THE GEOLOGY OF THE CHUKA-SOUTH AREA
(KENYA)

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1. INTRODUCTION

The Chuka-South area described in this report is the southern half of quarter-degree sheet 122 (sheets 122/3 and 122/4) of the topographical map 1:50,000 of Kenya. The area is bound by latitudes $0^{o}15'S$ and $0^{o}30'S$ and by the longitudes $37^{o}30'E$ and $38^{o}00'E$. These coordinates enclose an area of about 1500 square kilometres in central Kenya (Eastern Province). The area extends from the eastern slopes of Mt. Kenya to the eastern banks of Tana River.(See Fig. 1, 2 and 3)

The geological survey was carried out during six weeks between May and December 1985 as a part of a MSc thesis-research and was a part of The Training Project In Pedology of the Landbouw hogeschool of Wageningen (The Netherlands).The purpose of preparing the geological map and this report is to serve the soilsurvey carried out by the project named above by delivering a geological map and a geomorphological study of the project area.
The geological map should not be considered as a parent materials map, but with due reserve it can be used together with this report to derive the parent rocks.
The geological survey started with studying and making an interpretation of a Landsat image (scale 1:250,000) which also covers the area studied. This sattelite image was studied together with the geological reports on the geology of the area covered by the sattelite image. This resulted in a very general map of the area and its surroundings on which the major geological features are shown. A reduction of this interpretation is given in Fig. 3.
The geological map is a photo-geological map. The boundaries on the map are derived from aerial photograph interpretations (scale 1:50,000), and have been checked during the ground survey. Geological information was plotted in the field on the aerial photographs and where necessary the boundaries of the mapping units were adjusted to the field information.

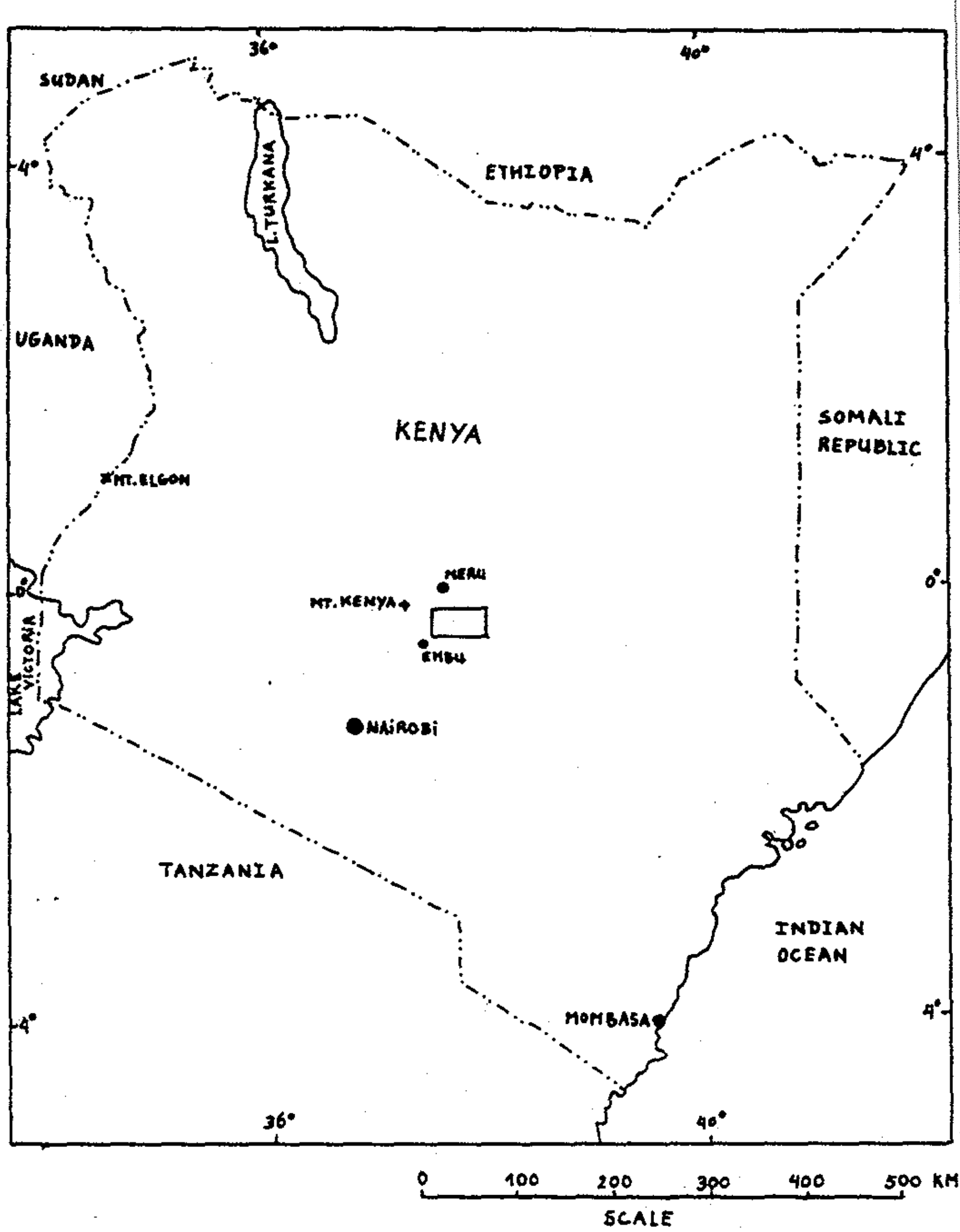


FIG. 1. -THE LOCATION OF THE CHUKA-SOUTH AREA IN KENYA.

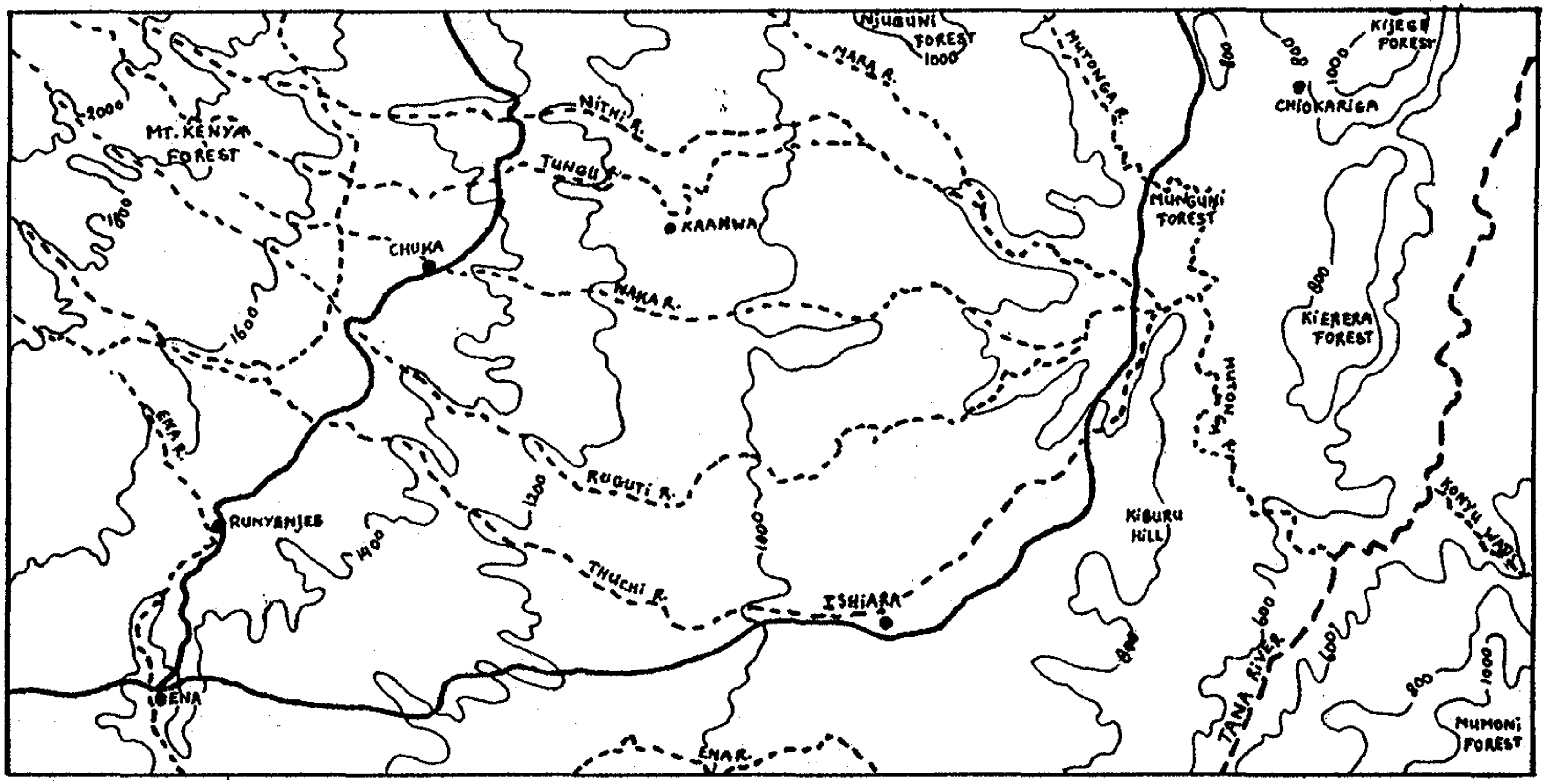


FIG. 2. -SIMPLIFIED TOPOGRAPHICAL MAP OF THE CHUKA-SOUTH AREA.
(This map is derived from the topographical map of Kenya, scale 1:250,000, mapsheet Chuka)

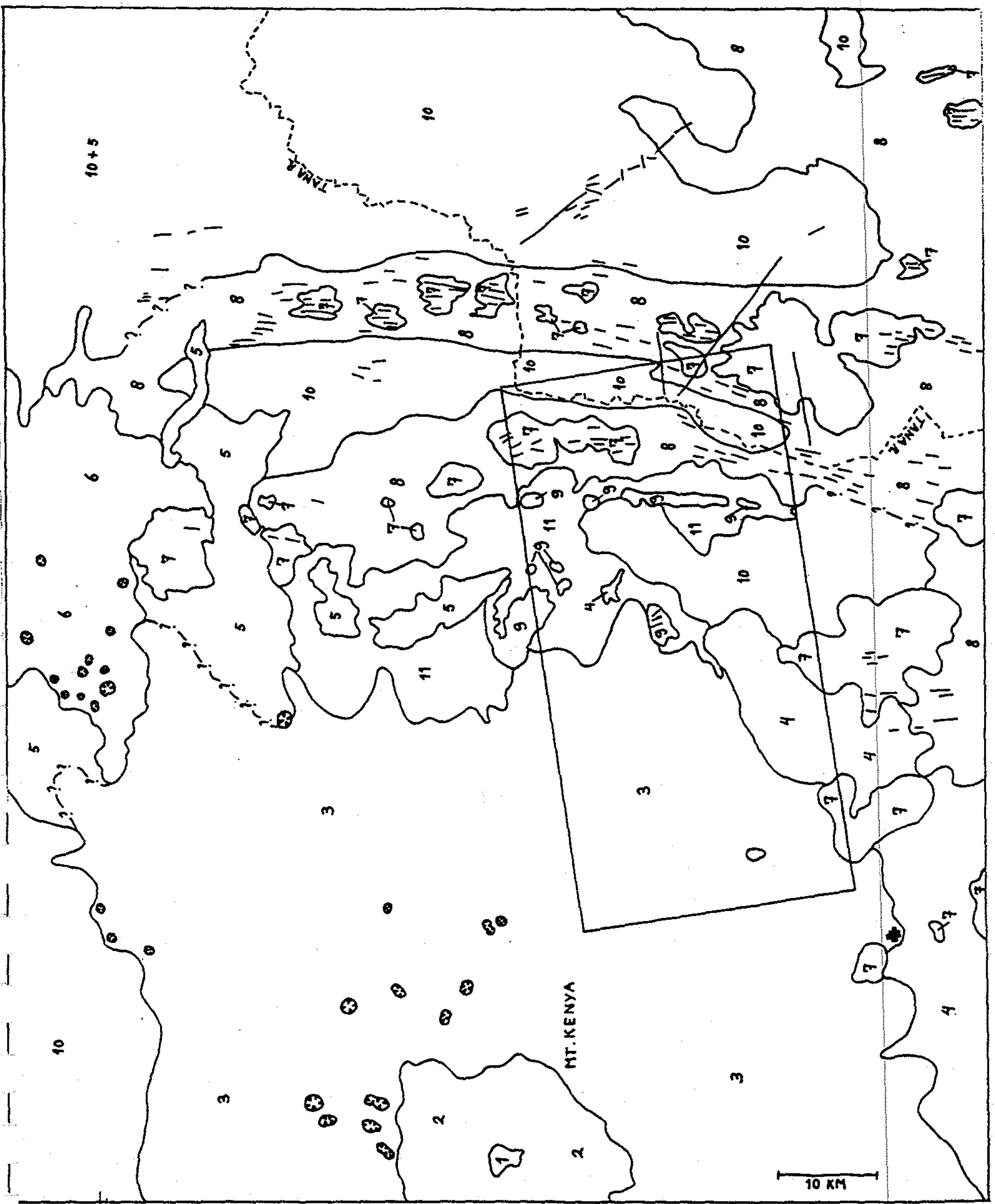


FIG. 3. -INTERPRETATION OF THE SATTELITE IMAGE.
The rectangle in the southern half of the interpretation is the Chuka-South area. For the legend see next page.

THE LEGEND TO FIG. 3.

1. Syenite plug.
2. Predominantly phonolites. (Bare rock, glaciers and Pleistocene moraines)
3. Complex of lahars and lavas.
4. Plateau-like lahars.
5. Nyambeni basalt plateaus.
6. Nyambeni multicentre volcano range.
7. Granitoids.
8. Granitoid rich zone.
9. Ultra-basic intrusives.
10. Banded complex of various gneisses and migmatites.
11. As 10. but with ultra-basic vein intrusions and granulites.

Craters.

Faults and joints.

The Physiography and Drainage of the area

The area is sloping from West to East. The highest altitude in the area is found in the north-western corner of the area. From this point with an altitude of about 2,200 m to the South-east the area comprises the eastern slopes of Mt. Kenya, which reflect the conical shape of the volcanic body. These slopes are steeply, sub-parallel dissected and run to an altitude of about 1,200 to 1,300 m. This area is drained by five major rivers which flow in gorge like valleys. These valleys are a part of the radial drainage pattern of the volcanic body. The rivers are fed by numerous smaller streams. In the southern part of the area a plateau like area extends from the 1,200-1,300 m contour-line further down towards the East where it ends at an altitude of about 1,000 m. Some of the large valleys mentioned above also dissect and drain this area.

In the northern part of the area such a plateau like area does not excist. Here a more sub-dendritically dissected area descends from the 1,200 m contour-line to the East to an altitude of about 900m. Also this part of the area is drained by some of the large rivers which also drain the first described sub-area. Numerous smaller rivers which feed these major rivers form a sub-dendritical drainage pattern in this sub-area.

The eastern part of the area is a less sloping strongly dendritically dissected area. This part of the area does not form a part of Mt.Kenya and its volcanic surrounding areas but is an area which mainly consists of the Precambrian metamorphic rocks of the Basement System. This area runs from about 900 to 1,000 m altitude in the West to altitudes of less than 600 m at Tana river valley in the East.The lowest point of the area is found at the very north-eastern corner of the area at a point called the Grand Fals. Here Tana river leaves the area via a series of imposing waterfalls and rapids.

The eastern part of the area is characterised by the many hills in this area. Most striking is the North-South range of steep and high hills which peak up to an altitude of 1,500m. West of these hills along Tana river, there is a lower North-South hill range. Also the eastern sub-area is drained by the same major rivers as the western sub-area but here these rivers do not flow through gorges as they do in the western, volcanic, sub-area. In the eastern sub-area the major rivers are not fed by perennial rivers as they are in the western sub-area but almost only by intermittent rivers . Only during the rainy seasons water flows in these intermittent rivers.

The perennial major rivers all water off in Tana river. So Tana river is the recipient of all the river water of the area

The Climate

The climate is strongly related to the physiography. The area is located at the wind-ward side of Mt.Kenya. This causes higher amounts of average annual rainfall in the higher, western part of the area. The longterm average annual rainfall exceeds 2,200 mm in the north-western corner of the area. The average annual rainfall decreases with the altitude towards the South-East. The lowest rainfall figures in the area are found in the Tana river region. Here the longterm average annual rainfall amounts less than 700 mm. Due to their higher altitudes the hills in the eastern region receive more rain than the average of the lower surrounding areas (See Fig. 4.).

The rainfall is concentrated into two rainy seasons. The first rainy season is from March to May with most of the rain falling during April. The second rainy season is from October to December with November as its wettest month. During the dry season from June to October some rain falls as drizzle during what is called the middle rains. (Rainfall data from the K.M.D.)

The evaporation increases from West to East. In the north-western corner of the area the annual potential evaporation is less than 1,650 mm. This amount increases towards Tana river up to 2,250 mm. (See Fig. 5)

This clearly indicates there is an excess of water in the western part of the area and a shortage of water in the eastern half of the area.

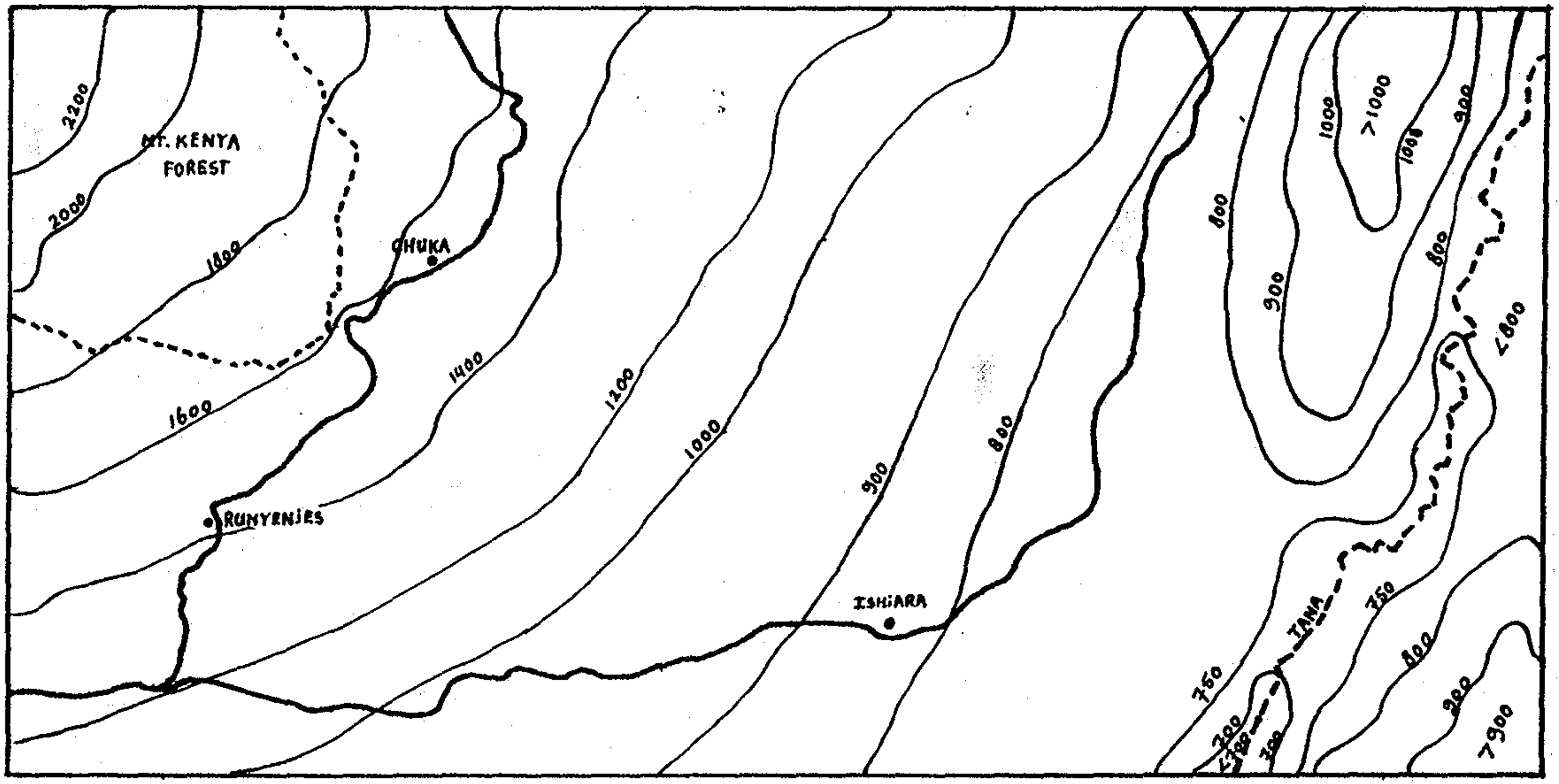


FIG. 4. -THE AVERAGE ANNUAL RAINFALL (IN MM) OF THE CHUKA-SOUTH AREA.

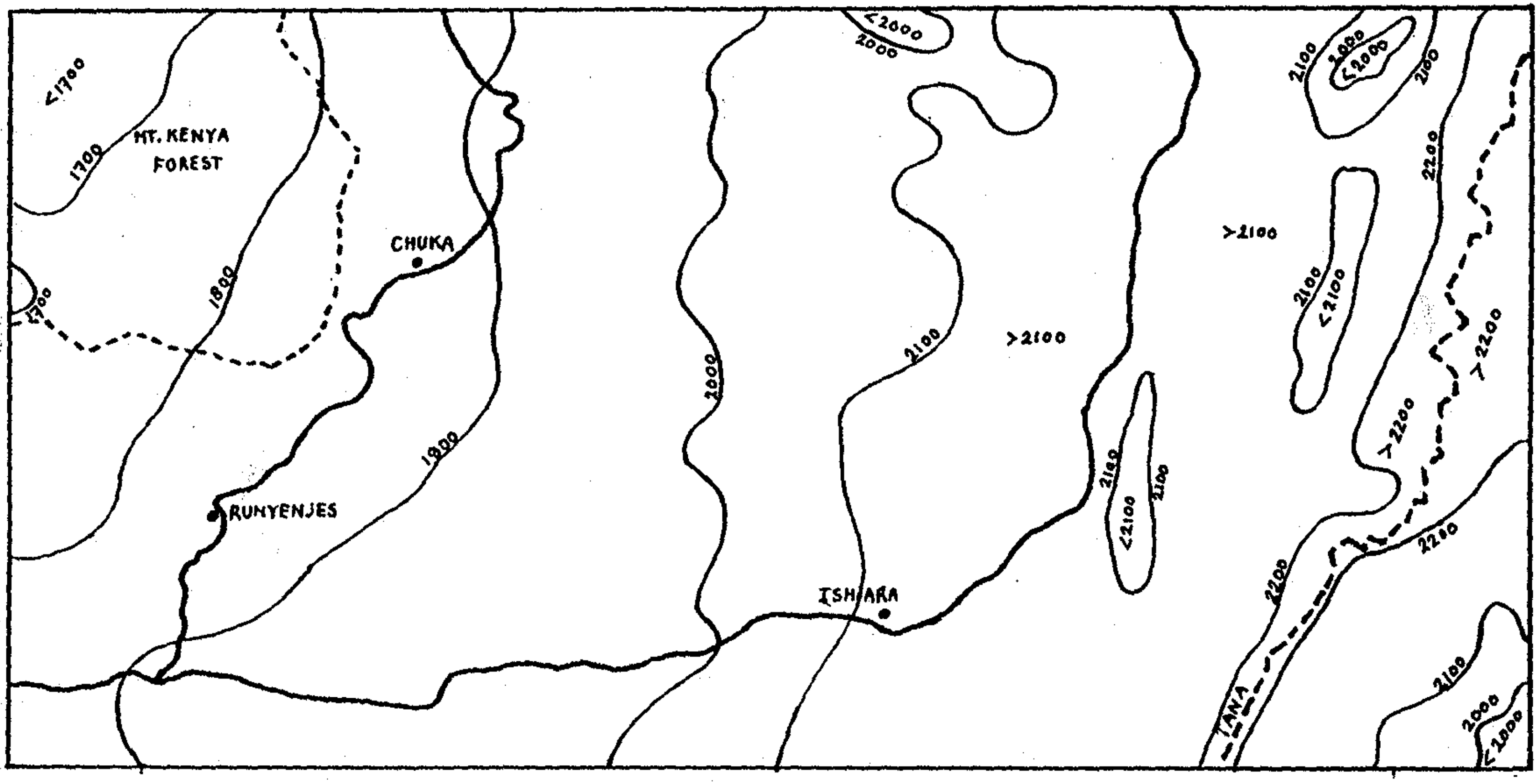


FIG.5.-THE ANNUAL POTENTIAL EVAPORATION (IN MM) OF THE CHUKA-SOUTH AREA.

