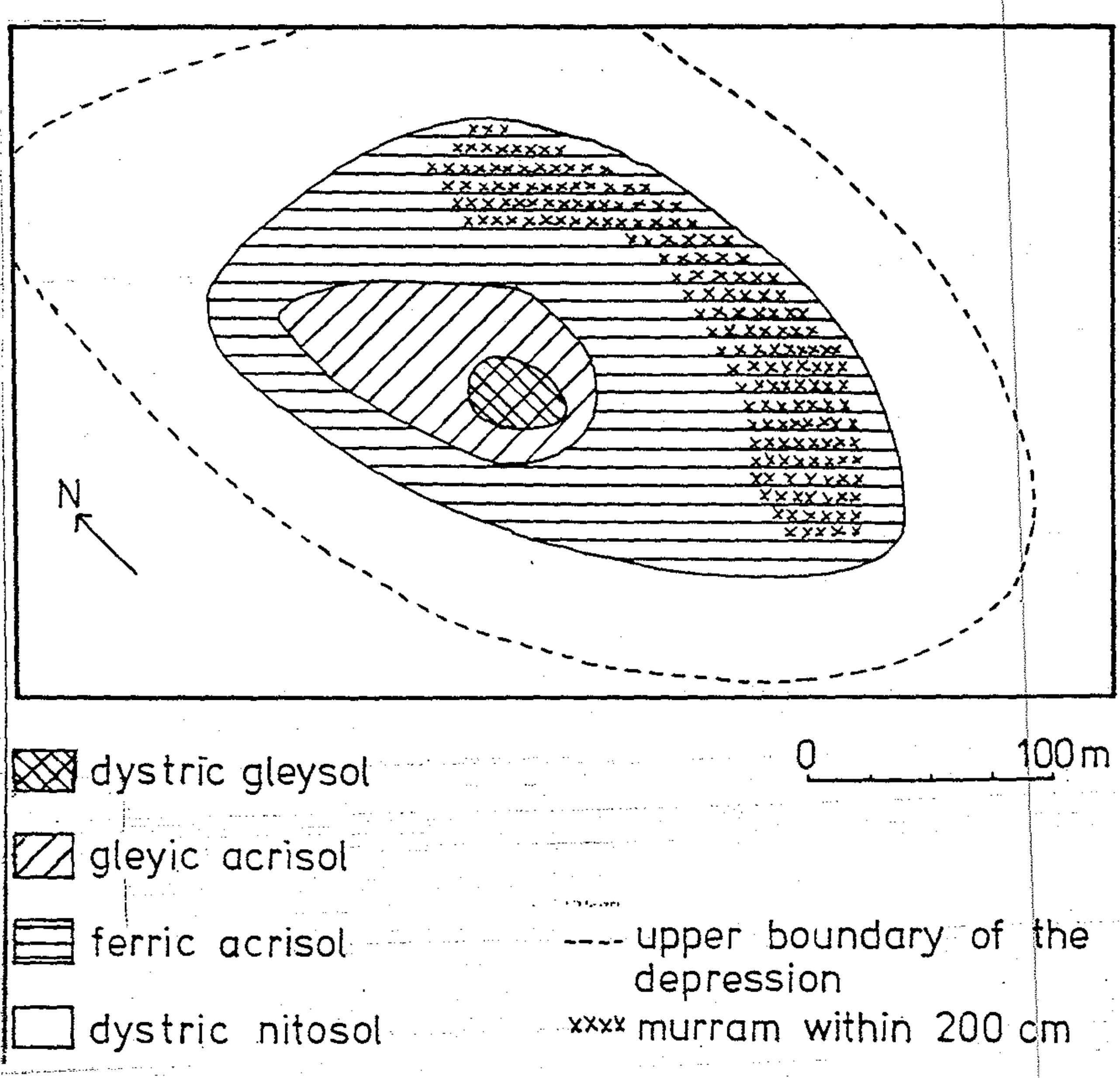


Figure 20 **Detailed soil map of the volcanic depression at Kegonge Sec. School.**

consists of two depressions, now connected. The narrow crossing also is reflected in the soils. Only a small part there consists of Gleysols. Murram has been found only in the south-east corner and below the crossing of the two depressions. In the north-east corner no augerings have been done, so there is no information about the presence of murram there. In this depression still ponds exist at the end of the dry season, but by than they have almost dried up. The groundwater-level was about 110 cm below the surface (just before the rainy season) so only vertic properties could be developed.
From figure 20 the existence of murram in the nort-east to south-east corner of the depression is very clear. On the opposite side no murram has been found. That side has steeper slopes which is reflected in the soils. Like in the depression of Kyamboa, there is a soil-sequence Gleysol - gleyic Acrisol - ferric Acrisol - dystric Nitosol.

5.2 Chemical data of the soils.

In the volcanic depressions are two profile pits, from which samples have been analysed in the National Agricultural Laboratories in Nairobi. In eight other volcanic depressions, soil samples were collected which were analysed on soil reaction (pH) and electric conductivity (EC).

PROFILE DESCRIPTION NO. 30

Date/ season	: 21/06/85; end rainy season
Sheet-observation no	: 122/3-30
Coordinates	: 3543 E, 99505 N
Elevation	: 1170 m
Author	: W. Simons
Soil mapping unit	: BV
Soil classification -FAO	: dystric GLEYSOL
- Soil Taxonomy	: haplaquept
Geology	: Mt. Kenya Volcanic Group
Parent material	: consolidated lahars
Physiography	: Bottomland
Macro-relief	: undulating
Slope (length, shape and pattern)	: complex
Slope gradient	: 1%
Position on slope	: -
Meso- and micro-relief	: nil
Vegetation/ landuse	: pasture, used for grazing
Erosion	: nil
Rock outcrops	: nil
Surface stoniness	: nil
Overwash	: nil
Surface runoff	: ponded
Surface sealing/crusting/cracking	: strong crusting, 5 mm thick
Drainage class	: poorly drained
Flooding	: frequent and regular
Groundwater level (actual)	: temporary shallow
Presence of salts/ alkali	: nil

Soilfauna influences : limited
Expected rooting depth : moderately deep

Horizons:

Ah 0-8 cm — Black (7.5YR 2/0) when moist; clay; strong fine subangular blocky structure; firm when moist, slightly sticky and plastic when wet; common biopores; common fine roots; clear and wavy transition to:

Cg 8-25/45 cm — Dark grayish brown (10YR 4/2) when moist; clay; many fine prominent yellowish red mottles; strong coarse subangular blocky structure; firm when moist, slightly sticky and plastic when wet; common biopores; common medium and fine roots; clear and smooth transition to:

Cgcs 25/45-65 cm — Dark grayish brown (10YR 4/2) when moist; very gravelly clay; may fine prominent red mottles; strong coarse subangular blocky structure; firm when moist, slightly sticky and plastic when wet; very frequent spherical iron concretions, 4-20 mm; few biopores; common fine roots; clear and smooth transition to:

G 65-90+ cm — Dark grayish brown (10YR 4/2) when moist; clay; strongly coherent porous massive structure; firm when moist, slightly sticky and plastic when wet; very few biopores; no roots.

Remark: ironstone layer at 30-35 cm.