The Vegetation

Also the vegetation changes from West to East. In the wettest, north-western corner of the area a part of the Mt.Kenya rainforest is preserved. This forest is bordered in the South and East by a zone where tea is the main cash-crop. Descending from this zone towards the 1,400 to 1,200 m contour-lines there is a zone in which coffee is the most important crop. In the plateau-like area there is a zone with mainly cropping of maize, beans, pigeon peas, cotton tobaco and mangoes. At the edge of the plateau-like area parts of the original Combretum savanna have been preserved.

In the eastern part of the area the vegetation is one of a drought resistant type; an Acacia bush savanna. Traditionally people cleared parts of this bush to grow sorghum and millet and where possible cotton. This was a shifting cultivation system. The parts of the area which lay fallow were used for grazing of cows and goats. The shifting cultivation system is rapidly changing into a more permanent cultivation system.

The highest hills are covered with a dense bush. Some hills are covered with a grass vegetation with scattered trees and shrubs.

As well as the physiography, the climate and vegetation show very close mutual relationships but they all show a close relation to the geology. The geology will be explained in the next chapters of this report.

2. THE GEOLOGICAL MAP UNITS

The two major features of the geology of Kenya are the Basement System and the Rift Valley with its accompanying volcanism.
Both the rocks of the Basement System and the volcanics related to the Rift Valley are found in the area studied. They form the two main components the area is built up from. This gives a bisection of the area into two sub-areas: the eastern part of the area with mainly the Precambrian Basement System rocks , and the western part with mainly the younger, predominantly Tertiary, volcanics from Mt.Kenya. This bisection is also used in the following sub-chapters in which the geological map units are described. A third sub-chapter is added, describing the predominantly Quaternary colluvial and fluviatile deposits. These deposits only cover a relatively small part of the area.

The units distinguished on the geological map are derived mainly from aerial photograph interpretations. The units have been distinguished on a petrographical basis. In the area studied there were remarkable good relationships between rocktypes, morphology, soils and vegetation in a large number of the units. For some units distinguished on the aerial photographs it was not clear if a boundary was a petrographical boundary or a soil or vegetation boundary. That is why the boundaries have been checked in the field. The ground survey was also necessary for giving accurate petrographical descriptions of the units, measuring strikes and dips, and taking hand specimens of the rocks. Sometimes petrographical boundaries were found in the field while these were not distinguished on the aerial photographs. These boundaries were traced back on the aerial photographs and where necessary and possible these boundaries were plotted on the map. Some boundaries are purely lithological, but most boundaries enclose units with a specific morphology, drainage pattern or other features which are related to the rock contents of that unit. The rock contents are described in the map-unit descriptions in the next sub-chapters.
The descriptions of the rocks are mainly macroscopically, but for some of the rocks descriptions of sections studied under the microscope already were available when preparing this report. In those cases these descriptions have been used. The other rocks will also be studied microscopically but the results of those studieds could not be included in this report yet.

2.1 The Basement System.

The Basement System forms a part of the Mozambique Belt. The Basement System comprises most of the Precambrian rocks of Kenya. The rocks of the Basement System are not the oldest rocks exposed in Kenya as its name suggests. The Nyanzian and Kavirondian Systems in the Southwest of Kenya comprise the oldest rocks. These rocks are of Archean age (2,700-2,300 my), while the rocks of the Basement System are of Katangan age (750-400 my). (10+22)
The rocks of the Mozambique belt originate from sediments deposited in a geosynclinal during the Katangan, the Upper

Precambrian of Africa. The Mozambique belt is strongly affected by tectonic disturbances during the Upper Precambrian. Orogenic events have upturned the remnants of the Nyanzian and Kavirondian Systems and have tightly folded the Basement System rocks.
In the period of the late Precambrian to early Paleozoic a more gentle orogenic took place.(22)
In addition to the major igneous rocks, the Precambrian is invaded by innumerable small masses and dykes which are from acid to ultra basic in character.(22)
The rocks of the Basement System have an approximate North-South orientation through Kenya. The crystalline rocks comprise principally various meta-sediments like schists, gneisses and marbles. Some of these metamorphic rocks are derived from volcanics. (22)

The units which have been distinguished in the Basement System area will be desribed in the following paragraphs.

2.1.1. Precambrian banded gabbroic-ultramafic complex (M)

M1:granulites, hornblende gabbro, talc tremolite complex

Field-occurence	This unit forms a large but not very high hill in the centre of the area. The slopes of the hill are gentle. The hornblende gabbros and granulites form low ridges. The talc-tremolite rock is only found in the lower parts in between the ridges. This partly discordant intrusive has a banded structure of hornblende gabbro, granulite and talc tremolite. (See Fig.6.) The strike in the western part is 345 and the strike in the eastern part is 45 in the whole unit the average dip is about 65^{o}W.Onthe aerial photographs a fault was observed but this fault could not be confirmed in the field. There are no extensive rock outcrops but the whole surface is covered with gravel and large boulders which indicate which rocktype can be found under the surface. The soils are very stony, clayey and brown and about 0.5 m deep. Most of the surface of this unit is covered with grasses and scattered trees.

Petrology

Granulites

The granulites in this unit are fine grained light grey rocks. The weathered surface is sometimes covered with rusty knobs. The rocks contain hypersthene, feldspars and quartz.
Towards the centre of the unit the granulites become darker and the rusty spots disappear. This type of granulite seems to contain much more hypersthene and less feldspars.

Hornblende gabbros

These black rocks, with greenish-blue weathering colours, consist almost completely of hornblende crystals. The average size of the hornblende grains of the gabbros in this unit is about 5 mm and rather angular. Plagioclase does occur as traces in these rocks.

Talc-tremolite rock

This rock type contains possibly also chlorite.
This soft silky irregular weathering rock with grayish green colours appears at the lower parts of the unit. The talc and tremolite (and chlorite?) is crystallized in flake like crystals up to 1 cm in diameter. The weathering colours vary from brown colours of conversions of spots of iron ore inside the rock to pinkish brown.
Although a variety of ultra mafics is found in this unit, no ores which can accompany this kind of intrusion were found in or near this unit.

observation no:037/094/095.
sample no:111/119/128/129/130.

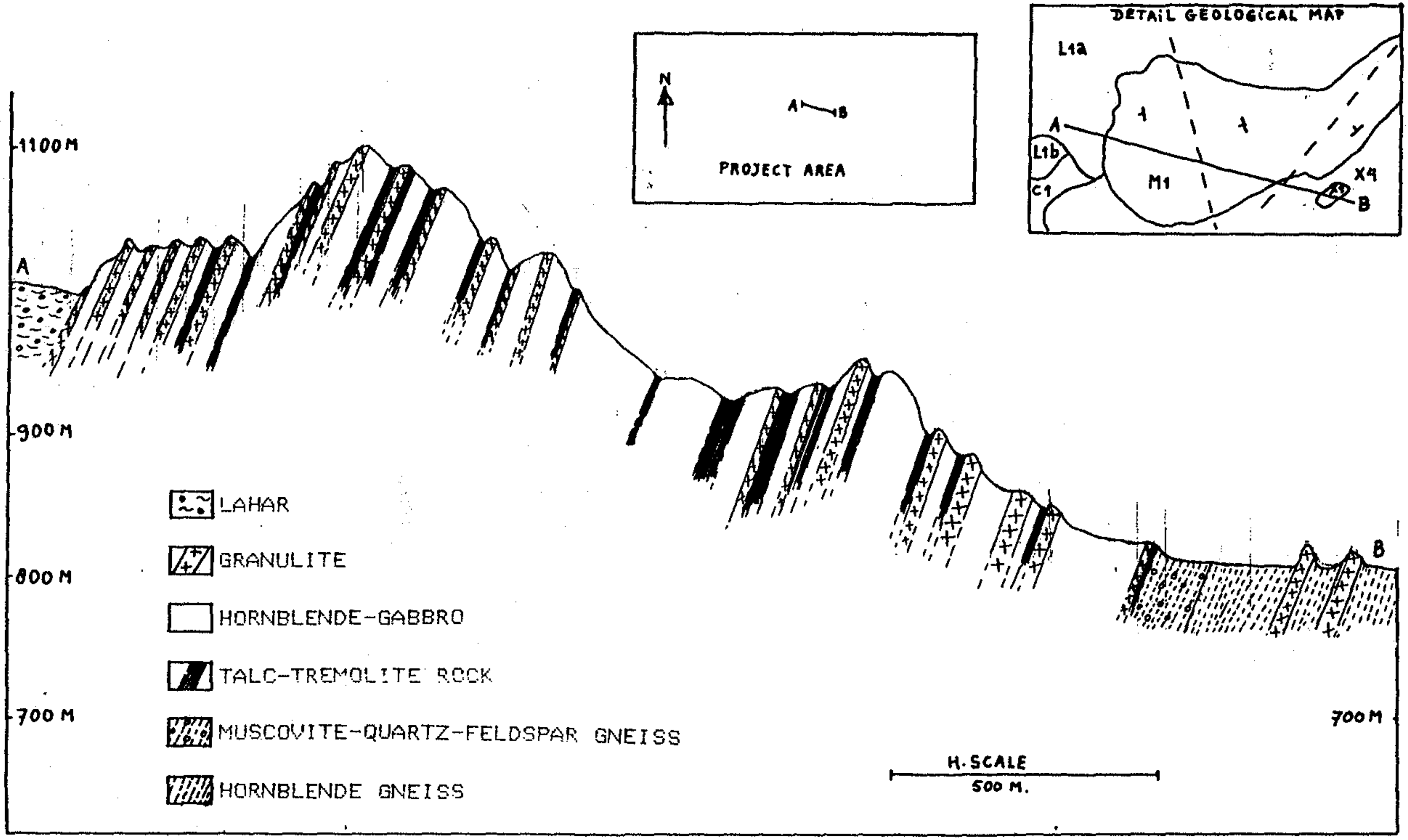


FIG. 6. -GEOLOGICAL CROSS SECTION THROUGH UNIT M1.

M2:Hornblende gabbro, talc tremolite, peridotite complex

Field-occurence	This unit consists of two cicular bodies which form small but high hills in the northern part of the area. The unit shows hardly any rockoutcrops. Hornblende gabbro and peridotite form the ridges (average strike 90),but the highest ridges are formed by a few augengneiss bands (average strike 0-10).The talc tremolite bands form steep straight valleys (average strike of the bands is 130). On the north-western slopes of Nandago hill, the southern part of this unit, chromite was found during the survey in association with the ultrabasics of this unit. The chromite occurs as residual deposits. The chromium ore has a lot of chlorite inclusions which makes the separation of the chromium from the chlorite difficult. Only two hills of this type were distinguished in the area. In this unit no granulite is found in contrary to the hornblende gabbro intrusions of all other M-units. As a compensation this unit contains a considerable amount of peridotite. The unit is dissected by two augengneiss bands which make this unit even more different from the other M-units. The augengneisses are not described here because these rocks are only an inclusion in this unit.
Petrography	Hornblende gabbro These gabbros contain larger hornblende crystals than those of M1. The diameter of the crystals can be more than 2 cm and the crystals are more spheroidal. Especially on the northern slope of Nandago hill these coarse grained gabbros form large boulders. Talc-tremolite rock This rock type contains possibly also chlorite. There are no major differences in macroscopic features with this type of rock from unit M1. Peridotite Locally this rock type is abundant in this unit. The weathered surface is brown to black and coarse. The rock itself is medium grained. The fresh cleavage surface is irregular through. The olivine crystals are shiny, glassy, brownish-greenish olivine coloured . The olivine crystals form the bulk of this rock. The diameter of the crystals is about 3 mm.

observation no:026/107.
sample no:075/076/077/109.

M3:Hornblende gabbro granulite complex

Field-occurence	This unit forms a hill range with no extensive rock outcrops on the slopes,and the hillcomplex Njuguni forest with some hills south of Njuguni Forest. The Njuguni Forest hill complex has a dense grass cover while on the eastern hill range a dense Acacia Commifera bush is observed. This is a striking difference for which no explanation is found yet. Probably this difference is related to the lithology, but more likely is that this is an anthropogene influence. This unit consist predominantly of granulite with hornblendegabbrobands in the centre of it.Thefew rock outcrops are the more weatheringresistant granulite or quartz pegmatites. The pegmatites are concordant. The lower slopes of these hills are formed by a considerable amount of hornblende-plagioclase gneiss. A subdivision can be made in this unit: -The western discordant intrusives, which are the Njuguni Forest complex and the smaller Twanguku hills (South of the Njuguni Forest, along the road from Chuka to the eastern intrusives). Their strike ranges from 270^{0} to 90^{0}. They are much alike unit M1. -The eastern concordant intrusives, which are more alike unit M2 ($350/70^{0}$W).
Petrography	Hornblende gabbros Macroscopically there are no differences with the hornblende gabbros of unit M1. For description of this rock type see M1. Granulites These granulites resemble the granulites of unit M1 macroscopically. The most important difference between units M1 and M3 is the sequence of rocks in the units. While in unit M1 there is a clear succession of granulite and gabbro bands in unit M3 there seems to be nucleus rich in gabbro bands with a wide halo consisting of granulites, which become lighter to the borders of the unit and which are dissected by pegmatite veins.

observation no:034/074/092/078/092/106/119/122.
sample no:134/135/136/144/145/146/147/148/149.

M4:Predominantly hornblende gabbro with granulites

Field-occurence	This unit forms small ridges and hills in the neighboorhoud of larger M-units. These units are small ultra mafic intrusives. They almost completely consist of hornblende gabbro with a small amount of granulites Some have talc-tremolite bands which form the lower parts of the unit. Granulite is not as predominantly as in unit M3. The granulites are mostly observed along the boundaries of the units.
Petrography	Hornblende gabbros These gabbros resemble the gabbros of unit M1 in macroscopical characteristics. This unit consists almost only of hornblende gabbros with a small amount of granulites, in contrary to the units M1 and M3 where the granulites seem to have a more prominent role. Granulites These granulites resemble the granulites of unit M1 in macroscopical characteristics.

observation no:091/113.
sample no:127/139/140.

2.1.2. Granites and granitoid gneisses (G)

G1: granitoid rocks and granites amidst Mt.Kenya volcanics

Field-occurence	These granitoid complexes are Basement inselbergs protruding from the Mt.Kenya volcanics in the western part of the area. This unit exhibits hills with steep slopes on which rock outcrops are common. The inselbergs are remnants of a former mountain range with a strike of South to South-west to North to North-east. Now adays only the higher peaks form the hills in the lahar complex. The range resembles the Kijegge-Kierera Forest range along Tana river. The agriculture in this unit is not as intensive as in the surrounding area. On one of the peaks a remnant of the natural vegetation is preserved, on other peaks trees are planted.
Petrography	Granites These granites are coarse-grained and have a granitic texture. The granites of the Kirimiri forest are the coarsest-grained granites. This granite consists mainly of quartz and pink feldspar while the other finer-grained granites consist of equal amounts of quartz and white feldspar with a smaller amount of hornblende. Augengneisses The granitoidgneisses in this unit are mainly augengneisses. They consist of medium- to coarse-grained quartz and feldspar with more or less orientated hornblendes and biotites and scattered through the rock larger feldspar megacrysts. In this unit also many pegmatite and some aplite veins occur.

observation no:007/018/043/044/045/046.
sample no:011/012/038/122/123/125/126.

G2:predominantly granitoid gneisses

Field-occurence: This unit exhibits hills and sometimes forms a hilly complex in the southern part of the area and West of the Kijege-Kierera Forest area. The unit West of Kijege-Kierera Forest comprises a rolling to hilly landscape with many incisions . These granitoid rock complexes consist predominantly of granitoid gneisses (strike 350-360) with many pegmatite veins. Augengneisses form ridges or small hills.

This unit crops out in two widely seperated regions:The hills South-west of Ishiara and the large area along Kijege - Kierera Forest area and Tana river.
The rocks near Ishiara are more migmatitic with a large granitoid component. The migmatitic rocks consist of very fine granular quartz and feldspar with hornblende and biotite in very thin bands winding through the rock.
The granitoid gneisses of the Kijege-Kierera Forest area are mainly quartz-feldspar-mica gneisses. Between these gneiss bands of more granitic composition, bands of hornblende-plagioclase gneisses occur. These bands are inclusions in this unit although they form a more important component in the northern part of the unit.

Petrography — Granitoid gneisses
The granitoid quartz-feldspar-mica gneisses are composed of fine grained quartz and pinkish white feldspar with no preferred orientation. Scattered through the rock there are parallel streaks of well orientated micas, predominantly biotite. Maybe the name gneissose microgranite is more appropriate for this kind of rock.
The granitoid gneisses of the western part of this unit have a coarser grain size.

observation no:039/62/089/109/110/111/114/127.
sample no:70/71/137/138/152/162/163.

G3:Predominantly gneissose granites

Field-occurence — This unit exhibits small hills within the granitoid gneisses area West of the Kijege-Kierera Forest area and in the gneisses area between this area and Mumoni Forest.
This unit consists of gneissose granites and some bands of augengneisses.
Many rock outcrops, especially at hill summits and tors, appear in this unit. The average strike is about 0.

Petrography — Gneissose granites
These granites resemble the granites of G5

macroscopically in composition and texture. Only in this type of rock more micas with a preferred orientation occur.

observation no:034/123.
sample no:107/121/138.

G4:Granodiorites and migmatites

Field-occurence

This unit South of Ishiara is a granodiorite intrusion with many joints and faults. Along the boundary of the unit the migmatites are predominant.
This complex forms a higher part of the the Basement System area. The summits of this unit are about 100m higher than the surrounding gneisses-migmatite area. The river Ena has cut a deep valley with steep slopes along a fault in this unit. In this area amphibolite bands and quartz veins are found. The hills are formed by granodiorites and the tors are usually formed by dioritic migmatites. In the area many discordant pegmatite vein intrusions and dolerite veins occur. Also concordant talc-tremolite bands occur and form ridges like the granitoid bands(strike 20).The lower parts of this unit are formed by various gneisses, usually hornblende plagioclase and biotite gneisses.

Petrography

Granodiorites
Black and white mottled coarse grained rock with granite like rounded off weathering shapes.
The rock consists of feldspars and hornblende which form the bulk of the minerals. The grainsize is a few mm up to 7 mm. The texture is granitic although the granodiorites near the border zones show slightly preferred orientation of the hornblendes

Migmatites
In the border zone of this unit the migmatites are abundant. This rock also tends to form rockoutcrops and tors with smoothly weathered surfaces and spheriodal boulders.
The migmatites consist of narrow bands with amphibolitic composition succeeded by light bands mainly consisting of quartz and plagioclase. The migmatites have a medium fine grain size. These rocks show a very bizarre folding and warping.

observation no:028/072/133/134/135.
sample no:087/088/089/90/164/165/166/167.

G5: Granites

Field-occurence	This unit forms the high mountain ranges as the Kijege-Kierera Forest area and Mumoni Forest. These hills form the highest parts of the Basement area. The hills exhibit steep slopes with many rock outcrops and tors. The hills form inselbergs wich peak up to altitudes of about 1,500 m. The parts above an altitude of 800m show a typical sugar-loaf appearence. The many straight valleys follow the courses of lineaments like joints and possibly faults. This unit consists predominantly of granites. The highest parts in the centre of the units consist of granites. Augengneisses and granites are usually found in discordant and concordant bands.
Petrography	Granites These granites form large rockoutcrops with very steep slopes. The massive outcrops have smooth surfaces which weather spheroidal. Scattered through the whole unit tors occur. The granite is coarse grained and has a granite texture. The bulk of the minerals is quartz and pinkish white feldspars (probably orthoclase). A large amount of the quartz is yellowish coloured. Scattered through the rock small biotite crystals occur. The intrusive granites are surrounded by a boundary zone of many metamorphic granitoid gneisses and migmatites. These rocks are fine grained and have a clear differentiation of bands mainly consisting of quartz and hornblende with feldspar. In between these bands there are narrow bands rich in biotites with a prefered orientation parallel to these bands.

observation no:082/116.
sample no:142.

2.1.3.The Banded migmatitic gneisses complex (X)

NOTE: This unit consists of sequences of banded gneisses and the various migmatitisation products of these gneisses. The units X2, X3, X4, X6,and X7 do not differ very much in the bulk of their rock types but a differentiation is made with respect to the types and amounts of the occurences of other types of rock, different from the main types of rocks. These different types of rocks are mainly the products of various degrees of metamorphism of the country-rock, like granitoid rocks and granulites, but also intrusive rocks, like hornblende gabbros.
The units X1 and X5 do differ clearly from the other X units and from each other. These units do have different types of rock which form the bulk of the rock types in these units but do belong to the banded migmatitic gneisses complex.

X1:Granulites

Field-occurence	This unit forms small steep hills without a soil cover on the slopes and a granite like appearence. These small hills occur scattered amidst the X4, X6 and X7-units but most of them are concentrated in the centre of the area. The steep hills consist mainly of granulites. Another type of rock which is common at the edges of these hills are migmatites. The migmatites transform gradually into granulites. These units are the spots where the surrounding country-rock is highly metamorphised.
Petrography	Granulites The rock has a fine grain size and is dark grey. It consists of hypersthene, clinopyroxeen, hornblende, biotite, plagioclase and quartz. Along the border of each part of the unit more migmatitic like granulites appear. These granulites have narrow bands rich in dark minerals with a prefered orientation.

observation no:012/036/075/096/098/099/100/105.
sample no:024/068/110/112/114/131/132/133.

X2:Hornblende-plagioclase migmatites with granitoids and some granulite bands

Field-occurence

This unit occurs in a rolling area just North of the centre of the area. This unit contains granitoids and granulite bands which form some ridges in this unit. The matrices in between these bands are the migmatised hornblende gneisses which form about 50% of this unit.In quartz pegmatite vein intrusions large tourmaline crystals are found.

Petrography

Migmatites

The migmatites are very dark and have a fine granular texture. In the normal type of migmatites the dark hornblende rich bands are very thin and are succeeded by thin bands consisting of quartz and feldspar. Both types of bands are intensely folded.

Large parts of the migmatites are more granitic. These parts are more coarse grained and irregular. Although the hornblendes still have a preferred orientation, the banded character is disturbed by larger patches of the quartz-feldspar mixture.

Locally the granitoid-like migmatites have a granulitic appearance. These parts tend to form outcrops like tors.

observation no:124/125/131.
sample no:156/157/158.

X3:Sequence of various banded gneisses with granitoid bands

Field-occurence

This unit is situated in a rolling area with only minor incisions of intermittent rivers. Tors and hills of granitoid rocks are very common in this area. The unit is situated East of the Kijege-Kierera Forest area and North and West of the Mumoni Forest area. This unit comprises a very varied sequence of gneisses and granitoid gneisses. The succession of hornblende-plagioclase gneisses with augengneisses with many aplite and pegmatite vein intrusions seems to be the most common sequence in this unit. Also some small hornblende gabbro and talc tremolite vein intrusions were observed. The latter were always concordant. Plagioclase muscovite granitoid gneisses are also part of the banded complex (average strike and dip (350/50^{o}W)) There are many

rock outcrops especially formed by the vein intrusives.
In the northern part of the unit the granitoid gneisses form the bulk of the rocks.
There are near Mumoni more hornblende gneisses which are partly migmatised. Also biotite gneiss and amphibolite bands are common on the East of Tana river.