Soil test report:

Depth in cm	0-8	8-25/45	25/45-65	65-90
Gravel %				
Sand %	23	15	33	13
Silt %	25	15	9	7
Clay %	52	70	58	80
Texture class	C	C	C	C
pH-H20 1:2.5 suspension	5.1	5.0	5.2	6.1
pH-KCl 1:2.5 "	3.3	3.6	4.1	4.9
EC (ms/cm) 1:2.5	0.05	0.07	0.05	0.18
C %	2.16	0.89	0.63	0.57
CEC (me/100g)	24.6	18.5	14.2	10.2
exch. Ca (me/100g)	2.1	1.9	1.7	3.5
exch. Mg (me/100g)	0.7	0.6	0.7	2.5
exch. K (me/100g)	0.4	0.2	0.2	0.2
exch. Na (me/100g)	0.2	0.2	0.2	0.2

sum cations (me/100g)	3.3	2.8	2.7	6.3
Bas. sat. (%)	13	15	18	62
Qualitative CaCO3	+	+	+	+

Depth in cm	0-20
pH	5.6
total Na (me/100g)	0.70
total K (me/100g)	0.32
total Ca (me/100g)	2.4
total Mg (me/100g)	0.7
total Mn (me/100g)	1.40
available P mg/kg	6
N (%)	0.18
C (%)	1.9
Hp (me/100g)	-

remarks: toxicities bracketed, deficiencies underlined
Hp = exchangeable acidity

PROFILE DESCRIPTION NO. 17

Date/ season	: 01/06/85; end rainy season
Sheet-observation no	: 122/3-17
Coordinates	: 3590 E, 99537 N
Elevation	:
Authors	: I. Aalders & H. Nobbe, J. van Hees & A. de Roo
Soil mapping unit	: BV
Soil classification -FAO	: gleyic Acrisol
- Soil Taxonomy	:
Geology	: Mt. Kenya Volcanic Group
Parent material	: consolidated lahars
Physiography	: Bottomland
Macro-relief	: flat
Slope (length, shape and pattern)	: -
Slope gradient	: 2%
Position on slope	: -
Meso- and micro-relief	: nil
Vegetation/ landuse	: waterplants/ -
Erosion	: very slight sheet erosion
Rock outcrops	: nil
Surface stoniness	: nil
Overwash	: nil
Surface runoff	: very slow
Surface sealing/crusting/cracking	: nil
Drainage class	: imperfectly
Flooding	: occasionally
Groundwater level (actual)	: temporary moderately deep
Presence of salts/ alkali	: nil
Soilfauna influences	: limited
Expected rooting depth	: very deep

Horizons:

AH1 0-35/40 cm Very dark reddish brown (5YR 2/4) when moist; clay; moderate fine granular structure; very friable when moist, slightly sticky and slightly plastic when wet; many biopores; gradual and wavy transition to:

AH2 35/40-65/70 cm Dark brown (7.5YR 3/2) when moist; clay; moderate fine subangular blocky and granular structure; many medium distinct black mottling and common coarse prominent orange mottling (5YR 6/8); very friable when moist, sticky and slightly plastic when wet; many biopores; frequent, medium roots; gradual and wavy transition to

Bt 65/70-105/110 cm Dark brown (7.5YR 3/4) when moist; clay, with fragments weathered rock; common medium distinct black, red and yellow mottles; moderate fine subangular blocky structure; patchy thin manganese cutans; friable when moist, slightly sticky and slightly plastic when wet; many biopores; very few coarse and common fine roots; gradual and wavy transition to:

Btg 105/110-130+ cm Brown (7.5YR 3/4) when moist; clay; frequent little black concretions; strong medium angular blocky structure; broken thin manganese cutans; very friable when moist, sticky and slightly plastic when wet; very few coarse and common fine roots.

Soil test report:

Depth in cm	0-35/40	35/40-65/70	65/70-105/110	105/110-130+
Gravel %				
Sand %	6	12	8	12
Silt %	36	24	20	14
Clay %	58	64	72	74
Texture class	C	C	C	C
pH-H2O 1:2.5	5.0	5.0	4.9	5.0
pH-KCl 1:2.5	4.4	4.8	4.3	4.1
EC (ms/cm) 1:2.5	0.04	0.04	0.04	0.03
C %	1.6	1.2	1.1	1.0
CEC (me/100g)	24.7	23.5	18.7	16.5
exch. Ca (me/100g)	5.0	3.2	2.0	1.3
exch. Mg (me/100g)	1.0	1.0	0.5	0.3
exch. K (me/100g)	0.2	0.1	0.1	0.1
exch. Na (me/100g)	0.1	0.2	0.1	0.1
TEB (me/100g)	6.3	4.5	2.7	1.8
Bas. sat. (%)	25	19	14	11
Qualitative CaCO3	+	+	+	+

Depth in cm	0-20
pH	5.2
total Na (me/100g)	0.2
total K (me/100g)	<u>0.25</u>
total Ca (me/100g)	5.2
total Mg (me/100g)	1.4
total Mn (me/100g)	0.80
available P (ppm)	38
N (%)	0.10
C (%)	1.37
Hp (m.e. %)	0.5

remarks: toxicities bracketed, deficiencies underlined
Hp = exchangeable acidity ; TEB = total exch. bases

SOIL SAMPLES.

Location	depth (cm)	pH-H2O	EC (mV/cm)	Soil
Mumbuni-I	0-20	4.8	94	ferric Acrisol
	40-60	4.5	107	
	100-110	4.6	103	
Karigiri	0-20	4.5	110	gleyic Acrisol
	40-60	7.4	43	
	100-110	8.2	87	
Kiamugi	0-20	4.7	99	dystric Gleysol
	40-60	4.5	108	
	100-110	5.0	80	
Gikuuri-II	0-20	5.1	77	pellic Vertisol
	40-60	6.0	31	
	100-110	5.5	58	
Rukira-II	0-20	4.7	95	pellic Vertisol
	40-60	5.2	74	
	100-110	5.2	74	
Kyamboa P.S.	0-20	4.46	110	vertic Gleysol
	40-60	4.97	84	
	100-110	5.72	45	
Kegonge S.S.	0-20	4.03	133	dystric Gleysol
	40-60	4.24	122	
	100-110	4.51	108	
Kivuria	0-20	5.69	46	ferric Acrisol
	40-60	5.18	73	
	100-110	5.42	60	

The chemical data from the profile pits in the volcanic depressions can be compared with two profile pits which are nearby the upper-slopes of the depression. The depression at Kigumo has a soil sequence from a gleyic Acrisol (17) to a humic Nitosol (18) on the Mountain Footridges, and the depression at Kavengero has a soil sequence from a dystric Gleysol (30) to a humic Acrisol (29) on the Plateau:

profile pit:	17	18	30	29
pH-H2O	5.0/5.0	5.2/5.5	5.1/6.1	5.8/5.1
pH-KCl	4.4/4.1	4.7/5.2	3.3/4.9	5.0/4.3
EC (mmhos/cm)	0.04/0.03	0.04/0.04	0.05/0.18	0.07/0.05
C (%)	1.58/1.00	1.46/0.37	2.16/0.57	2.65/0.49
CEC (me/100g)	24.7/16.5	20.5/15.1	24.6/10.2	31.5/16.1
Ca (me/100g)	5.0/1.3	4.0/3.2	2.1/3.5	7.7/3.8
Mg (me/100g)	1.0/0.3	2.4/0.6	0.65/2.45	3.55/2.50
K (me/100g)	0.22/0.07	0.12/0.05	0.35/0.15	1.95/0.59
Na (me/100g)	0.05/0.12	0.04/0.04	0.22/0.23	0.17/0.16
TEB (me/100g)	6.27/1.79	6.56/3.89	3.32/6.33	13.37/7.05
Bas. Sat (%)	25.4/10.8	32.0/25.8	13.5/62.1	42.4/43.8
Qual. CaCO3	+ / +	+ / +	+ / +	+ / +
pH	5.2	5.7	5.6	5.7
Na (me %)	0.17	0.16	0.70	0.14
K (me %)	0.25	0.18	0.32	1.16
Ca (me %)	5.2	7.2	2.4	11.2
Mg (me %)	1.4	3.3	0.7	3.6
Mn (me %)	0.80	0.98	1.40	1.24
P (ppm)	38	32	6	52
N (%)	0.10	0.24	0.18	0.17
C (%)	1.37	1.69	1.88	2.55
Hp (me %)	0.5	-	-	-

remarks: toxicities bracketed, deficiencies underlined.

From these data the following can be concluded on the chemical properties of the soils in the volcanic depressions:

- Soil reaction (pH-H2O) doesn't differ much from the environment. The depressions are slightly more acid.
- The depressions are not saline, they have the same low electric conductivity as their environment.
- The volcanic depressions have less exchangeable cations (TEB), especially Mg, but also K and Ca.
- N is very low in all profiles, and is deficienct.
- There is a P-deficiency in one of the two volcanic depressions.

Chapter 6. LANDUSE.

6.1. Current landuse.

All the volcanic depressions in the Chuka area are used by the local people.
The volcanic depressions are, due to the frequent ponding of the middle of the depressions, an ideal place to fetch drinking-water nearby, both for humans and cattle. Even in the dry seasons water can be fetched in most of the depressions by digging a shallow hole in their centre .

Besides the possibility to fetch water in the depressions, they are also in use by the local farmers to grow crops. However, most farmers let their cattle graze on the pasture, which is the natural vegetation nowadays. For the current landuse of the depressions see appendix 2. From the listing of the main characteristics of the volcanic depressions can be seen that, like the soils, the landuse also has a certain sequence due to climate and drainage. The landuse-sequence is given from the lowest point in the depression to the higher surrounding area.

In the flat middle of the volcanic depression the current landuse is extensive grazing if the drainage is very poor or poor and if there is regular and frequent ponding (e.g. Kyamboa pri. school). If the drainage is imperfectly or moderately well and the frequent and regular ponding is very short or absent crops are grown in the centre of the depressions. The crops found in these depressions are: sweet potatoes, sorghum, tobacco, sugarcane, bananas, beans and in parts of the area with less rainfall even maize is grown in the middle of the depressions.
In some depressions the centres are imperfectly or well drained but no crops are grown. This because these parts of the depressions are owned by the governement and the farmers are not allowed to farm this land.

The crops on the lower slopes of the edges of the volcanic depressions, with a gradient between 2 and 10%, are usually maize and bananas but also sugarcane, sorghum, tobacco and cowpeas are grown.

On the middle slopes, with a rolling topography, the same crops are grown as on the lower slopes. In the east of the Chuka area some cotton, millet and French beans are grown. Only on the slopes with very deep well drained soils, and if the climate is suitable, coffee is grown.

On the upper slopes and the surrounding area of the volcanic depressions, coffee is grown in the depressions which are situated in the suitable climate zone for coffee. In the other depressions, in the east of the Chuka area, with less rainfall, maize, tobacco, cotton, cowpeas and beans are grown.

Chapter 7. LAND EVALUATION.

7.1. Introduction.

In an attempt to increase the agricultural productivity on the flat bottoms of the volcanic depressions, the land suitability for several crops has been estimated. This physical land evaluation of the depressions, has been carried out according to the Kenyan approach of the land evaluation by matching its land qualities and the landuse requirements.
The land qualities of the bottoms of the volcanic depressions are described in section 7.2. The requirements of the various kinds of landuse are described in section 7.3, and the physical land suitability is described in section 7.4.

The volcanic depressions can be divided in two big groups; depressions with ponding during the rainy seasons, depressions without ponding and drained ones. For the depressions without ponding a normal land evaluation can be done with the normal growing periods, starting at the beginning of the rainy seasons. For the volcanic depressions with ponding different growing periods are proposed: planting and sowing of new crops at the end of the rainy season, when the ponds disappear, instead of planting and sowing at the beginning of a new rainy season.

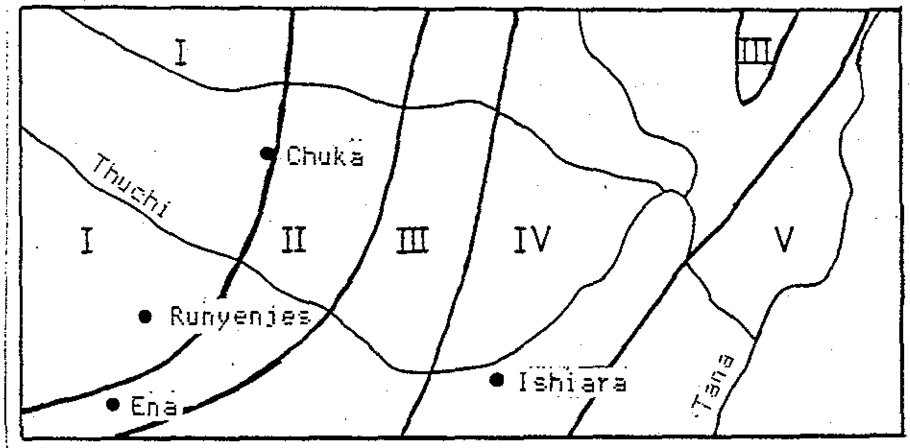
A complete physical landevaluation has been done for two volcanic depressions with ponding with sufficient chemical data, and for several others, from which only the land quality available nutrients has been estimated. Some land qualities are different in the dry season and rainy season. The ratings have been examined both for growing periods during the rainy seasons and for growing periods during the dry seasons. This has been done in case there are crops, suitable for this climate, which tolerate periods of waterlogging or crops which need periods of waterlogging.

7.2. Land qualities.

The physical suitability of land is determined by many different land qualities, which are often closely related.
The period for the normal growing season is 200 or 165 days (march-september or oktober-march). The growing period in ponded volcanic depressions is 105 or 120 days (december-march or june-september)
The rating of the land qualities has been done according to the " Proposal 3rd approximation for rating of land qualities " (WEEDA , 1985).
The land qualities considered are:
- availability of water: available moisture zone (AMZ)
  moisture storage capacity (MSC)
- temperature
- availability of nutrients

- hindrance by salinity and/or alkalinity
- resistance to erosion
- availability of oxygen for root growth
- possibilities for land preparation
- hindrance of natural vegetation
- hindrance of overgrazing and other mismanagement
- absence of flooding

The land quality water availability is not yet developed in this approximation. This rating has been done according to the " 2nd approximation for rating of land qualities " (BRAUN & VAN DE WEG, 1977).
The availability of water is thought to be dependent on the climate or agro-climatic zones and on the moisture storage capacity of the soil.
The climate factor is the ratio between the annual precipitation (r) and the annual average evapotranspiration Eo. With this ratio an estimation can be made of days per year with full moisture, according to: amount of days full moisture = 100/0.8 X r/Eo.
The agro-climatic zone map (BRAUN, 1980) gives 7 zones for moisture availability (figure 21).



No of zone	r/Eo.100%	description
I	80	humid
II	65-80	subhumid
III	50-65	semi-humid
IV	40-50	semi-humid to semi-arid
V	25-40	semi-arid
VI	15-25	arid
VII	<15	very arid

Figure 21. Agro-climatic zones. (source BRAUN, 1980)

The soil factor consists of the total productive available moisture (TPAM in mm) and the hindrance to root development

(effective soildepth, bulkdensity). The rating for this soil-moisture capacity can be found in the 2nd approximation.
It is assumed that in the volcanic depressions with ponding the moisture availability in the special growing season is sufficient, due to the high groundwater-level.
The ratings for the other land qualities can be found in the 3rd approximation.
The land qualities of several volcanic depressions are listed below. The land quality available nutrients is estimated for most of the depressions, according to the available chemical data from the profile pits no 30 and 17.

depres.	grow per.	AMZ	MSC	Temp zone	pH	Nutr av.	Sal. Alk.	Oxy av.	Eros res.	Land Prep	Nat. veg	Over gra.	Pond
(ponded)													
Kavengero	norm	III	2	2	2	4*	1	4	1	2	1	1	5
(30)	spec	III	2	2	2	4*	1	3	1	2	1	1	2
Kigumo	norm	II	2	3	2	2	1	3	1	1	1	1	4
(17)	spec	II	2	3	2	2	1	2	1	1	1	1	1
Kegonge	norm	II	1	3	3	(2)	1	4	1	2	1	1	5
	spec	II	1	3	3	(2)	1	3	1	2	1	1	2
Rukira-II	norm	II	2	3	2	(2)	1	4	1	2	1	1	5
	spec	II	2	3	2	(2)	1	3	1	2	1	1	2
Kyamboa	norm	II	1	3	2	(2)	1	4	1	2	1	1	5
	spec	II	1	3	2	(2)	1	3	1	2	1	1	2
Karigiri	norm	II	2	3	2	(2)	1	4	1	1	1	1	5
	spec	II	2	3	2	(2)	1	3	1	1	1	1	2
Kiamugi	norm	II	2	3	2	(2)	1	4	1	2	1	1	5
	spec	II	2	3	2	(2)	1	3	1	2	1	1	2
Gikuuri	norm	II	2	3	2	(2)	1	4	1	2	1	1	5
(II)	spec	II	2	3	2	(2)	1	3	1	2	1	1	2
Kivuria	norm	II	2	3	1	(2)	1	3	1	1	1	1	4
	spec	II	2	3	1	(2)	1	2	1	1	1	1	1
(not ponded)													
Mumbini-I	norm	III	2	2	2	(2)	1	1	1	1	1	1	2