Petrography

Hornblende-plagioclase gneisses
This type of rock is relatively soft and easily weathered. This makes it difficult to find fresh specimens of this rock type. In the field it can be seen in river incisions and in road cuts as rounded, blue-greenish, clayey weathered rocks. The rock is fine grained and consists of a alternation of very thin hornblende and quartz-plagioclase bands.

Granitoid gneisses
The granitoid gneisses are coarse grained and contain only small amounts of ferro-magnesian minerals. Sometimes muscovite is abundant. Among the minerals quartz and plagioclase are the most important. The rock has a granitic structure but the ferromagnesian minerals and micas have a prefered orientation. The weathering products of these rocks are light coloured and more sandy with coarser fragments.

Other gneisses
Other gneisses in this unit are e.g. quartz-feldspar-muscovite gneisses, which also contain sillimanite. Also other sillimanite-garnet-muscovite-biotite are found especially in the southeastern part of this unit. Except a large amount of sillimanite and garnet this rock probably also contains graphite.

observation no:011/031/115/117/118/123.
sample no:019/020/021/026/027/029/030/058/059/060/097/098/099/100/106/113/141/143.

X4:<u>Hornblende plagioclase gneisses with migmatitic and granulitic bands</u>

Field-occurence

This unit is situated in an undulating to rolling area. It comprises a large part of the Basement System area in the centre of the area and in the northern part of the area between Njuguni Forest and Mutharanga Forest.In this area there are more and larger river incisions and some terrace remains can be found along these rivers.
This unit consists predominantly of hornblende

plagioclase gneisses(330/45°-100°W).There are many discordant and concordant granulitic and pegmatite bands and vein intrusives. The granulites form ridges in the area, near unit M2 there are many migmatitic bands.Near unit M3 granulite ridges occur.

Petrography

Hornblende-plagioclase gneisses
These gneisses have been described for unit X3. The macroscopic characteristics of this type of rock do not differ in these two units. For description of this rock type see X3.
At some places this type of rock is darker and more amphibolite like but the hornblendes do not show any prefered orientation.
The migmatitic bands in this type of rock are the more weathering and erosion resistant parts of the rock. This type of rock forms most of the outcrops in this unit. The rock is more coarse grained. The light bands consisting of quartz and feldspar are better seperated from the darker hornblende containing bands although the banding is not very clear. The granulitic type tends to form hard boulders and is probably containing hypersthene. This type is only common in the neighbourhood of the ultra basic intrusives.

observation no:005/052/101/102/103/104/132.
sample no:068/159.

X5:<u>Hornblende-, biotite-, and hornblende-biotite gneisses and migmatites with dolerite veins</u>

Field-occurence

This gneiss complex South of occurence Ishiara is an undulating area in which many small intermittent rivers have incised. On the higher parts migmatite tors are common. The unit is sloping South East. The altitude in the NW is about 860 m and in the SE about 680 m.
The banded gneiss complex (strike 10°) contains hornblende gneisses, biotite gneisses, biotite-hornblende gneisses and migmatites. The migmatites and granitoid gneisses form the tors. Close to unit G4 the granitoid and migmatite component increases. In the complex are concordant talc-tremolite and granitoids bands. These bands form ridges in the gneiss complex. Throughout the whole area are concordant and discordant pegmatite and dolerite vein intrusions. The pegmatites in the southern part contain a considerable amount of magnetite which has been used for iron production during former times.

Tourmaline is also a mineral that can be found in these pegmatites.

Petrography

Hornblende plagioclase gneisses
These gneisses have been described in unit description X3

Biotite- and hornblende-biotite gneisses
These gneisses are medium fine grained. The dark biotite-plagioclase bands alternate with light quartz-feldspar bands. The latter are more coarse grained. The quartz can form clods up to 7 mm in the light bands

Migmatites
These rocks have the same composition as the gneisses described above. The bands are stronger folded and the bands do not have very clear boundaries. The grainsize is more homogenous medium-fine throughout the rock. These rocks are more weathering resistant than the gneisses and form most of the tors in this unit.

Dolerite veins
The dolerite veins in this unit do not have a large extent but are so common in the unit that a description should be given here. Most veins have a width between 0.5 and 2 m. and are extended over lengthes of sometimes more than hundreds of metres. The veins form low ridges in the eroded landscape. Where the dolerites are exposed the soils are darker coloured or the surface is covered with fragments of this rock. The dolerites consist of very fine grained hornblende and plagioclase with a clear preferred orientation which gives the rock a shale like appearance.

observation no:002/006/015/032/033/058/059/060/061/136.
sample no:002/003/016/032/091/103/104/105/168/169/170/171.

X6:hornblende gneisses with some hornblende gabbro veins and granulite bands

Field-occurence

This unit is situated in an undulating area around and in between the M-units. In this unit the gabbrobands, and other vein intrusions form low ridges or small hills. Many intermittent rivers dissect the area.
Hornblende gneiss is the most common rock type. But there are many small (mostly concordant) hornblende gabbro bands with accompanying granulites and dolerite and pegmatite vein

intrusions. The average strike of the hornblende gneisses is about 20.

Petrography

This unit is composed of rocks which already have been described in other unit descriptions. For description of these rocks see previous pages.
Hornblende gneiss see X3
Gabbros see M1
Dolerite see X5
Granulites see X1

observation no:016/030/090/093/108.
sample no:036/079/096.

X7:hornblende gneisses with hornblende gabbro veins

Field-occurence

This unit comprises a flat to undulating area in which many intermittent rivers have incised. Most of the rock outcrops occur in these valleys. The tors and ridges are granitoid rocks or vein intrusives.
In this hornblende-plagioclase gneiss unit many pegmatites, aplites granitoids and hornblende gabbros occur between the gneisses. Mostly the rock outcrops are the vein intrusives which form the higher parts in the area. (5/65^{o}W).

Petrography

The rocks comprised in this unit have been described in the previous unit descriptions.
For hornblende plagioclase gneisses see X3
for hornblende gabbro see M1. The hornblende gabbro veins in this unit seem to form the further extented intrusive veins of the large intrusions M3. Between the different parts of unit M3, in this unit concentrations of hornblende-gabbro veins are found which seem to form the connection between the highest parts of the M3 unit.

observation no:009/021/022/023/024/038/050/120/121.
sample no:017/022/023/053/054/055/056/057/061/062/063/064/120.

2.1.4. Quartzites and muscovite schists (Q)

Q:Quarzites and muscovite schists

Field-occurence	This unit is only found in the south-western part of the area. The quartzites build up a hill, while the schists, which are more weatherable, form the lower parts in these Basement System islands in the lahar complex. The schists are usually protected by surrounding more weathering resistant rocks, such as quartzites and granitoid gneisses. Banded quartzites and schists are especially well exposed at Karue hill. Here the sequence is quartzite bands (10-100cm), schist bands(5-10cm) and so on.(33/40^{o}W).
Petrography	Quartzites This is a medium fine grained, low grade metamorphic rock, which is mainly composed of quartz grains. The quartzites resemble a single band of sand in the Precambrian sedimentary series. It is composed of a series of bands of rock which forms one prominent outcrop in the area. Muscovite schists This rock is mainly composed of thin flakes of muscovite. Scattered through the whole rock smal garnets occur. The rock is also a low grade metamorphic rock. The rock is very easily weathered and very brittle and soft. The only outcrops are found in between the quartzite bands (Karue hill), at very steep slopes (Kirimiri Forest) and in a road cut (most southern occurence).

observation no:001/042.
sample no:001/004/039/040/041/042/043/044/067.

2.2 The volcanic rocks.

The volcanic deposits of the Chuka South area are closely related to the Rift Valley developement.

The Rift Valley in Kenya forms a part ofa belt of faults extending 4,000 km south-southeast from the junction of the Red Sea and the Gulf of Aden to the Zambezi River. The pattern of this system of rift valleys and block faults follows the grain of the Precambrian rocks. From Mbeya (Tanzania) two branches of the main rift system are clearly distinguishable. An eastern branch is running north-northeasterly around the southern border of the Tanzanian Shield through Kenya and Ethiopia to Djibouti. The western branch extends from Mbeya to Uganda. The central part of the eastern rift in Kenya is called the Gregory Rift. (1+15+19)

During the Pliocene numerous central volcanoes along the Gregory Rift were active. At about this time the broad shield volcano, of which Mt. Kenya is a remnant,was built up about 75 km East of the rift.
The main activity of the Mt. Kenya volcanism was during the Pliocene (3.5-2 my bp). (2) Partly contemporaneous with this activity was the activity of the Nyambeni multicenter volcano range which activity lasted from the Pliocene to Recent (4.5-0.5 my bp). (2+6) While the Nyambeni volcanoes produced mainly basalts, Mt. Kenya produced phonolite flows, and later more trachytic lavas from parasitic vents and fissures. (2+6)
During the Pleistocene a series of parasitic vents developed on the northeastern flank of Mt. Kenya from where basaltic lavas erupted contemporaneous with basaltic flows from the Nyambeni range. (4+6)

2.2.1. Phonolite flows (P)

P:Phonolite flows

Field-occurence	These inverted phonolite flows (see Fig. 11.) form narrow elongated ridges in the Basement area. On their slopes usually there is a colluvial deposit (C1). The phonolites show columnar jointing and their phenocrysts parallel to the flow direction. Below the phonolite cap sometimes fluviatile deposits are found. These fluviatile deposits are indicated by ooooo on the map.The phonolite flows have many rock outcrops on top.

Petrography Phonolites

Dark blueish black ground mass with many phenocrysts. Sometimes the phenocrysts form half of the bulk of the rock. The ground mass is very dense and very fine granular, it is built up from parallel plagioclase lathes. The phenocrysts are large nepheline and sanidine crystals. The phonolites from the phonolite flows are not very vesicular, but the phonolite boulders from the lahars can be very vesicular sometimes with calcite fillings.

observation no:008/064/073.
sample no:014/078.
(ooooo):080/081.

2.2.2 Complex of lahars and lava flows (L)

L1:Complex of lahars and lava flows

Field-occurence

The lahar complex area can be devided into 2 sub areas:

- -the more steeper, more strongly dissected, western part **(L1a)**
- -the more flatter, less dissected, plateau like, eastern part **(L1b)**

L1a:

In this area in the deep valleys with steep slopes rock outcropsoccur. These rock outcrops are of a firm dense lahar type. At some spots falls occur.These falls occur where the river broke throught the firm, dense lahars and incised into the softer underlying lahartypes.
A loose, porous lahar can only be observed in roadcuts since this lahar type is more weatherable and therefore under natural conditions covered with soil or eroded away. (See Fig. 7. and 8.)
Nowadays the parent material of the soils is the lahar, but in former times it must also have been volcanic ashes which are completely weathered now.

L1b:

In this unit only at the major incissions of the Thuchi, Ruguti, etc and near the scarp rock outcrops occur. The rockoutcrops are of a firm dense lahar type. The boundary between this unit and the Basement System terrain is in the southern part an scarp (up to 100 m high).

The lahars form the bulk of the rock types in this unit and often enclose boulders of many different rocktypes.
The lava flows, usually phonolite, (see Fig. 8.) are not very common. They are mostly narrow, thin and elongated flows, surrounded on all sides by lahars. Only one basalt flow has been observed at the bottom of the Nithi valley.
Other kinds oflava flows have not been observed.
The lahars contain boulders up to 5m (cross section). Usually these are phonolite boulders but also other kinds of trachytes are common. In the northern part of the area the lahars contain also large granite and granitoid gneisses boulders which resembles the granite of Gl.
Fossilised wood is also common in the lahars.

Petrography

Lahars:

:The lahars can be devided into 2 classes.

- the loose, porous lahars
- the firm, dense lahars

The latter has the appearance of a lava flow, and forms outcrops with a rounded out surface. The loose, porous lahars which have a more mudflow like appearance, get instable when saturated with water.

The firm dense lahar is the most prominent one. This rocktype shows a large variation in composition.

The ground mass is usually dark gray to brownish gray and extremely fine grained.

The dense groundmass probably originates from ashes. The groundmass contains angular and rounded fragments of other rock types with diameters ranging from afewmm to a few meters. These fragments are predominantly phonolite and trachyte but locally also Basement System rocks and wood occur. Locally vesicles with zeolite and calcite fillings occur.

Phonolites:

see description in unit P

Trachytes:

The trachytes in the lahars contain microphenocrystics, have a fluidal structure with interstitial glass between the plagioclase lathes. The microphenocrysts are composed of basic plagioclase, olivine and augite. The trachytes can be slightly vesicular.

observation no:004/013/014/017/019/020/027/035/039/040/047/048/049/053/054/055/056/057/063/066/067/076/081/083/084/085/086/087/088/128/129.

Bottomlands:068/069/070/071.

sample no:006/007/008/009/010/013/025/031/033/034/035/037/045/046/047/048/049/050/051/052/072/073/074/082/083/084/085/086/108.

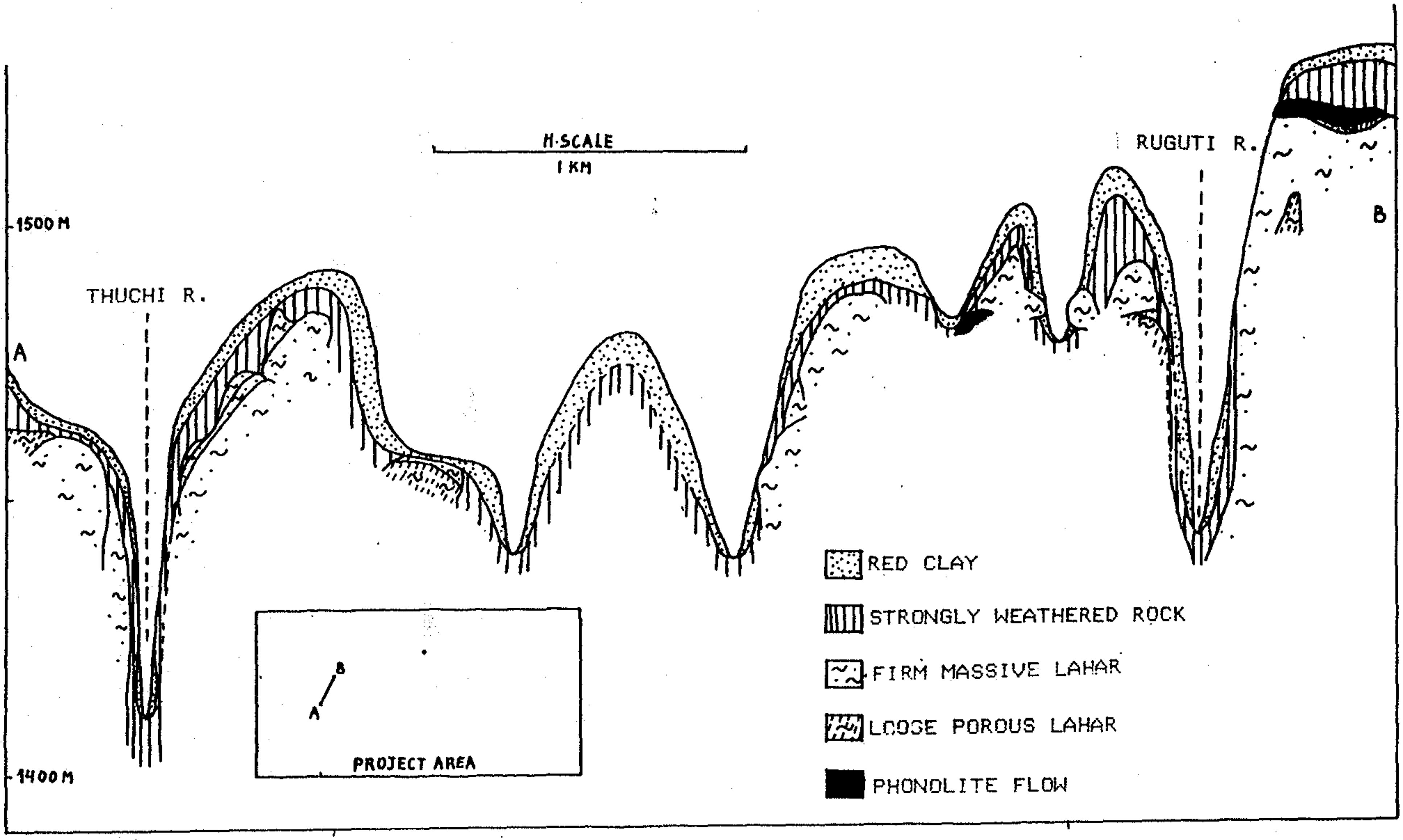


FIG. 7. -CROSS SECTION THROUGH A PART OF THE UNIT LIa, THE SLOPING LAHAR AND LAVA COMPLEX.

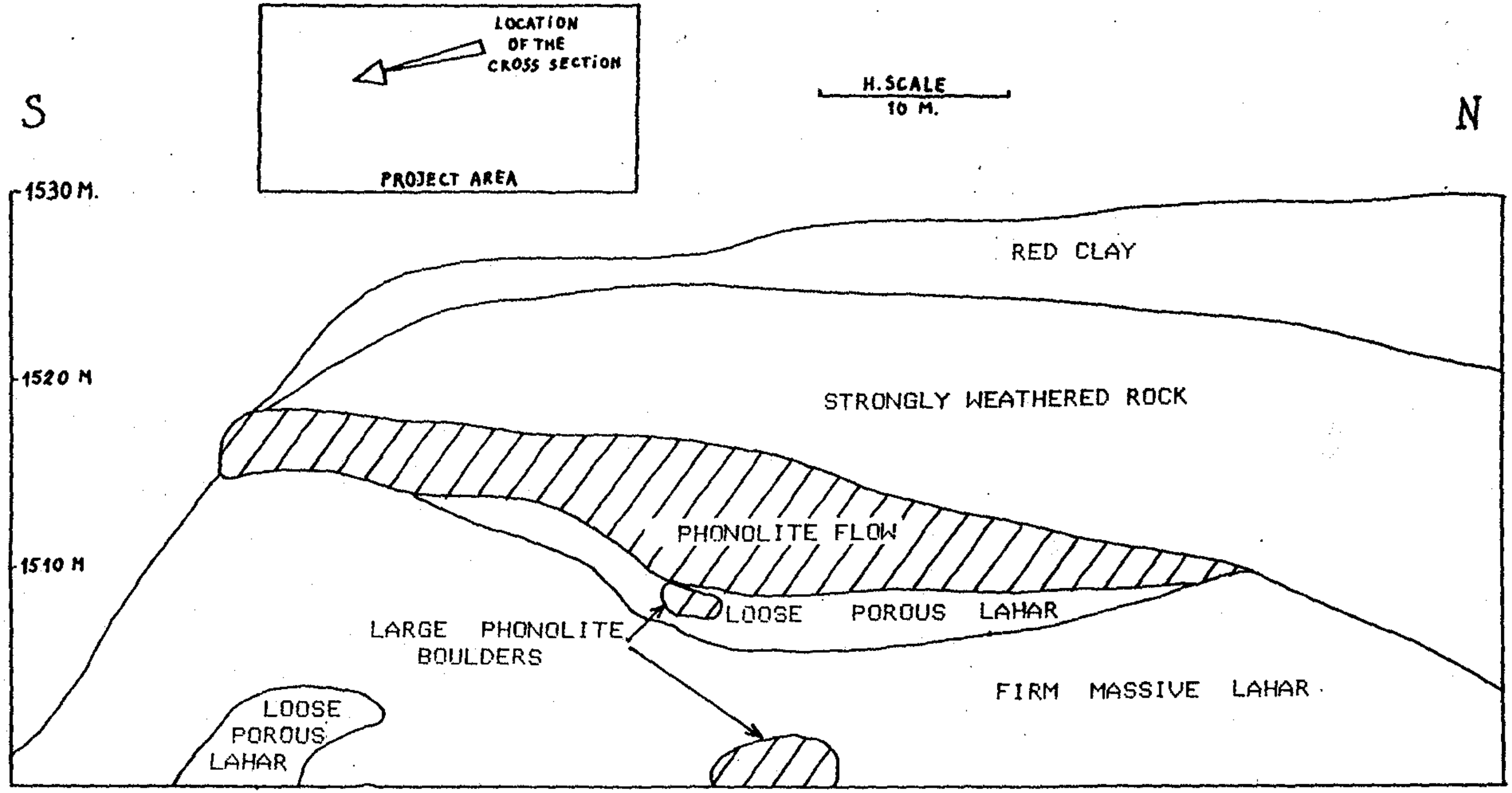


FIG. 8. -DETAIL OF FIG. 7., A PHONOLITE FLOW ENCLOSED BY LAHARS.

L2:Lahar complex which is overlying a granitoid complex

Field-occurence	This unit forms the higher parts of the lahar complexarea.Theunit canberecognised by the rock outcrops and the less denser vegetation on its middle slopes. On aerial photographs the change in drainage pattern is very striking. The L2 hills disturb the radial drainage pattern of Mount Kenya. The L2? area is probably the same as discribed above but it is situated in Mount Kenya forest and covered with a thick soil and therefore difficult to make observations. Probably the lahar thickness is many meters. The lahar thickness is often more than 10m. The rock outcrops of the granitoids and granites are mostly found on the steeper middle slopes. The lower slopes consist mainly of lahar from the surrounding lahar complex.
Petrography	Lahars See lahar description L1 Granites See granite description G1

observation no:041.
sample no:-

2.2.3. Nyambeni basalts

B:Nyambeni basalts

Field-occurence	Theseparts of the basalt flow whichshow an inversion of the relief are flat areaswhichform small plateaus in the Basement System area. These olivine basalts have an average thickness of 5 m. They are usually overlying fluviatile deposits (indicated with oooo). These basalts belong to the Nyambeni basalts. The nearest vent is about 20 km North of Njuguni forest. The flow has followed the former Mutonga valley and ended at Tana river.
Petrography	Nyambeni basalts These basalts show a columnar structure. They are dark grey and have sparse phenocrysts (greenish brown olivine). The phenocrysts are mostly smaller than 0.5 mm butarefoundup to2 mm.Thereare minute vesicles which sometimes contain a zeolite like material. The groundmass is dark grey. Extremely small brown mineral grains of groundmass size appear in the ground mass.

observation no:003/025/112.
sample no:005/070/071.

2.3 Colluvial and fluviatile deposits.

The fluviatile deposits are subdivided into two maingroups:
-The buried fluviatile deposits
-the terraces deposits

The buried fluviatile deposits

These fluviatile deposits are indicated by ●●●●● and ooooo on the geological map (See appendix 1).
These deposits are important for reconstruction of the history of the area, but have no extent large enough to map.
It is not surprising to find these deposits below lahar and lava flows since these flows are always following the lower parts of the area, e.g. rivervalleys. The terrace deposits are rich in Mount Kenya volcanics but sometimes deposits rich in quartz are found but they are still containing a considerable amount of volcanics.The oldest buried terrace remnants are found underlying the phonolite flows, these deposits contain a considerable Basement Sytem rock component.

The terrace deposits

Nearly all large rivers have built up river terraces in the Basement System area. These terraces are well recognizable on the aerial photographs because they have a different vegetation and are relatively flat and positioned along the rivers. There are three groups of deposits:

- The conglomerates, boulders and gravels.
  These deposits are sorted to some extent. (F1)
- The depositsrich in pyroclastics. (F2)
- The present river bed, predominantly sand and gravel. (F3)

The terrace-like lahar deposits are mostly found along the Naka, Mara and Mutonga. But is also found along Thuchi and Ruguti river near their confluence.

The colluvial deposits are especially common in the Basement System area. Only along the scarps and steep hills these deposits are extended enough to map.
The colluvial deposits are usually a mixture of soil material and rock debris.

2.3.1. The fluviatile deposits (F)

F1: The conglomerate, boulder and gravel deposits

Field-occurence	These areas are usually flat with a gentle slope towards the river. The terrace deposits are often eroded and it is therefore not uncommon to find Basement System outcrops in this unit (especially in gullies). The best description of this unit is eroded terrace remnants. Probably related to the terraces are some local scattered clay deposits, possibly deposited in the backswamps of the river. These deposits contain montmorillonite clay. These deposits were only found in the eastern parts of the Thuchi and Ruguti terraces.
Petrography	conglomerates The main components of the terrace deposits are the Mount Kenya volcanics (more than 90%). The deposits are usually large boulders and stones with intermediate layers of sand and gravel.