(2) = estimated
4* = P and Mg deficiency, else rating 2

7.3. Land-use requirements.

Crop-requirements for nine crops, common in the Chuka-Ishiara area, listed in the reports of the sample-strips (Bongers and Pulles, 1987) - the semi-detailed soil surveys which have been carried out in the research area -, have been used for the land-evaluation in the volcanic depressions. These crops are: maize, bullrush millet, sorghum, cowpea, bean, cassava, cotton, coffee and tea.
However, because of the special conditions in the volcanic

depressions, such as the different growing periods because of the ponding-problem, it has been examined which kinds of crops are adjusted to these conditions. The crop-requirements of the following crops, with possible good yields, have been examined: cocoyam, tannia, sweet potato, sugarcane, green gram, tomato and cabbage. Because of lack of information, only the global crop-requirements are listed:

crop	growing period (days)	tempera-ture (oC)	rainfall grow.per. (mm)	drought resist.	water-logging resist.
sweet potato	120-150	warm+cool	>750 (*)	high	med/high
sorghum	100-140	24-30	300-380	medium	med/high
cocoyam	180	900-1800 m.	>1250 (*)	low	high
tannia	180	900-1800 m.	>1250 (*)	low	high
cabbage	100-150	15-20	380-500	?	low
tomato	90-120	18-25	400-600	?	low
green gram	75-90	<1500 m.	650 (*)	medium	med/low
bean	60-120	15-20	300-500	low	med/low
sugarcane	270-1200	22-30	1500 (*)	low	med/high
cassava	365-730	25-29	1250 (**)	high	low

(*) : annual rainfall.
(**): no good yields in areas with a markedly bimodal rainfall.

crop	texture class * F M C VC	root depth	reaction: pH opt.	pH range	nutrients req.	spec.	Sali-nity tol.
sweet pot.	+ +		5.8-6.0		high	high K	
sorghum	+ + +	mod	5.5-6.5	5.0-8.5	med.	high N	low
cocoyam	+ +			4.5-8.0	high	high K	
tannia	+ +			4.5-8.0	high	high K	
cabbage	+	shal		6.0-7.5	high		med.
tomato	+	mod		5.0-7.0	high		low
green gram	+ +	mod	6.0-7.0	5.5-7.5			med.
bean	+ +	mod	6.0-7.0	5.5-7.5	med.		low
sugarcane	+ +	deep	6.0-7.5	4.5-8.5	high	high N	m/l
cassava	+ + +	deep		5.5-6.5	low		low

* F=fine M=medium C=coarse VC=very coarse
Sources: LANDON (1984), ACLAND (1971), MACDONALD (1984), NGUGI (1978).

7.4. Physical land suitability.

The land qualities of the volcanic depressions are matched with the land-use requirements. The table with the final suitability classes is listed below:

depression		maize	millet	sorghum	cowpea	bean	cassava	cotton	coffee / tea
Kavengero	norm	N	N	N	N	N	N	N	N
	spec	N	N	N*	N	N	N	N	N
Kigumo	norm	N	N	S3	N	N	N	S3	N
	spec	N	S3	S3	S3	S3	N	S3	N
Kegonge	norm	N	N	N	N	N	N	N	N
	spec	N	N	N	N	N	N	N	N
Rukira-II	norm	N	N	N	N	N	N	N	N
	spec	N	N	S3	N	N	N	N	N
Kyamboa	norm	N	N	N	N	N	N	N	N
	spec	N	N	S3	N	N	N	N	N
Karigiri	norm	N	N	N	N	N	N	N	N
	spec	N	N	S3	N	N	N	N	N
Kiamugi	norm	N	N	N	N	N	N	N	N
	spec	N	N	S3	N	N	N	N	N
Gikuuri-II	norm	N	N	N	N	N	N	N	N
	spec	N	N	S3	N	N	N	N	N
Kivuria	norm	N	N	S2	N	N	N	S3	N
	spec	N	S3	S2	S2	S2	N	S3	N
Mumbuni-I	norm	S3	S1	S3	S3	S3	S2	S2	N

S1 = highly suitable
S2 = moderately suitable
S3 = marginally suitable
N = unsuitable

N* = if P and Mg deficiencies are overcome, it becomes marginally suitable: S3

From these data it can be concluded that most of the volcanic depressions are not suitable to grow the common **crops** in the Chuka-Ishiara area during the common growing periods. However, when the growing periods are changed, especially sorghum is suitable to grow. The difference between depressions without ponding (Mumbuni-I) or very little ponding (Kivuria and Kigumo) and the frequently ponded depressions is clear: some crops, such as bean, cowpea, cotton and millet have a few possibilities only there. The Mumbuni-depression gives even better results.
The physical land suitability for the other crops mentioned above can only be estimated. When the land qualities and the land-use requirements are matched it becomes clear that the following crops have good possibilities in the ponded depressions, when planted or seeded shortly after the rainy seasons: **sweet potato, sorghum, cocoyam** and **tannia**. When ridges are used, by which the drainage becomes moderately well or well, there are also possiblities for tomato, green gram and cabbage. However, the low pH can give problems sometimes, and probably fertilizers have to be used. In volcanic depressions with little or no ponding, there are very good possibilities for sugarcane also. A few of these crops (sugarcane, sweet potato, and cabbage) are grown already in the Kigumo-depression.
Finally, when a system is introduced to drain the depressions, there will be much more possibilities to grow crops. However, the cattle-dip and waterhole functions of the volcanic depressions, are lost then.

In the volcanic depression at Kyamboa Pri. School, the largest one, the government of Kenya is examining the suitablity for **fishery**. It is thought to dig a water-supply canal from the Gitwa, a stream nearby, to the depression and a second canal to drain water away. Because the soil is not so very permeable here - the heavy clays cause the water to stagnate and form ponds, which still exist at the end of the dry seasons, unlike most of the other depressions, in which the ponds disappear quickly - it seems not a bad idea. In the research-area it is the only depression that has this possibility. On the map below, the best possible route for the supply-canal is shown (figure 22).

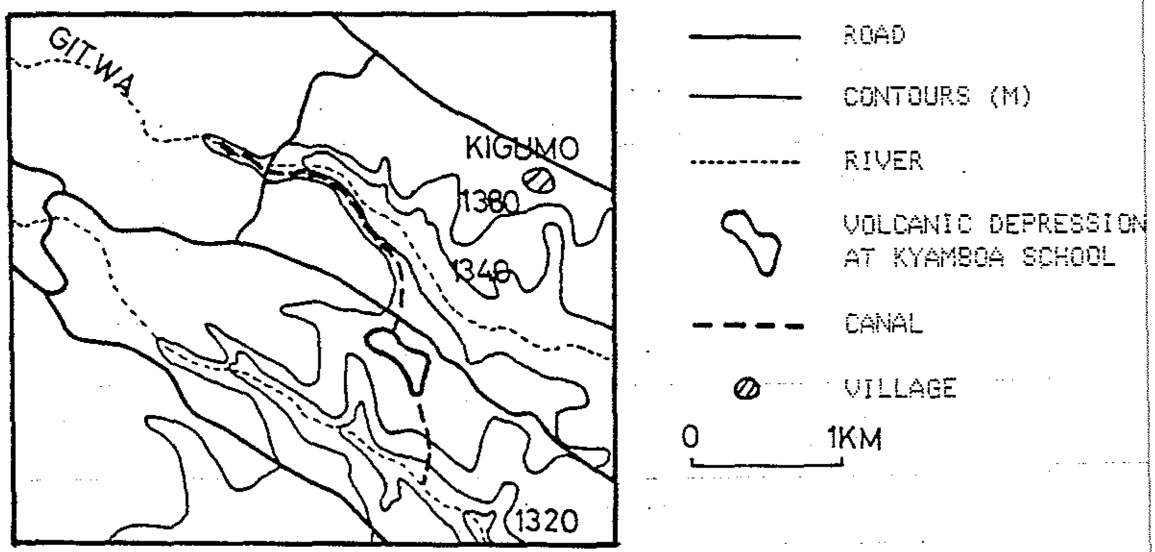


Figure 22. Water-supply canal for fishery in the volcanic depression at Kyamboa Pri. School.