Observation no:051/065/077/080/097.
Sample no:015/065/101.

F2: The deposits rich in pyroclastics

Field-occurence	These areas are the flat to undulating areas near the Grand Falls and Katwana ka Munanda at Tana river. These deposits are well preserved and form a flat area.
Petrography	Deposits rich in pyroclastics. The deposits consist mainly of pyroclastics. The deposits are well sorted but contain some larger pumicebombs. The Basement System component in the deposits comprises only a few percents.

observation no:010/029.
sample no:018/028/092/093/094/095.

F3: The river bed deposits

Field-occurence	This unit is the present Tana riverbed and two dry riverbeds East of Tana river.In Tana river many sandbanks were observed during the dry season. On these banks many Basement System boulders and stones occur. The dry riverbeds consist of gravel, clayey sand and sand strata.
Petrology	The sediments are predominantly sand and gravels. The clay is not deposited in the area since the velocity of the water is still too high.

observation no:-
sample no:-

2.3.2. Colluvium (C)

C1:Colluvium derived from Mount Kenya volcanics

Field-occurence	Almost all steep slopes consist of recent colluvial deposits. Locallly the underlying Basement System rocks crop out.These are usually the same rock types as in the Basement System units boundering to C1
Petrography	Colluvium Many boulders, stones and gravel of various sources. The boulders are usually phonolite boulders derived from the lahar. The stones are also mostly lahar derived but some originate from terrace material. The gravel is usually murram.

observation no:no observations were recorded in the observations list
sample no:-

C2:Colluvium derived from ultra basic rocks

Field-occurence	This unit is an undulating area with a large number of radial incissions.
Petrography	colluvium Recent colluvium of unit M2. Boulders of the in M2 descriped rock types were observed in this colluvium. Sometimes a rock outcrop of the underlying X4 was observed.

observation no:-
sample no:-

C3:Colluvium derived from basalts

Field-occurence	This unit is a colluvium derived from basalts,terrace remains and Basement System rocks. This unit forms the slopes from the basalt plateaus towards the lower Basement System terrain

Petrography

Colluvium

Basalt boulders are most common in this colluvium. At many spots the underlying Basement rocks crop out. In the northern unit these outcrops are hornblende gneisses and pegmatite vein intrusives. In the south eastern unit these outcrops are granitoids.

observation no:-
sample no:-

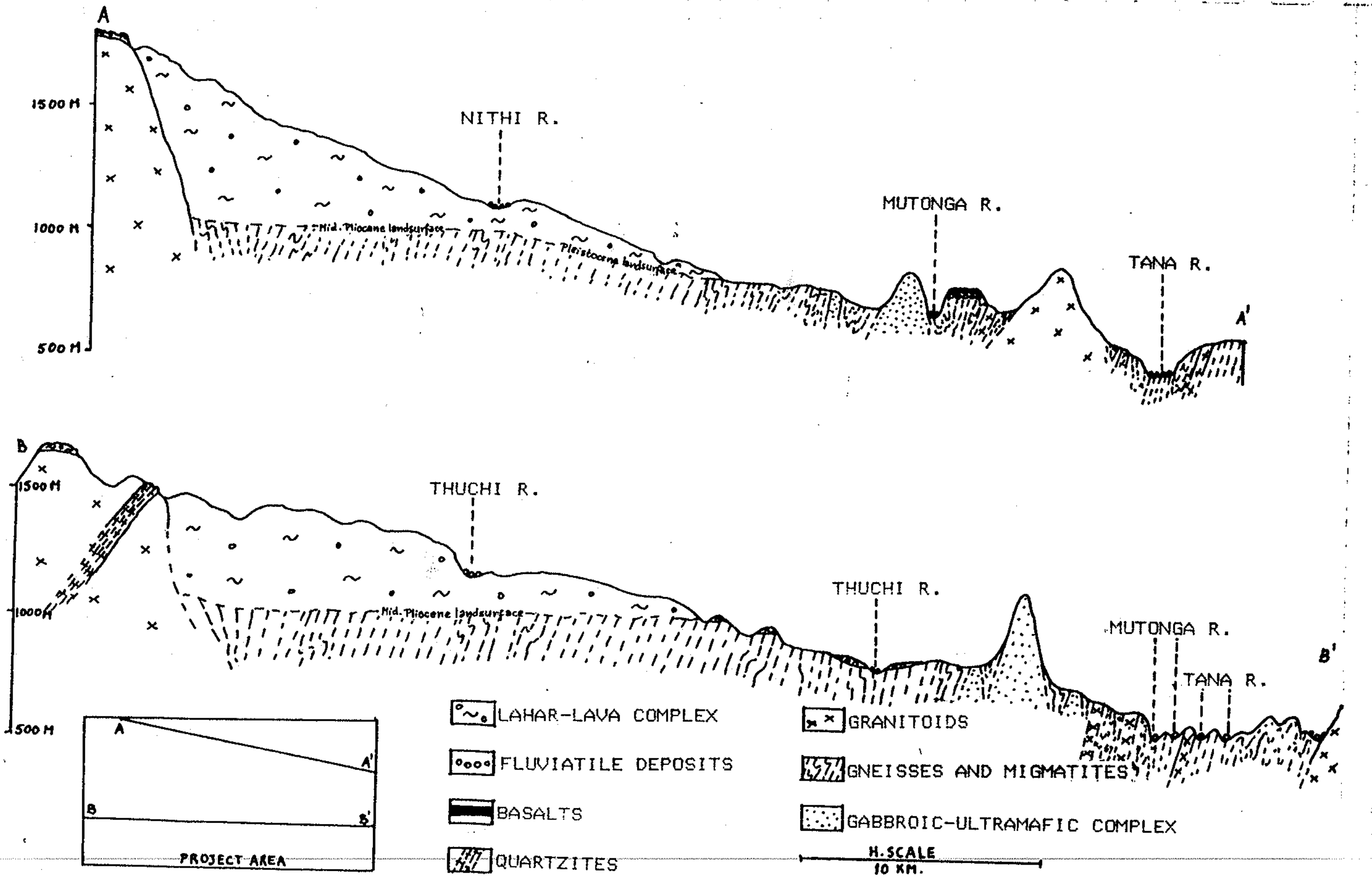


FIG. 9. -GEOLOGICAL CROSS SECTIONS THROUGH THE AREA.

3. GEOMORPHOLOGY OF THE CHUKA-SOUTH AREA

3.1 The landscapes and landtypes of the Chuka-South area.

The Chuka-South area can be divided into two major landscape types:
- The western volcanic landscape
- The eastern Basement System landscape.

These major landscapes comprise several sub-landscapes which were distinguised by their difference in landtype, relief and /or drainage pattern.

The Legend of the Geomorphological map

Volcanic landscape:			**V**
Mount Kenya slopes			VM
		parallel dissected	VM1
		subdendritically dissected	VM2
Hilly area			VH
Plateau-like area			VL
Valleys			VV
Depressions			VD
Scarp with footslopes			VS
Ridges			VR
Plateaus			VP
Basement System landscape:			**B**
Mountains			BM
Hills			BH
Footslopes			BF
Lowland area			BL
	Flat		BLf
	Rolling		BLr
		rectangular dissected	BLr1
		subparallel dissected	BLr2
		subdendritically to subparallel dissected	BLr3
	Hilly		BLh
		dendritically dissected	BLh1
		subparallel dissected	BLh2
Valley			BV
Present Riverbed			BR

The volcanic landscape:

The volcanic landscape comprises several sub-landscapes (see legend above)

The Mount Kenya slopes (VM).
This unit comprises the lower slopes of the large Mount Kenya volcanic body. This unit is characterised by an overall slope of 5-6% (NW to SE), and is strongly dissected. The crests have slopes of 1-5% and are usually long and narrow. The valleys included in this unit have slopes up to 80%. The valley slopes are longer than the crests slopes (see Fig. 10.).
The parallel dissected unit VM1 is stronger and steeper dissected than the subdendritically dissected unit VM2. The crests of unit VM2 are flatter and more extended (see Fig. 10.). The soils are always deep red clay soils, except in unit VM2 where bare rock occurs along the valleys and scarp.

The hilly area (VH).
This unit is a higher part in the volcanic landscape. This higher position is caused by Basement System rocks which only have a very shallow volcanic cover. These Basement System rocks formed high hills in the landscape which got covered by the volcanics. The Basement rocks were already dendritically dissected before they got covered by lahar deposits. Nowadays the lahar is partly removed and weathered. Because of this process the dendritically drainage pattern is prominent again (see Fig. 10.). The overall slope of the crest is 1-4% and the slopes towards unit VM1 are 10-30%.
The soils of this unit are usually deep red sandy clay soils.

The Plateau-like area (VL).
This flat area (overall slope 1-4%) comprises the most south-eastern lahar deposits of Mount Kenya. Its eastern boundary is a high steep Scarp (VS) but its western and northern boundaries are very gradual transitions to the VM1 and VM2 units. The VL unit has very deep red clay soils with shallow soils only along the Scarp and major Valleys (VV) (see Fig. 10.).

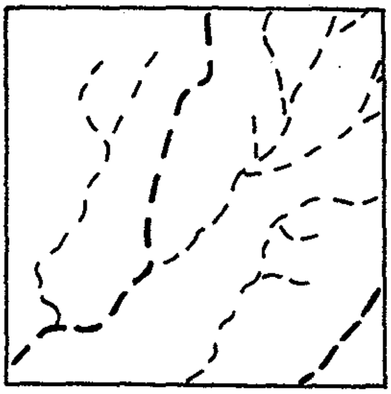
The Valleys (VV).
This unit comprises deep, steep, V-shaped valleys of the largest perennial rivers of the Chuka-South Area. These river originate near the summit of Mount Kenya in former glacier valleys .
Since the present rivers are far too small to have caused these large valleys (misfitted rivers) the cause of the dimensions of these valleys is certainly related to the more glaciated periods of Mount Kenya. Other causes of the formation of these valleys are probably the lahars which almost certainly have caused the steep and deep valley of Nithi river.
The slopes of the valleys are often over 100% and the overall slope of the valley profiles is 4-6%. The soils in the Valleys differ, in the western part the soils are always deep red clay soils and in the eastern part the soils are generally shallow gravelly clay soils.

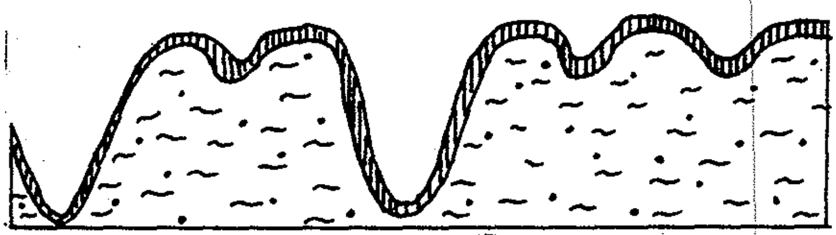
The Depressions (VD).
The Depressions are oval concave depressions which are usually found in clusters in units VM and VL.
These Depressions have different drainage and soil qualities. Some of them are almost always well drained while others form permanent swamps. Their slopes vary from 0 to 4%. Their soils are deep clay soils, the colour differs with the drainage condition from red to brown to black.
For development of these Depressions see chapter 3.3.

The Scarp with footslopes (VS).
This unit forms a boundary between the Volcanic landscape and the Basement System landscape. The Scarp slope is usually a few hundred percent and the slope of the underlying colluvial deposits (footslope) is 10-20%.
The soils on the colluvial deposits are stony, gravelly, deep brown sandy clay soils.

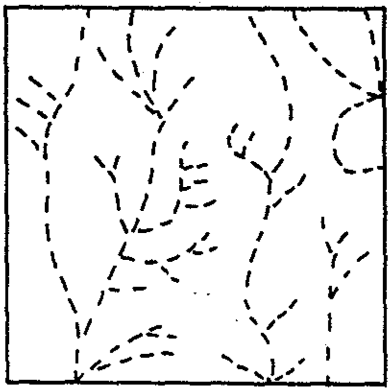
The Ridges (VR).
In the Basement System landscape some volcanic landtypes with a small extend occur. These landtypes are narrow elongated ridges which were caused by an isolated basalt or phonolite flow. The flow followed a river valley which caused the elongated shape of the Ridges. The relief of these flows has inverted in time (see Fig. 11.).
The Ridges have an overall slope of 2-5% and are usually bordered by unit VS. On these Ridges the very shallow soils are most prominent.

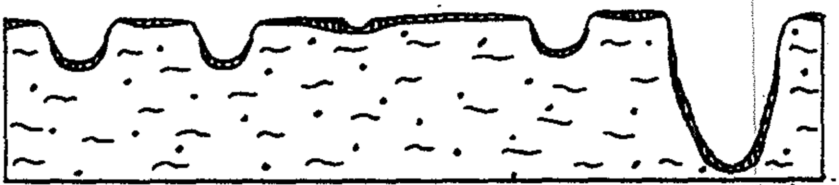
The Plateaus (VP).
The Plateaus are also isolated volcanic landtypes in the Basement System landscape. These Plateaus have the same origin as the Ridges (see Fig. 11.), or are the isolated remnants of the VL unit. These Plateaus have an overall slope of some percents and are usually bordered by unit VS.
The soils are usually deep gravelly brown clay soils.



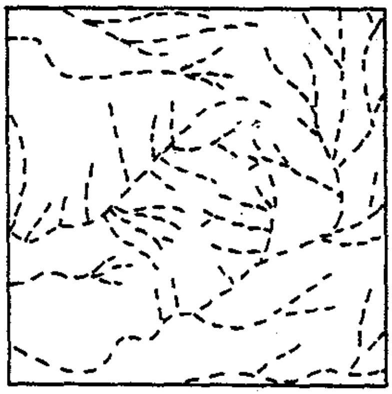


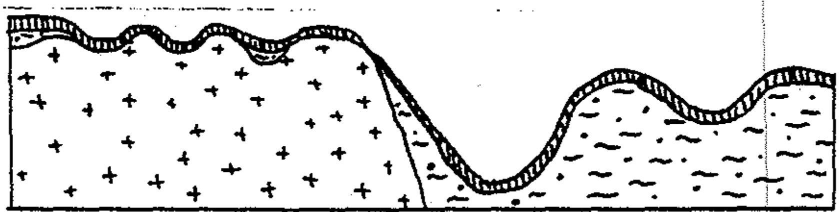
Geomorphological unit VM1:
A detail of the drainage pattern (left) and a schematical cross section (above).



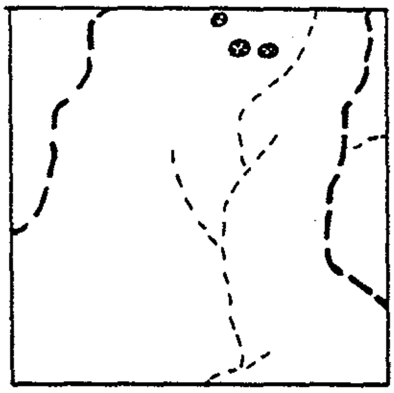


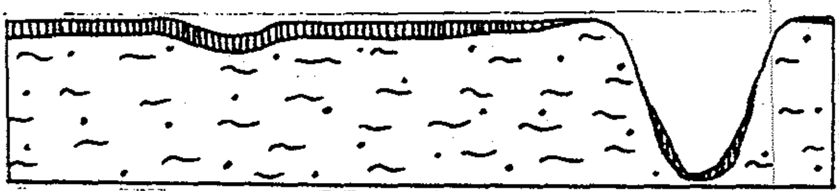
Geomorphological unit VM2:
A detail of the drainage pattern (left) and a schematical cross section (above).





Geomorphological unit VH:
A detail of the drainage pattern (left) and a schematical cross section (above).





Geomorphological unit VL:
A detail of the drainage pattern (left) and a schematical cross section (above).

REGOLITH LAHAR GRANITOIDS

FIG. 10. -DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATICAL CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE VOLCANIC AREA.
(Scales: drainage pattern maps 1:100,000 cross sections 1:40,000)

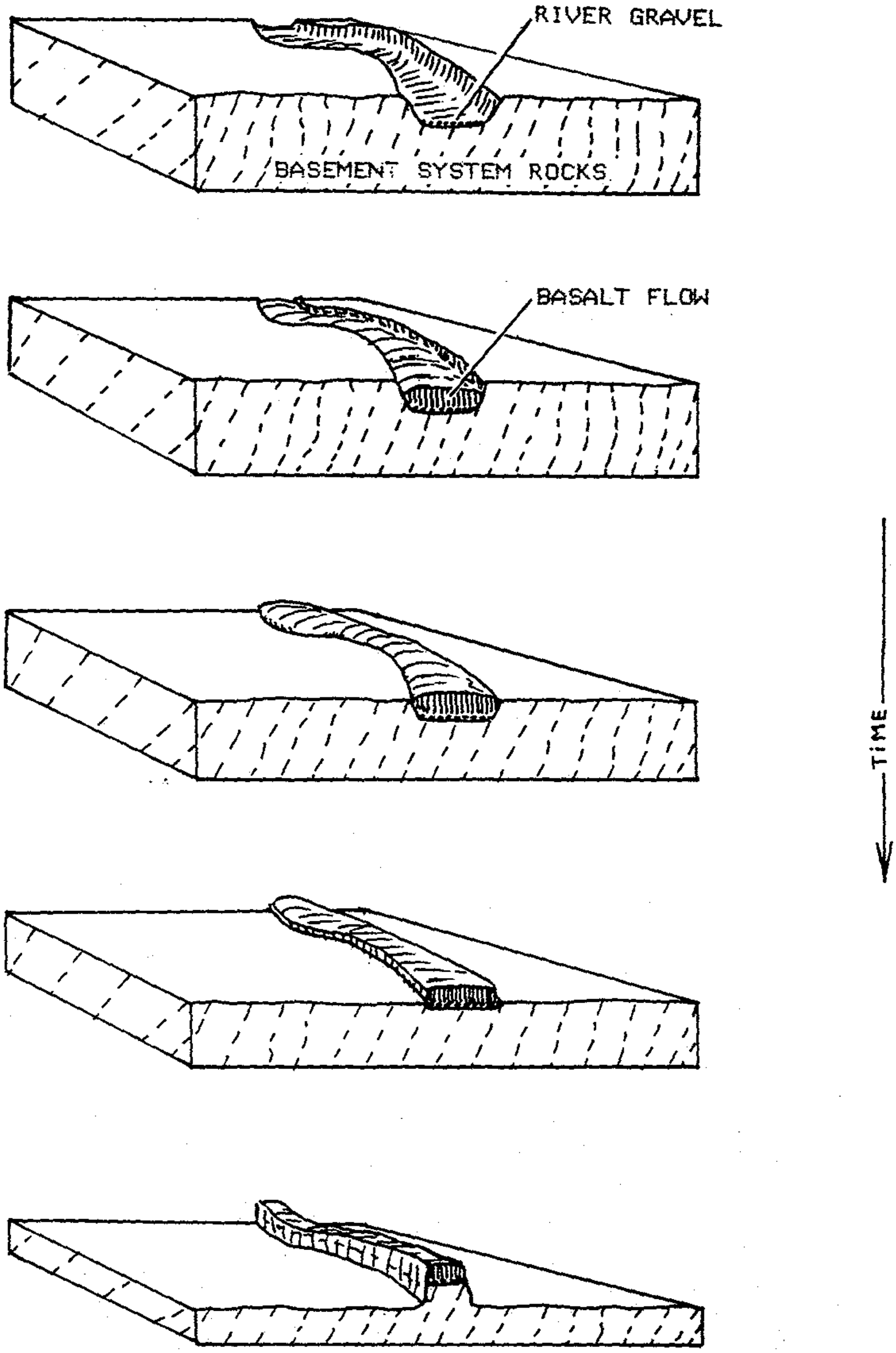


FIG. 11. -DEVELOPMENT OF A VOLCANIC RIDGE (VR) IN THE BASEMENT SYSTEM AREA BY A PROCESS OF RELIEF INVERSION. The same process resulted in the volcanic plateaus (VP) in the B.S. area.

The Basement System landscape:

The Basement System landscape also has many subdivisions.

The Mountains (BM).
The Mountains are the highest parts in the Basement System area. They have a relief intensity of more than 300m and their slopes are generally >30%. The granite Mountains like in the Kijegge and Mumoni Forest area partly have an inselberg appearance. Their upper parts consist of bare rock and have the common sugar-loaf appearance of an inselberg. The mountain which consists of the gabbroic-ultramafic complex rocktypes has not the appearance of an inselberg. In general the soils are found on the lower slopes of the Mountains and are rocky, moderately deep sandy clay soils.

The Hills (BH).
The Hills are the higher parts in the Basement System area with a relief intensity less than 300m. The Hills often differ in shape. The more rounded Hills usually consist of granitoids and ultramafics. The more oval, elongated Hills consist mainly of granulites and gabbros. Generally the rounded Hills have steeper slopes, usually with shallower soils. The slopes vary from 10->50% (see Fig. 12. cont.).
The soils are usually moderately deep but differ in their qualities.

The Footslopes (BF).
The Footslopes are only found at the basis of one Mountain and two Hills which consist of mafic and ultra mafic rock types. The overall slopes are 5-10%. The soils are stony deep brown sandy clay soils.

The Lowlands (BL),
The Lowlands form the lower parts of the Basement System landscape. The main rocktype in the Lowlands are the various gneisses described in chapter 2.1. The Lowlands have an overall slope of 3-5% from their western to their eastern boundaries, but the local relief is usually rolling, local slopes are usually 1-30%. The Lowlands show many gullies, ridges and small hills. Tors are also common in some parts of the Lowlands, especially where granitoids occur. The Lowlands are subdivided into 3 subunits according to their local relief.
the flat Lowlands BLf (overall slope 1-5%)
the rolling Lowlands BLr (overall slope 5-20%)
the hilly Lowlands BLh (overall slope 5-30%)

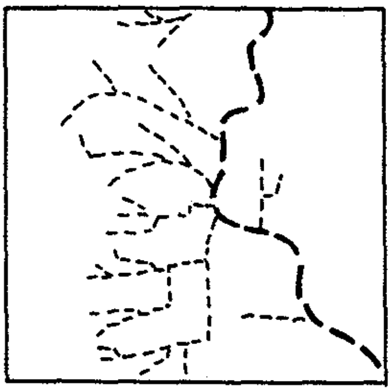
The flat Lowlands show some local dissections like erosion gullies, but the main character is flat. These areas are usually situated along rivers and are former river terraces. Locally remnants of the fluviatile deposits are found in this unit.

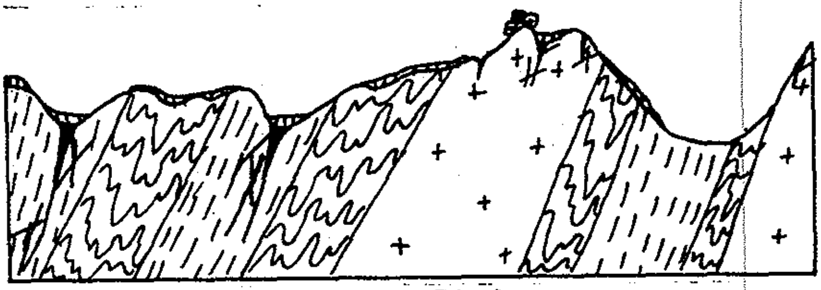
The rolling Lowlands are subdivided into three more sub-landtypes according to the local drainage pattern. These drainage patterns are closely related to the rockstructures and -types.
The rectangular dissected unit BLr1 is an area with a rectangular drainage pattern which is caused by the joints and fractures of this predominantly granitoid gneisses area.
The subparallel dissected unit BLr2 is an area with a subparallel drainage pattern which is caused by parallel granulite and migmatite ridges in this area.
The subdendritically to subparallel dissected unit BLr3 is an area with a mixture of drainage patterns, this area has a complex build up and comprises many elements of the other landtypes. (See Fig. 12. cont.)

The hilly Lowlands BLh also can be subdivided.
Unit BLh1 has a dendritical drainage pattern. This area is generally situated higher than the surrounding Lowlands. The main rock types in this area are granodiorites and their accompanying migmatites (see Fig. 12. cont.).
Unit BLh2 has a more subparallel drainage pattern. This area is found along the Kijegge Forest Mountains and has a footslope like appearance. It is the transition zone from the Mountains to the other Lowlands (see Fig. 12. cont.).

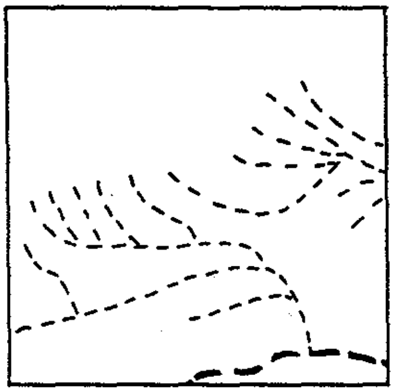
The Valley (BV).
In the Basement System landscape only one large Valley can be distinguished. It is the large Valley of Tana river. The Valley length-profile has an overall slope of some percents, and the slopes are up to 20%. In this Valley the Tana is following a straigth course since the river has cut its riverbed into a less resistant, straight hornblende gneiss band. The soils in the Valley are moderate deep stony, red sandy clay soils.

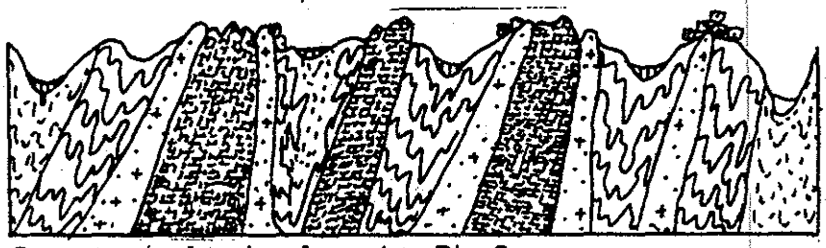
The Present Riverbed (BR).
This unit comprises the present riverbeds of Tana river, Konyu and Kalange wadi. This unit is flat, 1-3% overall slope, and consists mainly of sand and sandy clay. Stones and gravel are mostly found in the stream gully and on small terraces in the Riverbed.



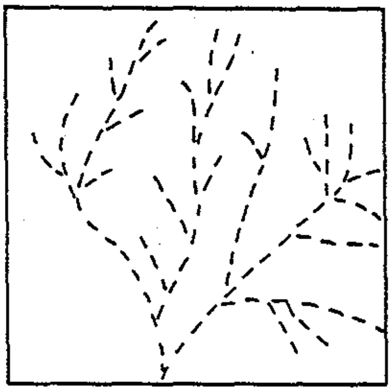


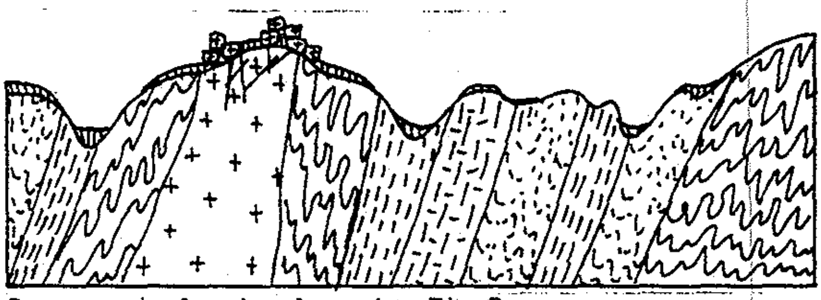
Geomorphological unit Blr1:
A detail of the drainage pattern (left)
and a schematical cross section (above).





Geomorphological unit BLr2:
A detail of the drainage pattern (left)
and a schematical cross section (above).



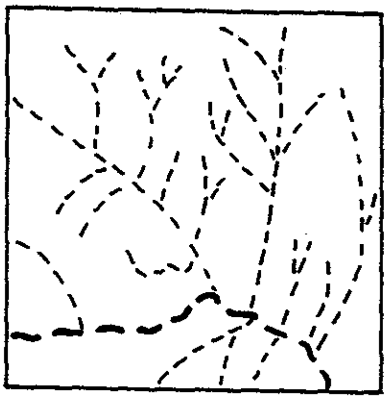


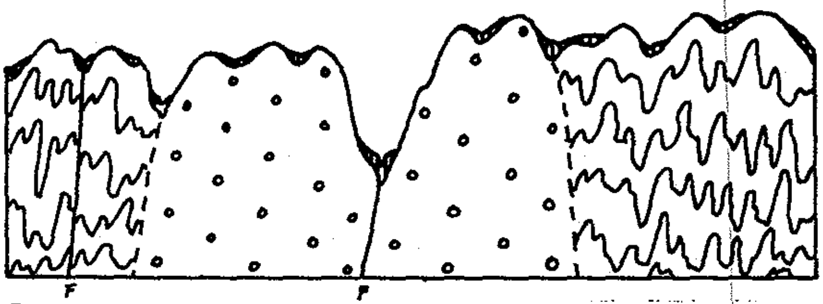
Geomorphological unit BLr3:
A detail of the drainage pattern (left)
and a schematical cross section (above).

REGOLITH — VARIOUS BANDED GNEISSES — MIGMATITE

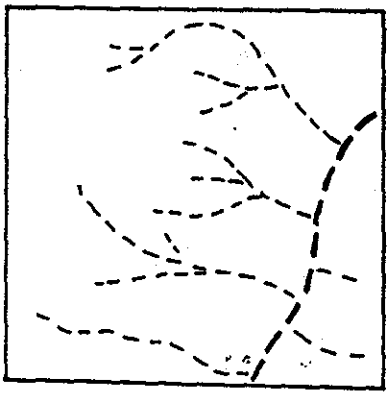
GRANITOIDS — GRANULITE — HORNBLENDE-GABBRO

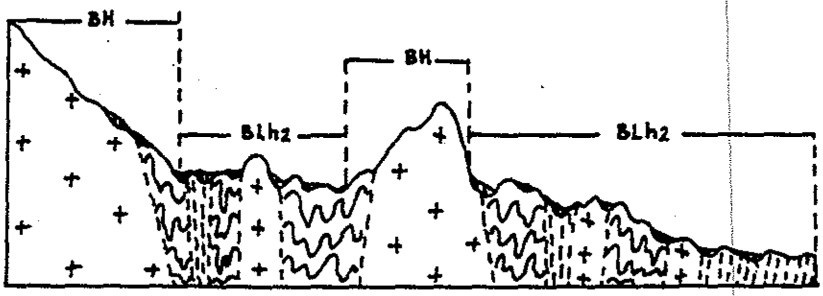
FIG. 12. -DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATICAL CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE BASEMENT SYSTEM AREA.
(Scales: drainage pattern maps 1:100,000 cross sections 1:40,000)





Geomorphological unit BLh1.
A detail of the drainage pattern (left) and a schematical cross section (above).





Geomorphological units BLh2 and BH.
A detail of the drainage pattern (left) and a schematical cross section (above).

REGOLITH | MIGMATITES | GRANODIORITE
GNEISSES | GRANITOIDS | F : FAULT

FIG. 12. (CONTINUATION)

3.2 Relation landtype-lithology

In the past the area has known various climates. Humid and semi arid climates have been following up each other many times. Under more humid climatic conditions, due to differential weathering of contrasting rocktypes, the weathering front showed different depths. During semi arid conditions the saprolite was stripped off (this is still happening). This cycle repeated several times and caused the landtypes of the Basement System landscape. In a matter of fact the Basement System landscape should be looked upon as an etch plain.
The different landtypes described in chapter 3.1 usually comprise different rocktypes.
For example the Mountains and the Hills (BM and BH) contain predominantly granites, granitoid gneisses and rocks from the gabbroic-ultra mafic complex. The fact that these rocktypes are almost only found in the higher parts of the Basement System landscape is caused by specific qualities of these rocktypes which makes them more weathering resistant.
More weathering resistant, indicates a relative slower weathering of these rocks compared to the surrounding rocktypes.

The above implies that the main causes of the relief differences in the Basement System landscape are the differences in resistance to chemical weathering.
The chemical weathering rate depends on environmental factors like the climate and vegetation and on therock-characteristics like the mineralogy and permeability. (21) The mineralogy determines factors like the chemistry and cohesion of the rock. The permeability determines factors like the extend of the surface in contact with the water, the duration of the contact and the rate of percolation. To a large extend the permeability is determined by the fractures of the rock. The type of fracture, the connections between the fractures and the depth of the fractures play an important role in the permeability.
Rocks with no fractures and an acid composition will be the most weathering resistant rocktypes. The granites are such a rocktype. These rocks form the highest parts in the Basement System landscape, the inselbergs in the etchplain.
The granitoid gneisses have more fractures and are acid.
These rocktypes form lower parts of the landscape than the granites and are rich in tors and hills.
The granulites and the rocks belonging to the gabbroic-ultramafic complex only have tight fractures, but have a more basic composition. These rock types usually form the lower and less steeper hills. These hills usually have a considerable soil cover.
The gneisses are heterogeneous, more fractured and have a basic composition. These gneisses form the lower parts in the Basement System landscape (the so called Lowlands).

In the volcanic area the relation landtype-lithology is not that clear. One of the reasons is the fact that the climatic changes where not so extreme in the higher situated volcanic area.

Another reason is the fact there are no contrasting rocktypes in the volcanic area, lahar deposits are the most common rocktype. Still there are differences in the drainage pattern and the density of incisions. This is probably related to the slope of Mount Kenya. This slope is gradually becoming less steep towards the East, and the density of incissions is also lesser towards the East, and the drainage pattern is changing from subparallel to subdendritic towards the East. These transitions are very diffuse.
In the volcanic area the resistance against erosion is probably a more landtype determinating factor.

In the semi-arid climates the saprolite is stripped off by erosion processes, and the physical weathering is more prominent. When the saprolite is very erosion resistant the removal of this saprolite will not take place and thus the lowering of the area will not take place.
The erosion rate depends on many factors:
-The shape and length of the slope
-The amounts, distribution and intensities of rainfall
-Cover of the soil e.g. vegetation
-Soil factors

One of the soil factors is the stability of the soil structure. In the Chuka-South area the soils on the volcanic parent materials are more stable than the soils developed on the Basement System rocks. This stability was tested with a so called structure stability test. The low stability of the soils on the Basement System rocks causes the soil to form an impermeable crust on these soils which favours run-off and erosion.
Another factor is laterite. Laterite appears in the volcanic soils as ironstone gravel (murram) but also as more continuous layers at the contacts between the weathered rock and soil. The laterite improves the resistance of the saprolite against erosion.
The saprolite cover also slows down the weathering processes of the underlying rock when its cover is thick enough.

The contact zone of the volcanic and Basement System landscape is a Scarp. The Scarp-development is a clear example of a landtype development related to the different resistances against erosion and weathering of the lahars and the Basement System rocks.
It is clear this Scarp is developed because the lahars have a higher resistance against the lowering activities of erosion than the adjecent Basement System rocks. First the lahars are covered by a thick, stable clay soil. This clay soil protects the largest part of the lahars against erosion while the Basement System rocks are covered by a thin, instable soil which does not supply a good protection of these rocks against weathering and erosion. These soil factors are not the only factors which explain the Scarp development. The lahars near the Scarp are insufficient covered by soils or laterites to protect them completely. Also the uncovered parts of the lahar area are still higher than the adjecent Basement System area. So also the characteristics of the rocks play an important part in the Scarp

development. The lahars have a lot more extended fractures than the adjecent gneisses and migmatites. The permeability of these fractures is high enough to let the water infiltrate and percolate fast enough to give weathering less opportunity than in the tight and undeep fractures in the gneisses and migmatites where the water percolates slowly. A part of the water what infiltrated into the lahars seeps out of the lahars at the face-slope of the Scarp. This water also contributes to the weathering and erosion of the adjecent Basement System rocks.
Factors as the consistence and chemical composition of the rocks can not be taken into account here because too little is known about these factors in the area studied.

Concluding can be said resistance of a rock against lowering is determined by a number of rock characteristics but also the soil and regolith cover play an important role in this resistance.

Not only the clear scarps at the end of a large part of the lahar flows indicates a higher resistance of the volcanic rocks against erosion but also a lot of volcanic deposits now form smaller plateaus or ridges in the Basement System landscape. These plateaus and ridges have a high position in the landscape thanks to a relief inversion which has taken place here.
The inversion- and Scarp heights in the area vary from less than 1m up to more than 100m. There are many factors on which the height of such an inversion or Scarp depends.
First there is the degree in which the resistance of the adjecent types of rock differ. The more these resistances differ the faster and the higher a Scarp will develop.
Second there is the height of the lithological contact above the local temporary base-level of erosion. The larger this height is, the higher the Scarp can become.
A third point is the hydrology. Water is needed for deep weathering of the rock and for eroding the rock. So in an area with a dry climate the development of a Scarp will be slower than in a humid climate.
Another factor is the thickness and extension of the superficial deposit. A very thin volcanic deposit will be eroded away before it can cause the development of a high Scarp.
Even more points which influence the height of a Scarp or the height of relief inversion can be listed. All these factors do not vary much enough in the area where the volcanics border the Basement System and where the scarps or relief inversions have been developed to explain the differences in Scarp- or inversion heights.
To explain these differences more satisfactory two more important factors should be considered.
First there is the topographical situation of the volcanic deposit. A volcanic deposit in a deep valley in the Basement System rocks will not form a Scarp or relief inversion as high as the Scarp or relief inversion caused by a comparable volcanic deposit which was deposited contemporaneous but covering a topographically higher area (e.g. the higher situated terrace deposits).

Secondly there is the factor time. The development of a Scarp or relief inversion takes time. The more time the process is proceeding, the greater the Scarp or inversion height can be.
This last point offers the possibility to determine the relative ages of comparable volcanic deposits with different Scarp or relief inversion heights. When the rock characteristics and the topographical positions of volcanic deposits are the same it can be said the volcanic deposit with the largest Scarp or greatest inversion height is the oldest. This can be used for comparing the relative ages of different lahar depositions in the area, and to some extend also to compare the relative ages of lahars and lavas. This last application is more difficult because the flowing of the lavas was more confined to the deeper valleys, while the lahars also covered areas between the valleys. Also the resistance against erosion of the lavas is higher than the resistance of the lahars. Other methods are more appropriate to determine the relative ages of lahars compared to those of lavas.

3.3 The Depressions in the lahar landscapes

The Depressions are oval concave depressions in the Mount Kenya volcanic area. Very often these depressions are called "volcanic sinkholes".They are no sinkholes since these Depressions often form seasonal swamps.

Most of the Depressions are found in the Plateau-like lahar area. These Depressions are usually found in a number of clusters in the area. In all cases studied, lahar was the rocktype in and around these Depressions.

Some Depressions are almost always wet and others almost always dry. These differences in drainage condition are related with the colour of their soil. Some contain red soils while others contain grey and/or black soils.

The initial development of the Depressions is not clear yet. There are a number of theories about their development.

Some of these development theories are:

- development by locally gas-rich lahars
- development related to joints
- development related to tunnel-flow in lahars
- development related to differential setting of the lahar

1-development by locally gas rich lahars

This theory is based on the idea that some lahars are locally rich in gas. When they loose their gas excesses the lahar is sinking locally. This assumes that the Depressions were formed during the consolidation of the lahar.

2-development related to joints

In this theory the lahar is consolidated first. This consolidation causes joints and cracks to develope in the lahar. Along these joints water percolation starts. The Depressions should be considered as a kind of sinkholes along these joints.

3-development related to tunnel-flow in lahars

In this theory it is assumed that it is possibly to have tunnel flow in lahars. This phenomena is described for lava flows but it is never mentioned to occur in lahar flows. The tunnel flow occurs when the top of the flow is starting to consolidate while the central inner part of the flow is still flowing. When also the central part in the flow has consolidated a tunnel is left inside the flow. This tunnel collapes locally and forms local depressions.

4-development related to differential setting of the lahars

This theory is based on the fact that the setting after consolidation is locally different. This may cause these depressions. When a lahar covers an area this area becomes more flat but where the lahar deposits are the thickest (the former lowest parts) the setting will be the largest at these spots. This can cause local depressions.

When it is assumed that the Depressions were developed contemporaneously with or before the consolidation, three stages of development after the consolidation of the lahar can be distinguished. These stages can be distinguished by considering the different types of cross sections of the depressions (See Fig. 13).

First stage After the lahar is consolidated water starts accumulating and a lake or swamp is developing. The soil formation at the edges of the depression and its surroundings is proceeding much quicker than inside the depression. This difference in soil formation speed is caused by the poorly drainage conditions inside such a depression.

Second stage When the process of stage one has continued in time the transition zone regolith-rock hasreached the depression bottom level. In this stage the depression edges are periodically better drained. These changing drainage conditions favour the laterite formation. A considerable ironstone (gravel) layer is formed.

Third stage Whenthe regolith-rock transition zone has reached a level below the depression bottom, one has the situation of an inverted topography of the regolith-rock zone. Still there exists some periodical water accumulation in the more well drained Depressions. This accumulation is caused by the ironstone (gravel) layer along the edge.

(See Fig. 13.)

The rate and stage of developement is not only determined by the factor time but also influenced by some other local factors such as the overall drainage of an area, the extend and shape of the depression.

Due to these differing local factors all three stages still exist in the Chuka South area.

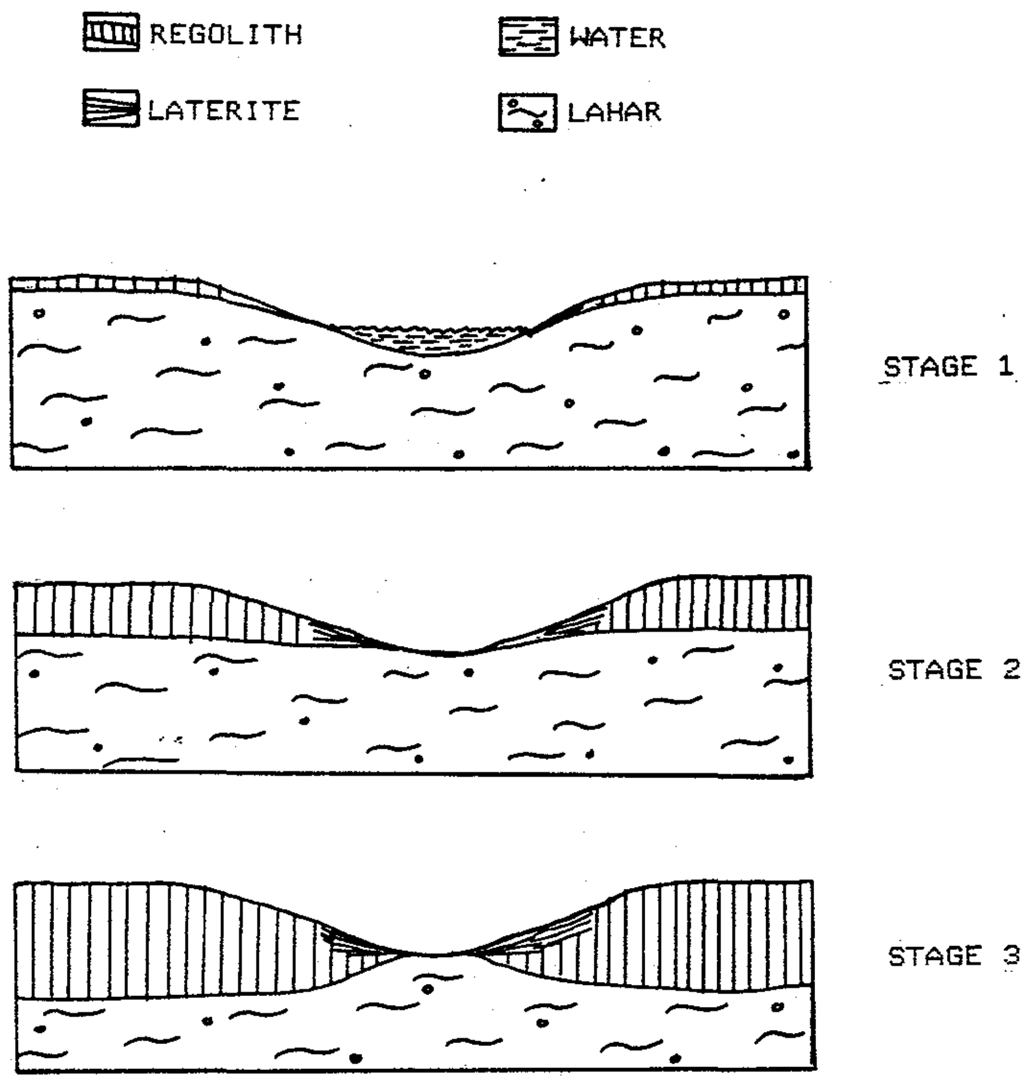


FIG. 13. -SCHEMATIC DEVELOPMENT OF THE DEPRESSIONS IN THE LAHAR AFTER CONSOLIDATION OF THE LAHAR.
For explanation see text.

4. THE GEOLOGICAL AND GEOMORPHOLOGICAL HISTORY OF THE AREA.

-Precambrian

During the Katangan, the upper Precambrian, various types of sediments accumulated in a geosynclinal like depression under marine conditions. These sediments formed thick shaly series and one band of quartzites. These quartzites now can be found Southwest of Runyenjes (obser. 001). Limestone or conglomerates are not present in the area.

In the diageneted and probably also (partly) metamorphosed sediments some masses of hornblende gabbros intruded. These invasions of the hornblende gabbros have arisen very high grades of metamorphism in the shaly host rocks. This metamorphism produced hypersthene bearing granulites which now form suites with the hornblende gabbros (obser. 122). Amphibole from an amphibolite inclusion in charnockite in Kenya has given a K-Ar age of 855 +/-30 my, that provides a minimum age for these intrusive rocks. (9)

At the end of the Katangan era to the begin of the Paleozoic the main orogenetic processes in this period deformed, metamorphosed and tilted the Precambrian rocks. (22) Probably during these orogenic events masses of granitic magma invaded the sheared paragneisses. Dated events show broad grouping of ages in the 450-680 my range and include the emplacement of synorogenic and late orogenic pegmatite and granite, regional metamorphic mineral growth or modification. (10) These intrusives form large batholiths which consist of granitoid orthogneisses and granites. One of these batholiths now forms the Kijege-Kierera Forest hill range (obser. 126). This granite intrusion did not give rise to very important metamorphic changes of the surrounding rocks. Here a narrow border-area of the host rocks got more migmatised. Another granite area is the Mumoni Forest. In this area the granites comprise only a small part of the rocks, especially the peaks and other higher parts. The intensely migmatised gneisses are more abundant in this area than in the Kijege-Kierera Forest area.

A wider area around and in-between the granite complexes shows numerable outcrops of augengneisses and gneissose granites (obser. 011).

The granitic intrusions are accompanied by pegmatite and aplite vein intrusions. Some pegmatite veins intersect some of the granulites of the gabbroic-ultramafic complex. This indicates an older age of these ultra basic (hornblende-gabbro) intrusions which caused the granulitic metamorphism, compared with the age of the granitic intrusions.

-Paleozoic-Tertiary

Since the orogenic and tectonic events of the late Precambrian - early Paleozoic until Tertiary times no major disturbances took place. The movements in this period have been confined mainly to general uplift and periods of denundation, culminating in planation. (1+22)

The Paleozoic was dominantly an era of denundation. (1+22)

After uplift and denundation during the late Jurassic , the uplift of the Kenyan and Ethiopian domes (swells) started during

the end Cretaceous with an uplift of more than 400 m in central Kenya, decreasing eastwards. At the coast there was subsidence. (1+7)
This uplift was followed by a period of crustal stability during which an end Cretaceous etchplain was formed.
No remnants of Paleozoic or Mesozoic landsurfaces are present in the area.