Chapter 8. CONCLUSIONS AND SUGGESTIONS.

8.1. Conclusions.

The following main conclusions can be made:

- **about the geology and geomorphology**

  On the south-western slopes of Mount Kenya there are about 140 mostly elliptical formed depressions in consolidated lahars, from volcanic origin. They all have a direction - of the largest axis of the ellips - , which corresponds with the direction of the laharflows.
  About their origin there are four theories:

  - During the deposition of the lahar the large amount of water drains out of the mudflow to the surface, concentrates, and forms little lakes. After consolidation of the lahar and the disappearance of the water, depressions stay behind. The direction is caused by the still slowly flowing lahar before the complete deposition of the lahar.
  - Due to local differences in texture and watercontent of the lahar, some parts sink to a lower level during deposition and consolidation. The direction is caused by the still slowly flowing lahar.
  - During the deposition of the lahar, a crust is formed by the evaporation of water in the upper layers, and subsidence occurs because the lower parts are still flowing. The direction is caused by the still flowing lahar.
  - Due to melting of glacier ice, captured in the lahar during the movement and the deposition of the lahar, some parts sink to a lower level during deposition of the lahar.

- **about the soils**

  There is a general soil sequence from the bottoms to the upper slopes of the depressions, depending on climate, drainage class and ponding. This sequence is:
  - pellic **vertisol**
  - vertic / dystric / humic **gleysol**
  - gleyic **acrisol**
  - ferric **acrisol**
  - chromic / humic / orthic **acrisol**
  - dystric / humic **nitosol**.

  Apart from the chromic / humic / orthic acrisols and the nitosols, all these soil-types appear on the bottoms of the volcanic depressions.

- **about the landuse**

  Most of the bottoms of the depressions are pastures used for grazing cattle. With the exception of three depressions no crops are grown, because of the farmers' fear of ponding or because the depressions are governement property. The slopes of the volcanic depressions are in use to grow various kinds of crops.

- **about the landsuitability**

  When the growing periods are adjusted (growing periods june - september and december - march) some crops, like sorghum, sweet potato, cocoyam and tannia can be grown on the bottoms of the depressions. In depressions with no ponding also sugarcane is possible. When ridges are used, some other crops like tomato, cabbage and green gram have possibilities. In one depression there are plans for fishery.

8.2. Suggestions.

The research on the origin of the depressions should be concentrated on possible textural differences in the lahar by taking rock-samples below the depressions and in the surroundings of the depressions. Some vital information on the draining out of lahars and the genesis of specific landforms can possibly be collected in Colombia, in the area of the Nevado del Ruiz, where recently a lahar came down.

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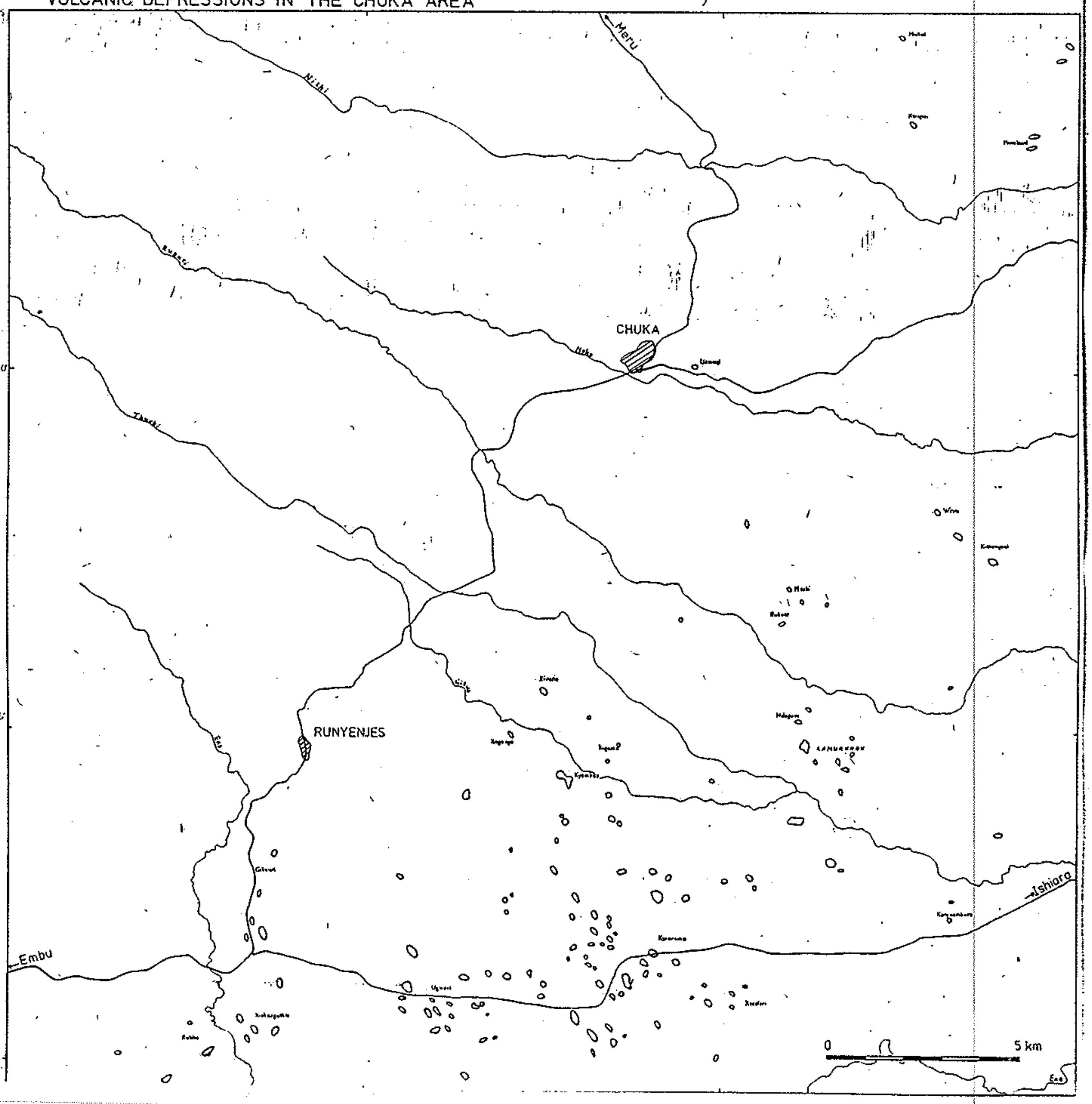
APPENDICES

VOLCANIC DEPRESSIONS IN THE CHUKA AREA



APPENDIX 2. VOLCANIC DEPRESSIONS IN THE CHUKA AREA

Listing of the main characteristics of the volcanic depressions. A soil-sequence is given from the lowest point in the depression to the higher surrounding area. The crops which grow on the soils are also listed.

Name	GIKUURI-I
East-coordinates	373330
South-coordinates	2718
Direction (degrees)	210/030
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
VERTIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-BANANAS
DYSTRIC NITOSOL	COFFEE

Name	GIKUURI-II
East-coordinates	373335
South-coordinates	2752
Direction (degrees)	335/155
Depth of water in rainy season(cm)	250
Depth of rotten rock (cm)	180
Existence of murram	ENE CORNER
Drained by stream?	NO

SOIL	LANDUSE
PELLIC VERTISOL	EXTENSIVE GRAZING
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-BANANAS
DYSTRIC NITOSOL	COFFEE-MAIZE-BANANAS

Name	GIKUURI-III
East-coordinates	373327
South-coordinates	2740
Direction (degrees)	330/150
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-BANANAS
DYSTRIC NITOSOL	COFFEE

Name	KAMARUNGU-I
East-coordinates	374108
South-coordinates	2513
Direction (degrees)	0/0
Depth of water in rainy season(cm)	15
Depth of rotten rock (cm)	120
Existence of murram	-
Drained by stream?	YES

SOIL	LANDUSE
VERTIC GLEYSOL	EXTENSIVE GRAZING
CHROMIC ACRISOL	COFFEE-BEANS-COWPEAS

Name	KAMURUNGU-II
East-coordinates	374117
South-coordinates	2524
Direction (degrees)	340/160
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	130
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
CHROMIC ACRISOL	MAIZE-COW PEAS-BAN.