-Tertiary and Quaternary
During the Paleogene no spectacular events took place in the area. Since the Lower Miocene the evolution of the area made more pace. In this period the area was uplifted again. Central Kenya was uplifted 300 m, the South and East of Kenya about 100-150 m, while the coast again was a zone of flexuring and subsidence. (1+15)
During this uplift the northwestern flank of the Kenyan dome started wrapping down, initiating a broad, partially faulted depression, extending from northeastern Kenya via Lake Turkana to southern Sudan, seperating the partially developed Kenyan and Ethiopian domes. (1+15)
This uplift was followed by a planation during which the lower Miocene etchplain, the best known etchplain of Kenya, developed. At several places in Kenya sedimentation took place in channels on this surface. None such sediments could be located in the area. (1+22)
The Pliocene gave the most spectacular uplift of the area in its history since the Precambrian.
Central Kenya was uplifted 1,500 m. The coastal zone was downflexed again. During this stage a true graben, the Rift Valley, was formed by downwraping and strong faulting. (1+3+15)
Together with this uplift the beginnings of Mt. Kenya came alive. Seventy-five km East of the Rift Valley the Mt. Kenya volcano body was built up. (1) The main eruptive phase of Mt. Kenya was during the second half of the Pliocene. (2+4) In this period a few phonolite flows (obser. 008,064) and a single basalt (obser. 019) flow entered the area. The bulk of the volcanics in the area consist of lahars which cover about one-third of the area. While the Mount Kenya volcano cone was building up, numerous hot mudstreams, the lahars, ran down its slopes. These mudflows can have various origins. The mudflows can be caused by the boiling over of the craterlake Dbefore an eruption. The ejection of the crater-water and pyroclastics causes a hot mudstream. Another cause can be found in the heavy rains on the slopes of the volcano which were covered with instable successions of pyroclastics. The saturated ashes can have formed landslides and mudflows especially in periods of seismic activity. A third possibility by which a mudflow can be triggered is the melting of the icecap on the peak of the volcano because of the increased heat from the magma before the eruption. The mudstreams were loaded with pyroclastics from the slopes and they eroded more and more on their way down the slopes, forming deep incisions. Even when the tail of the mudflow was not fed anymore by the materials from its origin it did feed itself, uptaking the materials eroded on its way. The specific gravity of the mudflow was that high that enormous boulders were transported floating in or drifting

on top of the lahar. The hot lahar streams stopped when enough steam was escaped to reduce the liquidity of the lahar.
The lahars in the area consist of a matrix of transported pyroclastics in which various rockfragments, boulders etc are enclosed. The component of phonolite boulders in the lahars is very high. Also non volcanic, Basement System rock, boulders do appear in the lahars. (20)
The lahars and lavas ran through the valleys and other low parts of the area. When the discharge capacity of the valley was exceeded, the adjecent terrain was also overflown. This happened on large scale with the lahar flows which covered extended areas. The phonolite and basalt flows were mainly confined to the river valleys and adjecent terraces.
Everywhere where the volcanics covered the Basement System rocks or fluviatile deposits in the Basement area, an inversion of the relief took place. The parts of the Basement area which did not get covered with volcanics got lowered faster than the parts which are or were covered with volcanics. In this way the lower parts where the volcanics were deposited became the higher parts of this area (See Fig. 11.). This inversion of the relief is clearly illustrated between Thuchi and Ruguti river North-east of Ishiara, where a phonolite flow forms a high ridge in the Basement System area. Where the volcanics border only with one edge to the Basement area, a scarp is formed at this edge. E.g. West of Ishiara where a scarp clearly indicates the eastern border of the lahars there.

With the help of the possibility to determine the relative ages of volcanic deposits, by comparing the scarp- or relief inversion heights as described in chapter 3.2 and some other methods (which will be explained when used) a chronological general review of the volcanic depositions in the area can be given.

The deposition of the volcanics in the area took place in three main phases.
1. The first phase coincided with the main active phase of Mt.Kenya. During this phase the Mt. Kenya volcanic body was built up. According to agings of Mt.Kenya volcanics, this period lasted from about 3.1 to 2 my bp. (2)
During this period the bulk of the lahars and the phonolite flows were deposited in the area. The most clear example of a phonolite flow in the area is the phonolite flow between Ruguti and Thuchi river, the so called Ugulere flow. This phonolite flow has filled up a riverbed. This is proved by the rivergravel found under the phonolite. This gravel has a very high Basement System component as well at the extreme eastern end of the flow as at the western part of this flow where it disappears under the lahars. This indicates that the river, which course the phonolite flow has followed, did not flow through an area where the volcanics were extended as far to the East as they are now. In that case the gravels under the western part of the Ugulere flow would have had a higher volcanic component. This gravel possibly indicates the Ugulere flow is older than the lahars at the eastern border of the volcanic area. At this border the Ugulere flow disappears under the plateau-like lahars, which also cover a small part of

the flow. This also suggests the phonolite flow is older than the plateau-like lahars, but there is still the possibility the phonolite flow did follow a deep valley in the plateau-like lahars and this valley was filled up later by other lahar flows through this valley. Concluding it can be said this phonolite flow is a little older than or as old as the plateau-like lahars. The plateau-like lahars show a high scarp at their eastern edge.This scarp is the highest scarp in the whole area. This indicates this lahar is the oldest lahar of all lahars bordering Basement System System rocks. These lahars have covered the Middle Pliocene landsurface.
The volcanic body of Mt.Kenya got higher but also more extended during this phase. Later the lahars which cover the slopes of the volcanic body got extended so far towards the East that they cover a part of the plateau-like lahars. That these sloping lahars cover partially the plateau-like lahars and these plateau-like lahars are not lahars which originate from these younger slopes is shown by the sharp and continuous boundary between sloping lahars and plateau-like lahars. This boundary is indicated by a clear kink at the transition of the sloping lahars with an overall slope of 4% to the plateau-like lahars with an overall slope of 2%. When the plateau-like lahars were younger and thus originating from the sloping lahars this boundary could not be that clear and continuous.
The sloping lahars, and to a lesser extend also the plateau-like lahars, got dissected by valleys which form a part of the radial drainage pattern of the volcanic body. Also the Basement area got more dissected and got lowered by erosion. A scarp was developing at the eastern edge of the lahars. The relief inversion of the Ugulere flow had started.

2.The second phase. During this phase lahars came down from the northern part of the sloping lahars. Adjecent to this part of the sloping lahars there were no plateau-like lahars. So these younger lahars flowed from the sloping lahar area into the Basement System area which already was eroded and lowered. This has given these lahars an irregular surface and a different drainage pattern from the older lahars. These lahars have not formed a real continuous scarp because of their irregular dissection, but at the scarping parts of this younger lahar area the scarps are considerably lower than those of the plateau-like lahars. This indicates these lahars are younger than the plateau-like lahars. This impression is supported by the fact that under the lahars near Nandago hill, which belong to these younger lahars, gravels are found in which the volcanic component of the uppermost gravels is very high. This means the river which terraces this lahar has covered flowed through an area where already volcanics were deposited and being eroded.
During this phase the Nyambeni basalts have entered the eastern part of the area. These basalts have an inversion height lower than the inversion height of the Ugulere flow from the first phase. These basalts have the same characteristics with respect to their erodibility as the Ugulere phonolites. Also the deposition circumstances of both the basalts and the phonolite were the same, that is in rivervalleys with about the same

dimensions. This means these basalts are younger than the phonolite flow from the first phase.In the very northern part of the area where the basalts have overflowed larger areas, the inversion heights are about the same as the scarp heights of the lahars from this phase. This may indicate the younger lahars and these Nyambeni basalts originate from a same period after the main active phase of Mt.Kenya. The theory that the two volcanics are from the same period of volcanic activity is also supported by the location of the younger lahars. Their location indicates that the lahars from this phase are related to the parasitic cones on the north-eastern slopes of Mt.Kenya. These parasitic cones were active during the pleistocene activity of the Nyambeni range and can have triggered the younger lahars to flow.
Because this phase is a younger one than the main active phase of Mt.Kenya, which lasted from 3.1 to 2.6 my bp, this phase should be considered to have taken place during the Lower Pleistocene and before the activity of the Nyambeni volcanic Range ceased (about 0.5 my bp). (2+6)

3.The third phase. During this last phase a very few lahars were deposited in the area. Most of these lahars were and still are confined to the river valleys and appear to be river terraces. One of the lahars has overflowed the terraces of a river. This lahar now forms a plateau.Under this lahar plateau river terrace gravels are found. Downstream the lahar flow is confined to the former riverbed again. This plateau hardly shows any relief inversion. The highest scarps at the edges of the plateau and lahar flow are about 1.5 m high. Most lahars from this period are mainly still situated in the river valleys and show no relief inversion. This indicates these lahars are from a period which is younger than the second phase. The location of these lahars along the rivers which all descend from the flank of Mt.Kenya where the parasitic cones were active during the Pleistocene indicates that these lahars are also related to the activity of these parasitic cones. This implicates these lahars also have a Pleistocene age, but they are younger than the lahars of the second phase.
These youngest lahars which are confined to the river valleys will be refered at as the "terrace-like lahars" because the present rivers have cut their riverbed into these lahars what gives the lahars a terrace like appearance. The terrace-like lahars are found in the eastern parts of the valleys of Mutonga, Mara, and Nithi river, especially near their confluences. Near the confluence of Mara and Mutonga river also some of these lahars are found in the valleys of Thuchi and Ruguti river. The origin of these terrace-like lahars can be found on the north-eastern slopes of Mt.Kenya which Mutonga, Mara and Nithi river cross before entering the area. Probably the lahars had Nithi river as their main transport route. The very erosive lahar flows have eroded the Nithi valley, causing its very deep and wide shape. The many slumps have widened the valley even more.
Befor weit enters the area studied, Mutonga river follows a course from the north-eastern flanks of Mt.Kenya to the East, through an area where extended areas are covered with Nyambeni basalts. This explains the high basalt component in the terrace-

like lahars of Mutonga river. This high basalt component also proves these lahars are younger than or as old as the period in which the southern Nyambeni basalts were deposited.
Near their confluence the terrace-like lahars have covered a larger continuous area. This can be explained by a congestion of the lahars in the confluence area of Mutonga, Mara, Ruguti and Thuchi river. All the supplied lahars could not be carried off by the Mutonga river valley downstream the confluence, what caused a congestion upstream the confluence. This congestion caused the lahars to cover larger areas adjecent to the river valleys upstream the confluence. It also caused the lahars to enter the Thuchi and Ruguti river. This explains the small amount of these lahars in Thuchi and Ruguti river valleys near the confluence. This entering of lahars into the valleys of Thuchi and Ruguti river and the filling up of the valleys near the confluence with lahars probably also caused a congestion of the water in Thuchi and Ruguti river, causing the deposition of the extended terraces along these rivers. These terraces can also find their cause in a period with higher amounts of water flowing through the rivers and supplying more sediments. Such a period can be related to a period in which the glaciers on top of Mt.Kenya were melting as a result of climatic changes, e.g. at the end of the Pleistocene, or as a result of volcanic activity or both.

The best exposures of the terrce-like lahars are near the Mutonga and Mara confluence. In the road cuts through these lahars the same build up of the lahar deposits of all three rivers is observed. The Basement basis on which the lahars are deposited shows an a-symmetric valley. The northern Basement bank is gently sloping and lower than the steep and higher southern Basement bank. In this Basement basis a red clayey paleosol is developed. On the northern bank this soil is less developed and thin. On the southern bank the soil is deeper and better developed. Only on the southern bank the paleosol is covered with a sequence of thin tufa strata. These tufa strata consit of ashes which have been deposited in a wet swampy environment, as is shown by the shrinkage-cracks and types of plant-fossils. The thickness of these strata ranges from 20 cm at Mara river to 50 cm near Mutonga river. The tufa, soil and Basement are covered by lahar deposits. On the northern bank near the river this deposit has a maximum thickness of about 15m. On the southern bank this thickness has a maximum of about 2m. The lahars are covered with a very thin and non-continuous layer of gravel. In the lahars themselves there are lenticular bodies of gravel. The present river has cut its valley in these lahars. At the contact lahars-Basement rock a terrace of large round boulders is formed. Locally these boulders are cemented with secondary lime. The slopes of the lahars towards the present riverbed are steep and high on the northern bank and low and gradually descending at the southern bank. (See Fig. 13.)

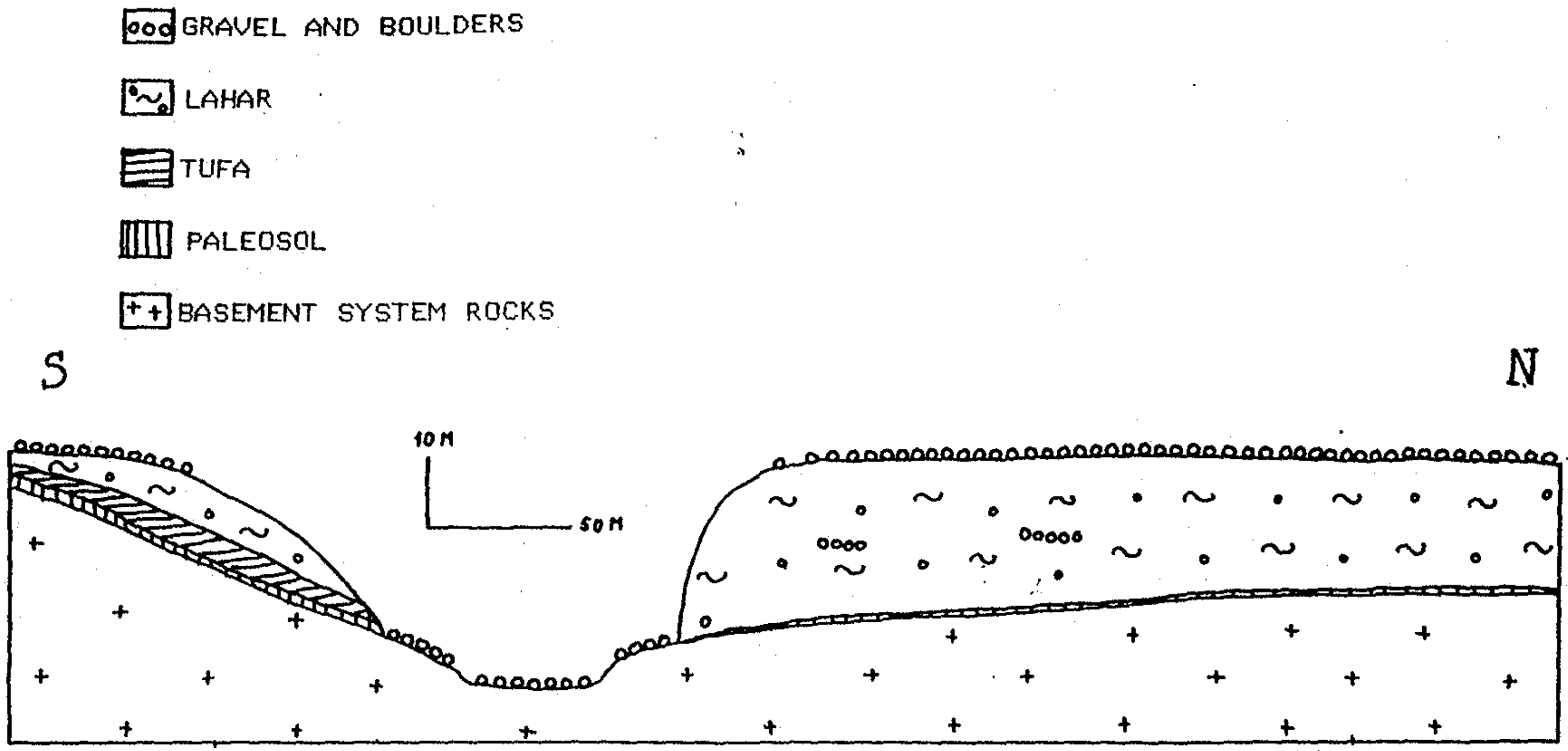


FIG. 14. -GENERAL CROSS SECTION TROUGH THE TERRACE-LIKE LAHARS.

On the basis of this build up of the lahars near the confluence the history of these terrace-like lahars can be reconstructed. This history is appliable on the terrace-like lahars of all the three large rivers with these terrace-like lahars in the area.

1. First there was a river which had cut a riverbed in the Basement rock. This river was relocating its riverbed towards the South. This caused the gentle sloping northern riverbank with a young, thin soil on this bank and a steep, high southern bank with a deeper, older soil. This sliding off of the river is probably caused by a relative uplift of the northern part of the area or a relative down-ward movement of the southern part of the area. (See Fig. 14.A.)

2. During periods of higher volcanic activity parts of the glaciers on Mt.Kenya melted and high amounts of volcanic ashes were blown into the air. This also caused an increase in the amount of rain falling on the slopes of the mountain. This resulted in inundations of the riverbanks. The water of the rivers from the north-eastern slopes of the mountain contained a large amount of ashes. These ashes could be deposited on the southern, higher bank of the river, wich was only inundated during very high floods. The thin layer of water on the southern bank offered the right, quiet environment for the sedimentation of the ash particles between the vegetation. When the water withdrew from the bank, ash particles were stopped by the grasses. This process was repeated several times, building up a sequence of tufa strata on the southern bank.

Probably these floodings coincided with a partly filling up of the rivervalley by lahars. This makes the floodings better explicable. (See Fig. 14.B and C)

3. A number of lahar flows filled up the river valley. The setting of the lahars in the former riverbed was the largest because of the greater thickness of the lahars in this gully. This caused a slight depression in the lahars above the former riverbed. This depression was the most appropriate place for the river to find its new course and to form a new riverbed. The water flowing over the fresh lahars rinsed out the gravel in the lahars leaving a layer of gravel on top of the lahars when cutting out a new riverbed. This process was repeated several times. The gravel on top of every lahar was only preserved in lenticular bodies when a new lahar covered the old one. Only the gravel on top of the last lahar was preserved as a thin sheet of sub-rounded gravel near ther present river valley.(See Fig. 14.D. to F)

4. The river incised the lahars more and more at the place of the pre-volcanic riverbed in the Basement System rocks. Where the new riverbed reached the Basement contact the river got confined to a more narrow riverbed, leaving a kind of terrace of large round boulders on the lithological contact. (See Fig. 14.G. and H.)

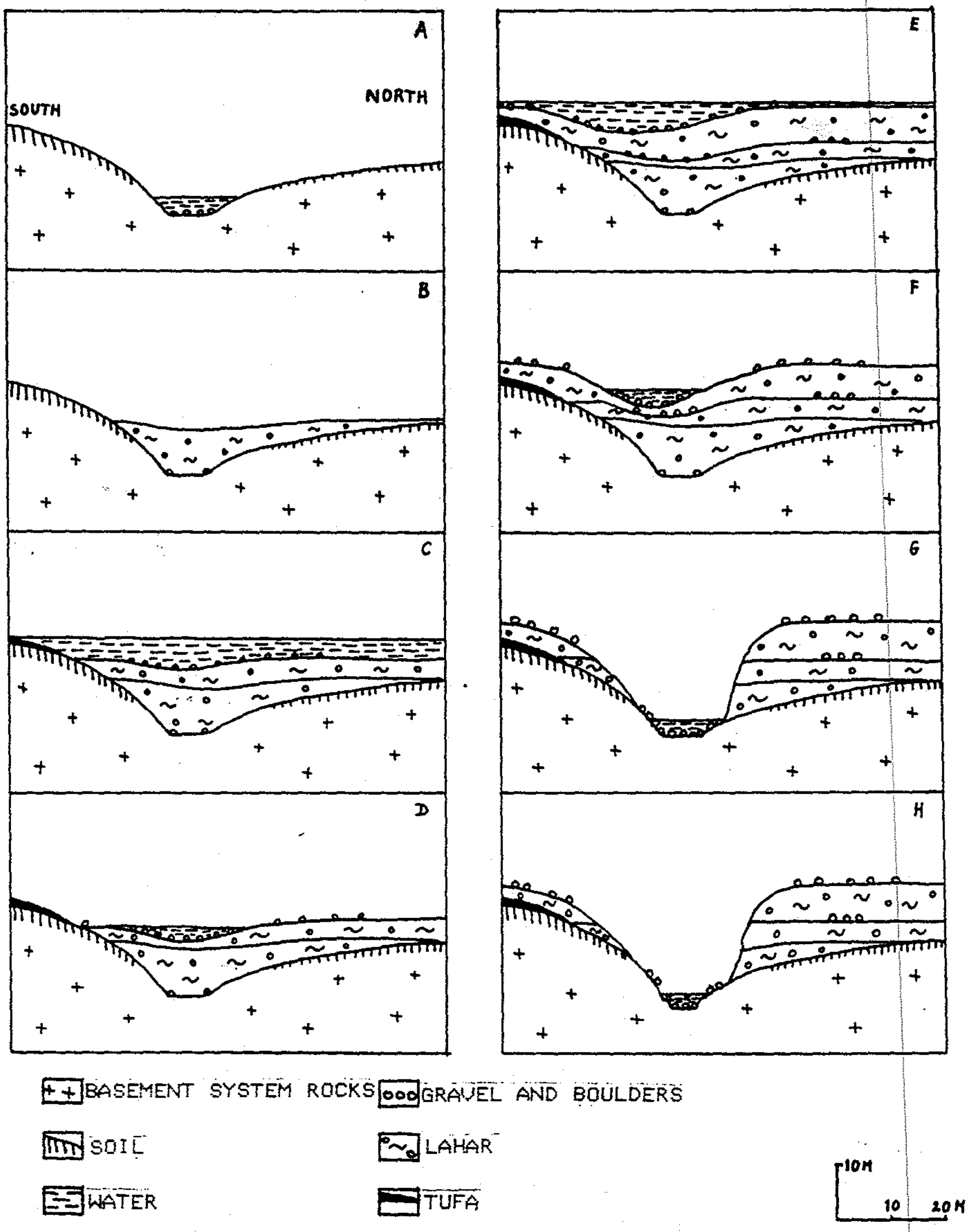


FIG. 15. -DEVELOPMENT OF THE TERRACE-LIKE LAHARS.
For explanation see text.

This third phase of volcanic depositions was probably during the Pleistocene. During the Pleistocene also other processes influenced the geology and geomorphology of the area. There were tectonic movements of the Upper Tana basin in which the Chuka-South area is located. Pluvials and inter-pluvials did alternate during the Pleistocene. This caused the building up and removal of terraces while in the whole area the erosion continued lowering the area. Deep red clay soils were and are developing in the lahar area. In the area with the plateau-like lahars laterite was formed at spots where temporarely cyclic stagnation of the ground water at the border between soil and lahar took place. This laterite is mainly found as round grains, the so called murram. The laterite and deep, stable soils of the lahar area have stabilized this area to a great extend. The Basement System area got more and more lowered.

In recent times the erosion is still removing the Pleistocene terraces and lowering the area. Laterite development only takes place at some spots. Much of the older laterite is eroding away or being excavated for road building.

5. ECONOMIC GEOLOGY

Chromite

During the survey one residual deposit of chromite was found North-west on Nandago hill. Further investigation yielded even more residual deposits North East of the summit. The deposits consist of chromite stones and boulders and have an average thickness of one meter.The largest boulder was 30-40-50 cm, which indicates a minimum thickness of 30 cm of the largest vein proved. Three samples were analysed by A.J. Kuyper in Wageningen. The samples revealed an Cr_2O_3 content of respectively 35%, 27% and 36% which indicates an average Cr_2O_3 content of >30%. The chromite seems to originate from thin bands in the North West slopes of Nandago hill. Prospecting is needed to make an accurate estimation about the total amount of chromite.

Copper

In Kitui district some small copper deposits were found. In the Konyu wadi a small (probably)malachite containing hornblende gneiss band occurs. The concordant band has a 20cm thickness and is not very extended (few meters). Near the Tana bridge at Katama some copper oxide patches were found in a pegmatite vein .

Garnets

Around Ishiara several residual garnet deposits were found. The garnets are up to 2 cm in cross section, usually unclear and fractured, The deposits are only a few square meters each. At Konyu wadi also garnets are found. These garnets occur in sillimanite gneisses. The garnets are usually small (average 0.5 cm) but also large garnets were found (up to 3 cm) Only very few garnets look suitable as gem stone. They have a beautiful deep red colour.
Around Ena river, near the granodiorite intrusion a granitoid gneiss band with many garnets occurs. These garnets are sometimes up to 10 cm in cross section. This granitoid band is about 2 m wide. This band is continuing South of Chuka-South area where abandoned garnet concessions are.