Name	KANYUAMBORA
East-coordinates	374312
South-coordinates	2736
Direction (degrees)	295/115
Depth of water in rainy season(cm)	100
Depth of rotten rock (cm)	25
Existence of murram	NNE TO SSE
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	- (BARE SOIL)
FERRIC ACRISOL	MAIZE
CHROMIC ACRISOL	TOBACCO

Name	KARIGIRI
East-coordinates	374240
South-coordinates	1635
Direction (degrees)	290/110
Depth of water in rainy season(cm)	350
Depth of rotten rock (cm)	125
Existence of murram	NNE CORNER
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE
DYSTRIC NITOSOL	MAIZE

Name	KARURUMO-I
East-coordinates	373903
South-coordinates	2805
Direction (degrees)	310/130
Depth of water in rainy season(cm)	150
Depth of rotten rock (cm)	>
Existence of murram	NE CORNER
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE - BANANAS
DYSTRIC NITOSOL	MAIZE - COTTON

Name	KARURUMO-II
East-coordinates	373920
South-coordinates	2812
Direction (degrees)	320/140
Depth of water in rainy season(cm)	0
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	YES

SOIL	LANDUSE
FERRIC ACRISOL	MAIZE
DYSTRIC NITOSOL	COTTON

Name	KASAFARI-I
East-coordinates	374010
South-coordinates	2837
Direction (degrees)	335/155
Depth of water in rainy season(cm)	15
Depth of rotten rock (cm)	130
Existence of murram	EVERYWHERE
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	EXTENSIVE GRAZING
CHROMIC CAMBISOL	'MONEL' BEANS
HUMIC CAMBISOL	'MONEL' BEANS

Name	KASAFARI-II
East-coordinates	373947
South-coordinates	2846
Direction (degrees)	325/145
Depth of water in rainy season(cm)	0
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	YES

SOIL	LANDUSE
GLEYIC ACRISOL	SORGHUM
FERRIC ACRISOL	
DYSTRIC NITOSOL	COFFEE-COTTON-SORGH.

Name	KAVENGERO
East-coordinates	374133
South-coordinates	2650
Direction (degrees)	
Depth of water in rainy season(cm)	150
Depth of rotten rock (cm)	>
Existence of murram	IN CENTRE
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING

Name	KEGONGE SEC. SCHOOL
East-coordinates	373703
South-coordinates	2506
Direction (degrees)	335/155
Depth of water in rainy season(cm)	300
Depth of rotten rock (cm)	110
Existence of murram	ENE CORNER
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-COFFEE
DYSTRIC NITOSOL	COFFEE-BEANS

Name	KIAMUGI
East-coordinates	373935
South-coordinates	1953
Direction (degrees)	255/075
Depth of water in rainy season(cm)	150
Depth of rotten rock (cm)	110
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-COWPEAS
DYSTRIC NITOSOL	COFFEE-MAIZE

Name	KIGUMO
East-coordinates	373845
South-coordinates	2515
Direction (degrees)	
Depth of water in rainy season(cm)	30
Depth of rotten rock (cm)	>
Existence of murram	_
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	SWEET POTATO-CABBAGE
?	SUGARCANE - MAIZE
HUMIC NITOSOL	COFFEE

Name	KITHANGANI-I
East-coordinates	374347
South-coordinates	2238
Direction (degrees)	310/130
Depth of water in rainy season(cm)	0
Depth of rotten rock (cm)	>
Existence of murram	_
Drained by stream?	YES

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-COWPEAS

Name	KITHANGANI-II
East-coordinates	374317
South-coordinates	2215
Direction (degrees)	310/130
Depth of water in rainy season(cm)	150
Depth of rotten rock (cm)	>
Existence of murram	_
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
DYSTRIC NITOSOL	SORGHUM-MILLET-COWP.

Name	KITHUNGUTHIA-I
East-coordinates	373326
South-coordinates	2911
Direction (degrees)	300/140
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	250
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
PELLIC VERTISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE
DYSTRIC NITOSOL	COFFEE-BEANS

Name	KITHUNGUTHIA-II
East-coordinates	373342
South-coordinates	2918
Direction (degrees)	250/050
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
DYSTRIC NITOSOL	COFFEE-MAIZE

Name	KITHUNGUTHIA-III
East-coordinates	373321
South-coordinates	2912
Direction (degrees)	335/130
Depth of water in rainy season(cm)	100
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
DYSTRIC NITOSOL	MAIZE-COFFEE

Name	KIVURIA
East-coordinates	373730
South-coordinates	2430
Direction (degrees)	335/155
Depth of water in rainy season(cm)	120
Depth of rotten rock (cm)	160
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
FERRIC ACRISOL	SWEET POTATOES/MAIZE
DYSTRIC NITOSOL	COFFEE-BEANS

Name	KYAMBOA PRI. SCHOOL
East-coordinates	373748
South-coordinates	2543
Direction (degrees)	295/115 342/162
Depth of water in rainy season(cm)	300
Depth of rotten rock (cm)	130
Existence of murram	NE CORNER
Drained by stream?	NO

SOIL	LANDUSE
VERTIC GLEYSOL	EXTENSIVE GRAZING
HUMIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	MAIZE-SUGARCANE
CHROMIC ACRISOL	MAIZE-BANANAS
DYSTRIC NITOSOL	COFFEE-BEANS

Name	MAABI
East-coordinates	374055
South-coordinates	2300
Direction (degrees)	255/75
Depth of water in rainy season(cm)	60
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	ALM

SOIL	LANDUSE
GLEYIC ACRISOL	EXTENSIVE GRAZING
FERRIC ACRISOL	BANANAS-MAIZE
DYSTRIC NITOSOL	COFFEE

Name	MUMBUNI-I
East-coordinates	374420
South-coordinates	1643
Direction (degrees)	255/075
Depth of water in rainy season(cm)	0
Depth of rotten rock (cm)	250
Existence of murram	CENTRE
Drained by stream?	NO

SOIL	LANDUSE
FERRIC ACRISOL	MAIZE-SORGHUM
FERRIC ACRISOL	TOBACCO
DYSTRIC NITOSOL	MAIZE-BEANS

Name	MUMBUNI-II
East-coordinates	374418
South-coordinates	1650
Direction (degrees)	265/065
Depth of water in rainy season(cm)	90
Depth of rotten rock (cm)	165
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
HUMIC GLEYSOL	EXTENSIVE GRAZING
DYSTRIC NITOSOL	MAIZE-SORGHUM

Name	NDAGONI
East-coordinates	374113
South-coordinates	2440
Direction (degrees)	295/115
Depth of water in rainy season(cm)	90
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
GLEYIC ACRISOL	SUGARCANE-BANANAS
DYSTRIC NITOSOL	COFFEE-MAIZE

Name	RUBATE
East-coordinates	374051
South-coordinates	2328
Direction (degrees).	240/060
Depth of water in rainy season(cm)	150
Depth of rotten rock (cm)	>
Existence of murram	–
Drained by stream?	NO

SOIL	LANDUSE
DYSTRIC GLEYSOL	EXTENSIVE GRAZING
FERRIC ACRISOL	TOBACCO-MAIZE
DYSTRIC NITOSOL	COFFEE

Name	RUKIRA-I
East-coordinates	373235
South-coordinates	2907
Direction (degrees)	242/062
Depth of water in rainy season(cm)	10
Depth of rotten rock (cm)	>
Existence of murram	–
Drained by stream?	NO

SOIL	LANDUSE
FERRIC ACRISOL	MAIZE-BEANS
DYSTRIC NITOSOL	MAIZE

Name	RUKIRA-II
East-coordinates	373250
South-coordinates	2930
Direction (degrees)	235/55
Depth of water in rainy season(cm)	175
Depth of rotten rock (cm)	>
Existence of murram	–
Drained by stream?	NO

SOIL	LANDUSE
PELLIC VERTISOL	EXTENSIVE GRAZING
CHROMIC ACRISOL	MAIZE
DYSTRIC NITOSOL	COFFEE

Name	RUKIRA-III
East-coordinates	373215
South-coordinates	2953
Direction (degrees)	210/030
Depth of water in rainy season(cm)	200
Depth of rotten rock (cm)	150
Existence of murram	-
Drained by stream?	NO

SOIL	LANDUSE
FERRIC ACRISOL	SORGHUM
DYSTRIC NITOSOL	COFFEE-EXT.GRAZING

Name	WERU
East-coordinates	374300
South-coordinates	2155
Direction (degrees)	310/130
Depth of water in rainy season(cm)	0
Depth of rotten rock (cm)	>
Existence of murram	-
Drained by stream?	YES

SOIL	LANDUSE
GLEYIC ACRISOL	MAIZE-POTATOES
CHROMIC ACRISOL	COTTON-FRENCH BEANS

APPENDIX 3. SOIL UNITS IN THE VOLCANIC DEPRESSIONS.

Soil unit **Pellic Vertisol**

Acreage	:
Number of augerings in unit	:3
Parent material	:consolidated lahars
Macro relief	:flat
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:pasture, used for grazing
Soils, general	:poorly drained, very deep, brownish black, firm, clay
Range of characteristics	
,colour	:A,B: brownish black
,texture	:A,B: clay
,structure	:
,consistence	:A,B: firm when moist, sticky and plastic when wet
Chemical properties	:pH: 0-20 cm 4.8 40-60 cm 5.2 110 cm 5.2 EC: 0-20 cm 95 mV/cm 40-60 cm 74 mV/cm 110 cm 74 mV/cm
Diagnostic properties	:gilgai microrelief, slickensides, hydromorphic properties within 50 cm
Classification	:pellic Vertisol
Representative profile	:augering at Rukira-II
In general	:ponding twice a year, 100 cm deep

Soil unit Vertic Gleysol

Acreage	:
Number of augerings in unit	:13
Parent material	:consolidated lahars
Macro relief	:flat
Erosion	:nil
Rockiness/stoniness	:fairly stony
Land use	:pasture, used for grazing
Soils, general	:poorly drained, deep, very dark reddish brown to brownish gray, firm, clay
Range of characteristics	
,colour	:A: very dark reddish brown B: brownish gray
,texture	:A,B: clay
,structure	:A: medium subangular blocky B: fine angular blocky
,consistence	:A,B: firm when moist, sticky and plastic when wet
Chemical properties	:pH: 0-20 cm 4.5 40-60 cm 5.0 110 cm 5.7 EC: 0-20 cm 110 mV/cm 40-60 cm 84 mV/cm 110 cm 45 mV/cm
Diagnostic properties	:vertic properties, hydromorfic properties within 50 cm
Classification	:vertic Gleysol
Representative profile	:profile pit 1. Kyamboa Pri. School
In general	:ponding twice a year, 200 cm deep

Soil unit **Humic Gleysol**

Acreage	:
Number of augerings in unit	:3
Parent material	:consolidated lahars
Macro relief	:flat
Erosion	:nil
Rockiness/stoniness	:fairly rocky, fairly stony
Land use	:pasture, used for grazing
Soils, general	:poorly drained, deep, brownish black to brownish gray, firm, clay
Range of characteristics	
,colour	:A: brownish black B: brownish gray
,texture	:A,B: clay
,structure	:A: fine subangular blocky B: fine angular blocky
,consistence	:A,B: firm when moist, sticky and plastic when wet
Chemical properties	:
Diagnostic properties	:hydromorphic properties within 50 cm, umbric A horizon
Classification	:humic Gleysol
Representative profile	:profile pit 3. Kyamboa Pri. School
In general	:ponding twice a year, 200 cm deep

Soil unit Dystric Gleysol

Acreage	:
Number of augerings in unit	:26
Parent material	:consolidated lahars
Macro relief	:flat
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:pasture, used for grazing
Soils, general	:imperfectly to poorly drained, deep to very deep, dull yellowish brown to brownish gray, firm, clay
Range of characteristics	
,colour	:A: dull yellowish brown B: brown to grayish brown C: brownish gray
,texture	:A,B,C: clay
,structure	:A,B:fine to medium subangular blocky C: weak fine subangular blocky
,consistence	:A,B,C: firm when moist, sticky and plastic when wet
Chemical properties	:pH: 0-20 cm 4.0 40-60 cm 4.2 110 cm 4.5 EC: 0-20 cm 133 mV/cm 40-60 cm 122 mV/cm 110 cm 108 mV/cm
Diagnostic properties	:hydromorphic properties within 50 cm
Classification	:dystric Gleysol
Representative profile	:profile groove at Kegonge Sec School
In general	:ponding twice a year, various depths

Soil unit **Gleyic Acrisol**

Acreage	:
Number of augerings in unit	:31
Parent material	:consolidated lahars
Macro relief	:flat to gently undulating
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:pasture, used for grazing, food crops (sugarcane, sweet potato, banana, cabbage)
Soils, general	:poorly drained, deep to very deep, grayish brown, firm, silty clay to clay
Range of characteristics	
,colour	:A:brown B:grayish brown C:brown to grayish yellow brown
,texture	:A:silty clay B:clay C:silty clay to clay
,structure	:
,consistence	:A,C:friable when moist,sticky and slightly plastic when wet B: firm when moist,sticky and plastic when wet
Chemical properties	:pH: 0-40 cm 5.0 40-65 cm 5.0 65-105 cm 4.9 105-130 cm 5.0 EC 0-40 cm 0.04 mmhos/cm 40-65 cm 0.04 mmhos/cm 65-105 cm 0.04 mmhos/cm 105-130 cm 0.03 mmhos/cm
Diagnostic properties	:hydromorphic properties within 50 cm, Argillic B horizon
Classification	:gleyic Acrisol
Representative profile	:augering at Kegonge school
In general	:ponding twice a year, various depths

Soil unit **Ferric Acrisol**

Acreage	:
Number of augerings in unit	:31
Parent material	:consolidated lahars
Macro relief	:undulating
Erosion	:nil to moderate sheet erosion
Rockiness/stoniness	:nil
Land use	:food crops (maize, bananas, sweet potatoes, sorghum), tobacco
Soils, general	:moderately well to well drained, moderately deep to very deep, very dark reddish brown, firm, silty clay to clay, sometimes with murram within 120 cm
Range of characteristics	
,colour	:A:very dark reddish brown B:very dark reddish brown to brownish gray
,texture	:A:silty clay B:clay
,structure	:
,consistence	:A:friable when moist, sticky and plastic when wet B:firm when moist, sticky and plastic when wet
Chemical properties	:pH 0-20 cm 5.69 40-60 cm 5.18 100-110 cm 5.42 EC 0-20 cm 46 mV/cm 40-60 cm 73 mV/cm 100-110 cm 60 mV/cm
Diagnostic properties	:ferric properties, Argillic B
Classification	:ferric Acrisol
Representative profile	:augering at Kyamboa school
In general	:ponding twice a year, various depths

Soil unit **Humic Acrisol**

Acreage	:
Number of augerings in unit	:2
Parent material	:consolidated lahars
Macro relief	:undulating
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:food crops (maize, bananas)
Soils, general	:moderately well drained, very deep, very dark reddish brown, firm, clay
Range of characteristics	
,colour	:A,B:very dark reddish brown
,texture	:A,B:clay
,structure	:
,consistence	:A:friable when moist, sticky and plastic when wet B:firm when moist, sticky and plastic when wet
Chemical properties	:
Diagnostic properties	:Umbric A, Argillic B horizon
Classification	:humic Acrisol
Representative profile	:augering at Kyamboa school
In general	:occasional ponding

Soil unit **Chromic Acrisol**

Acreage	:
Number of augerings in unit	:6
Parent material	:consolidated lahars
Macro relief	:gently undulating
Erosion	:slight sheet erosion
Rockiness/stoniness	:nil
Land use	:food crops (beans, cotton, cowpeas)
Soils, general	:well drained, very deep, very dark reddish brown, very friable to firm, silty clay to clay
Range of characteristics	
,colour	:A,B,C: very dark reddish brown
,texture	:A,C: silty clay B: clay
,structure	:
,consistence	:A: very friable when moist, slightly sticky and slightly plastic when wet B: friable to firm when moist, sticky and slightly plastic when wet C: friable when moist, slightly sticky and slightly plastic when wet
Chemical properties	:
Diagnostic properties	:Argillic B, chromic properties
Classification	:Chromic Acrisol
Representative profile	:Augering at Kamarungu
In general	:flooding absent