Graphite

This mineral is said to be found in and around the granodioritic intrusion. Local prospectors said that it was found in the area, and showed dolerite vein intrusions which should contain graphite.No graphite could be proved to occur int his area.
At Konyu wadi in Kitui district some graphite containing gneisses were found but these gneisses contain only very small amounts graphite.

Magnetite

This mineral is very common in the pegmatite veins in the Basement System area. It only occurs in minor amounts. The major amounts are probably mined already by the local people who used the magnetite for their iron production. The remnants of the melting ovens are still visible.

Mica

Mica crystals are not uncommon in pegmatite veins, but mostly their crystals are small. At two spots larger crystals where observed. Near Njuguni forest at the former mica exploration side were very large crystals were found near and in pits. These pits were dug in large pegmatite veins. The crystals were sometimes up to 30 cm in diameter. For futher information about former exploration and prospecting in the area see (24). In the central part of the area a pegmatite vein with large crystals was found (crystals up to 20 cm in cross section). These crystals looked poor in quality.

Murram

This ironstone gravel is an excellent material for constructing all-weather roads. It is used very much in the Mount Kenya volcanic area for this purpose. The murram is mostly found on the plateau-like lahar area along the valleys and the scarp. It is also found along the edges of the Depressions. At these sides there are many murram pits. Murram is also found on the riverterrace remains near the perennial rivers.

Precious stones

In the area semi-precious stones were found. These semi-precious stones are mined by the local people to earn some extra money. The semi-precious stones are garnets, tourmaline, amethyst and some feldspars. The tourmaline occurs in pegmatite veins and forms black columnar cristals up to 5cm, they are often found together with garnets. The amethyst is more rare.These crystals are usually unclear and rough. A Kenyan who showed us some clear ametyst cristals told us that they were found in the Nyambeni basalt of the Materi plateau. The feldspars are found in the pegmatite veins and the Mount Kenya volcanics.

Sand and clay

Sand is hardly found in the western volcanic area. In the Basement System area it is very common in the intermittent rivers.
Especially in Kitui district large intermittent rivers occur with considerable amounts of sand. A rough estimation of the amount of sand in the Konyu river in this area is about thousands of tons of sand. The sands are poorly sorted, coarse and contain sometimes considerable amounts of clay.
Clay is not often used for brick production. Only a few places are known in the area where bricks are being produced. At the Ishiara water supply camp the local dark red sandy clay is used. West of Runyenjes also the local brown sandy clay from the Basement hills is used for brick production. At Ena river the red sandy clay from the river terrace is used. The more popular (and common used) building stone in the area are lahar stones. These stones are produced in some local quarries.

Water

Water is an important factor especially in the areas were it is rare during the dry season. This occurs predominantly in the Basement System area.
See the report on the hydrogeology of the area by the authors of this report. (In preparation)

SUMMARY

1.
The area described in this report is the Chuka-South area. The area comprises the southern half of quarter-degree sheet 122 (Sheets 122/3 and 122/4) of the topographical map scale 1:50,000 of Kenya. The area is bound by latitudes $0^{o}15'S$ and $0^{o}30'S$ and by the longitudes $37^{o}30'E$ and $38^{o}00'E$. These coordinates enclose an area of about 1,500 square kilometres in Central Kenya (Eastern Province).

The area is sloping from the eastern slopes of Mt.Kenya from an altitude of about 2,200 m to the western banks of Tana river to an altitude of about 600 m .

The area is located at the windward side of Mt.Kenya. This causes higher amounts of rainfall in the higher western part of the area (up to 2,200 mm/year) and less rainfall near Tana river in the eastern part of the area (up to 600 mm/year). The potential annual evaporation increases from the West to the East (from less than 1,700 mm to more than 2,200 mm).

The vegetation is closely related to the geology and climate. In the north-western corner of the area rainforest is found. Descending to the East a tea-zone and a coffee-zone are found. At an altitude of about 1,000 m some remnants of an original Combretum savanna are found. In the eastern part of the area an Accacia bush and an almost completely permanent growing of millet and sorghum and grazing are found.

2.
The two major features of the geology of Kenya, the Precambrian Basement System and the Tertiary Rift Valley. Both have determined the geology of the Chuka-South area.
The Basement System rocks form the lower, eastern part of the area. Volcanics related to the Rift processes cover the higher, western part of the area. These differences have caused a clear bisection of the area.

<u>The Basement System</u> comprises most of the Precambrian rocks of Kenya. The Basement System forms a part of the Mozambique Belt. The rocks of the Mozambique Belt originate from sediments deposited in a geosyncline during the Precambrian. The Basement System rocks are of Katangan age. The sediments have been metamorphised, invaded by intrusive bodies, uptilted, folded, sheared etc.
In the the Basement System of the Chuka-South area four main units were distinguished:

1: The banded gabbroic-ultramafic complex. This complex comprises mainly hornblende gabbros and hypersthene bearing granulites. In some units also talc-tremolite rock, peridotite and chromite were found. The units of this complex are intrusions of mainly hornblende gabbros. The intrusions are accompanied by the high-

grade metamorphic granulites and intrusive talc, tremolite, peridotite and chromite.

2: The granitoids. These units are build up by granites, a granodiorite, gneissose granites and granitoid gneisses. The granites form large intrusive bodies and are accompanied by surrounding granitoid gneisses. The granodiorite also forms an intrusive body and is surrounded by migmatites.
The granite intrusions are accompanied by many pegmatite and aplite vein intrusions which intersect all other Basement System units.

The other to main units are the metamorphised sediments.
3: The banded migmatitic gneisses complex. This complex consists mainly of hornblende gneisses and one unit is build up by mainly hornblende and biotite gneisses. The gneisses are dissected by many doleritic, pegmatite and aplite veins. In one unit also granulites are common next to the gneisses and migmatites.

4: The quartzites and muscovite schists. This small unit is only found as a part of the Basement System islands in the southern part of the western volcanic area. The metamorphic grade of these meta-sediments is considerably lower than the metamorphic grade of the other meta-sediments. The quartzites originate from a band of sandy sediments in the mostly shaly sediments which now form the migmatitic gneisses.

The volcanic rocks in the Chuka-South area are closely related to the Rift Valley development. During the Pliocene numerous volcanoes were active at the margins of the Rift Valley. In this period the broad shield volcano Mt. Kenya was built up. Mt. Kenya is one of the volcanoes along the Rift Valley. Contemporaneous with the build up of Mt. Kenya also the the multicentre volcano of the Nyambeni range was built up. The main activity of the Mt. Kenya volcano was from 3.5 to 2 my bp. The activity of the Nyambeni multicentre volcano was from 4.5 to 0.5 my bp. Both volcanic centres delivered volcanic deposits in the Chuka-South area. Mt. Kenya delivered the bulk of the volcanic deposits. Most of these deposits are lahars, the consolidated mudflows which ran down the slopes of the volcanic body as erosive, destructive, hot masses of pyroclastics, water and enormous boulders of various origins. The deposits of the Nyambeni range are basalts. These basalts are only found in the eastern Basement System area.

The depositions of the volcanics have taken place in three main phases:
-The first phase was during the main activity of Mt. Kenya (upper Pliocene). In this period some phonolite flows and many metres of lahars were deposited in the area. The lahars which covered the relatively flat landsurface also have a flat topography and form the so called "plateau-like lahars". The younger lahars from this phase partly cover the plateau-like lahars and form a part of the slopes of Mt. Kenya.

-The second phase was during the activity of the parasitic cones on the north-eastern flank of Mt.Kenya (Plio-Pleistocene). In this period lahars from the parasitic cones area entered the area from the North-west and covered an area East of and in between the lahars from the first phase. In this period also the basalts from the Nyambeni range entered the area. The basalts entered the area from the North and flowed through Mutonga river to Tana river.

-The third phase (Pleistocene) is also related to the activity of the parasitic cones of Mt. Kenya. During this most recent phase only a minor amount of lahars entered the area. These lahars flowed from the North-west through the valleys of the major rivers in the lahars from the other two phases and were deposited in the Basement System area, in and along the valleys.

Also many river terraces were deposited in the Chuka-South area but most of these terraces have been eroded away. The flat topography of the areas which were covered with terraces often still remains but only at spots the terrace material can be found back. During the most recent part of the geological history of the area colluvium is deposited along the steepest slopes in the area.

3.

The geomorphology of the area is closely related to the geology and geological history of the area. The bisection of the area is also very clear in the different landscapes of the area. There is a volcanic landscape and a Basement System landscape.
The volcanic landscape is sloping East. This slope is gradually getting less towards the East. The south-eastern part of the volcanic area is a plateau-like area. The rest of the volcanic area is steeper and stronger dissected.
Locally in the volcanic landscape oval, concave depressions are common.
The boundary between the oldest volcanics and the Basement System is formed by a high scarp. The isolated parts of the Basement System area which have been covered with volcanics have undergone an inversion of their relief and form high ridges and plateaus in the Basement System landscape. The older the volcanic deposit is, the higher the scarp or relief inversion is.
The Basement System area is also sloping East but to a lesser extent. Here a clear relation between lithology and landtype excists. In this landscape Mountains, Hills and Lowlands are distinguished. The Mountains and Hills are built up by the resistant rocktypes as granites and the gabbroic-ultramafic complex. The Lowlandsare predominantly built up by the less resistant migmatitic gneisses.

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APPENDIX1: THE LEGEND OF THE GEOLOGICAL MAP

Quaternary	**-Colluvial deposits**	**(C)**
	-Colluvium derived from Mount Kenya volcanics	(C1)
	-Colluviumderivedfrommaficto ultra mafic rocks	(C2)
	-Colluvium derived from basalts	(C3)
	-Fluviatile terrace deposits	**(F)**
	-conglomerate, boulders and gravel deposits	(F1)
	-deposits rich in pyroclastics	(F2)
	-riverbed deposits	(F3)
	-Nyambeni Basalts	**(B)**
	with underlying fluviatile deposits (pre- or syn -volcanic)	(●●●)
Tertiary	**-Lahar complex**	**(L)**
	-Complex of lahars and lava flows	(L1)
	-Lahar complex which is overlying a granite/granitoid complex	(L2)
	-Phonolite flows	**(P)**
	with underlying fluviatile deposits (pre- or syn-volcanic)	(ooo)
Pre-Cambrium	**-Banded gabbroic-ultramafic complex**	**(M)**
	-granulites, hornblende gabbro, talcum-tremolite complex	(M1)
	-hornblende gabbro, talcum tremolite peridotite complex	(M2)
	-hornblende gabbro, granulite complex	(M3)
	-predominantly hornblende gabbro with granulites	(M4)
	-Granites and granitoid gneisses	**(G)**
	-granitoids and granites amidst Mount Kenya volcanics	(G1)
	-predominantly granitoid gneisses	(G2)
	-predominantly gneissose granites	(G3)
	-granodiorites and migmatites	(G4)

-granites (G5)

-Banded migmatitic gneisses complex (X)

-granulites (X1)
-hornblende-plagioclase migmatites with granitoid and some granulite bands (X2)
-successionofvarious bandedgneisses with granitoid bands (X3)
-hornblende-plagioclasegneisseswith migmatitic and granulitic bands (X4)
-hornblende-, biotite-,and hornblende biotite gneisses and migmatites with dolerite veins (X5)
-hornblende gneisses with some hornbl. gabbro veins and granulite bands (X6)
-hornblende gneisses with hornblende gabbro veins (X7)

-Quartzites and muscovite schists (Q)

-Strike outcrops of resistant rock

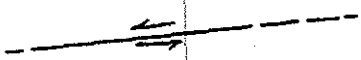
-Dolerites ---(D)---

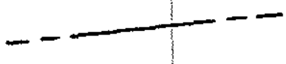
-Pegmatites ---(E)---

-Talc-tremolite ---(T)---

-Granitoids ---(Ga)---

-Granulites ---(Gu)---

-Fault 

-Other Lineaments (joints etc.) 

-Scarp 

-Depression 

-Strike and Dip 

-Indefinite contact between younger and older pliocene volcanics (shaded edge on youngest side of the lahar) 

APPENDIX 2: THE LEGEND OF THE GEOMORPHOLOGICAL MAP.

Volcanic landscape:			V
Mount Kenya slopes			VM
		parallel dissected	VM1
		subdendritically dissected	VM2
Hilly area			VH
Plateau-like area			VL
Valleys			VV
Depressions			VD
Scarp with footslopes			VS
Ridges			VR
Plateaus			VP
Basement System landscape:			B
Mountains			BM
Hills			BH
Footslopes			BF
Lowland area			BL
	Flat		BLf
	Rolling		BLr
		rectangular dissected	BLr1
		subparallel dissected	BLr2
		subdendritically to subparallel dissected	BLr3
	Hilly		BLh
		dendritically dissected	BLh1
		subparallel dissected	BLh2
Valley			BV
Present Riverbed			BR

APPENDIX 3: OBSERVATION LIST.

The coordinates refer to the coordinates of the topographical map of East Africa, scale 1:50,000, mapsheets 122/3 and 122/4.

no :001
name location :Karue hill
coordinates :99493-3374
observation(s):quartzites with muscovite schists in between (33/40W)
sample(s) :001;004;039;040;041;042;043;044.

---

no :002
name location :West of Ishiara water supply camp
coordinates :99502-3627
observation(s):Basement outcrop (biotite gneiss) with overlying lahar.
sample(s) :002;003;016.

---

no :003
name location :Materi plateau
coordinates :99640-3780
observation(s):basalt (thickness few meters) with underlying terrace remains.
sample(s) :005.

---

no :004
name location :Itugururu, air strip
coordinates :99542-3569
observation(s):lahar outcrop
sample(s) :006.

---

no :005
name location :Kamutiria, plain
coordinates :99645-3665
observation(s):lahar plain (15m in thickness) with underlying hornblende gneisses.
sample(s) :007.

---

no :006
name location :West of Ishiara water supply camp
coordinates :99502-3625
observation(s):lahar outcrop.
sample(s) :008;009.

---

no :007
name location :Kevote
coordinates :99517-3374
observation(s):pegmatite vein intrusion
sample(s) :011;012.

```
no                :008
name location :plateau North of Thuchi bridge
coordinates     :99576-3723
observation(s):inverted phonolite flow with underlying terrace
                  remains.(phonolite 10-15 m in thickness)
sample(s)       :014:081.
-----------------------------------------------------------------
no                :009
name location :South of Kiburu
coordinates     :99512-3745
observation(s):pegmatite vein intrusion.
sample(s)       :017.
-----------------------------------------------------------------
no                :010
name location :Katwana ka Munanda
coordinates     :99642-3858
observation(s):Tana terrace rich in pumice and other volcanics
sample(s)       :018;093:094;095.
-----------------------------------------------------------------
no                :011
name location :Konyu wadi
coordinates     :99534-3867
observation(s):biotite feldspar gneisses,biotite hornblende
                  gneisses, biotite gneisses and hornblende gneisses
                  with many pegmatites. All these gneisses are
                  banded and to some extent migmatized.The bands are
                  several meters in thickness.
sample(s)       :021;020:026;029;030;058;059;060;106;113.
-----------------------------------------------------------------
no                :012
name location :Njuguni forest, South
coordinates     :99708-3674
observation(s):muscovite (large cristals in pegmatite vein)
                  granulites are the most common rock in the area.
sample(s)       :024;114.
-----------------------------------------------------------------
no                :013
name location :plateau West of Nandago hill
coordinates     :99695-3680
observation(s):phonolite rich plateau lahar (5 m )with underlying
                  volcanic river gravel with underlying clay layer
                  of a few cm, with underlying quartz rich river
                  gravel but still containing a volcanic component.
sample(s)       :025;074.
-----------------------------------------------------------------
no                :014
name location :Gitwa bridge
coordinates     :99521-3523
observation(s):trachyte boulder (3 m) in lahar
sample(s)       :031.
-----------------------------------------------------------------
```

no :015
name location :Ishiara water supply camp
coordinates :99500-3630
observation(s):hornblende gabbro and dolerite minor intrusives, migmatites are the most common rocks
sample(s) :032;091.

---

no :016
name location :D472 between Mara river and Rugutti river
coordinates :99622-3735
observation(s):hornblende gneiss
sample(s) :036

---

no :017
name location :Duke's view
coordinates :99574-3440
observation(s):lahar containing diverent kinds of other rocks also containing fossillized wood.
sample(s) :037:051;052.

---

no :018
name location :North of Kevote
coordinates :99527-3377
observation(s):granitoid, augengneiss.
sample(s) :038.

---

no :019
name location :Nithi valley at Gituntu
coordinates :99685-3511
observation(s):at valley bottom phonolite flow or according to Schoemann: basalt. The valey slopes consist of lahar.
sample(s) :045;049:050.

---

no :020
name location :Ruguti valley at Kangoro
coordinates :99612-3454
observation(s):lahar with overlying phonolite flow, see cross section Ruguti
sample(s) :046;047;048.

---

no :021
name location :Thuchi River at Ciangera
coordinates :99528-3698
observation(s):granulite and migmatite in tors
sample(s) :053;054:055.

---

no :022
name location :Kogari
coordinates :99501-3742
observation(s):aplite in augengneiss
sample(s) :056

---

no :023
name location :Ndenderu hill
coordinates :99493-3758
observation(s):muscovite biotite gneiss in lower slope.Also migmatites containing a lot of hornblende.
sample(s) :057;149.

---

no :024
name location :Wadi East of Ciangera
coordinates :99493-3742
observation(s):hornblende gneisses with anthophyllite amphibolite and aplites and pegmatites. with overlying terrace rich in calc tuffa with fossile leaves
sample(s) :061;062;063;064;065.

---

no :025
name location :plateau South of Kierera
coordinates :99542-3805
observation(s):inverted basalt plateau, basalt about 5m in thickness. with underlying river boulders.
sample(s) :070;071.

---

no :026
name location :Nandago hill
coordinates :99698-3698
observation(s):chromite, talc-tremolite ,peridotite and hornblende gabbro.
sample(s) :075:076;077;109.

---

no :027
name location :between Mara river and Njuguni forest
coordinates :99698-3655
observation(s):partly inverted phonolite flow
sample(s) :078.

---

no :028
name location :river near Ena river
coordinates :99462-3630
observation(s):talc-tremolite ridges in hornblende gneiss complex
sample(s) :087;088.

---

no :029
name location :Grand Falls
coordinates :99706-3884
observation(s):terrace with calc tuffa about 20 m above Grand Falls
sample(s) :092.

---

no :030
name location :Mutonga river
coordinates :99685-3760
observation(s):small hornblende gabbro hill
sample(s) :096.

---

no :031
name location :North of Grand Falls
coordinates :99708-3885
observation(s):biotite-hornblendite in biotite-hornblende gneiss
sample(s) :100.

---

no :032
name location :South East of Ishiara
coordinates :99484-3664
observation(s):tourmaline in pegmatite
sample(s) :103.

---

no :033
name location :North East of Ishiara
coordinates :99515-3675
observation(s):garnets in granotoid gneiss and pegmatites
sample(s) :104.

---

no :034
name location :top Ndenderu hill
coordinates :99495-3764
observation(s):granitiod and granite on the southern top. The northern top consists of granulite and hornblende gabbro.
sample(s) :107;121.

---

no :035
name location :Kamutiria school
coordinates :99648-3662
observation(s):lahar with secondairy $CaCO_3$
sample(s) :108

---

no :036
name location :Toibetia East
coordinates :99563-3633
observation(s):granulite / migmatites complex in tors
sample(s) : 110:112.

---

no :037
name location :Kithangani
coordinates :99598-3614
observation(s):granulite (dark and light variaty)
sample(s) :111;119.

---

no :038
name location :North of Thuchi bridge, Ishiara
coordinates :99524-3655
observation(s):migmatite in hornblende gneisses
sample(s) :120.

---

no :039
name location :fall West of Runyenjes
coordinates :99526-3392
observation(s):very dense lahar 10 m in thickness. with underlying porous lahar. In the latter caves have developed behind the fall. In these caves remains of stone age camping have been found.
sample(s) :

---

no :040
name location :Kibogi, highest parts
coordinates :99540-3362
observation(s):lahar
sample(s) :

---

no :041
name location :Kibogi, slopes
coordinates :99532-3365
observation(s):lahar with granite and granitoid outcrops
sample(s) :

---

no :042
name location :South eastern slope Kirimiri
coordinates :99533-3382
observation(s):25/80^{o}W muscovite schists
sample(s) :067.

---

no :043
name location :top Kirimiri
coordinates :99535-3379
observation(s):pink (feldspar rich) granites and augengneisses
sample(s) :123.

---

no :044
name location :Kirigi
coordinates :99714-3342
observation(s):two granite hills and West of these hills large granite lahar complex.
sample(s) :122.

---

no :045
name location :Maranga
coordinates :99452-3419
observation(s):migmatites, granitoids on top (50/45^{o}N approx.) lower slopes biotite muscovite schists (23/30^{o}W) on the lowest slopes there is a large lahar content.
sample(s) :125.

---

no :046
name location :East of Ugweri
coordinates :99492-3452
observation(s):granite outcrop on small hill.
sample(s) :126

---

no :047
name location :Kathungu
coordinates :99542-3467
observation(s):profile pit no 1,lahar
sample(s) :

---

no :048
name location :South East Mukuria
coordinates :99515-3530
observation(s):profile pit no 3,lahar
sample(s) :

---

no :049
name location :East Kanyuambora
coordinates :99499-3599
observation(s):profile pit no 4,lahar
sample(s) :

---

no :050
name location :Ciangera
coordinates :99529-3699
observation(s):profile pit no 5, granulite
sample(s) :

---

no :051
name location :South of Thuchi bridge
coordinates :99563-3725
observation(s):profile pit no 6, backswamp clay
sample(s) :

---

no :052
name location :West of Kanjuki
coordinates :99633-3685
observation(s):profile pit no 8, hornblende gneisses.
sample(s) :

---

no :053
name location :South East of Kiegumo (North)
coordinates :99652-3624
observation(s):profile pit no 10, lahar
sample(s) :

---

no :054
name location :Kinoru
coordinates :99667-3602
observation(s):profile pit no 11, lahar
sample(s) :

---

no :055
name location :South West Mariani
coordinates :99638-3552
observation(s):profile pit no 12, lahar
sample(s) :

---

no :056
name location :North West Rukuriri
coordinates :99598-3365
observation(s):profile pit no 13, lahar
sample(s) :

---

no :057
name location :forest North West of Rukuriri
coordinates :99604-3359
observation(s):profile pit no 14, lahar
sample(s) :

---

no :058
name location :South of Ishiara
coordinates :99487-3632
observation(s):profile pit no 31, biotite gneiss
sample(s) :

---

no :059
name location :Hospital Ishiara
coordinates :99497-3646
observation(s):profile pit no 33, hornblende biotite gneiss
sample(s) :

---

no :060
name location :South of Karangare
coordinates :99502-3673
observation(s):profile pit no 40, biotite gneiss
sample(s) :

---

no :061
name location :South East of Karangare
coordinates :99505-3673
observation(s):profile pit no 39, gneisses
sample(s) :

---

no :062
name location :Wadi Kamarandi
coordinates :99593-3777
observation(s):quartz feldpar gneisses(strike 240) alsosome
biotite feldspar gneisses.
sample(s) :70;71.

```
no              :063
name location   :Edge Nandago plateau
coordinates     :99691-3673
observation(s)  :lahar
sample(s)       :72;73;74.
---------------------------------------------------------------
no              :064
name location   :river South East Makengi
coordinates     :99704-3650
observation(s)  :inverted phonolite flow, with columnar structures
                 an its phenocrysts in the flow direction.
sample(s)       :78.
---------------------------------------------------------------
no              :065
name location   :Ruguti bridge
coordinates     :99612-3741
observation(s)  :some terrace deposits, probably two levels.
                 the lowest level is cemented by Fe and Mn oxides
sample(s)       :
---------------------------------------------------------------
no              :066
name location   :Mara bridge
coordinates     :99623-3742
observation(s)  :terrace profile, top level 1-2 m gravel and
                 boulders cemented with clay and Fe Mn oxides.
                 level below basalt rich gravels between lahar
                 like layers. close to the river this level is more
                 sortened out and less lahar like.
sample(s)       :82;83.
---------------------------------------------------------------
no              :067
name location   :Mutonga bridge
coordinates     :99661-3745
observation(s)  :washed lahar like deposits on Basement
                 Profile description from top downwards:
                 VI -lahar like deposits
                 V  -fine sand layers with pumice
                 IV -ash layer (10-20cm) rich in pumice with and
                     tubidite like contact with V
                 III-ash layer (10-20cm) with plant remains
                 II -ash layer with clay (10 cm)
                 I  -red sandy clay soil on aplite (50 cm)
sample(s)       :84;85;86.
---------------------------------------------------------------
no              :068
name location   :bottomland Mukuria
coordinates     :99526-3504
observation(s)  :augering (middle)
                 0 -  70cm dark reddish brown silty clay, with some
                           black mottles
                 70- 220cm gray clay,with brown red mottles, more
                           coarse fragments when deeper.
                 220-      rock or iron stone
---------------------------------------------------------------
```

no :069
name location :bottomland South East Mukuria
coordinates :99517-3535
observation(s):augering (half way)

0 - 80cm black to very dark grey clay, with peaty and silty layers
80 - 120cm dark brown sandy clay with many coarse fragments.
120- sapprolite or iron stone

augering (middle)

0 - 70cmvery dark gray silty clay with some rockfragments.
70 - 100cm grayish brown sandy clay with spots of coarse sand.
100- 130cm grayish brown loamy sand
130- 150cm dark brown loamy sand, with Fe and Mn oxides.
150- iron stone.

---

no :070
name location :bottomland Karurumo
coordinates :99484-3498
observation(s):augering (edge)

0-50cm dark reddish brown silty clay loam with murram.
50- iron stone.

---

no :071
name location :bottomland East Gachungu
coordinates :99518-3475
observation(s):augering (edge)

0-120cm brown silty clay to sandy clay, with many coarse fragments,murram.
120- iron stone.

---

no :072
name location :Ena river
coordinates :99460-3635
observation(s):fault with amphibolite and quartz.(360/70W)
sample(s) :89;90.

---

no :073
name location :South East Iganbangombe
coordinates :99548-3660
observation(s):inverted phonolite flow
sample(s) :-

---

no :074
name location :Kaara ka Mbabu
coordinates :99657-3653
observation(s):granulite / hornblende gabbro hill, disconcordant, the strike is aprox. East-West
sample(s) :136.

```
no               :075
name location :South Kaara ka Mbabu
coordinates    :99635-3643
observation(s):granulite hill
sample(s)      :-
-------------------------------------------------------------
no               :076
name location :North West Kaara ka Mbabu
coordinates    :99660-3640
observation(s):lahar
sample(s)      :-
-------------------------------------------------------------
no               :077
name location :Ishiara
coordinates    :99504-3652
observation(s):river terrace thuchi >8m pit observation
sample(s)      :-
-------------------------------------------------------------
no               :078
name location :Kamarandi
coordinates    :99500-3737
observation(s):granulites and norites on lower slope
sample(s)      :-
-------------------------------------------------------------
no               :079
name location :East Ndenderu
coordinates    :99489-3768
observation(s):remain river terrace, gravel has no volcanic
               component, therefore it may be pre volcanic.
sample(s)      :-
-------------------------------------------------------------
no               :080
name location :Irira
coordinates    :99480-3790
observation(s):river terrace Tana.
sample(s)      :-
-------------------------------------------------------------
no               :081
name location :Kanjuki East
coordinates    :99628-3715
observation(s):inverted lahar flow
sample(s)      :-
-------------------------------------------------------------
no               :082
name location :Chiokarige South East
coordinates    :99678-3830
observation(s):granitoids and migmatites
sample(s)      :-
-------------------------------------------------------------
no               :083
name location :Karandini
coordinates    :99578-3454
observation(s):road cut, lahar
sample(s)      :-
-------------------------------------------------------------
```

no :084
name location :Thambo
coordinates :99588-3456
observation(s):road cut, lahar
sample(s) :-

---

no :085
name location :Thambo
coordinates :99581-3455
observation(s):road cut, lahar
sample(s) :-

---

no :086
name location :Njuri
coordinates :99593-3455
observation(s):road cut, lahar
sample(s) :-

---

no :087
name location :Thuita
coordinates :99602-3453
observation(s):road cut, lahar
sample(s) :-

---

no :088
name location :Ruguti West
coordinates :99608-3451
observation(s):road cut, lahar and phonolite
sample(s) :-

---

no :089
name location :Kanyuambora
coordinates :99475-3571
observation(s):granitoid hill with migmatites and granitoid quartz feldspar gneiss with orientated biotite.
sample(s) :162;163.

---

no :090
name location :South Mutonga bridge
coordinates :99655-3742
observation(s):hornblende feldspar gneiss (335/75W) with amphibolite bands
sample(s) :-

---

no :091
name location :Kanguru
coordinates :99710-3783
observation(s):mainly gabbro norite with some granulite. sample isn't representative.
sample(s) :127.

---

no :092
name location :Mutharanga forest
coordinates :99702-3770
observation(s):mafic hill with on it's nothern side an granitoid hill. Some gabbro norites were found on its lower slopes.
sample(s) :-

---

no :093
name location :Kanguru valley
coordinates :99710-3781
observation(s):giant pegmatite vein intrusion (15m thick)
sample(s) :-

---

no :094
name location :Kithangani top
coordinates :99601-3624
observation(s):Concordant ridges of gabbro norite and granulite and some talc-tremolite.(strike 15))
sample(s) :128;129;130.

---

no :095
name location :South Kithangani
coordinates :99586-3618
observation(s):At the edge of the hill the granulite becomes lowerin colour index and pegmatites are more abundant.
sample(s) :-

---

no :096
name location :Gaitarene
coordinates :99577-3630
observation(s):tors of granulite/migmatie complex in hornblende gneiss matrix
sample(s) :-

---

no :097
name location :Ruguti
coordinates :99560-3633
observation(s):terrace remains of the Ruguti
sample(s) :-

---

no :098
name location :South East of Kithangani
coordinates :99593-3643
observation(s):hornblende-plagioclase gneisses with some granulites, the gneisses are finer in texture and more acid Eastwards. Also some Quartz feldspar muscovite gneiss was found. The tors mainly consist granulite/migmatite of complex.
sample(s) :068.

---

no :099
name location :ridge Makanyanga
coordinates :99588-3665
observation(s):very dark hornblende rich granulites (strike 100)
sample(s) :132

---

no :100
name location :hills West of Kithinge
coordinates :99608-3680
observation(s):granulite (dark) hills in a hornblende plagioclase gneiss matrix.
sample(s) :133

---

no :101
name location :West Nandago
coordinates :99695-3695
observation(s):hornblende gneiss (320/100^{o}W) with concordant and disconcordant granitoid vein intrusions.
sample(s) :-

---

no :102
name location :South West Nandago
coordinates :99688-3705
observation(s):hornblende plagioclase gneisses (340/45^{o}W) often with discordant granitoid and augengneiss vein intrusions.
sample(s) :-

---

no :103
name location :East on Nandago
coordinates :99698-3708
observation(s):series East West ridges which mainly consists of gabbro norite and peridotite. The valleys inbetween consists mainly of talc-tremolite. Cutting these EW ridges are NS ridges of granitoids and augengneiss.
sample(s) :-

---

no :104
name location :Between Nandago Hill and Njuguni forest
coordinates :99710-3698
observation(s):complex of hornblende gneisses granitoid gneisses with pegmatite vein intrusives.
sample(s) :-

---

no :105
name location :East Njuguni forest
coordinates :99713-3688
observation(s):Hornblende gneisses with light granulite ridges in between.
sample(s) :-

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no :106
name location :Njuguni forest
coordinates :99715-3678
observation(s):Dark granulites and scattered hornblende gabbro boulders.
sample(s) :134;135.

---

no :107
name location :Kampogo
coordinates :99719-3700
observation(s):This hill isn't mapped on the topographical map it resembles Nandago in its features. We assume that this hill also consists of ultra mafic rocks.
sample(s) :-

---

no :108
name location :hill East Kanjuki
coordinates :99620-3732
observation(s):hornblende plagioclase gneisses with granulite bands (310/35^{o}W). Hunderd meters East an granulite tor.
sample(s) :-

---

no :109
name location :North Materi
coordinates :99662-3780
observation(s):granitoid plagioclase hornblende gneisses (10/70^{o}W). White sandy soils.
sample(s) :137.

---

no :110
name location :river North of Materi
coordinates :99666-3781
observation(s):river incission in migmatites. Augengneiss tor close to river (10/50^{o}W).
sample(s) :-

---

no :111
name location :South Chiokariga
coordinates :99679-3785
observation(s):hills and tors of augengneisses andgneissose granites (330/60^{o}W).
sample(s) :138.

---

no :112
name location :North West Materi
coordinates :99660-3769
observation(s):ridge with olivine basalts on top. Hornblende plagioclase gneisses with many concordant pegmatites and aplite vein intrusions. (320/60^{o}SW)
sample(s) :139

---

no :113
name location :East Mutonga
coordinates :99665-3770
observation(s):A hill which consists completely of hornblende gabbro.
sample(s) :140.

---

no :114
name location :South Materi
coordinates :99607-3782
observation(s):Concordant talc tremolite ridge which is very rich in serpentine. (strike 320) Surrounding area consists out of gneissose granites and augengneisses. Parallel to the ridge is a giant pegmatite vein intrusion. A few hunderd meters to the South is a small talc tremolite hill which seems to be part of the same band. (strike at hill 20) The band seems to continue untill about 99504.
sample(s) :141.

---

no :115
name location :South West Kierera forest.
coordinates :99607-3779 and 99585-3798
observation(s):small hornblende gabbro vein intrusions in granitoid complex. (strike 0) the hornblende gabbros contain a lot of plagioclase.
sample(s) :-

---

no :116
name location :South Kierera forest
coordinates :99581-3805
observation(s):Granitoid complex: The lower parts consist of granitoid gneisses, the higher parts (hills and tors)of gneisose granites and augengneisses ($10/70^{o}$W). Migmatites (also some more mafic) are found everywhere in the complex. At 99580-3796 a ridge of hornblende plagioclasegranitoid gneiss ($50/50^{o}$N).
sample(s) :142.

---

no :117
name location :South East of Kierera
coordinates :99600-3840
observation(s):plagioclase hornblende gneisses ($20/40^{o}$W) and concordant many granitoid and pegmatites bands.(only a few meters in thickness)
sample(s) :143.

---

no :118
name location :East Kierera
coordinates :99635-3855
observation(s):hornblende plagioclase gneisses (50/40°W) with concordant granitoid gneisses (but less than with 117).
sample(s) :-

---

no :119
name location :South East on Kiburu hill
coordinates :99515-3746
observation(s):migmatitic hornblende gneisses and many granulites
sample(s) :144

---

no :120
name location :South East of Kiburu hill
coordinates :99512-3745
observation(s):hornblende plagioclase gneiss bands (350/80°W) of about 10 meters in thickness, some smaller bands of muscovite plagioclase gneisses(strike 350 to 0) A lot of granulite colluvial boulders.
sample(s) :-

---

no :121
name location :South Kiburu hill
coordinates :99509-3744
observation(s):between Kiburu range and Kamarandi hill a gneissose granite band (strike 0) resembles the granitoids of Ndenderu hill. More to the West a few small (several meters in thickness) concordant dolerite vein intrusives were observed.
sample(s) :-

---

no :122
name location :Top Kiburu range
coordinates :99520-3740
observation(s):granulite (most common rock in the hill) with some hornblende gabbro veins (width about 10 meters) in the centre. A concordant giant quartz vein on the top (w:10 m.,l:>30m.).Near the top also remnants of former homesteads were observed (see sample 145).
On the slopes many of one size rounded quartz boulders were observed.
sample(s) :145;146;147;148;149.

---

no :123
name location :East Katama
coordinates :99470-3830
observation(s):granitoids and augengneisses with many pegmatite vein intrusions.
sample(s) :-

APPENDIX 4: SAMPLE LIST.

The coordinates refer to the coordinates of the topographic map of Kenya, scale 1:50,000, mapsheets 122/3 and 122/4.

sample no	name	coordinates
no 001	quartzite	99493-3374
no 002	biotite gneiss	99502-3627
no 003	biotite gneiss	99502-3627
no 004	schist	99493-3374
no 005	pleistocene basalt	99640-3780
no 006	lahar	99542-3569
no 007	volcanic bomb from lahar	99645-3665
no 008	phonolite	99502-3625
no 009	phonolite	99502-3625
no 010	lahar	99572-3742
no 011	pegmatite	99517-3374
no 012	quartz with pegmatite	99517-3374
no 013	trachyte	99603-3742
no 014	pleistocene alluvial gravel	99572-3725
no 015	petro calcic	99556-3690
no 016	schist	99521-3523
no 017	pegmatite	99512-3745
no 018	tufa from Tana terrace	99642-3858
no 019	pegmatite	99534-3867
no 020	pegmatite with magnetite	99534-3867
no 021	pegmatite with epidote	99534-3867
no 022	magnetite	99501-3742
no 023	magnetite	99501-3742
no 024	muscovite	99708-3674
no 025	rhomb porphyric phonolite	99708-3674
no 026	malachite like minerals	99534-3867
no 027	feldspar	99481-3788
no 028	gneiss from Tana terrace	99481-3788
no 029	biotite-feldspar gneiss	99534-3867
no 030	remain iron melting	99534-3867
no 031	trachyte	99521-3523
no 032	gabbro norite	99500-3630
no 033	volcanic glass	99534-3523
no 034	vytrophyre	99648-3662
no 035	vytrophyre	99653-3508
no 036	hornblende gneiss	99622-3735
no 037	ignimbrite	99574-3440
no 038	granitoid, augengneiss	99527-3377
no 039	quartzite	99493-3374
no 040	pegmatite	99493-3374
no 041	schist with garnets	99493-3374
no 042	amphibole quartzite	99493-3374
no 043	quartz with schist and garnet	99493-3374
no 044	schist	99493-3374
no 045	phonolite	99685-3511
no 046	phonolite	99612-3454
no 047	contact lahar/phonolite	99612-3454

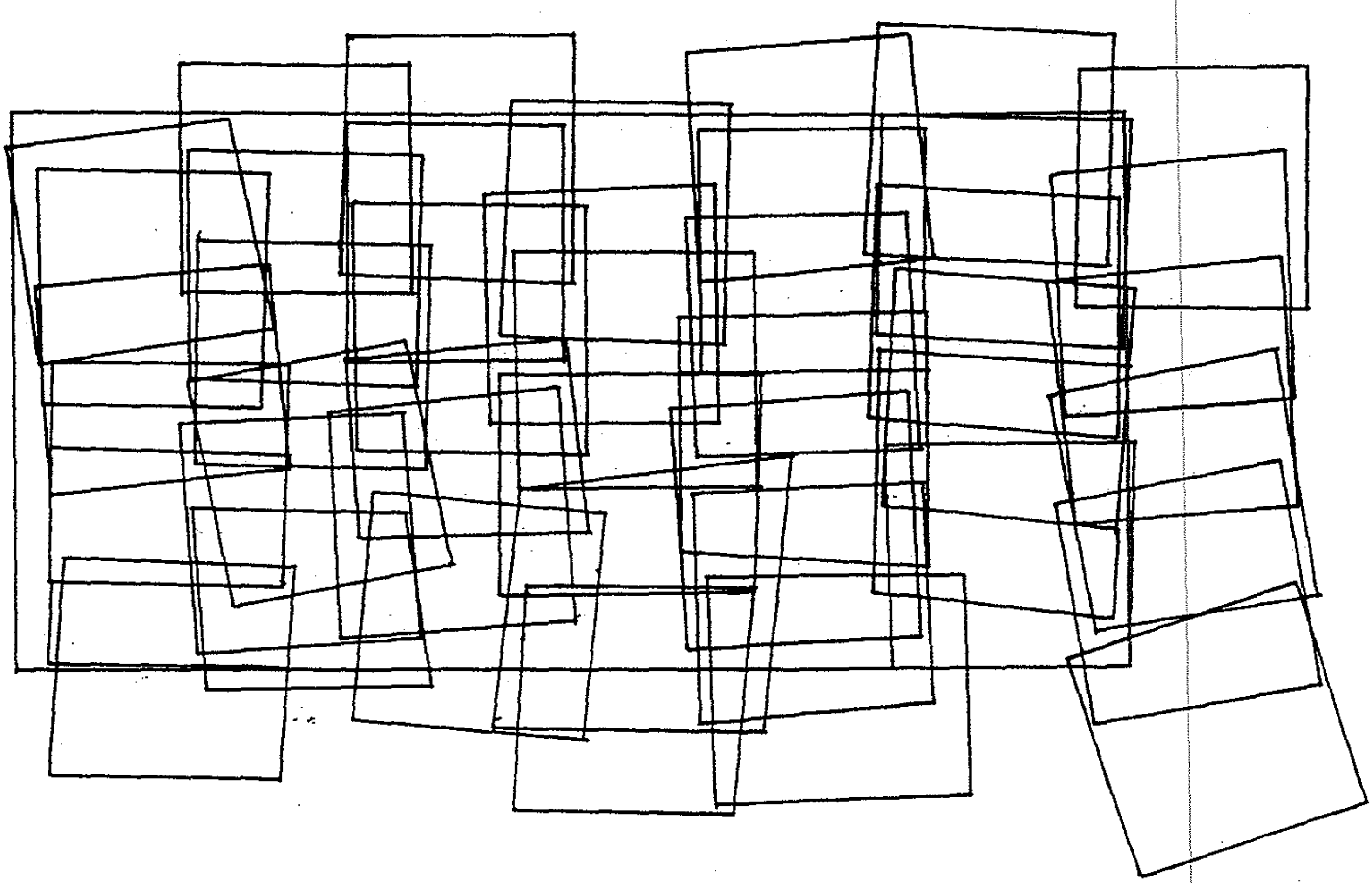
no 048	lahar below 047	99612-3454
no 049	secondary calcite in lahar	99685-3511
no 050	some phenocrysts from lahar	99685-3511
no 051	fossilized wood from lahar	99685-3511
no 052	clay from lahar	99612-3454
no 053	granulite	99528-3698
no 054	granulite	99528-3698
no 055	granulite	99528-3698
no 056	aplite, band in augengneiss	99501-3742
no 057	muscovite-biotite gneiss	99493-3758
no 058	epidote and pyroxeen in pegm.	99534-3867
no 059	epidote and pyroxene in pegm. and biotite-hornblende gneiss	99534-3867
no 060	garnet, sillimanite, epidote in hornblende-biotite gneiss	99534-3867
no 061	granulite	99508-3738
no 062	anthophyllite	99508-3738
no 063	amphibolite	99508-3738
no 064	hornblende crystal	99508-3738
no 065	calc tufa with fossiles	99508-3738
no 066	magnetite in pegmatite	99484-3664
no 067	schist	99533-3382
no068	quartz-feldspar-gneiss	99593-3643
no 069	ammonite	kilifi area
no 070	basalt	99542-3805
no 071	phonolite boulder from terrace below 070	99542-3805
no 072	clay sample	99562-3673
no 073	clay sample	99562-3673
no 074	dark phonolite from lahar	99695-3680
no 075	chromite	99698-3698
no 076	talc-tremolite	99698-3698
no 077	peridotite	99698-3698
no 078	phonolite	99698-3655
no 079	petrocalcic	99562-3727
no 080	sample terrace	99573-3719
no 081	conglomerate	99573-3719
no 082	sample terrace	99622-3742
no 083	sample terrace	99622-3742
no 084	sample terrace	99622-3744
no 085	sample terrace	99622-3744
no 086	sample terrace	99622-3744
no 087	talc-tremolite	99462-3630
no 088	talc-tremolite with serpentine	99462-3630
no 089	sand sample	99456-3655
no 090	(grano?) diorite	99460-3635
no 091	diorite	99500-3630
no 092	terrace with tuffa	99706-3884
no 093	pumice from Tana terrace	99635-3855
no 094	sand sample	99635-3855
no 095	tufa bomb from Tana terrace	99635-3855
no 096	gabbro norite with lot of pyroxenes	99685-3760
no 097	pegmatite with hornblende	99534-3867

no 098	pegmatite with tourmaline	99534-3867
no 099	pegmatite with unknown min.	99534-3867
no 100	biotite/hornblendite	99708-3885
no 101	heavy mineral sample	99571-3725
no 102	vitrophyre-ignimbrite	hells gate
no 103	tourmaline	99484-3664
no 104	garnets	99515-3675
no 105	hornblende	99484-3664
no 106	biotite gneiss with malachite	99534-3867
no 107	granitoid	99495-3764
no 108	sec. salts in lahar	99648-3662
no 109	peridotite	99698-3698
no 110	granulite	99563-3633
no 111	granulite	99598-3614
no 112	granulite with norite	99563-3633
no 113	epidote in quartz	99534-3867
no 114	muscovite	99708-3674
no 115	coral,pleistocene	kilifi area
no 116	ostrea sp., Jura	kilifi area
no 117	sec. silica	hells gate
no 118	volcanic glass	hells gate
no 119	light coloured granulite	99598-3614
no 120	migmatite	99524-3655
no 121	granite	99714-3342
no 122	gneissose granite	99714-3342
no 123	augengneiss	99533-3382
no 124	syenite	telekivalley
no 125	migmatite	99452-3419
no 126	granite	99492-3452
no 127	biotite/hornblendite	99710-3783
no 128	gabbro norite	99601-3624
no 129	talc-tremolite	99601-3624
no 130	granulite	99601-3624
no 131	granulite	99563-3633
no 132	very dark granulite	99588-3665
no 133	granulite	99608-3680
no 134	dark coloured granulite	99702-3697
no 135	light coloured granulite	99702-3697
no 136	hornblende gabbro	99657-3653
no 137	plagioclase hornblende gneiss	99662-3780
no 138	gneissose granite	99679-3785
no 139	hornblende gabbro	99655-3770
no 140	hornblende gabbro	99655-3770
no 141	talc-tremolite rich in serpentine	99607-3782
no 142	augengneiss	99581-3805
no 143	hornblende gneiss	99600-3840
no 144	granulite	99515-3746
no 145	olivine basalt artefact	99520-3740
no 146	hornblende gabbro vein in granulite	99520-3740
no 147	hornblende gabbro	99520-3740
no 148	rounded quartz boulder	99520-3740
no 149	migmatite	99493-3758
no 150	rhyolite	Mount Kenya

no 151	ignimbrite	Hell s gate
no 152	granitoid quartz feldspar muscovite gneiss	99642-3800
no 153	granulite like hornblende gneiss	99650-3650
no 154	hornblende gneiss	99650-3650
no 155	amphibolitic hornblende gneiss	99650-3650
no 156	migmatitic hornblende gneiss	99645-3684
no 157	migmatitic hornblende gneiss	99645-3684
no 158	granulitic hornblende gneiss	99645-3684
no 159	hornblende gneiss	99620-3730
no 160	granite	99637-3818
no 161	granitoid gneiss	99637-3818
no 162	granitoid gneiss	99475-3571
no 163	granitoid quartz feldspar gneiss	99475-3571
no 164	grano? diorite	99450-3609
no 165	dolerite	99457-3625
no 166	dolerite	99449-3625
no 167	quartzite	99449-3625
no 168	granitoid gneiss	99473-3658
no 169	biotite feldspar gneiss	99473-3658
no 170	dolerite	99473-3658
no 171	migmatite	99473-3658

APPENDIX 5: AERIAL PHOTOGRAPHS INDEX MAP

The uppermost figure shows the location of the areas covered by the aerial photographs. The lowermost diagram shows the codes and numbers of the photographs.



CHUKA I	CHUKA II	CHUKA III	ISHIARA I	ISHIARA II	ISHIARA III	TSEIKURU I
38	82	118	31	25	98	179
39	81	119	30	26	97	180
40	80	120	29	27	96	181
41	79	121	28	28	95	182
42	78	122	27	29	94	183
43	77	123	26	30 31	93	184