Soil unit **Orthic Acrisol**

Acreage	:
Number of augerings in unit	:1
Parent material	:consolidated lahars
Macro relief	:undulating to rolling
Erosion	:moderate sheet and slightly rill
Rockiness/stoniness	:nil
Land use	:cash crops (coffee)
Soils, general	:well drained, extremely deep, very dark reddish brown, very friable to firm, silty clay to clay
Range of characteristics	
,colour	:A,B,C: very dark reddish brown
,texture	:A: silty clay B,C: clay
,structure	:
,consistence	:A: very friable when moist, sticky and plastic when wet B,C: firm when moist, sticky and plastic when wet
Chemical properties	:
Diagnostic properties	:Argillic B horizon
Classification	:Orthic Acrisol
Representative profile	:Augering at Kyamboa Pri. School
In general	:flooding absent

Soil unit **Humic Nitosol**

Acreage	:
Number of augerings in unit	:1
Parent material	:consolidated lahars
Macro relief	:undulating
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:food crops (beans) cash crops (coffee, cotton)
Soils, general	:moderately well drained, extremely deep, dark reddish brown, friable to firm, silty clay to clay
Range of characteristics	
,colour	:A,B: dark reddish brown
,texture	:A: silty clay B: clay
,structure	:
,consistence	:A: friable when moist, sticky and plastic when wet B: firm when moist, sticky and plastic when wet
Chemical properties	:
Diagnostic properties	:Umbric A, Argillic B > 150 cm
Classification	:Humic Nitosol
Representative profile	:augering at Kasafari
In general	:flooding absent

Soil unit **Dystric Nitosol**

Acreage	:
Number of augerings in unit	:22
Parent material	:consolidated lahars
Macro relief	:gently undulating
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:food crops (maize, beans, potatoes) cash crops (coffee, cotton)
Soils, general	:somewhat excessively drained, extremely deep, very dark reddish brown, friable to firm, silty clay to clay
Range of characteristics	
,colour	:A,B: very dark reddish brown
,texture	:A: silty clay B: clay
,structure	:
,consistence	:A: very friable to friable when moist, slightly sticky to sticky and plastic when wet B: friable to firm when moist,sticky and plastic when wet
Chemical properties	:pH 0-20 cm 5.2 EC 0-20 cm 0.04 mmhos/cm
Diagnostic properties	:Argillic B horizon
Classification	:Dystric Nitosol
Representative profile	:augering at Kyamboa Pri. School
In general	:flooding absent

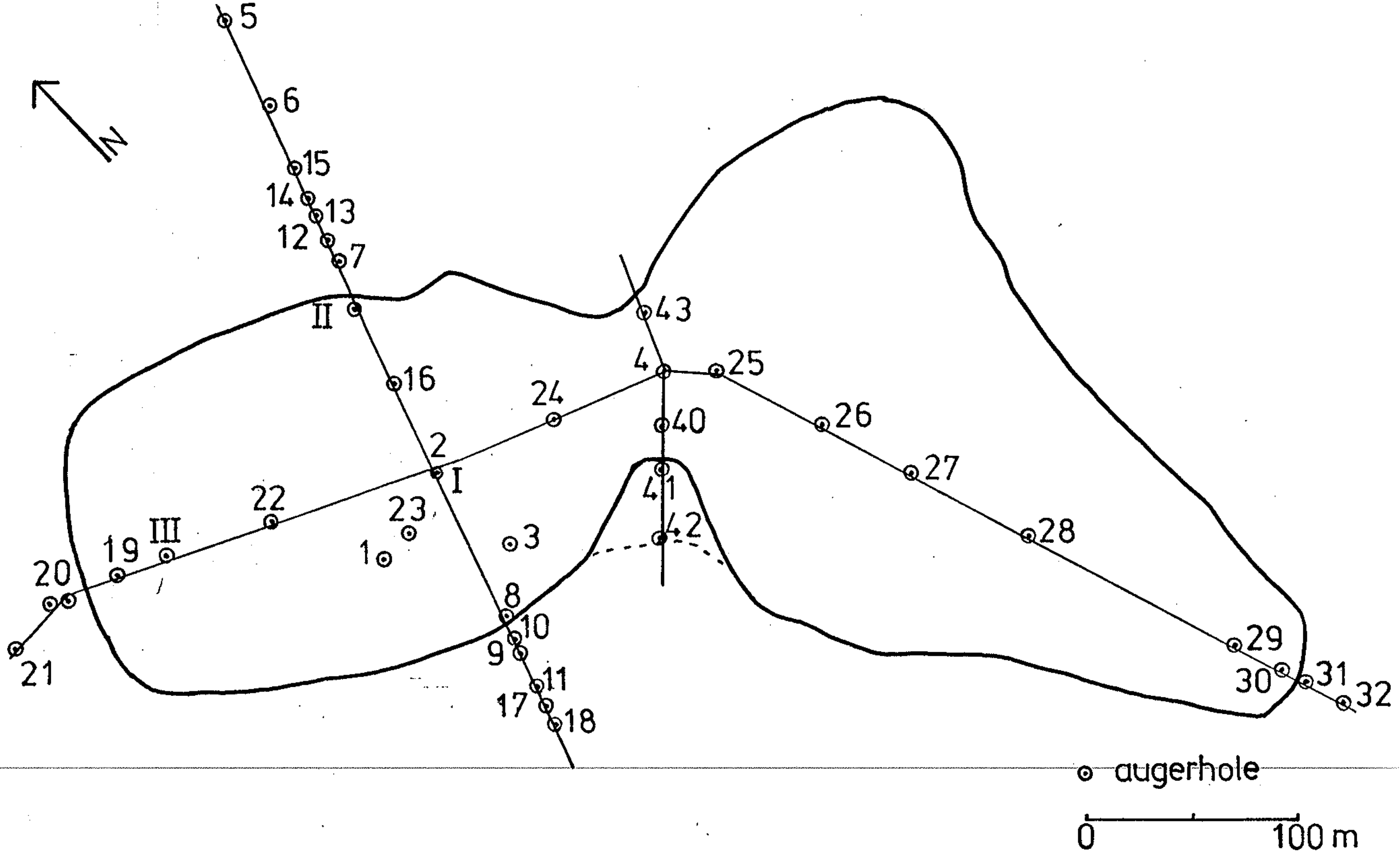
Soil unit Chromic Cambisol

Acreage	:
Number of augerings in unit	:2
Parent material	:consolidated lahars
Macro relief	:rolling
Erosion	:slight sheet erosion
Rockiness/stoniness	:nil
Land use	:extensive grazing
Soils, general	:somewhat excessively drained, extremely deep, very dark reddish brown to dark brown, very friable, silty clay loam
Range of characteristics	
,colour	:A: very dark reddish brown B: dark brown
,texture	:A,B: silty clay loam
,structure	:
,consistence	:A,B: very friable when moist, slightly sticky and slightly plastic when wet
Chemical properties	:
Diagnostic properties	:Cambic B horizon, chromic properties
Classification	:Chromic Cambisol
Representative profile	:augering at Kasafari-I
In general	:flooding absent

Soil unit **Humic Cambisol**

Acreage	:
Number of augerings in unit	:1
Parent material	:consolidated lahars
Macro relief	:gently undulating
Erosion	:nil
Rockiness/stoniness	:nil
Land use	:cash crops ('Monel' beans)
Soils, general	:well drained, extremely deep, dark reddish brown to dark brown, friable, silty clay loam
Range of characteristics	
,colour	:A: dark reddish brown B: dark brown
,texture	:A,B: silty clay loam
,structure	:
,consistence	:A: friable when moist, slightly sticky and slightly plastic when wet B: friable when moist, sticky and plastic when wet
Chemical properties	:
Diagnostic properties	:Umbric A, Cambic B horizon
Classification	:Humic Cambisol
Representative profile	:augering at Kasafari-I
In general	:flooding absent

VOLCANIC DEPRESSION AT KYAMBOA PRI. SCHOOL



VOLCANIC DEPRESSION AT KEGONGE SEC. SCHOOL